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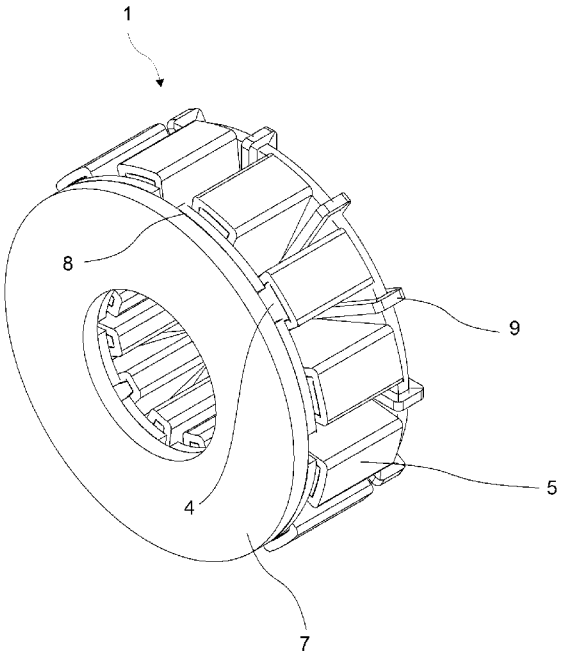
(54) Title: PERMANENT MAGNET AXIAL-FLUX ELECTRIC MACHINE WITH AUXILIARY WINDING ARRANGEMENT

Fig. 3



(57) Abstract: The present invention relates to an axial flux electric machine (1) comprising a stator assembly (2) and a rotor assembly (3), said stator assembly (2) having a stator yoke (6) and stator teeth (4) with windings wound around said stator teeth (4), said rotor assembly (3) having a rotor yoke (7) and a plurality of permanent magnets (8), each one disposed at a different relative position on said rotor yoke (7).

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Description

PERMANENT MAGNET AXIAL-FLUX ELECTRIC MACHINE WITH AUXILIARY WINDING ARRANGEMENT

[0001] The present invention relates to permanent magnet axial-flux electric machine with an auxiliary winding arrangement.

[0002] It is well-known that permanent-magnet synchronous motors (PMSM) are motors having high efficiency, operating without excitation windings and with electronic switching. These motors are widely used due to their desirable properties. PMSMs are categorized as radial, axial and transverse depending on the direction of the magnetic flux. Radial flux motors are the most common due to their similar structure to conventional motors, lamination and windings and ease of manufacture. Axial flux motors are less common because they require a different structure or use of insulated pure iron powder or so called Soft Magnetic Composite (SMC).

[0003] In recent years, axial flux motors have become common in a wider range of applications due to advances in material science. Axial flux permanent magnet machines have their distinct advantages over radial flux permanent magnet machines in that they require less core material due to higher power-to-weight ratio and as a result of the disc shaped rotor and stator structure, smaller size is ensured. Compared to radial flux motors, axial flux motors have high power and torque density (W/m^3, Nm/m^3). As high output power can be obtained with small motor sizes, axial flux type motors are being used more and more, especially in applications such as electric cars, bikes and wind turbines.

[0004] Output power of axial flux motors is proportional to the cube of the outside radius of the motor. Its axial length is limited by the windings around the stator coils. If the number of windings can be kept limited, the axial length of the motor will be minimized. However, if the number of windings is not sufficient, the axial length of the motor must be increased to obtain the number of windings necessary.

[0005] Among others, a prior art publication in the technical field of the invention may be referred to as US2008061649, which discloses an axial gap motor

in which a stator and a rotor are arranged parallel to a rotating shaft. More particularly, the publication discloses an axial gap motor, which can be easily manufactured and achieve an improvement in efficiency. In the axial gap motor the stator includes a back yoke defining a magnetic path, a plurality of stator cores each having a central portion parallel to the rotating shaft, each of the plurality of stator cores being coupled to the back yoke, and a plurality of stator coils, each wound around the central portion of a corresponding one of the stator cores.

[0006] Another patent publication is WO2014087389, which discloses coils for axial flux permanent magnet motors where the coils are made up of coil elements of lap type with slots where the coil element is manufactured by casting, or a combination off milling or punching and water cutting or wire cutting or similar. It is also made slots for the connector which connects each coil element. The publication additionally discloses coils for three phased axial flux permanent magnet motors where the coils are of wave winding type and manufactured by casting, or a combination of milling or punching and water cutting or wire cutting. The first phase of the coils can be made up of a single coil element or assembled from smaller parts and have slots which all face up when placed on the assembly table. These slots are arranged so that the slots fit together with the slots that are facing down in the second coil element which has slots on both sides. The slots in the second element which face up together with the slots in the first coil element which are not filled by slots in the second coil element are arranged so that they are filled with the slots in the third coil element which only has slots facing down and can be identical with the first coil element. Other examples may be referred to as US20140285048, US20130307366 and US20120212085.

[0007] The present invention, on the other hand, addresses the situation where auxiliary windings are used in addition to windings of the stator coils whereby the number of windings on the stator coils can be decreased. In this manner, the axial length of the motor can be shortened and the motor has a more compact structure.

[0008] The present invention provides permanent magnet axial-flux electric

machine with auxiliary windings as provided by the characterizing features defined in Claim 1.

[0009] Primary object of the present invention is to provide a permanent magnet axial-flux electric machine having a shortened axial length.

[0010] The present invention proposes an axial flux electric machine comprising a stator assembly and a rotor assembly. A plurality of symmetrically disposed toroidal windings in the form of auxiliary windings are distributed on the stator yoke to at least partially radially extend through planar sides of said stator yoke between each pair of stator coils.

[0011] Accompanying drawings are given solely for the purpose of exemplifying a permanent magnet axial-flux electric machine, whose advantages over prior art were outlined above and will be explained in brief hereinafter.

[0012] The drawings are not meant to delimit the scope of protection as identified in the Claims, nor should they be referred to alone in an effort to interpret the scope identified in said Claims without recourse to the technical disclosure in the description of the present invention. The drawings are only exemplary in the sense that they do not necessarily reflect the actual dimensions and relative proportions of the respective components of the system.

[0013] Fig. 1 demonstrates a perspective view of a conventional axial flux electric machine with stator and rotor assemblies.

[0014] Fig. 2 demonstrates a perspective view of the stator assembly with the stator yoke and stator teeth in assembled condition according to the present invention.

[0015] Fig. 3 demonstrates a perspective view of the axial flux electric machine with stator and rotor assemblies and auxiliary stator windings according to the present invention.

[0016] Fig. 4 demonstrates a side view of the axial flux electric machine with stator and rotor assemblies and auxiliary stator windings according to the present invention.

[0017] The following numerals are assigned to different part number used in the detailed description:

1. Axial flux electric machine

2. Stator assembly
3. Rotor assembly
4. Stator teeth
5. Stator coil
6. Stator yoke
7. Rotor yoke
8. Permanent magnet
9. Auxiliary winding

[0018] The present invention relates to permanent magnet (8) axial-flux electric machine (1) conventionally having stator and rotor assemblies (2 and 3).

[0019] Permanent magnets (8) are attached to the rotor yoke (7). Both of the stator and rotor yokes (6, 7) are conventionally assembled with stator teeth (4) carrying stator coils (5) generating axial flux. Stator teeth (4) can be preferably formed separately to be attached to the yoke. Permanent magnets (8) can be fixedly attached on the rotor yoke (7) through respective projections (not shown). Preferably, stator teeth (4) can be manufactured using insulated pure iron powder (Soft Magnetic Composite (SMC) material) and can be wound separately to be attached to the stator yoke (6) also through respective projections (not shown). SMC material and ferromagnetic sheet lamination can be used in combination to obtain stator and rotor assemblies (2 and 3).

[0020] In accordance with the present invention, toroidal windings in the form of auxiliary windings (9) are added to the stator yoke (6) structure so as to be disposed between each pair of stator coil (5). Auxiliary windings (9) at least partially radially extending through both planar sides of the stator yoke (6) are typically supported thereon in a secured manner.

[0021] Auxiliary windings (9) are wound on coils in three phases on the stator. In order to obtain the desired output power from the axial flux electric machine (1), ampere-turns of the system need to be sufficient. When the system has insufficient ampere-turns, the current or the number of windings must be increased. Increasing the current increases motor losses and decreases the efficiency of the motor. On the other hand, increasing the number of windings is not always suitable as in these cases it is

necessary to increase the length of the stator teeth (4) and to increase the outer axial dimension of the motor. Instead of these approaches, the invention provides additional winding area by placing windings on the yoke between the coils.

[0022] According to the present invention, it is found that when an amount corresponding to 23% of the windings on the stator coils (5) is additionally wound on the stator yokes (6), average torque increases 11.5% without causing extra oscillations.

[0023] Therefore, a direct consequence of the proposed arrangement is observable when comparing motor performances and particularly output torque with and without auxiliary windings (9). As the auxiliary windings (9) are not placed in the axial direction, their contribution is not as much as windings wound around the stator teeth (4). However, these auxiliary windings (9) yet produce a discernible effect, namely by increasing the output power or the efficiency of the axial flux electric machine (1).

[0024] If increasing the efficiency is desired, decreasing the number of windings on the stator coils (5) and using coils having larger diameter will decrease the resistance and minimize copper losses. In this manner the same ampere-turns will be obtained. Another advantage of this system is that it is possible to obtain higher output power from the same current by keeping the number of winding around the stator teeth (4) constant and adding auxiliary windings (9) on the yoke.

[0025] In a nutshell, the present invention proposes an axial flux electric machine (1) comprising a stator assembly (2) and a rotor assembly (3), said stator assembly (2) having a stator yoke (6) and stator teeth (4) with windings wound around said stator teeth (4), said rotor assembly (3) having a rotor yoke (7) and a plurality of permanent magnets (8), each one disposed at a different relative position on said rotor yoke (7).

[0026] In one aspect of the present invention, a plurality of symmetrically distributed toroidal windings in the form of auxiliary windings (9) are disposed on the stator yoke (6) in the manner that each of said auxiliary windings (9) fully encloses a radial extension of said stator yoke (6).

[0027] In a further aspect of the present invention, each of said toroidal windings

in the form of auxiliary windings (9) are disposed between each pair of stator coil (5).

[0028] In a further aspect of the present invention, said auxiliary windings (9) at least partially radially extend through both planar sides of the stator yoke (6) in the manner to be supported in a secured manner.

[0029] In a further aspect of the present invention, each of stator and rotor yokes (6, 7) is made of laminated sheets.

[0030] In a further aspect of the present invention, stator teeth (4) are manufactured using soft magnetic composite materials, wound in an unassembled condition with the stator yoke (6) and then attached to the stator yoke (6).

[0031] In a further aspect of the present invention, stator teeth (4) and permanent magnets (8) comprise slots on their bottom surface for attachment with respective projections of the stator and rotor yokes (6, 7).

[0032] In a further aspect of the present invention, toroidal windings in the form of auxiliary windings (9) are fixedly attached to the stator yoke (6) and held in place by clipping means (not shown) projecting from said stator yoke (6).

[0033] Therefore, the present invention provides that an axial flux motor occupying less axial space can be designed with the help of auxiliary windings (9) without compromising motor performance.

Claims

1. An axial flux electric machine (1) comprising a stator assembly (2) and a rotor assembly (3), said stator assembly (2) having a stator yoke (6) and stator teeth (4) with windings wound around said stator teeth (4), said rotor assembly (3) having a rotor yoke (7) and a plurality of permanent magnets (8), each one disposed at a different relative position on said rotor yoke (7), **characterized in that**;

   a plurality of symmetrically distributed toroidal windings in the form of auxiliary windings (9) are disposed on the stator yoke (6) in the manner that each of said auxiliary windings (9) fully encloses a radial extension of said stator yoke (6).
2. An axial flux electric machine (1) as in Claim 1, **characterized in that** each of said toroidal windings in the form of auxiliary windings (9) are disposed between each pair of stator coils (5).
3. An axial flux electric machine (1) as in Claim 1 or 2, **characterized in that** said auxiliary windings (9) at least partially radially extend through both planar sides of the stator yoke (6) in the manner to be supported in a secured manner.
4. An axial flux electric machine (1) as in any preceding Claim, **characterized in that** each of stator and rotor yokes (6, 7) is made of laminated sheets.
5. An axial flux electric machine (1) as in any preceding Claim, **characterized in that** stator teeth (4) are manufactured using soft magnetic composite materials, wound in an unassembled condition with the stator yoke (6) and then attached to the stator yoke (6).
6. An axial flux electric machine (1) as in any preceding Claim, **characterized in that** stator teeth (4) and permanent magnets (8) comprise slots on their bottom surface for attachment with respective projections of the stator and rotor yokes (6, 7).
7. An axial flux electric machine (1) as in any preceding Claim, **characterized in that** toroidal windings in the form of auxiliary windings (9) are fixedly attached to the stator yoke (6) and held in place by clipping means projecting from said stator yoke (6).

Fig. 1

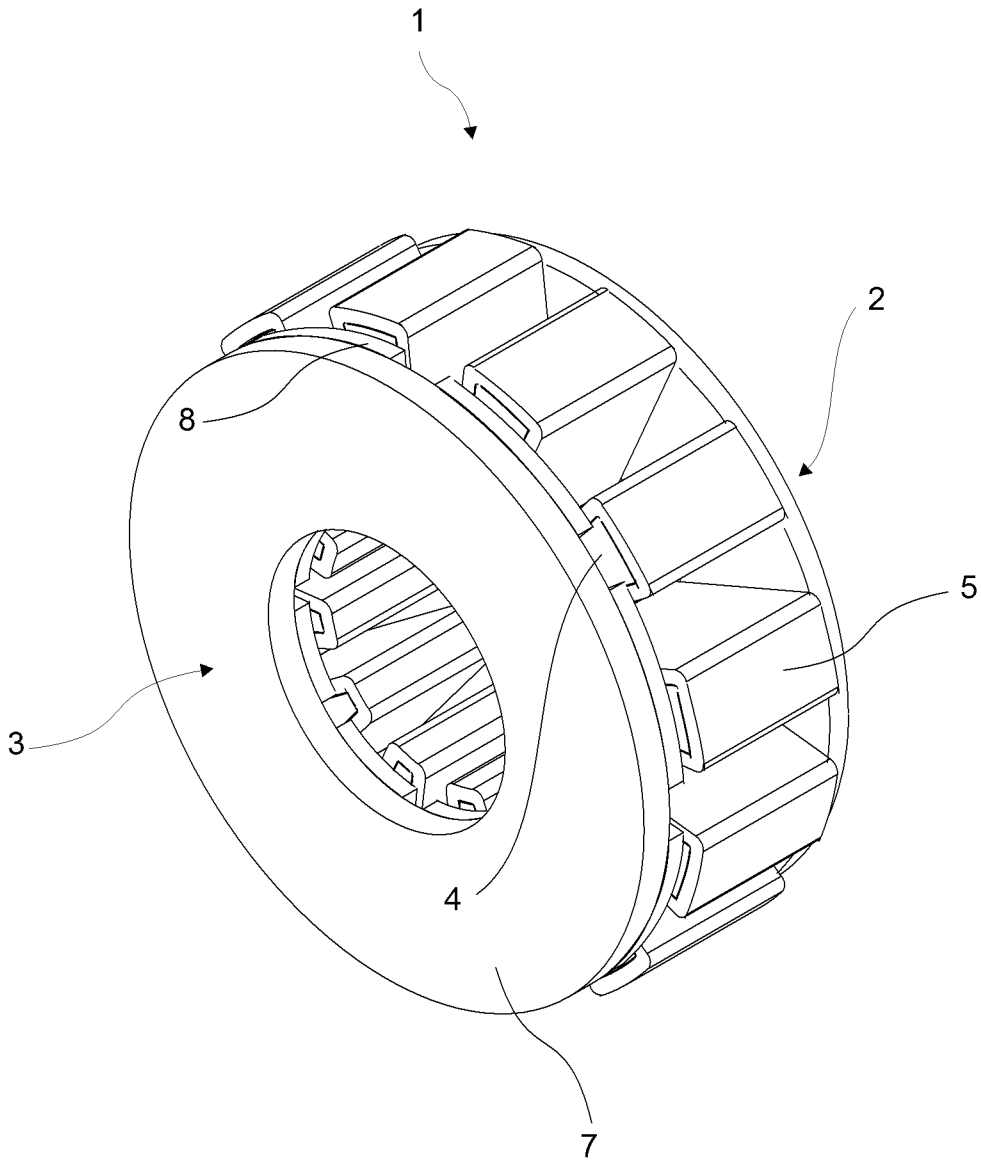


Fig. 2

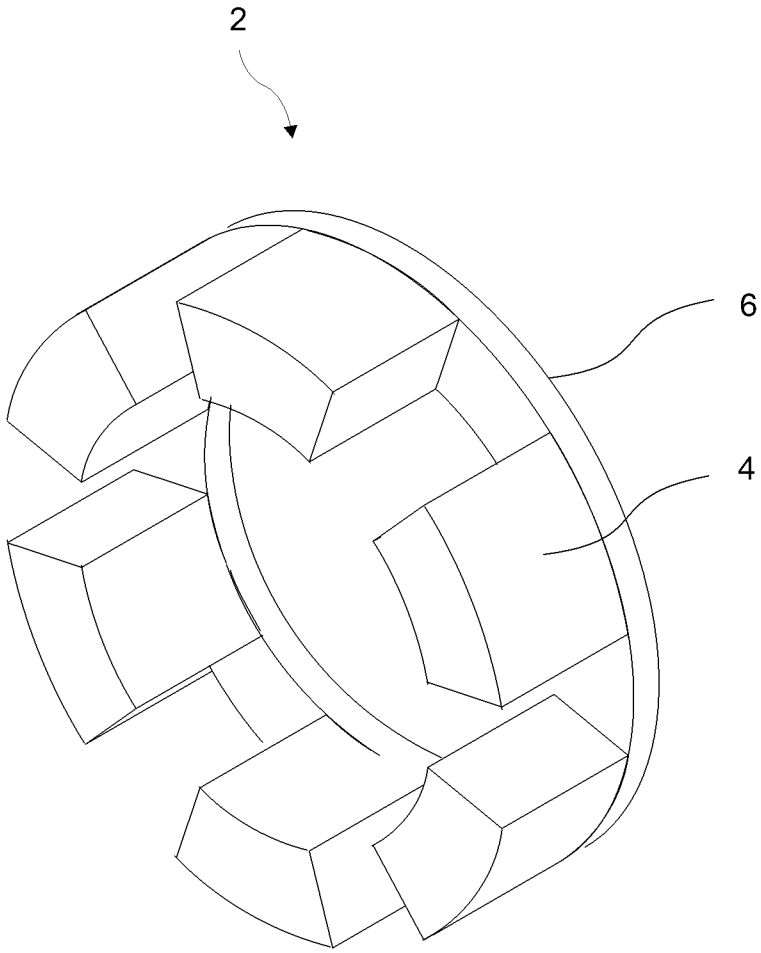


Fig. 3

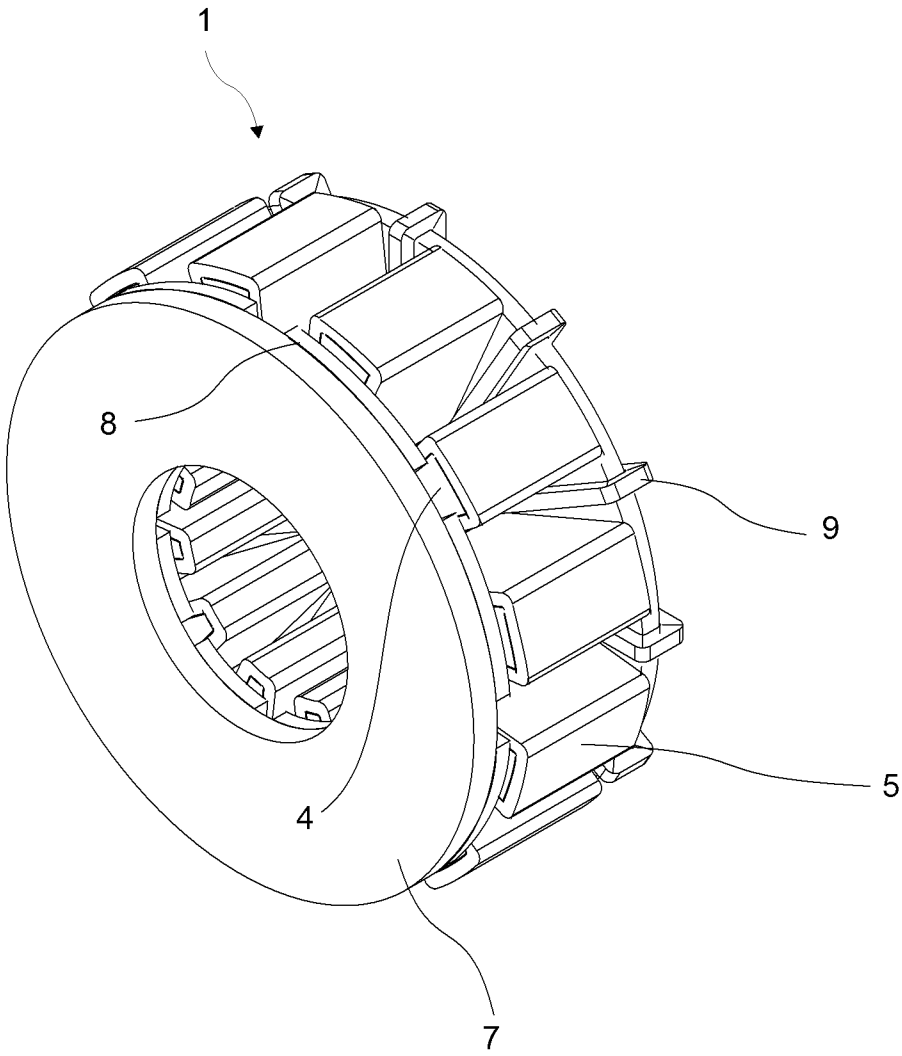
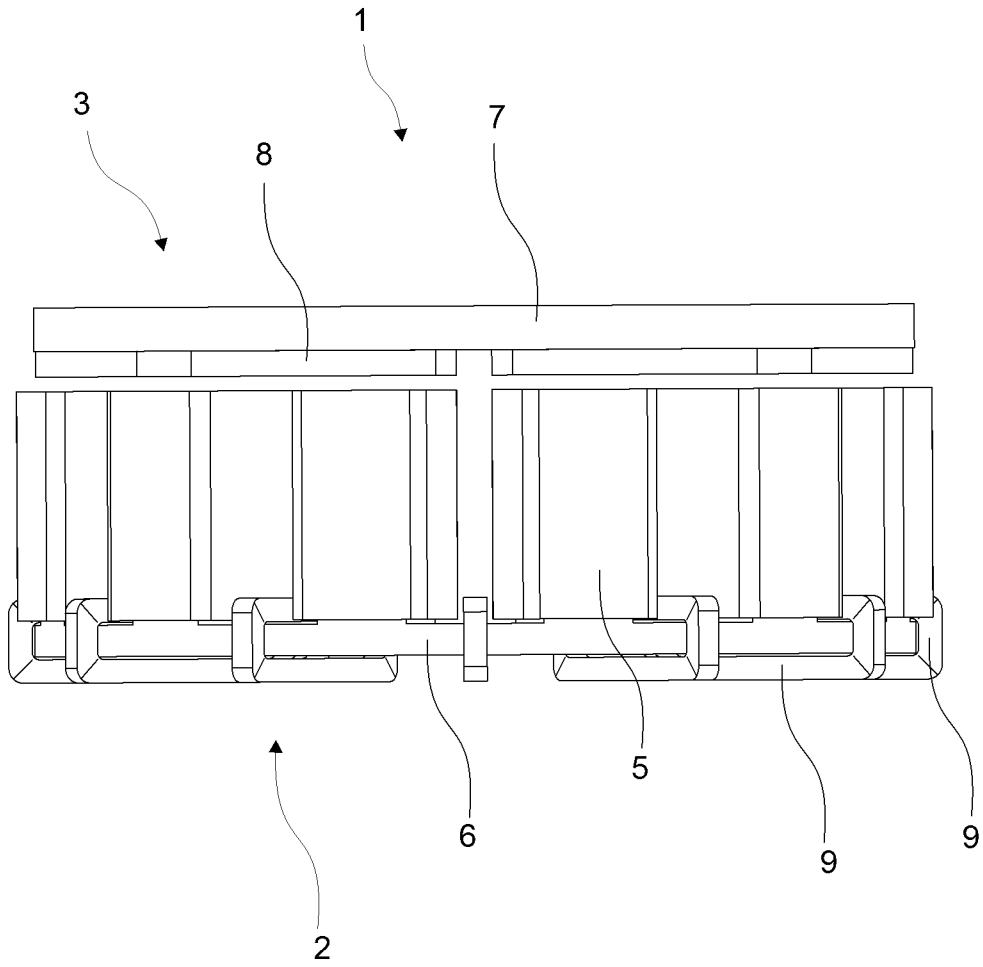


Fig. 4



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2017/055665

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K21/24 H02K1/27 H02K3/20
ADD.

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)
H02K

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)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2015/171674 A1 (LEE YEE-CHUN [US] ET AL) 18 June 2015 (2015-06-18)	1-4
A	paragraph [0094] - paragraph [0096]; figures 6C,7,8,9A,B paragraph [0136] - paragraph [0139]; figures 11A,B paragraph [0192]; figures 19A,B	5-7
A	EP 1 593 190 B1 (SEB SA [FR]) 16 July 2008 (2008-07-16) paragraphs [0042], [0046]; figure 6	5,6
A	EP 1 418 657 A1 (YAMAHA MOTOR CO LTD [JP]) 12 May 2004 (2004-05-12) paragraph [0035] - paragraph [0042]; figures 1-3	6

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2017/055665

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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