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(54) **Title:** BRUSHLESS DC ELECTRIC MOTOR

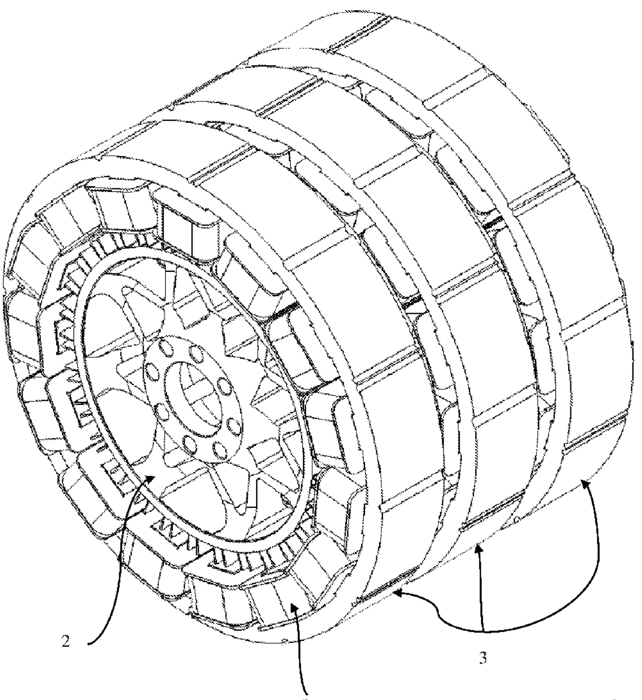

FIG.3

(57) **Abstract:** A brushless DC electric motor for supplying multiphase supply voltage is composed of at least one rotor (2) fitted with permanent magnets (7). Number of rotors (2) ideally corresponds to the number of phases of the supply voltage. The rotors (2) are mounted on a shaft (1). The motor is composed of a split stator (3) with slots (5) to support the coils (8) of the stator windings. Each part of the stator (3) is electrically connected to the inverter to supply only one of the phases of the supply voltage, and at the same time the parts of the stator (3) are arranged relative to each other so that at least two parts of the stator (3) have a non-zero angular displacement of the slots (5) relative to each other.

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Brushless DC electric motor

Field of the Invention

The invention relates to the construction of a brushless DC electric motor supplied with multiphase supply voltage with windings in delta or wye configuration.

Background of the Invention

The brushless DC electric motor is known to the public under several names, including but not limited to electronically commutated electric motor, or perhaps the most frequently used name “BLDC motor” including the English abbreviation, which is based on the English words “brushless direct current electro motor”.

In the basic construction, the BLDC motor is composed of a rotor, which is fitted with permanent magnets along the perimeter. Each permanent magnet forms a permanent magnetic pole. Furthermore, the BLDC motor consist of a slotted stator, supporting the coils of stator windings. The stator can therefore be understood as a ring with electric coils along the perimeter of the ring, with the core of the coil being the so-called “stator tooth”. Tooth faces from which magnetic field lines of the electrically induced magnetic field emerge are oriented relative to the permanent magnets of the rotor to induce a magnetic interaction causing a force effect. The rotor can rotate inside or outside the stator, with the rotor being coupled to a shaft to transmit the force effect - mechanical energy. The number of permanent magnetic poles and the number of stator slots for the BLDC motor are determined by the design calculation.

Another part of the BLDC motor is the so-called “inverter”, which controls the activation of individual coils with supply voltage for the electrical induction of the magnetic pole and creates a controlled rotating magnetic field. The inverter consists of semiconductor electronics.

Last but not least, the BLDC motor includes a sensor for monitoring the position of permanent magnetic poles of the rotor relative to the stator slots. According to the information about the position of the rotor relative to the stator, the inverter activates a specific electrically induced magnetic pole with supply voltage to initiate a magnetic interaction.

An example of the BLDC motor may be the invention of US 2006/279162 (A1). In the exemplary invention, the BLDC motor is connected to a fuel pump. The above technical features of the basic construction of the BLDC motor are present in the exemplary invention.

It is also known from the background of the invention that permanent magnets can be arranged in the so-called “Halbach array” for higher power of the BLDC motor, the effect of which is to augment the magnetic fluxes on one side of the arranged array of the permanent magnets while cancelling the fluxes to near zero on the other side of the arranged array of the permanent magnets. An exemplary invention may be the solution of patent application US 2019/0058384 A1, in which the Halbach array arrangement is applied to the permanent magnets of the rotor of the BLDC motor.

The disadvantages of the known multi-pole BLDC motors operating with multiphase supply voltage are that there is not too much space in the stator slots for the turns of the stator coil windings. The lack of space in the stator slots is compensated (by optimization) by reducing the number of turns of the stator coil windings for the individual phases of supply voltage. This has a negative effect on the total power of the BLDC motor and, in addition, complicates the removal of waste heat from the BLDC motor, since in many cases the design of the high-power BLDC motor does not leave enough space for trouble-free coolant flow.

Some inventors try to solve the problem of overcoming the power limitation of the BLDC motor, for example, by increasing the size of the electric motor (so-called “sizing”), thus increasing the size of the stator slots. However, this is only applicable in cases where the larger dimensions and weight of the BLDC motor are not an obstacle, which would be an obstacle for the use of BLDC motors, for instance, in aviation or other means of transport.

Other inventors, in turn, solve the problem of limited power of the current design of the BLDC motor by mounting several BLDC motors on a single shaft, which together contribute to the rotating power of the machine. An example of such a solution is the invention in document CN 200941582 (Y).

However, one of the disadvantages of the above invention is that at present the synchronization of inverters of the individual BLDC motors is not perfect. The individual BLDC motors can act against each other with the force effect on the shaft, leading to a loss of overall power and strain on the components of the electric machine. If this problem of imperfect synchronization of inverters is solved by couplings to compensate for non-synchronized contribution of the force effect to the common shaft, the total size and weight of the complete BLDC motor body increases, including the risk of failure in the installed mechanical components of the BLDC motor.

The task of the invention is to propose a brushless DC electric motor (BLDC motor) supplied with multiphase supply voltage, which would allow to run the BLDC motor at higher powers, which would not fundamentally affect the resulting size and weight of the BLDC motor compared to the previously used construction of the BLDC motor.

Summary of the Invention

This task is accomplished by providing a brushless DC electric motor (BLDC motor) for supplying multiphase supply voltage according to the present invention.

The brushless DC electric motor (BLDC motor) for supplying multiphase supply voltage is composed of at least one rotor fitted with permanent magnets to form permanent magnetic poles. The rotor is mounted on a shaft, which serves to transfer mechanical energy between the BLDC motor and the external device connected to the shaft. At the same time, the number of permanent magnets on the rotor is determined by the design calculation for the BLDC motor. The design calculation is a standardized procedure for determining the number of permanent magnets to the number of stator slots.

Furthermore, the BLDC motor includes a slotted stator for the coils of the stator windings, which serve for the electrical induction of magnetic poles, while the number of stator slots is determined by the standardized design calculation. Furthermore, the BLDC motor includes at least one inverter for controlling the electrical induction of the magnetic poles on the stator coils, and at least one sensor for monitoring the position of rotation of the rotor relative to the stator.

The summary of the invention is based on the fact that the BLDC motor is formed by a stator split into parts depending on the number of supply voltage phases, each part of the stator having the number of slots according to the design calculation divided by the number of supply voltage phases. The number of parts of the stator corresponds to the number of phases of the supply voltage. This is advantageous because each part of the stator gains more space in the slots for the coils of the stator winding by reducing the number of slots to the original number, so it is possible to apply more turns of the electrical conductor, thus achieving a lower current load per mm^2 of the overall cross-section of the stator winding in the slot as well as amplifying the electromagnetic field of the individual stator tooth. At the same time, each part of the stator is electrically connected to the inverter to supply with only one of the phases of the supply voltage, which is an essential condition for the preferable functioning of the invention. The individual parts of the stator can be connected in the usual way for the operation of the machine. It is also important that at least two parts of the stator are arranged relative to each other so as to have a non-zero angular displacement of the teeth relative to each other. This displacement is important in terms of the magnetic interaction between the permanent magnetic pole and the induced magnetic pole. If the parts of the stator were arranged with zero angular displacement relative to each other, the rotation of the rotor could lead to a situation where the magnetic interaction would not contribute to the rotating action of force.

It is important to emphasize that from the point of view of the operation of the BLDC motor, nothing changes, as the sum of the number of slots corresponds to the standardized design calculation of the number of slots on the stator. The inverter functions in the same way as in the current construction of the BLDC motor, with the only difference that the windings in the common stator slot do not alternate for electrical induction. The timing of the activation of the electric induction of the magnetic field is still the same, the force effect of the magnetic interaction on the rotor does not change.

Another indisputable advantage of the invention is that, due to the distribution of the number of slots in several parts of the stator, the teeth on the parts of the stator have a larger front face, which corresponds in size to the faces of the permanent magnetic poles. For this reason, the magnetic interaction between the permanent magnetic pole and the induced magnetic pole is of higher quality, which in turn results in higher efficiency of the BLDC motor according to the invented construction.

In a preferred embodiment of the construction of the BLDC motor according to the invention, the BLDC motor comprises as many rotors as phases of the supply voltage. The rotors are mounted on a common shaft, each rotor having the number of permanent magnets according to the design calculation, and each rotor forming a pair with its own part of the stator. The disadvantage of a single rotor is the disruption of the magnetic field lines during the magnetic interaction between the induced magnetic fields and the permanent magnetic fields of the adjacent parts of the stator. Where a rotor is created for each part of the stator, the disruptive interaction on the lines of force of the permanent magnetic fields is minimized.

The advantages of the invention include the higher power of the BLDC motor, because increasing the space in the slots makes it possible to apply several turns of electrical conductor to the coils of the stator windings, thus reducing the current load in the stator windings while the BLDC motor is running. In terms of the components of the BLDC motor - the inverter and the sensor for monitoring the rotation of the rotor(s) relative to the parts of the stator, basically nothing changes. In addition, the installation size of the BLDC motor does not change fundamentally, since one large stator is essentially split into several parts. Furthermore, the invented construction of the BLDC motor has the advantage that the widening of the slots allows the finished coils to be fitted to the teeth of the parts of the stator, which greatly facilitates the production of the invented BLDC motor and additionally ensures that the coils are homogeneous in terms of winding of the electrical conductor, so the designer can take into account the same behaviour of the coils of the stator winding throughout the BLDC motor (waste heat distribution, waveform of the electric induction of the magnetic field). Last but not least, it is advantageous that due to the widening of the slots on the parts of the stator and the application of a single coil of the stator winding (for a single phase of supply voltage), it is possible to better remove waste heat from the BLDC motor.

Explanation of drawings

The present invention will be explained in detail by means of the following figures where:

Fig. 1 presents a schematic section of the ordinary BLDC motor to supply three-phase supply voltage,

Fig. 2 presents a schematic section of the invented BLDC motor to supply three-phase supply voltage,

Fig. 3 presents an axonometric view of an illustrative model of the invented BLDC motor,

Fig. 4 presents an axonometric view of an illustrative model of the invented BLDC motor without showing the parts of the stator,

Fig. 5 presents an axonometric view of an illustrative model of the invented BLDC motor without showing the parts of the stator and selected coils,

Fig. 6 shows a table of a standardized design calculation of winding factors for different combinations of the number of permanent magnetic poles and slots, where the number of permanent magnetic poles is plotted on the horizontal axis and the number of slots is plotted on the vertical axis.

Example of the invention embodiments

It shall be understood that the specific cases of the invention embodiments described and depicted below are provided for illustration only and do not limit the invention to the examples provided here. Those skilled in the art will find or, based on routine experiment, will be able to provide a greater or lesser number of equivalents to the specific embodiments of the invention which are described here.

Fig. 1 shows a diagram of an ordinary construction of a BLDC motor comprising a shaft 1, a rotor 2, a stator 3, teeth 4 of a stator 3, slots 5 of a stator 3, and a highlighted face 6 of a slot 5. Although it is written about the face 6 of the slot 5, this is given by the sectional view. In fact, the face 6 is interlaid with the volume of the slot 5. There are permanent magnets 7 on the rotor 2, alternating in horizontal and vertical configurations to form a Halbach array with an amplified magnetic effect in relation to the teeth 4 of the stator 3. Such a construction of the BLDC motor, including cooling, can be found, for example, in the invention known from the patent application CZ 2020-574.

As shown in Fig. 1, the face 6 of the slot 5 is narrow at first sight, and thus limits the size of the non-illustrated coil of the stator winding. In addition, it is important to note that the face 6 of the slot 5 is split into halves, with half of the non-illustrated coil of the stator winding extending into each of the halves.

Fig. 2 shows a diagram of a part of the invented construction of the BLDC motor, namely a single part of the stator 3 out of three. As can be seen, the shaft 1 and the rotor 2 remained basically the same. The change is evident in the part of the stator 3 which, at first sight, has a smaller number of larger slots 5, as shown by the highlighted face 6. The increase in the face 6 indicates that it is possible to apply more turns of the conductor forming the coils 8 of the stator windings to the slots 5, thus it is possible to increase the operating current load and thus positively affect the performance and efficiency of the new construction of the BLDC motor. The face 6 has increased by 2/3 of the original size of the face 6 compared to the original construction.

As shown in Fig. 3, the invented construction of the BLDC motor comprises three parts of the stator 3, while Fig. 4 shows that the three parts of the stator 3 are angularly displaced relative to the axis of rotation of the rotor 2 as the centre of the assembly of the stator 3. Fig. 3 and 4 also illustrate the location of the coils 8 of the stator winding, which can be easily mounted on the teeth 4 of the parts of the stator 3 in terms of the production process.

In Fig. 5, some of the coils 8 of the stator windings are not illustrated to show that the invented construction of the BLDC motor may include three rotors 2. As shown in the figure, the rotors 2 are arranged in the same way in the assembly, or with a zero angular rotation, in other words in alignment.

As for the example of a specific embodiment of the new construction of the BLDC motor, it can have the following parameters:

For the number of 30 permanent magnetic poles on the rotor 2, the design calculation determines 45 slots 5 on the stator 3. This means that each part of the stator 3 has 15 slots 5. The parts of the stator 3 are displaced (rotated) relative to each other by an angle of 8°. There are also three rotors 2, each with the number of 30 permanent magnetic poles. There are 20 mm wide gaps between the rotors 2 to reduce the effect of magnetic interaction from adjacent components. The new construction of the BLDC motor allows the flow of working current of about 70 A, while in the original construction according to the prior art the limit was about 33 A. These are calculated values for an exemplary embodiment of the invention, which guarantee machine operation without significant increase in temperature and losses due to waste heat.

To design other specific examples of the new construction of the BLDC motor, a person skilled in the art can use a table known from the literature based on the standardized design calculation of winding factors for different combinations of the number of permanent magnetic poles and slots 5, which is shown in Fig. 6. For orientation in the table, the number of permanent magnetic poles is plotted on the horizontal axis and the number of slots 5 of the stator 3 is plotted on the vertical axis. Non-functional combinations are marked with crosses, the coefficient of the winding factors is indicated by a dimensionless number. The number of slots 5 is always divided among as many parts of the stator 3 as there are phases of the supply voltage.

The person skilled in the art will be able to suggest other variants of the invented construction of the BLDC motor with the stator 3 by working routinely with the knowledge of the table in Fig. 6, with the knowledge of the standardized design calculation and on the basis of a suitable inverter for n-phase of the supply voltage.

As for the other components of the BLDC motor, they remain basically the same. The inverter has conductors installed for each of the phases of the supply voltage on the given part of the stator 3. The sensor for monitoring the position of rotation of the rotor 2 / rotors 2 remains the same.

The rotor 2 can be mounted inside the stator 3 or outside, depending on the construction of the BLDC motor, whether it is a machine with a rotating casing or an inner rotor 2.

A practical experiment has shown that it is possible to use the new construction of the BLDC motor to generate electrical energy while transferring external mechanical energy to the shaft 1. The coils 8 of the stator winding with a larger number of turns have a positive effect on the amount of induced electrical energy.

Industrial applicability

The brushless DC electric motor for supplying multiphase supply voltage according to the invention finds its application in electric vehicles, as well as in the aviation industry focused on electric propulsion, and in other areas of human endeavour where it is necessary to convert electrical energy into mechanical energy and vice versa.

List of reference numerals

1 shaft
2 rotor
3 stator
4 tooth
5 slot
6 slot space
7 permanent magnet
8 coil of the stator winding

CLAIMS

1. Brushless DC electric motor for supplying multiphase supply voltage consisting of at least one rotor (2) fitted with permanent magnets (7) mounted on a shaft (1), as well as one stator (3) with slots (5) to support the coils (8) of stator windings, as well as at least one inverter for controlling the electric induction of magnetic poles, and at least one sensor for monitoring the rotation of the rotor (2) relative to the stator (3,) **characterized in that** it is formed by a stator (3) split into the number of parts corresponding to the number of phases of the supply voltage, while each part of the stator (3) has the number of slots (5) corresponding to the original number of slots divided by the number of phases of the supply voltage, further each part of the stator (3) is electrically connected to the inverter to supply only one of the total number of phases of the supply voltage, and at the same time the parts of the stator (3) are arranged relative to each other so that at least two parts of the stator (3) have a non-zero mutual angular displacement of the slots (5) relative to each other.

2. Brushless DC electric motor according to claim 1, **characterized in that** it comprises the same number of rotors (2) mounted on a common shaft (1) as the number of phases of the supply voltage, and each rotor (2) makes a pair with its own part of the stator (3).

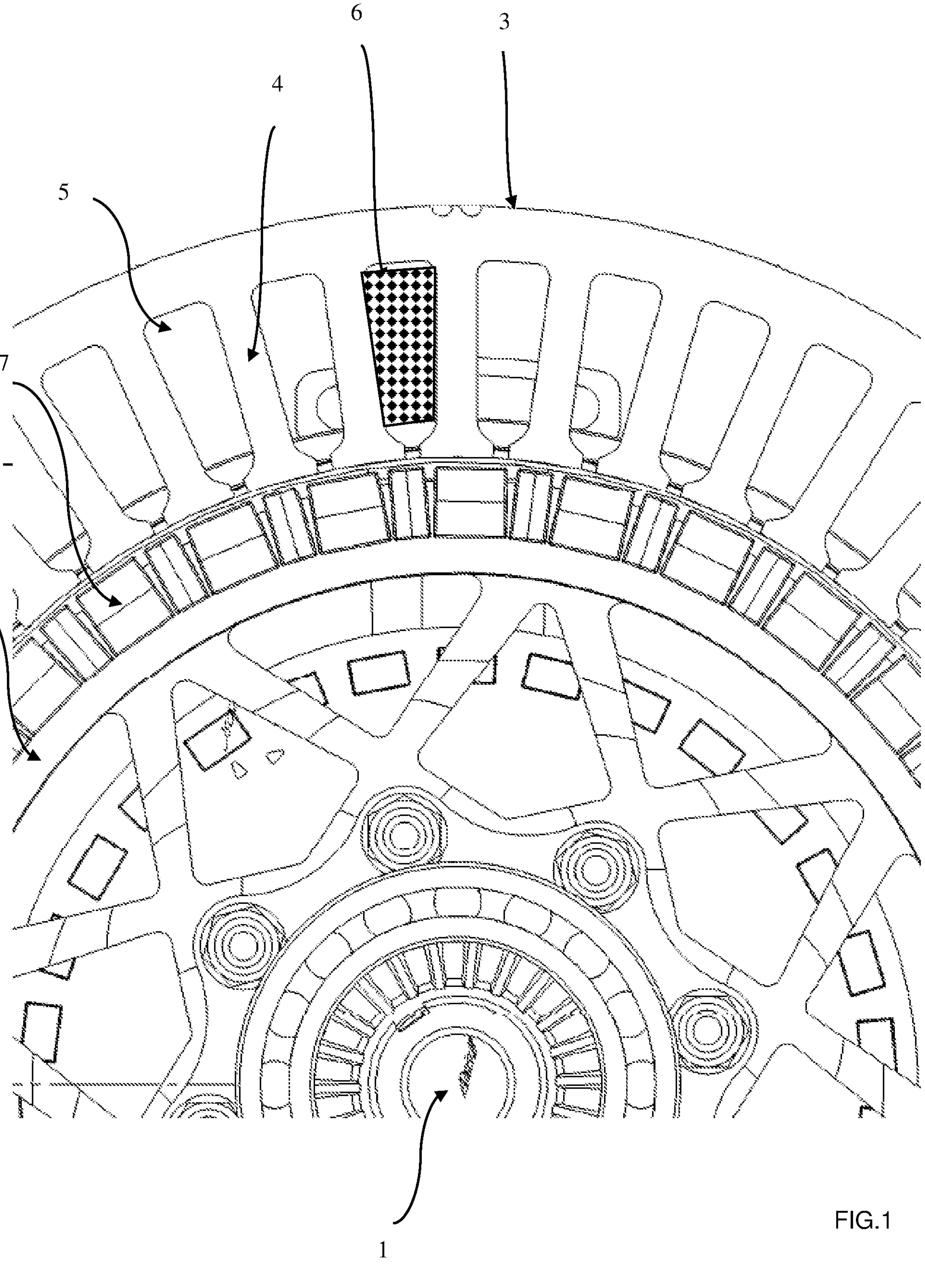

FIG.1

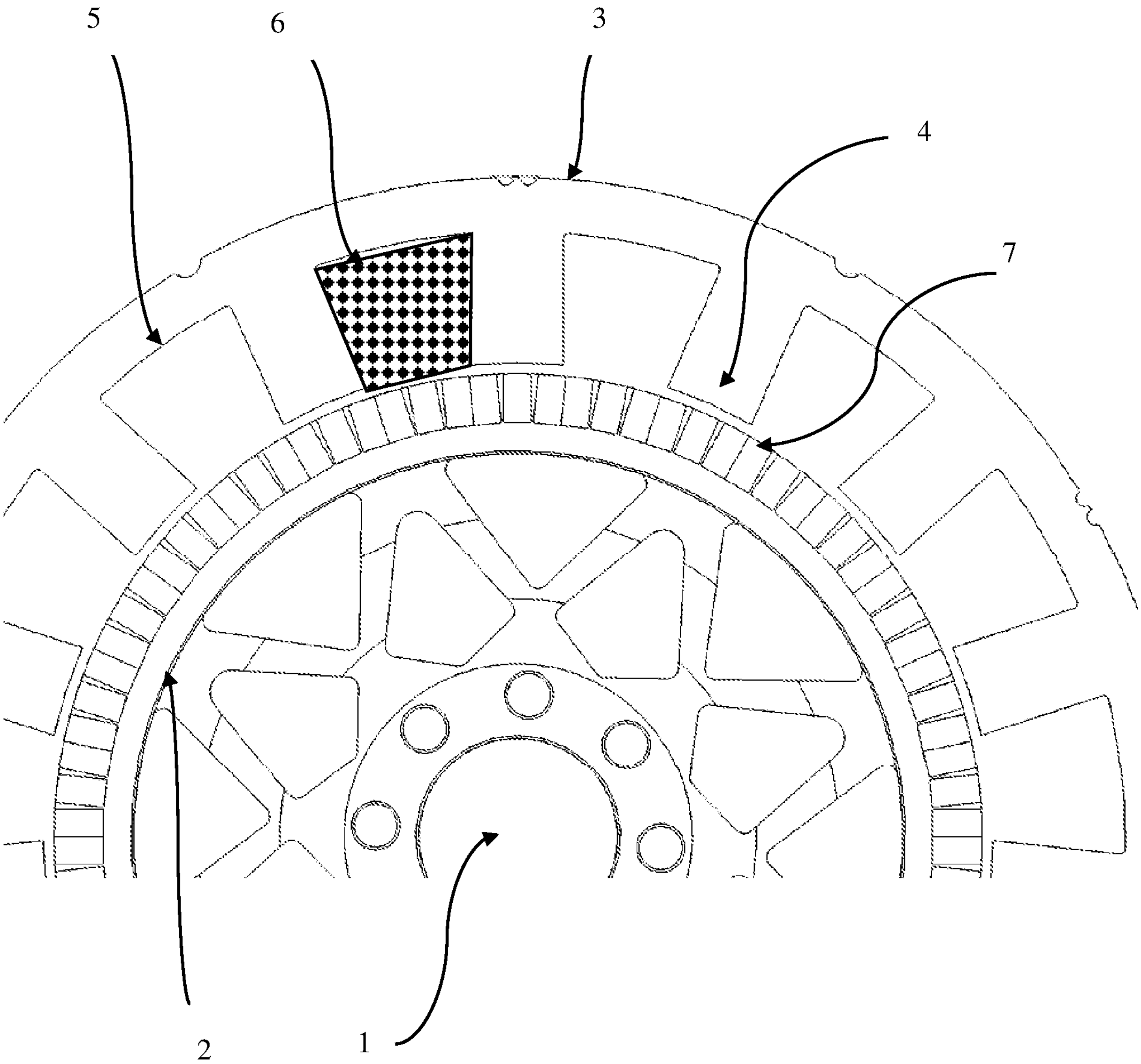

FIG. 2

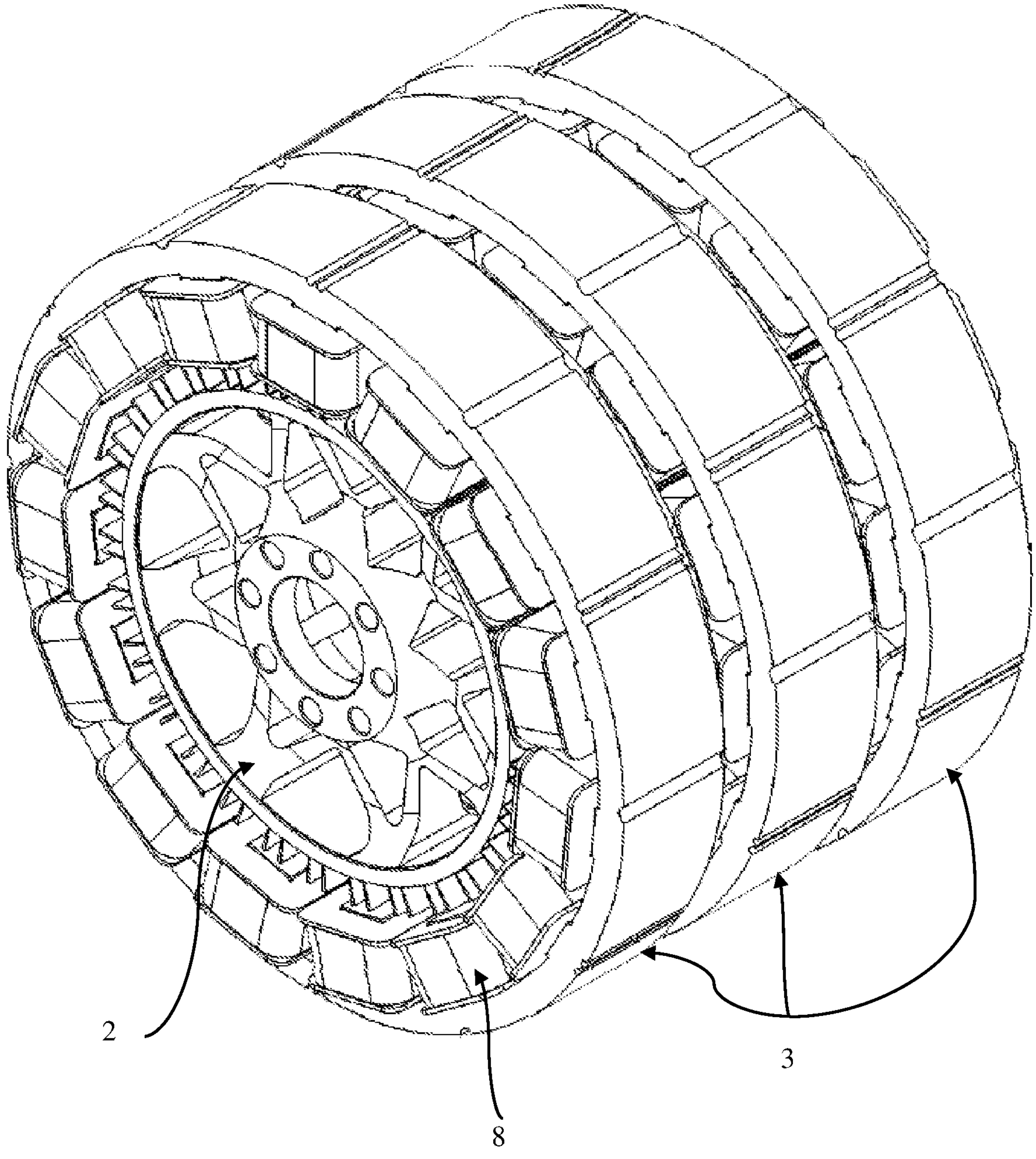

FIG.3

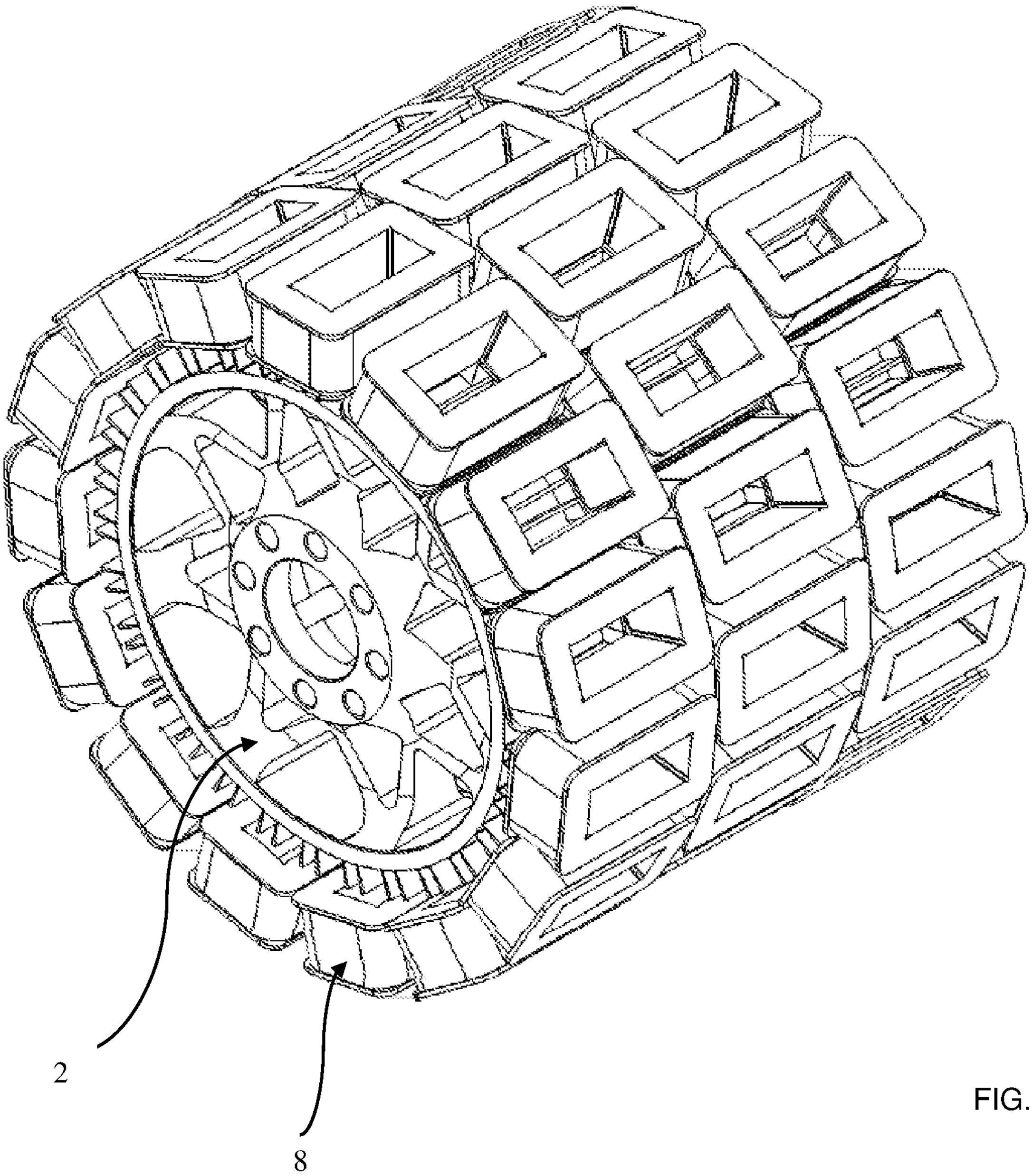

FIG. 4

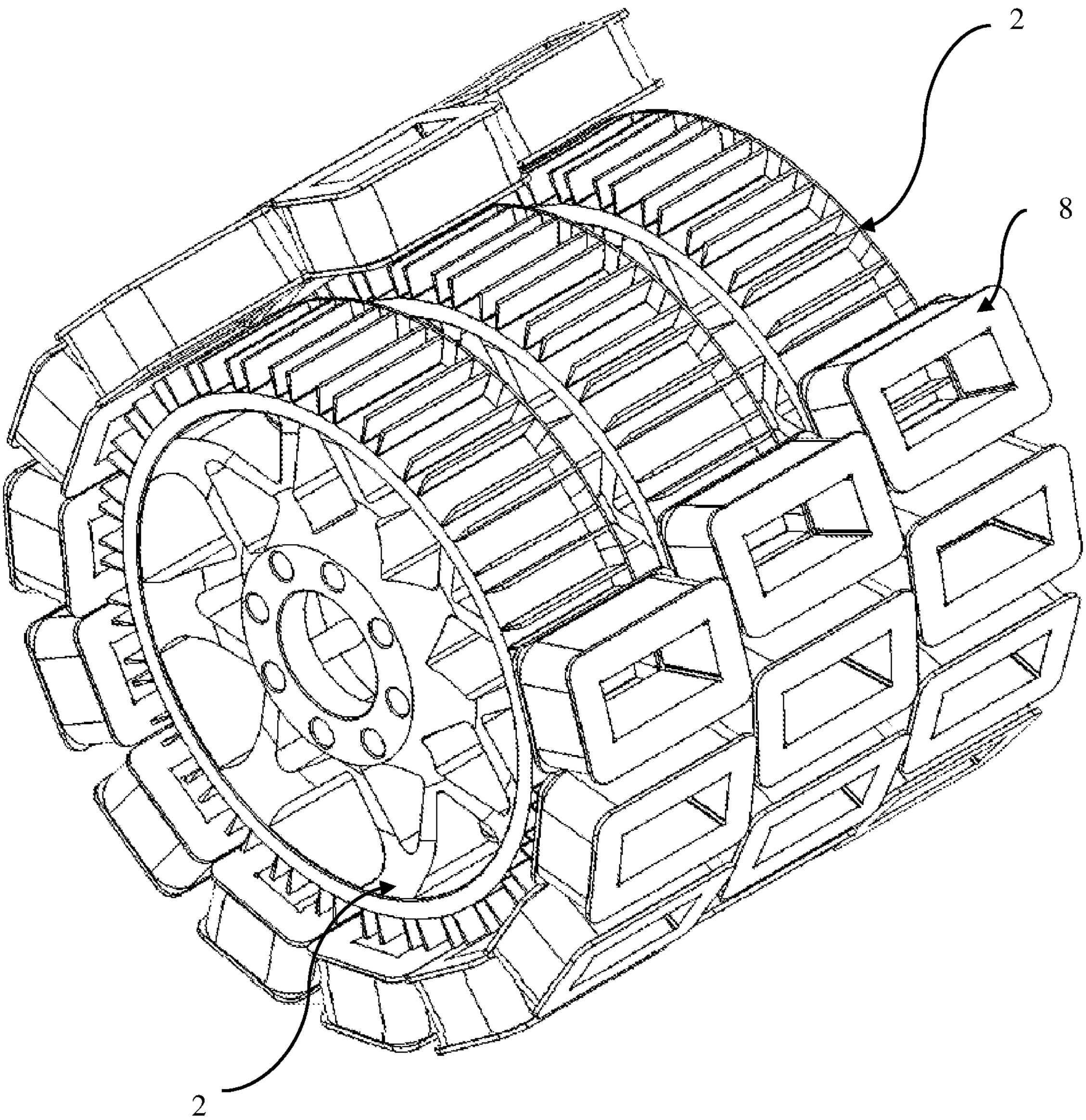

FIG. 5

	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
6	0,86	xxx	0,86	0,59	xxx	0,50	0,86	xxx	0,86	0,59	xxx	0,50	0,86	xxx	0,86	0,50	xxx	0,50	0,86	xxx
9	0,61	0,86	0,94	0,94	0,86	0,61	0,32	xxx	0,32	0,61	0,86	0,94	0,94	0,86	0,61	0,32	xxx	0,32	0,61	0,86
12	1,00	xxx	0,86	0,93	xxx	0,93	0,86	xxx	< 0,86	< 0,86	xxx	< 0,86	< 0,86	xxx	0,86	0,93	xxx	0,93	0,86	xxx
15		xxx	0.62	0,86	xxx	0,95	0,95	xxx	0,86	0,62	xxx	< 0,86	< 0,86	xxx	< 0,86	0,62	xxx	0,62	0,86	xxx
18		1,00	< 0,86	0,64	0,86	0,90	0,94	xxx	0,95	0,90	0,86	0,64	< 0,86	< 0,86	< 0,86	< 0,86	xxx	< 0,86	< 0,86	< 0,86
21			< 0,86	< 0,86	xxx	0,86	0,89	xxx	0,95	0,95	xxx	0,89	0,86	xxx	< 0,86	< 0,86	xxx	< 0,86	< 0,86	xxx
24			1,00	< 0,86	xxx	0,76	0,86	xxx	0,93	0,93	xxx	0,93	0,93	xxx	0,86	< 0,86	xxx	< 0,86	< 0,86	xxx
27				< 0,86	< 0,86	< 0,86	< 0,86	0,86	0,87	0,91	0,94	0,95	0,95	0,94	0,91	< 0,86	0,86	< 0,86	< 0,86	< 0,86
30				1,00	xxx	< 0,86	< 0,86	xxx	0,86	0,87	xxx	0,93	0,95	xxx	0,95	0,87	xxx	0,87	0,86	xxx
33					xxx	< 0,86	< 0,86	xxx	< 0,86	0,86	xxx	0,90	0,92	xxx	0,95	0,92	xxx	0,92	0,90	xxx
36					1,00	< 0,86	< 0,86	xxx	< 0,86	< 0,86	0,86	0,86	0,90	0,93	0,94	0,95	xxx	0,95	0,94	0,93
39						< 0,86	< 0,86	xxx	< 0,86	< 0,86	xxx	0,86	0,86	xxx	0,91	0,95	xxx	0,95	0,95	xxx
42						1,00	< 0,86	xxx	< 0,86	< 0,86	xxx	< 0,86	0,86	xxx	0,89	0,94	xxx	0,94	0,95	xxx

FIG. 6

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2022/050048

A. CLASSIFICATION OF SUBJECT MATTER
INV. H02K16/04 H02K21/16 H02P6/14
ADD. H02K1/14 H02K29/06

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 H02P

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 7 755 241 B2 (WYREMBA HANS-PETER [DE]) 13 July 2010 (2010-07-13) column 6, line 8 - column 7, line 2; figures 8-15 column 5, lines 36-39 column 8, lines 1-16 -----	1,2
X	JP S57 180362 A (MATSUSHITA ELECTRIC IND CO LTD) 6 November 1982 (1982-11-06) figures 4-7 -----	1,2
X	FR 2 861 226 A1 (PRECILEC [FR]) 22 April 2005 (2005-04-22) page 4, lines 8-25; figures 1-5 -----	1,2
X	CN 112 072 882 A (SHENZHEN CHENGXIN TECH CO LTD) 11 December 2020 (2020-12-11) figures 1-8 -----	1,2

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

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
10 August 2022	22/08/2022

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Maître, Jérôme

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/CZ2022/050048

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CN 112072882	A	11-12-2020	NONE			