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(54) **EXTERNAL ROTOR ELECTRIC MACHINE WITH SMC BLOCKS INTERPOSED BETWEEN PERMANENT MAGNETS**

ELEKTRISCHE AUSSENLÄUFERMASCHINE MIT ZWISCHEN PERMANENTMAGNETEN ANGEORDNETEN SMC-BLÖCKEN

MACHINE ÉLECTRIQUE À ROTOR EXTERNE À BLOCS CMS INTERCALÉS ENTRE DES AIMANTS PERMANENTS

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Description

FIELD

[0001] The present disclosure relates to external rotor electric machines. More specifically, the present disclosure is concerned with an external rotor electric machine requiring less permanent magnets.

BACKGROUND

[0002] Electric motors using rear-earth permanent magnets are used in various devices and assemblies, mainly due to their good performances. However, the earth's resources are not infinite and rare-earth permanent magnets are getting very expensive. Accordingly, the reduction of the usage of rear-earth permanent magnets in electric motors is being studied.

Prior art for applying permanent magnets in electric motors can be found in DE102013202137A1 WO2014/174572A1, EP0226586A1, US2013/200746A1 and US2002/047432A1 DE102013202137A1 relates to a rotor arrangement for a drive motor comprising a cylindrical magnetic return path element and permanent magnets which are arranged on the magnetic return path element with a radial direction of polarity in the circumferential direction in order to form the rotor poles and where the magnetic return path element has recesses which are spaced apart from one another and in which the permanent magnets are arranged, so that rotor poles are formed by a region of the magnetic return path element, which region is situated between the recesses and the permanent magnets. WO2014/174572A1 discloses a permanent magnet type motor with reduced torque ripple where the rotor is composed of m stages of rotor component units arranged in an axial direction, and the m stages of rotor component units are skewed to have a stage-skew structure with a skew angle θ, and where in the m stages of rotor component units each include rare-earth permanent magnets.

[0003] EP0226586A1 discloses an internal rotor electric machine in which the rotor has magnets and magnetically conductive blocks with two sizes.

[0004] US2013/200746A1 discloses an external rotor electric machine in which the external rotor has magnets and a stator with SMC blocks.

[0005] US2002/047432A1 discloses an internal rotor electric machine with magnets and magnetically conductive blocks with two sizes.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] In the appended drawings:

Figure 1 is a side sectional view of an external rotor electric machine according to an illustrative embodiment;

Figure 2 is a front sectional elevation view of an external rotor electric machine

Figure 3 is a front elevation view of another external rotor electric machine

Figure 4 is a front elevation view of an external rotor electric machine according to an illustrative embodiment; and

Figure 5 is a perspective view of the external rotor of an external rotor electric machine according to another illustrative embodiment.

DETAILED DESCRIPTION

[0007] Generally stated, is it proposed to decrease the quantity of permanent magnets used in an external rotor electric machine by increasing the space between adjacent permanent magnets, or by decreasing the size of the magnets, and by inserting blocks of soft magnetic material (aka ferromagnetic material) such as, for example, SMC (Soft Magnetic Composite) or magnetic powders, therebetween. These blocks will be referred to as "SMC blocks" in the present disclosure and appended claims. This addition of SMC blocks reduces the quadrature axis reluctance since it decreases the air gap thickness in the quadrature axis flux path. Accordingly, this creates a stronger supplemental reluctance torque in the electric machine, which improves performances thereof.

[0008] It has been found that by using powder metallurgy, it is possible to produces SMC blocks suitable to be positioned between adjacent permanent magnets and therefore replace some of the permanent magnets in an external rotor electric machine. As non-limiting examples, magnetic powders such as ATOMET 1 and ATOMET 3 manufactured by Rio Tinto have been found suitable to make the SMC blocks.

[0009] In accordance with an illustrative embodiment, there is provided an external rotor electric machine comprising an internal stator and an external rotor coaxial with the internal stator. The external rotor including an inner surface facing the internal stator; at least two permanent magnets and at least two SMC blocks. The permanent magnets and the SMC blocks being alternately positioned in a circumferential row on the inner surface of the rotor.

[0010] The use of the word "a" or "an" when used in conjunction with the term "comprising" in the claims and/or the specification may mean "one", but it is also consistent with the meaning of "one or more", "at least one", and "one or more than one". Similarly, the word "another" may mean at least a second or more.

[0011] As used in this specification and claim(s), the words "comprising" (and any form of comprising, such as "comprise" and "comprises"), "having" (and any form of having, such as "have" and "has"), "including" (and any form of including, such as "include" and "includes") or "containing" (and any form of containing, such as "contain" and "contains"), are inclusive or open-ended and do not exclude additional, unrecited elements or process

steps.

[0012] In the present specification and in the appended claims, various terminology which is directional, geometrical and/or spatial in nature such as "longitudinal", "horizontal", "front", rear", "upwardly", "downwardly", etc. is used. It is to be understood that such terminology is used for ease of description and in a relative sense only and is not to be taken in any way as a limitation upon the scope of the present disclosure.

[0013] The expression "connected" should be construed herein and in the appended claims broadly so as to include any cooperative or passive association between mechanical parts or components. For example, such parts may be assembled together by direct connection, or indirectly connected using further parts therebetween. The connection can also be remote, using for example a magnetic field or else.

[0014] Other objects, advantages and features of the present external rotor electric machine with reduced quantity of permanent magnets will become more apparent upon reading of the following non-restrictive description of illustrative embodiments thereof, given by way of example only with reference to the accompanying drawings.

[0015] An external rotor electric machine 10 is illustrated in a side sectional view in appended Figure 1. The electric machine 10 includes an internal stator 12 made of stacked laminations 14 and provided with coils 16 (schematically illustrated in Figure 2) conventionally placed in outwardly facing slots 17. The electric machine 10 also includes an external cylindrical rotor 18 having an inner surface 20 to which are mounted permanent magnets 22, 23 and SMC blocks 24. Permanent magnets 22 have their north pole facing the stator 12 and permanent magnets 23 have their south pole facing the stator 12.

[0016] As can be better seen from Figure 2, which is a front elevation view of the electric machine 10, the SMC blocks 24 and the permanent magnets 22, 23 are alternatively mounted to the inner surface 20 of the rotor 18. In other words, the permanent magnets 22, 23 and the SMC blocks 24 are alternately positioned in a circumferential row on the inner surface 20 of the rotor 18.

[0017] One skilled in the art will understand that an adhesive (not shown) may be provided between the SMC blocks 24 and the inner surface 20 of the rotor 18 and between the magnets 22, 23 and the inner surface 20. Alternatively, other mechanical elements (not shown) can be used to adequately mount the SMC blocks 24 and the magnets 22, 23 to the rotor 18.

[0018] In the electric machine 10, the SMC blocks 24 and the permanent magnets 22, 23 have the same dimensions and shape. Accordingly, the number of permanent magnet material reduction is about 50% compared to an all-magnets similar machine.

[0019] Figure 2 also shows the direct axis flux path 26 and the quadrature axis flux path 28. As can be understood, the air gap thickness of the quadrature axis flux path is decreased by the addition of the SMC blocks 24. The reluctance torque is therefore increased by the addition of the SMC blocks 24. Accordingly, the total torque of the electric machine is increased without an increase in input voltage.

[0020] Turning now to Figure 3 of the appended drawings, an examplary external rotor electric machine 100 will be described. It is to be noted that since the electric machine 100 is very similar to the electric machine 10 of figures 1 and 2, only the differences therebetween will be described hereinbelow, for concision purpose.

[0021] In the electric machine 100, the permanent magnets 122, 123 are not the same size and shape as the SMC blocks 124.

[0022] As will easily be understood by one skilled in the art, the profiled of the magnets creates sinewave-liked flux distribution in the air gap, which reduces the cogging torque, the harmonics in back EMF and the torque ripple. The addition of the SMC blocks 124 reduces the air gap in the quadrature axis and therefore the reluctance. Therefore the shape and size of the SMC blocks 124 in radial direction have no-relationship. However, in the circumferential direction, the size of the SMC blocks 124 should be adequate to allow the placement of the magnets and SMC blocks.

[0023] One skilled in the art will understand that the shape and size of the magnets and of the SMC blocks may be optimized to meet the specific application requirement during design process while reducing the quantity of magnet as much as possible.

[0024] In this illustrated example, there is a reduction of about 30% of the quantity of permanent material compared to a conventional machine using only permanent magnets.

[0025] One skilled in the art will understand that the reduction of the quantity of permanent magnet material used can be changed by changing the size of the permanent magnets and of the SMC blocks.

[0026] Turning now to Figure 4 of the appended drawings, an external rotor electric machine 200 according to an illustrative embodiment will be described. It is to be noted that since the electric machine 200 is very similar to the electric machines 10 and 100 described hereinabove, only the differences therebetween will be described hereinbelow, for concision purpose.

[0027] In the electric machine 200, the permanent magnets 222, 223 are not equally spaced and as a consequence, two sizes of SMC blocks 224A and 224B are present.

[0028] Indeed, to further decrease the cogging torque and the torque ripple in the machine 200, the permanent magnets 222, 223 are not equally spaced on the inner surface 20 of the rotor 18. As can be seen from this figure, the 360 degrees electric angle 226 separating two consecutive magnets 222 having their north pole facing the stator 12 is not conventionally divided in two by the magnet 223 positioned therebetween. The poles are therefore shifted.

[0029] The angle shifting of poles depends on the design requirements of the electric machine. Generally stated, 30 electric degree shifting is chosen to reduce the 6^{th} torque harmonic while 15 degree is chosen to reduce the 12^{th} torque harmonic, and so on.

[0030] In the case shown in Figure 4, a 15-degree pole shifting is applied in this configuration since the cogging and torque ripple reduction are required in the 12^{th} harmonic. Indeed, an electric angle 228 is 165 degrees instead of the conventional 180 degrees.

[0031] The SMC blocks 224A and 224B are therefore not the same size to keep a substantially equal distance between adjacent SMC blocks and magnets. The SMC blocks 224A being smaller than the SMC blocks 224B. The SMC block 224A may therefore be viewed as a small SMC block and the SMC block 224B may therefore be viewed as a large SMC block.

[0032] Turning now to Figure 5 of the appended drawings, an external rotor electric machine 300 according to another illustrative embodiment will be described. It is to be noted that since the electric machine 300 is very similar to the electric machines 10, 100 and 200 described hereinabove, only the differences therebetween will be described hereinbelow, for concision purpose.

[0033] As can be seen from this figure, the inner surface of the rotor 302 includes four (4) circumferential rows of magnets 222, 223 and of SMC blocks 224A and 224B. Each row is identical and similar to the embodiment shown in Figure 4.

[0034] However, each row is angularly shifted with regards to the previous longitudinally adjacent row. While this angular shift is of three (3) degrees according to another embodiment, other angular shift angles can also be foreseen.

[0035] This shifting from one row of segments to the next has been found to further reduce cogging torque and torque ripple.

[0036] As will be understood by one skilled in the art, the electric machines 10, 100, 200 and 300 illustrated herein and described hereinabove are schematic and lack many required elements for their operation. Indeed, only the elements relating to the comprehension of the external rotor electric machine with reduced quantity of permanent magnets have been shown and discussed.

[0037] It is to be understood that the external rotor electric machine with reduced quantity of permanent magnets is not limited in its application to the details of construction and parts illustrated in the accompanying drawings and described hereinabove. The external rotor electric machine with reduced quantity of permanent magnets is capable of other embodiments and of being practiced in various ways. It is also to be understood that the phraseology or terminology used herein is for the purpose of description and not limitation. Hence, although the external rotor electric machine with reduced quantity of permanent magnets has been described hereinabove by way of illustrative embodiments thereof, it can be modified, without departing from the scope of the claimed invention.

Claims

1. An external rotor electric machine (200) comprising:

an internal stator (12); and
an external rotor (18) coaxial with the internal stator (12);
the external rotor (18) including a cylindrical inner surface (20) facing the internal stator (12); and
at least two permanent magnets (222, 223) and at least two Soft Magnetic Composite blocks, SMC blocks, (224A, 224B),
wherein each of the at least two permanent magnets (222, 223) and each of the at least two SMC blocks (224A, 224B) are alternately positioned in a circumferential row on the cylindrical inner surface (20) of the external rotor (18);
wherein the at least two SMC blocks are of two different sizes, wherein one half of the at least two SMC blocks (224A, 224B) are small SMC blocks (224A),
wherein the other half of the at least two SMC blocks (224A, 224B) are large SMC blocks (224B) and wherein the small and large SMC blocks differ in size in the circumferential direction.

2. The external rotor electric machine (200) as recited in claim 1, wherein the shape and size of the at least two permanent magnets (222, 223) is different from the shape and size of the at least two SMC blocks (224A, 224B).

3. The external rotor electric machine (200) as recited in claim 1, wherein one half of the at least two permanent magnets (222) are so mounted to the inner surface (20) of the rotor (18) as to have a north pole facing the internal stator (12) and the other half of the at least two permanent magnets (223) are so mounted to the inner surface of the rotor (18) as to have a south pole facing the internal stator (12).

4. The external rotor electric machine (200) as recited in claim 3, wherein the circumferential positioning of the permanent magnets (222, 223) and SMC blocks (24) follows a sequence consisting of a permanent magnet (222) having a north pole facing the internal stator (12), a SMC block (224A, 224B), a permanent magnet (223) having a south pole facing the internal stator (12) and a SMC block (224A, 224B).

5. The external rotor electric machine (200) as recited in claim 1, wherein one half of the at least two permanent magnets (222) are so mounted to the inner

surface of the rotor (18) as to have a north pole facing the internal stator (12) and the other half of the at least two permanent magnets (223) are so mounted to the inner surface of the rotor (18) as to have a south pole facing the internal stator (12).

6. The external rotor electric machine (200) as recited in claim 5, wherein the circumferential positioning of the at least two permanent magnets (222, 223) and at least two SMC blocks (224A, 224B) follows a sequence consisting of a permanent magnet (222) having a north pole facing the internal stator (12), a small SMC block (224A), a permanent magnet (223) having a south pole facing the internal stator (12) and a large SMC block (224B).

7. The external rotor electric machine (200) as recited in claim 6, including at least two longitudinally adjacent circumferential rows of at least two permanent magnets (222, 223) and at least two SMC blocks (24); each circumferential row being so positioned onto the inner surface (20) of the external rotor (18) as to be angularly shifted with respect to a longitudinally adjacent circumferential row.

8. The external rotor electric machine (200) as recited in claim 7, including four longitudinally adjacent circumferential rows of at least two permanent magnets (222, 223) and at least two SMC blocks (224A, 224B).

9. The external rotor electric machine (200) as recited in claim 1, including at least two longitudinally adjacent circumferential rows each including at least two permanent magnets (222, 223) and at least two SMC blocks (224A, 224B); each circumferential row being so positioned onto the inner surface of the external rotor (18) as to be angularly shifted with respect to a longitudinally adjacent circumferential row.

10. The external rotor electric machine (200) as recited in claim 9, including four longitudinally adjacent circumferential rows of at least two permanent magnets (222, 223) and at least two SMC blocks (224A, 224B).

Patentansprüche

1. Elektrische Maschine (200) mit Außenläufer, umfassend:

einen Innenstator (12) und
einen Außenläufer (18), koaxial zu dem Innenstator (12);
wobei der Außenläufer (18) eine zylindrische Innenfläche (20) aufweist, die dem Innenstator (12) zugewandt ist; und
mindestens zwei Permanentmagnete (222, 223) und mindestens zwei weichmagnetische Verbundblöcke, SMC-Blöcke, (224A, 224B), wobei jeder der mindestens zwei Permanentmagnete (222, 223) und jeder der mindestens zwei SMC-Blöcke (224A, 224B) abwechselnd in einer Umfangsreihe auf der zylindrischen Innenfläche (20) des Außenläufers (18) angeordnet sind;
wobei die mindestens zwei SMC-Blöcke zwei verschiedene Grö-βen haben, wobei eine Hälfte der mindestens zwei SMC-Blöcke (224A, 224B) kleine SMC-Blöcke (224A) sind,
wobei die andere Hälfte der mindestens zwei SMC-Blöcke (224A, 224B) große SMC-Blöcke (224B) sind und wobei die kleinen und großen SMC-Blöcke sich in der Umfangsrichtung in ihrer Größe unterscheiden.

2. Elektrische Maschine (200) mit Außenläufer nach Anspruch 1, wobei die Form und Größe der mindestens zwei Permanentmagneten (222, 223) sich von der Form und Größe der mindestens zwei SMC-Blöcke (224A, 224B) unterscheidet.

3. Elektrische Maschine (200) mit Außenläufer nach Anspruch 1, wobei eine Hälfte der mindestens zwei Permanentmagneten (222) so an der Innenfläche (20) des Läufers (18) angebracht ist, dass ein Nordpol dem Innenstator (12) zugewandt ist, und die andere Hälfte der mindestens zwei Permanentmagneten (223) so an der Innenfläche des Rotors (18) angebracht ist, dass ein Südpol dem Innenstator (12) zugewandt ist.

4. Elektrische Maschine (200) mit Außenläufer nach Anspruch 3, wobei die Positionierung der Permanentmagneten (222, 223) und SMC-Blöcke (24) in Umfangsrichtung einer Abfolge folgt, die einen Permanentmagneten (222) mit einem dem Innenstator (12) zugewandten Nordpol, einen SMC-Block (224A, 224B), einen Permanentmagneten (223) mit einem dem Innenstator (12) zugewandten Südpol und einen SMC-Block (224A, 224B) umfasst.

5. Elektrische Maschine (200) mit Außenläufer nach Anspruch 1, wobei eine Hälfte der mindestens zwei Permanentmagnete (222) so an der Innenfläche des Läufers (18) angebracht ist, dass ein Nordpol dem Innenstator (12) zugewandt ist, und die andere Hälfte der mindestens zwei Permanentmagneten (223) so an der Innenfläche des Läufers (18) angebracht ist, dass ein Südpol dem Innenstator (12) zugewandt ist.

6. Elektrische Maschine (200) mit Außenläufer nach Anspruch 5, wobei die Positionierung der mindestens zwei Permanentmagneten (222, 223) und der

mindestens zwei SMC-Blöcken (224A, 224B) in Umfangsrichtung in einer Abfolge erfolgt, die einen Permanentmagneten (222) mit einem dem Innenstator (12) zugewandten Nordpol, einen kleinen SMC-Block (224A), einne Permanentmagneten (223) mit einem dem Innenstator (12) zugewandten Südpol und einen großen SMC-Block (224B) umfasst.

7. Elektrische Maschine (200) mit Außenläufer nach Anspruch 6, mit mindestens zwei in Längsrichtung benachbarten Umfangsreihen von mindestens zwei Permanentmagneten (222, 223) und mindestens zwei SMC-Blöcken (24); wobei jede Umfangsreihe so auf der Innenfläche (20) des Außenläufers (18) positioniert ist, dass sie in Bezug auf eine in Längsrichtung benachbarte Umfangsreihe winkelmäßig versetzt ist.

8. Elektrische Maschine (200) mit Außenläufer nach Anspruch 7, die vier in Längsrichtung benachbarte Umfangsreihen mit mindestens zwei Permanentmagneten (222, 223) und mindestens zwei SMC-Blöcken (224A, 224B) aufweist.

9. Elektrische Maschine (200) mit Außenläufer nach Anspruch 1, mit mindestens zwei in Längsrichtung benachbarten Umfangsreihen, die jeweils mindestens zwei Permanentmagnete (222, 223) und mindestens zwei SMC-Blöcke (224A, 224B) enthalten, wobei jede Umfangsreihe so auf der Innenfläche des Außenläufers (18) positioniert ist, dass sie in Bezug auf eine in Längsrichtung benachbarte Umfangsreihe winkelmäßig versetzt ist.

10. Elektrische Maschine (200) mit Außenläufer nach Anspruch 9, mit vier in Längsrichtung benachbarten Umfangsreihen mit mindestens zwei Permanentmagneten (222, 223) und mindestens zwei SMC-Blöcken (224A, 224B).

Revendications

1. Machine électrique à rotor externe (200) comprenant :

un stator interne (12) ; et
un rotor externe (18) qui est coaxial par rapport au stator interne (12) ;
le rotor externe (18) incluant une surface interne cylindrique (20) qui fait face au stator interne (12) ; et
au moins deux aimants permanents (222, 223) et au moins deux blocs composites magnétiques doux, soit des blocs SMC, (224A, 224B) ; dans laquelle chacun des au moins deux aimants permanents (222, 223) et chacun des au moins deux blocs SMC (224A, 224B) sont positionnés en alternance selon une rangée circonférentielle sur la surface interne cylindrique (20) du rotor externe (18) ;
dans laquelle les au moins deux blocs SMC sont de deux dimensions différentes ; dans laquelle une moitié des au moins deux blocs SMC (224A, 224B) est constituée par des petits blocs SMC (224A) ;
dans laquelle l'autre moitié des au moins deux blocs SMC (224A, 224B) est constituée par des grands blocs SMC (224B) ; et dans laquelle les petits et grands blocs SMC diffèrent en termes de dimension dans la direction circonférentielle.

2. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 1, dans laquelle la forme et la dimension des au moins deux aimants permanents (222, 223) sont différentes de la forme et de la dimension des au moins deux blocs SMC (224A, 224B).

3. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 1, dans laquelle une moitié des au moins deux aimants permanents (222) est montée sur la surface interne (20) du rotor (18) de telle sorte qu'un pôle Nord fasse face au stator interne (12) et l'autre moitié des au moins deux aimants permanents (223) est montée sur la surface interne du rotor (18) de telle sorte qu'un pôle Sud fasse face au stator interne (12).

4. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 3, dans laquelle le positionnement circonférentiel des aimants permanents (222, 223) et des blocs SMC (24) suit une séquence constituée par un aimant permanent (222) qui comporte un pôle Nord qui fait face au stator interne (12), un bloc SMC (224A, 224B), un aimant permanent (223) qui comporte un pôle Sud qui fait face au stator interne (12) et un bloc SMC (224A, 224B).

5. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 1, dans laquelle une moitié des au moins deux aimants permanents (222) est montée sur la surface interne du rotor (18) de telle sorte qu'un pôle Nord fasse face au stator interne (12) et l'autre moitié des au moins deux aimants permanents (223) est montée sur la surface interne du rotor (18) de telle sorte qu'un pôle Sud fasse face au stator interne (12).

6. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 5, dans laquelle le positionnement circonférentiel des au moins deux aimants permanents (222, 223) et des au moins deux blocs SMC (224A, 224B) suit une séquence constituée par un aimant permanent (222) qui com-

porte un pôle Nord qui fait face au stator interne (12), un petit bloc SMC (224A), un aimant permanent (223) qui comporte un pôle Sud qui fait face au stator interne (12) et un grand bloc SMC (224B).

7. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 6, incluant au moins deux rangées circonférentielles adjacentes longitudinalement d'au moins deux aimants permanents (222, 223) et d'au moins deux blocs SMC (24) ; chaque rangée circonférentielle étant positionnée sur la surface interne (20) du rotor externe (18) de telle sorte qu'elle soit décalée angulairement par rapport à une rangée circonférentielle adjacente longitudinalement.

8. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 7, incluant quatre rangées circonférentielles adjacentes longitudinalement d'au moins deux aimants permanents (222, 223) et d'au moins deux blocs SMC (224A, 224B).

9. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 1, incluant au moins deux rangées circonférentielles adjacentes longitudinalement dont chacune inclut au moins deux aimants permanents (222, 223) et au moins deux blocs SMC (224A, 224B) ; chaque rangée circonférentielle étant positionnée sur la surface interne du rotor externe (18) de telle sorte qu'elle soit décalée angulairement par rapport à une rangée circonférentielle adjacente longitudinalement.

10. Machine électrique à rotor externe (200) telle que revendiquée selon la revendication 9, incluant quatre rangées circonférentielles adjacentes longitudinalement d'au moins deux aimants permanents (222, 223) et d'au moins deux blocs SMC (224A, 224B).

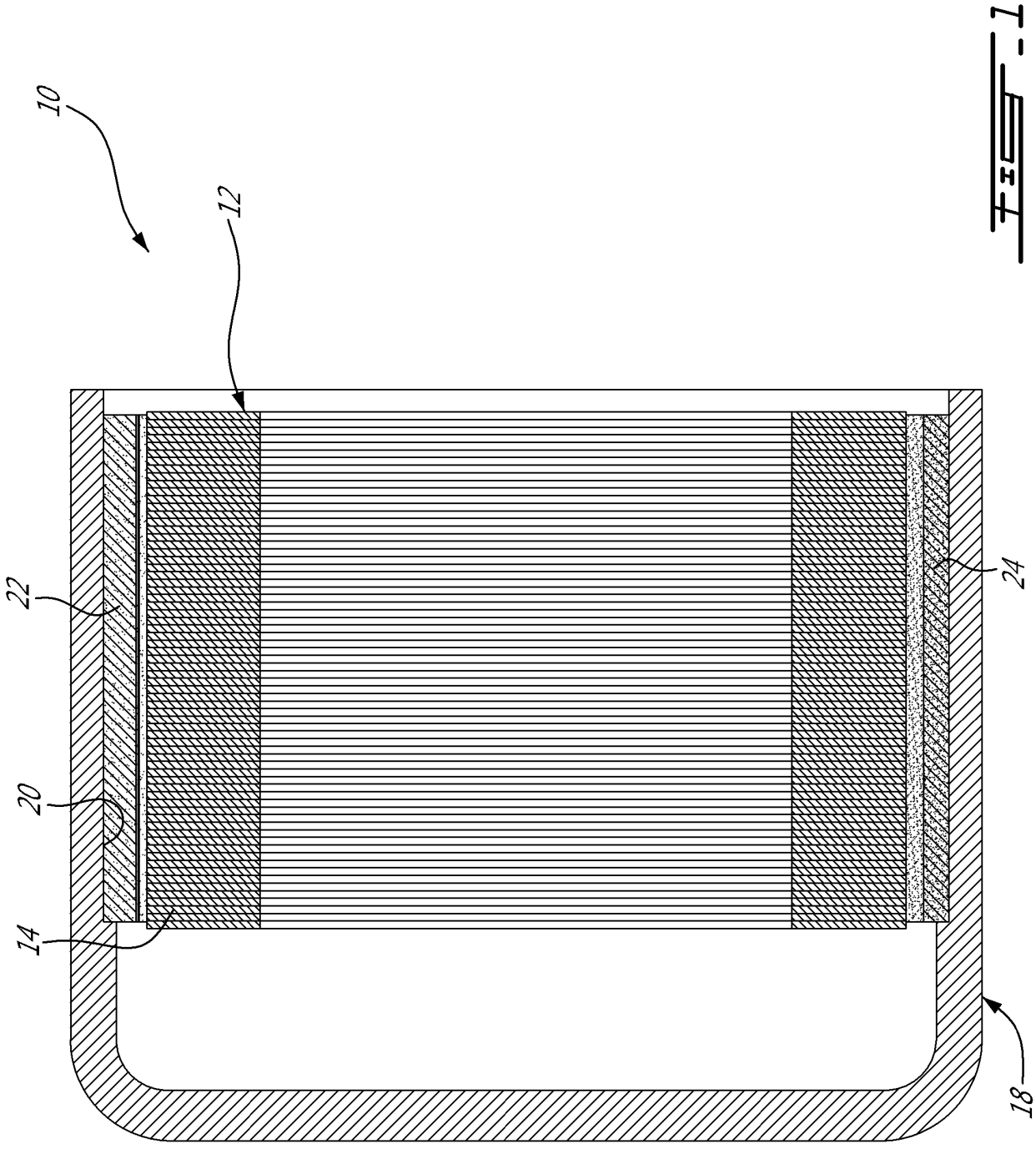


Fig. 1

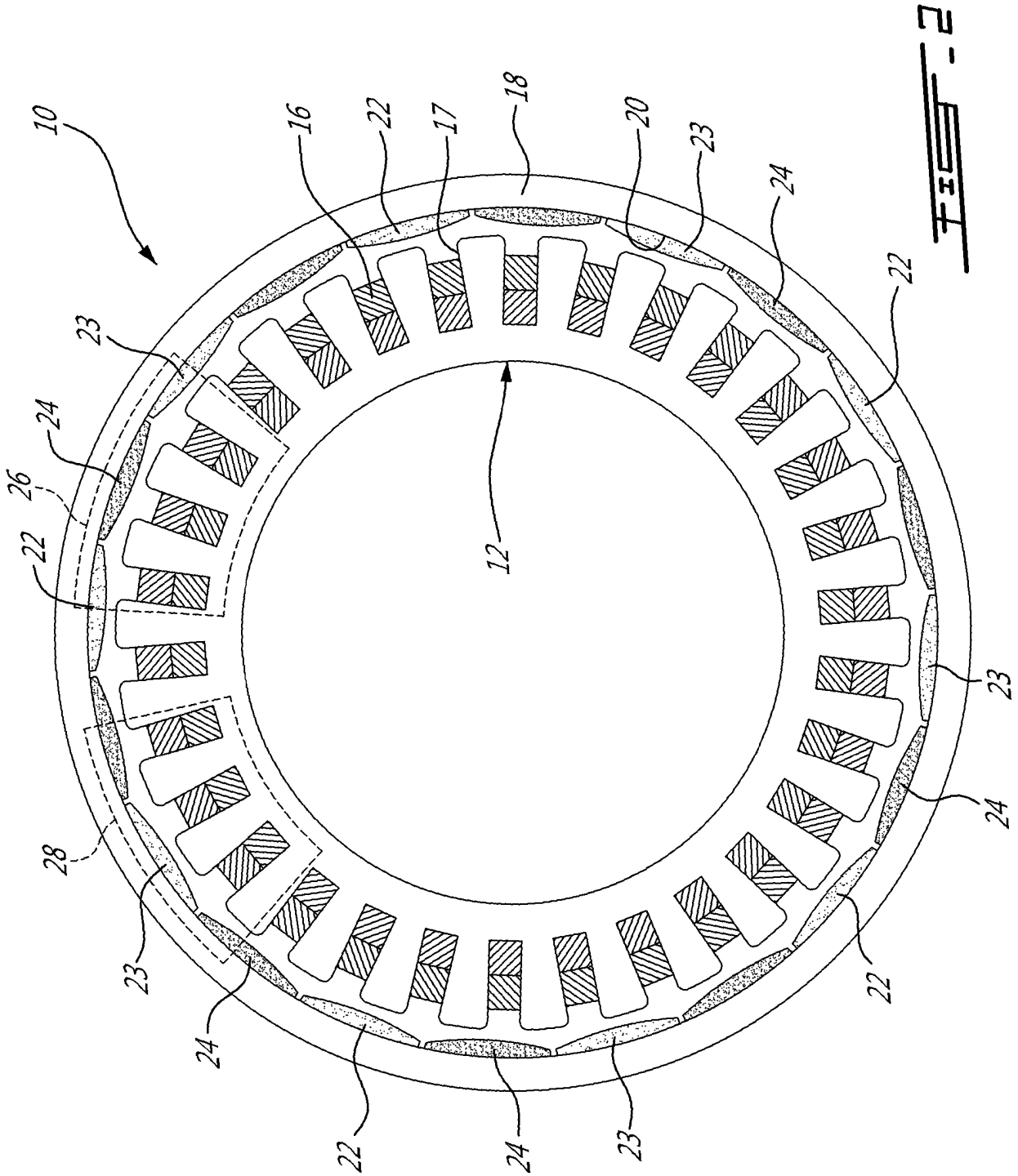
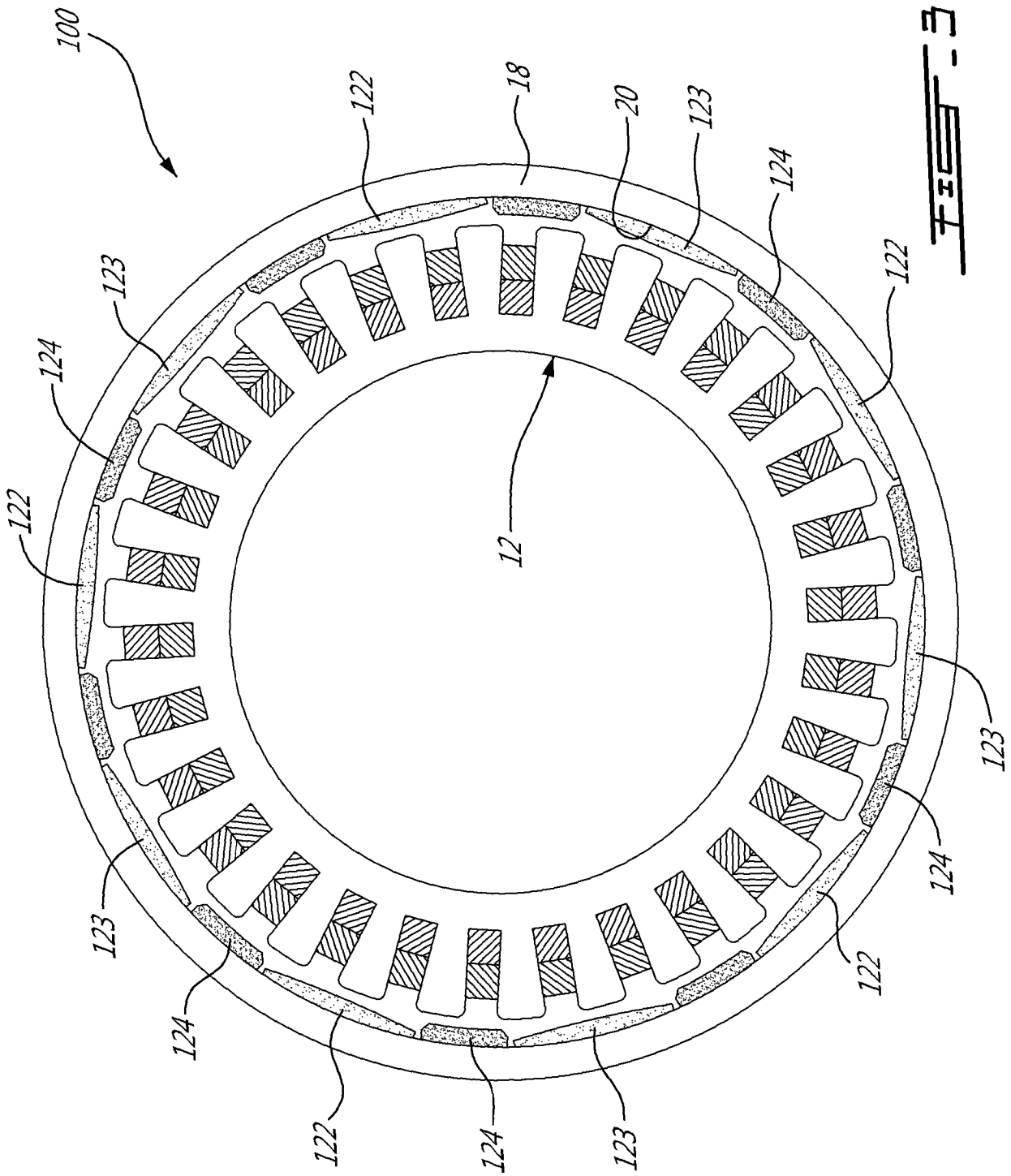


Fig-2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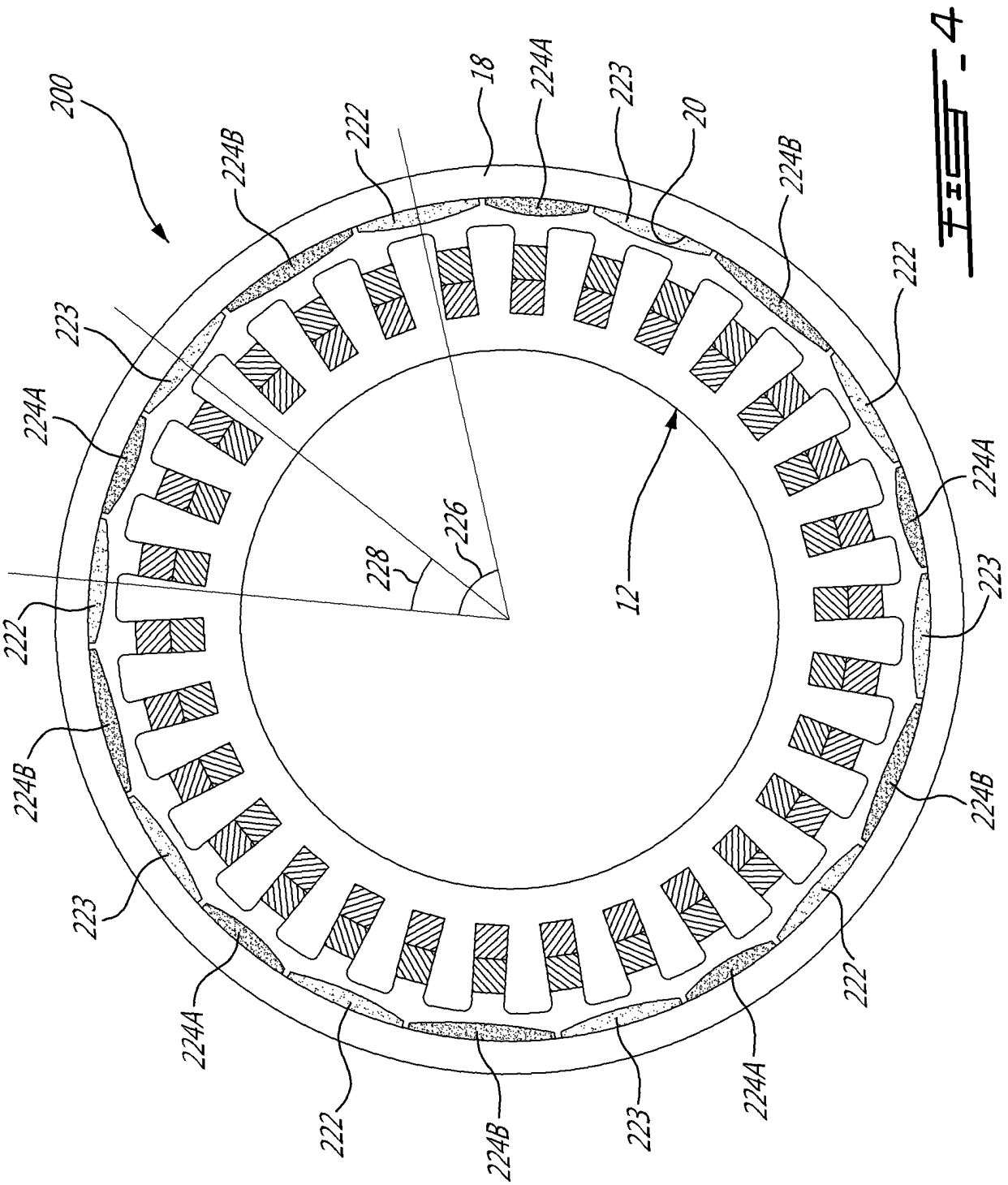
123

Fig. 3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224A
223
224B
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224A
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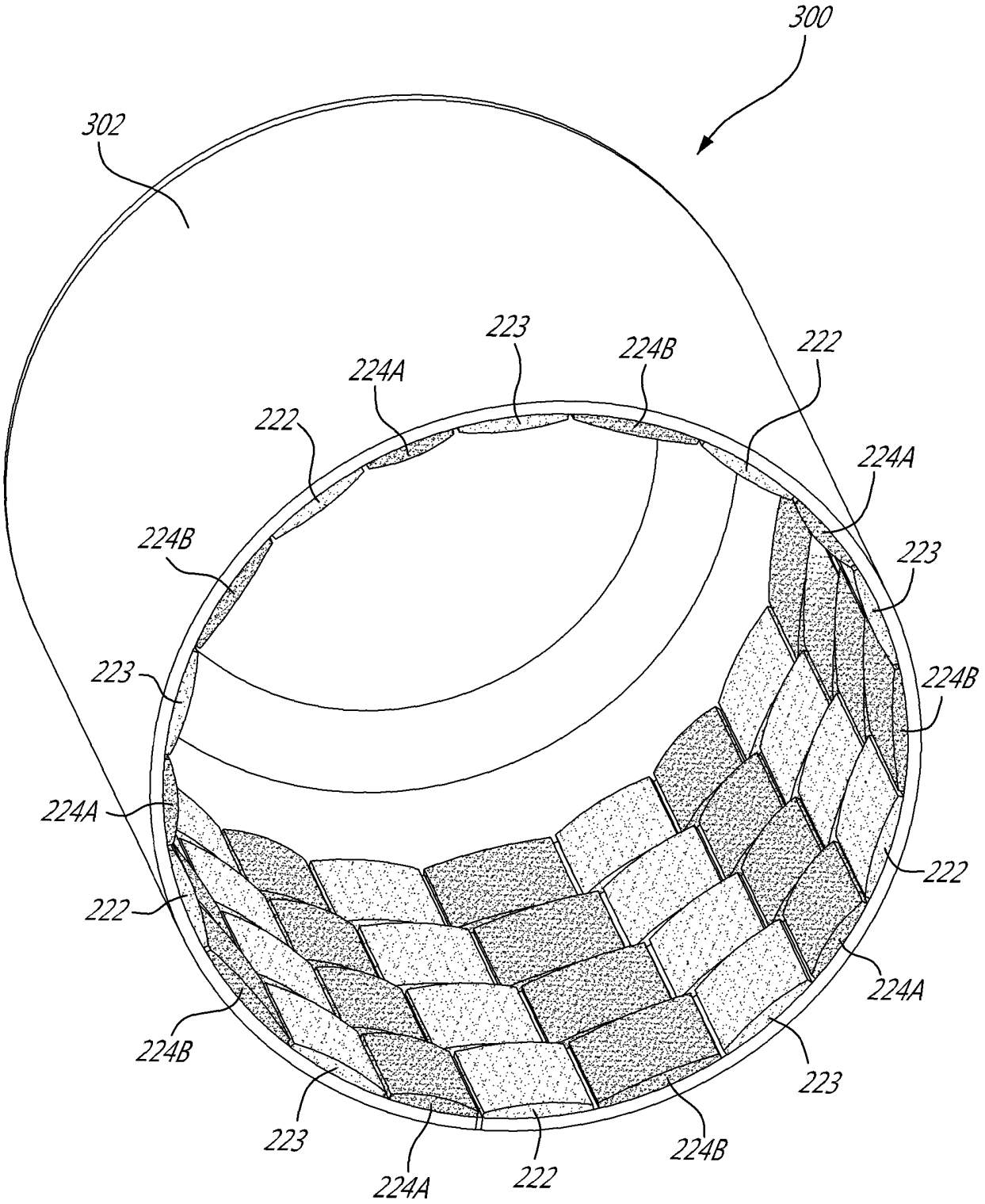
224A
223
224B
222
12
228
226

Fig. 4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224A
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224A
224B
223
223
224B
224A
222
222
224A
224B
223
223
224B
224A
222

Fig. 5

REFERENCES CITED IN THE DESCRIPTION

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