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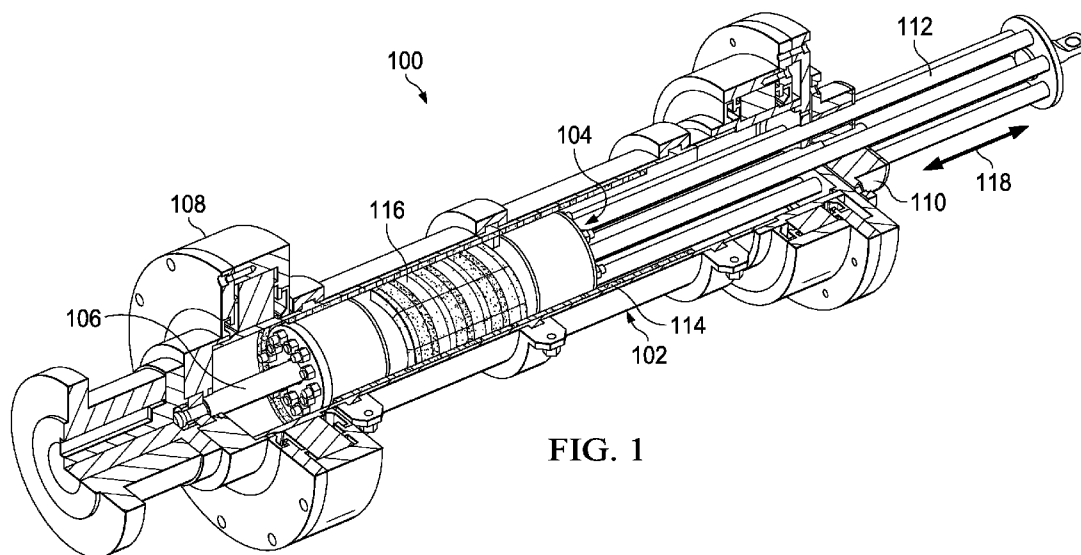


FIG. 1

(57) Abstract: A magnetic linear actuator includes a rotor, a first end cap, a second end cap, a translator, and a guide rod. The rotor includes a first helical array of magnets. The first end cap is disposed at a first end of the rotor. The second end cap is disposed at a second end of the rotor. The second end is opposite the first end. The translator is disposed within the rotor, and includes a second helical array of magnets. The guide rod passes through the translator and includes a first end that engages the first end cap, and a second end that engages the second end cap.



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MAGNETIC LINEAR ACTUATOR

BACKGROUND

A linear actuator is a device that creates straight line motion. Various techniques are employed to produce linear motion. Some linear actuators apply hydraulic pressure to move a piston. Other implementations of a linear actuator convert rotary motion into linear motion. For example, a threaded shaft, or a nut or roller screw assembly coupled to the threaded shaft, may be rotated to longitudinally extend or retract the shaft. An electric motor may provide the rotation needed to translate the shaft.

SUMMARY

[0001] Magnetic linear actuators that include a guide rod to restrain lateral and rotary motion of the translator are disclosed herein. In one example, a magnetic linear actuator includes a rotor, a first end cap, a second end cap, a translator, and a guide rod. The rotor includes a first helical array of magnets. The first end cap is disposed at a first end of the rotor. The second end cap is disposed at a second end of the rotor. The second end of the rotor is opposite the first end of the rotor. The translator is disposed within the rotor, and includes a second helical array of magnets. The guide rod passes through the translator and includes a first end that engages the first end cap, and a second end that engages the second end cap. The first end of the guide rod is affixed to the first end cap, and the second end of the guide rod is affixed to the second end cap. The guide rod comprises one or more splines that extend over a length of the guide rod. The translator includes a spline bearing keyed to engage the one or more splines of the guide rod, a first longitudinal end comprising a first aperture for passage of the guide rod, and a second longitudinal end, opposite the first longitudinal end, comprising a second aperture for passage of the guide rod. The translator includes a shaft extending

from the second end, and the second end cap includes aperture through which the shaft passes. The first helical array of magnets includes magnets arranged as a Halbach array; and the second helical array of magnets includes magnets arranged as a Halbach array. The translator is configured to convert rotary motion to linear motion, and move longitudinally within the rotor responsive to rotation of the rotor. The guide rod is configured to restrain rotation and lateral movement of the translator.

[0002] In another example, a magnetic linear actuator includes a rotor, a translator, and a guide rod. The rotor includes a first helical array of magnets. The translator includes a second helical array of magnets, and is configured to convert rotary motion to linear motion and move longitudinally within the rotor responsive to rotation of the rotor. The guide rod passes through a first longitudinal end and a second longitudinal end of the translator, and is configured to restrain rotary and lateral motion of the translator. The magnetic linear actuator also includes a first end cap and a second end cap. The first end cap is disposed at a first end of the rotor, and engages a first end of the guide rod. The second end cap is disposed at a second end of the rotor, and engages a second end of the guide rod. The first end of the guide rod is affixed to the first end cap, and the second end of the guide rod is affixed to the second end cap. The guide rod includes one or more splines that extend over a length of the guide rod. The translator includes a spline bearing keyed to engage the one or more splines of the guide rod. The first longitudinal end of the translator includes a first aperture for passage of the guide rod. The second longitudinal end of the translator is opposite the first longitudinal end of the translator, and comprises a second aperture for passage of the guide rod. The translator includes a shaft extending from the second end, and the second end cap includes aperture through which the shaft passes. The first helical array

of magnets includes magnets arranged as a Halbach array, and the second helical array of magnets includes magnets arranged as a Halbach array.

In a further example, a method for magnetic linear actuation includes rotating a rotor comprising a first helical array of magnets. A translator, comprising a second helical array of magnets, is longitudinally translated within the rotor responsive to rotation of the rotor. An air gap between the first helical array of magnets and the second helical array of magnets is maintained by restraining lateral motion of the translator via a guide rod that passes through a first longitudinal end and a second longitudinal end the translator. The method may also include restraining rotary motion of the translator via the guide rod. The method may also include engaging a first end of the guide rod at a first end cap disposed at a first longitudinal end of the rotor, and engaging a second end of the guide rod at a second end cap disposed at a second longitudinal end of the rotor. The method may also include moving a shaft coupled to the translator through an aperture of the second end cap with movement of the translator. Magnets of the first helical array may be arranged as a Halbach array. Magnets of the second helical array may be arranged as a Halbach array.

BRIEF DESCRIPTION OF THE DRAWINGS

[0003] For a detailed description of various examples, reference will now be made to the accompanying drawings in which:

[0004] FIGS. 1 and 2 show partially sectional views of an example magnetic linear actuator that includes a guide rod to restrain rotary and lateral motion in accordance with the present disclosure;

[0005] FIG. 3 shows a cross-sectional view of an example translator and guide rod for use in a magnetic linear actuator in accordance with the present disclosure;

[0006] FIG. 4 shows a cross-sectional view of an example translator and guide rod for use in a magnetic linear actuator in accordance with the present disclosure;

[0007] FIGS. 5A and 5B show a view of an example air gap provided between a rotor and a translator of a magnetic linear actuator in accordance with the present disclosure;

[0008] FIG. 6 shows an example magnet array in which the magnets are arranged in a north-south orientation;

[0009] FIG. 7 shows an example magnet array in which the magnets are arranged as a Halbach array;

[0010] FIGS. 8A and 8B show examples of magnets arranged as a helical Halbach array on a rotor and translator of a magnetic linear actuator in accordance with the present disclosure; and

[0011] FIG. 9 shows a flow diagram for a method for magnetic linear actuation in accordance with the present disclosure.

DETAILED DESCRIPTION

[0012] The following discussion is directed to various exemplary embodiments. However, one of ordinary skill in the art will understand that the examples disclosed herein have broad application, and that the discussion of any embodiment is meant only to be exemplary of that embodiment, and not intended to suggest that the scope of the disclosure, including the claims, is limited to that embodiment. The exemplary embodiments presented herein, or any elements thereof, may be combined in a variety of ways, i.e., any element from one exemplary embodiment may be used in any other exemplary embodiment, without departing from the scope of the disclosure.

[0013] The drawing figures are not necessarily to scale. Certain features and components herein may be shown exaggerated in scale or in somewhat schematic form

and some details of conventional elements may not be shown in interest of clarity and conciseness.

[0014] In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to...”. Also, the term “couple” or “couples” is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection of the two devices, or through an indirect connection that is established via other devices, components, nodes, and connections. In addition, as used herein, the terms “axial” and “axially” generally mean along or parallel to a given axis (e.g., central axis of a body or a port), while the terms “radial” and “radially” generally mean perpendicular to the given axis. For instance, an axial distance refers to a distance measured along or parallel to the axis, and a radial distance means a distance measured perpendicular to the axis.

[0015] Linear actuators that convert rotary motion generated by an electric motor to linear motion are subject to a number of limitations. For example, the linear force produced by such actuators is generally lower than the force provided by a hydraulic device, friction between the various components of such actuators limits the life of the actuator, and the cost of the actuators may be relatively high. Moreover, threads and pneumatics of conventional linear actuators can be overloaded and damaged.

[0016] Magnetic linear actuators reduce or eliminate friction between parts by using interaction of magnetic fields to convert rotary motion to linear motion. When magnetic linear actuators are overloaded, they slip but are not damaged. The magnetic linear actuators disclosed herein include a translator and rotor, each of which includes a helical array of magnets producing a magnetic field. Rotation of one of the translator or rotor induces linear motion of one or the other of the translator or rotor by interaction of the

magnetic fields. For example, rotation of the rotor may induce linear motion of the translator to maintain alignment of the magnetic fields. To reduce the size of the air gap between the translator and rotor, and thereby increase the strength of the magnetic flux between the translator and rotor, the magnetic linear actuators of the present disclosure include a guide rod that passes through the translator. The guide rod enables longitudinal movement of the translator while inhibiting lateral and rotary motion of the translator to maintain a relatively small air gap between the translator and rotor.

[0017] FIG. 1 shows a partially sectional view of a magnetic linear actuator 100 that includes a guide rod to restrain rotary and lateral motion in accordance with the present disclosure. The magnetic linear actuator 100 includes a rotor 102, a translator 104, a guide rod 106, an end cap 108, an end cap 110, and a shaft 112. The rotor 102 may be generally cylindrical in shape and includes magnets 114 arranged in a helical array about an inner surface of the rotor 102. The rotor 102 may rotate on bearings disposed at both longitudinal ends thereof.

[0018] The translator 104 is disposed within the bore of the rotor 102. The bore and the translator 104 may be generally cylindrical in shape. The translator 104 includes magnets 116 arranged in a helical array disposed on the outer circumference of the translator 104. A shaft 112 extends from the translator 104 in some implementations of the magnetic linear actuator 100. Interaction of the magnetic fields produced by the magnets 114 and the magnets 116 cause the translator 104 to move longitudinally (in the direction 118) responsive to rotation of the rotor 102. Rotation of the rotor 102 in a first direction may cause the translator 104 to move longitudinally within the rotor 102 from the first end of the rotor 102 to the second end of the rotor 102, and rotation of the rotor 102 in a second direction (opposite the first direction) may cause the translator 104 to move longitudinally within the rotor 102 from the second end of the rotor 102 to the

first end of the rotor 102. Thus, rotation of the rotor 102 produces force in the direction 118 as the translator 104 moves towards or away from the end cap 110.

[0019] The magnetic field strength between the rotor 102 and the translator 104 (and the force produced by linear movement of the translator 104 within the rotor 102) is increased by reducing the air gap between the magnets 114 and the magnets 116. As the size of the air gap is reduced, eccentricity (deflection) of the translator 104 is increasingly likely to cause the magnets 116 to contact the magnets 114 or other inner surface of the rotor 102, and damage the rotor 102 and/or the translator 104. To prevent such damage, the guide rod 106 passes through and restricts movement of the translator 104. The guide rod 106 is a splined shaft that allows longitudinal movement of the translator and restrains or inhibits lateral and rotary motion of the translator 104. The translator 104 includes a guide ring (e.g., linear bearings) that engages grooves of the guide rod 106 to restrain lateral and rotary movement of the translator 104. Because lateral movement of the translator is restrained by the guide rod 106, the air gap between the rotor 102 and the translator 104 may be reduced and the magnetic field strength between the rotor 102 and the translator 104 may be increased. For example, in some implementations of the magnetic linear actuator 100, the air gap may be in a range of 0.006 inches to 0.10 inches.

[0020] The guide rod 106 engages and is affixed to the end cap 108 and the end cap 110. The end cap 108 is disposed at one end of the rotor 102, and the end cap 110 is disposed at the opposite end of the rotor 102. Accordingly, one end of the guide rod 106 engages and is affixed to the end cap 108, and an opposite end of the guide rod 106 engages and is affixed to the end cap 110 to inhibit rotation and lateral motion of the guide rod 106.

[0021] As rotation of the rotor 102 in a first direction causes the translator 104 to move towards the end cap 110, the shaft 112 moves and extends through an aperture of the end cap 110. As rotation of the rotor 102 in a second direction causes the translator 104 to move towards the end cap 108, the shaft 112 moves and retracts through the aperture of the end cap 110. The magnetic linear actuator 100 may include any number of shafts 112, and the end cap 110 may include a number of apertures corresponding to the number of shafts 112.

[0022] FIG. 2 shows another view of the magnetic linear actuator 100 with a sectional view of the translator 104. In FIG. 2, the guide rod 106 is shown passing through (passing between the two longitudinal ends of) the translator 104. The translator 104 includes a linear spline bearing 120 (a self-sealed linear spline bearing) through which the guide rod 106 passes to restrain lateral and rotary motion of the translator 104, while enabling longitudinal movement of the translator 104. The shaft 112 is shown affixed to and extending from the translator 104, and passing through the aperture 202 and seal 204 of the end cap 110.

[0023] FIG. 3 shows a view of the translator 104 in isolation. The translator 104 is subjected to axial (longitudinal), radial (lateral), and rotary forces responsive to rotation of the rotor 102. The translator 104 includes a cylindrical body 302, and end plate 304 attached to a first end of the cylindrical body 302, and an end plate 306 attached to a second (opposite) end of the cylindrical body 302. The guide rod 106 passes through an aperture 308 in the end plate 304, and a corresponding aperture in the end plate 306. The guide rod 106 allows longitudinal movement of the translator 104, and restrains lateral and rotary movement of the translator 104.

[0024] FIG. 4 shows a cross-sectional view of the translator 104. The translator 104 includes a linear spline bearing 120 through which the guide rod 106 passes to restrain

lateral and rotary motion of the translator 104, while enabling longitudinal movement of the translator 104. Some implementations of the translator 104 may include seals, such as the seals through which the guide rod 106 passes, and a guide ring, which may be a bushing or a linear bearing keyed to engage grooves of the guide rod 106 and inhibit rotation of the translator 104.

[0025] FIGS. 5A and 5B show a view of an example air gap 502 provided between the rotor 102 and the translator 104. The air gap 502 may be about 2 millimeters wide in some implementations of the magnetic linear actuator 100.

[0026] In some implementations of the rotor 102 and the translator 104, the magnets 114 and the magnets 116 are arranged as Halbach arrays. FIG. 6 shows an example magnet array 600 in which the magnets 602-610 are arranged in a north-south orientation. The magnets 602, 606, and 610 are oriented in one direction, and the magnets 604 and 608 are oriented in the opposite direction. In a Halbach array, the magnets are not arranged in a north-south orientation or alternating polarity as in the magnet array 600. Rather, in a Halbach array, the magnets are arranged in a north-east-south-west orientation that pushes the flux of the array in one direction. Because flux density and linkage are important to increasing performance in electric rotating machines, the Halbach array is very advantageous.

[0027] FIG. 7 shows an example Halbach array 700. The Halbach array 700 includes magnets 702-710, where each successive magnet is rotated 90° counterclockwise with respect to the previous magnet (e.g., magnet 704 is rotated 90° counterclockwise with respect to magnet 702, magnet 706 is rotated 90° counterclockwise with respect to magnet 704, etc.). This arrangement increases the magnet flux on side 712 of the of the Halbach array 700, and decreases the magnetic flux on the side 714 of the Halbach array 700. In an implementation of the rotor 102, a side of the magnets 114 nearest the

translator 104 corresponds to the side 712 of the Halbach array 700, and in an implementation of the translator 104, the side of the magnets 116 nearest the rotor 102 corresponds to the side 712 of the Halbach array 700.

[0028] FIGS. 8A and 8B show a portion of the rotor 102 with magnets 114 arranged as a helical Halbach array, and a portion of the translator 104 with magnets 116 arranged as a helical Halbach array. A set of four helical bands 802 forms a Halbach array, where each band includes magnets oriented in one of the four orientations that make up the Halbach array. For example, helical band 804 includes only magnets with north orientation, helical band 806 includes only magnets with east orientation, helical band 808 includes only magnets with south orientation, and helical band 810 includes only magnets with west orientation.

[0029] FIG. 8B shows alignment of the magnets 114 and the magnets 116. As the rotor 102 rotates, the translator 104 is displaced to maintain the illustrated alignment of the magnets 114 and the magnets 116. As explained above, the guide rod 106 maintains the air gap 812 between the rotor 102 and the translator 104.

[0030] FIG. 9 shows a flow diagram for an example method 900 for magnetic linear actuation in accordance with the present disclosure. Though depicted sequentially as a matter of convenience, at least some of the actions shown can be performed in a different order and/or performed in parallel. Additionally, some implementations may perform only some of the actions shown. Operations of the method 900 may be performed by an implementation of the magnetic linear actuator 100.

[0031] In block 902, the guide rod 106 engages and is affixed to the end cap 108 at a first end, and engages and is affixed to the end cap 110 at a second end that is opposite the first end. The guide rod 106 passes through the translator 104.

[0032] In block 904, the rotor 102 is rotated. For example, an electric motor coupled to the rotor 102 may be activated to rotate the rotor 102.

[0033] In block 906, rotation of the rotor 102 cause the translator 104 to move longitudinally within the rotor 102. That is, interaction of the magnetic fields generated by the magnets 114 and the magnets 116 causes the translator 104 to move longitudinally with the rotor 102 to maintain alignment of the magnetic fields as the rotor 102 rotates. Longitudinal movement of the translator 104 may apply force in either direction 118 of movement of the translator 104 (bidirectional force). Rotation of the rotor 102 and linear movement of the translator 104 are provided relative to a same axis.

[0034] In block 908, the guide rod 106 restrain lateral and rotary motion of the translator 104 by exerting a force on the translator 104 that opposes lateral and rotary forces induced by rotation of the rotor 102.

[0035] In block 910, the air gap between the rotor 102 and the translator 104 is maintained by restricting eccentricity of the translator 104.

[0036] In block 912, the shaft 112 moves and extends or retracts through the end cap 110 responsive to the longitudinal movement of the translator 104.

[0037] While several embodiments have been provided in the present disclosure, it may be understood that the disclosed systems and methods might be embodied in many other specific forms without departing from the spirit or scope of the present disclosure. The present examples are to be considered as illustrative and not restrictive, and the intention is not to be limited to the details given herein. For example, the various elements or components may be combined or integrated in another system or certain features may be omitted, or not implemented.

[0038] In addition, techniques, systems, subsystems, and methods described and illustrated in the various embodiments as discrete or separate may be combined or

integrated with other systems, components, techniques, or methods without departing from the scope of the present disclosure. Other items shown or discussed as coupled may be directly coupled or may be indirectly coupled or communicating through some interface, device, or intermediate component whether electrically, mechanically, or otherwise. Other examples of changes, substitutions, and alterations are ascertainable by one skilled in the art and may be made without departing from the spirit and scope disclosed herein.

CLAIMS

What is claimed is:

1. A magnetic linear actuator, comprising:
 - a rotor comprising a first helical array of magnets;
 - a first end cap disposed at a first end of the rotor;
 - a second end cap disposed at a second end of the rotor, wherein the second end is opposite the first end;
 - a translator disposed within the rotor, and comprising a second helical array of magnets; and
 - a guide rod that passes through the translator and comprises:
 - a first end that engages the first end cap; and
 - a second end the engages the second end cap.
2. The magnetic linear actuator of claim 1, wherein:
 - the first end of the guide rod is affixed to the first end cap; and
 - the second end of the guide rod is affixed to the second end cap.
3. The magnetic linear actuator of claim 1, wherein the guide rod comprises one or more splines that extend over a length of the guide rod.
4. The magnetic linear actuator of claim 3, wherein the translator comprises:
 - a spline bearing keyed to engage the one or more splines of the guide rod;
 - a first longitudinal end comprising a first aperture for passage of the guide rod;
 - and
 - a second longitudinal end, opposite the first longitudinal end, comprising a second aperture for passage of the guide rod.

5. The magnetic linear actuator of claim 1, wherein:
the translator comprises a shaft extending from the second end, and
the second end cap comprises aperture through which the shaft passes.
6. The magnetic linear actuator of claim 1, wherein:
the first helical array of magnets comprises magnets arranged as a Halbach array; and
the second helical array of magnets comprises magnets arranged as a Halbach array.
7. The magnetic linear actuator of claim 1, wherein the translator is configured to convert rotary motion to linear motion, and move longitudinally within the rotor responsive to rotation of the rotor.
8. The magnetic linear actuator of claim 1, wherein the guide rod is configured to restrain rotation and lateral movement of the translator.
9. A magnetic linear actuator, comprising
a rotor comprising a first helical array of magnets;
a translator comprising a second helical array of magnets, and configured to convert rotary motion to linear motion and move longitudinally within the rotor responsive to rotation of the rotor; and
a guide rod that passes through a first longitudinal end and a second longitudinal end the translator, and is configured to restrain rotary and lateral motion of the translator.
10. The magnetic linear actuator of claim 9, further comprising:
a first end cap disposed at a first end of the rotor, and engaging a first end of the guide rod;
a second end cap disposed at a second end of the rotor, and engaging a second

end of the guide rod.

11. The magnetic linear actuator of claim 10, wherein:
the first end of the guide rod is affixed to the first end cap; and
the second end of the guide rod is affixed to the second end cap.
12. The magnetic linear actuator of claim 9, wherein the guide rod comprises one or more splines that extend over a length of the guide rod.
13. The magnetic linear actuator of claim 12, wherein:
the translator comprises a spline bearing keyed to engage the one or more splines of the guide rod;
the first longitudinal end of the translator comprises a first aperture for passage of the guide rod; and
the second longitudinal end of the translator is opposite the first longitudinal end of the translator, and comprises a second aperture for passage of the guide rod.
14. The magnetic linear actuator of claim 9, wherein:
the translator comprises a shaft extending from second end, and
the second end cap comprises aperture through which the shaft passes.
15. The magnetic linear actuator of claim 9, wherein:
the first helical array of magnets comprises magnets arranged as a Halbach array; and
the second helical array of magnets comprises magnets arranged as a Halbach array.
16. A method for magnetic linear actuation, comprising:
rotating a rotor comprising a first helical array of magnets;
longitudinally translating a translator, comprising a second helical array of

magnets, within the rotor responsive to rotation of the rotor;
maintaining an air gap between the first helical array of magnets and the second
helical array of magnets by restraining lateral motion of the translator via
a guide rod that passes through a first longitudinal end and a second
longitudinal end the translator.

16. The method of claim 15, further comprising restraining rotary motion of the translator via the guide rod.

17. The method of claim 16, further comprising:

engaging a first end of the guide rod at a first end cap disposed at a first
longitudinal end of the rotor; and

engaging a second end of the guide rod at a second end cap disposed at a
second longitudinal end of the rotor.

18. The method of claim 16, further comprising moving a shaft coupled to the translator through an aperture of the second end cap with movement of the translator.

19. The method of claim 15, wherein magnets of the first helical array are arranged as a Halbach array.

20. The method of claim 15, wherein magnets of the second helical array are arranged as a Halbach array.

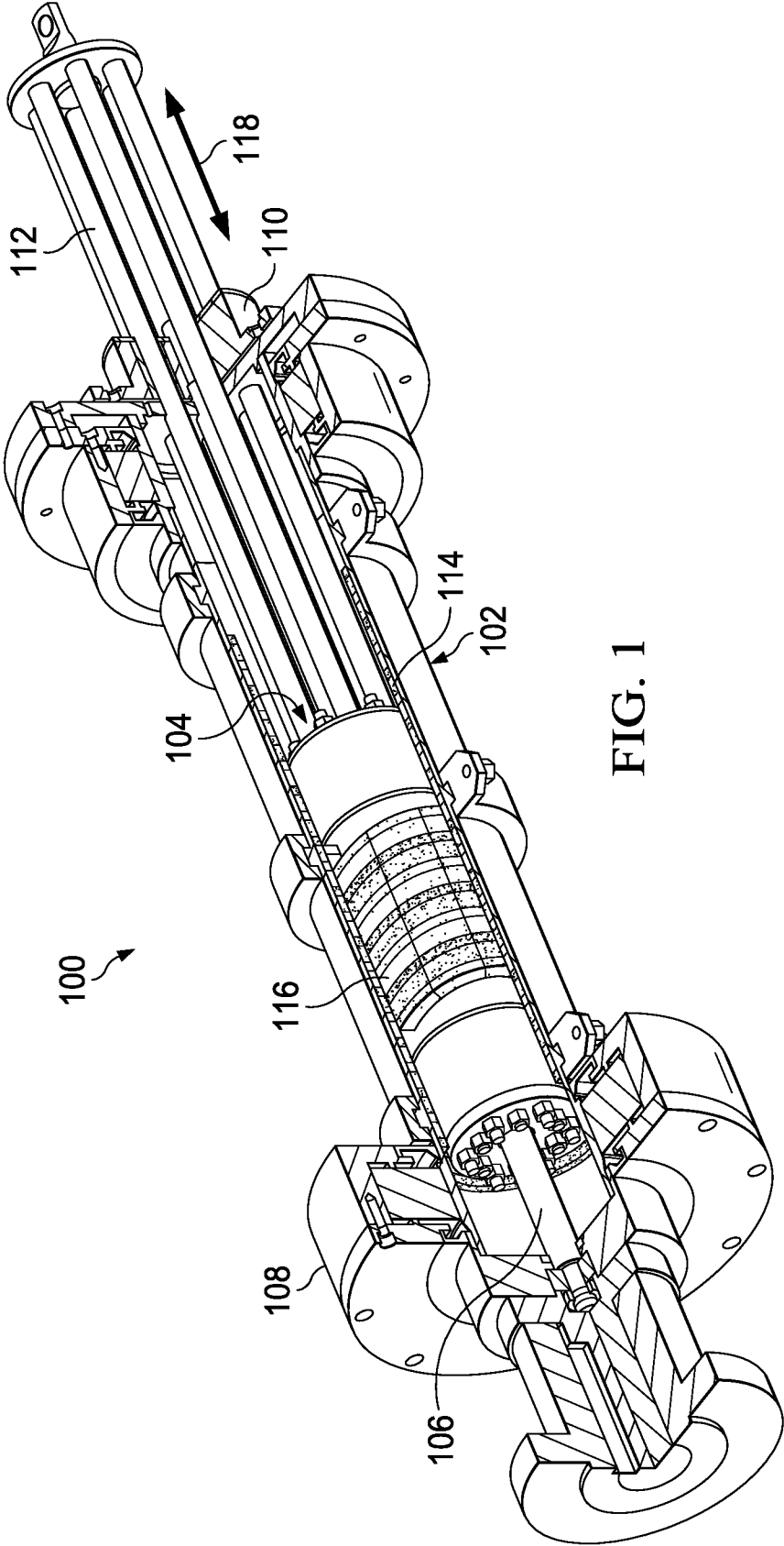


FIG. 1

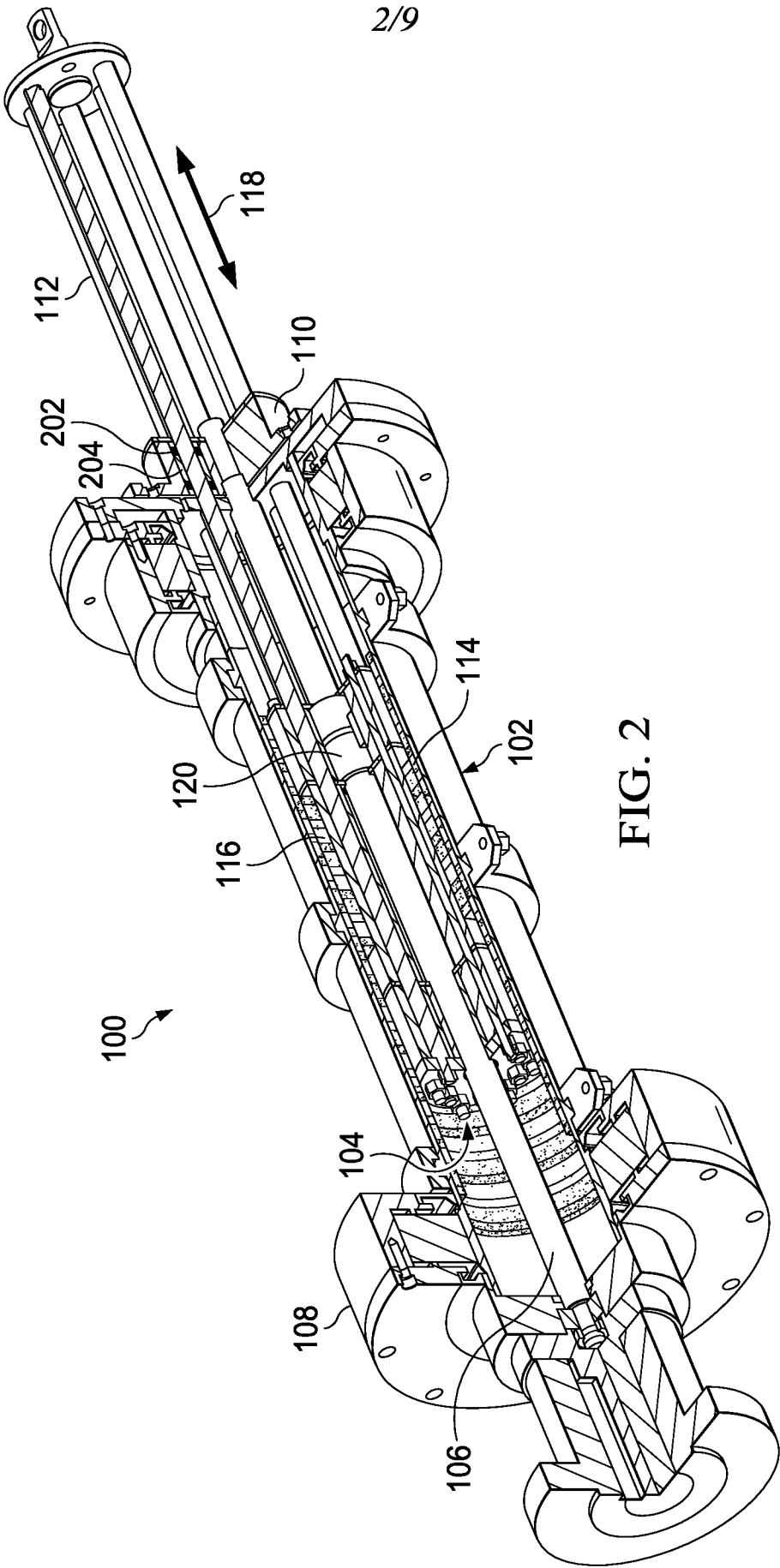
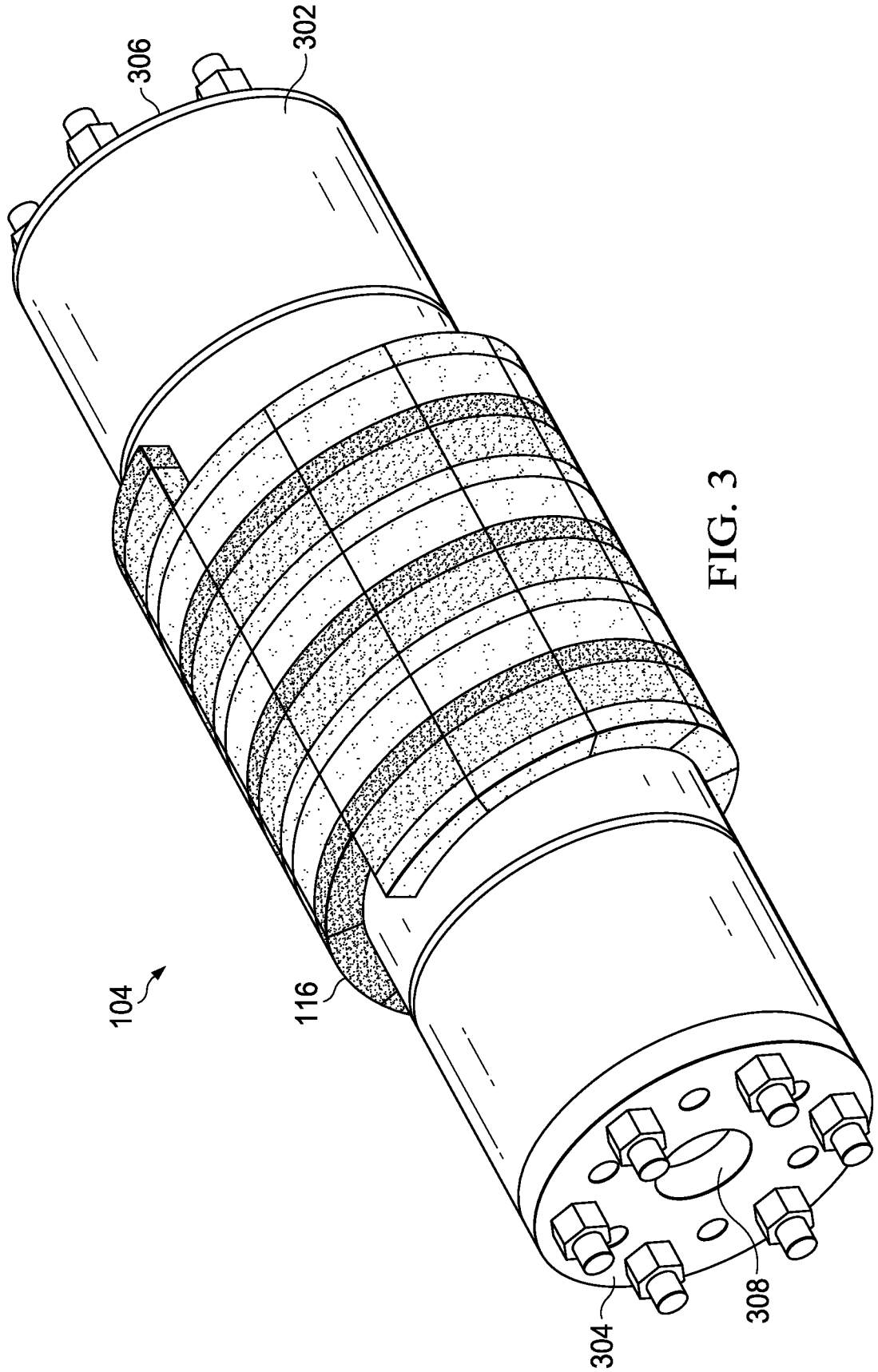
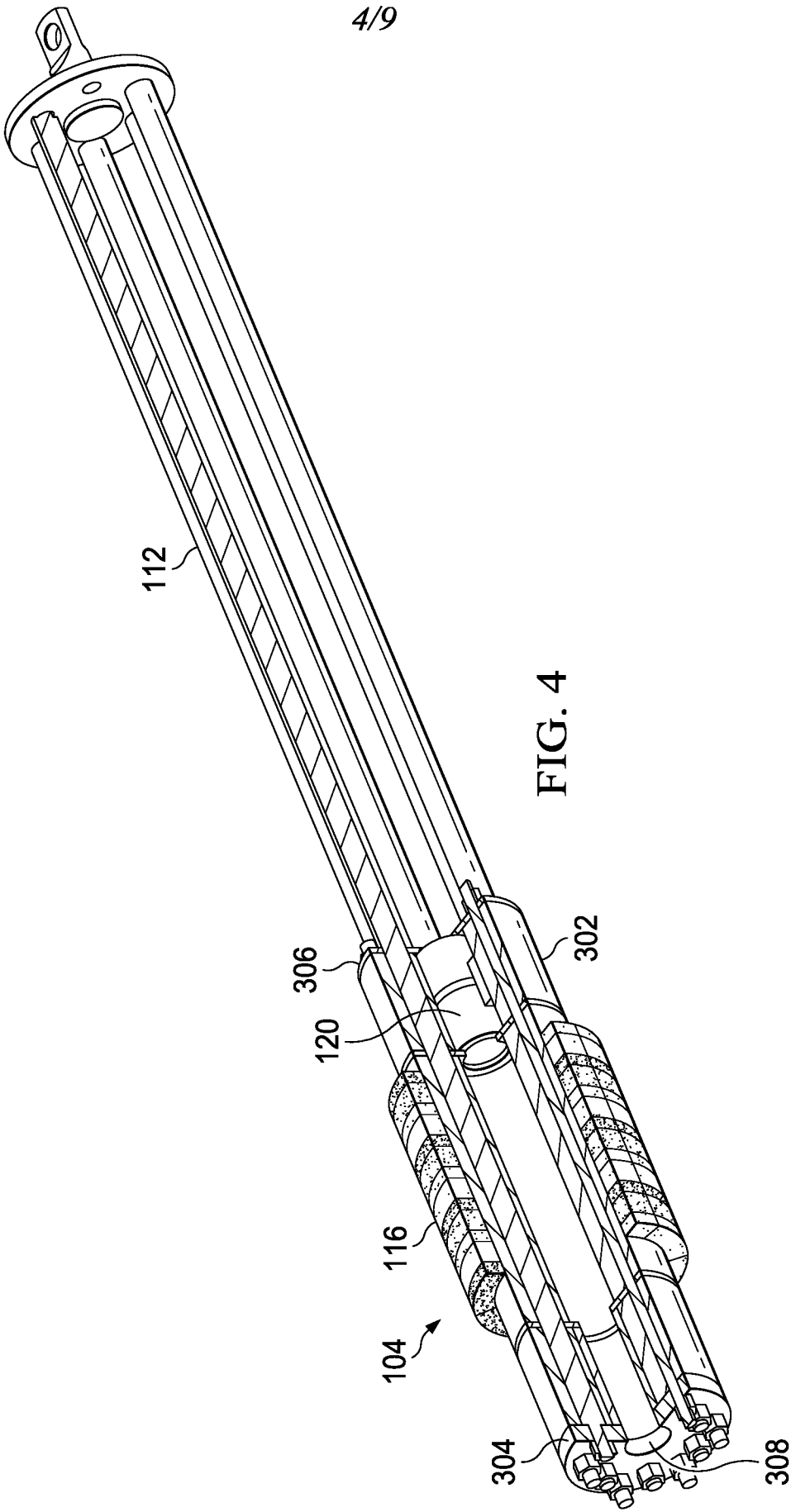


FIG. 2

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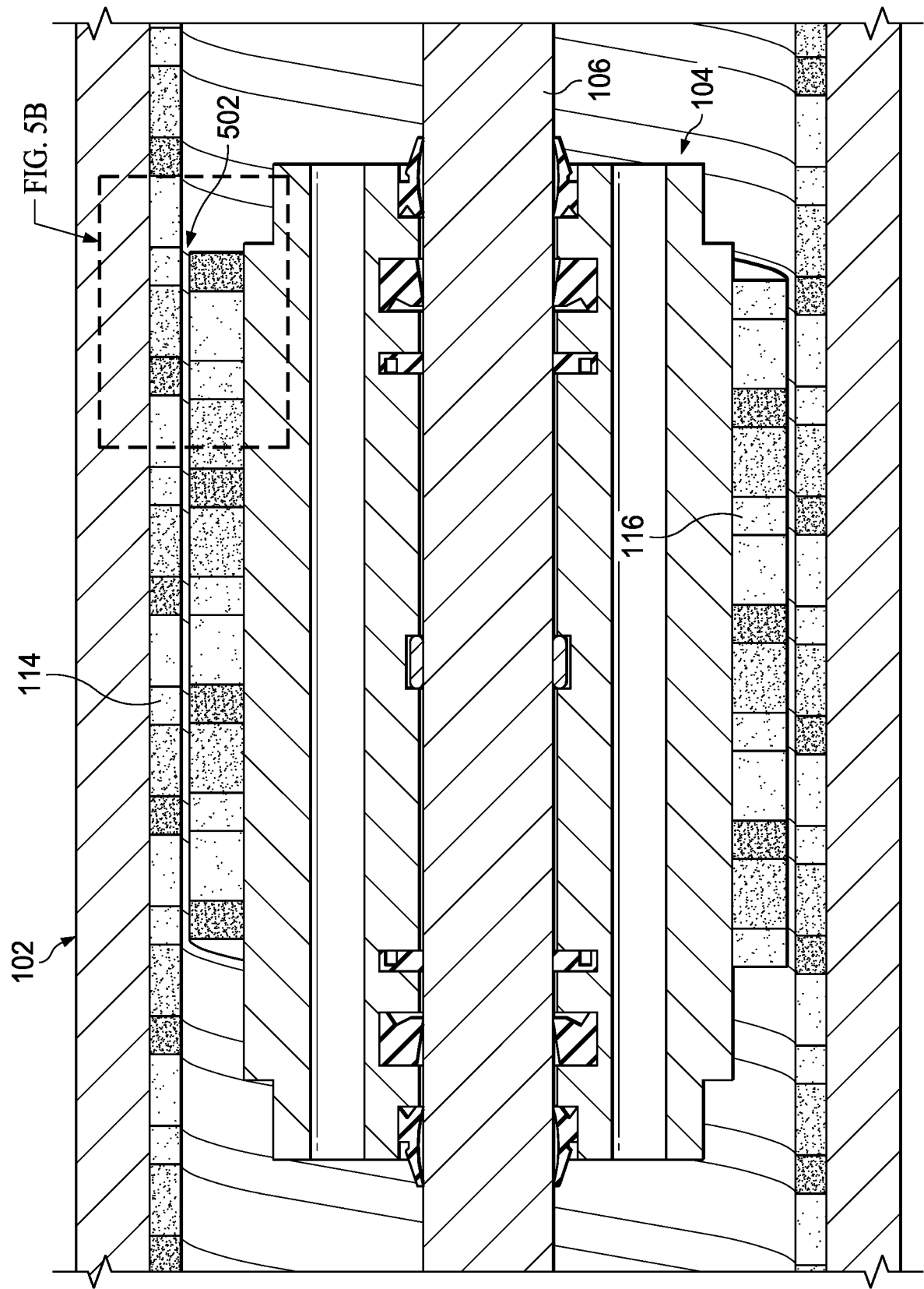


FIG. 5A

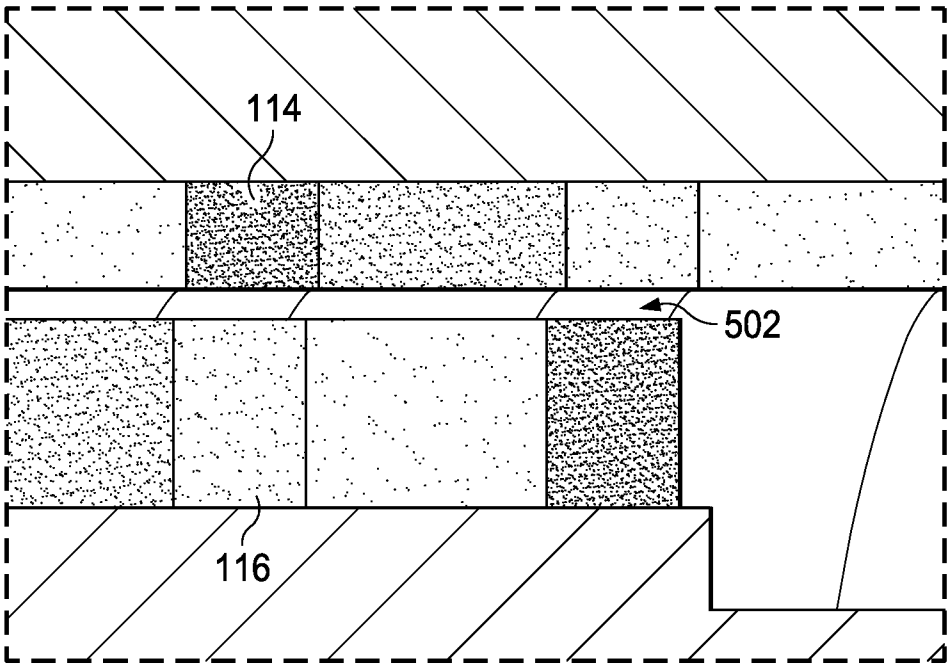


FIG. 5B

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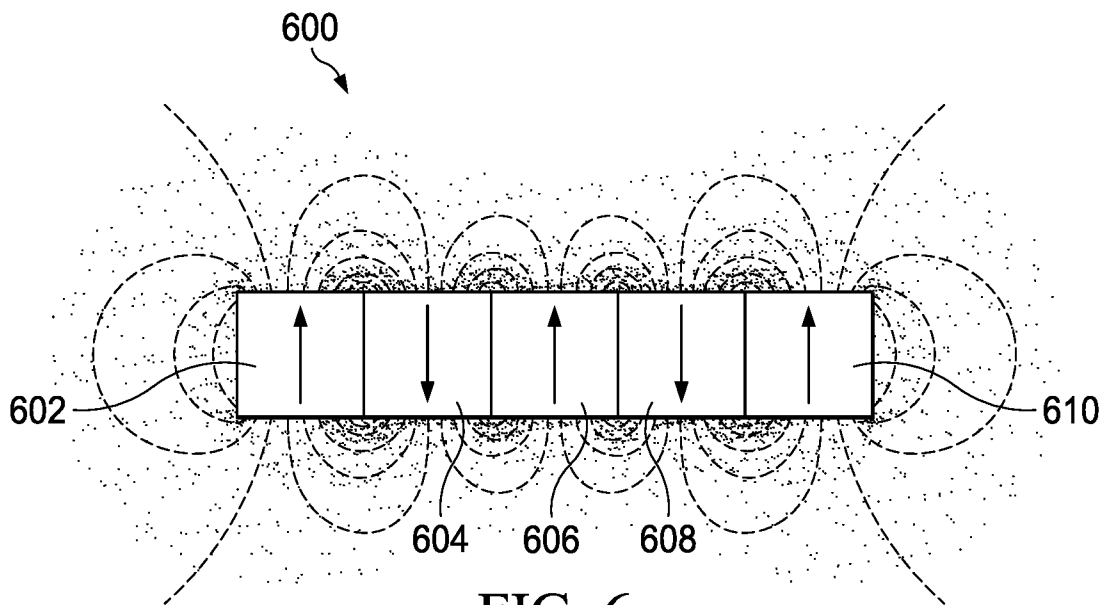


FIG. 6

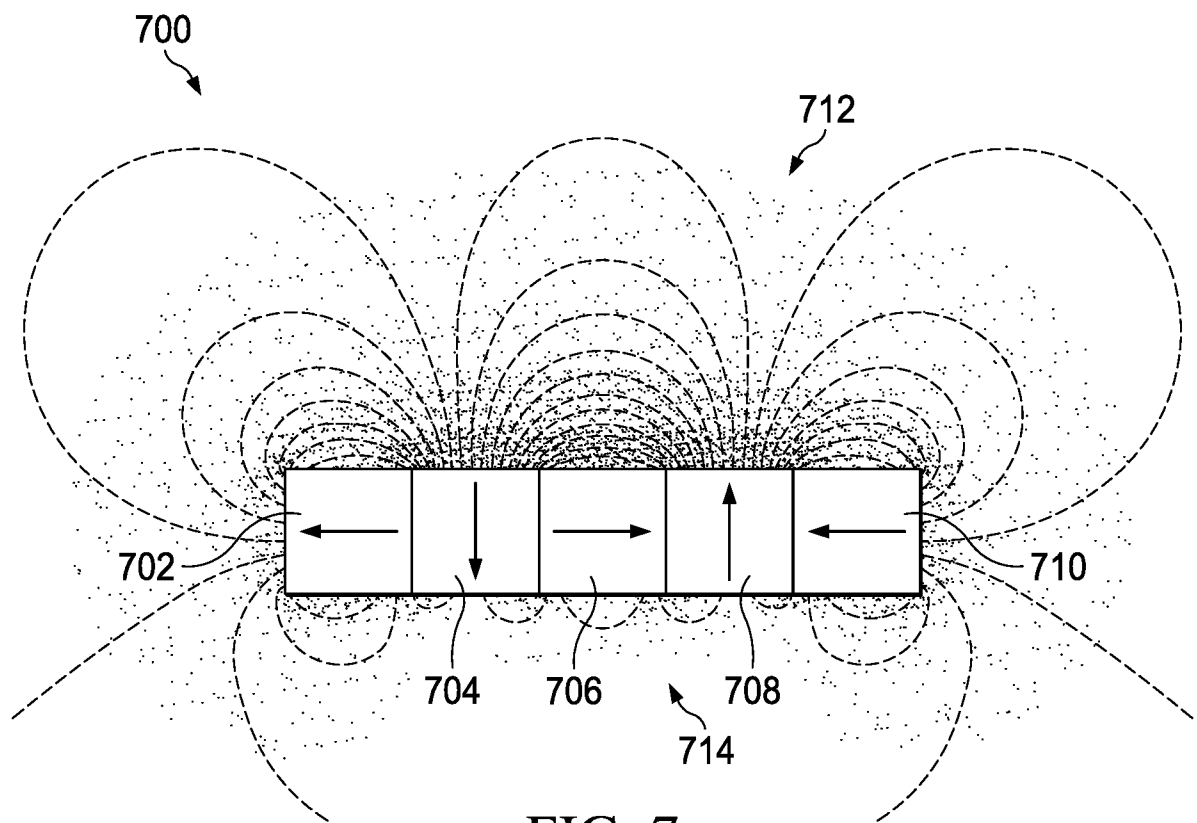


FIG. 7

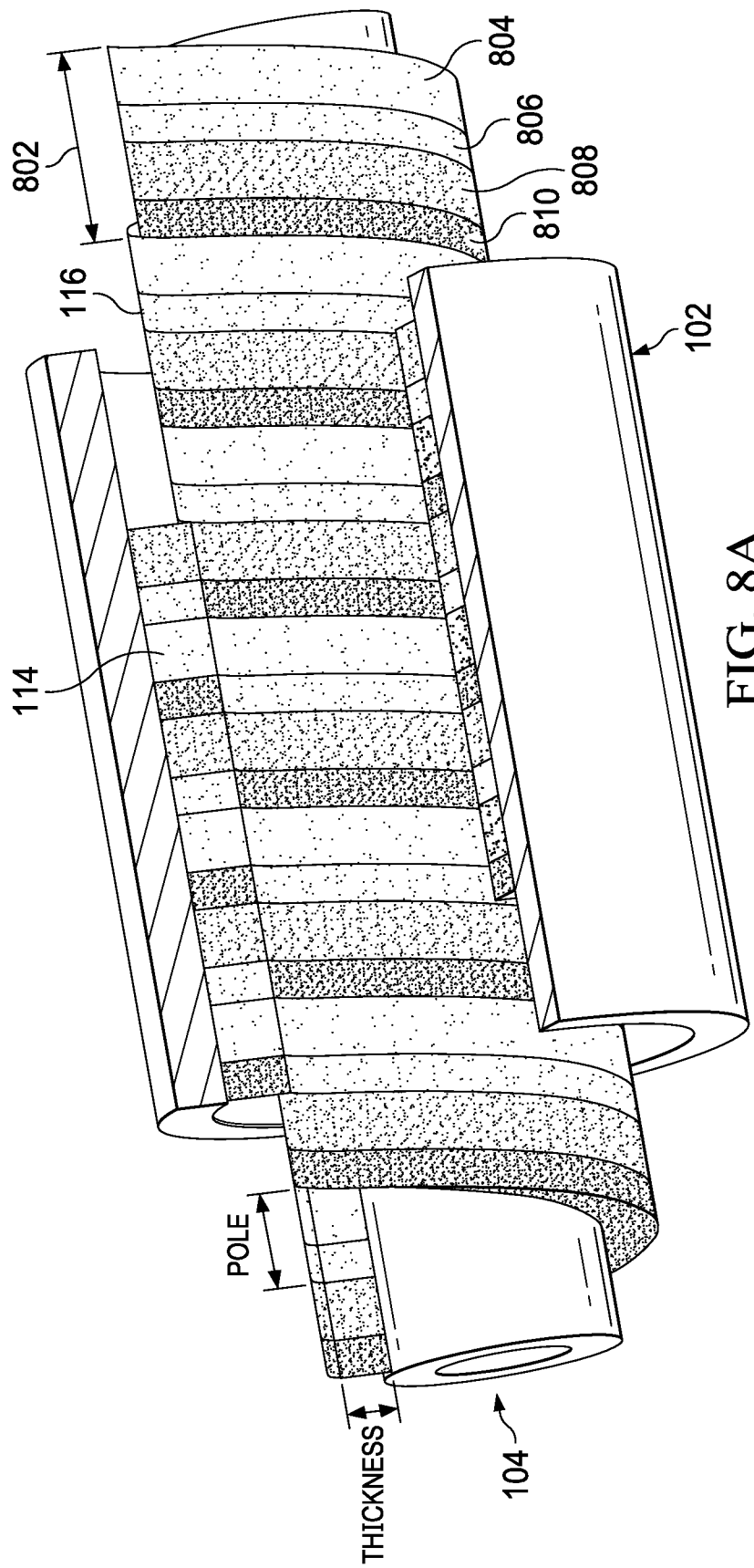


FIG. 8A

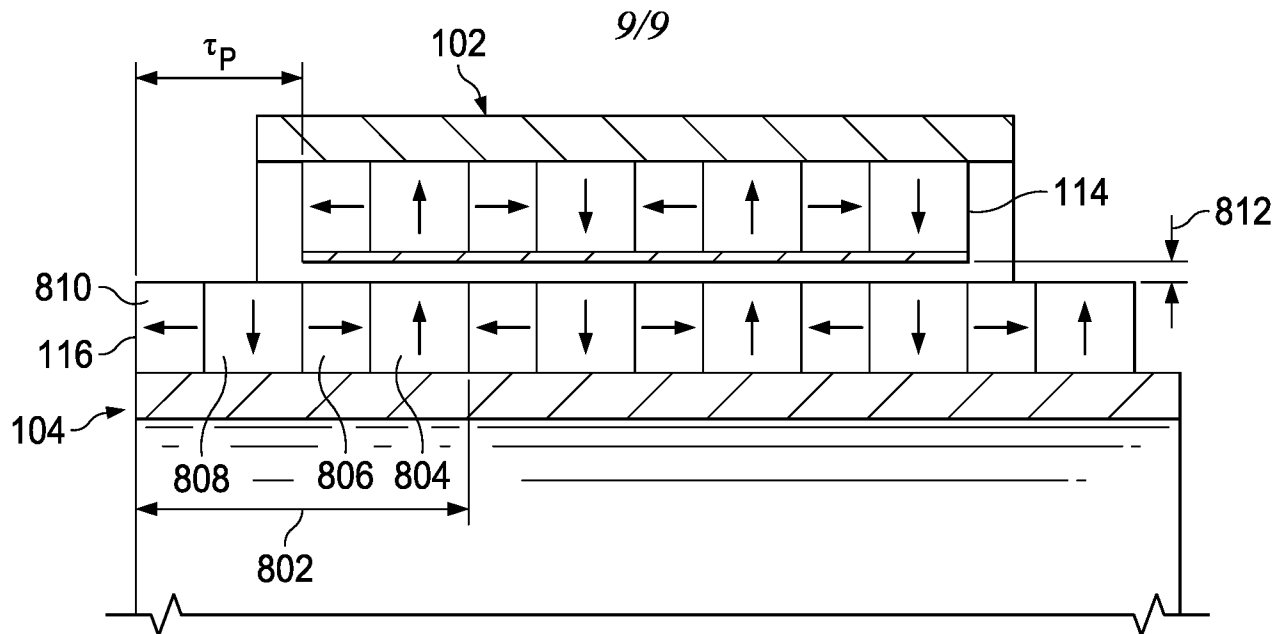


FIG. 8B

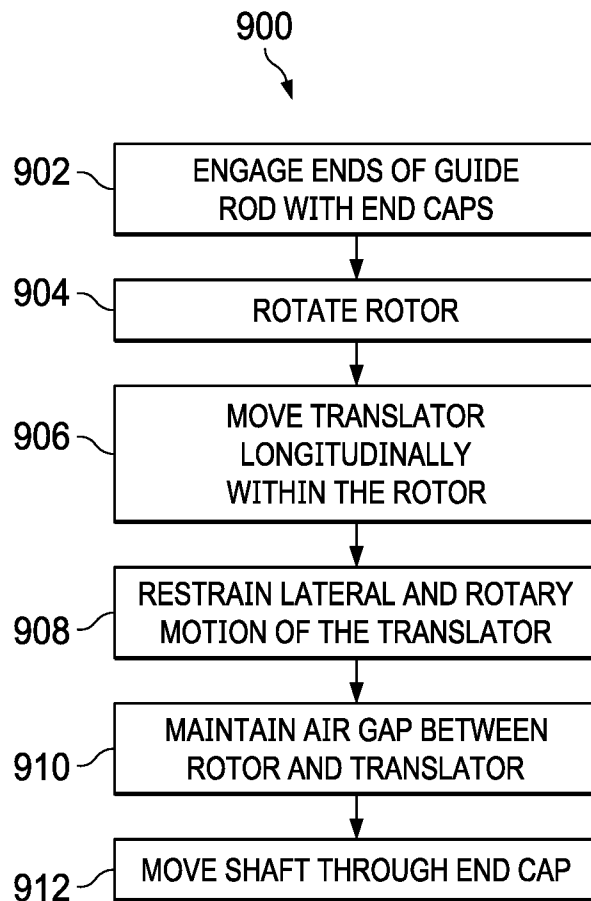


FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 21/13651

A. CLASSIFICATION OF SUBJECT MATTER

IPC - H02K 7/06, H02K 41/02, H02K 1/06 (2021.01)

CPC - H02K 7/06, H02K 1/27, H02K 1/2706, H02K 1/2726, H02K 1/2733, H02K 7/083, H02K 7/09, H02K 41/02, H02K 41/031, H02P 6/006, H02P 25/06, H01F 7/122, H01F 7/1646, H01F 2007/1692, H02K 1/278, H02K 1/2786, H02K 1/28, H02K 5/1672, H02K 1/12, H02K 1/14, H02K 1/17, H02K 1/18, H02K 1/185, H02K 1/187, H02K 49/104, F16H 61/32

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)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	EP 2 790 306 A2 (Nise, S.r.l.) 07 April 2014 (07.04.2014), entire document, especially Fig 1-3; para [0001]; para [0004]; para [0006]; para [0023] - [0024]; para [0029]; para [0031]; para [0039] - [0041]; para [0046]	1-2, 5-11, 14-15, 16a, 16b, 17-20 ----- 3-4, 12-13
Y --- A	US 2016/0169215 A1 (Baker Hughes Incorporated) 16 June 2016 (16.06.2016), entire document, especially Fig 3-5; para [0001]; para [0029]; para [0031]	1-2, 5, 7-11, 14 ----- 3-4, 12-13
Y	US 2016/0265618 A1 (Aalborg Universitet) 15 September 2016 (15.09.2016), entire document, especially Fig. 5-6; para [0097]; para [0100];	1, 6, 9, 15, 16a, 16b, 17--20
A	US 9,985,497 B2 (Elumotion Limited) 29 May 2018 (29.05.2018), entire document	1-20
A	US 2005/0269893 A1 (Fujimoto) 08 December 2005 (08.12.2005), entire document	1-20
A	US 2016/0123123 A1 (ZiLift Holdings, Limited) 05 May 2016 (05.05.2016), entire document	1-20
A	US 2011/0260564 A1 (Rodger et al.) 27 October 2011 (27.10.2011), entire document	1-20



Further documents are listed in the continuation of Box C.



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Date of the actual completion of the international search

22 March 2021

Date of mailing of the international search report

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