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Declarations under Rule 4.17:
— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

(54) Title: METAL FELT AND BRUSH STRUCTURES AS SEALING ELEMENTS IN METAL-METAL MUD MOTORS

(57) Abstract: A mud motor and a drill string having the mud motor. The mud motor includes a stator and a rotor. A lining between the stator and the rotor includes fibers forming a fiber pattern. The lining is a coating of at least one of a lobed inner surface of the stator and a lobed outer surface of the rotor.

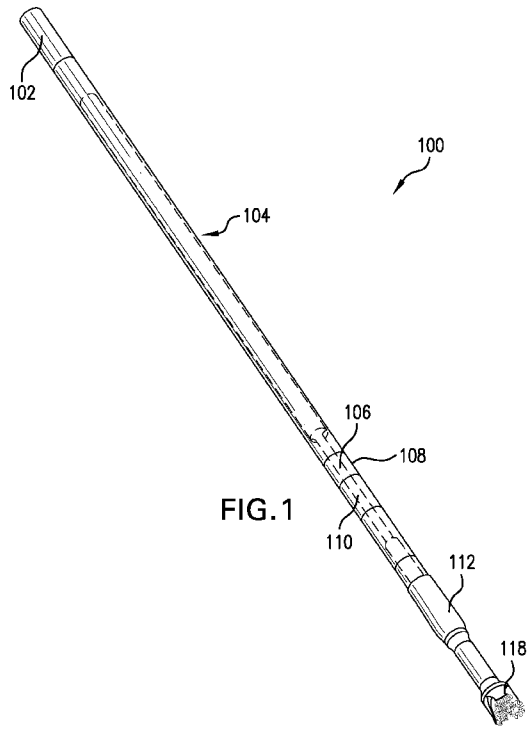


FIG. 1

WO 2022/026572 A1

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METAL FELT AND BRUSH STRUCTURES AS SEALING ELEMENTS IN METAL-METAL MUD MOTORS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of United States Application No 63/059,856, filed July 31, 2020, which is incorporated by reference herein in its entirety.

BACKGROUND

[0002] In the resource recovery industry, a mud motor is used in a drill string downhole, e.g. to power various tools of the drill string, such as a drill bit, using a flow of mud through the drill string. The mud motor includes a stator and a rotor that rotates within the stator, rubbing against the stator as it rotates. Often an elastomeric motor lining is placed on a surface of either the rotor or the stator in order to reduce friction and improve motor efficiency. However, these elastomeric layers decompose at high temperatures, thereby degrading performing. Alternatively, the elastomeric layer can be left off, instead allowing the stator and rotor to meet at a metal-metal interface. The metal-metal interface however leaves the efficiency and operation of the mud motor susceptible to dimensional tolerances. Therefore, there is a need to provide a lining to a mud motor that operates effectively and over a long time period at high temperatures.

SUMMARY

[0003] In one aspect, a mud motor is disclosed. The mud motor includes a stator, a rotor and a lining between the stator and the rotor, the lining including fibers forming a fiber pattern.

[0004] In another aspect, a drill string is disclosed. The drill string includes a mud motor having a stator and a rotor. A lining between the stator and the rotor includes fibers forming a fiber pattern.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

[0006] FIG. 1 shows a lower section of a drill string;

[0007] FIG. 2 shows a cross section of the mud motor in an embodiment; and

[0008] FIGS. 3A-3D show various fiber structures or fiber patterns suitable for forming a lining of the mud motor in various embodiments.

DETAILED DESCRIPTION

[0009] A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

[0010] Referring to FIG. 1, a lower section of a drill string 100 is shown. Drill string 100 is configured to drill a borehole into the earth's subsurface. The lower section includes a top sub 102 and a mud motor 104 connected to the top sub 102. The mud motor 104 connects at its lower end to a flexible shaft 106 and that passes through a lower sub 108 located below the mud motor 104. The lower sub 108 may include an adjustable kick off 110 and a stabilizer 112 which can be used to orient the drill string 100. A drill bit 118 at the lower end of the lower sub 108 is used to cut a formation. In operation, a drilling fluid or mud, flows through the drill string 100 from a surface location to exit the drill string at the drill bit 118. As the mud passes through the mud motor 104, the mud rotates a rotor of the mud motor with respect to a stator of the mud motor, therefore causing a rotation of the flexible shaft 106. Rotation of the flexible shaft 106 causes a rotation of the drill bit 118 which is mechanically coupled to the flexible shaft 106.

[0011] FIG. 2 shows a cross section 200 of the mud motor 104 in an embodiment. The cross-section shows a housing 202, a stator 204 within the housing 202 and a rotor 206. FIG. 2 shows housing 202 and stator 204 separated. Alternatively, housing 202 and stator 204 may be one integral part. The stator 204 includes a lobed inner surface 208 and the rotor 206 includes a lobed outer surface 210. The number of lobes on the rotor 206 is less than the number of lobes on the stator, thereby causing an eccentric rotation of the rotor. The lobed inner surface 208 or the lobed outer surface 210 or both can be coated with a lining. The lining material preferably is elastic for high efficiency, ease of assembly, and reasonable tolerances. In one embodiment, an elastomer (e.g. rubber) is used as a material for the lining. However, elastomer has the disadvantage that it does not withstand high temperatures, such as temperatures higher than 150°C, e.g. higher than 175 °C or even 200 °C. In another embodiment, fiber structures are used as a material for the lining. The fiber structures are made of fibers forming a fiber pattern as discussed below with respect to FIGS. 3A-3D.

[0012] FIGS. 3A-3D show various fiber structures or fiber patterns suitable for forming a lining of the mud motor in various embodiments. The disclosed fiber patterns form

structures which are used as a sealing element for its associated surface. For ease of explanation, the fiber patterns are discussed as being applied to the lobed inner surface 208 of the stator 204. However, it is to be understood that the associated surface can also be the lobed outer surface 210 of the rotor 206. FIG. 3A shows a fiber pattern in which the fibers of the lining form a felt pattern over the lobed inner surface 208. A felt pattern includes a plurality of fibers 302 that have been matted and pressed together. The matting or pressing process produces fibers 302 of the felt structure that are randomly oriented or otherwise unaligned with each other. FIG. 3B shows an illustrative embodiment of fibers 302 forming a web pattern on the lobed inner surface 208. The web pattern is an ordered pattern of fibers 302, generally forming a two-dimensional pattern. As shown in FIG. 3B, the fibers 302 form a windowpane structure in which fibers intersect each other at approximately right angles. However, a web patterns can include any other desired fiber pattern, including hexagonal web patterns, parallelogram web patterns, etc. FIG. 3C shows fibers 302 forming a mesh pattern. In the mesh pattern, fibers 302 are aligned parallel to each along a selected direction parallel and crossing over to the lobed inner surface 208 of the stator. FIG. 3D shows fibers 302 aligned to form a brush pattern at the lobed inner surface 208. In a brush pattern, the fibers 302 are aligned perpendicular, or substantially perpendicular, to the lobed inner surface 208.

[0013] The fibers 302 can be made of any suitable metal to form the fiber patterns. Exemplary material for the fibers include metals such as nickel, nickel alloy, stainless steel, low ally steel, copper or copper alloy. In other embodiments, the material of the fibers can be a carbon fiber, a glass fiber or a polymeric fiber.

[0014] The lining can be adhered to the surface of either the stator or the rotor using any suitable adhering method, including a sintering process, a soldering process, a welding process, a brazing process, or applying an adhesive between the lining and its associated surface. In one embodiment, physical vapor deposition (PVD) or chemical vapor deposition (CVD) can be used to chemically grow or deposit the fibers onto the outer surface. The fibers can be coated by a suitable coating material to provide improved chemical, thermal and corrosion resistance or better tribological or mechanical properties.

[0015] As seen in FIGS. 3A-3D, the fiber patterns can include gaps 304 between the fibers 302. In various embodiments, the gaps 304 can be left open or vacant. In other embodiments, the gaps 304 can be filled or partially filled with a secondary material. The secondary material can be a polymer, such as an elastomer, polytetrafluoroethylene (PTFE) polyether ether ketone (PEEK), or other composite material etc., or any combination thereof.

In one embodiment, the gaps 304 are at least partially filled with a material but are free of elastomer or rubber. A lining made of fiber patterns and free of elastomer is beneficial as the absence of the elastomer enables the lining to withstand higher temperatures, such as temperatures higher than 150 C, e.g. 175 C, or even 200 C. For example, a mud motor comprising a lining made of fiber patterns, such as a lining made of fiber patterns and free of elastomer, is operable at high temperature downhole conditions (for examples, at temperatures higher than 150° C, 175° C, or even 200 C) for a significant amount of time, such as a time larger than 40, 120, or even 360 circulation hours (i.e. the amount of hours the drilling fluid is circulated through the motor). Such a mud motor allows drilling runs in a downhole environment with an environmental temperature higher than 150 C, 175 C, or even 200 C, wherein the drilling runs last 40, 120, or even 360 circulation hours without the need to pull the mud motor out of the borehole for the reason of insufficient motor efficiency (e.g. insufficient motor torque, insufficient motor power, or insufficient rotational velocity of the rotor relative to the stator of the motor).

[0016] Set forth below are some embodiments of the foregoing disclosure:

[0017] Embodiment 1: A mud motor. The mud motor includes a stator, a rotor and a lining between the stator and the rotor, the lining including fibers forming a fiber pattern.

[0018] Embodiment 2: The mud motor of any prior embodiment, wherein the lining is a coating of at least one of a lobed inner surface of the stator and a lobed outer surface of the rotor.

[0019] Embodiment 3: The mud motor of any prior embodiment, wherein the lining is adhered by at least one of: (i) an adhesive; (ii) a sintering process; (iii) a soldering process; (iv) a welding process; and (v) a brazing process.

[0020] Embodiment 4: The mud motor of any prior embodiment, wherein the fiber pattern further comprises one of: (i) a felt pattern; (ii) a web pattern; (iii) a mesh pattern; and (iv) a brush pattern.

[0021] Embodiment 5: The mud motor of any prior embodiment, wherein a material of the fibers includes at least one of: (i) nickel; (ii) nickel alloy; (iii) stainless steel; (iv) low alloy steel; (v) copper; (vi) copper alloy; (vii) carbon fiber; (viii) glass fiber; and (ix) polymeric fiber.

[0022] Embodiment 6: The mud motor of any prior embodiment, wherein the fiber pattern includes a gap between the fibers.

[0023] Embodiment 7. The mud motor of any prior embodiment, further comprising a secondary material in the gap, the secondary material being at least one of: (i)

polytetrafluoroethylene (PTFE); (ii) polyether ether ketone (PEEK); (iii) a polymer; and (iv) an elastomer.

[0024] Embodiment 8: The mud motor of any prior embodiment, wherein the gap is unfilled.

[0025] Embodiment 9: The mud motor of any prior embodiment, wherein the mud motor is configured to operate at temperatures higher than 150 C for more than 40 circulation hours.

[0026] Embodiment 10: A method of manufacturing a mud motor. A mud motor is formed including a stator and a rotor. A lining is disposed between the stator and the rotor, the lining including fibers forming a fiber pattern.

[0027] Embodiment 11: The method of any prior embodiment, wherein the lining is a coating of at least one of a lobed inner surface of the stator and a lobed outer surface of the rotor.

[0028] Embodiment 12: The method of any prior embodiment, wherein the lining is adhered by at least one of: (i) an adhesive; (ii) a sintering process; (iii) a soldering process; (iv) a welding process; and (v) a brazing process.

[0029] Embodiment 13: The method of any prior embodiment, wherein the fiber pattern further comprises one of: (i) a felt pattern; (ii) a web pattern; (iii) a mesh pattern; and (iv) a brush pattern.

[0030] Embodiment 14: The method of any prior embodiment, wherein a material of the fibers include at least one of: (i) nickel; (ii) nickel alloy; (iii) stainless steel; (iv) low alloy steel; (v) copper; (vi) copper alloy; (vii) carbon fiber; (viii) glass fiber; and (ix) polymeric fiber.

[0031] Embodiment 15: The method of any prior embodiment, wherein the fiber pattern includes a gap between the fibers.

[0032] Embodiment 16: The method of any prior embodiment, wherein the gaps are filled with a secondary material, wherein the secondary material is at least one of: (i) PTFE (polytetrafluoroethylene); (ii) PEEK (polyether ether ketone); (iii) a polymer; and (iv) an elastomer.

[0033] Embodiment 17: The method of any prior embodiment, wherein the one or more gaps are unfilled.

[0034] Embodiment 18: The method of any prior embodiment, wherein the mud motor is configured to operate at temperatures higher than 150 C for more than 40 circulation hours.

[0035] The use of the terms "a" and "an" and "the" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Further, it should be noted that the terms "first," "second," and the like herein do not denote any order, quantity, or importance, but rather are used to distinguish one element from another. The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity).

[0036] The teachings of the present disclosure may be used in a variety of well operations. These operations may involve using one or more treatment agents to treat a formation, the fluids resident in a formation, a wellbore, and / or equipment in the wellbore, such as production tubing. The treatment agents may be in the form of liquids, gases, solids, semi-solids, and mixtures thereof. Illustrative treatment agents include, but are not limited to, fracturing fluids, acids, steam, water, brine, anti-corrosion agents, cement, permeability modifiers, drilling muds, emulsifiers, demulsifiers, tracers, flow improvers etc. Illustrative well operations include, but are not limited to, hydraulic fracturing, stimulation, tracer injection, cleaning, acidizing, steam injection, water flooding, cementing, etc.

[0037] While the invention has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the claims. Also, in the drawings and the description, there have been disclosed exemplary embodiments of the invention and, although specific terms may have been employed, they are unless otherwise stated used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention therefore not being so limited.

What is claimed is:

1. A mud motor (104), comprising:

a stator (204);

a rotor (206); and

a lining between the stator (204) and the rotor (206), the lining including fibers (302) forming a fiber pattern.

2. The mud motor (104) of claim 1, wherein the lining is a coating of at least one of a lobed inner surface (208) of the stator (204) and a lobed outer surface (210) of the rotor (206).

3. The mud motor (104) of claim 2, wherein the lining is adhered by at least one of: (i) an adhesive; (ii) a sintering process; (iii) a soldering process; (iv) a welding process; and (v) a brazing process.

4. The mud motor (104) of claim 1, wherein the fiber pattern further comprises one of: (i) a felt pattern; (ii) a web pattern; (iii) a mesh pattern; and (iv) a brush pattern.

5. The mud motor (104) of claim 1, wherein a material of the fibers includes at least one of: (i) nickel; (ii) nickel alloy; (iii) stainless steel; (iv) low alloy steel; (v) copper; (vi) copper alloy; (vii) carbon fiber; (viii) glass fiber; and (ix) polymeric fiber.

6. The mud motor (104) of claim 1, wherein the fiber pattern includes a gap (304) between the fibers (302).

7. The mud motor (104) of claim 6, further comprising a secondary material in the gap (304), the secondary material being at least one of: (i) polytetrafluoroethylene (PTFE); (ii) polyether ether ketone (PEEK); (iii) a polymer; and (iv) an elastomer.

8. The mud motor (104) of claim 6, wherein the gap (304) is unfilled.

9. A method for manufacturing a mud motor (104), the method comprising:

forming a mud motor (104) comprising a stator (204) and a rotor (206); and

disposing a lining between the stator (204) and the rotor (206), the lining including fibers (302) forming a fiber pattern.

10. The method of claim 8, wherein the lining disposed between the stator (204) and the rotor (206) by coating at least one of a lobed inner surface (208) of the stator (204) and a lobed outer surface (210) of the rotor (206) with the lining.

11. The method of claim 10, further comprising adhering the lining by at least one of: (i) an adhesive; (ii) a sintering process; (iii) a soldering process; (iv) a welding process; and (v) a brazing process.

12. The method of claim 9, wherein the fiber pattern further comprises one of: (i) a felt pattern; (ii) a web pattern; (iii) a mesh pattern; and (iv) a brush pattern.

13. The method of claim 9, wherein a material of the fibers (302) include at least one of: (i) nickel; (ii) nickel alloy; (iii) stainless steel; (iv) low alloy steel; (v) copper; (vi) copper alloy; (vii) carbon fiber; (viii) glass fiber; and (ix) polymeric fiber.

14. The method of claim 9, wherein the fiber pattern includes one or more gaps (304) between the fibers.

15. The method of claim 14, wherein the gaps are filled with a secondary material, wherein the secondary material is at least one of: (i) PTFE (polytetrafluoroethylene); (ii) PEEK (polyether ether ketone); (iii) a polymer; and (iv) an elastomer.

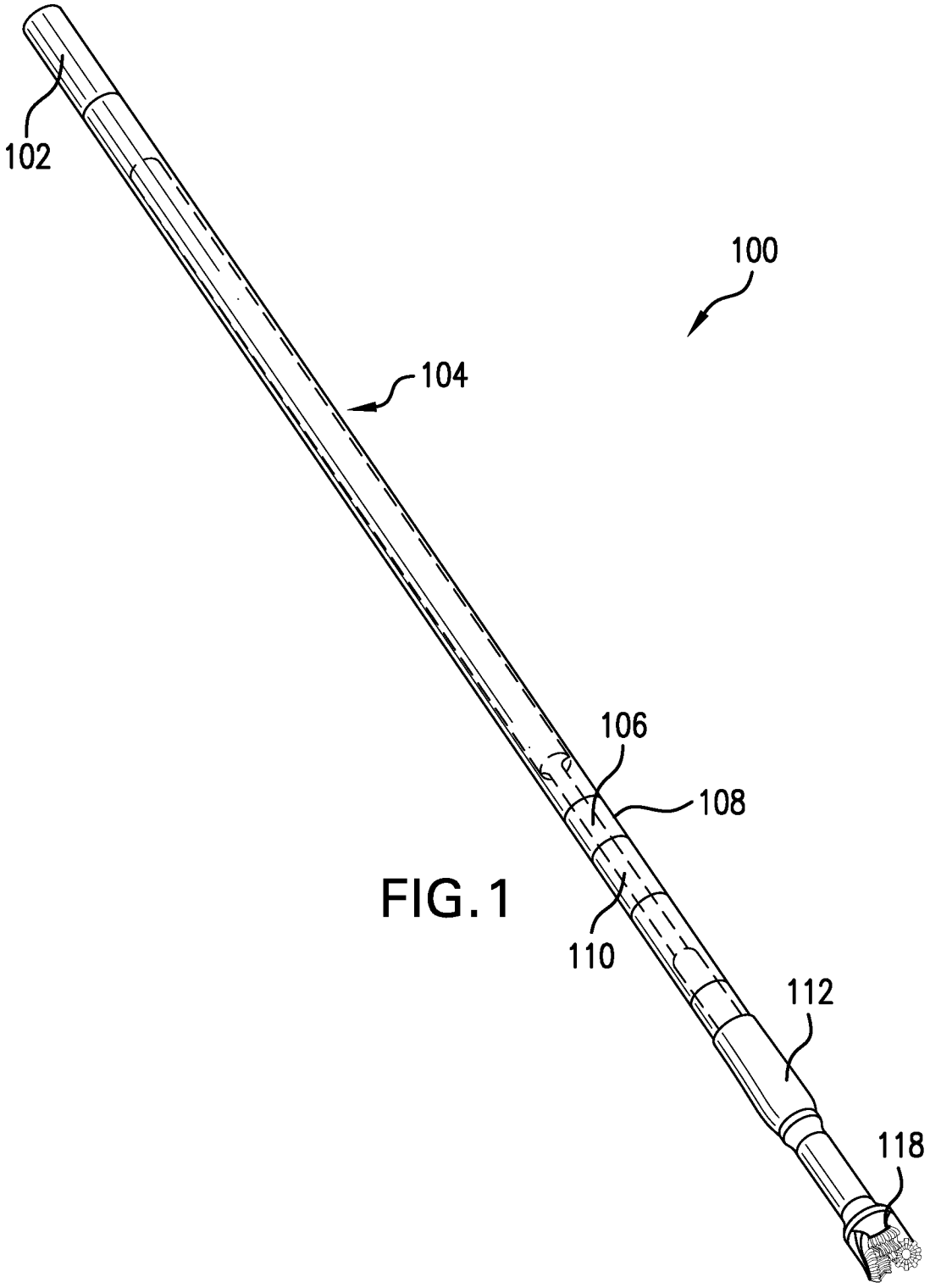


FIG. 1

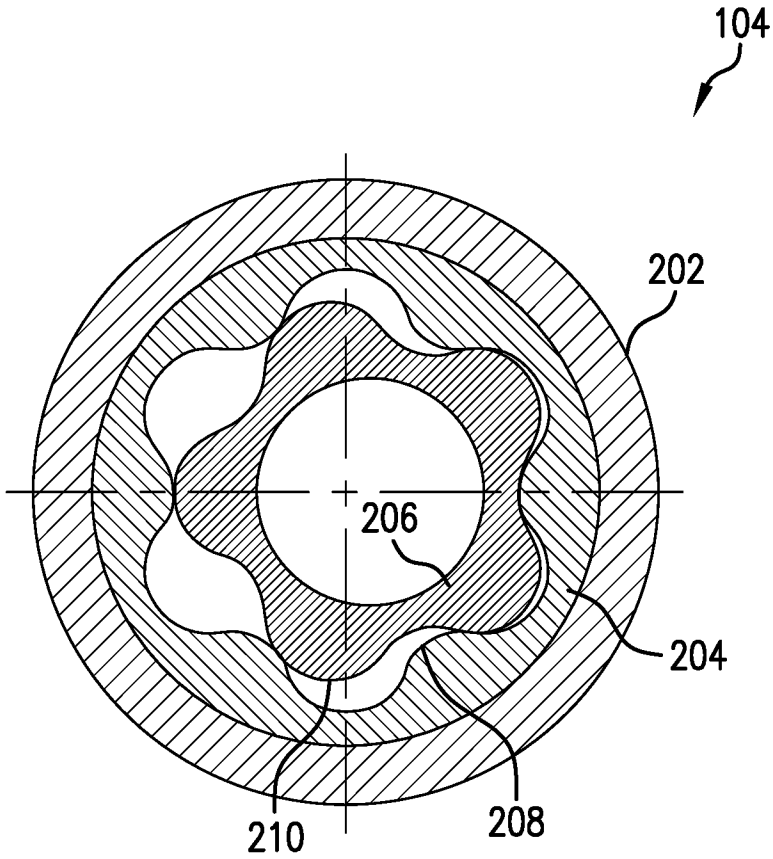


FIG.2

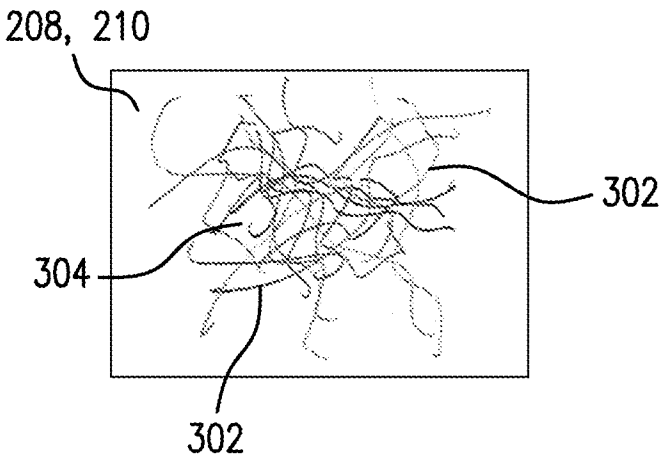


FIG.3A

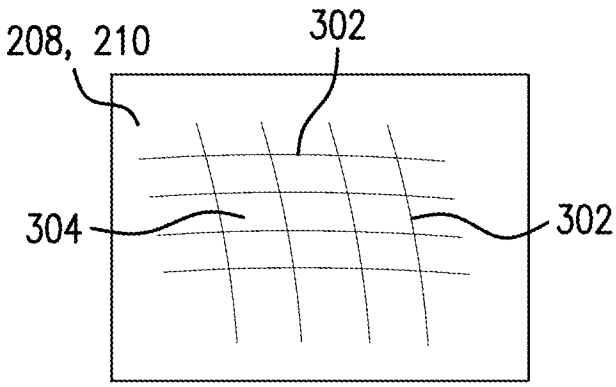


FIG.3B

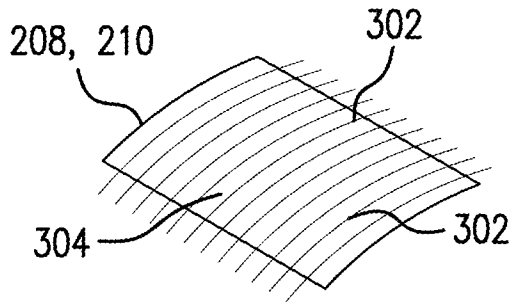


FIG.3C

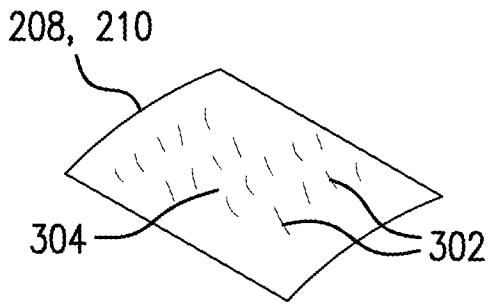


FIG.3D

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2021/043494

A. CLASSIFICATION OF SUBJECT MATTER

E21B 4/02(2006.01)i; **E21B 4/00**(2006.01)i; **F01C 1/22**(2006.01)i; **F04C 13/00**(2006.01)i

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)

E21B 4/02(2006.01); B23P 11/00(2006.01); B23P 15/00(2006.01); F01C 1/107(2006.01); F01C 1/22(2006.01)

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

Korean utility models and applications for utility models
Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: mud motor, stator, rotor, lining, fiber, coat

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	CN 205422525 U (JILIN UNIVERSITY) 03 August 2016 (2016-08-03) paragraph [0026]; claims 1-5; and figures 2-3	1-2,4-6,8-10,12-14
Y		3,7,11,15
Y	US 6604922 B1 (HACHE, JEAN-MICHEL) 12 August 2003 (2003-08-12) column 7, lines 53-67; claim 23; and figures 12-13	3,11
Y	US 2009-0152009 A1 (SLAY et al.) 18 June 2009 (2009-06-18) claims 1-11; and figures 3-9	7,15
A	US 2013-0052067 A1 (HOHL et al.) 28 February 2013 (2013-02-28) claims 1-9; and figures 4-5	1-15
A	US 2013-0014995 A1 (SCOTT et al.) 17 January 2013 (2013-01-17) claims 1-7; and figures 1-2	1-15

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 November 2021	**03 November 2021**

Name and mailing address of the ISA/KR	Authorized officer
Korean Intellectual Property Office **189 Cheongsa-ro, Seo-gu, Daejeon** **35208, Republic of Korea**	**PARK, Tae Wook**
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/US2021/043494

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