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(54) **MUD MOTOR ROTOR WITH CORE AND SHELL**

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F03C 4/00	(2006.01)
F04C 18/00	(2006.01)
F04C 2/107	(2006.01)

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(58) **Field of Classification Search**
CPC F04C 2/084; F04C 2/1071; F04C 2/1076; F04C 13/008; F04C 2230/21; F04C 2230/91; F04C 2250/20; Y10T 29/49242; E21B 4/02
See application file for complete search history.

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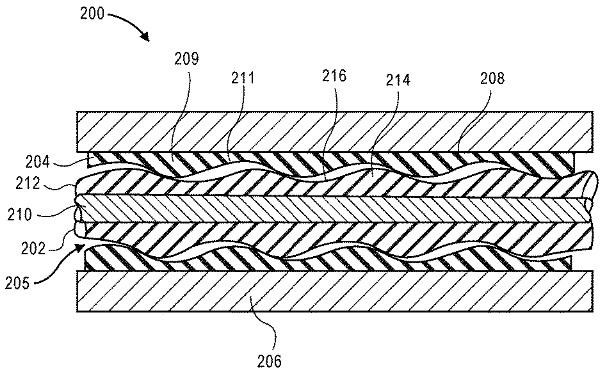
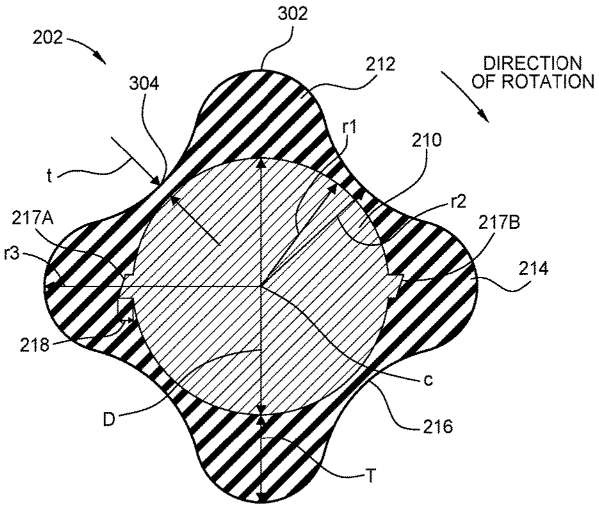
(57) **ABSTRACT**

A rotor for a mud motor includes a core having a first outer shape, and a shell positioned around the core, the shell having a second outer shape that is different from the first outer shape, the second outer shape defining one or more lobes and one or more cavities that are configured to engage a bore of a stator during rotation of the rotor relative to the stator. A thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness to a maximum thickness.

19 Claims, 5 Drawing Sheets





(51) **Int. Cl.**

E21B 4/02	(2006.01)
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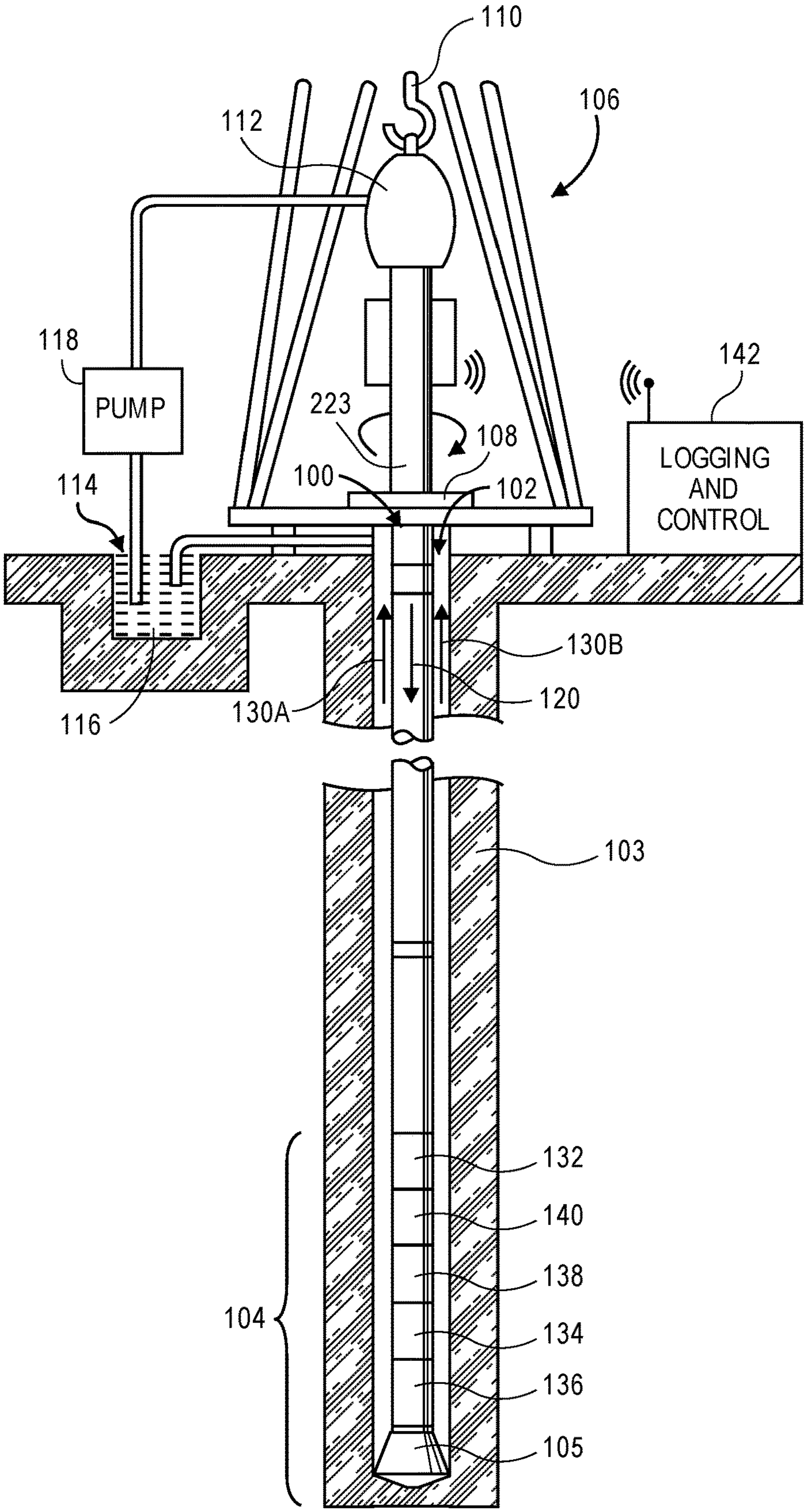
110
106
112
118
PUMP
142
LOGGING AND CONTROL
223
108
100
102
114
130B
120
130A
116
103
132
140
138
134
136
105
104

FIG. 1

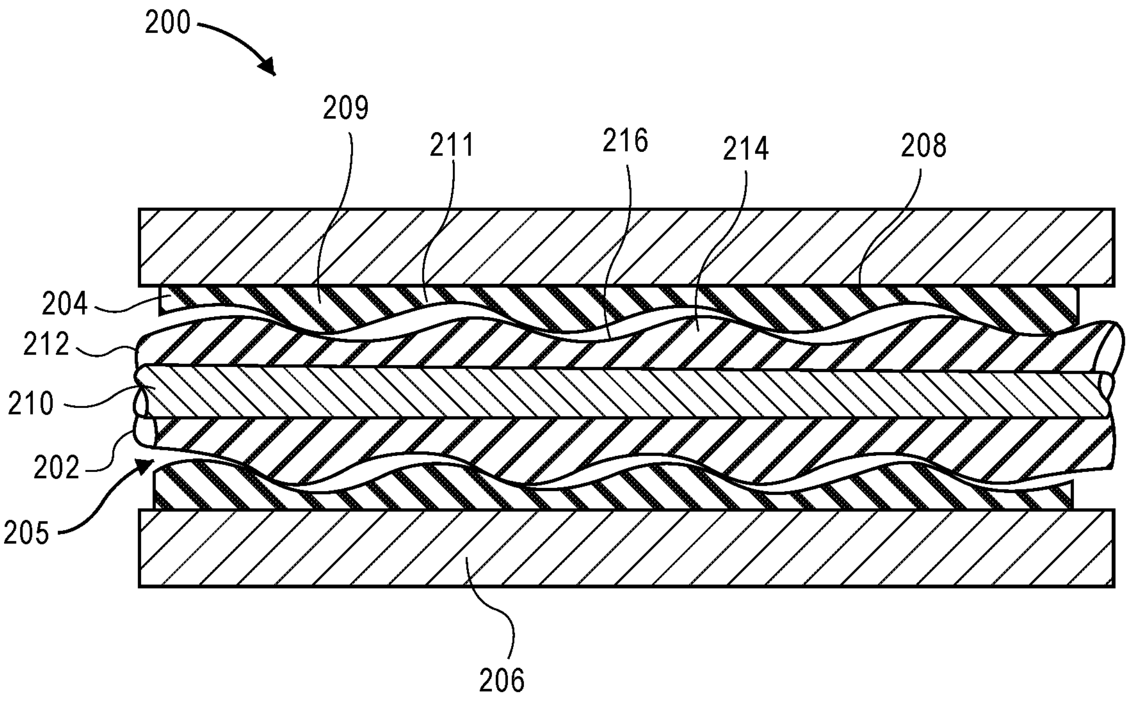

FIG. 2

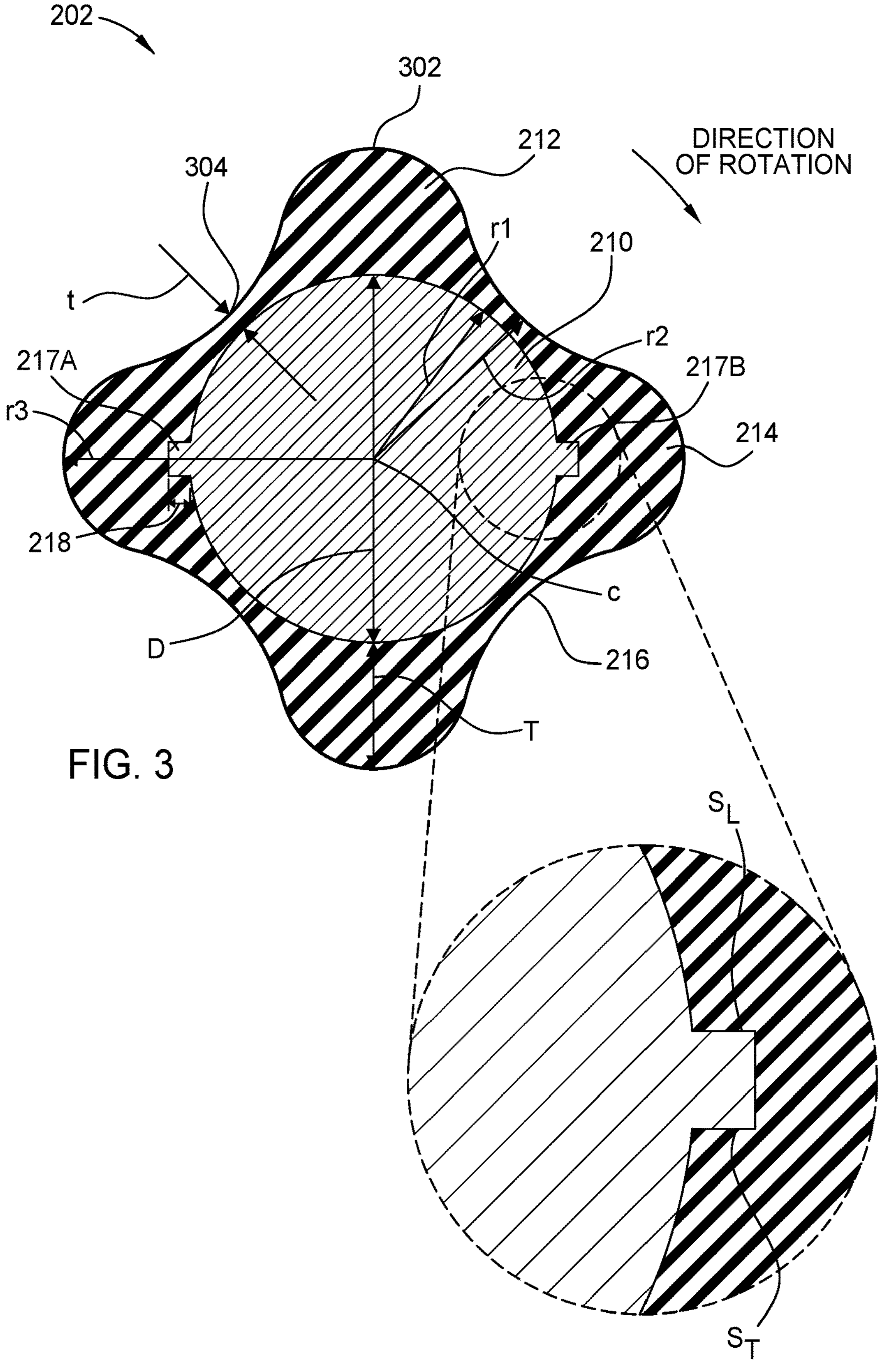
202
302
212
304
DIRECTION OF ROTATION
r1
210
t
r2
217A
217B
r3
214
218
c
D
216
T
S_L
S_T

FIG. 3

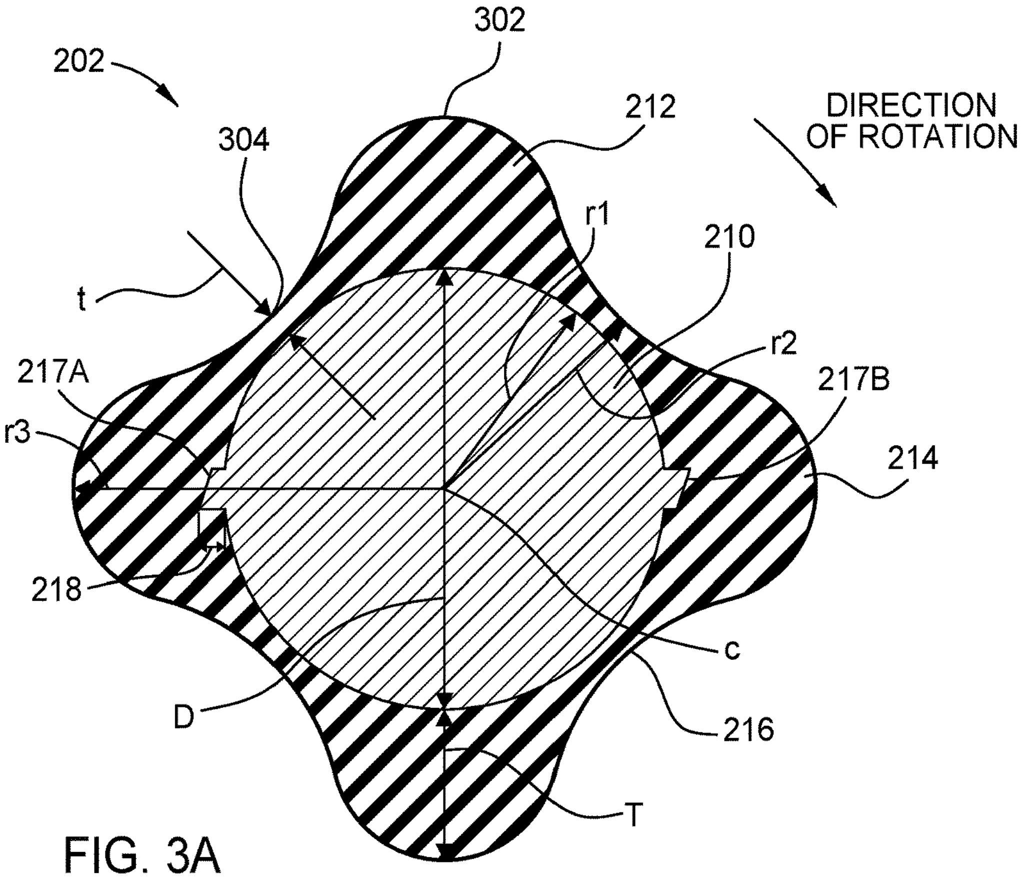
302
202
212
DIRECTION OF ROTATION
304
r1
210
t
r2
217A
217B
r3
214
218
c
D
216
T

FIG. 3A

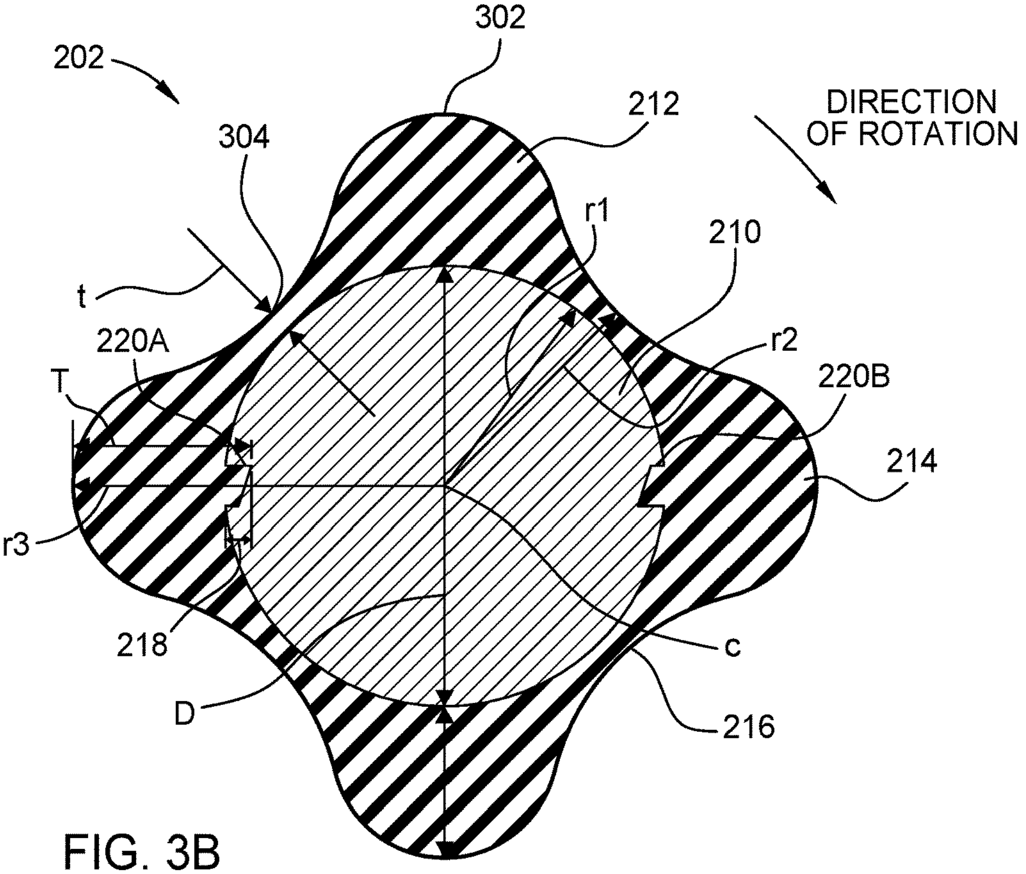
302
202
212
DIRECTION OF ROTATION
304
r1
210
t
r2
220A
220B
T
214
r3
218
c
D
216

FIG. 3B

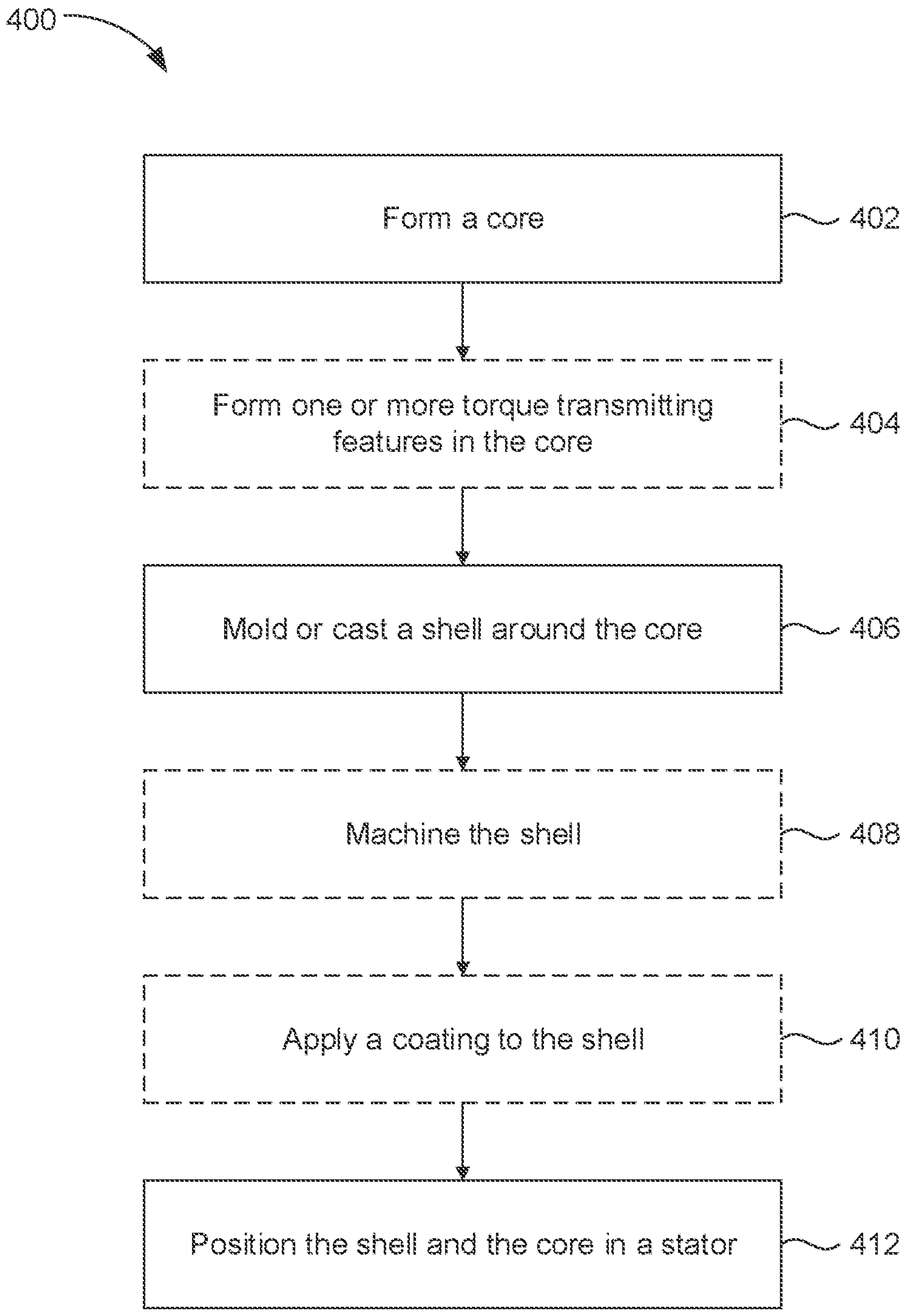
400
Form a core
402
Form one or more torque transmitting features in the core
404
Mold or cast a shell around the core
406
Machine the shell
408
Apply a coating to the shell
410
Position the shell and the core in a stator
412

FIG. 4

MUD MOTOR ROTOR WITH CORE AND SHELL

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of, and priority to, U.S. Patent Application No. 62/985,135 entitled "Mud Motor Rotor With Core And Shell" filed Mar. 4, 2020, which is incorporated herein by this reference in its entirety.

BACKGROUND

Downhole or "mud" motors are used in drilling assemblies, e.g., in the oil and gas industry, to turn a drill bit at the end of a drill string, generate electricity, or otherwise produce rotation of a tool within the wellbore. The mud motors may be powered by flowing drilling fluid ("mud") through the drill string. The mud is also used to lubricate the drill string and to carry away cuttings in the annulus between the drill string and the wellbore wall. Thus, the mud may include particulate matter, potentially in addition to solvents and other liquids. As such, the mud provides a readily-available energy source to drive the downhole mud motor, but also presents a harsh working environment for the components of the mud motor.

One type of mud motor that has been used with success in this environment is a progressive cavity or Moineau-style motor. This type of mud motor generally includes a helical rotor received inside a bore of a stator. The stator bore generally has inwardly-extending, curved lobes alternating with outwardly-extending, curved cavities or "chambers". Pressure in the fluid drives the helical rotor to rotate within the bore of the stator. To accommodate the harsh environment, rotors may be made from relatively strong, corrosion-resistant metal alloys. For example, if the drilling mud is expected to include chloride, which is corrosive to steel alloys that include chromium, tungsten-carbide rotors may be employed. However, such materials may be expensive, making up a large portion of the total expense of the mud motor.

SUMMARY

A rotor for a mud motor is disclosed. The rotor includes a core having a first outer shape, and a shell positioned around the core, the shell having a second outer shape that is different from the first outer shape, the second outer shape defining one or more lobes and one or more cavities that are configured to engage a bore of a stator during rotation of the rotor relative to the stator. A thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness to a maximum thickness.

A method for manufacturing a rotor for a mud motor is also disclosed. The method includes forming a shell around a core. The shell has a different outer shape than the core. The shell defines one or more lobes and one or more cavities, the one or more lobes and the one or more cavities being configured to engage a bore of a stator of the mud motor during rotation of the rotor with respect to the stator. A thickness of the shell varies as proceeding around the rotor, from a non-zero minimum thickness to a maximum thickness.

A method for manufacturing a mud motor is also disclosed. The method includes forming a core having a first outer shape, and forming a shell having a second outer shape around the core, the first outer shape being different from the second outer shape. The second outer shape includes one or more lobes and one or more cavities. The shell and the core at least partially form a rotor of the mud motor, and wherein a thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness of at least about 1 mm to a maximum thickness that is greater than the minimum thickness and at most about 25% of a maximum cross-sectional dimension of the rotor. The method further includes positioning the rotor in a stator, such that the shell is configured to engage an inner bore of the stator during rotation of the rotor relative to the stator.

This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present teachings and together with the description, serve to explain the principles of the present teachings. In the figures:

FIG. **1** illustrates an example of a wellsite system, according to an embodiment.

FIG. **2** illustrates a cross-sectional side view of a portion of a mud motor, according to an embodiment.

FIGS. **3**, **3**A and **3**B illustrate axial cross-sections of rotors of the mud motor, according to embodiments.

FIG. **4** illustrates a method for manufacturing a mud motor, according to an embodiment.

DETAILED DESCRIPTION

Reference will now be made in detail to embodiments, examples of which are illustrated in the accompanying drawings and figures. In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be apparent to one of ordinary skill in the art that the invention may be practiced without these specific details. In other instances, well-known methods, procedures, components, circuits and networks have not been described in detail so as not to unnecessarily obscure aspects of the embodiments.

It will also be understood that, although the terms first, second, etc. may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first object could be termed a second object, and, similarly, a second object could be termed a first object, without departing from the scope of the invention. The first object and the second object are both objects, respectively, but they are not to be considered the same object.

The terminology used in the description of the invention herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used in the description of the invention and the appended claims, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will also be understood that the term "and/or" as used herein refers to and encompasses any possible combinations of one or more of the associated listed items. It will be further understood that the terms "includes," "including," "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof. Further, as used herein, the term "if" may be construed to mean "when" or "upon" or "in response to determining" or "in response to detecting," depending on the context.

FIG. **1** illustrates a wellsite system according to examples of the present disclosure may be used. The wellsite can be onshore or offshore. In this example system, a drill string **100** is suspended in a bore **102** formed in subsurface formations **103**. The drill string **100** has a bottom hole assembly (BHA) **104** which includes a drill bit **105** at its lower end. A surface system **106** includes platform and derrick assembly positioned over the borehole **102**, the assembly including a rotary table **108**, kelly (not shown), hook **110**, and rotary swivel **112**. The drill string **100** is rotated by the rotary table **108** energized by a driver, which engages the kelly (not shown) at the upper end of the drill string **100**. The drill string **100** is suspended from the hook **110**, attached to a traveling block (also not shown), through the kelly (not shown) and the rotary swivel **112** which permits rotation of the drill string **100** relative to the hook **110**. A top drive system could be used instead of the rotary table system shown in FIG. **1**.

In the illustrated example, the surface system **106** further includes drilling fluid or mud **114** stored in a pit **116** formed at the well site. A pump **118** delivers the drilling fluid to the interior of the drill string **100** via a port (not shown) in the swivel **112**, causing the drilling fluid to flow downwardly through the drill string **100** as indicated by the directional arrow **120**. The drilling fluid exits the drill string **100** via ports (not shown) in the drill bit **105**, and then circulates upwardly through an annulus region between the outside of the drill string **100** and the wall of the borehole **102**, as indicated by the directional arrows **130**A and **130**B. In this manner, the drilling fluid cools and lubricates the drill bit **105** and carries formation cuttings up to the surface as it is returned to the pit **116** for recirculation.

The BHA **104** of the illustrated embodiment may include a measuring-while-drilling (MWD) tool **132**, a logging-while-drilling (LWD) tool **134**, a rotary steerable directional drilling system **136** and motor, and the drill bit **105**. It will also be understood that more than one LWD tool and/or MWD tool can be employed, e.g., as represented at **138**.

The LWD tool **134** is housed in a drill collar and can contain one or a plurality of logging tools. The LWD tool **134** may include capabilities for measuring, processing, and storing information, as well as for communicating with the surface equipment. In the present example, the LWD tool **134** may include one or more tools configured to measure, without limitation, electrical resistivity, acoustic velocity or slowness, neutron porosity, gamma-gamma density, neutron activation spectroscopy, nuclear magnetic resonance and natural gamma emission spectroscopy.

The MWD tool **132** is also housed in a drill collar and can contain one or more devices for measuring characteristics of the drill string and drill bit. The MWD tool **132** further includes an apparatus **140** for generating electrical power for the downhole system. This may typically include a mud turbine generator powered by the flow of the drilling fluid, it being understood that other power and/or battery systems may be employed. In the present embodiment, the MWD tool **132** may include one or more of the following types of measuring devices, without limitation: a weight-on-bit measuring device, a torque measuring device, a vibration measuring device, a shock measuring device, a stick slip measuring device, a direction measuring device, and an inclination measuring device. The power generating apparatus **140** may also include a drilling fluid flow modulator for communicating measurement and/or tool condition signals to the surface for detection and interpretation by a logging and control unit **142**. In some embodiments, the power generating apparatus **140** is configured to transfer energy (e.g., pressure) in the drilling fluid to rotational energy.

FIG. **2** illustrates a cross-sectional side view of a mud motor **200** (an example of the apparatus **140** of FIG. **1**), according to an embodiment. As shown, the mud motor **200** may be a Moineau-style, progressive-cavity motor, and may thus include a helical rotor **202** and a corresponding stator **204**. The stator **204** defines a bore **205**, and the rotor **202** is received therein, as shown. The rotor **202**/stator **204** combination may be housed in a tube **206**, which may surround an outer surface **208** of the stator **204**. As such, the outer surface **208** may interface (e.g., contact potentially via a layer of adhesive and/or one or more other layers) with the tube **206** when assembled therein. The stator **204** may also include inwardly-extending lobes **209** alternating with outwardly-extending cavities **211**. The lobes **209** and cavities **211** may cooperatively define the bore **205**.

The rotor **202** may not be monolithic, but may, for example, include at least two components, e.g., a central core **210** and a shell **212** that surrounds the core **210**. Further, the shell **212** may define outwardly-extending lobes **214** alternating with inwardly-extending cavities **216**. The lobes **214** and cavities **216** may interface with the lobes **209** and cavities **211** of the inner bore **205** of the stator **204**, such that fluid (e.g., drilling mud) flowing through the bore **205** causes the rotor **202** to rotate relative to the stator **204**, in accordance with principles of operation of a progressive cavity mud motor.

FIGS. **3**, **3**A and **3**B illustrate axial cross-sections of rotors of the mud motor, according to embodiments. As shown, the core **210** may have a first cross-sectional, outer shape. For example, the core **210** may be a cylindrical rod or shaft (as also depicted in FIG. **2**), and thus may have the circular cross-sectional shape illustrated. In another embodiment, the core **210** may be helical. In other embodiments, the core **210** may be polygonal (e.g., square) in cross-section, or may have any other suitable shape. In some embodiments, the core **210** may be made from metal, e.g., a steel alloy. Some steel alloys are prone to corrosion in the downhole fluid environment. For example, steel alloys that include chromium may be subject to corrosion if allowed in contact with the downhole fluid, as the downhole fluid often includes chloride.

Thus, the shell **212** may be a positioned around and may fully encase the cross-section of the core **210**. The shell **212** may be configured to engage the bore **205** of the stator **204**. Accordingly, the shell **212** may be exposed to the downhole fluid environment, and may thus be formed from a material configured to survive this environment and, e.g., protect the core **210**, while being cost-effective to produce. Further, the material may be configured to resist substantial softening or degradation that would impair operation of the rotor **202** in temperatures experienced in the downhole environment. Examples of temperatures in which the shell **212** may be configured to operate range from 110° C. to about 160° C., or higher. In some embodiments, the shell **212** is formed using a material that has a lower strength than the core **210**, a lower melting point than the core **210**, and/or a different coefficient of expansion than the core **210**. Examples of materials that may be used for the shell **212** include carbon fiber-reinforced composites, thermoplastics such as nylon, other plastics, combinations thereof, and/or other materials. In some embodiments, a coating may be applied to the shell **212**, so as to reduce friction between the shell **212** and the stator **204** and/or to protect the shell **212** from degradation in the downhole fluids.

The shell **212** may extend outward from the core **210** and define a second outer shape that is different from the first outer shape of the core **210**. This may be unlike a coating, for example, because a coating on a cylindrical core **210** may generally also define a cylindrical shape. As shown in FIG. **4**, the shell **212** may define at least a portion of the lobes **214** and cavities **216**, which are not apparent in the, e.g., cylindrical, core **210**. Thus, not only does the shell **212**, in some embodiments, prevent the underlying core **210** from exposure to the drilling fluid (thereby potentially preventing corrosion of the core **210**), but the shell **212** may provide a geometry which may be more complex than the geometry of the core **210**, e.g., including helical lobes **214** and cavities **216** versus, e.g., a cylindrical geometry for the core **210**.

The shell **212** and the core **210** may each have a center, which may represent a line extending therethrough. In the illustrated embodiment, the shell **212** and the core **210** have the same center c. In some embodiments, the shell **212** and/or core **210** may each be generally symmetric about the centerline, although deviations from precise symmetry may occur due to tolerances in manufacturing, etc. In some embodiments, the center of the shell **212** may be different from the center of the core **210**, e.g., such that the centers orbit one another when the rotor **202** rotates. Further, in still other embodiments, the shell **212** and/or the core **210** may not be symmetric about a centerline, but may be asymmetrically shaped.

In an embodiment, the shell **212** may vary in radial thickness as proceeding circumferentially around the center c, e.g., around the core **210**. For example, the shell **212** may have a maximum thickness T and a non-zero minimum thickness t, and may vary therebetween. In the illustrated embodiment, in which the core **210** is cylindrical, the maximum thickness T may be located at a peak **302** of the lobe **214**, while the minimum thickness t may be located at a trough **304** of the cavity **216**. Further, in this embodiment, the shell **212** may define a continuous curved surface that defines thicknesses smoothly transitioning between the maximum thickness T and the minimum thickness t.

The minimum thickness t may be configured to be sufficient for the shell **212** to survive in operation, and thus the specific dimension thereof may depend on the properties of the particular material chosen for the shell **212**. The minimum thickness t may, however, be thicker than most or all coatings. For example, the minimum thickness t may be about 1 mm, about 2 mm, between about 1 mm and about 10 mm, between about 2 mm and about 5 mm, or any other suitable range. The maximum thickness T may vary depending, e.g., on the application for the rotor **202**, as different mud motor applications may call for differently-sized rotors **202**. In general, however, the maximum thickness T may be between about 10% and about 50%, between about 15% and about 40%, or between about 20% and about 30% of the maximum cross-sectional dimension (e.g., diameter D) of the core **310**.

In other embodiments, the core **210** may be non-cylindrical, which may make the geometry of the shell **212** more complex. The core **210** may define a radial line **r1** between its center (in this case, center c) and its outer surface. Since the core **210** in the illustrated embodiment is cylindrical, the radial line **r1** is its radius, and may be remain roughly constant (e.g., within reasonable tolerances) as proceeding 360 degrees around the center c. In other embodiments, the radial line **r1** may vary in length depending on its angular orientation. For example, the core **210** may have helical lobes, and the peaks of lobes of the core **210** may rotationally lag the peaks of the shell **212**, thereby providing circumferential support for the shell **212**.

The shell **212** may also define one or more radial lines, e.g., radial lines **r2** and **r3**. For example, the radial line **r2** may extend from the center of the shell **212** (e.g., the center c) to the trough **304** of the cavity **216**. The radial line **r3** may extend from the center c to the peak **302** of the lobe **214**. Accordingly, the length of the radial line **r2** may be the shortest distance between the outer surface of the rotor **202** and the center c, and the length of the radial line **r3** may be the longest distance between the outer surface of the rotor **202** and the center c. However, the position of the radial line **r2** may or may not coincide with the location of the minimum thickness t and/or the radial line **r3** may or may not coincide with the location of the maximum thickness T. In an embodiment in which the core **210** is non-cylindrical, the minimum thickness t may be located at a position that is offset from the trough **304**, and/or the maximum thickness T may be located at a position that is offset from the peak **302**.

Further, a line bisecting the rotor **202** proceeds twice through the thickness of the shell **212** and once through the core **210**. The core **210** and shell **212** may be configured such that, for any such line, a maximum of between about 40% and about 60% (e.g., maximum of about 50%) of its length extends through the material of the shell **212**, with the remaining portion extending through the core **210**. Stated otherwise, the maximum thickness T of the shell **212** may be, at most between about 20% and about 30% (e.g., about 25%) of the maximum cross-sectional dimension of the rotor **202**, since the maximum thickness T of the shell **212** may be traversed twice by a single line bisecting the rotor **202**.

The shell **212** may be cast or molded (e.g., injection molded) directly onto and around the core **210**. For example, a mold having substantially the desired shape of the shell **212** may be positioned around the core **210**, and material for the shell **212** may be injected or otherwise introduced (e.g., in a melted, generally liquid form) therein. Once the material has hardened, the shell **212** may be formed on the core **210**. In another embodiment, a mold or cast may be configured to form a cylindrical (or another shape) blank for the shell **212** and may be positioned around the core **210**. The material for the shell **212** may be introduced between the mold/cast and the core **210**, and hardened. A machining operation may then be applied to cut the shell **212** into a desired shape (e.g., helical with the lobes **214** and cavities **216**). In some embodiments, the blank that is formed by the introduction of molten material into the mold/cast may not be cylindrical, but may be helical, or otherwise a "rough" shape for the shell **212**, with the machining process then being applied to the formed shell **212** to produce its final shape. In other embodiments, the shell **212** may be three-dimensional (3D) printed onto the core **210**. In some embodiments, the 3D printed shell may be machined for a desired finish or shape, but in other embodiments, may not be machined after printing.

In some embodiments, torque-transmitting or "gripping" features between the shell **212** and the core **210** may be provided. In the illustrated embodiment, tabs **217**A and **217**B are provided as an example of such gripping features. The tabs **217**A, **217**B extend radially outwards from the core **210** and into the shell **312**. While the tabs **217**A, **217**B are shown as diametrically opposed, this is merely an example, and they may be positioned in any suitable location. Further, the tabs **217**A, **217**B (or any other gripping features) may be sized and/or positioned so as to avoid impacting conformity with the prescribed minimum thickness t and/or prescribed maximum thickness T for the shell **212**, as discussed above. The tabs **217** or other torque-transmitting features may extend a tab distance **218** from the surface of the core **210**. For example, the tab distance **218** may be between 10% to 150%, 25% to 100%, or 50% to 75% of the minimum thickness t of the shell **212**. In some embodiments, the tabs **217**A, **217**B may be offset from the peaks of the shell **212**, thereby providing circumferential support for the shell **212**. Moreover, the rotor **202** may include more than two torque-transmitting features or tabs. In some embodiments, the quantity of torque-transmitting features may correspond to the number of lobes of the shell **212**. For example, a rotor **202** having four lobes on the shell **212** may include a core **210** having four torque-transmitting features. In some embodiments, the quantity of torque-transmitting features may exceed the number of lobes of the shell **212**.

In other embodiments, the torque-transmitting features may include ridges and/or grooves formed (e.g., axially) along the outer diameter surface of the core **210**. In still other embodiments, knurling or any other suitable structures may be provided as part of the torque-transmitting features. It may be appreciated that torque-transmitting features such as ridges, grooves, and knurling may extend from or into the surface of the core **210** less than the tab distance **218** of the tabs **217**A, **217**B discussed above.

When cast or molded onto the core **210**, the inner surface of the shell **212** may form around the tabs **217**A, **217**B, or otherwise form a structure (e.g., ridges **220** as shown in FIG. **3**B, grooves as shown in FIG. **3**A, reverse knurling) that is complementary to the gripping features provided by the core **210**. As such, the gripping features may provide a radially-extending, circumferentially-facing load-transmitting interface between the shell **212** and the core **210**, which may be generally perpendicular to a torque force directed generally tangent to the core **210**. The geometry of the torque-transmitting features may be rectangular-shaped, triangular-shaped, or dome-shaped, among other geometries. The torque-transmitting features may be arranged about the core **210** with a leading surface (S_L) that is larger than a trailing surface (S_T), wherein the leading surface and trailing surface are with respect to rotation of the shell and wherein the leading surface is configured to receive more torque from the shell **210** than the trailing surface when the rotor **202** rotates within the stator **204**.

During operation, pressurized fluid (e.g., drilling mud) is forced into the bore **205** (FIG. **2**), between the rotor **202** and the stator **204**. The geometry of the complementary lobes **209**, **214** and cavities **211**, **216** of the rotor **202** and the stator **204** converts some of the potential energy stored as pressure into kinetic energy in the form of rotation of rotor **202** via torque force on the outside of the rotor **202**, i.e., the shell **212**. This torque force is transmitted to the core **210** by engagement with the shell **212**. The gripping features (e.g., the tabs **217**A, **217**B) may thus serve to prevent relative movement of the shell **212** over the core **210** ("slippage") by providing the aforementioned perpendicular interface, thereby avoiding reliance solely on friction between shell **212** and the core **210**. Moreover, the shell **212** and core **210** may have unequal coefficients of thermal expansion, since they may be made from different materials. Thus, the gripping features, by extending radially, may provide torque transmission even when the shell **212** has expanded partially away from tight engagement around the core **210**.

In some embodiments, the core **210** and/or shell **212** may provide other gripping features, e.g., shoulders or recesses in/on the core **210**, which may serve to prevent the shell **212** from slipping axially with respect to the core **210**. In some embodiments, the shape of the core **210** itself may be configured to provide torque support for the shell **212**.

It will be appreciated that forming the shell **212** from a material such as plastic may reduce the lifecycle of the rotor **202** in comparison to all-metal rotors. Such all-metal rotors may be expensive to manufacture, however, as they may be made from corrosion-resistant materials. That is, if the outer surface thereof of a corrosion-resistant all-metal rotor is damaged, the entire rotor may be replaced. Moreover, since the stator **204** is at least partially made from rubber, the stator **204** may provide an upper bound for the lifecycle of the mud motor **200**, and thus reducing the lifecycle of the rotor **202** may have no or little impact on the overall lifecycle of the mud motor **200**. For example, the rotor **202** and the stator **204** may be configured to be switched out after approximately the same amount of time in operation, rather than an all-metal rotor outlasting the stator.

FIG. **4** illustrates a flowchart of a method **400** for manufacturing a mud motor, e.g., specifically a rotor of the mud motor, according to an embodiment. Execution of the method **400** may result in one or more embodiments of the mud motor **200** discussed above, and thus the method **400** is described herein with reference thereto. However, execution of other embodiments of the method **400** may result in other mud motors. Furthermore, although the worksteps of the method **400** are provided in a specific order, it will be appreciated that the order may be rearranged and/or the worksteps may be combined, separated, performed in parallel, etc.

The method **400** includes forming a core **210**, as at **402**. The core **210** may be cast, forged, sintered, or otherwise formed from a metal, e.g., a steel alloy. The core **210** may have a first outer shape, e.g., a cylinder or helix. In at least one embodiment, one or more torque-transmitting features may be formed in or on the core **210**, as at **404**. For example, one or more ridges and/or one or more grooves may be formed along the length of the core **210**.

The method **400** may include forming (e.g., molding or casting) a shell **212** around the core **210**, as at **406**. For example, the core **210** may be received into a mold, and a material (e.g., molten plastic) may be introduced (e.g., injected) into the mold or cast. The material may be allowed to solidify, cure, or otherwise harden. The mold or cast may then be removed, leaving the shell **212** formed around the core **210**.

In some embodiments, the method **400** may further include machining the shell **212**, as at **408**. For example, in the molding/casting process discussed above, the mold/cast may provide a blank or basic shape for the shell **212**. The shell **212** may then be machined at **408** to form the final outer shape for the shell **212**. In other embodiments, the casting/molding process may be sufficient to create a desired outer shape for the shell **212**, and the machining at **308** may be omitted. Accordingly, either by casting/molding or both by casting/molding and machining (or any other suitable forming technique), the shell **212** may have an outer shape that is different from the first outer shape of the core **210**. For example, the shell **212** may define one or more lobes **214** and one or more cavities **216**, which are not found in the first outer shape of the core **210**.

In some embodiments, a coating, e.g., a low-friction coating, may be applied to the shell **212**, as at **410**. The coating may follow the contour of the second shape of the shell **212**, although some variations in thickness of the coating may be apparent.

In some embodiments, the shell **212** and the core **210** may provide at least a portion of the rotor **202**, and thus assembly of the mud motor **200** may include positioning the shell **212** and the core **210** within the stator **204**, as at **412**. Accordingly, the shell **212** may be configured to engage the bore of the stator **204**, which may be provided with lobes and/or cavities that cooperate with the lobes **209** and cavities **211** of the shell **212**. As such, whether coated or uncoated, the shell **212** may be configured to engage the stator **204**.

The foregoing description, for purpose of explanation, has been described with reference to specific embodiments. However, the illustrative discussions above are not intended to be exhaustive or to limit the invention to the precise forms disclosed. Many modifications and variations are possible in view of the above teachings. Moreover, the order in which the elements of the methods are illustrated and described may be re-arranged, and/or two or more elements may occur simultaneously. The embodiments were chosen and described in order to best explain the principals of the invention and its practical applications, to thereby enable others skilled in the art to best utilize the invention and various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A rotor for a mud motor, comprising:

a core having a first outer shape and a core feature comprising a radially-extending ridge, wherein the core feature is arranged about the core, wherein the radially-extending ridge comprises a circumferentially-facing leading surface and a circumferentially-facing trailing surface with respect to a direction of rotation of a shell positioned around the core, and the leading surface is larger than the trailing surface, wherein the leading surface is configured to receive more torque from the shell than the trailing surface; and

the shell positioned around the core, the shell having a second outer shape that is different from the first outer shape and a shell feature comprising a groove, wherein the groove is configured to interface with the core feature to transmit torque to the core, the second outer shape defining one or more lobes and one or more cavities that are configured to engage a bore of a stator during rotation of the rotor relative to the stator, wherein a thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness to a maximum thickness.

2. The rotor of claim **1**, wherein the minimum thickness is defined between the core and a trough of one of the one or more cavities, and wherein the maximum thickness is defined between the core and a peak of one of the one or more lobes.

3. The rotor of claim **1**, wherein the shell has a lower strength than the core, a lower melting point than the core, and a different coefficient of thermal expansion than the core.

4. The rotor of claim **1**, wherein the core comprises metal and the shell comprises a plastic, a composite material, or a combination of the plastic and the composite material.

5. The rotor of claim **1**, wherein the first outer shape of the core is helical.

6. The rotor of claim **1**, wherein the maximum thickness of the shell is between about 20% and about 30% of a maximum cross-sectional dimension of the rotor, and wherein the minimum thickness is between about 1 mm and about 10 mm.

7. The rotor of claim **1**, further comprising a coating applied to the shell, wherein the coating comprises a material having a lower friction coefficient than a material of the shell.

8. The rotor of claim **1**, wherein the core comprises a steel alloy having chromium, and the shell is configured to protect the core from contact with a downhole fluid.

9. A method for manufacturing a mud motor, comprising:

forming a core having a first outer shape;

forming a shell having a second outer shape around the core, the first outer shape being different from the second outer shape, wherein the second outer shape comprises one or more lobes and one or more cavities, wherein the shell and the core at least partially form a rotor of the mud motor, and wherein a thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness of at least about 1 mm to a maximum thickness that is greater than the minimum thickness and at most about 25% of a maximum cross-sectional dimension of the rotor; and

positioning the rotor in a stator, such that the shell is configured to engage an inner bore of the stator during rotation of the rotor relative to the stator.

10. The method of claim **9**, wherein the minimum thickness of the shell is defined at a trough of one of the one or more cavities of the shell, and the maximum thickness of the shell is defined at a peak of one of the one or more lobes of the shell.

11. The method of claim **9**, further comprising machining the shell to produce the second outer shape of the shell.

12. A rotor for a mud motor, comprising:

a core having a first outer shape and a core feature comprising a groove; and

a shell positioned around the core, the shell having a second outer shape that is different from the first outer shape and the shell comprises a radially-extending ridge, wherein the radially-extending ridge comprises a circumferentially-facing leading surface and a circumferentially-facing trailing surface with respect to a direction of rotation of the shell, the leading surface is larger than the trailing surface and the radially-extending ridge is configured to interface with the core feature to transmit torque to the core, wherein the leading surface is configured to receive more torque from the shell than the trailing surface;

wherein the second outer shape defines one or more lobes and one or more cavities that are configured to engage a bore of a stator during rotation of the rotor relative to the stator, wherein a thickness of the shell varies as proceeding around the core, from a non-zero minimum thickness to a maximum thickness.

13. The rotor of claim **12**, wherein the minimum thickness is defined between the core and a trough of one of the one or more cavities, and wherein the maximum thickness is defined between the core and a peak of one of the one or more lobes.

14. The rotor of claim **12**, wherein the shell has a lower strength than the core, a lower melting point than the core, and a different coefficient of thermal expansion than the core.

15. The rotor of claim **12**, wherein the core comprises metal and the shell comprises a plastic, a composite material, or a combination of the plastic and the composite material.

16. The rotor of claim **12**, wherein the first outer shape of the core is helical.

17. The rotor of claim **12**, wherein the maximum thickness of the shell is between about 20% and about 30% of a maximum cross-sectional dimension of the rotor, and wherein the minimum thickness is between about 1 mm and about 10 mm.

18. The rotor of claim **12**, further comprising a coating applied to the shell, wherein the coating comprises a material having a lower friction coefficient than a material of the shell.

19. The rotor of claim **12**, wherein the core comprises a steel alloy having chromium, and the shell is configured to protect the core from contact with a downhole fluid.

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