US 20220145705A1

(19) United States
(12) Patent Application Publication
Munguia
(10) Pub. No.: US 2022/0145705 A1
(43) Pub. Date: May 12, 2022

(54) **OFFSET COUPLING FOR MUD MOTOR DRIVE SHAFT**

(71) Applicant: **Halliburton Energy Services, Inc.**, Houston, TX (US)

(72) Inventor: **Joseph Robert Munguia**, Houston, TX (US)

(73) Assignee: **Halliburton Energy Services, Inc.**, Houston, TX (US)

(21) Appl. No.: **17/094,963**

(22) Filed: **Nov. 11, 2020**

Publication Classification

(51) **Int. Cl.**

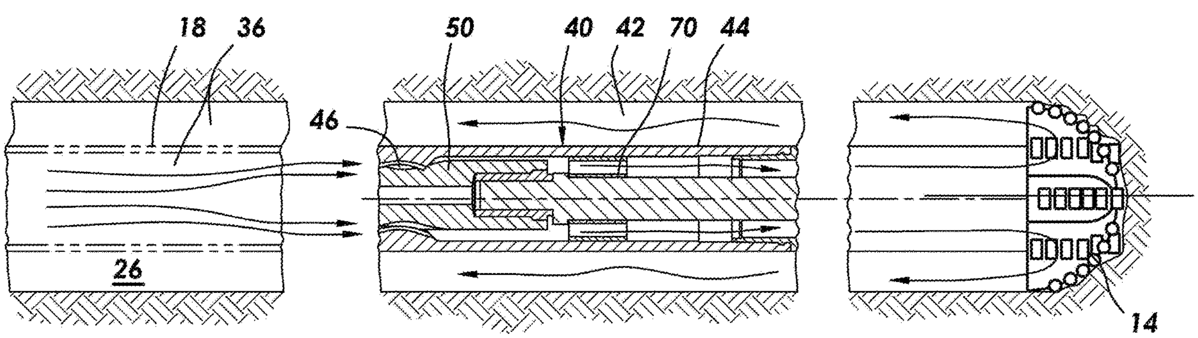
E21B 4/02	(2006.01)
E21B 3/00	(2006.01)
E21B 4/00	(2006.01)

(52) **U.S. Cl.**

CPC ***E21B 4/02*** (2013.01); ***E21B 4/006*** (2013.01); ***E21B 3/00*** (2013.01)

(57) **ABSTRACT**

A rotary transfer mechanism is disclosed for a motor, pump, or other downhole tool that accommodates the eccentric motion of a rotor without the need for a flex shaft, articulating joint or CV joint. In one configuration, the rotor is coupled to the drive shaft at a radial offset from the drive shaft axis. The orbiting motion of the rotor, rather than rotation of the rotor about its own axis, generates a torque on the drive shaft, by applying a tangential force to the drive shaft at the location of the radial offset. The radial offset may be set equal to the orbital radius so that no radial movement or flex is required at the drive shaft to accommodate the eccentric rotor movement.



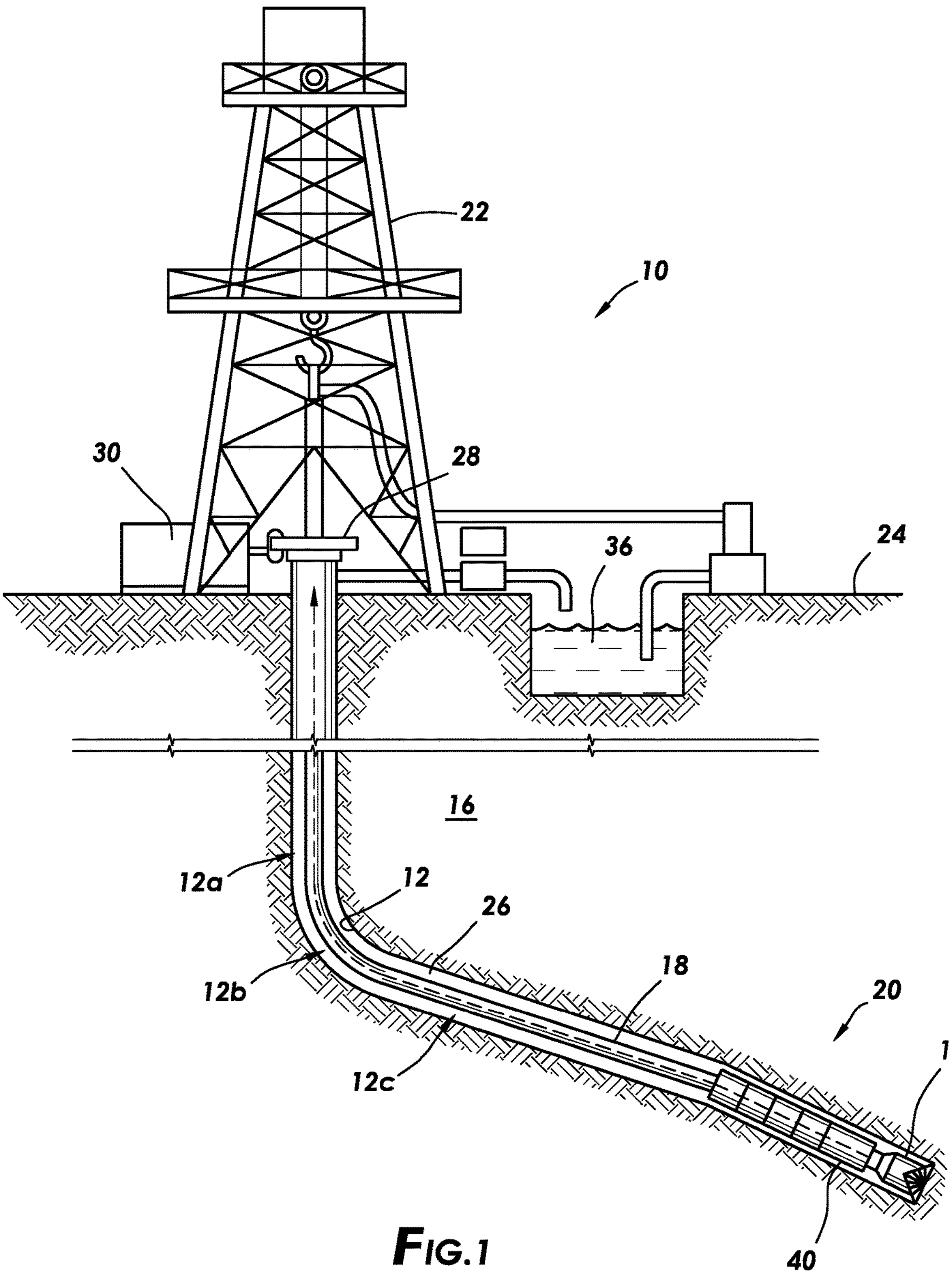


FIG.1

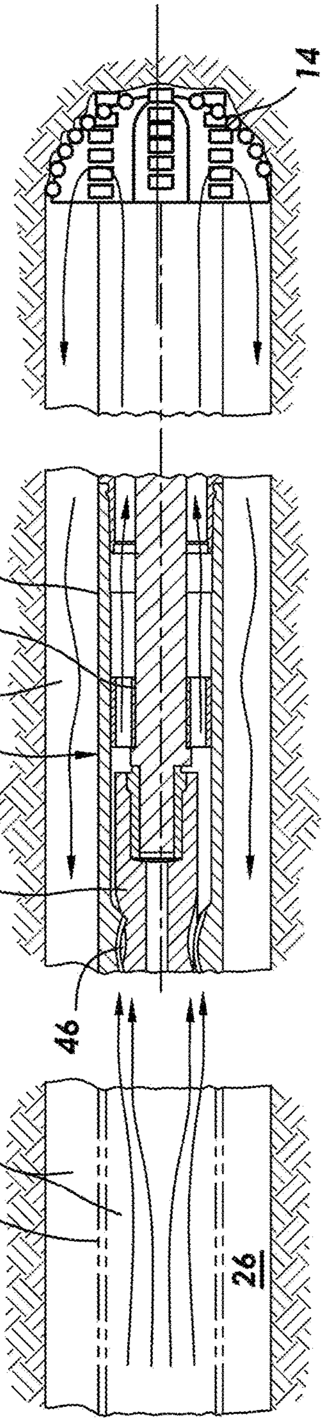

14
44
70
42
40
50
46
36
18
26

FIG.2

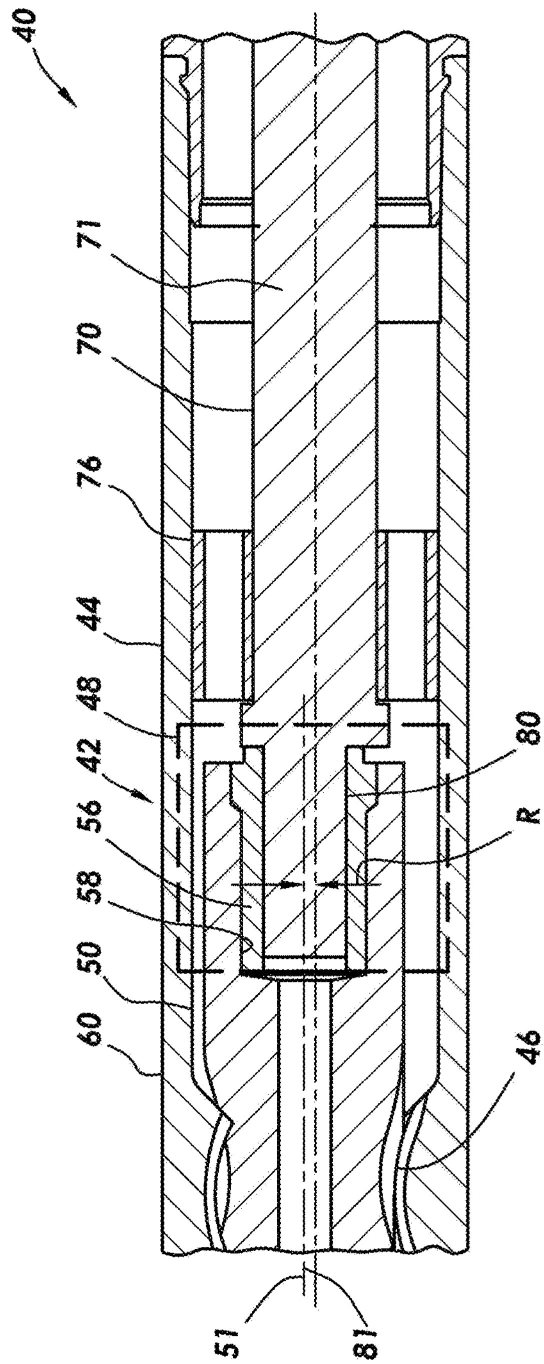

40
71
70
76
44
48
42
56
58
50
60
80
R
46
51
81

FIG.3

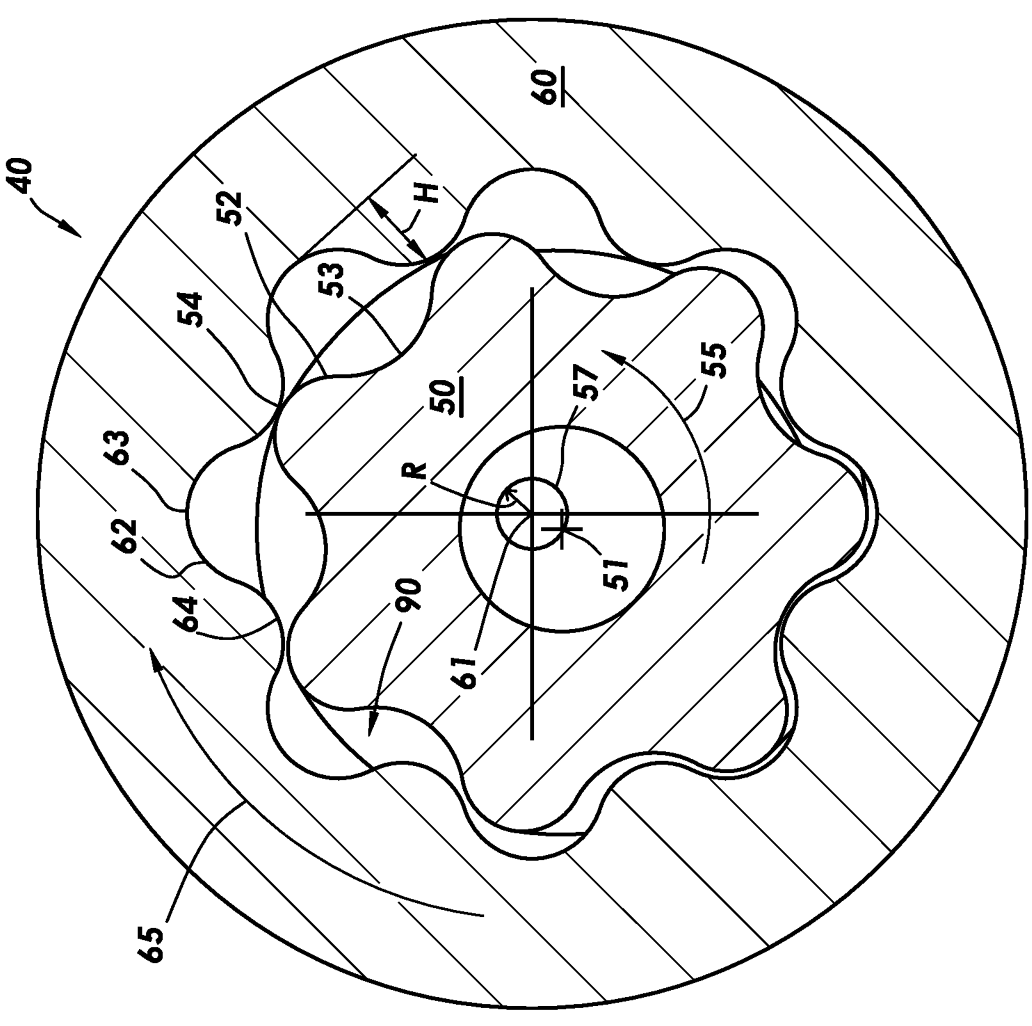


FIG.4

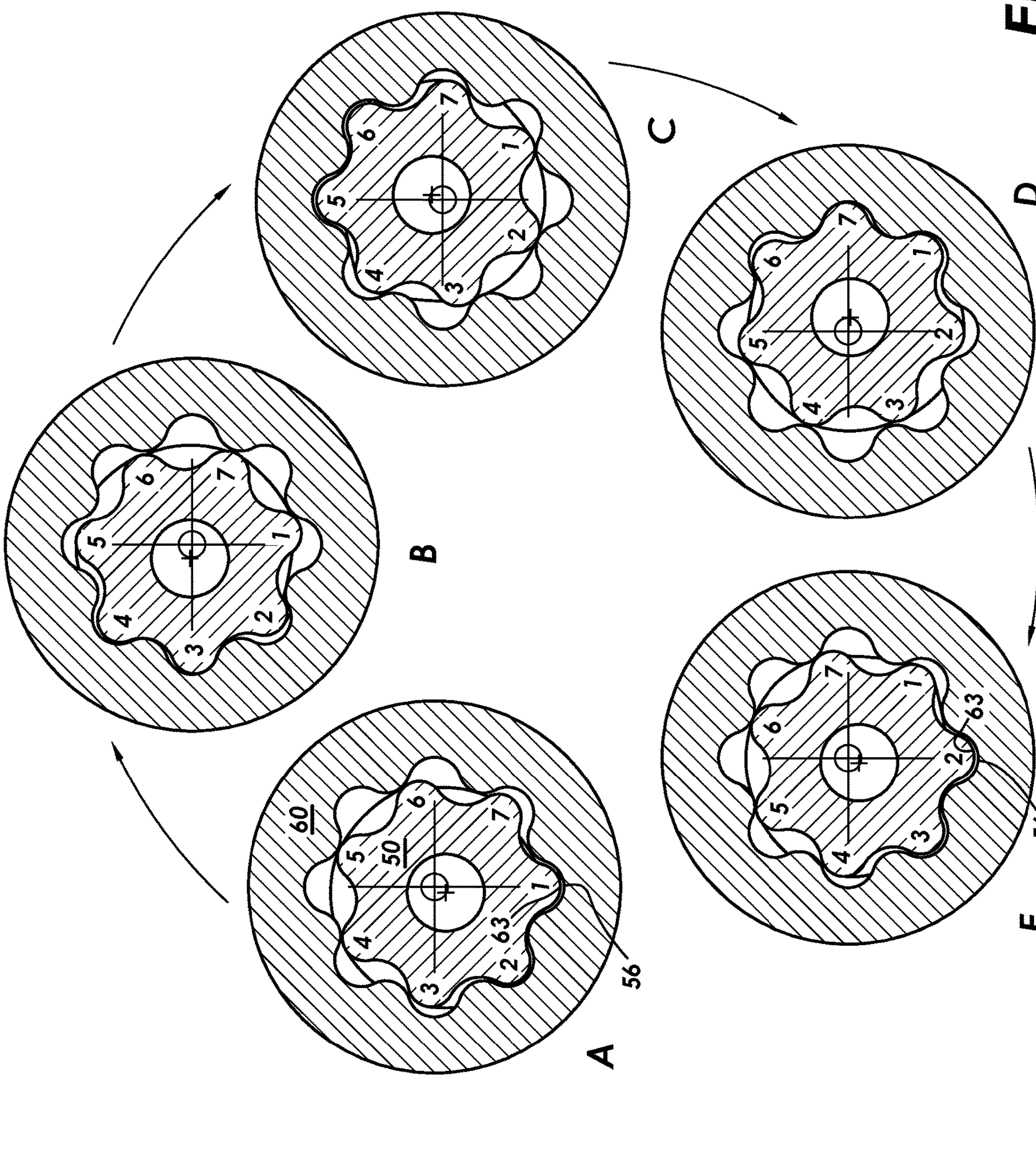


FIG.5

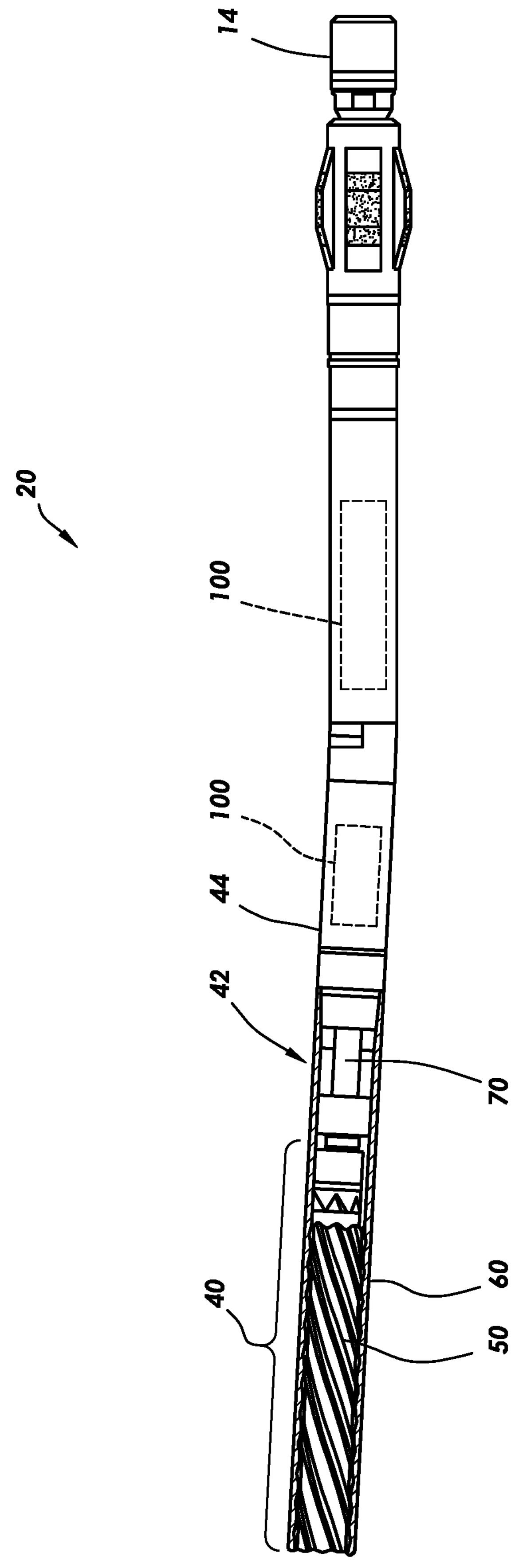


FIG.6

OFFSET COUPLING FOR MUD MOTOR DRIVE SHAFT

BACKGROUND

[0001] Wells are constructed for the potential recovery of hydrocarbons such as oil and gas from underground formations. Typically, a well is drilled with a tubular drill string that is progressively assembled to reach the desired well depth. A casing string may then be lowered into selected portions of the wellbore and cemented in place to reinforce the wellbore. The casing may be perforated at selected intervals to provide flowpaths for extracting hydrocarbon fluids from a production zone(s) of the formation. The formation may also be stimulated such as by hydraulically fracturing or acidizing the formation in the vicinity of the production zone. Finally, a production tubing string may be run into the well to the production zone, protecting the casing and providing a flow path to a wellhead through which the oil and gas can be produced.

[0002] Each of the phases of well construction may be costly and labor-intensive. One aspect of the cost is the challenge of working in a harsh downhole environment, which may expose tools to high temperatures, pressures, forces, and a multitude of potentially corrosive or reactive working fluids and formation fluids. Tools and methods must be designed and built to withstand the harsh downhole environment. A tool is often required to be run in multiple trips into a single well. Some tools are used repeatedly as part of a fleet and are maintained with the expectation that they function reliably over the life of many wells.

[0003] Downhole motors and pumps are examples of tools that encounter high stresses. Certain motor and pump designs involve the flow of pressurized fluid through a plurality of cavities defined between a rotor and stator, which results in eccentric motion of the rotor. The eccentric motion and corresponding interaction between various components can be both mechanically complex and stressful. Past efforts to accommodate the eccentric motion of tools like mud motors have included the use of articulating joints and/or constant velocity (CV) joints to accommodate multiple degrees of movement. These special joints increase complexity and possible failure modes. Flexible shafts (i.e. flex shafts) have also been tried to reduce reliance on these types of joints, but can induce high bending moments to surrounding components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] These drawings illustrate certain aspects of some of the embodiments of the present disclosure and should not be used to limit or define the disclosure.

[0005] FIG. **1** is an elevation view of a representative drilling system **10** in which a rotary transfer mechanism may be implemented according to one or more embodiments of the present disclosure.

[0006] FIG. **2** is a side view of the mud motor run by the drilling system of FIG. **1**.

[0007] FIG. **3** is an enlarged view of the mud motor further detailing the motor and the rotary transfer mechanism of FIG. **2**.

[0008] FIG. **4** is a cross-sectional view of the mud motor for further discussing the eccentric movement of the rotor with respect to the stator.

[0009] FIG. **5** is a sequential diagram of the motor as the rotor completes one full clockwise orbital revolution about the stator.

[0010] FIG. **6** is a side view of an example BHA wherein the drive shaft is coupled to the drill bit by an intermediate gearbox.

DETAILED DESCRIPTION

[0011] A rotary transfer mechanism is disclosed for use with tools such as motors and pumps, to accommodate eccentric motion of a rotor without the need for articulating joints, CV joints, or flex shafts. The rotor may both rotate about its own axis, while simultaneously orbiting around another axis such as the stator axis (which may be in opposite directions). The rotor may be coupled to the drive shaft at a radial offset from the drive shaft axis, such that the orbiting motion of the rotor applies a torque to the drive shaft. As a result, in at least some embodiments, rotation may be transferred from the rotor to the drive shaft by the orbiting motion, rather than by rotation of the rotor about its own axis. A bearing may be provided to allow relative rotation between the rotor and the drive shaft where the rotor is coupled to the drive shaft (e.g. a bearing at an offset pin).

[0012] In one configuration, the rotor may be coupled to the drive shaft using an offset pin, which is radially offset from the drive shaft axis by some amount. The amount of radial offset may be equal to the orbital radius of the rotor as measured by the movement of the rotor axis with respect to the stator axis, so that the offset pin travels on the same radius (distance from the drive shaft axis and/or BHA axis) as the rotor. A bearing may be provided on the drive shaft to support rotation of the drive shaft about the drive shaft axis. Another bearing may be provided at the offset pin to support relative rotational movement between the drive shaft and rotor where they are coupled. The rotor may therefore rotate about the rotor axis and simultaneously orbit about another, e.g. stator axis, and no radial movement is required at the drive shaft to accommodate this motion. Thus, the need for a flex shaft, CV joint, or articulating joint may be eliminated in at least some embodiments.

[0013] For context, FIG. **1** provides an elevation view of a representative drilling system **10** in which a rotary transfer mechanism may be implemented according to one or more embodiments of the present disclosure. The rotary transfer mechanism is used in this example with a mud motor **40**, but may alternatively be used with other tools, such as pumps, that rely on the flow of a working fluid through a progressing cavity defined by a rotor and stator. Although drilling system **10** is illustrated in the context of a terrestrial drilling operation, it will be appreciated by those skilled in the art that aspects of the disclosure may also be practiced in connection with offshore platforms and or other types of hydrocarbon exploration and recovery systems.

[0014] The drilling system **10** is used in forming a wellbore **12** traversing a geologic formation **16**. A drilling rig **22** at the surface **24** of the wellsite provides a support structure and surface equipment for drilling. A drill string **18** is supported from the drilling rig **22** and may be progressively assembled by adding segments of tubing as the well is drilled. A bottomhole assembly (BHA) **20** generally depicted at a lower end of the drill string **18** includes a rotary drill bit **14**, mud motor **40**, and other components not explicitly shown such as bearing assemblies, steering mechanisms, measurement, and telemetry systems. The rotary drill bit **14** includes cutting structures that, when rotated, cut into the geological formation **16** such as by shearing, scraping, gouging, or otherwise disintegrating the formation material. The drill bit **14** may be rotated by rotating the entire drill string **18** from the surface using a turntable **28** powered by an engine **30** on the drilling rig **22**. The drill bit **14** may also be rotated by the mud motor **40** relative to the drill string **18**.

[0015] The option to rotate the drill bit **14** using either the mud motor **40** or the drill string **18** has a variety of different uses. For example, in directional drilling, a bent housing (not explicitly shown) in the BHA **20** may be used to provide a directional bias to the lower end of the drill string. To drill a straight section, the drill string **18** and the drill bit **14** may be rotated together, in what may be called a rotating mode. In rotating mode, the bent housing turns with the rest of the drill string **18** to eliminate the effect of the directional bias on the trajectory of the wellbore **12** as it is being drilled. To deviate from the current drilling trajectory, drill string rotation may be halted and the drill bit **14** rotated using only the mud motor **40**, in what may be called a sliding mode. The bent housing remains rotationally stationary, so the directional bias of the bent housing causes a directional change as drilling progresses. Thus, any number of straight or deviated sections may be drilled by selectively rotating or not rotating the drill string **18** during drilling. FIG. **1** shows, for example, a vertical section **12***a*, a build section **12***b*, and a tangent section **12***c*.

[0016] While drilling, pressurized drilling fluid (i.e. mud) **36** may be flowed down the drill string **18** and up through an annulus between the drill string **18** and formation **16**, to lubricate the drill bit **14** and remove cuttings to the surface **24**. That same pressured drilling fluid **36** may be used to power the mud motor **40**, which generates torque in response to the circulation of the drilling fluid **36**. The mud **36** also lubricates the rotary drill bit **14** and flushes geologic cuttings from the path of the rotary drill bit **14**. The mud **36** exiting the drill bit **14** flows up through an annulus **26** defined between the drill string **18** and the geologic formation **16**. The geologic cuttings and other debris are carried by the mud **36** to the surface **24** where the cuttings and debris can be removed from the mud stream.

[0017] FIG. **2** is a side view of the mud motor **40** run by the drilling system **10** of FIG. **1** according to an example configuration. The motor **40** is included with a lower end of drill string **18** to optionally drive rotation of the drill bit **14**. The motor **40** is cut away to reveal a portion of a rotary transfer mechanism **42**, which includes a rotor **50** coupled to a drive shaft **70** and disposed within a motor housing **44**. Pressurized mud **36** is shown flowing down through the drilling string **18** to the mud motor **40**. When it is desired to power the drill bit **14** with the motor **40**, the pressured mud **36** can be directed through a progressing cavity **46** defined by a plurality of helical stator lobes further discussed below. The flow through the motor **40** causes a rotary motion of the rotor **50**. Within the rotary transfer mechanism **42**, rotary motion of the rotor **50** is transferred to the drive shaft **70** as discussed below, which drives rotation of the drill bit **14**. The flow path of the mud **36** continues downhole from the mud motor **40**, out through nozzles on the drill bit **14**, and up through the annulus **26**, to wash away formation cuttings and other debris.

[0018] FIG. **3** is an enlarged view of the mud motor **40** further detailing the motor **40** and the rotary transfer mechanism **42** of FIG. **2**. The motor **40** includes a stator **60** that is fixed relative to the motor housing **44**. The stator **60** may be a separate part secured to the motor housing **44**, or the motor housing **44** may itself be the stator **60**. The rotor **50** is moveably disposed inside the stator **60** in this configuration, such that the rotor moves around the inside of the stator **60**, although an alternate configuration could instead have a stator disposed inside a rotor, wherein the rotor moves around the outside of the stator. The drive shaft **70** is rotatably supported about a drive shaft axis **71**. The structure comprising the motor housing **44** may extend past the rotor **50** to also house the drive shaft **70**, either as a single, unitary housing section or separate housing sections coupled together end to end. Although not required, the drive shaft **70** and motor housing **44** are both of generally circular cross-section, with the drive shaft **70** centered within the housing **44**, such that the drive shaft axis **70** is coaxial with the stator **60** in this embodiment. (Coaxial in this context refers to having a common geometrical axis and does not necessarily imply that one item is inside the other.) The rotor **50** follows a compound movement with respect to the stator **60**, including rotation of the rotor about its own axis (rotor axis) **51** and an eccentric component wherein the rotor axis **51** simultaneously orbits about an orbital axis. The orbital axis coincides with a stator axis and the drive shaft axis **71** in this configuration.

[0019] The rotor **50** is coupled to a drive shaft **70** at a location radially offset from the drive shaft axis **71** by a radial offset "R." More particularly, in this embodiment, the rotor **50** is coupled to the drive shaft **70** at an interface or coupling **48** that includes a pin **80** on the drive shaft **70** received within a pin receptacle **58** on the rotor **50**. The pin **80** has a pin axis **81** that is parallel to and offset from the drive shaft axis **71** by the radial offset R. The pin **80** is coaxial (centrally disposed within) the rotor **50** in this embodiment, i.e. the rotor axis **51** aligns with pin axis **81**, and the stator **60** is radially aligned with the drive shaft **70**, so that the rotor axis **51** orbit about the drive shaft axis **71**. Alternative configurations are possible within the scope of this disclosure wherein the stator is not necessarily aligned with the drive shaft, in which case the drive shaft axis does not necessarily coincide with the orbital axis. The orbiting of the rotor **50** thereby drives rotation of the drive shaft **70** by applying a tangential force to the drive shaft **70** via the pin **80** at a moment arm equal to the radial offset R, with a resulting torque applied to the drive shaft **70**. In at least this embodiment, the orbital radius matches the radial offset R, so that no radial movement of the drive shaft axis **71** is required (e.g. no articulating joint or flex shaft required) to accommodate the eccentric movement of the rotor **50**.

[0020] Bearings are optionally included to support relative rotation between parts. In FIG. **3**, a first bearing, referred to as rotor bearing **56**, supports relative rotation between the drive shaft **70** and rotor **50** about the rotor axis **51**. More particularly, the pin **80** will rotate within the pin receptacle **58** as the rotor **50** orbits and applies the tangential force to the drive shaft **70** at pin **80**. The rotor bearing **56** is disposed between the pin **80** and the pin receptacle **58** and may be a type of roller bearing or may be a fixed bearing with a low-friction material. A second bearing, referred to as a drive shaft bearing **76**, supports rotation of the drive shaft **70** about its own, drive shaft axis **71**. The drive shaft bearing aligns the drive shaft axis **71** with the stator axis **61**. The drive shaft bearing **76** in this configuration also serves as a spacer, or more specifically a centralizer, to radially position and centralize the drive shaft **70** within the housing **44**.

[0021] According to this structure and the various modifications within the scope of this disclosure, the drive shaft **70** is not required to articulate (e.g. using an articulating joint and/or CV joint), nor flex, to accommodate the eccentric motion of the rotor **50**. The drive shaft axis **71** may remain level, parallel with the rotor axis **50**, and parallel with the stator axis **61** (e.g., FIG. **4**). Since no radial movement of the drive shaft **70** is required to accommodate the eccentric movement of the rotor **50**, the drive shaft bearing **76** may abut an inner diameter of the housing **44** to better support the drive shaft **70** and prevent lateral/radial movement of the drive shaft **70**, which provides a very stable rotational transfer between the rotor **50** and drive shaft **70**.

[0022] It should be recognized that a rotary transfer mechanism according to this disclosure is not limited to use with a mud motor, wherein powered rotation of the rotor drives rotation of the drive shaft. One of ordinary skill will appreciate, for example, that the rotary transfer mechanism **42** of

[0023] FIG. **3** could be used in a different downhole system and operated in a sort of a reverse fashion as a pump. Specifically, rotation of the drive shaft **70** may be powered, e.g., from a motor on the right, in the opposite direction as described above, to apply a torque to the rotor **50** at the offset pin **80**. The motion of the rotor **50** is thereby reversed, to pump a working fluid from right to left. Such a pump would have some or all the technical advantages described herein, such as avoiding the need for an articulating joint or flex shaft to accommodate the eccentric motion of the rotor **50**.

[0024] FIG. **4** is a cross-sectional view of the mud motor **40** illustrating the eccentric movement of the rotor **50** that drives rotation of the drive shaft **70** of FIG. **3**. As was explained in FIG. **3**, the rotor **50** is coupled to the drive shaft **70** at the offset pin **80**, such that the rotor **50** and offset pin **80** are coaxial (i.e. rotor axis **51** coincides with the center of the offset pin **80**.) In this configuration, the rotor **50** is moveably disposed inside the stator **60**, although it is possible to alternately configure it with a stator disposed inside a rotor. The rotor **50** has an undulating outer surface **52** that meshes with an undulating inner surface **62** of the stator **60**. The outwardly extending portions of the undulating outer surface **52** are referred to herein as rotor lobes **54**, with corresponding rotor recesses **53** therebetween. The inwardly extending portions of the undulating inner surface **62** of the stator **60** are referred to herein as the stator lobes **64**, with corresponding stator recesses **63** therebetween. By design, the rotor **50** has one fewer rotor lobe **54** than the stator **60** has stator lobes **64**. In this configuration, the stator **60** includes **8** stator lobes **64**, and the rotor **50** includes **7** rotor lobes **54**.

[0025] A plurality of cavities **90** are defined between the rotor **50**, stator **60**, and the respective lobes **54**, **64**, which extend axially (into and out of the page) in a sort of helical arrangement. As fluid passes through the cavities **90**, the undulating outer surface **52** of the rotor **50** rolls along the undulating inner surface **62** of the stator **60**. In so doing, the rotor **50** simultaneously rotates about its own rotor axis **51** in one direction (in this example, a counter-clockwise direction **55**) as the rotor axis **51** orbits about the stator axis **61** in the opposite (in this example clockwise) direction **65**. The generally circular orbital path traced by the rotor axis **51** as it orbits around the stator axis **61** is indicated at **57**. Each 360-degree orbital revolution of the rotor **50** rotates the drive shaft **70** a full rotation about the drive shaft axis **71**. (The rotor **50** only rotates a fraction of a turn about its own rotor axis **51** per orbital revolution, as will be further discussed below in relation to FIG. **5**.)

[0026] Still referring to FIG. **4**, the torque applied by the rotor **50** to the drive shaft **70** may be affected by a magnitude of the orbital radius of the rotor axis **51** about the stator axis **61**. The rotor **50** is coupled to the drive shaft along the rotor axis **51**, which in this embodiment coincides with the circular orbit **57** about the stator axis **61**. The moment arm in this case is equal to the radial offset "R" labeled here again for reference. In designing a rotary transfer mechanism for a particular application, the radial offset "R" is one of the variable that may be selected to select a desired moment arm applied by the rotor **50** to the drive shaft, torque at that location. Increasing R may increase the torque applied, and vice-versa. The rotor and stator geometry, including but not limited to the diameters of the rotor **50** and stator **60**, the heights of the rotor lobes **54** and stator lobes **64**, and the number of lobes **54**, **64**, may all have an effect on the offset radius R, the amount of torque and RPMs (revolutions per minute), and so forth. For example, increasing a height "H" of the stator lobes **64** may allow for increasing the offset radius R, which may in turn lead to changing the diameters of the stator **60** and/or rotor **50** in the design.

[0027] FIG. **5** is a sequential diagram of the motor **40** of FIG. **4** to help visualize the simultaneous rotation of the rotor about its own rotor axis **51** as it simultaneously orbits in the other direction. The sequence shows the rotor **50** completing one full clockwise orbital revolution about the stator **60** from its initial position at "A" at the bottom of the stator **60** all the way to that same orbital position at "E." To help visualize the movement of the rotor **50**, the seven rotor lobes **54** are labeled from **1** to **7**. At "A" the rotor lobe **54** labeled "**1**" is initially at a bottom of the stator **60** (with respect to the orientation of the view of FIG. **5**), within one of the stator recesses **63**. As can be seen, one full orbit (360 degrees clockwise) of the rotor **50** inside the stator **60** advances the rotor **50** by one rotor lobe **54** counter-clockwise so that the adjacent rotor lobe **54** labeled "**2**" replaces the rotor lobe labeled "**1**" after one full orbit from "A" to "E." It would take seven full orbits for the rotor lobe labeled "**1**" to return to its initial position shown at "A." Thus, the rate of rotation of the drive shaft **70** around the drive shaft axis **71** (FIG. **3**) will be equal to the rate at which the rotor **50** orbits, which will be seven times the rotation rate of the rotor **50** about the rotor axis **51**. This may be different (e.g. higher bit speed and lower torque) than in a conventional mud motor wherein the rotation of the rotor (rather than the orbiting of the rotor) may drive rotation of a drive shaft, for a 1:1 correspondence between the rotation rate of the rotor and the rotation rate of the drive shaft. This aspect may be factored into the design of the mud motor to achieve the desired balance of torque to drill bit speed.

[0028] It can be seen that in the case of a motor having N stator lobes and N−1 rotor lobes, the drill bit speed is N−1 times the rotor speed about its own rotor axis. Thus, another parameter that may be varied is the number of rotor and stator lobes in the motor. In the example of FIGS. **4** and **5**, there are N=8 stator lobes and N−1=7 rotor lobes, and the drill bit speed is 7 times the rotor speed. This ratio of drill bit speed to rotor speed may be varied by changing the number rotor and stator lobes. For example, a motor with

N=7 stator lobes and N−1=6 rotor lobes may multiply the drill bit speed by a factor of 6. A motor with N=5 stator lobes and N−1=4 rotor lobes may multiple the drill bit speed by a factor of 5. And so on.

[0029] Yet another way to obtain a desired ratio of drill bit speed to rotor speed is with the addition of a gear box between the drive shaft and drill bit. FIG. **6** is a side view of an example BHA **20** wherein the drive shaft **70** is coupled to the drill bit **14** by an intermediate gearbox **100** somewhere along the housing **44**, such as at either of two alternative locations indicated in dashed linetype. The rotor **50** may still drive rotation speed of the drive shaft **70** by a factor of N−1 times the rotation speed of the rotor **50** about its own axis as described in FIG. **5**. However, the optional gearbox **100** may then step down that drive shaft speed so that the drill bit speed is some value less than the drive shaft speed, closer to the rotation speed of the rotor **50** about its own axis. In one example, while the rotary transfer mechanism **42** steps up the speed of the drive shaft **70** relative to the rotor **50** by a factor of N−1 as described above, the gearbox **100** may step down the drill bit speed, in one example, by the same factor of N−1, such that the drill bit speed is about equal to the speed of the rotor **50** about its own axis. Thus, the rotary transfer mechanism **42** may desirably power rotation of the drive shaft **70** without requiring the complexity of a flex shaft, CV joint, or articulating joint that might otherwise be required in a conventional mud motor, but while still achieving the desired drill bit speed, and without necessarily increasing the expected drill bit speed as compared with conventional mud motors.

[0030] In addition to various apparatus, aspects of this disclosure further include methods of transferring rotation from a rotor to or from a drive shaft, and in particular, methods that do not require radial movement of any part of the drive shaft to accommodate the eccentric motion of the rotor. One example method involves flowing a pressurized fluid through a plurality of cavities defined by helical rotor lobes and stator lobes, such that the rotor rotates about its rotor axis while simultaneously orbiting about another axis, such as the stator axis. The method may further include supporting a drive shaft about a drive shaft axis, and more specifically, supporting the drive shaft so the drive shaft axis remains level and parallel to the housing and/or to a stator axis as it rotates about its drive shaft axis. The method further includes coupling the rotor to the drive shaft at a radial offset from the drive shaft axis, and preferably, where the radial offset is equal to an orbital radius of the rotor. The method also includes applying a tangential force by the rotor to the drive shaft as it orbits. The orbiting of the rotor, rather than rotation of the rotor about its rotor axis, may drive rotation of the drive shaft.

[0031] Thus, a rotary transfer mechanism has been disclosed, which may be used in a positive displacement motor, pump, or other downhole tool, wherein a rotor may transfer rotation to a drive shaft by the orbiting motion, rather than by rotation of the rotor about its own axis. This may eliminate radial movement of the drive shaft, thereby avoiding the need for flex shafts, articulating joints, or the like. The systems and methods of the present disclosure may include any of the various features disclosed herein, in any viable combination, including but not limited to anything discussed above and any of the following statements.

[0032] Statement 1. A rotary transfer mechanism for use downhole, comprising: a stator having a plurality of helical stator lobes; a rotor having a rotor axis and a plurality of helical rotor lobes disposed about the rotor axis, the stator lobes and rotor lobes cooperating to define a plurality of cavities between the rotor and stator, such that the rotor rotates about the rotor axis while the rotor orbits about a stator axis; a drive shaft rotatably supported about a drive shaft axis; and wherein the rotor is coupled to the drive shaft at a radial offset from the drive shaft axis.

[0033] Statement 2. The rotary transfer mechanism of Statement 1, wherein the drive shaft is coaxial with the stator, and the rotor axis is at the radial offset from the drive shaft axis.

[0034] Statement 3. The rotary transfer mechanism of Statement 1 or 2, wherein the radial offset is equal to an orbital radius of the rotor axis about the stator axis.

[0035] Statement 4. The rotary transfer mechanism of any of Statements 1 to 3, wherein the rotor is coupled to the drive shaft using an offset pin that is coaxial with the rotor and radially offset from the drive shaft axis.

[0036] Statement 5. The rotary transfer mechanism of any of Statement 1 to 4, further comprising one or both of a rotor bearing supporting relative rotation between the drive shaft and rotor about the rotor axis and a drive shaft bearing supporting rotation of the drive shaft about the drive shaft axis.

[0037] Statement 6. The rotary transfer mechanism of any of Statements 1 to 5, further comprising a housing, wherein the drive shaft bearing radially secures the drive shaft within the housing.

[0038] Statement 7. The rotary transfer mechanism of any of Statements 1 to 6, wherein the drive shaft bearing holds the drive shaft axis in alignment with the stator axis.

[0039] Statement 8. The rotary transfer mechanism of any of Statements 1 to 7, wherein the drive shaft is supported such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits.

[0040] Statement 9. The rotary transfer mechanism of any of Statements 1 to 8, wherein the rotor orbits without flexure of the drive shaft.

[0041] Statement 10. The rotary transfer mechanism of any of Statements 1 to 9, wherein the drive shaft is supported without an articulating joint at either end.

[0042] Statement 11. The rotary transfer mechanism of any of Statements 1 to 10, wherein the rotor is disposed inside the stator.

[0043] Statement 12. The rotary transfer mechanism of any of Statements 1 to 10, wherein the stator is disposed inside the rotor.

[0044] Statement 13. The downhole rotary transfer mechanism of any of Statements 1 to 12, wherein the rotor and stator cooperate as a motor with a pressurized fluid source in fluid communication with the plurality of cavities to drive the rotor with respect to the stator.

[0045] Statement 14. A positive displacement motor, comprising: a stator having a stator axis and a plurality of helical stator lobes disposed about the stator axis; a rotor having a rotor axis and a plurality of helical rotor lobes disposed about the rotor axis, the stator lobes and rotor lobes cooperating to define a plurality of cavities between the rotor and stator; a pressurized fluid source in fluid communication with the plurality of cavities to drive rotation of the rotor with respect to the stator such that the rotor axis orbits at an orbital radius about the stator axis while the rotor rotates about the rotor axis; a drive shaft rotatably supported about a drive shaft axis, wherein the rotor is coupled to the drive shaft with an offset pin offset from the drive shaft axis by an amount equal to the orbital radius; and wherein the drive shaft is supported such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits, without flexure of the drive shaft, and without an articulating joint between the drive shaft and rotor.

[0046] Statement 15. The positive displacement motor of Statement 14, further comprising: a rotor bearing supporting relative rotation between the drive shaft and rotor about the rotor axis.

[0047] Statement 16. The positive displacement motor of Statement 14 or 15, further comprising: a drive shaft bearing supporting rotation of the drive shaft about the drive shaft axis.

[0048] Statement 17. The positive displacement motor of any of Statements 14 to 16, further comprising a housing, wherein the drive shaft bearing radially secures the drive shaft within the housing.

[0049] Statement 18. The positive displacement motor of any of Statements 14 to 17, wherein the drive shaft bearing aligns the drive shaft axis with the stator axis.

[0050] Statement 19. The positive displacement motor of any of Statement 14 to 18, wherein the rotor is disposed inside the stator.

[0051] Statement 20. The positive displacement motor of any of Statements 14 to 18, wherein the stator is disposed inside the rotor.

[0052] Statement 21. A drilling method, comprising positioning a bottom hole assembly including a drill bit downhole; flowing a pressurized fluid through a plurality of cavities defined between a rotor and a stator, such that a rotor axis orbits about an orbital axis; applying a tangential force from the rotor to the drive shaft at a moment arm about a drive shaft axis such that the orbiting of the rotor drives rotation of the drive shaft; and applying the rotation of the drive shaft to the drill bit to rotate the drill bit.

[0053] Statement 22. The drilling method of Statement 20, wherein the rotor is coupled to the drive shaft with an offset pin offset from the drive shaft axis, and the tangential force from the rotor is applied to the drive shaft via the offset pin.

[0054] Statement 23. The drilling method of Statement 21, wherein the offset pin is offset from the drive shaft axis by an amount equal to an orbital radius of the rotor.

[0055] Statement 24. The drilling method of Statement 23, further comprising supporting the drive shaft such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits, without flexure of the drive shaft, and without an articulating joint between the drive shaft and rotor.

[0056] The particular examples disclosed above are illustrative only, and may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Although individual examples are discussed, the disclosure covers all combinations of all of the examples. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. It is therefore evident that the particular illustrative examples disclosed above may be altered or modified and all such variations are considered within the scope and spirit of those examples. If there is any conflict in the usages of a word or term in this specification and one or more patent(s) or other documents that may be incorporated herein by reference, the definitions that are consistent with this specification should be adopted.

What is claimed is:

1. A rotary transfer mechanism for use downhole, comprising:

a stator having a plurality of helical stator lobes;

a rotor having a rotor axis and a plurality of helical rotor lobes disposed about the rotor axis, the stator lobes and rotor lobes cooperating to define a plurality of cavities between the rotor and stator, such that the rotor rotates about the rotor axis while the rotor orbits about a stator axis;

a drive shaft rotatably supported about a drive shaft axis; and

wherein the rotor is directly coupled to the drive shaft at a radial offset from the drive shaft axis.

2. The rotary transfer mechanism of claim **1**, wherein the drive shaft is coaxial with the stator, and the rotor axis is at the radial offset from the drive shaft axis.

3. The rotary transfer mechanism of claim **2**, wherein the radial offset is equal to an orbital radius of the rotor axis about the stator axis.

4. The rotary transfer mechanism of claim **1**, wherein the rotor is coupled to the drive shaft using an offset pin that is coaxial with the rotor and radially offset from the drive shaft axis.

5. The rotary transfer mechanism of claim **1**, further comprising one or both of a rotor bearing supporting relative rotation between the drive shaft and rotor about the rotor axis and a drive shaft bearing supporting rotation of the drive shaft about the drive shaft axis.

6. The rotary transfer mechanism of claim **5**, further comprising a housing, wherein the drive shaft bearing radially secures the drive shaft within the housing.

7. The rotary transfer mechanism of claim **6**, wherein the drive shaft bearing holds the drive shaft axis in alignment with the stator axis.

8. The rotary transfer mechanism of claim **1**, wherein the drive shaft is supported such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits.

9. The rotary transfer mechanism of claim **8**, wherein the rotor orbits without flexure of the drive shaft.

10. The rotary transfer mechanism of claim **8**, wherein the drive shaft is supported without an articulating joint at either end.

11. The rotary transfer mechanism of claim **1**, wherein the stator axis does not align with the drive shaft axis.

12. The rotary transfer mechanism of claim **1**, further comprising a gearbox coupled between the drive shaft and drill bit to reduce a drill bit speed relative to a drive shaft speed.

13. The downhole rotary transfer mechanism of claim **1**, wherein the rotor and stator cooperate as a motor with a pressurized fluid source in fluid communication with the plurality of cavities to drive the rotor with respect to the stator.

14. A positive displacement motor, comprising:

a stator having a stator axis and a plurality of helical stator lobes disposed about the stator axis;

a rotor having a rotor axis and a plurality of helical rotor lobes disposed about the rotor axis, the stator lobes and rotor lobes cooperating to define a plurality of cavities between the rotor and stator;

a pressurized fluid source in fluid communication with the plurality of cavities to drive rotation of the rotor with respect to the stator such that the rotor axis orbits at an orbital radius about the stator axis while the rotor rotates about the rotor axis;

a drive shaft rotatably supported about a drive shaft axis, wherein the rotor is directly coupled to the drive shaft with an offset pin offset from the drive shaft axis by an amount equal to the orbital radius; and

wherein the drive shaft is supported such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits, without flexure of the drive shaft, and without an articulating joint between the drive shaft and rotor.

15. The positive displacement motor of claim **14**, further comprising:

one or both of a rotor bearing and a drive shaft bearing, the rotor bearing supporting relative rotation between the drive shaft and rotor about the rotor axis, the drive shaft bearing supporting rotation of the drive shaft about the drive shaft axis.

16. The positive displacement motor of claim **15**, further comprising a housing, wherein the drive shaft bearing radially secures the drive shaft within the housing and aligns the drive shaft axis with the stator axis.

17. A drilling method, comprising:

positioning a bottom hole assembly including a drill bit downhole;

flowing a pressurized fluid source through a plurality of cavities defined between a rotor and a stator, such that a rotor axis orbits about an orbital axis;

applying a tangential force from the rotor to the drive shaft with the rotor directly coupled to the drive shaft at a moment arm about the drive shaft axis such that the orbiting of the rotor drives rotation of the drive shaft; and

applying the rotation of the drive shaft to the drill bit to rotate the drill bit.

18. The drilling method of claim **17**, wherein the rotor is coupled to the drive shaft with an offset pin offset from the drive shaft axis, with a resulting torque applied to the drive shaft via the offset pin.

19. The drilling method of claim **18**, wherein the offset pin is offset from the drive shaft axis by an amount equal to an orbital radius of the rotor.

20. The drilling method of claim **19**, further comprising:

supporting the drive shaft such that the drive shaft axis remains parallel with the rotor axis as the rotor axis orbits, without flexure of the drive shaft, and without an articulating joint between the drive shaft and rotor.

* * * * *