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(54) **APPARATUS AND METHOD FOR HIGH TEMPERATURE DRILLING OPERATIONS**

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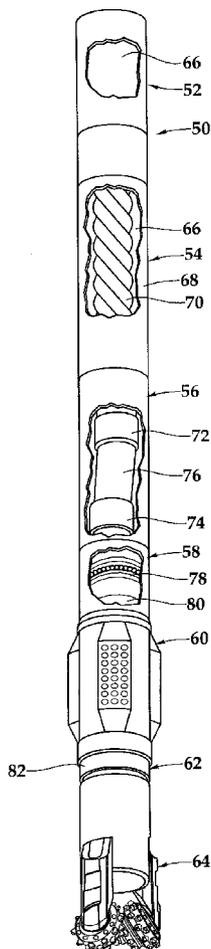
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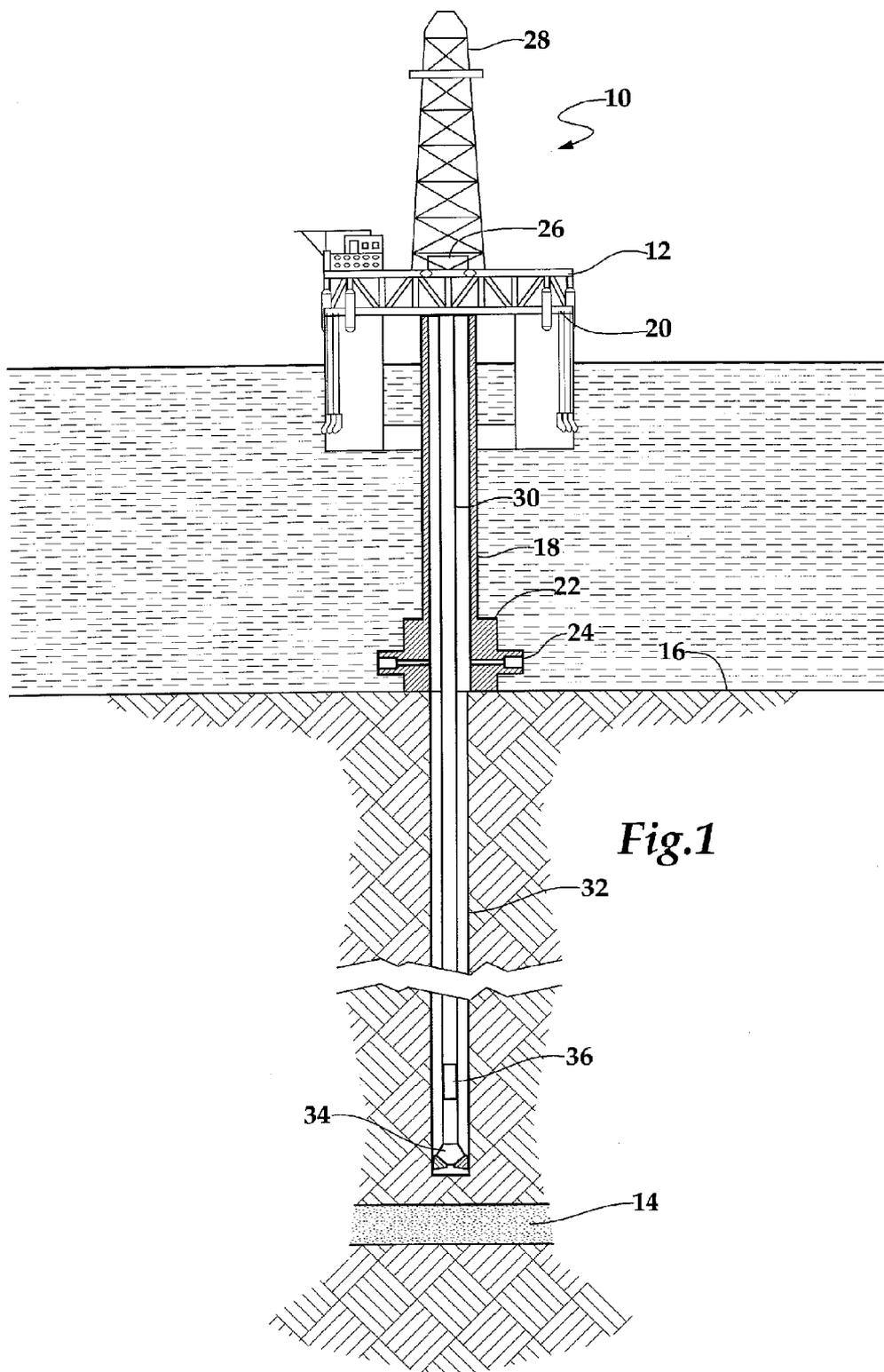
Related U.S. Application Data

(63) Continuation-in-part of application No. 12/002,710, filed on Dec. 18, 2007.

(57) **ABSTRACT**

An apparatus (50) for drilling a wellbore that transverses a subterranean hydrocarbon bearing formation. The apparatus (50) includes a drill string (52) having an inner fluid passageway (66). A drill bit (64) is disposed at a distal end of the drill string (52) and is operable to rotate relative to at least a portion of the drill string (52). A fluid motor (54) is disposed within the drill string (52) and is operable to rotate the drill bit (64) in response to a circulating fluid received via the inner fluid passageway (66) of the drill string (52). The fluid motor (54) has a stator (68) with (n) lobes and a rotor (70) with (n-1) lobes. The stator (68) includes an inner surface formed from a first material and the rotor (70) includes an outer surface formed from a second material that is dissimilar to the first material.





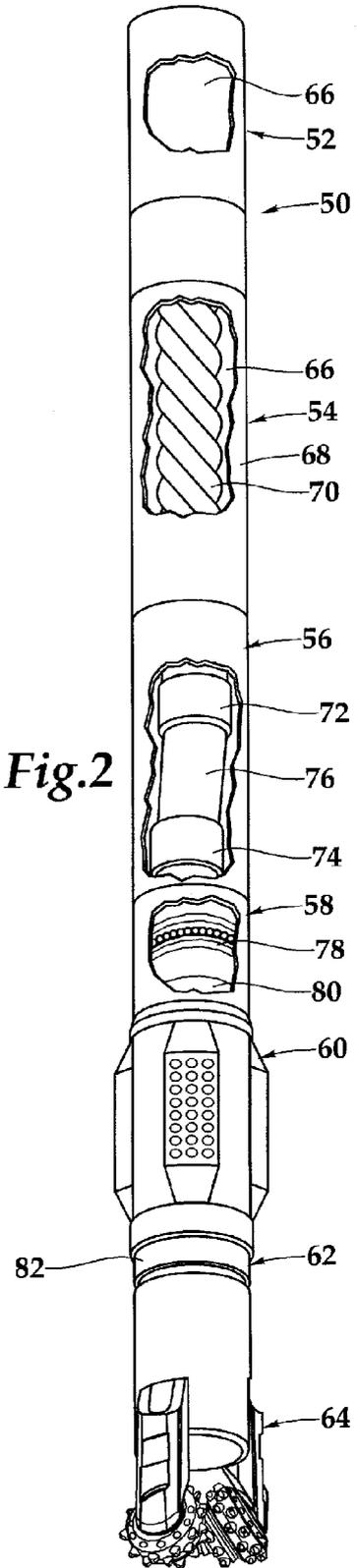


Fig.2

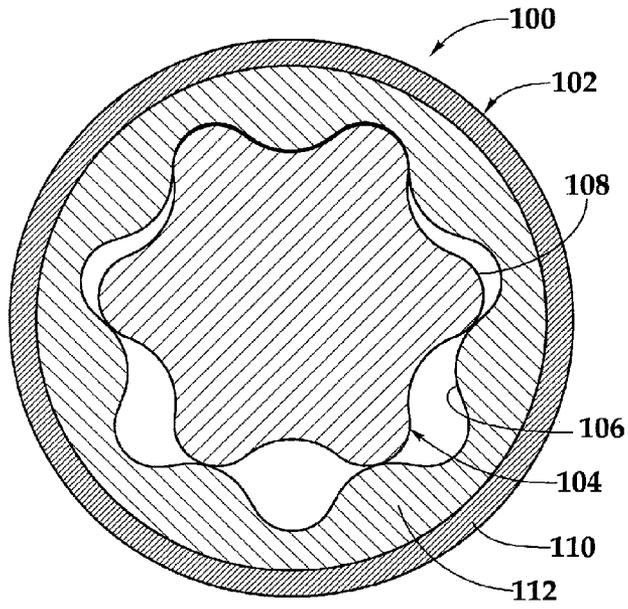


Fig.3

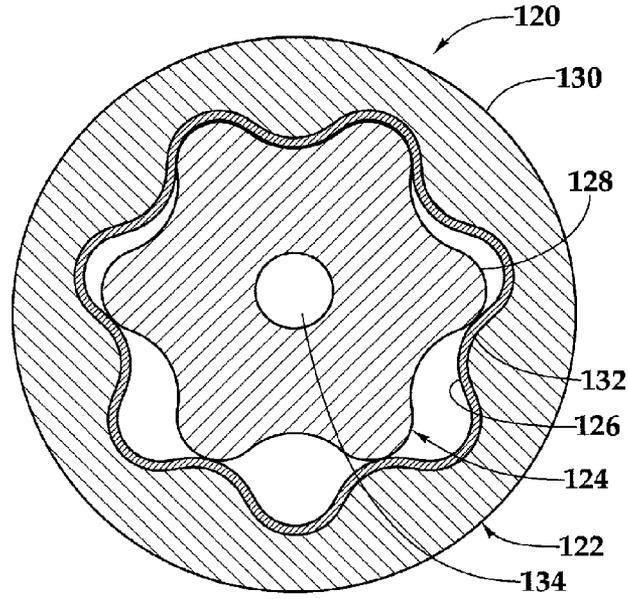


Fig.4

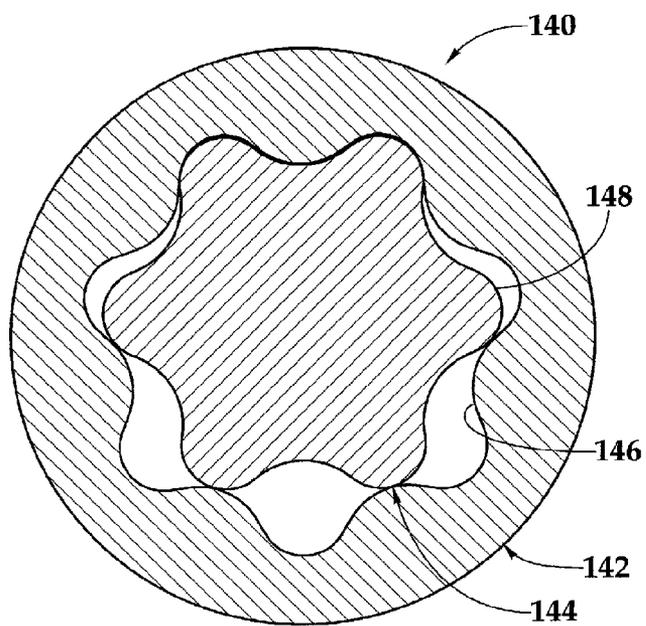


Fig.5

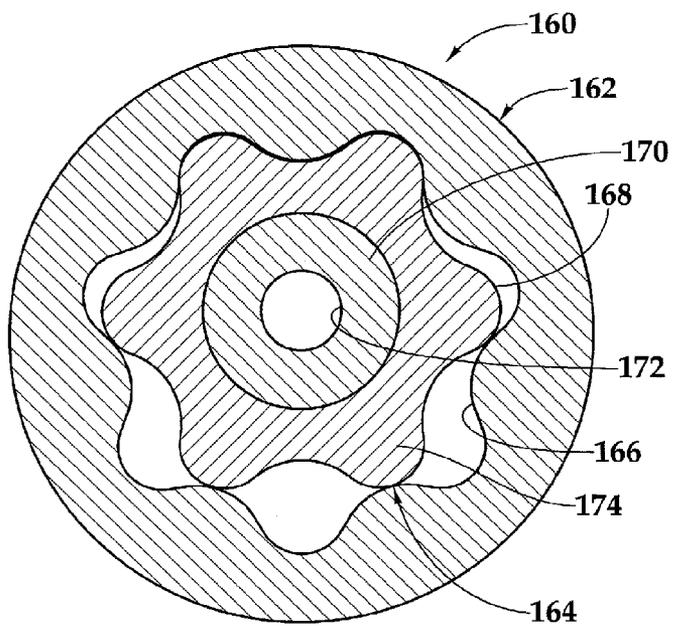


Fig.6

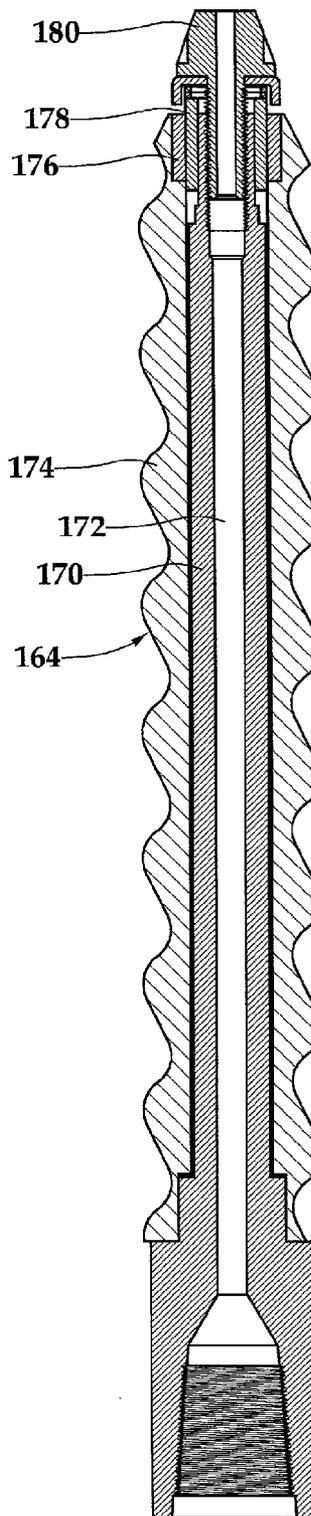


Fig.7

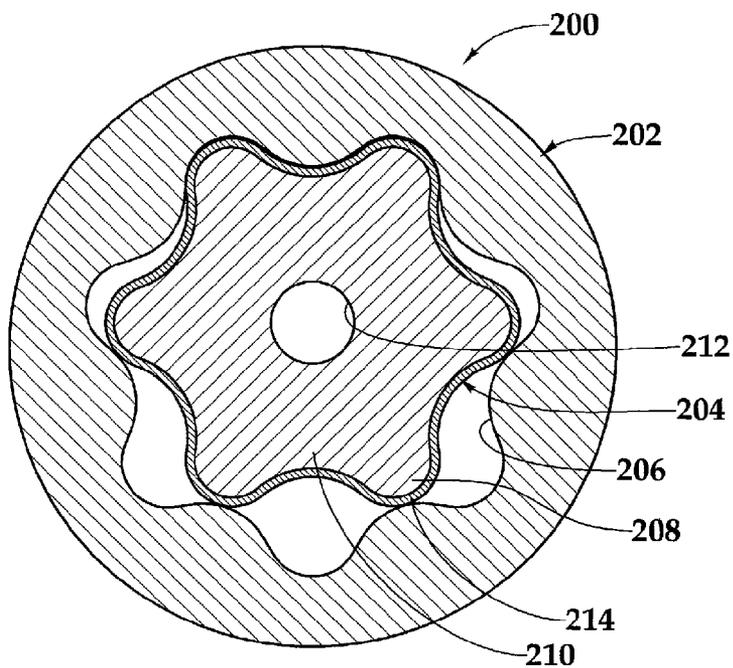


Fig.8

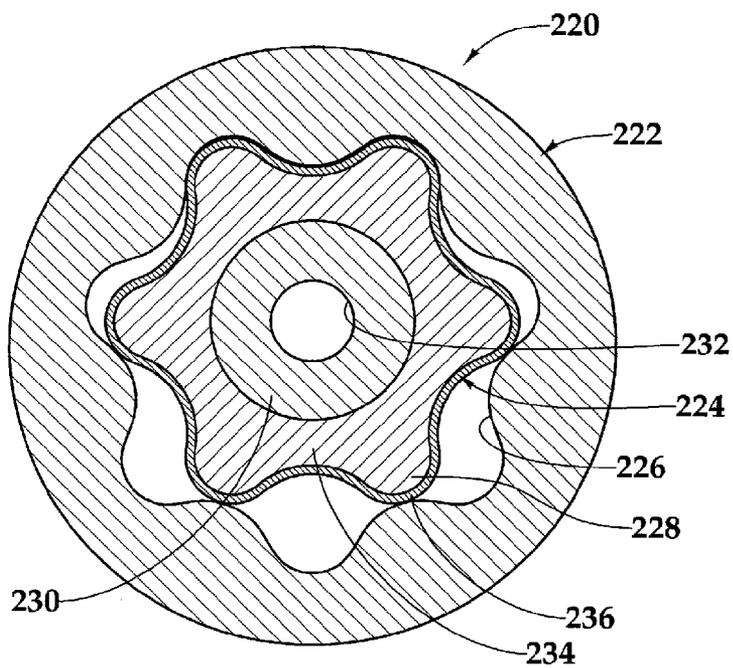


Fig.9

APPARATUS AND METHOD FOR HIGH TEMPERATURE DRILLING OPERATIONS

CROSS-REFERENCE TO RELATED PATENT APPLICATIONS

[0001] This is a continuation-in-part application of copending application Ser. No. 12/002,710, filed on Dec. 18, 2007.

TECHNICAL FIELD OF THE INVENTION

[0002] This invention relates, in general, to rotor and stator assemblies for use in fluid motors and progressive cavity pumps and, in particular, to an improved rotor and stator assembly for use in high temperature operations.

BACKGROUND OF THE INVENTION

[0003] Without limiting the scope of the present invention, its background will be described with reference to stator and rotor assemblies of power sections of positive displacement fluid motors for use in downhole drilling operations, as an example.

[0004] In a typical power section of a positive displacement fluid motor used in drilling a wellbore that traverses subterranean hydrocarbon bearing formations, power generation is based upon the Moineau pump principle. In this type of motor design, a stator and rotor assembly converts the hydraulic energy of a pressurized circulating fluid to the mechanical energy of a rotating shaft. The rotor and stator are typically of lobed design, with the rotor and stator having similar lobes profiles. The rotor is generally formed from steel having one less lobe than the stator, which is typically lined with an elastomer layer.

[0005] In general, the power section may be categorized based upon the number of lobes and effective stages. The rotor and stator lobes are of a helical configuration with one stage equating to the linear distance of a full wrap of the stator helix. The rotor and stator lobes and helix angles are designed such that the rotor and stator seal at discrete intervals, which results in the creation of axial fluid chambers or cavities that are filled by the pressurized circulating fluid. The action of the pressurized circulating fluid causes the rotor to rotate and precess within the stator. Motor power characteristics are generally a function of the number of lobes, lobe geometry, helix angle and number of effective stages. Motor output torque is directly proportional to the differential pressure developed across the rotor and stator. In drilling operations, bit rotation speed is directly proportional to the circulating fluid flow rate between the rotor and stator.

[0006] It has been found, however, that typical rotor and stator assemblies have certain output limitations. For example, operations above a maximum differential pressure may cause fluid leakage between the rotor and stator seals which may result in no rotation of the bit due to the rotor becoming stationary or stalling in the stator. Likewise, operations above a maximum torque production value may result in accelerated rotor and stator wear as well as stalling.

[0007] In conventional power sections, solid metal rotors or tubular rotors with bypass jet nozzles are precision machined to close axial and radial tolerances. The rotors may be hard chrome plated or may include a carbide coating to maximize wear resistance and typically have between 1 and 9 lobes. The stators typically include an injection molded elastomer that is bonded to the stator housing and forms the inner surface of the

stator. The stators typically have between 2 and 10 lobes, such that in any rotor and stator assembly, the rotor has one less lobe than the stator.

[0008] It has been found, however, that conventional power sections commonly fail due to failure of the elastomeric element of the stator. For example, these failures may occur due to high mechanical loading, elastomer fatigue or incompatibility of the circulating fluid and the elastomer. In addition, high temperature affects commonly result in the failure of the elastomeric element. Excessive temperatures may result from the high downhole temperature as well as hysteresis heat buildup caused by repeated flexing of the elastomer by the rotor. This heat buildup may be exacerbated by expansion of the elastomer, which increases the compressive interference between the rotor and the stator. This heat buildup not only reduces the life cycle of the elastomer but may also lead to a failure in the bond between the elastomer and the metal surface of the stator housing.

[0009] Therefore, need has arisen for an improved rotor and stator assembly for use in fluid motors of downhole drilling systems. A need has also arisen for such an improved rotor and stator assembly that is capable of withstanding high mechanical loading and is not incompatible with circulating fluids. Further, a need has arisen for such an improved rotor and stator assembly that can be operate at the elevated temperatures experienced during the drilling of a wellbore that traverses subterranean hydrocarbon bearing formations.

SUMMARY OF THE INVENTION

[0010] The present invention disclosed herein is directed to an improved rotor and stator assembly for use in downhole drilling systems to convert the hydraulic energy of a circulating fluid to the mechanical energy of a rotating shaft to turn a drill bit. The rotor and stator assembly of the present invention is capable of withstanding high mechanical loading and displays no incompatibility with circulating fluids. In addition, the rotor and stator assembly of the present invention can be operated at the elevated temperatures experienced during the drilling of a wellbore that traverses subterranean hydrocarbon bearing formations.

[0011] In one aspect, the present invention is directed to an apparatus for drilling a wellbore that transverses a subterranean formation. The apparatus includes a drill string having an inner fluid passageway. A drill bit is disposed at a distal end of the drill string and is operable to rotate relative to at least a portion of the drill string. A fluid motor is disposed within the drill string and is operable to rotate the drill bit in response to a circulating fluid received via the inner fluid passageway of the drill string.

[0012] The fluid motor has a stator with (n) lobes and a rotor with (n-1) lobes, wherein the lobes of both the rotor and the stator may be helical and wherein (n) may be between 2 and 10, inclusive. The stator has an inner surface formed from a first material and the rotor has an outer surface formed from a second material that is dissimilar to the first material.

[0013] In one embodiment, the stator includes a stator housing and a stator sleeve. In this embodiment, the stator housing and a stator sleeve may be formed from dissimilar materials. In another embodiment, the stator includes a stator housing and a stator coating. In this embodiment, the stator housing and the stator coating may be formed from dissimilar materials.

[0014] In one embodiment, the rotor may be a solid externally profiled rod. In another embodiment, the rotor includes

rotor bore operable to provide a bypass for a portion of the circulating fluid. In a further embodiment, the rotor includes a rotor mandrel and a rotor sleeve. In this embodiment, the rotor mandrel and the rotor sleeve may be formed from dissimilar materials. In yet another embodiment, the rotor includes a rotor member and a rotor coating. In this embodiment, the rotor member and the rotor coating may be formed from dissimilar materials. In an additional embodiment, the rotor includes a rotor mandrel, a rotor sleeve and a rotor coating. In this embodiment, the rotor mandrel and the rotor sleeve may be formed from a material that is dissimilar to the material of the rotor coating.

[0015] In another aspect, the present invention is directed to a fluid motor for use in drilling a wellbore that transverses a subterranean formation to impart rotary motion to a drill bit in response to a circulating fluid. The fluid motor includes a helical stator with (n) lobes and a helical rotor with (n-1) lobes. The stator has an inner surface formed from a first material and the rotor has an outer surface formed from a second material that is dissimilar to the first material. In this aspect, the rotor may include a rotor mandrel and a rotor sleeve that are formed from dissimilar materials.

[0016] In a further aspect, the present invention is directed to a method for drilling a wellbore that transverses a subterranean formation. The method includes disposing a drill bit on a distal end of a drill string having an inner fluid passageway, positioning a fluid motor within the drill string, the fluid motor having a stator with (n) lobes and a rotor with (n-1) lobes, the stator having an inner surface formed from a first material, the rotor having an outer surface formed from a second material that is dissimilar to the first material, pumping a circulating fluid through the inner fluid passageway of the drill string and the fluid motor, converting the hydraulic energy of the circulating fluid to mechanical energy in the fluid motor causing rotation of the rotor and rotating the drill bit in response to the rotation of the rotor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] For a more complete understanding of the features and advantages of the present invention, reference is now made to the detailed description of the invention along with the accompanying figures in which corresponding numerals in the different figures refer to corresponding parts and in which:

[0018] FIG. 1 is schematic illustration of an offshore oil and gas platform operating an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0019] FIG. 2 is a side elevation view partially in cut away of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0020] FIG. 3 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0021] FIG. 4 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0022] FIG. 5 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0023] FIG. 6 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0024] FIG. 7 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention;

[0025] FIG. 8 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention; and

[0026] FIG. 9 is a cross sectional view of a power section of an apparatus for drilling a wellbore according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0027] While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts, which can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention, and do not delimit the scope of the invention.

[0028] Referring initially to FIG. 1, an offshore oil and gas production platform operating an apparatus for drilling a wellbore according to the present invention is schematically illustrated and generally designated 10. A semi-submersible platform 12 is centered over a submerged oil and gas formation 14 located below sea floor 16. A semi-submersible platform 12 is centered over a submerged oil and gas formation 14 located below sea floor 16. A subsea conduit 18 extends from deck 20 of platform 12 to wellhead installation 22 including blowout preventers 24. Platform 12 has a hoisting apparatus 26 and a derrick 28 for raising and lowering pipe strings such as drill string 30.

[0029] A wellbore 32 is being extended through the various earth strata with the intent of traversing subterranean hydrocarbon bearing formation 14. At its distal end, work string 30 include drill bit 34. Disposed uphole of drill bit 34 in drill string 30 is a fluid motor 36. As explained in more detail below, circulating fluid is pumped through an interior fluid passageway of drill string 30 to fluid motor 36. Fluid motor 36 converts the hydraulic energy of the circulating fluid to mechanical energy in the form of a rotating rotor. The rotor is coupled to drill bit 34 via a transmission shaft or other coupling to cause rotation of drill bit 34, which allows for wellbore 32 to be extended.

[0030] Even though FIG. 1 depicts a vertical wellbore, it should be understood by those skilled in the art that the apparatus for drilling a wellbore according to the present invention is equally well suited for use in horizontal or deviated wellbores. Accordingly, it should be understood by those skilled in the art that the use of directional terms such as above, below, upper, lower, upward, downward and the like are used in relation to the illustrative embodiments as they are depicted in the figures, the upward direction being toward the top of the corresponding figure and the downward direction being toward the bottom of the corresponding figure. Also, even though FIG. 1 depicts an offshore operation, it should be understood by those skilled in the art that the apparatus for drilling a wellbore according to the present invention is equally well suited for use in onshore operations.

[0031] Referring now to FIG. 2, therein is depicted an apparatus for drilling a wellbore according to the present invention that is generally designated 50. In the illustrated embodiment, drilling apparatus 50 includes a lower end of drilling string 52, a power section or fluid motor 54, a transmission section 56, a bearing section 58, a stabilizer section 60 and a drill bit

section 62 including a drill bit 64. Drill string 52 includes an interior fluid passageway 66 for transporting the circulating fluid that drives fluid motor 54, cools drill bit 64 and carries cutting back to the surface. The circulating fluid may be fresh or salt water-based, oil-based, oil emulsion or the like and is selected based upon factors that are known to those skilled in the art. Fluid motor 54 includes an internally profiled stator 68 and an externally profiled rotor 70, various configurations of which will be discussed in detail below.

[0032] Transmission section 56 includes a pair of articulated connections 72, 74 and a transmission shaft 76, which work together to eliminate the eccentric motion of rotor 70 while transmitting torque and downthrust. While a particular transmission section has been illustrated, it should be understood by those skilled in the art that other types of transmissions could be used in conjunction with the present invention including transmissions having multi-element designs utilizing universal couplings. Bearing section 58 may include a variety of bearing 78 such as thrust bearings for supporting the downthrust from transmission section 56 and the reactive upward loading from the applied weight on drill bit 64 and one or more sets of radial bearings for absorbing lateral side loading of the drive shaft 80. Drive shaft 80 transmits both axial and torsional loading to drill bit 64. Stabilizer section 60 includes a plurality of sleeves or pads that provide both stabilization and protection to drilling apparatus 50. Drill bit section 62 including a drill bit box 82 that threadably receives drill bit 64 to couple drive shaft 80 with drill bit 64.

[0033] Referring next to FIG. 3, therein is depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated 100. Power section 100 includes a stator 102 and a rotor 104. In the illustrated embodiment, stator 102 has a multi-staged, profiled inner surface defining a plurality of stator lobes 106 that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. As illustrated, stator 102 has 7 lobes. Those skilled in the art will recognize, however, that even though the stators of the present invention are depicted with a particular number of lobes, other numbers of lobes both less than and greater than the number shown are within the scope of the present invention. The number of stator lobes to be used in a particular power section will be determined based upon factors including the desired speed of rotation and the desired torque wherein power sections of the same diameter having fewer stator lobes generally operate at higher speeds and deliver lower torques as compared to power sections having a greater number stator lobes that tend to operate at lower speeds but deliver greater torques. In the present invention, between 2 and 10 stator lobes is generally desirable, however, a power section having a stator with more than 10 stator lobes is also possible and considered within the scope of the present invention.

[0034] In the illustrated embodiment, rotor 104 has a profiled outer surface that closely matches the profiled inner surface of stator 102 to provide a close fitting relationship such as an interference fit or a clearance cross sectional fit of up to about eighty thousandths of an inch. The profiled outer surface of rotor 104 defines a plurality of rotor lobes 108 that have a helical configuration. As illustrated, rotor 104 has 6 lobes. Those skilled in the art will recognize, however, that even though the rotors of the present invention are depicted with a particular number of lobes, other numbers of lobes both less than and greater than the number shown are within

the scope of the present invention. The number of rotor lobes to be used in a particular power section will be determined based upon the number of stator lobes in that power section with the number of rotor lobes being one less than the number of stator lobes. For example, if the number of stator lobes is (n) then the number of rotor lobes is (n-1). Accordingly, as illustrated, the number of rotor lobes (6) is one less than the number of stator lobes (7).

[0035] In the illustrated embodiment, stator 102 includes a stator housing 110 and a stator sleeve 112. Stator housing 110 is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Stator housing 110 has an inner surface that is sized to receive stator sleeve 112 therein. Stator sleeve 112 is coupled to stator housing 110 using a system of tapers, orientation keys, matched surfaces, threaded components or the like that are designed to torsionally and longitudinally support stator sleeve 112 within stator housing 110 during operation. Stator sleeve 112 is preferably formed from a malleable metal such as steel alloys, aluminum alloys, copper alloys including beryllium coppers, bronze and bronze alloys such as magnesium bronzes and aluminum bronzes or similar metals.

[0036] As illustrated, rotor 104 is a solid rotor that is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. In some embodiments, the surface of rotor 104 may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like. Preferably, the treatment process modifies surface properties but not surface geometry. When the above-described embodiments of rotor 104 and stator 102 are used and rotor 104 is rotating and precessing within stator 102, there is metal-to-metal contact between the outer surface of rotor 104 and the inner surface of stator 102 which are formed from dissimilar metals. For example, the stainless steel surface of rotor 104 is contacting the malleable metal surface of stator sleeve 112. The use of metals for the contact points of rotor 104 and stator 102 enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section 100. The use of dissimilar metals at the contact points of rotor 104 and stator 102 enhances the wear resistance of power section 100.

[0037] Alternatively, stator sleeve 112 may be formed from a nanocomposite material. Preferably, the nanocomposite material is formed from a polymer host material having plurality of nano-sized materials, particle or structures therein that improve the physical and chemical properties of the polymer such as impact strength, stress relaxation resistance, compression set, durability and modulus, tear strength, creep, resistance to thermal and hysteresis failure and resistance to chemical degradation. In certain embodiments, the least dimension of the nanomaterial is in the range from approximately 0.1 nanometers to approximately 500 nanometers.

[0038] The polymer host material may be an elastomer, a thermoset, a thermoplastic or the like. For example, the polymer host material may be polychloroprene rubber (CR), natural rubber (NR), polyether urethane (EU), styrene butadiene rubber (SBR), ethylene propylene (EPR), ethylene propylene diene (EPDM), a nitrile rubber, a copolymer of acrylonitrile and butadiene (NBR), carboxylated acrylonitrile butadiene (XNBR), hydrogenated acrylonitrile butadiene (HNBR), commonly referred to as highly-saturated nitrile (HSN), carboxylated hydrogenated acrylonitrile butadiene (XHNBR), hydrogenated carboxylated acrylonitrile butadiene (HXNBR) or similar material. Alternatively, the polymer host

material may be a fluoro carbon (FKM), such as tetrafluoroethylene and propylene (FEPM), perfluoroelastomer (FFKM) or similar material. As another alternative, the polymer host material may be polyphenylene sulfide (PPS), polyetherketone-ketone (PEKK), polyetheretherketone (PEEK), polyetherketone (PEK), polytetrafluoroethylene (PTFE), polysulfone (PSU) or similar material.

[0039] The nanomaterials may have a variety of structures including plates, spheres, cylinders, tubes, fibers, three-dimensional structures, linear molecules, molecular rings, branched molecules and crystalline, amorphous and symmetric shapes. The nanomaterials may be formed from a variety of materials, such as carbon, silica, metals, graphite, diamond, ceramics, metal oxides, other oxides, calcium, calcium carbonate, inorganic clays, minerals and polymer materials. For example, the nanomaterials may be formed from silicon material, such as polysilane resins, polycarbosilane resins (PCS), polysilsesquioxane resins (POS) and polyhedral oligomeric silsesquioxane resins (POSS). Alternatively, the nanomaterials may be derived from montmorillonite, bentonite, hectorite, attapulgite, kaolin, mica and illite. As a further alternative, the nanomaterials may be metal oxides of zinc, iron, titanium, magnesium, silicon, aluminum, cerium, zirconium and equivalents thereof, as well as mixed metal compounds, such as indium-tin and equivalents thereof.

[0040] Preferably, the nanomaterials may be nanotubes, such as carbon nanotubes (CNT) including single wall CNTs, multi-wall CNTs, arrays of CNTs, chemically functionalized CNTs and the like. Alternatively, the nanomaterials may be nanofibers derived, for example, from graphite, carbon, glass, cellulose substrate, polymer materials or the like.

[0041] The polymer host material and the nanomaterials may interact via interfacial interactions, such as co-polymerization, crystallization, van der Waals interactions, covalent bonds, ionic bonds and cross-linking interactions which improve the physical and chemical characteristics of the polymer thereby resulting in an extended life for stator sleeve 112. In addition, the nanomaterials may be functionalized to enhance the effective surface area and improve the availability of potential chemical reactions or catalysis sites for chemical functional groups on the nanomaterials.

[0042] One of the benefits provided by power section 100 of the present invention is the simplicity of redressing the power section 100 after certain operating cycles. Even though the useful life of power section 100 exceeds that of conventional drilling motors, particularly in high temperature service, proper maintenance is preferred. Power section 100 is designed such that stator sleeve 112 is the most likely component to show wear. As such, when it is desired to redress power section 100, stator sleeve 112 is decoupled from stator housing 110 and a replacement stator sleeve 112 is then installed. This entire process can take place on site with little rig downtime.

[0043] Referring next to FIG. 4, therein is depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated 120. Power section 120 includes a stator 122 and a rotor 124. In the illustrated embodiment, stator 122 has a multi-staged, profiled inner surface defining 7 stator lobes 126 that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. Rotor 124 has a profiled outer surface that closely matches the profiled inner surface of stator 122 to provide an interference fit therewith or a clearance cross sectional fit of

up to about eighty thousandths of an inch. The profiled outer surface of rotor 124 defines 6 rotor lobes 128 that have a helical configuration.

[0044] In the illustrated embodiment, stator 122 includes a stator housing 130 and a stator coating 132. Stator housing 130 is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Stator housing 130 has a profiled inner surface defining an internal portion of stator lobes 126 that receives stator coating 132 thereon. Stator coating 132 is preferably a metal coating on the inner surface of stator housing 130 that has a thickness between about fifty thousandths of an inch and about one hundred thousandths of an inch and preferably between about seventy thousandths of an inch and about eighty thousandths of an inch. Even though particular thicknesses have been described, those skill in the art will understand that stator coating 132 could have other thicknesses both greater than and less than those described including thicknesses between about one thousandth of an inch and about four hundred thousandths of an inch.

[0045] Stator coating 132 may be applied to stator housing 130 using a vapor deposition process, a metallizing process, an arc spraying process, a thermospray process, a flame spray process, a plasma spray process, a high velocity oxy-fuel process or the like. In these and other embodiments, stator coating 132 may be formed from a pure metal, a metal oxide or a metal alloy including stainless steel, carbon steel, nickel or nickel alloys such as nickel-chrome, nickel-chrome-boron and cobalt-nickel-chrome, aluminum, aluminum alloys or aluminum oxide, bronze or bronze alloys such as magnesium bronzes and aluminum bronzes, copper or copper alloys including beryllium coppers, molybdenum, tin, zinc or zinc alloys, Monel, Hastalloy, tungsten carbide, tungsten carbide-nickel, tungsten carbide-cobalt, chromium carbide, chromium oxide, titanium or titanium oxide, miconium oxide, cobalt-molybdenum-chromium or similar materials. The surface of stator coating 132 may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like.

[0046] As illustrated, rotor 124 is a tubular rotor that is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Rotor 124 includes a rotor bore 134 that provides a bypass passageway through rotor 124 for circulating fluids, which helps prevent rotor stall under certain conditions. When rotor 124 is rotating and precessing within stator 122, the metal-to-metal contact of the outer surface of rotor 124 with the inner surface of stator 122, is of dissimilar metals. For example, the stainless steel surface of rotor 124 is contacting the malleable metal surface of stator coating 132. The use of metals for the contact points of rotor 124 and stator 122 enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section 120. The use of dissimilar metals at the contact points of rotor 124 and stator 122 enhances the wear resistance of power section 120.

[0047] Alternatively, stator coating 132 may be formed from a nanocomposite material such as those described above. The nanocomposite material is preferably formed from a polymer host material, such as an elastomer, a thermoset, a thermoplastic or the like and the nanomaterials may be formed from materials, such as carbon, silica, metals, graphite, diamond, ceramics, metal oxides, other oxides, calcium, calcium carbonate, inorganic clays, minerals and poly-

mer materials. Preferably, the nanomaterials may be nanotubes, such as chemically functionalized CNTs.

[0048] Referring next to FIG. 5, therein is depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated 140. Power section 140 includes a stator 142 and a rotor 144. In the illustrated embodiment, stator 142 has a multi-staged, profiled inner surface defining 7 stator lobes 146 that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. Rotor 144 has a profiled outer surface that closely matches the profiled inner surface of stator 142 to provide an interference fit therewith or a clearance cross sectional fit of up to about eighty thousandths of an inch. The profiled outer surface of rotor 144 defines 6 rotor lobes 148 that have a helical configuration.

[0049] In the illustrated embodiment, stator 142 is a solid metal stator that is preferably formed from a ferrous metal including steels such as stainless steels. Rotor 144 is a solid rotor that is preferably formed from a malleable metal such as copper or copper alloys including beryllium coppers as well as bronze or bronze alloys such as magnesium bronzes and aluminum bronzes. The surface of stator 142, rotor 144 or both may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like. When rotor 144 is rotating and precessing within stator 142, the metal-to-metal contact of the outer surface of rotor 144 with the inner surface of stator 142, is of dissimilar metals. For example, the stainless steel surface of stator 142 is contacting the malleable metal surface of rotor 144. The use of metals for the contact points of rotor 144 and stator 142 enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section 140. The use of dissimilar metals at the contact points of rotor 144 and stator 142 enhances the wear resistance of power section 140.

[0050] Referring next to FIG. 6, therein is depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated 160. Power section 160 includes a stator 162 and a rotor 164. In the illustrated embodiment, stator 162 has a multi-staged, profiled inner surface defining 7 stator lobes 166 that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. Rotor 164 has a profiled outer surface that closely matches the profiled inner surface of stator 162 to provide an interference fit therewith or a clearance cross sectional fit of up to about eighty thousandths of an inch. The profiled outer surface of rotor 164 defines 6 rotor lobes 168 that have a helical configuration.

[0051] In the illustrated embodiment, stator 162 is a solid metal stator that is preferably formed from a ferrous metal including steels such as stainless steels. Rotor 164 includes a tubular rotor mandrel 170 having a rotor bore 172 and a rotor sleeve 174. Rotor mandrel 170 may be formed from a metal such as a ferrous metal including steels and preferably stainless steels. Rotor bore 172 provides a bypass passageway through rotor 164 for circulating fluids, which helps prevent rotor stall under certain conditions. Rotor mandrel 170 has an outer surface that is sized to receive rotor sleeve 174 thereon which utilizes as system of tapers, matched surfaces, orientation keys 176, 178 and threaded components such as end cap 180 designed to torsionally and longitudinally support rotor sleeve 174 on rotor mandrel 170 during operation, as best seen in FIG. 7. Rotor sleeve 174 is preferably formed

from a malleable metal such as steel alloys, aluminum alloys, copper alloys, bronze alloys and the like. The surface of stator 162, rotor sleeve 174 or both may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like.

[0052] When rotor 164 is rotating and precessing within stator 162, the metal-to-metal contact of the outer surface of rotor 164 with the inner surface of stator 162, is of dissimilar metals. For example, the stainless steel surface of stator 162 is contacting the malleable metal surface of rotor sleeve 174. The use of metals for the contact points of rotor 164 and stator 162 enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section 160. The use of dissimilar metals at the contact points of rotor 164 and stator 162 enhances the wear resistance of power section 160.

[0053] As an alternative, rotor sleeve 174 may be formed from a nanocomposite material such as those described above. The nanocomposite material is preferably formed from a polymer host material, such as an elastomer, a thermoset, a thermoplastic or the like and the nanomaterials may be formed from materials, such as carbon, silica, metals, graphite, diamond, ceramics, metal oxides, other oxides, calcium carbonate, inorganic clays, minerals and polymer materials. Preferably, the nanomaterials may be nanotubes, such as chemically functionalized CNTs.

[0054] In addition, use of rotor 164 having a rotor mandrel 170 and a rotor sleeve 174 facilitates variation of the stiffness of rotor 164 to compliment the stiffness of stator 162 which prevents accelerated wear when the stator flexes due to mechanical loading during operation and differences in relative rotor and stator stiffness. A further benefit provided by power section 160 of the present invention is the simplicity of redressing the power section 160 after certain operating cycles. Specifically, power section 160 is designed such that rotor sleeve 174 is the most likely component to show wear. As such, when it is desired to redress power section 160, rotor sleeve 174 is decoupled from rotor mandrel 170 and a replacement rotor sleeve 174 is then installed. This entire process can take place on site with little rig downtime.

[0055] Referring next to FIG. 8, therein are depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated 200. Power section 200 includes a stator 202 and a rotor 204. In the illustrated embodiment, stator 202 has a multi-staged, profiled inner surface defining 7 stator lobes 206 that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. Rotor 204 has a profiled outer surface that closely matches the profiled inner surface of stator 202 to provide an interference fit therewith or a clearance cross sectional fit of up to about eighty thousandths of an inch. The profiled outer surface of rotor 204 defines 6 rotor lobes 208 that have a helical configuration.

[0056] In the illustrated embodiment, stator 202 is a solid metal stator that is preferably formed from a ferrous metal including steels such as stainless steels. Rotor 204 includes a rotor member 210 having a rotor bore 212 and a rotor coating 214. Rotor member 210 is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Rotor bore 212 provides a bypass passageway through rotor 204 for circulating fluids, which helps prevent rotor stall under certain conditions. Rotor member 210 has a profiled outer surface defining an internal portion of rotor lobes 208 that receives rotor coating 214 thereon. Rotor coat-

ing **214** is preferably a metal coating on the outer surface of rotor member **210** that has a thickness between about fifty thousandths of an inch and about one hundred thousandths of an inch and preferably between about seventy thousandths of an inch and about eighty thousandths of an inch. Even though particular thicknesses have been described, those skill in the art will understand that rotor coating **214** could have other thicknesses both greater than and less than those described including thicknesses between about one thousandth of an inch and about four hundred thousandths of an inch.

[0057] Rotor coating **214** may be applied to rotor mandrel **210** using a vapor deposition process, a metallizing process, an arc spraying process, a thermospray process, a flame spray process, a plasma spray process, a high velocity oxy-fuel process or the like. In these and other embodiments, rotor coating **214** may be formed from a pure metal, a metal oxide or a metal alloy including stainless steel, carbon steel, nickel or nickel alloys such as nickel-chrome, nickel-chrome-boron and cobalt-nickel-chrome, aluminum, aluminum alloys or aluminum oxide, bronze or bronze alloys such as magnesium bronzes and aluminum bronzes, copper or copper alloys including beryllium coppers, molybdenum, tin, zinc or zinc alloys, Monel, Hastalloy, tungsten carbide, tungsten carbide-nickel, tungsten carbide-cobalt, chromium carbide, chromium oxide, titanium or titanium oxide, mirconium oxide, cobalt-molybdenum-chromium or similar materials. The surface of rotor coating **214**, stator **202** or both may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like.

[0058] When rotor **204** is rotating and precessing within stator **202**, the metal-to-metal contact of the outer surface of rotor **204** with the inner surface of stator **202**, is of dissimilar metals. For example, the stainless steel surface of stator **202** is contacting the malleable metal surface of rotor coating **214**. The use of metals for the contact points of rotor **204** and stator **202** enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section **200**. The use of dissimilar metals at the contact points of rotor **204** and stator **202** enhances the wear resistance of power section **200**.

[0059] Alternatively, rotor coating **214** may be formed from a nanocomposite material such as those described above. The nanocomposite material is preferably formed from a polymer host material, such as an elastomer, a thermoset, a thermoplastic or the like and the nanomaterials may be formed from materials, such as carbon, silica, metals, graphite, diamond, ceramics, metal oxides, other oxides, calcium, calcium carbonate, inorganic clays, minerals and polymer materials. Preferably, the nanomaterials may be nanotubes, such as chemically functionalized CNTs.

[0060] Referring next to FIG. 9, therein are depicted a cross sectional view of a power section of an apparatus for drilling a wellbore according to the present invention that is generally designated **220**. Power section **220** includes a stator **222** and a rotor **224**. In the illustrated embodiment, stator **222** has a multi-staged, profiled inner surface defining **7** stator lobes **226** that have a helical configuration wherein each stage is defined by the linear distance of one full wrap of the stator helix. Rotor **224** has a profiled outer surface that closely matches the profiled inner surface of stator **222** to provide an interference fit therewith or a clearance cross sectional fit of up to about eighty thousandths of an inch. The profiled outer surface of rotor **224** defines **6** rotor lobes **228** that have a helical configuration.

[0061] In the illustrated embodiment, stator **222** is a solid metal stator that is preferably formed from a ferrous metal including steels such as stainless steels. Rotor **224** includes a rotor mandrel **230** having a rotor bore **232**, a rotor sleeve **234** and a rotor coating **236**. Rotor mandrel **230** is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Rotor bore **232** provides a bypass passageway through rotor **224** for circulating fluids, which helps prevent rotor stall under certain conditions. Rotor mandrel **230** has an outer surface that is sized to receive rotor sleeve **234** thereon. Rotor sleeve **234** is coupled to rotor mandrel **230** using a system of tapers, orientation keys, matched surfaces, threaded components or the like that are designed to torsionally and longitudinally support rotor sleeve **234** on rotor mandrel **230** during operation, as described above with reference to FIG. 7. Rotor sleeve **234** is preferably formed from a metal such as a ferrous metal including steels and preferably stainless steels. Rotor sleeve **234** has a profiled outer surface defining an internal portion of rotor lobes **228** that receives rotor coating **236** thereon. Rotor coating **236** is preferably a metal coating on the outer surface of rotor sleeve **234** that has a thickness between about fifty thousandths of an inch and about one hundred thousandths of an inch and preferably between about seventy thousandths of an inch and about eighty thousandths of an inch, however, other thicknesses both greater than and less than that described are considered to be within the scope of the present invention.

[0062] Rotor coating **236** may be applied to rotor sleeve **234** using a vapor deposition process, a metallizing process, an arc spraying process, a thermospray process, a flame spray process, a plasma spray process, a high velocity oxy-fuel process or the like. In these and other embodiments, rotor coating **236** may be formed from a pure metal, a metal oxide or a metal alloy including stainless steel, carbon steel, nickel or nickel alloys such as nickel-chrome, nickel-chrome-boron and cobalt-nickel-chrome, aluminum, aluminum alloys or aluminum oxide, bronze or bronze alloys such as magnesium bronzes and aluminum bronzes, copper or copper alloys including beryllium coppers, molybdenum, tin, zinc or zinc alloys, Monel, Hastalloy, tungsten carbide, tungsten carbide-nickel, tungsten carbide-cobalt, chromium carbide, chromium oxide, titanium or titanium oxide, mirconium oxide, cobalt-molybdenum-chromium or similar materials. The surfaces of rotor coating **236**, stator **222** or both may receive a treatment process such as salt bath nitriding, gas nitriding, plasma nitriding, ion nitriding, ion plating, inductive hardening or the like.

[0063] When rotor **224** is rotating and precessing within stator **222**, the metal-to-metal contact of the outer surface of rotor **224** with the inner surface of stator **222**, is of dissimilar metals. For example, the stainless steel surface of stator **222** is contacting the malleable metal surface of rotor coating **236**. The use of metals for the contact points of rotor **224** and stator **222** enhances the heat resistance, fatigue resistance and circulating fluid compatibility of power section **220**. The use of dissimilar metals at the contact points of rotor **224** and stator **222** enhances the wear resistance of power section **220**.

[0064] As an alternative, rotor coating **236** may be formed from a nanocomposite material such as those described above. The nanocomposite material is preferably formed from a polymer host material, such as an elastomer, a thermoset, a thermoplastic or the like and the nanomaterials may be formed from materials, such as carbon, silica, metals,

graphite, diamond, ceramics, metal oxides, other oxides, calcium, calcium carbonate, inorganic clays, minerals and polymer materials. Preferably, the nanomaterials may be nanotubes, such as chemically functionalized CNTs.

[0065] In addition, use of rotor **224** having rotor mandrel **230** and rotor sleeve **234** facilitates variation of the stiffness of rotor **224** to compliment the stiffness of stator **222** which prevents accelerated wear when the stator flexes due to mechanical loading during operation and differences in relative rotor and stator stiffness. A further benefit provided by power section **220** of the present invention is the simplicity of redressing the power section **220** after certain operating cycles. Specifically, power section **220** is designed such that rotor coating **236** on rotor sleeve **234** is the most likely component to show wear. As such, when it is desired to redress power section **220**, rotor sleeve **234** is decoupled from rotor mandrel **230** and a replacement rotor sleeve **234** with a rotor coating **236** is then installed. This entire process can take place on site with little rig downtime.

[0066] Even though specific rotors and stators have been described as operating with specific stators, it is to be clearly understood that any of the rotors described above can operate with any of the stators described above without departing from the principles of the present invention. For example, in certain implementations, it may be desirable to operate a rotor having a rotor mandrel and a rotor sleeve with a stator having a stator sleeve or a stator coating. Likewise, in other implementations, it may be desirable to operate a rotor having a rotor coating with a stator having a stator sleeve or a stator coating. In addition, even though specific rotor and stator embodiments have been described, it is to be clearly understood that components of one rotor or stator design may be used together or removed from another rotor or stator design without departing from the principles of the present invention. For example, a stator having a stator housing and stator sleeve could also have a stator coating. Likewise, a rotor having a rotor mandrel may not include a rotor bore.

[0067] While this invention has been described with reference to illustrative embodiments, this description is not intended to be construed in a limiting sense. Various modifications and combinations of the illustrative embodiments as well as other embodiments of the invention will be apparent to persons skilled in the art upon reference to the description. It is, therefore, intended that the appended claims encompass any such modifications or embodiments.

What is claimed is:

1. An apparatus for drilling a wellbore that transverses a subterranean formation, the apparatus comprising:
 a drill string having an inner fluid passageway;
 a drill bit disposed at a distal end of the drill string and operable to rotate relative to at least a portion of the drill string; and
 a fluid motor disposed within the drill string and operable to rotate the drill bit in response to a circulating fluid received via the inner fluid passageway of the drill string, the fluid motor having a stator with (n) lobes and a rotor with (n-1) lobes, the stator having an inner surface formed from a first metal, the rotor having an outer surface formed from a second metal that is dissimilar to the first metal, thereby providing metal-to-metal contact during operation.

2. The apparatus as recited in claim **1** wherein the stator further comprises a stator housing and a stator sleeve, the stator housing and a stator sleeve formed from dissimilar metals.

3. The apparatus as recited in claim **1** wherein the stator further comprises a stator housing and a stator coating, the stator housing and the stator coating formed from dissimilar metals.

4. The apparatus as recited in claim **1** wherein the stator further comprises a stator housing, a stator sleeve and a stator coating, the stator housing and the stator sleeve formed from metal dissimilar to the stator coating.

5. The apparatus as recited in claim **1** wherein the rotor further comprises a solid metal rotor.

6. The apparatus as recited in claim **1** wherein the rotor further comprises rotor bore operable to provide a bypass for a portion of the circulating fluid.

7. The apparatus as recited in claim **1** wherein the rotor further comprises a rotor mandrel and a rotor sleeve, the rotor mandrel and the rotor sleeve formed from dissimilar metals.

8. The apparatus as recited in claim **1** wherein the rotor further comprises a rotor member and a rotor coating, the rotor member and the rotor coating formed from dissimilar metals.

9. The apparatus as recited in claim **1** wherein the rotor further comprises a rotor mandrel, a rotor sleeve and a rotor coating, the rotor mandrel and the rotor sleeve formed from metal dissimilar to the metal of the rotor coating.

10. A fluid motor for use in drilling a wellbore that transverses a subterranean formation to impart rotary motion to a drill bit in response to a circulating fluid, the fluid motor comprising:

a helical stator with (n) lobes, the stator having an inner surface formed from a first metal; and

a helical rotor with (n-1) lobes, the rotor having an outer surface formed from a second metal that is dissimilar to the first metal, thereby providing metal-to-metal contact during operation.

11. The fluid motor as recited in claim **10** wherein the stator further comprises a stator housing and a stator sleeve, the stator housing and a stator sleeve formed from dissimilar metals.

12. The fluid motor as recited in claim **10** wherein the stator further comprises a stator housing and a stator coating, the stator housing and the stator coating formed from dissimilar metals.

13. The fluid motor as recited in claim **10** wherein the stator further comprises a stator housing, a stator sleeve and a stator coating, the stator housing and the stator sleeve formed from metal dissimilar to the stator coating.

14. The fluid motor as recited in claim **10** wherein the rotor further comprises a solid metal rotor.

15. The fluid motor as recited in claim **10** wherein the rotor further comprises rotor bore operable to provide a bypass for a portion of the circulating fluid.

16. The fluid motor as recited in claim **10** wherein the rotor further comprises a rotor mandrel and a rotor sleeve, the rotor mandrel and the rotor sleeve formed from dissimilar metals.

17. The fluid motor as recited in claim **10** wherein the rotor further comprises a rotor member and a rotor coating, the rotor member and the rotor coating formed from dissimilar metals.

18. The fluid motor as recited in claim **10** wherein the rotor further comprises a rotor mandrel, a rotor sleeve and a rotor

coating, the rotor mandrel and the rotor sleeve formed from metal dissimilar to the metal of the rotor coating.

19. A method for drilling a wellbore that transverses a subterranean formation, the method comprising:

disposing a drill bit on a distal end of a drill string having an inner fluid passageway;

positioning a fluid motor within the drill string, the fluid motor having a stator with (n) lobes and a rotor with (n-1) lobes, the stator having an inner surface formed from a first metal, the rotor having an outer surface formed from a second metal that is dissimilar to the first metal, providing metal-to-metal contact during operation;

pumping a circulating fluid through the inner fluid passageway of the drill string and the fluid motor;

converting the hydraulic energy of the circulating fluid to mechanical energy in the fluid motor causing rotation of the rotor; and

rotating the drill bit in response to the rotation of the rotor.

20. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a stator having a stator housing and a stator sleeve, the stator housing and a stator sleeve formed from dissimilar metals.

21. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a stator having stator housing and a stator coating, the stator housing and the stator coating formed from dissimilar metals.

22. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a stator having stator housing, a stator sleeve and a stator coating, the stator housing and the stator sleeve formed from metal dissimilar to the stator coating.

23. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a solid metal rotor.

24. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a rotor having a rotor bore operable to provide a bypass for a portion of the circulating fluid.

25. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a rotor having a rotor mandrel and a rotor sleeve, the rotor mandrel and the rotor sleeve formed from dissimilar metals.

26. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a rotor having a rotor member and a rotor coating, the rotor member and the rotor coating formed from dissimilar metals.

27. The method as recited in claim **19** wherein positioning a fluid motor within the drill string further comprises positioning a fluid motor within the drill string including a rotor having a rotor mandrel, a rotor sleeve and a rotor coating, the rotor mandrel and the rotor sleeve formed from metal dissimilar to the metal of the rotor coating.

28. A fluid motor for use in drilling a wellbore that transverses a subterranean formation to impart rotary motion to a drill bit in response to a circulating fluid, the fluid motor comprising:

a helical stator with (n) lobes, the stator having an inner surface; and

a helical rotor with (n-1) lobes, the rotor having a rotor mandrel and a rotor sleeve, the rotor sleeve positioned exteriorly of at least a portion of the rotor mandrel, the rotor having an outer surface that contacts the inner surface of the stator as the rotor rotates and precesses within the stator.

29. The fluid motor as recited in claim **28** wherein the rotor mandrel and the rotor sleeve are formed from dissimilar materials.

30. The fluid motor as recited in claim **29** wherein the rotor mandrel is formed from a metal and the rotor sleeve is formed from a nanocomposite material.

31. The fluid motor as recited in claim **29** wherein the rotor mandrel and a rotor sleeve are formed from dissimilar metals.

32. The fluid motor as recited in claim **28** wherein the rotor further comprises a rotor coating, the rotor coating forming on the outer surface of the rotor sleeve.

33. The fluid motor as recited in claim **32** wherein the rotor mandrel and the rotor sleeve are formed from material that is dissimilar to the rotor coating.

34. The fluid motor as recited in claim **33** wherein the rotor mandrel and the rotor sleeve are formed from metal and the rotor coating is formed from a nanocomposite material.

35. The fluid motor as recited in claim **33** wherein the rotor mandrel and a rotor sleeve are formed from metal dissimilar to the rotor coating.

36. The fluid motor as recited in claim **28** wherein the outer surface of the rotor and the inner surface of the stator are formed from dissimilar materials.

37. The fluid motor as recited in claim **36** wherein the outer surface of the rotor and the inner surface of the stator are formed from dissimilar metals.

38. The fluid motor as recited in claim **36** wherein one of the outer surface of the rotor and the inner surface of the stator is formed from a nanocomposite material and the other of the outer surface of the rotor and the inner surface of the stator is formed from a metal.

39. A fluid motor for use in drilling a wellbore that transverses a subterranean formation to impart rotary motion to a drill bit in response to a circulating fluid, the fluid motor comprising:

a helical stator with (n) lobes, the stator having a stator housing and a stator sleeve, the stator sleeve positioned interiorly of at least a portion of the stator housing, the stator having an inner surface; and

a helical rotor with (n-1) lobes, the rotor having an outer surface that contacts the inner surface of the stator as the rotor rotates and precesses within the stator.

40. The fluid motor as recited in claim **39** wherein the stator housing and the stator sleeve are formed from dissimilar materials.

41. The fluid motor as recited in claim **40** wherein the stator housing is formed from a metal and the stator sleeve is formed from a nanocomposite material.

42. The fluid motor as recited in claim **40** wherein the stator housing and the stator sleeve are formed from dissimilar metals.

43. The fluid motor as recited in claim **39** wherein the outer surface of the rotor and the inner surface of the stator are formed from dissimilar materials.

44. The fluid motor as recited in claim 43 wherein the outer surface of the rotor and the inner surface of the stator are formed from dissimilar metals.

45. The fluid motor as recited in claim 43 wherein one of the outer surface of the rotor and the inner surface of the stator

is formed from a nanocomposite material and the other of the outer surface of the rotor and the inner surface of the stator is formed from a metal.

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