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(54) **Highly reinforced elastomer for use in downhole stators**

(57) A Moineau stator for a downhole drilling motor and a method for fabricating the stator are disclosed. The stator includes an internal helical cavity component fabricated from an improved elastomeric material formulated to provide both high resilience and good processability. For example, in one exemplary embodiment the elastomer material includes rheological parameters M_L in a range from about 1.0 to about 4.0 lb·in and M_H in a range from about 75 to about 110 lb·in according to ASTM D2084 at 380 degrees F. Stators in accordance with this invention may exhibit improved efficiency (and may thus provide improved torque output) as compared with conventional stators without substantially increasing manufacturing costs.

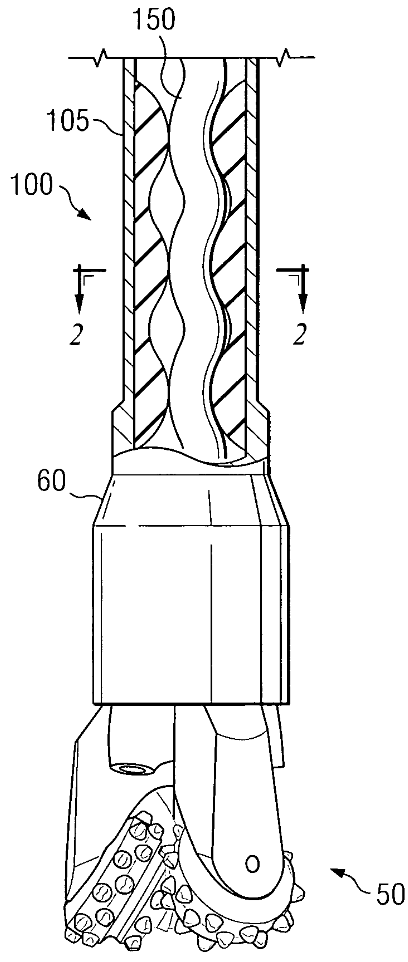


FIG. 1

EP 1 892 416 A1

Description

FIELD OF THE INVENTION

[0001] This invention relates generally to Moineau style power sections useful in subterranean drilling motors, and more specifically relates a drilling motor including an improved elastomer material.

BACKGROUND OF THE INVENTION

[0002] Moineau style hydraulic motors and pumps are conventional in subterranean drilling and artificial lift applications, such as for oil and/or gas exploration. Such motors make use of hydraulic power from drilling fluid to provide torque and rotary power, for example, to a drill bit assembly. While downhole drilling motors fall into the general category of Moineau-type motors, they are generally subject to greater working loads, temperatures, and more severe chemical and abrasive environments than Moineau motors and pumps used for other applications. As such, the demands on drilling motor components (rotor and stator components) typically far exceed the demands on the components of other Moineau-type motors and pumps. For example, drilling motors may be subject to a pressure drop (from top to bottom across the motor) of up to 1500 psi at temperatures of up to about 200 degrees C. Furthermore, a conventional stator may exceed 25 feet in length. Achieving suitable processability (e.g., flowability) in order to injection mold the elastomer materials tends to be difficult at such lengths. Moreover, many rubber compounds are known to deteriorate in the presence of hydrocarbons.

[0003] The power section of a typical Moineau style motor includes a helical rotor disposed within the helical cavity of a corresponding stator. When viewed in circular cross section, a typical stator shows a plurality of lobes in the helical cavity. In most conventional Moineau style power sections, the rotor lobes and the stator lobes are preferably disposed in an interference fit, with the rotor including one fewer lobe than the stator. Thus, when fluid, such as a conventional drilling fluid, is passed through the helical spaces between rotor and stator, the flow of fluid causes the rotor to rotate relative to the stator (which may be coupled, for example, to a drill string). The rotor may be coupled, for example, through a universal connection and an output shaft to a drill bit assembly. Rotation of the rotor therefore causes rotation of the drill bit in a borehole.

[0004] Conventional stators typically include an elastomeric helical cavity component bonded to an inner surface of a steel tube. The helical cavity component in such conventional stators is made substantially entirely of elastomer (rubber) and provides a resilient surface with which to facilitate the interference fit with the rotor. The elastomeric material typically includes a Nitrile Butadiene Rubber (NBR) or a variation of NBR referred to as Hydrogenated Nitrile Butadiene Rubber (HNBR) (which is also referred to in the art as Highly Saturated Nitrile (HSN)). NBR and HNBR elastomers are commonly used owing to their chemical resistance, processability, mechanical properties, dynamic properties, and high temperature resistance.

[0005] The chemical and dynamic properties of NBR and HNBR elastomers are controlled, in part, by the acrylonitrile (ACN) content of the elastomer. Conventional elastomers used in downhole drilling motors include about 30-40% ACN. Elastomers having less than about 30% ACN typically have compromised chemical resistance, while elastomers having more than about 40% ACN typically have inadequate dynamic properties.

[0006] One drawback with conventional stators including an all elastomer helical cavity component is that a tradeoff in elastomer properties has been required. One such tradeoff has been between the resilience (rigidity) of the elastomer and its processability (its flowability during injection molding). For example, U.S. Patent 6,905,319 to Guo states: "processability is generally inversely related to the stiffness of the rubber. This is particularly true in injection-mold processes.... Typically, a stiffer compound will demand much more processing power and time, thereby increasing manufacturing costs" (column 4, lines 4-12). Despite the potential advantages of using a stiffer elastomer, Guo discloses an elastomer having a hardness of about 74 on the Shore A scale (ASTM D2240). Guo's teaching is consistent with conventional wisdom in the art, which suggests that rigid elastomers (e.g., those having a Shore A hardness of about 90 as well as other mechanical properties described in more detail below) are not suitable for use in downhole stators due to inherently poor processability. The elastomeric materials in conventional stators typically have a hardness (Shore A) in the range from 65-75.

[0007] One significant drawback with conventional stators is that the elastomer helical cavity component deforms under torque loads (due to the low rigidity of the elastomer). This deformation creates a gap on the unloaded side of the stator lobe, thereby allowing drilling fluid to pass from one cavity to the next without producing any work (i.e., without causing rotation of the rotor). This is known in the art as "RPM drop-off." When the torque reaches a critical level, substantially all of the drilling fluid bypasses the stator lobes and the rotor stalls.

[0008] Stators including a comparatively rigid helical cavity component (e.g., fabricated from an elastomer lined metal or composite material) have been developed to address this problem. The use of rigid stator materials has been in part due to the above described conventional wisdom in the art and to the poor processability of known, high modulus rubbers. U.S Patents 5,171,138 to Forrest and 6,309,195 to Bottos et al., for example, disclose stators having helical cavity components in which a thin elastomer liner is deployed on the inner surface of a rigid, metallic stator former. The use of such rigid stators is disclosed to preserve the shape of the stator lobes during normal operations (i.e., to prevent lobe deformation) and therefore to improve stator efficiency and torque transmission.

[0009] While rigid stators have been disclosed to improve the performance of downhole power sections (e.g., to improve torque output), fabrication of such rigid stators is complex and expensive as compared to that of the above described conventional elastomer stators. Most fabrication processes utilized to produce long, internal, multi-lobed helixes in a metal reinforced stator are tooling intensive (such as helical broaching) and/or slow (such as electric discharge machining). As such, rigid stators of the prior art are often only used in demanding applications in which the significant added expense is acceptable.

[0010] Other reinforcement materials have also been disclosed. For example, U.S. Patent 6,183,226 to Wood et al. and U.S. Patent Publication 20050089429, disclose stators in which the helical cavity component includes an elastomer liner deployed on a fiber reinforced composite reinforcement material. The fabrication of composite reinforced stators has also proven difficult. For example, removal of the tooling (the stator core) from the injected composite has proven difficult due to the close fitting tolerances and the thermal mismatches between the materials.

[0011] Comparatively rigid (resilient) elastomer helical cavity components are also known in the art (e.g., having a Shore A hardness of about 90). However, as described above, such rigid elastomers typically suffer from poor processability and poor dynamic properties, which tends to result in more difficult and costly stator fabrication and a shortened service life of the stator. Therefore, there exists a need for a downhole stator having an improved elastomeric material. In particular, there exists a need for an elastomeric material having improved rigidity while maintaining suitable processability and other properties such as dynamic properties and temperature and chemical resistance.

SUMMARY OF THE INVENTION

[0012] The present invention addresses one or more of the above-described drawbacks of conventional downhole drilling motors. Aspects of this invention include a stator for use in a downhole drilling motor. The stator includes an internal helical cavity component fabricated from an improved elastomeric material formulated to provide both high resilience and good processability. For example, in one exemplary embodiment the elastomer material includes at least 15 parts by weight of a phenolic resin plasticizer per 100 parts by weight of the nitrile rubber. The phenolic resin plasticizer preferably further includes a hexa cross linking agent. In another exemplary embodiment, the elastomer material includes rheological parameters M_L in a range from about 1.0 to about 4.0 1b·in and M_H in a range from about 75 to about 110 lb·in. M_L and M_H are representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat.

[0013] Exemplary embodiments of the present invention advantageously provide several technical advantages. For example, exemplary embodiments of the invention advantageously reduce the above described tradeoffs associated with elastomer material selection (in particular in regard to resilience and processability). As such, stators in accordance with this invention may exhibit improved efficiency (and may thus provide improved torque output) as compared with conventional stators without substantially increasing manufacturing costs. Moreover, stators in accordance with this invention may provide comparable torque output with stators including rigid metallic lobes, but at significantly reduced expense. An additional benefit of exemplary embodiments of the invention is higher temperature capability due to reduced internal heat generation in the center of the lobe. Reduced heat generation also tends to reduce elastomer breakdown in the lobes and thereby prolong service life of the stator.

[0014] In one aspect, this invention includes a Moineau stator for a drilling motor. The stator includes an outer tube and a helical cavity component deployed substantially coaxially in the outer tube. The helical cavity component provides an internal helical cavity and includes a plurality of internal lobes. The helical cavity component further includes an elastomeric material, the elastomeric material including (i) a 33-3 nitrile butadiene rubber having about 30 percent by weight acrylonitrile and a Mooney viscosity of about 30, (ii) at least 60 parts by weight carbon black per 100 parts by weight of the nitrile rubber, and (iii) at least 15 parts by weight phenolic resin plasticizer per 100 parts by weight of the nitrile rubber, the phenolic resin plasticizer further including a hexa cross linking agent.

[0015] In another aspect, this invention includes a Moineau stator for a drilling motor. The stator includes an outer tube and a helical cavity component deployed substantially coaxially in the outer tube. The helical cavity component provides an internal helical cavity and includes a plurality of internal lobes. The helical cavity component is fabricated from an elastomeric material, the elastomeric material including a nitrile rubber having from about 30 to about 40 percent acrylonitrile. The elastomeric material further includes rheological parameters M_L in a range from about 1.0 to about 4.0 1b·in and M_H in a range from about 75 to about 110 lb·in, wherein M_L and M_H are representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat.

[0016] In still another aspect, this invention includes a method for fabricating a stator. The method includes providing an elastomeric compound including a nitrile rubber having from about 30 to about 40 percent acrylonitrile. The elastomeric compound further includes rheological parameters M_L in a range from about 1.0 to about 4.0 1b·in and M_H in a range from about 75 to about 110 lb·in, wherein M_L and M_H are representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat. The method further includes injecting the elastomeric compound into a tubular stator housing to form a helical cavity component, the helical cavity component providing an internal helical cavity and including a plurality of internal lobes.

[0017] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter, which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realize by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0018] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIGURE 1 depicts a conventional drill bit coupled to a Moineau style drilling motor utilizing an exemplary stator embodiment of the present invention.

FIGURE 2 is a circular cross sectional view of the Moineau style stator as shown on FIGURE 1.

FIGURE 3 plots RPM versus pressure drop for an exemplary embodiment of a downhole drilling motor in accordance with the invention. The exemplary drilling motor of this invention is compared with conventional drilling motors; one including an elastomeric helical cavity component and another including a rigid metal reinforced helical cavity component.

DETAILED DESCRIPTION

[0019] As described above, conventional Moineau drilling motors have used an elastomeric helical cavity component bonded to a steel housing. However, due to the behavior of the selected elastomer material in various competing conditions, there have been inevitable tradeoffs in the choice of a desired elastomer material. Such tradeoffs typically result in the selected elastomer having at least one less-than-optimal material property (e.g., lower-than-desired resilience, suboptimal processability, and/or inadequate dynamic properties) and as described above, these tradeoffs tend to compromise various stator fabrication and/or performance metrics.

[0020] Lower than desired elastomer resilience results in inadequate torque transmission. As described above, elastomeric materials with insufficient resilience undergo excessive deformation at high torque loads (due to the low rigidity of the elastomer), which allows drilling fluid to pass from one cavity to the next without producing any work. The result is a loss in rotor RPM (and therefore drill bit RPM). In severe conditions the rotor can stall in the stator. Several material properties may be measured to determine the resilience of an elastomeric material. Such properties include, elastic modulus (e.g., at tensile strains of 25 and 100%), compression modulus (e.g., at compressive strains 5, 10, and 15%), and hardness (Shore A).

[0021] While increased elastomer resilience is known to reduce RPM drop-off (thereby improving torque transmission), it is also known to degrade elastomer processability. As described above in the Background section, conventional wisdom in the downhole drilling industry suggests that resilient elastomer materials are not suitable for downhole stators due to inherently high viscosity (poor flowability of the pre-cured elastomer) at conventional injection molding temperatures. The processability of the elastomer is particularly important in longer and/or smaller diameter stators. Longer stators (e.g., greater than 20 feet) are often used in an attempt to minimize RPM drop off. Smaller diameter stators (e.g., less than four inch diameter) are commonly used in side tracking or other coiled tubing applications. It is known to those of skill in the art that increasing stator length and decreasing lobe diameter significantly increase the required pressure and time (and therefore expense) required to fabricate a stator via injection molding.

[0022] One measure of processability commonly used in the art is a property referred to as Mooney viscosity (e.g., measured according to ASTM D1646). Mooney viscosities in the range from about 20 to about 60 are sometimes considered to provide suitable processability. However, such measurements can be difficult and time consuming. Rheological properties can also be used to determine both the processability and the resilience (rigidity) of an elastomer. For example, the minimum torque, M_L, as determined via ASTM D2040, tends to be a good indicator of elastomer processability, while the maximum torque, M_H, tends to be a good indicator of elastomer resilience. An elastomer typically has good processability (suitable flowability at conventional injection molding temperatures) when M_L is in the range from about 1.0 to about 4.0 lb·in when measured at 380 degrees F with no preheat. High elastomer resilience (for reducing RPM drop-off) is typically indicated when M_H is in the range from about 75 to about 110 1b·in as also measured at 380 degrees F with no preheat. Conventional stators typically have an M_H of about 55 lb·in or less.

[0023] Often increasing the resilience of an elastomer also degrades the dynamic properties of the elastomer. Such degradation of the dynamic properties is known to cause localized heating of the elastomer lobes due to the viscoelastic behavior of the elastomer (and its poor thermal conductivity). This in turn can result in thermal degradation of the elastomer and ultimately in failure of the stator (due to a phenomenon referred to in the art as "chunking" in which the stator lobes become embrittled and subsequently crack and tear apart). The dynamic properties are typically determined in the art by measuring a quantity referred to as tanδ, which is the ratio of the loss (or viscoelastic) modulus to the storage (or elastic) modulus. Increasing tanδ typically indicates increasing viscoelastic behavior and therefore degraded dynamic properties. While there is no universally agreed upon industry standard measurement technique for determining tanδ, the Applicant has found that a 250 degree F tanδ value as determined in an RPA, after cure temperature sweep at a frequency of 10 Hz and a strain of 7% provides a suitable indication of the dynamic properties of a stator elastomer for use in a downhole stator. Tanδ values of less than about 0.25 typically indicate suitable dynamic properties; however, the Applicant has also found that stators employing highly resilient elastomers can accommodate somewhat compromised dynamic properties via reducing the strain in the interference fit between rotor and stator.

[0024] With reference now to FIGURES 1 and 2, one exemplary embodiment of a Moineau style power section 100 according to this invention is shown in use in a downhole drilling motor 60. Drilling motor 60 is coupled to a drill bit assembly 50 in a configuration suitable for drilling a subterranean borehole, such as in an oil and/or gas formation. Drilling motor 60 includes a helical rotor 150 deployed in the helical cavity of Moineau style stator 105. The rotor 150 it operatively positioned in the cavity to cooperate with the plurality of lobes. Applying fluid pressure to the cavity causes the rotor 150 to rotate in cooperation with the lobes in order to allow pressurized drilling fluid that is introduced at an upper end of the stator 105 to be expelled at the lower end and subsequently exhausted from the drill bit into a borehole. Rotation of rotor 150 causes drill bit 50 to rotate in the borehole.

[0025] With reference now to FIGURE 2, power section 100 is shown in circular cross section, as shown by the section lines on FIGURE 1. Moineau style stator 105 includes an outer stator tube 140 (e.g., a steel tube) retaining an elastomeric helical cavity portion 110. Helical cavity portion 110 is shaped to define a plurality of helical lobes 120 (and corresponding grooves) on an inner surface thereof. In the exemplary embodiment shown, the differing helical configurations on the rotor and the stator provide, in circular cross section, 4 lobes on the rotor and 5 lobes on the stator. It will be appreciated that this 4/5 design is depicted purely for illustrative purposes only, and that the present invention is in no way limited to any particular choice of helical configurations for the power section design.

[0026] With continued reference to FIGURES 1 and 2, helical cavity component 110 is fabricated from an improved elastomeric material that, despite the teachings and conventional wisdom in the art, is formulated to be both rigid and processable. In one exemplary embodiment the elastomer material includes rheological parameter M_L in the range from about 1.0 to about 4.0 1b·in and parameter M_H in the range from about 75 to about 110 lb·in as determined via ASTM D2040 at 380 degrees F with no preheat. In other exemplary embodiments M_L may be in the range from about 1.0 to about 3.5 lb·in or even 1.0 to 3.0 1b·in at 380 degrees F with no preheat. Advantageous embodiments may also include one or more of the mechanical properties in one of the ranges shown in Table I.

TABLE I

Elastomeric Property	Preferred Range	Most Preferred Range
25% Tensile Modulus (psi)	> 400	550 - 750
100% Tensile Modulus (psi)	> 800	900 - 1200
5% Compression Modulus (psi)	> 100	110 - 150
10% Compression Modulus (psi)	> 200	225 - 325
15% Compression Modulus (psi)	> 300	350 - 475
Hardness (Shore A)	> 85	88 - 94

[0027] In one exemplary embodiment, elastomer formulations including Nysyn 33-3 nitrile butadiene rubber (having 33 percent acrylonitrile and a Mooney viscosity of 30), at least 15 parts of a phenolic resin plasticizer per 100 parts nitrile rubber, and at least 60 parts carbon black per 100 parts nitrile rubber have been found to have both desirable resilience and processability (e.g., M_L in the range from about 1.0 to about 4.0 and M_H in the range from about 75 to about 110). Such formulations have also been found to have desirable dynamic properties (e.g., a 250 degree F tanδ value of less than about 0.25).

[0028] Table II lists exemplary formulations A, B, C, and D in accordance with the present invention as well as a prior art formulation STD. It will be appreciated that this invention is not limited by the precise formulations listed in Table II.

The artisan of ordinary skill will readily recognize that the various components in those formulations may be substituted with suitable equivalents. In the exemplary embodiments shown, Akrochem P55 phenolic resin is utilized. It will be appreciated that the invention is not limited to any particular phenolic resin. It will also be understood that Akrochem P55 also includes from about 6.5 to about 8.5 percent of a hexa cross-linking agent.

TABLE II

Formulation	STD	A	B	C	D
NYSYN 33-3	100.00	100.00	100.00	100.00	100.00
ASD 75 - 75% Sulfur in NBR	4.80	4.80	4.80	4.80	4.80
911C - 85% ZnO in NBR	5.00	5.00	5.00	5.00	5.00
Stearic Acid	1.00	1.00	1.00	1.00	1.00
Agerite Resin D	3.00	3.00	3.00	3.00	3.00
DUSANTOX 6 PPD	2.00	2.00	2.00	2.00	2.00
N774 Ultra Carbon Black	60.00	60.00	60.00	80.00	100.00
Cumar - R13	15.00	--	--	--	15.00
Akrochem P55 Phenolic Resin	10.00	15.00	25.00	25.00	10.00
Diisodecyl Phthalate	10.00	15.00	10.00	10.00	10.00
Paraplex G25	5.00	7.50	5.00	5.00	5.00
50% PVI in SBR	1.00	1.00	1.00	1.00	1.00
PB(OBTS)75	2.00	2.00	2.00	2.00	2.00
PB(TMTM)75	0.15	0.15	0.15	0.15	0.15
TOTAL	218.95	216.45	218.95	238.95	258.95

[0029] Table III lists characteristic properties measured for the formulations listed in Table II. These properties were determined in accordance with the test methodologies listed in Table IV.

TABLE III

Elastomeric Property	STD	A	B	C	D
Tensile Strength (psi)	2294	2093	2120	1749	2209
Ultimate Elongation (psi)	381	303	252	259	294
25% Tensile Modulus (psi)	210	323	511	695	366
100% Tensile Modulus (psi)	478	701	991	1093	873
5% Compression Modulus (psi)	56	84	108	122	--
10% Compression Modulus (psi)	111	170	224	276	--
15% Compression Modulus (psi)	171	261	344	423	--
Tear Strength (1b/in)	203	219	237	234	194
Hardness (Shore A)	75	84	88	91	88
Rheological Parameter M_L (lb·in)	2.3	2.8	3.0	3.3	3.4
Rheological Parameter M_H(lb·in)	63	73	88	80	68
Tanδ at 250°F	0.15	0.18	0.20	0.23	0.24

TABLE IV

Elastomeric Property	Test Method
Tensile Strength (psi)	ASTM D412, Die C
Ultimate Elongation (psi)	ASTM D412, Die C
25% Tensile Modulus (psi)	ASTM D412, Die C
100% Tensile Modulus (psi)	ASTM D412, Die C
5% Compression Modulus (psi)	ASTM D575
10% Compression Modulus (psi)	ASTM D575
15% Compression Modulus (psi)	ASTM D575
Tear Strength (1b/in)	ASTM D624 Die C
Hardness (Shore A)	ASTM D2240
Rheological Parameter M_L	ASTM 2084, 380 °F no preheat
Rheological Parameter M_H	ASTM 2084, 380 °F no preheat
Tanδ at 250°F	RPA Aftercure, 10 Hz, 7% strain

[0030] With reference now to FIGURE 3, the performance of three exemplary drilling motors is contrasted at a flow rate of 600 gallons per minute. The three drilling motors were each sized and shaped in accordance with Dyna-Drill Model No. DD675783.0 having a length of 125 inches, an outer diameter of 6.75 inches, and a 7/8 inch lobe. The drilling motors differed only in the materials used to fabricated the helical cavity component of the respective stators: (i) the conventional elastomer stator being fabricated with elastomer STD in Table II, (ii) the stator in accordance with this invention being fabricated with elastomer C shown in Table II, and (iii) a prior art stator having a Rigid, metallic helical cavity component with an elastomeric liner deployed on an inner surface thereof.

[0031] FIGURE 3 plots RPM versus pressure drop (psi) from the top to the bottom of the stator. As shown, the drilling motor including elastomer C in accordance with this invention advantageously undergoes significantly reduced RPM drop off as compared to that of conventional drilling motor STD. For example, at a pressure drop of 1000 psi drilling motor C (including elastomer C) exhibits an RPM drop of only about 45 rpm versus an RPM drop off of about 105 rpm for the conventional stator (including elastomer STD). The performance of drilling motor C even compares favorably with prior art drilling motors including a stator with an elastomer lined, rigid metallic helical cavity component (an RPM drop off of 45 rpm versus 30 rpm at 1000 psi).

[0032] Exemplary embodiments of this invention advantageously obviate the need for the above described tradeoff in elastomer rigidity and processability. Moreover, exemplary embodiments of this invention may even obviate the need for stators having rigid, metallic helical cavity components (except perhaps in the most demanding applications).

[0033] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alternations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

Claims

1. A stator for use in a downhole drilling motor, the stator comprising:

    an outer tube;
    a helical cavity component deployed substantially coaxially in the outer tube, the helical cavity component providing an internal helical cavity and including a plurality of internal lobes; and
    the helical cavity component including an elastomeric material, the elastomeric material including:

        33-3 nitrile butadiene rubber having about 30 percent by weight acrylonitrile and a Mooney viscosity of about 30;
        at least 60 parts by weight carbon black per 100 parts by weight of the nitrile rubber; and
        at least 15 parts by weight phenolic resin plasticizer per 100 parts by weight of the nitrile rubber, said phenolic resin plasticizer further including a hexa cross linking agent.

2. The stator of claim 1, wherein the phenolic resin plasticizer includes from about 6.5 to about 8.5 percent by weight of the hexa cross linking agent.

3. The stator of claim 1 or claim 2, wherein the elastomeric material comprises about 25 parts by weight of the phenolic resin plasticizer per 100 parts by weight of the nitrile rubber.

4. The stator of any preceding claim, wherein the elastomeric material comprises about 25 parts by weight of the phenolic resin plasticizer and about 80 parts by weight carbon black per 100 parts by weight of the nitrile rubber.

5. The stator of any preceding claim, wherein the helical cavity component is fabricated substantially entirely from the elastomeric material.

6. The stator of any preceding claim, wherein the elastomeric material includes the following tensile properties:

a modulus at 25% elongation in a range from about 550 to about 750 psi; and
a modulus at 100% elongation in a range from about 900 to about 1200 psi.

7. The stator of any preceding claim, wherein the elastomeric material includes the following compressive properties:

a modulus at 5% compression in a range from about 110 to about 150 psi;
a modulus at 10% compression in a range from about 225 to about 325 psi; and
a modulus at 15% compression in a range from about 350 to about 475 psi.

8. The stator of any preceding claim, wherein the elastomeric material comprises a Shore A hardness in the range from about 88 to about 94.

9. The stator of any preceding claim, wherein the elastomer material comprises rheological parameters M_L in a range from about 1.0 to about 4.0 lb·in and M_H in a range from about 75 to about 110 lb·in, said M_L and said M_H representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat.

10. The stator of any preceding claim, wherein the elastomer material comprises an aftercure tanδ at 250 degrees F of less than about 0.25.

11. A stator for a downhole drilling motor comprising:

an outer tube;
a helical cavity component deployed substantially coaxially in the outer tube, the helical cavity component providing an internal helical cavity and including a plurality of internal lobes; and
the helical cavity component being fabricated from an elastomeric material, the elastomeric material including a nitrile rubber having from about 30 to about 40 percent acrylonitrile, the elastomeric material further including rheological parameters M_L in a range from about 1.0 to about 4.0 1b·in and M_H in a range from about 75 to about 110 1b·in, said M_L and said M_H representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat.

12. The stator of claim 11, wherein the elastomeric material comprises at least 15 parts by weight phenolic resin plasticizer per 100 parts by weight of the nitrile rubber, the phenolic resin plasticizer including a hexa cross linking agent.

13. The stator of claim 11 and or claim 12, wherein the elastomeric material comprises about 80 parts by weight carbon black per 100 parts by weight of the nitrile rubber.

14. The stator of any of claims 11 to 13, wherein the nitrile rubber comprises a 33-3 nitrile butadiene rubber having about 30 percent by weight acrylonitrile and a Mooney viscosity of about 30.

15. The stator of any of claims 11 to 14, wherein the elastomeric material includes the following tensile properties:

a modulus at 25% elongation in a range from about 550 to about 750 psi; and
a modulus at 100% elongation in a range from about 900 to about 1200 psi.

16. The stator of any of claims 11 to 15, wherein the elastomeric material includes the following compressive properties:

a modulus at 5% compression in a range from about 110 to about 150 psi;
a modulus at 10% compression in a range from about 225 to about 325 psi; and
a modulus at 15% compression in a range from about 350 to about 475 psi.

17. The stator of any of claims 11 to 16, wherein the elastomeric material comprises a Shore A hardness in the range from about 88 to about 94.

18. The stator of any of claims 11 to 17, wherein the elastomer material comprises an aftercure tanδ at 250 degrees F of less than about 0.25.

19. The stator of any of claims 11 to 18, wherein M_L is in a range from about 1.0 to about 3.5 lb·in.

20. The stator of any of claims 11 to 19, wherein M_L is in a range from about 1.0 to about 3.0 lb·in

21. A method of manufacturing a stator for a downhole drilling motor, the method comprising:

(a) providing an elastomeric compound including a nitrile rubber having from about 30 to about 40 percent acrylonitrile, the elastomeric compound further including rheological parameters M_L in a range from about 1.0 to about 4.0 lb·in and M_H in a range from about 75 to about 110 lb·in, said M_L and said M_H representative of a minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat; and
(b) injection molding the elastomeric compound into a tubular stator housing to form a helical cavity component, the helical cavity component providing an internal helical cavity and including a plurality of internal lobes.

22. The method of claim 21, wherein the nitrile rubber comprises a Nysyn 33-3 nitrile butadiene rubber having about 33 percent acrylonitrile and a Mooney viscosity of about 30.

23. The method of claim 21 or claim 22, wherein the elastomeric compound comprises about 25 parts by weight phenolic resin plasticizer per 100 parts by weight of the nitrile rubber, the phenolic resin plasticizer including a hexa cross linking agent.

24. The method of any of claims 21 to 23, wherein the elastomeric compound comprises about 80 parts by weight carbon black per 100 parts by weight of the nitrile rubber.

25. A subterranean drilling motor comprising:

a rotor having a plurality of rotor lobes on a helical outer surface of the rotor;
a stator including a helical cavity component, the helical cavity component providing an internal helical cavity and including a plurality of internal stator lobes;
the rotor deployable in the helical cavity of the stator such that the rotor lobes are in a rotational interference fit with the stator lobes, rotation of the rotor in a predetermined direction causing the rotor lobes to (i) contact the stator lobes on a loaded side thereof as the interference fit is encountered, and (ii) pass by the stator lobes on a non-loaded side thereof as the interference fit is completed; and
the internal stator lobes fabricated from an elastomeric material including (i) a 33-3 nitrile butadiene rubber having about 30 percent by weight acrylonitrile and a Mooney viscosity of about 30, (ii) about 80 parts by weight carbon black per 100 parts by weight of the nitrile rubber, (iii) and about 25 parts by weight phenolic resin plasticizer per 100 parts by weight of the nitrile rubber, said phenolic resin plasticizer further including a hexa cross linking agent.

26. A subterranean drilling motor comprising:

a rotor having a plurality of rotor lobes on a helical outer surface of the rotor;
a stator including a helical cavity component, the helical cavity component providing an internal helical cavity and including a plurality of internal stator lobes;
the rotor deployable in the helical cavity of the stator such that the rotor lobes are in a rotational interference fit with the stator lobes, rotation of the rotor in a predetermined direction causing the rotor lobes to (i) contact the stator lobes on a loaded side thereof as the interference fit is encountered, and (ii) pass by the stator lobes on

a non-loaded side thereof as the interference fit is completed; and
the internal stator lobes fabricated from an elastomeric material having the following properties:

rheological parameter M_L in a range from about 1.0 to about 4.0 lb-in ;
rheological parameter M_H in a range from about 75 to about 110 lb·in;
a tensile modulus at 25% elongation from about 550 to about 750 psi;
a tensile modulus at 100% elongation from about 900 to about 1200 psi;
a Shore A hardness in the range from about 88 to about 94; and
wherein said M_L and said M_H are representative of minimum and maximum torque as determined according to ASTM D2084 at 380 degrees F with no preheat.

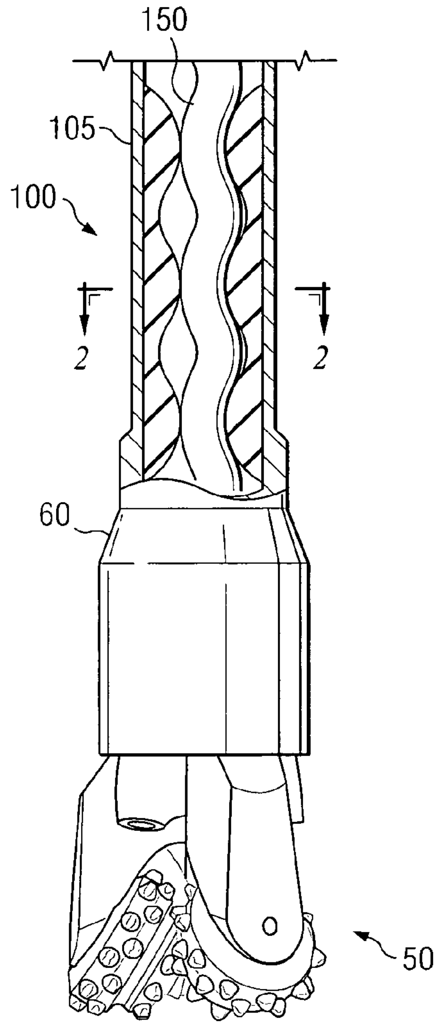


FIG. 1

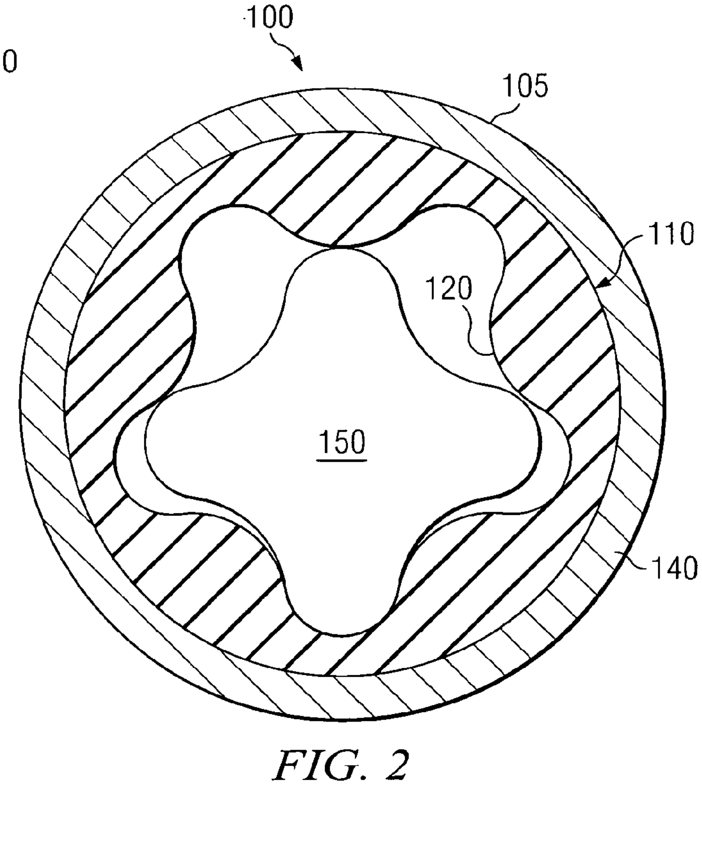
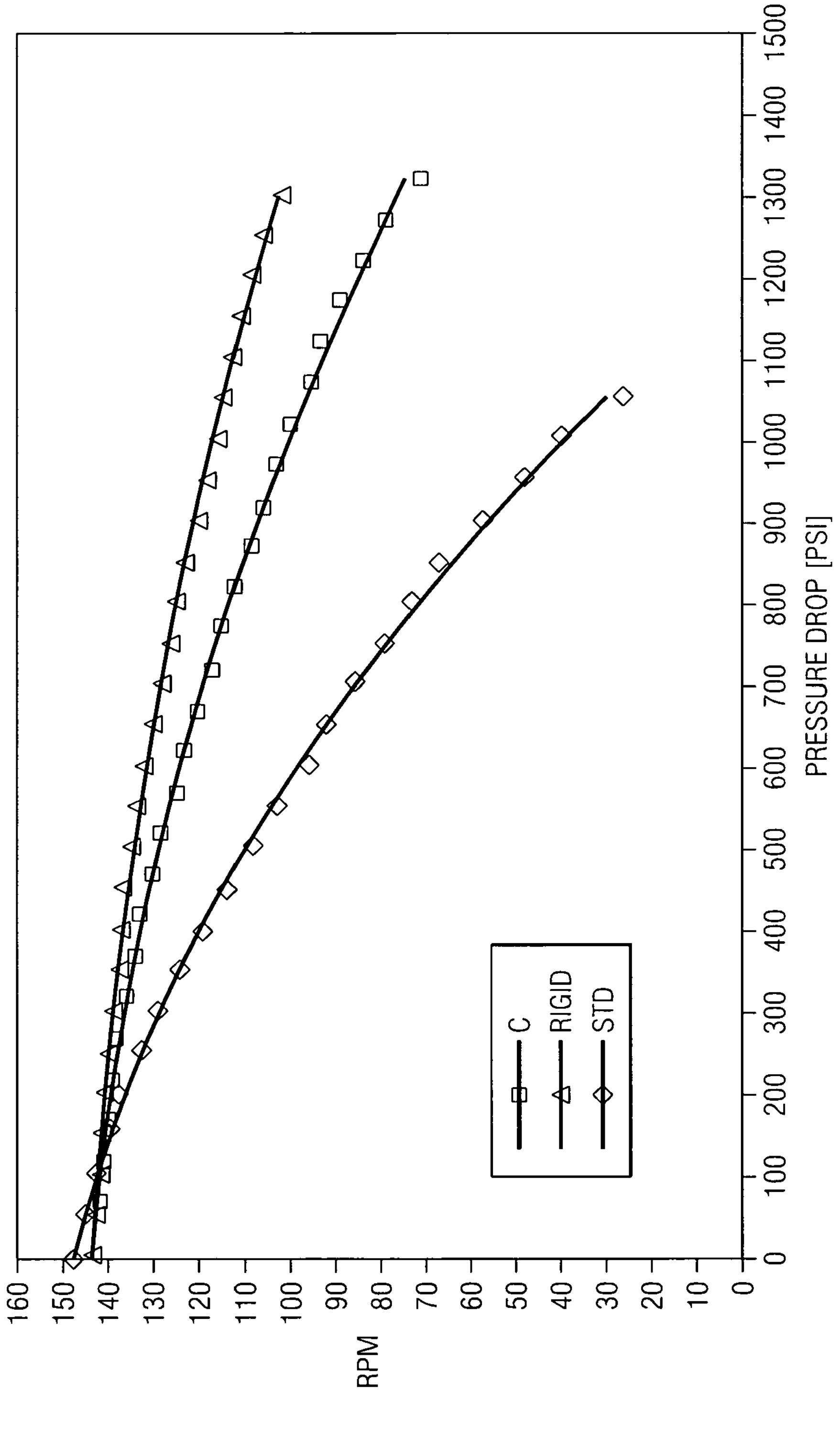


FIG. 2

FIG. 3


RPM
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EUROPEAN SEARCH REPORT

Application Number
EP 07 25 3324

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
D,A	US 6 905 319 B2 (GUO LILLIAN [US]) 14 June 2005 (2005-06-14) * figures 1,2 * * column 1, line 33 - line 49 * * column 3, line 66 - column 4, line 30 * * table 3 * * claims 1,8,12 * -----	1-26	INV. F04C2/107 E21B4/02
A	GB 2 297 092 A (PILECI ANTONIO FERNANDO [GB]) 24 July 1996 (1996-07-24) * page 1, line 16 - line 18 * * page 2, line 1 - line 5 * * claims 1,2,5 * -----	1-26	
A	EP 0 744 440 A (MITSUI PETROCHEMICAL IND [JP] MITSUI CHEMICALS INC [JP]) 27 November 1996 (1996-11-27) * page 2, line 17 - line 21 * * page 14, line 31 - line 36 * * page 25, line 14 * -----	1-26	

TECHNICAL FIELDS SEARCHED (IPC)
F04C E21B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	14 November 2007	Lequeux, Frédéric

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2

EPO FORM 1503 03.82 (P04C01)

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14-11-2007

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
US 6905319	B2	14-06-2005	CA	2417565	A1	29-07-2003
			DE	10304183	A1	07-08-2003
			GB	2386647	A	24-09-2003
			US	2003143094	A1	31-07-2003
GB 2297092	A	24-07-1996	NONE			
EP 0744440	A	27-11-1996	CA	2177239	A1	25-11-1996
			CN	1314432	A	26-09-2001
			CN	1148608	A	30-04-1997
			DE	69600513	D1	17-09-1998
			DE	69600513	T2	21-01-1999
			US	5912303	A	15-06-1999

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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Patent documents cited in the description

- US 6905319 B, Guo **[0006]**
- US 6183226 B, Wood **[0010]**
- US 20050089429 A **[0010]**