To address issues of durability of pressure compensation systems in roller cone rock bits, a composite diaphragm of a pressure compensation system for a roller cone drill bit includes an inner surface that defines an inner cavity and is formed of a first elastomeric material. The inner cavity is configured to serve as a lubricant reservoir. An external surface is disposed opposite the inner surface and is formed of a second elastomeric material that is different than the first elastomeric material.
COMPOSITE DIAPHRAGM FOR ROLLER CONE PRESSURE COMPENSATION SYSTEM

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates generally to rock bit drilling tools, and more specifically concerns roller cone drilling tools and the lubrication and pressure compensation systems used within such roller cone drilling tools.

BACKGROUND

[0002] A roller cone rock bit is the cutting tool used in oil, gas, and mining fields to break through the earth formation to shape a well bore. Load and motion of the bit are transferred to the bearings inside three head and cone assemblies. For the bit where a journal bearing is employed, the main journal bearing is charged with as much as 80 percent of the total radial load. The main journal bearing is composed of the head (as the shaft), the bushing, and the cone (as the housing). This bearing is lubricated and sealed. An outer circumference of the seal is compressed by a gland of the cone so that the seal moves together with the cone and slides against the head (at a sealing surface or seal boss) on the inner circumference of the seal. The seal is thus confined in the seal gland to secure the lubricant within the bearing and prevent debris from invading into the bearing. The longer the seal excludes contamination from the bearing, the longer the bearing life. Therefore, the seal can become the limit of the rock bit life.

[0003] In downhole applications, sealed bearing rolling cone rock bits incorporate a pressure compensation system to account for downhole pressure. One part of the pressure compensation system is a flexible member, commonly an elastomeric diaphragm. This elastomeric compound is selected to work reliably under a variety of downhole conditions; including high temperatures, a harsh chemical environment, as well as meeting required material properties (tensile modulus, compression set, elongation, etc.). As downhole tools are used in more and more demanding applications, the ability to meet all required minimum properties for reliable operation is increasingly challenging.

SUMMARY

[0004] To address issues of durability of pressure compensation systems in roller cone rock bits, a composite diaphragm of a pressure compensation system for a roller cone drill bit includes an inner surface that defines an inner cavity and is formed of a first elastomeric material. The inner cavity is configured to serve as a lubricant reservoir. An external surface is disposed opposite the inner surface and is formed of a second elastomeric material that is different than the first elastomeric material.

[0005] The materials of the composite diaphragm are selected for specific properties based on the function performed by the specific portion of the composite diaphragm. For example, the first elastomeric material of the inner surface is exposed to the lubricant in the lubricant system, while the external surface formed of the second elastomeric material is exposed to the downhole environment. In this embodiment, the second elastomeric material is more heat resistant than the first elastomeric material.

[0006] In a further embodiment, a flange portion of the composite diaphragm that performs a sealing function when compressed is formed of a material that has a greater stiffness than the rest of the composite diaphragm.

[0007] Other aspects, features, and advantages will become apparent from the following detailed description when taken in conjunction with the accompanying drawings, which are a part of this disclosure and which illustrate, by way of example, principles of the inventions disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 illustrates a partially broken away view of a leg of a roller cone rock bit employing a composite diaphragm;

[0009] FIG. 2 illustrates a detailed view certain components of the pressure compensation system shown in FIG. 1 including the composite diaphragm;

[0010] FIG. 3 illustrates an alternate embodiment of the composite diaphragm; and

[0011] FIG. 4 illustrates an additional alternate embodiment of the composite diaphragm.

DETAILED DESCRIPTION OF THE DRAWINGS

[0012] Reference is made to FIG. 1 which illustrates a partially broken away view of a leg 10 of a roller cone rock bit, which may also refer to a roller cone bit, employing a composite diaphragm 12 according to the teachings of the present disclosure. A typical roller cone rock bit is formed of three legs 10, where each leg 10 supports a roller cone 14. A body portion of the bit includes an upper threaded portion that forms a tool joint connection which facilitates connection of the bit to a drill string (not shown). A bearing shaft 16 extends from the leg 10 and supports the roller cone 14. A plurality of cutting structures 18 are supported by an outer surface of the roller cone 14. The cutting structures 18 may be any cutting structure suitable for earth boring, drilling out a frac plug or other downhole tool, and the like. In certain embodiments, the cutting structures 18 are tungsten carbide inserts that are brazed into the roller cone 14. In other embodiments, the cutting structures may be tooth-shaped structures milled into the cone 14. Still other embodiments employ multiple cutting structures 18 in a single cone 14. The cutter inserts may be conical-shaped, dome-shaped, chisel-shaped, double conical-shaped, oxoid-shaped, or any other shape suitable for drilling a wellbore or drilling out a frac plug or a casing plug. The roller cone 14 may be formed of steel or a matrix material.

[0013] The roller cone or cutting cone 14 is rotatably positioned on the bearing shaft 16, which functions as a journal or it may support a plurality of rollers as the load carrying elements (a roller bearing system). In the illustrated embodiment, a cylindrical surface on the bearing shaft and an inner cylindrical surface of a bushing 19 which has been press fit into the cone 14. This bushing 19 is a ring-shaped structure typically made of beryllium copper, although the use of other materials is known in the art. Alternate embodiments may not employ a bushing and the surface of the shaft 16 may directly contact a surface of the cone 14.

[0014] The cone 14 is axially retained on the bearing shaft 16, and further supported for rotation, by a set of ball bearings 20 that ride in the annular raceway 22 defined at an interface between the bearing shaft 16 and cone 14. The ball bearings 20 are delivered to the raceway 22 through a shaft lubricant channel 24, and are held in place in the annular raceway 22 by a ball plug 26 disposed in the shaft lubricant channel 24. The ball plug 26 is shaped to allow lubricant to flow through the
shaft lubricant channel 24 where it can lubricate the interface of the shaft 16, the balls 20, and the cone 14.  

[0015] A lubricant system 28 includes the shaft lubricant channel 24, a leg lubricant channel 32 and a pressure compensation system 30. Lubricant (typically, grease) is added to occupy the lubricant channels 24, 32 and the space between the bearing shaft 16 and the roller cone 14. The lubrication system provides lubrication to, and retains lubricant in, the journal bearing between the cone 14 and the bearing shaft 16. The lubricant serves to help support the load transferred to the shaft 16 by the cone 14. Such load is supported by both asperity contact and hydrodynamic pressure of the lubricant.  

[0016] An elastomeric seal 34 retains the lubricant in the lubricant system and prevents any materials (drilling mud and debris) in the well bore from entering into the lubricant system 28 and interfering with the bearing surfaces of the shaft 16 and cone 14 bearing area. The elastomeric seal 34 is disposed in an annular groove formed in the cone 14 that is referred to as a seal gland 36. The groove 36 and a sealing surface 38 of the shaft 16 align with each other when the cone 14 is rotatably positioned on the bearing shaft 16. The elastomeric o-ring seal 34 seals the lubrication system 28 when it is compressed between the surface(s) of the gland 36 and the sealing surface 38. The lubricant not only lubricates the bearing surfaces, but also provides a measure of lubricant on the surfaces of the seal 34 and the sealing surface 38, which allows the compressed seal 34 to slide along the sealing surface 38 as the cone rotates.  

[0017] The seal is designed to withstand high pressures that occur in downhole drilling applications. That high pressure, together with a designed high compression rate of the seal in the gland, compresses the seal tightly against the sealing surface 38. The lubricant which is present in the sealing zone at the seal surface 38 provides lubrication to the seal and takes away friction heat. In the event that the seal is not well lubricated, it slides dryly against the seal boss and a large amount of friction heat is generated. This friction heat is known to be the root cause of seal failure.  

[0018] Each leg includes a pressure compensation system 30 to control the pressure differential between the lubricant system 28, particularly the seal 34, and the pressure of the borehole external to the bit. During operation of the bit, the rotating cone 14 oscillates along the head in at least an axial manner. This motion is commonly referred to in the art as a "cone pump." Cone pumping is an inherent motion resulting from the external force that is imposed on the cone by the rocks during the drilling process. The oscillating frequency of this cone pump motion is related to the rotating speed of the bit. The magnitude of the oscillating cone pump motion is related to the manufacturing clearances provided within the bearing system. When cone pump motion occurs, the interstitial volume defined between the foregoing cylindrical and radial surfaces of the bearing system changes. This change in volume squeezes the lubricant provided within the interstitial volume.  

[0019] The pressure compensation system 30 includes the composite diaphragm 12 that is disposed in a shoulder portion 40 of the leg 10. The change in interstitial volume and squeezing of the lubricant grease results in the generation of a lubricant pressure pulse. Over a very short period of time, responsive to this pressure pulse, grease flows between the bearing system and the composite diaphragm 12 through the series of lubricant channels, such as leg lubricant channel 32 and shaft lubricant channel 24. The composite diaphragm 12 is designed to relieve or dampen the pressure pulse by compensating for volume changes.  

[0020] Referring simultaneously to FIGS. 1 and 2, the pressure compensation system 30 includes a reservoir 42 formed by the composite diaphragm 12 that communicates via the lubricant channel 32 with the bearing area between the shaft 16 and the roller cone 14. The composite diaphragm 12 is disposed in a leg cavity 48 and it equalizes the pressure differential across the elastomeric o-ring packing seal 34 by expanding or contracting radially and axially with respect to a longitudinal axis 44 of the leg cavity 48 in response to pressure differential across the seal 34.  

[0021] Referring now to FIG. 2, which is a detailed view of the pressure compensation system 30 supporting the composite diaphragm 12. A drill fluid channel 46 opens to an external area of the bit proximate the base of the cone 14 and extends into the leg cavity 48 in which the composite diaphragm 12 is disposed. An external surface 50 of the composite diaphragm 12 is exposed to and acted on by the drilling fluid and downhole pressures external to the bit. An internal surface 52 of the composite diaphragm 12 is separated from the external environment of the borehole and is contacted and acted on by the lubricant and the lubricant pressure in the lubricant system 28. The leg lubricant channel 32 fluidly connects the bearing surfaces of the roller cone 14 and shaft 16 with the lubricant cavity or reservoir 42 of the composite diaphragm 12. Thus, the composite diaphragm 12 is disposed between the lubricant system 28 and the external environment of the borehole and thereby expands and contracts according to the relative pressures in the lubricant system 28 and the downhole environment.  

[0022] A cap 54 secures the composite diaphragm 12 in place by compressing a flange portion 56 of the diaphragm 12 between the cap 54 and the internal surface of the body of the bit.  

[0023] In operation, the diaphragm 12 limits the pressure differential between the lubricant system 28 and the pressure in the well bore. More specifically, the composite diaphragm 12 elastically expands or contracts within the leg cavity 48 to equalize the pressure differential between the lubricant system 28 and the bore hole, therefore minimizing the pressure differential across the o-ring seal 34.  

[0024] The composite diaphragm 12 is a thin-walled elastomeric member defining an inner cavity 42 that serves as the lubricant reservoir 42 and is open on one end. The walls may have a uniform or nonuniform thickness. A nonuniform thickness embodiment is illustrated. The diaphragm 12 includes a body and an annular flange 56 disposed at a base of the composite diaphragm 12. The body includes a cylindrical portion 58 that blends into a tapered portion 60 that tapers radially inward toward the longitudinal axis 44. The body also includes a tip portion 62 that is delimited by the tapered portion 60. The tip portion 62 is generally circular in shape and is disposed at the tip of the composite diaphragm 12 opposite the flange 56. According to an alternate embodiment, the body may not include a tapered portion 60. Rather, the tip portion 62 may be delimited by the cylindrical portion 58.  

[0025] In one embodiment, the inner cavity 42 is defined by an inner surface 52, which is in contact with the lubricant. An external surface 50 opposite the inner surface 52 generally contacts the drilling fluid or other fluid, such as fracking fluid that may be present in the well bore. The external surface 50 is formed of a different material than the inner surface 52. The
external surface 50 may be formed of a material that is resistant to chemicals that may be found in fracking fluid. The material of the external surface 50 may be selected to also be resistant to swell, heat, and have other properties related to accommodating the downhole environment.

For example, the external surface 50 of the body of the composite diaphragm 12 may be formed of a fluorocarbon polymer ("FKM") or a perfluoro-carbon polymer ("FFKM") shell which provides enhanced chemical and heat resistant properties compared to the material of the inner surface 52. The material of the inner surface 52 may be hydrogenated nitrile butadiene rubber ("HNBR"). HNBR is also known as highly saturated nitrile ("HSN").

For example, the external surface 50 of any one or more of the tip portion 62, the tapered portion 60, and the cylindrical portion 58 may be formed from the chemical and heat resistant material, such as FKM or FFKM. In the embodiment illustrated, the external surface 50 of all of the tip portion 62, the tapered portion 60, and the cylindrical portion 58 is formed from FKM or FFKM.

The inner surface 52 of any one or more of the tip portion 62, the tapered portion 60, and the cylindrical portion 58 is formed of a different material than the external surface 50. The inner elastomer is selected for a balance of properties which focus on the mechanical needs of the composite diaphragm 12 based on the design of the compensation system 30. Some material properties that may be considered in selecting a material for the inner surface 52 include, but are not limited to, the material's tear strength, modulus, elongation, and the like. According to the present embodiment, the inner surface 52 may be formed from an HNBR material, which has favorable tear modulus and elongation properties.

According to an alternate embodiment of the present disclosure, certain portions of the composite diaphragm 12 may be formed from different materials than the materials of other portions. In the embodiment shown in FIG. 3, the tip portion 62, both the external surface 50 of the tip portion 62 and the inner surface 52 of the tip portion 62, is formed from a material that is more suitable for the purpose of the tip portion 62. For example, the tip portion 62 may define a pressure relief hole 64 that is generally closed, but opens quickly to relieve a spike in lubricant pressure, then returns to its closed position. Due to the stress on the material resulting from the rapid opening of the pressure relief hole 64, the material surrounding the pressure relief hole 64 is molded from an elastomeric material with increased tear strength over the other portions of the composite diaphragm 12. For example, the body portion of the composite diaphragm 12 is formed of at least two different HNBR materials. The tip portion is formed from an HNBR material that has a greater tear strength than the material of the body (cylindrical portion 58 and tapered portion 60). The HNBR material of the cylindrical portion 58 and the tapered portion 60 is formed from an HNBR material that is less expensive and/or more easily molded or has other desirable properties.

In the embodiment illustrated in FIG. 3, the flange portion 56 of the composite diaphragm 12 is formed of a different material than the other portions of the composite diaphragm 12. The flange portion 56 is compressed to form a seal. The integrity of this seal is at least partially dependent on the stiffness of the material and the ability of the material of the flange portion 56 to resist compression set. Therefore, the flange portion 56 may be formed of a relatively stiff material that is known to resist compression set at elevated temperatures, while the other body portions (cylindrical portion 58, tapered portion 60, and tip portion 62) of the composite diaphragm 12 are formed of material, such as HNBR, that is selected for other properties including cost of material or cost of manufacturing. An example of an elastomeric material with a stiffness and resistance to compression set at elevated temperatures that is suitable for the flange portion 56 is an FKM material available under the trade name Viton® and manufactured by DuPont.

The embodiment shown in FIG. 4 is an example of a composite diaphragm 12 that combines the other illustrated and described embodiments. It should be understood that the teachings of the present disclosure include combinations of any number of the embodiments illustrated and described. The embodiment shown in FIG. 4 includes a material for the flange portion 56 that is selected for its stiffness and resistance to compression set. The tip portion 62 includes a relief hole 64 and the material proximate and defining the relief hole 64 is selected for its increased tear strength, as described above with respect to the embodiment illustrated in FIG. 3. The remaining portions of the composite diaphragm 12 (the cylindrical portion 58 and the tapered portion 60) include a material for the inner surface 52 that is selected to be compatible with lubricant and an external surface 50 that is selected to be compatible with the drilling fluid, such as FKM or FFKM, as described above with respect to FIGS. 1 and 2.

The composite diaphragm 12 may be fabricated using multi-material compression molding techniques that are known in the elastomeric molding art. For example, U.S. Pat. No. 6,179,296 to Cawthorne, which is hereby incorporated by reference, describes a dual-material bearing seal that is formed by conventional compression molding techniques.

In the embodiment shown and described with respect to FIGS. 1 and 2 of the present disclosure, it is desired that a first elastomeric material forming the inner surface 52 and a second elastomeric material forming the outer surface or shell 50 be in the early forming stages but not be allowed to fully cure. The first and second elastomeric materials are combined together and placed into a compression mold having the approximate configuration of the completed composite diaphragm 12, and the two materials are covalentized to form a unitary construction. To facilitate covalentization between the first and second elastomeric materials, it is desired that the first and second elastomeric materials be chemically compatible with each other. In an alternate embodiment, a suitable adhesive that bonds two elastomeric materials together is applied to the elastomeric surfaces that will contact each other. A non-limiting example of a suitable adhesive is CHEMLOCK 252, manufactured by Lord Corp. of Cary, N.C.

The teaching of the present disclosure extends to elastomeric components of assemblies that include metallic or other rigid components, such as bellows.

The foregoing describes only some embodiments of the invention(s), and alterations, modifications, additions and/or changes can be made thereto without departing from the scope and spirit of the disclosed embodiments, the embodiments being illustrative and not restrictive. Furthermore, the present invention has been described in connection with what are presently considered to be the most practical and preferred embodiments, but it is to be understood that the invention is not to be limited to the disclosed embodiments. On the contrary, the invention is intended to cover various modifications and equivalent arrangements included within
the spirit and scope of the invention(s). Also, the various embodiments described above may be implemented in conjunction with other embodiments, e.g., aspects of one embodiment may be combined with aspects of another embodiment to realize yet other embodiments. Further, each independent feature or component of any given assembly may constitute an additional embodiment.

What is claimed is:

1. A composite diaphragm of a pressure compensation system for a roller cone drill bit, comprising:
   - an inner surface formed of a first elastomeric material and defining an inner cavity configured to serve as a lubricant reservoir; and
   - an external surface disposed opposite the inner surface and formed of a second elastomeric material, the second elastomeric material being different than the first elastomeric material.

2. The composite diaphragm of claim 1 wherein the second elastomeric material is either a fluoroelastomer material or a perfluoroelastomer material.

3. The composite diaphragm of claim 2 wherein the first elastomeric material is a hydrogenated nitrile butadiene rubber material.

4. The composite diaphragm of claim 1 wherein the second elastomeric material resists heat degradation better than the first elastomeric material.

5. The composite diaphragm of claim 1 wherein the first and second elastomeric materials are covalanized during forming of the composite diaphragm.

6. The composite diaphragm of claim 1 wherein an adhesive bonds the first elastomeric material to the second elastomeric material.

7. The composite diaphragm of claim 1 further comprising a flange portion, the flange portion formed of a third elastomeric material having a stiffness greater than either the first or second elastomeric material.

8. A composite diaphragm of a pressure compensation system for a roller cone drill bit, comprising:
   - a body portion defining an inner cavity and being formed from a first elastomeric material; and
   - a flange portion extending radially from the body portion and being formed from a second elastomeric material, the second elastomeric material having a stiffness greater than the first elastomeric material.

9. The composite diaphragm of claim 8 wherein the second elastomeric material is a fluoroelastomer material.

10. The composite diaphragm of claim 9 wherein the body portion comprises a tip portion defining a pressure relief hole and the tip portion is formed of a hydrogenated nitrile butadiene rubber material.

11. A roller cone rock bit, comprising:
   - a plurality of legs, each leg supporting a shaft and a pressure compensation system;
   - a roller cone rotatably mounted to the shaft and supporting a plurality of cutting structures;
   - a seal disposed between the shaft and the roller cone; and
   - the pressure compensation system comprising a composite diaphragm having an inner surface and an external surface opposite the inner surface, either the inner or the external surface being exposed to a lubricant, the composite diaphragm formed of a plurality of elastomeric materials.

12. The roller cone rock bit of claim 11 wherein the inner surface is exposed to the lubricant and functions as a reservoir for the lubricant.

13. The roller cone rock bit of claim 11 wherein the composite diaphragm further comprises a flange portion, a generally cylindrical portion extending from the flange portion, and a tapered portion extending from the generally cylindrical portion.

14. The roller cone rock bit of claim 13 wherein the tapered portion of the composite diaphragm is delimited by a tip portion.

15. The roller cone rock bit of claim 14 wherein the tip portion of the composite diaphragm defines a pressure relief hole.

16. The roller cone rock bit of claim 11 wherein the plurality of elastomeric materials comprises a first elastomeric material and a second elastomeric material, and the composite diaphragm further comprises a flange portion formed of the second elastomeric material, the second elastomeric material having a stiffness greater than a stiffness of the first elastomeric material.

17. The roller cone rock bit of claim 11 wherein the plurality of elastomeric materials comprises a first elastomeric material and a second elastomeric material, and the composite diaphragm further comprises a tip portion defining a pressure relief hole, the tip portion formed of the second elastomeric material, the second elastomeric material having a tear strength greater than a tear strength of the first elastomeric material.

18. The roller cone rock bit of claim 17 wherein the second elastomeric material is a hydrogenated nitrile butadiene rubber material.

19. A composite diaphragm for a roller cone rock bit, comprising:
   - a body portion including a generally cylindrical portion and a tip portion;
   - a flanged portion disposed at a base of the body portion; the generally cylindrical portion having an inner surface formed of a first elastomeric material and defining an inner cavity configured to serve as a lubricant reservoir and an external surface disposed opposite the inner surface and formed of a second elastomeric material, the second elastomeric material being different than the first elastomeric material; and
   - the tip portion defining a pressure relief hole and being formed of a third elastomeric material.

20. The composite diaphragm of claim 19 wherein the third elastomeric material is a hydrogenated nitrile butadiene rubber material.

21. The composite diaphragm of claim 20 wherein the first elastomeric material is also a hydrogenated nitrile butadiene rubber material and the third elastomeric material has a greater tear strength than the first elastomeric material.

22. The composite diaphragm of claim 21 wherein the flanged portion is formed from a fluoroelastomer material.

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