Sealing arrangements for a rotary cone rock-bit comprising a leg extending from a bit body and a cone rotatably mounted to the leg. A seal is disposed radially between the cone and the leg. A footprint defines an area of contact between the seal and the leg. Compression of the seal generates a contact pressure between the seal and the leg. An axial centerline evenly bisects the footprint into a mud side and a grease side. A contact pressure profile defines the contact pressure over the footprint, wherein the contact pressure on the mud side of the footprint is greater than the contact pressure on the grease side of the footprint.
ROCK-BIT SEALS WITH ASYMMETRIC CONTACT PROFILES

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] Not Applicable.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not Applicable.

BACKGROUND

[0003] The present invention relates generally to sealed bearing earth boring drill bits, such as rotary cone rock bits. More particularly, the present invention relates to seal rings for use in rotary cone rock bits. Still more particularly, the present invention relates to journal bearing seal rings used to isolate a lubricated bearing area from abrasive wellbore fluids.

[0004] Rock bits are employed for drilling wells in subterranean formations for oil, gas, geothermal steam, minerals, and the like. Such drill bits commonly have a body connected to a drill string and three cutter cones mounted on the body. The cutter cones are rotateably mounted on steel journals or pins integral with the bit body at its lower end. A lubricated bearing is often used to support rotation of the cutter cone about the journal pins. Journal bearing seal rings are used to isolate the lubricated bearing from abrasive fluids moving through the well.

[0005] Journal bearing seal rings are often constructed from an elastomer or rubber material and have a symmetric axial cross-sectional geometry. The particular geometric configuration of the seal surfaces produces a given amount of seal deflection that defines the degree of contact pressure or “squeeze” applied by the dynamic and static seal surfaces against respective journal bearing and cone surfaces.

[0006] The contact pressure generated by the journal bearing seal ring is the force that protects the journal bearing from wellbore fluids. Failure of the journal bearing seal ring can allow wellbore fluids to contaminate the journal bearing and can lead to failure of the bearing. Once the bearing fails, or becomes severely worn, the cutter cone may no longer operate properly and the drill bit will have to be replaced. Replacement of a drill bit can be a time consuming process, because it requires a cessation of drilling operations and removal of the entire drill string from the wellbore. Therefore, any improvement that maximizes the life of a drill bit is beneficial.

[0007] Conventional journal bearing seals perform best within a narrow range of contact pressures and fluid conditions. Because the seal bears against a rotating surface between the seal and the leg, lubricant is often used to decrease the friction forces in this sealing area. If the contact pressure is too high, lubricant will not be able to reach the sealing interfaces and the heat generated by sliding contact of the seal and the leg will increase. If the contact pressure is too low, abrasive particles can enter the sealing interfaces and increase wear of both the seal and the leg. In either condition, the life of the seal will be greatly reduced over a seal operating with proper lubrication and without abrasive particles.

[0008] Thus, there remains a need to develop journal bearing seal rings that overcome some of the foregoing difficulties while providing more advantageous overall results.

SUMMARY OF THE PREFERRED EMBODIMENTS

[0009] The embodiments of the present invention are directed toward sealing arrangements for a rotary cone rock-bit comprising a leg extending from a bit body and a cone rotateably mounted to the leg. A seal is disposed radially between the cone and the leg. A footprint defines an area of contact between the seal and the leg. Compression of the seal generates a contact pressure between the seal and the leg. An axial centerline evenly bisects the footprint into a mud side and a grease side. A contact pressure profile defines the contact pressure over the footprint, wherein the contact pressure on the mud side of the footprint is greater than the contact pressure on the grease side of the footprint.

[0010] In certain embodiments, a bit for drilling a borehole into earth formations comprises a journal shaft extending from a bit body and a rolling cone cutter mounted on the journal shaft and being adapted to rotate about a cone axis. A seal gland is formed by the shaft and the cone and comprises a first seal engaging surface on the shaft and a second seal engaging surface on the cone. An annular seal is disposed in the gland. The annular seal comprises a radially inner surface sealingly engaging the first seal engaging surface and a radially outer seal surface sealingly engaging the second seal engaging surface. A seal footprint on one of the seal engaging surfaces is defined by the portion of the seal contacting the one seal engaging surface. The footprint has a footprint length measured axially relative to the cone axis and being bisected by a footprint centerline that is perpendicular to the cone axis. The seal creates a pressure profile on one of the seal engaging surface axially along the footprint, the pressure profile being asymmetric relative to the centerline.

[0011] Thus, the present invention comprises a combination of features and advantages that enable it to overcome various problems of prior devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description of the preferred embodiments of the invention, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] For a more detailed description of the preferred embodiment of the present invention, reference will now be made to the accompanying drawings, wherein:

[0013] FIG. 1 is a perspective view of a prior art rock bit;

[0014] FIG. 2 is a partial cross-sectional view of the rock bit of FIG. 1;

[0015] FIG. 3A is a partial cross-sectional view of a prior art seal;

[0016] FIG. 3B illustrates the seal of FIG. 3A disposed in a seal gland;

[0017] FIG. 3C illustrates the contact pressure profile of the seal of FIG. 3A;
[0018] FIG. 4A is a partial cross-sectional view of a seal constructed in accordance with embodiments of the invention;

[0019] FIG. 4B illustrates the seal of FIG. 4A disposed in a seal gland;

[0020] FIG. 4C illustrates the contact pressure profile of the seal of FIG. 4A;

[0021] FIGS. 5A-B through 9A-B are partial cross-sectional views of and contact pressure profiles generated by radial seals that have asymmetric external features;

[0022] FIGS. 10A-B through 12A-B are partial cross-sectional views of and contact pressure profiles generated by radial seals that have asymmetric internal features;

[0023] FIGS. 13A-B through 22A-B are partial cross-sectional views of and contact pressure profiles generated by radial seals that have a combination of internal and external asymmetrical features;

[0024] FIGS. 23A-B through 26A-B are partial cross-sectional views of and contact pressure profiles generated by radial seals having multiple material interfaces;

[0025] FIGS. 27A-B through 31A-B are partial cross-sectional views of and contact pressure profiles generated by symmetrical radial seals disposed within asymmetrical seal glands.

[0026] FIG. 32A is a partial cross-sectional view of a seal constructed in accordance with embodiments of the invention;

[0027] FIG. 32B illustrates the seal of FIG. 32A disposed in a seal gland;

[0028] FIG. 32C illustrates the contact pressure profile of the seal of FIG. 32A;

[0029] FIGS. 33A-33F are cross-sectional views of O-ring seals constructed in accordance with embodiments of the invention;

[0030] FIGS. 34A-34D are cross-sectional views of composite O-ring seals constructed in accordance with embodiments of the invention;

[0031] FIG. 35 is a cross-sectional view of a dual seal assembly constructed in accordance with embodiments of the invention; and

[0032] FIG. 36 is a cross-sectional view of a dual seal assembly constructed in accordance with embodiments of the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0033] Referring now to FIG. 1, a rock bit comprises body 10 having three cutter cones 11 mounted on its lower end. A threaded pin 12 is at the outer end of body 10 for assembly of the rock bit onto a drill string. A plurality of hardened inserts 13 are pressed into holes in the surfaces of cutter cones 11 for bearing on the rock formation being drilled. Nozzles 15 in body 10 introduce drilling fluid into the space around cutter cones 11 for cooling and carrying away formation chips drilled by the bit.

[0034] FIG. 2 is a partial longitudinal cross-section of the rock bit, extending radially from the rotational axis 14 of the rock bit through one of the three legs on which the cutter cones 11 are mounted. Each leg includes a journal pin 16 extending downwardly and radially, inwardly on the rock bit body 10. Journal pin 16 includes a cylindrical bearing surface 17 including lubrication gap 18.

[0035] Cutter cone 11 comprises an inner cavity with a cylindrical bearing surface 21. Bearing surface 21 interfaces with bearing surface 17 to form the journal bearing that supports rotation of cutter cone 11. The bit may also comprise ball bearings 24 that carry thrust loads tending to remove cone 11 from the journal pin 16 and thereby retain the cone on the journal pin.

[0036] Grease, or another appropriate lubricant, lubricates the bearing surfaces between the journal pin 16 and the cone 11. A supply of grease is provided by a grease reservoir in cavity 29. Grease is supplied to the bearing surfaces through lubricant passages 31 and 32. Grease is retained in the bearings by a radial seal 33 between cone 11 and journal pin 16. A pressure compensation subassembly, including belows 37, is included in the grease reservoir in cavity 29, and acts to maintain the pressure of the grease within a desired pressure range.

[0037] Referring now to FIG. 3A, one example of a radial seal 40 comprises a rectangular body 42 and symmetrical, curved end surfaces 44 and 46. Radial seal 40 is formed from a resilient material and may have end portions 48 formed of a second resilient material having different properties that the material forming body 42. End portions 48 are molded to body 42 along straight, symmetrical interfaces 49.

[0038] FIG. 3B shows radial seal 40 disposed within a seal gland 50 formed by a seal groove 52 and a cylindrical sealing surface 54. Radial seal 40 is compressed within seal gland 50 and forms a contact footprint 56 on a cylindrical sealing surface 54. Footprint 56 is bisected by axial centerline 58 such that linear dimensions 60 and 62 are equal. For purposes of this discussion, axial centerline 58 divides the seal into an abrasive side 64 and lubricant side 66. Axial centerline 58 may or may not mark the physical interface between the abrasive fluid on one side of the seal and the lubricating fluid on the other side of the seal.

[0039] Referring now to FIG. 3C, the contact pressure profile exerted by radial seal 40 on sealing surface 54 is represented by curve 70. Curve 70 is divided by centerline 58 into an abrasive-side area 72 and a lubricant-side area 74, which are symmetrical about centerline 58. The abrasive-side peak contact pressure 76 and the lubricant-side peak contact pressure 78 both occur at point 80, which is located on centerline 58.

[0040] Radial seal 40 thus provides a distribution of sealing contact pressure along sealing surface 54 that is symmetric about centerline 58. Seals that generate a symmetrical contact pressure distribution, such as seal 40, perform best within a narrow range of contact pressures. If the contact pressure is too high, lubricant will not be able to reach the sealing interfaces and the heat generated by sliding contact of the seal and the cone will increase. Similarly, if the contact pressure is too low, abrasive particles can enter the sealing interfaces and increase wear of both the seal and the cone. In either condition, the life of the seal will be
greatly reduced over a seal operating with proper lubrication and without abrasive particles.

[0041] Referring now to FIG. 4A, a radial seal 80 comprises a rectangular body 82 and an asymmetrical, curved end surface 84 having a protruding portion 86. Radial seal 80 is formed from a first resilient material and end portion 88 is formed of a second resilient material having different properties that the material forming body 82. End portion 88 is molded to body 82 along an asymmetrical interface 89 such that the region of end portion 88 adjacent to protruding portion 86 has a greater thickness of the second resilient material.

[0042] FIG. 4B shows radial seal 80 disposed within a seal gland 90 and a cylindrical sealing surface 94. Radial seal 80 is compressed within seal gland 90 and forms a contact footprint 96 on cylindrical sealing surface 94. Footprint 96 is bisected by axial centerline 98 such that linear dimensions 100 and 102 are equal. For purposes of this discussion, axial centerline 98 divides the seal into an abrasive side 104 and a lubricant side 106. Axial centerline 98 may or may not mark the physical interface between the abrasive fluid on one side of the seal and the lubricating fluid on the other side of the seal.

[0043] Referring now to FIG. 4C, the contact pressure profile exerted by radial seal 80 on sealing surface 94 is represented by curve 110, which illustrates that the contact pressure profile is asymmetric about centerline 98. Asymmetric end portion 88 of seal 80 helps to generate the asymmetric contact pressure profile by having an increased volume of seal material on one side of the seal. Contact pressure profile curve 110 is divided by centerline 98 into an abrasive-side 112 and a lubricant-side 114.

[0044] The area under contact pressure profile curve 110 represents the total contact pressure applied to the seal. The asymmetric contact pressure profile created by seal 80 results in a area under curve 110 on abrasive-side 112 being greater than the area under curve 110 on the lubricant-side 114. In some embodiments, the area under curve 110 on the lubricant-side is 95% of the area under curve 110 on abrasive-side 114. In some embodiments, the area under curve 110 on the lubricant-side is 75% of the area under curve 110 on abrasive-side 114. The asymmetrical contact pressure profile curve 110 translates into less contact pressure on lubricant-side 114 and more contact pressure on abrasive-side 112. The asymmetrical distribution encourages increased lubrication and reduced interaction with abrasive particles.

[0045] The peak contact pressure 116 on abrasive-side 112 is also higher than the peak contact pressure 118 on lubricant-side 114. The highest peak contact pressure may indicate the interface between the abrasive fluids and the lubricating fluids. By shifting the highest peak contact pressure toward abrasive-side 112, less of footprint 96 is exposed to abrasive fluids.

[0046] Thus, the asymmetrical contact pressure profile 110 has a peak contact pressure point 116 that is shifted toward abrasive side 104, causing a sharp increase in contact pressure on the abrasive side and a more gradual increase in contact pressure on lubricant side 106. The high contact pressure on abrasive side 104 acts to prevent abrasive particles from entering the sealing interface. The lower contact pressure profile on lubricant side 106 allows lubricants to more easily enter the sealing interface.

[0047] Some of the performance advantages of seal 80 can be seen by comparing the contact pressure distribution shown in FIG. 3C with that of FIG. 4C. By shifting the peak contact pressure 116 more toward the abrasive side of the seal, as opposed to the centered location of peak contact pressure 76, the surface area of the seal that is exposed to the abrasive fluid is reduced. Providing a lower magnitude, gradually increasing contact pressure profile on lubricant side 114, as opposed to lubricant side 74, a greater surface area of seal 80 will be exposed to lubricant. Both of these conditions allow for reduced friction between seal 80 and sealing surface 94. With reduced friction comes longer seal life and more reliable performance.

[0048] Generation of a desirable contact pressure distribution profile is not limited to seals similar to seal 80, but may be achieved as a variety of seal configurations. As illustrated by seal 80, the external geometry of the seal and/or the geometry of the internal material interface may be asymmetric. Non-composite and single material seals may also be used. The sealing surfaces on either, or both, the cone and the leg may also be shaped so as to generate an asymmetric contact pressure distribution. Further, the asymmetric contact pressure distribution is not limited to that shown in FIG. 4C and may be any distribution that provides desirable performance.

[0049] FIGS. 5A-B through 31A-B illustrate a variety of seal arrangements that provide asymmetrical contact pressure distributions. FIGS. 5A-B through 9A-B illustrate radial seals that have asymmetric external features. FIGS. 10A-B through 12A-B illustrate radial seals that have asymmetric internal features. FIGS. 13A-B through 22A-B illustrate radial seals that have a combination of internal and external asymmetrical features. FIGS. 23A-B through 26A-B illustrate radial seals having multiple asymmetrical material interfaces. FIGS. 27A-B through 31A-B illustrate symmetrical radial seals disposed within asymmetrical seal glands.

[0050] Referring now to FIGS. 5A-B through 9A-B, FIGS. 5A-9A illustrate a radial seal that has asymmetrical external features and FIGS. 5B-9B illustrate exemplary asymmetrical contact pressure distributions that are generated by each respective seal. In FIGS. 5A-8A, although only one end of each seal is shown, it is understood that the opposing end of each seal may have a different construction or the same construction as the illustrated end of the seal. FIG. 9A illustrates a full cross-section of a radial seal. In each illustration, lower edge of the seal is the grease (lubricant) side and the upper edge of the seal is the mud (abrasive drilling fluid) side.

[0051] Referring now to FIGS. 5A and 5B, radial seal 100 comprises end portion 102 that has a ridge 104 of increased thickness on the mud side of the seal so as to generate contact pressure profile 106 that is asymmetrical about centerline 108 of the seal contact footprint.

[0052] In FIGS. 6A and 6B, radial seal 110 comprises end portion 112 that has two ridges 114 of increased thickness, with the ridge on the mud side of the seal having a greater thickness than the one on the grease side. Seal 110 generates contact pressure profile 116 that is asymmetrical about centerline 118 of the seal contact footprint. 
[0053] In FIGS. 7A and 7B, radial seal 120 comprises end portion 122 that has multiple ridges 124 of increased thickness. Seal 120 generates contact pressure profile 126 that is asymmetrical about centerline 128 of the seal contact footprint.

[0054] In FIGS. 8A and 8B, radial seal 130 comprises a radial groove 132 on body 134 that reduces the volume of seal material on the grease side of the seal. Seal 130 generates contact pressure profile 136 that is asymmetrical about centerline 138 of the seal contact footprint.

[0055] In FIGS. 9A and 9B, radial seal 140 has a tapered cross-section such that end portion 142 is larger than end portion 144. End portion 144 is offset toward the mud side of the seal so as to increase sealing force on the mud side. Seal 140 generates contact pressure profile 146 that is asymmetrical about centerline 148 of the seal contact footprint.

[0056] FIGS. 1A-B through 12A-B illustrate radial seals that have asymmetric internal features. Referring now to FIGS. 10A-B through 12A-B, FIGS. 10A-12A illustrate one end of a radial seal that has asymmetric internal features found on the interface between two materials used to form the seal. FIGS. 10B-12B illustrate exemplary asymmetrical contact pressure distributions that are generated by each respective seal. Although only one end of each seal is shown, it is understood that the opposing end of each seal may have a different construction or the same construction as the illustrated end of the seal. In each illustration, lower edge of the seal is the grease (lubricant) side and the upper edge of the seal is the mud (abrasive drilling fluid) side.

[0057] In FIGS. 10A and 10B, radial seal 150 comprises end portion 152 that has asymmetrical material boundary 154 shaped so as to provide a thicker region of the end portion material on the mud side of the seal. Seal 150 generates contact pressure profile 156 that is asymmetrical about centerline 158 of the seal contact footprint.

[0058] In FIGS. 11A and 11B, radial seal 160 comprises end portion 162 that has asymmetrical material boundary 164 having two regions of increased thickness, with the thicker of the two regions on the mud side of the seal. Seal 160 generates contact pressure profile 166 that is asymmetrical about centerline 168 of the seal contact footprint.

[0059] In FIGS. 12A and 12B, radial seal 170 comprises end portion 172 that has asymmetrical material boundary 174 that has multiple regions of increased thickness. Seal 170 generates contact pressure profile 176 that is asymmetrical about centerline 178 of the seal contact footprint.

[0060] FIGS. 13A-B through 22A-B illustrate radial seals that have a combination of internal and external asymmetrical features. FIGS. 13A-22A illustrate one end of a radial seal that has asymmetrical internal and external features and FIGS. 13B-22B illustrate exemplary asymmetrical contact pressure distributions that are generated by each respective seal. In FIGS. 13A-16A and 18A-21A, although only one end of each seal is shown, it is understood that the opposing end of each seal may have a different construction or the same construction as the illustrated end of the seal. In each illustration, lower edge of the seal is the grease (lubricant) side and the upper edge of the seal is the mud (abrasive drilling fluid) side.

[0061] In FIGS. 13A and 13B, radial seal 180 comprises an asymmetrical, curved end portion 182 that also has asymmetrical, v-shaped material boundary 184. End portion 182 and boundary 184 are shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 186 that is asymmetrical about centerline 188 of the seal contact footprint.

[0062] In FIGS. 14A and 14B, radial seal 190 comprises an asymmetrical, curved end portion 192 with two ridged protrusions, wherein the protrusion that is closer to the mud side of the seal is larger. Seal 190 also comprises an asymmetrical, v-shaped material boundary 194, wherein the deepest part of the v-shape is toward the mud side of the seal. Seal 190 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 196 that is asymmetrical about centerline 198 of the seal contact footprint.

[0063] In FIGS. 15A and 15B, radial seal 200 comprises an asymmetrical, curved end portion 202 with multiple ridged protrusions, wherein the protrusion that is closer to the mud side of the seal is the largest. Seal 200 also comprises an asymmetrical, v-shaped material boundary 204, wherein the deepest part of the v-shape is toward the mud side of the seal. Seal 200 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 206 that is asymmetrical about centerline 208 of the seal contact footprint.

[0064] In FIGS. 16A and 16B, radial seal 210 comprises an asymmetrical, curved end portion 212 and a groove 213 on the lubricant side of the seal body. Seal 210 also comprises an asymmetrical, v-shaped material boundary 214, wherein the deepest part of the v-shape is toward the mud side of the seal. Seal 210 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 216 that is asymmetrical about centerline 218 of the seal contact footprint.

[0065] In FIGS. 17A and 17B, radial seal 220 comprises an asymmetrical, curved end portion 222 that is larger than opposite end portion 223. End portion 223 is offset toward the mud side of the seal so as to increase sealing force on the mud side. Seal 220 also comprises an asymmetrical, v-shaped material boundary 224, wherein the deepest part of the v-shape is toward the mud side of the seal. Seal 220 generates contact pressure profile 226 that is asymmetrical about centerline 228 of the seal contact footprint.

[0066] In FIGS. 18A and 18B, radial seal 230 comprises an asymmetrical, curved end portion 232 that also has an asymmetrical, curved material boundary 234. End portion 232 and boundary 234 are shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 236 that is asymmetrical about centerline 238 of the seal contact footprint.

[0067] In FIGS. 19A and 19B, radial seal 240 comprises an asymmetrical, curved end portion 242 with two ridged protrusions, wherein the protrusion that is closer to the mud side of the seal is larger. Seal 240 also comprises an asymmetrical, curved material boundary 244, wherein the deepest part of the end portion is toward the mud side of the seal. Seal 240 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to
generate contact pressure profile 246 that is asymmetrical about centerline 198 of the seal contact footprint.

[0068] In FIGS. 20A and 20B, radial seal 250 comprises an asymmetrical, curved end portion 252 with multiple ridged protrusions, wherein the protrusion that is closer to the mud side of the seal is the largest. Seal 250 also comprises an asymmetrical, curved material boundary 254, wherein the deepest part of the end portion is toward the mud side of the seal. Seal 250 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 256 that is asymmetrical about centerline 258 of the seal contact footprint.

[0069] In FIGS. 21A and 21B, radial seal 260 comprises an asymmetrical, curved end portion 262 and a groove 263 on the lubricant side of the seal body. Seal 260 also comprises an asymmetrical, curved material boundary 264, wherein the deepest part of the end portion is toward the mud side of the seal. Seal 260 is shaped so as to provide a thicker region of the end portion material on the mud side of the seal so as to generate contact pressure profile 266 that is asymmetrical about centerline 268 of the seal contact footprint.

[0070] In FIGS. 22A and 22B, radial seal 270 comprises an asymmetrical, curved end portion 272 that is larger than opposite end portion 273. End portion 273 is offset toward the mud side of the seal so as to increase sealing force on the mud side. Seal 270 generates contact pressure profile 276 that is asymmetrical about centerline 278 of the seal contact footprint.

[0071] FIGS. 23A-B through 26A-B illustrate radial seals having multiple asymmetrical material interfaces formed between a plurality of component material layers. FIGS. 23A-26A illustrate one end of a composite radial seal and FIGS. 23B-26B illustrate exemplary asymmetrical contact pressure distributions that are generated by each respective seal. Although only one end of each seal is shown, it is understood that the opposing end of each seal may have a different construction or the same construction as the illustrated end of the seal. In each illustration, lower edge of the seal is the grease (lubricant) side and the upper edge of the seal is the mud (abrasive drilling fluid) side.

[0072] In FIGS. 23A and 23B, radial seal 280 comprises an end portion 282 formed from two layers seal material having different properties such that the mud-side layer 283 provides a higher contact pressure than lubricant-side layer 284. Seal 280 generates contact pressure profile 286 that is asymmetrical about centerline 288 of the seal contact footprint.

[0073] In FIGS. 24A and 24B, radial seal 290 comprises an end portion 292 formed from two layers seal material having different properties such that the mud-side layer 293 provides a higher contact pressure than lubricant-side layer 294. The boundary 295 between end portion 292 layers 293 and 294 the seal body is also asymmetrical so that seal 290 generates contact pressure profile 296 that is asymmetrical about centerline 298 of the seal contact footprint.

[0074] In FIGS. 25A and 25B, radial seal 300 comprises an end portion 302 formed from two different seal materials having different properties such that the embedded region 303 has a higher elastic modulus and/or hardness than the surrounding region 304. Seal 300 generates contact pressure profile 306 that is asymmetrical about centerline 308 of the seal contact footprint.

[0075] In FIGS. 26A and 26B, radial seal 310 comprises a plurality of layers 312 of seal material having different properties arranged such that the mud-side layer 313 provides a higher contact pressure than lubricant-side layer 314. Seal 310 generates contact pressure profile 316 that is asymmetrical about centerline 318 of the seal contact footprint.

[0076] FIGS. 27A-B through 31A-B illustrate radial seals disposed within asymmetrical seal glands. The radial seals are shown as being symmetrical seals but could also be asymmetrical seals, such as those described above. FIGS. 27A-31A illustrate the radial seal disposed in a seal gland and FIGS. 27B-31B illustrate exemplary asymmetrical contact pressure distributions that are generated by each respective seal arrangement. In each illustration, lower edge of the seal is the grease (lubricant) side and the upper edge of the seal is the mud (abrasive drilling fluid) side.

[0077] In FIGS. 27A and 27B, radial seal 320 is disposed within seal gland 322 comprising seal groove 324 and engages seal surface 325. Seal surface 325 is angled, or curved, across a portion of the face of seal 320 such that the mud side of the seal is compressed more than the lubricant side of the seal. Seal 320 generates contact pressure profile 326 that is asymmetrical about centerline 328 of the seal contact footprint.

[0078] In FIGS. 28A and 28B, radial seal 330 is disposed within seal gland 332 comprising seal groove 334 and engages seal surface 335. The bottom of seal groove 334 is angled, or curved, such that the mud side of seal 330 is compressed more than the lubricant side of the seal. Seal 330 generates contact pressure profile 336 that is asymmetrical about centerline 338 of the seal contact footprint.

[0079] In FIGS. 29A and 29B, radial seal 340 is disposed within seal gland 342 comprising seal groove 344 and engages seal surface 345. Seal surface 345 and the bottom of seal groove 344 are angled, or curved, such that the mud side of seal 340 is compressed more than the lubricant side of the seal. Seal 340 generates contact pressure profile 346 that is asymmetrical about centerline 348 of the seal contact footprint.

[0080] In FIGS. 30A and 30B, radial seal 350 is disposed within seal gland 352 comprising seal groove 354 and engages seal surface 355. Seal surface 355 is angled, or curved, across the entire face of seal 350 such that the mud side of the seal is compressed more than the lubricant side of the seal. Seal 350 generates contact pressure profile 356 that is asymmetrical about centerline 358 of the seal contact footprint.

[0081] In FIGS. 31A and 31B, radial seal 360 is disposed within seal gland 362 comprising seal groove 364 and engages seal surface 365. Seal surface 365 and the bottom of seal groove 364 are angled, or curved, such that the mud side of seal 360 is compressed more than the lubricant side of the seal. Seal 360 generates contact pressure profile 366 that is asymmetrical about centerline 368 of the seal contact footprint.

[0082] An asymmetrical contact pressure profile may also be generated by an o-ring type seal. Referring now to FIG.
an asymmetric boundary 510. FIG. 34C shows seal 512 having first material 514 and second material 516 joined at an asymmetric boundary 518.

[0087] FIG. 34D shows seal 520 having first material 522 and second material 524 joined at boundary 526. Second material 524 also has flat surface 528. Although the features of FIG. 34A-B are only shown on side end of each seal, it is understood that in some applications the asymmetric features may be on more than one side of the seal. The embodiments shown are not inclusive and many other configurations and variations of asymmetric profile seals may also be created.

[0088] FIG. 35 shows a dual seal assembly 600 comprising a symmetric seal 602 and asymmetric seal 604. Seal assembly 600 creates a seal between cone 606 and leg 608 forming a barrier between a mud side 610 and a lubricant side 612. Symmetric seal 602 forms a contact pressure profile 614 along leg 608 that is symmetrical about a centerline bisecting the profile. Asymmetric seal 604 forms a contact pressure profile 616 along leg 608 that is asymmetrical about a centerline bisecting the profile.

[0089] FIG. 36 shows a dual seal assembly 620 comprising a first asymmetric seal 622 and second asymmetric seal 624. Seal assembly 620 creates a seal between cone 626 and leg 628 forming a barrier between a mud side 630 and a lubricant side 632. The first asymmetric seal 622 forms a contact pressure profile 634 along leg 628 that is asymmetrical about a centerline bisecting the profile. The second asymmetric seal 624 forms a contact pressure profile 626 along leg 628 that is asymmetrical about a centerline bisecting the profile.

[0090] While preferred embodiments of this invention have been shown and described, modifications thereof can be made by one skilled in the art without departing from the scope or teaching of this invention. The embodiments described herein are exemplary only and are not limiting by size, shape and/or directionality of the rotating body against the stationary body. Many variations and modifications of the system and apparatus are possible and are within the scope of the invention. For example, the relative dimensions of various parts, the materials from which the various parts are made, and other parameters can be varied, so long as the apparatus retain the advantages discussed herein. Accordingly, the scope of protection is not limited to the embodiments described herein, but is only limited by the claims that follow, the scope of which shall include all equivalents of the subject matter of the claims.

What is claimed is:

1. A rotary cone rock-bit comprising:
   a bit body;
   a leg extending from said bit body;
   a cone rotatably mounted to said leg;
   a first seal disposed radially between said cone and said leg;
   a footprint defining an area of contact between said first seal and said leg, wherein compression of said first seal generates a contact pressure between said first seal and said leg;

32A, an radial o-ring seal 370 has a generally circular cross-section with a flattened face 372 on one side of the seal. FIG. 32B shows seal 370 disposed within a seal gland 374 formed by a seal groove 376 and a cylindrical sealing surface 378. Face 372 of seal 370 is disposed on the mud-side of the seal gland and toward sealing surface 378. Seal 370 is compressed within seal gland 374 and forms a contact footprint 380 on cylindrical sealing surface 378. Footprint 380 is bisected by axial centerline 382 such that linear dimensions 384 and 386 are equal. For purposes of this discussion, axial centerline 382 divides the seal into an mud side 388 and a grease side 390. Axial centerline 382 may or may not mark the physical interface between the mud on one side of the seal and the grease on the other side of the seal.

[0083] Referring now to FIG. 32C, the contact pressure profile exerted by radial seal 370 on sealing surface 378 is represented by curve 392, which illustrates that the contact pressure profile is asymmetric about centerline 382. The abrupt contour change at face 372 generates a peak contact pressure 394 on the mud side 388 of centerline 382. Contact pressure profile 392 is divided by centerline 382 into a mud-side area 394 and a grease-side area 396. Although centerline 382 runs through the middle of footprint 380, it divides the area under curve 392 into a mud-side area 396 that is larger and provides a higher gradient of contact pressure than a grease-side area 398.

[0084] FIGS. 33A-33F illustrate a number of alternate embodiments of o-ring type seals having asymmetric cross-sections. FIG. 33A shows seal 460 having a flat region 462, on which, when installed, the flat region is oriented on the mud-side of the dynamic sealing interface. FIG. 33B shows seal 464 having flat sides 466 for fitting into the rectangular sides of a groove and a flat region 468 that is oriented on the mud-side of the dynamic sealing interface. FIG. 33C shows seal 470 having flat face 472, and curved face 474, which has an increased diameter. FIG. 33D shows seal 476 having flat face 478, and multiple curved faces 486, each with a different radius of curvature. FIG. 33E shows seal 488 having curved groove 490. FIG. 33F shows seal 492 having multiple flat faces 494.

[0085] In each of these seal designs, the portion of the seal that has material removed is oriented toward the mud-side of the dynamic sealing surface. The removed material creates a stress concentration that generates a peak in the contact force on the dynamic sealing surface toward the mud-side of the seal. Although the features of FIG. 33A-F are only shown on side end of each seal, it is understood that in some applications the asymmetric features may be on more than one side of the seal. The embodiments shown are not inclusive and many other configurations and variations of asymmetric profile seals may also be created.

[0086] FIGS. 34A-34D illustrate a number of alternate embodiments of composite o-ring type seals having asymmetric cross-sections or asymmetric boundaries between the two component materials. FIG. 34A illustrates seal 496 comprising a first material 498 and a second material 500 with an asymmetric material boundary 502. Boundary 502 is formed such that the depth of second material 500 is greater on one side so as to create a peak in the contact force on the mud-side of the dynamic sealing surface. FIG. 34B shows seal 504 having first material 506 and second material 508 joined at an asymmetric boundary 510. FIG. 34C shows seal 512 having first material 514 and second material 516 joined at an asymmetric boundary 518.
an axial centerline that evenly bisects said footprint into
a mud side and a grease side; and
a contact pressure profile defining the contact pressure
over said footprint, wherein the contact pressure on
the mud side of said footprint is greater than the contact
pressure on the grease side of said footprint.
2. The rotary cone rock-bit of claim 1 wherein the contact
pressure on the grease side of said footprint is less than 95% of
the contact pressure on the mud side of said footprint.
3. The rotary cone rock-bit of claim 1 wherein the contact
pressure on the grease side of said footprint is less than 75% of
the contact pressure on the mud side of said footprint.
4. The rotary cone rock-bit of claim 1 wherein the
maximum contact pressure is on the mud side of said
footprint.
5. The rotary cone rock-bit of claim 1 wherein said first
seal further comprises:
a body constructed from a first resilient material; and
a first end portion constructed from a second resilient
material, wherein said first end portion is connected to
said body along a first interface.
6. The rotary cone rock-bit of claim 5 wherein said first
end portion has an asymmetrical outer surface arranged such
that a greater volume of the second resilient material is
disposed on the mud side of said seal.
7. The rotary cone rock-bit of claim 1 further comprising
a second seal disposed radially between said cone and said
leg, wherein said second seal is adjacent to and on the mud
side of said first seal.
8. A bit for drilling a borehole into earthen formations, the
bit comprising:
a bit body;
a journal shaft extending from said bit body;
a rolling cone cutter mounted on said journal shaft and
being adapted to rotate about a cone axis;
a seal gland between said shaft and said cone and compris-
ing a first seal engaging surface on said shaft and a
second seal engaging surface on said cone;
an annular seal disposed in said gland, said annular seal
comprising: a radially inner surface sealingly engaging
said first seal engaging surface; a radially outer seal
surface sealingly engaging said second seal engaging
surface; and
a seal footprint on one of said seal engaging surfaces, said
footprint being defined by the portion of said seal
contacting said one seal engaging surface, said foot-
print having a footprint length measured axially relative
to said cone axis and being bisected by a footprint
centerline that is perpendicular to said cone axis;
wherein said seal creates a pressure profile on one of said
seal engaging surface axially along said footprint, said pressure
profile being asymmetric relative to said center-
line.
9. The drill bit of claim 8 wherein said seal divides a
lubricant side from a drilling fluid side, and wherein said
pressure profile includes a maximum pressure peak located
on said drilling fluid side.
10. The drill bit of claim 9 wherein a curve representing
the pressure profile on the lubricant side defines an area that
is less than 95% of an area defined by a curve representing
the pressure profile on the frilling fluid side.
11. The drill bit of claim 9 wherein a curve representing
the pressure profile on the lubricant side defines an area that
is less than 75% of an area defined by a curve representing
the pressure profile on the frilling fluid side.
12. The drill bit of claim 8 wherein said seal further
comprises:
a body constructed from a first resilient material; and
a first end portion constructed from a second resilient
material, wherein said first end portion is connected to
said body along a first interface.
13. The drill bit of claim 12 wherein said first end portion
has an asymmetrical outer surface arranged such that a
greater volume of the second resilient material is disposed
on the drilling fluid side of said centerline.
14. The drill bit of claim 12 wherein the first interface is
asymmetric.
15. The drill bit of claim 8 wherein said seal creates a
pressure profile on said second seal engaging surface.
16. A rotary cone rock-bit seal comprising:
a first seal in contact with a rotating surface along a first
footprint;
a first centerline through the midpoint of the first foot-
print, wherein said first centerline divides said first seal
into a drilling fluid side and a lubricant side; and
a first contact pressure profile formed between said first
seal and the rotating surface, wherein said first contact
pressure profile is asymmetric about said first center-
line.
17. The rotary cone rock-bit of claim 16 wherein said first
contact pressure profile on the drilling fluid side of said first
seal defines an area larger than an area defined by said first
contact pressure profile on the lubricant side of said first
seal.
18. The rotary cone rock-bit of claim 16 wherein said first
contact pressure profile comprises a peak contact pressure
that is located on the drilling fluid side of said first center-
line.
19. The rotary cone rock-bit seal of claim 16 wherein said
first seal is constructed of a resilient material, wherein a
majority of the resilient material is located on the drilling
fluid side of said first seal.
20. The rotary cone rock-bit seal of claim 16 wherein said
first seal is constructed of a first material and a second
material bonded along a boundary that is asymmetric about
the first centerline.
21. The rotary cone rock-bit seal of claim 16 wherein said
first seal has an asymmetric surface profile in contact with
the rotating surface.
22. The rotary cone rock-bit seal of claim 16 further
comprising:
a second seal in contact with a rotating surface along a
second footprint, wherein said second seal is adjacent
to the drilling fluid side of said first seal;
a second centerline through the midpoint of the second
footprint, wherein said second centerline divides said
second seal into a drilling fluid side and a lubricant
side; and
a second contact pressure profile formed between said second seal and the rotating surface.

23. The rotary cone rock-bit seal of claim 22 wherein said second contact pressure profile is asymmetric about said second centerline.

24. The rotary cone rock-bit of claim 23 wherein said second contact pressure profile on the drilling fluid side of said second seal defines an area larger than an area defined by said second contact pressure profile on the lubricant side of said second seal.

25. The rotary cone rock-bit of claim 23 wherein said second contact pressure profile comprises a peak contact pressure that is located on the drilling fluid side of said second centerline.

26. The rotary cone rock-bit seal of claim 23 wherein said second seal is constructed of a resilient material, wherein a majority of the resilient material is located on the drilling fluid side of said second seal.

27. The rotary cone rock-bit seal of claim 23 wherein said second seal is constructed of a first material and a second material bonded along a boundary that is asymmetric about the second centerline.

28. The rotary cone rock-bit seal of claim 22 wherein said second contact pressure profile is symmetric about said second centerline.