# United States Patent [19]

**Kern et al.**

[11] **3,807,513**

[45] **Apr. 30, 1974**


[54] **DOWNHOLE DRILLING TOOL BEARING AND SEAL ASSEMBLY**


[75] Inventors: **Loyd R. Kern**, Irving; **John H. Striegler**, Richardson, both of Tex.

[73] Assignee: **Atlantic Richfield Company**, New York, N.Y.



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[21] Appl. No.: **329,725**

[52] **U.S. Cl.** ..... **175/107**, 277/59

[51] **Int. Cl.** ..... **E21b 27/00**

[58] **Field of Search** ..... 175/107; 277/59



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*Primary Examiner*—James A. Leppink

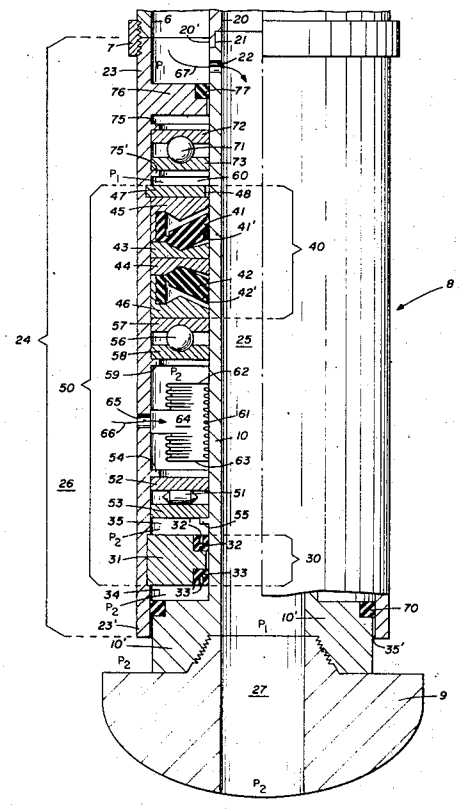
*Attorney, Agent, or Firm*—Roderick W. MacDonald



[57] **ABSTRACT**

A downhole drilling tool for use with a downhole motor and bit wherein the shaft that connects the downhole motor with the bit has a housing around the outside thereof. The housing is spaced from the shaft to define an annular chamber between the shaft and housing. In the annular chamber an inner chamber is defined by spaced apart first and second seal means. The seal means are both bidirectional acting seals. Preferably, one of the seal means is designed to take any pressure difference between the interior of the shaft and the exterior of the housing by having at least two unidirectional seal elements, at least one seal element being oriented toward the bit end of the shaft and at least one seal element being oriented toward the opposite or downhole motor end of said shaft so that fluid within the inner chamber cannot escape therefrom and fluid outside the inner chamber on either end thereof in said annular chamber cannot be forced into the inner chamber. At least one bearing means in the inner chamber.


**42 Claims, 12 Drawing Figures**



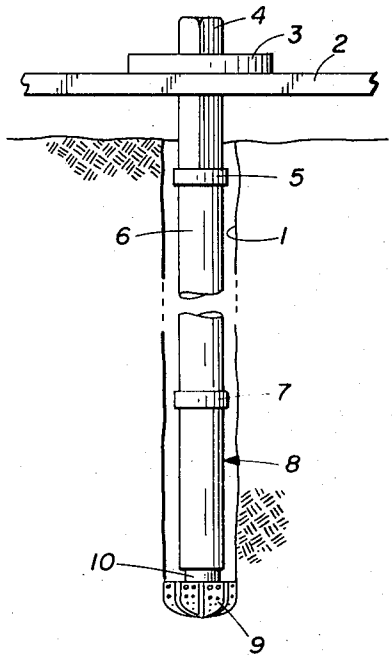



FIG. 1

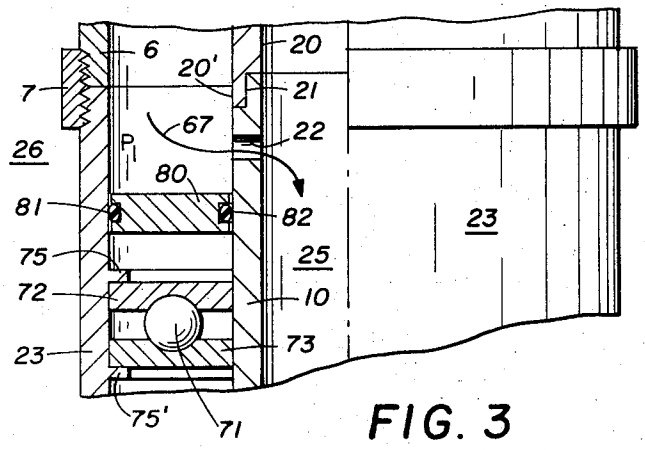



FIG. 3

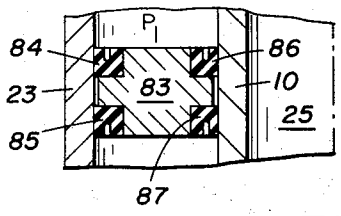



FIG. 4

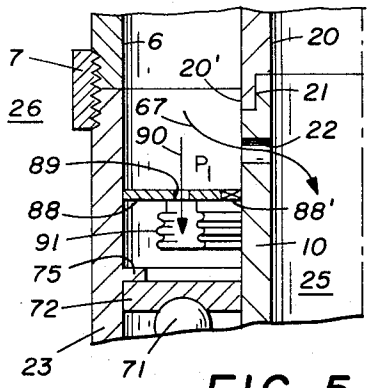



FIG. 5

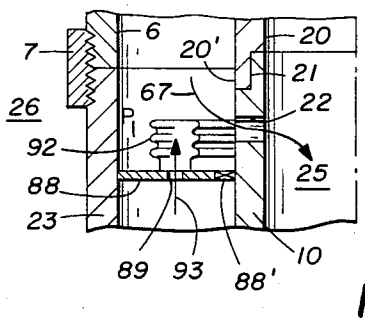



FIG. 6

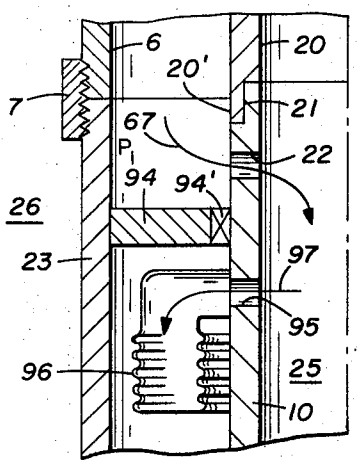



FIG. 7

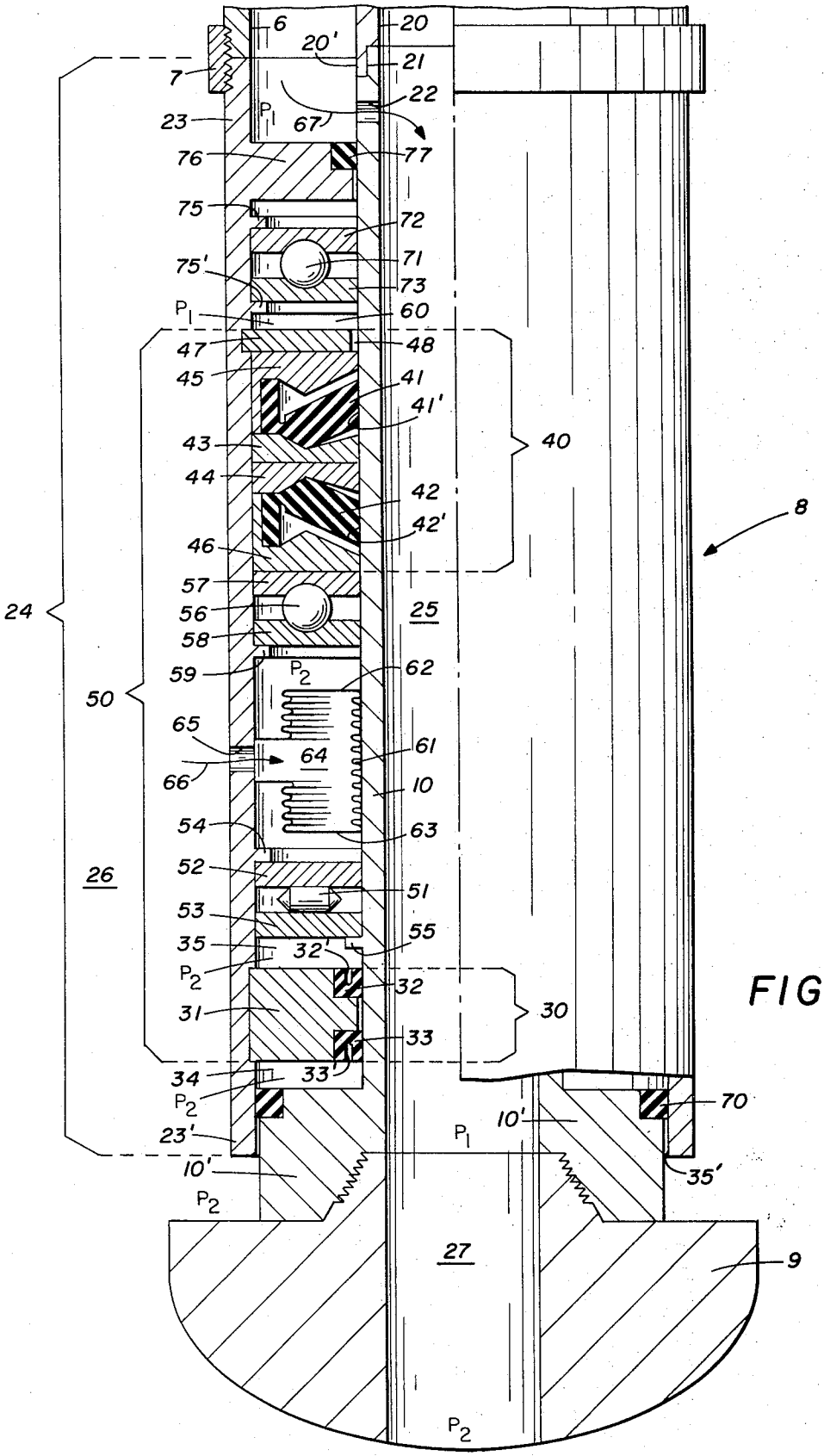

6
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20'
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22
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76
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75'
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41'
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FIG. 2

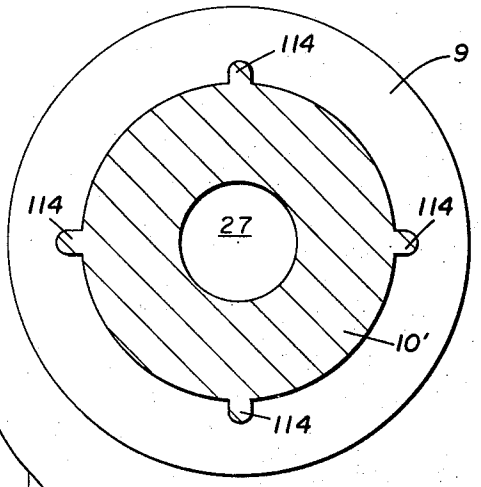

114
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114
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10'
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FIG. 9

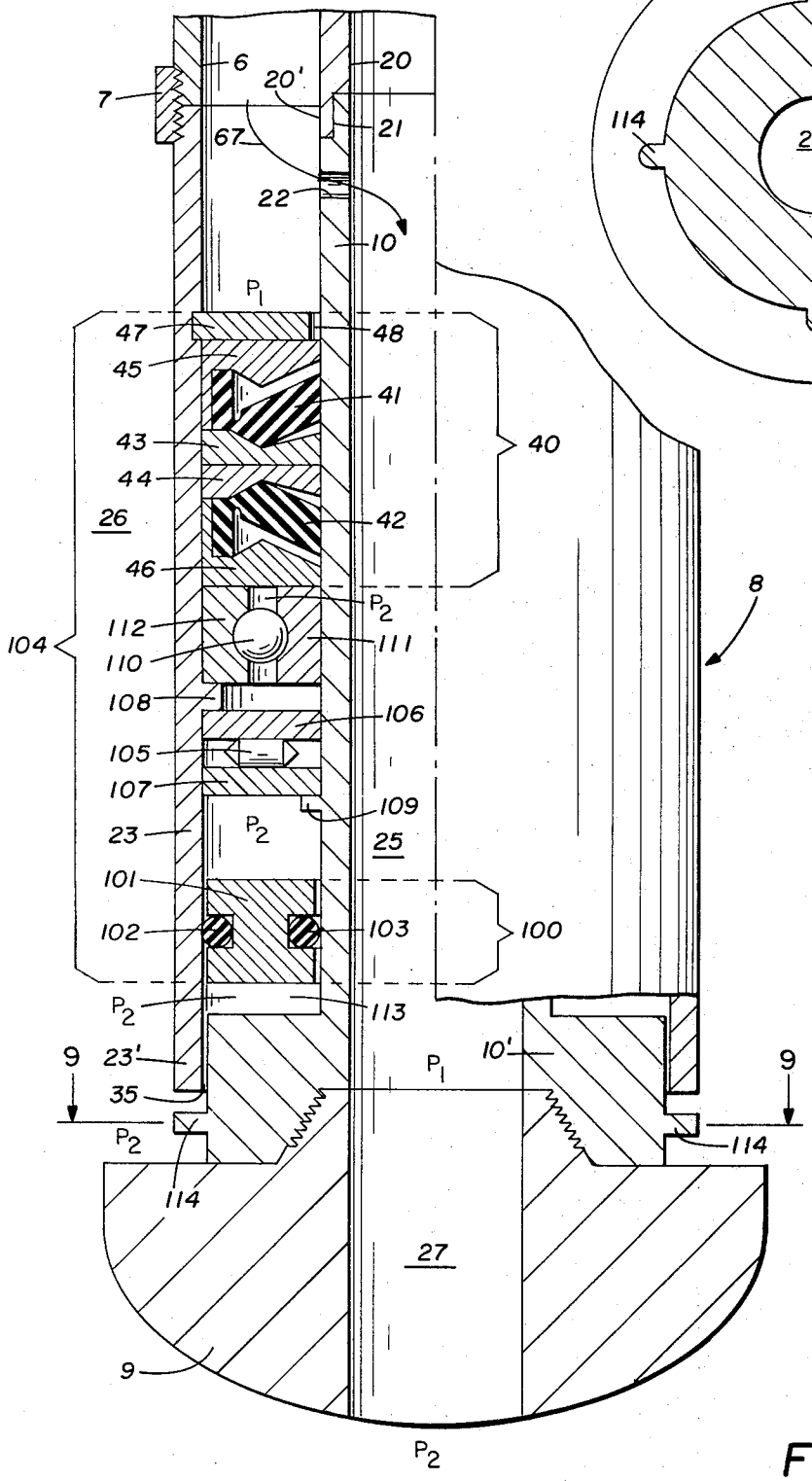

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23'
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FIG. 8

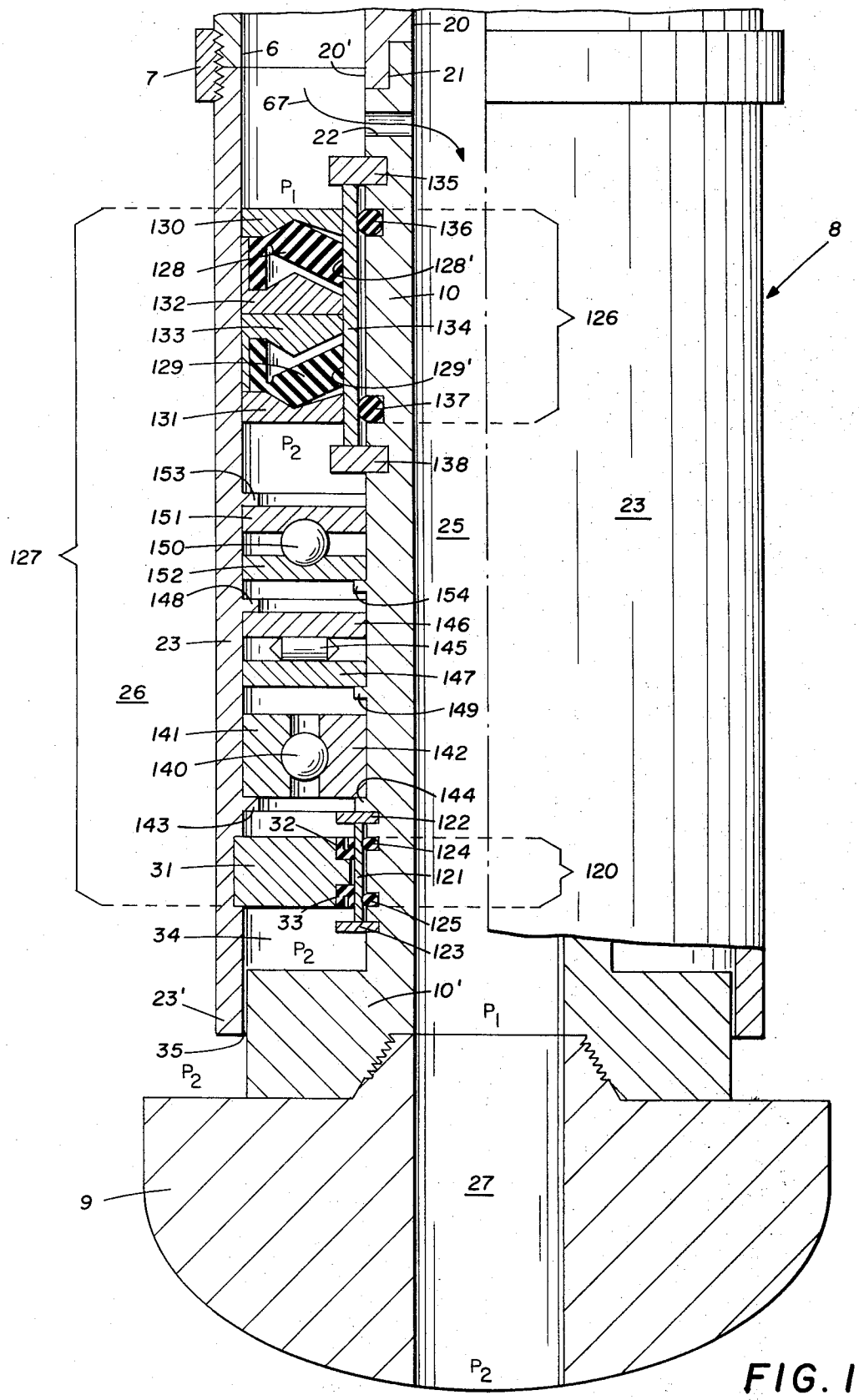

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FIG. 10

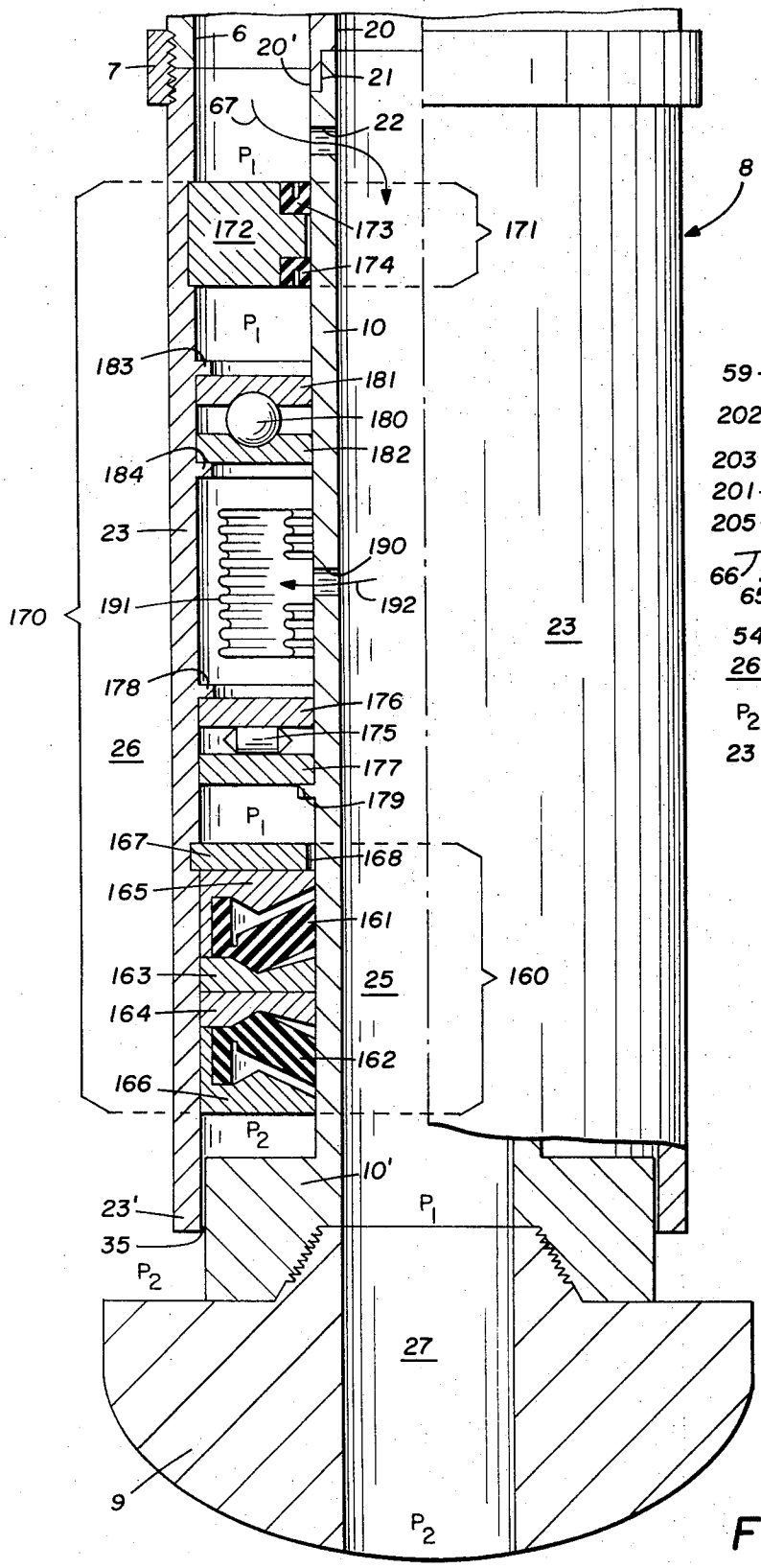

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FIG. 11

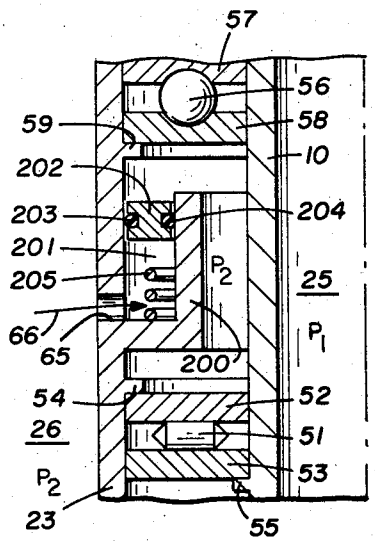

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FIG. 12

# DOWNHOLE DRILLING TOOL BEARING AND SEAL ASSEMBLY

## BACKGROUND OF THE INVENTION

For the purpose of describing and claiming this invention and for discussing the background prior art, the term "unidirectional seal element" is meant to encompass all seal elements which when in operation will perform a sealing function when forced in one direction but will not perform a sealing function when forced in the opposite direction. Such sealing elements are known in the art and variously referred to as chevron seals, U-cup seals, lip seals, and the like. "Bidirectional acting seal means" is meant to cover a seal means that performs its desired sealing function from at least two different directions, e.g., when fluid approaches the seal means from the top and/or the bottom of the seal means.

In downhole drilling tools chevron seal elements have been employed in a manner in which a plurality of the seal elements are stacked one on top of another and all seal elements are oriented in the same direction so that all perform their sealing function when a fluid approaches from one direction but not from the opposite direction. An example is U.S. Pat. No. 2,626,780, which shows a stack of chevron seal elements oriented in one direction. For example, FIG. 1 of this patent shows a chevron stack oriented downwardly so that fluid rising upwardly against the stack would force the seal elements outwardly and cause the stack to perform a sealing function in preventing the upward flowing fluid from passing by the stack, whereas fluid passing downwardly would force the seal elements inwardly and no sealing function would be performed thereby allowing downwardly flowing fluid past the stack.

## SUMMARY OF THE INVENTION

It has now been surprisingly discovered that in the context of a downhole drilling tool having an inner chamber containing both bearings and a fluid such as bearing lubricant, and at either end of which inner chamber a different fluid such as drilling fluid is present, one of the seal means at either end of the inner chamber taking any pressure differential across it such as the normal pressure drop created by the drilling fluid passing through a bit, it is vitally important to the operation of the tool that the seal means be bidirectional acting in their sealing function. It has also been found to be extremely advantageous if the seal means that is to take the pressure differential contains unidirectional seal elements and that at least two of these seal elements are oriented in opposite directions to one another so that there is at least one seal element oriented toward the bit end of the tool and at least one seal element oriented toward the downhole motor end. The other of the seal means must be bidirectional in its sealing effect and can but need not contain opposing unidirectional seal elements.

It has further been discovered that with the use of the reversed unidirectional seal elements at either or both ends of the inner chamber, it can be advantageous to employ a movable piston means in the inner chamber.

It has also been discovered that for the seal means that is not taking a substantial pressure drop a bidirectional sealing movable piston can be used as a seal means for the inner chamber.



Further, sealing surface means as hereinafter defined can be advantageously employed with either or both of the seal means which define the inner chamber, particularly in conjunction with the specific seal means which is to take the pressure drop between the inside of the tool and the outside of the tool.

Also, in accordance with this invention, additional bearing means and seal means (including a movable piston) can be employed outside the inner chamber but in the annular chamber between the shaft and housing, particularly above the seal means of said inner chamber which is closest to the downhold motor.

Accordingly, it is an object of this invention to provide a new and improved well drilling apparatus. It is another object to provide a new and improved downhole drilling tool. It is another object to provide a new and improved bearing and seal assembly for a downhole drilling tool. It is another object to provide a new and improved apparatus for sealing between two relatively moving members of the downhole tool whereby a seal means therein takes the pressure differential between the inside and outside of the tool. It is another object to provide a new and improved pressure balanced seal and bearing assembly for a downhole tool. It is another object to provide a new and improved seal means for taking a pressure differential in a downhole tool.

Other aspects, objects and advantages of this invention will be apparent to those skilled in the art from this disclosure and the appended claims.

## DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows well drilling apparatus in which this invention can be employed.

FIG. 2 shows one embodiment of this invention which employs upper and lower bidirectional acting seal means to define the upper and lower end of the inner chamber, each bidirectional seal means in this particular embodiment containing reversed unidirectional seal elements.

FIG. 3 shows another embodiment within this invention wherein a movable piston is employed as the bidirectional seal means above the inner chamber, this particular embodiment being useful in other embodiments such as FIGS. **2, 8, 10, 11,** and **12.**

FIG. 4 shows another embodiment of a movable piston which is useful in the embodiments of FIGS. **2, 3, 8, 11** and **12.**

FIGS. 5 through 7 show other embodiments of movable pistons useful in the same manner as the movable piston of FIG. 3. FIG. 8 shows another embodiment within this invention wherein the lower or second seal means for the inner chamber is a movable bidirectional sealing piston.

FIG. 9 shows a cross-section of the tool of FIG. 8.

FIG. 10 shows an embodiment within this invention wherein the seal means for the inner chamber employ sealing surface means so that a better sealing effect is achieved for each seal means.

FIG. 11 shows another embodiment within this invention wherein the lower or second seal means of the inner chamber is employed to take the pressure differential between the inside and outside of the tool in contrast to FIG. 2 wherein the upper or first seal means of the inner chamber takes this pressure differential.

FIG. 12 shows a modification of FIG. 2 as to the substitution of a movable piston for a bellows means in the

pressure adjusting mechanism of the inner chamber of FIG. 2.

More specifically, FIG. 1 shows a wellbore 1 in the earth's surface under the working floor 2 of a conventional rotary drilling rig.

Working floor 2 carries the conventional rotary table 3 which is powered by a conventional earth surface motor means (not shown) and which, when rotated, in turn rotates square kelly 4. Kelly 4 is coupled by means of coupling 5 to drill string 6 which is normally composed of a plurality of individual sections of drill pipe coupled together by couplings such as coupling 5. Drill string 6 is coupled by means of coupling 7 at its lower end to downhole tool 8 which in turn carries diamond bit 9 on shaft 10.

In operation, rotary table 3 is rotated by a surface motor and in turn rotates, respectively, kelly 4, drill string 6, tool 8, and bit 9. Tool 8 is then operated on its own to speed up the rotation of bit 9 to any desired rate for the particular drilling condition. In the case of slim hole drilling, if the very high rotational rate for the bit were to be achieved solely by rotating drill string 6 with the surface motor, catastrophic vibration of drill string 6 could be encountered. At high rotational speeds of a long drill string, the pipe tends to bounce from one side of the wellbore to the other at a faster and faster rate until catastrophic vibration sets in and results in failure of the drill string such as by twisting off one section of drill pipe from an adjacent section of drill pipe at their common coupling joint. By use of the apparatus of this invention, drill string 6 can be rotated by rotary table 3 at a rate which avoids catastrophic vibration. However, by operation of downhole tool 8, the bit is still rotated at slim hole rotation rates of at least about 400 rpm, generally from about 400 to about 3,000 rpm, in small diameter, e.g., up to about 6 inches, preferably from about 2 to about 4 inches, boreholes.

Downhole tool 8 can be located substantially any place along the length of drill string 6 but is preferably closer to the bit than the earth's surface when the borehole is deeper than the total length of the bit and tool 8. Tool 8 is generally located adjacent the bit as shown in FIG. 1. One or more tools 8 can be employed and can be spaced upwardly from the bit along the length of the drill string as desired.

Generally, any conventional downhole motor means can be employed in tool 8, such motor means being commercially available and known in the art and include downhole electric motors, turbine operated motors such as a "turbodrill," motors which are in reality a fluid pump in reverse such as a "Dyna-drill," and the like. Fluid-pump-in-reverse motors are fully and completely disclosed in U.S. Pat. No. 3,112,801, the disclosure of which is incorporated herein by reference.

FIG. 2 is a partial cross-sectional interior of tool 8 and shows bit 9 to threadably engage hollow shaft 10 which in turn engages shaft 20. Shaft 20 is powered by a conventional downhole motor means (not shown). Shaft 10 can engage shaft 20 in any manner such as by a plurality of splines 20' on shaft 20 engaging a plurality of matching slots 21 in shaft 10. Shafts 10 and 20 can be made integral but are preferably separable for ease of replacement of the downhole motor.

Shaft 20 has one or more apertures 22 therein which serve as means to pass drilling fluid around the annular chamber formed between the exterior of shaft 10 and the interior of housing 23, this annular chamber extending from the top or downhole motor end of shaft 10 (represented by slots 21) down to the lower or bit end 10' of shaft 10. The annular chamber is generally delineated in its longitudinal extent by bracket 24 and is laterally delineated to be of an annular configuration extending from shaft 10 to housing 23.

Annular chamber 24 contains the bearing and seal assemblage of the downhole tool including the seal which is to take the pressure drop between the interior 25 of shaft 10 and the exterior 26 of housing 23. This pressure drop is caused by the drilling fluid passing through and out of bit 9 as represented by pressures $P_1$ and $P_2$. Pressure $P_1$ is normally greater than pressure $P_2$, the differential between the pressures representing the pressure drop experienced by the drilling fluid as it passes through the interior conduit 27 of bit 9 and across the bit face. Thus, the drilling fluid in the upper (downhole motor) end of annular chamber 24 and in the interior 25 of shaft 10 is at the higher pressure $P_1$ whereas the drilling fluid on the outside of bit 9 and the outside bit end 23' of housing 23 is at the lower pressure $P_2$. A seal means in annular chamber 24 must take this pressure differential, i.e., must maintain the pressure differential so that on one side of the seal means is the higher pressure $P_1$ while on the other side of the seal means is the lower pressure $P_2$. This pressure differential must be maintained even though the shaft 10 and housing 23 are moving relative to one another thereby requiring a dynamic seal between these two members.

Annular chamber 24 contains a first, upper seal means denoted by bracket 40 and a second, lower seal means denoted by bracket 30. Second seal means 30 is composed of an annular ring 31 which is fixed to the inner surface of housing 23 and carries on its inner (shaft-facing) surface at the upper and lower corners thereof unidirectional seal elements 32 and 33. More than two seal elements can be used if desired. These seal elements in FIG. 2 are represented as resilient, e.g., rubber, U-cup rings. Note that seal element 32 is oriented in a direction opposite to seal element 33 in that opening 32' is oriented toward the downhole motor end of annular chamber 24 whereas opening 33' is oriented toward the bit end of annular chamber 24. Thus, drilling fluid entering zone 34 by way of space 35' between the exterior of shaft bit end 10' and the interior of housing bit end 23' will meet seal element 33, enter opening 33', and force 33 against shaft 10 to effectively seal out drilling fluid and to prevent drilling fluid from passing upwardly past seal element 33. Seal element 32, being a unidirectional seal element, would not seal out drilling fluid passing upwardly from zone 34 past block 31. Seal element 32, however, will prevent fluid such as lubricant which may be in zone 35 and which tends to pass downwardly toward zone 34 because lubricant will fill opening 32' and force seal element 32 against shaft 10. Thus, by the use of reversed unidirectional seal elements on block 31 fluid is prevented from passing in either direction past block 31. This has been found to be extremely advantageous in the operation of this invention as will be explained in more detail hereinafter.

First seal means 40 is placed near the downhole motor end of annular chamber 24 and, like second seal means 30, contains at least two unidirectional acting seal elements at least one of the seal elements being oriented to stop fluid which is moving in annular chamber

24 toward the bit end of that annular chamber and at least one other of the unidirectional seal elements being oriented to stop fluid which is moving in annular chamber 24 toward the downhole motor end of that annular chamber. More specificially, first seal means 40 is composed of two resilient lip seal elements 41 and 42 (more than two can be used if desired), seal element 41 being oriented toward the downhole motor end of annular chamber 24 and seal element 42 being oriented toward the bit end of annular chamber 24. Both seal elements 41 and 42 have matching rigid, e.g., metal, back-up or support rings 43 and 44, respectively, for one side of the lip seal. Seal elements 41 and 42 also have rigid, e.g., metal, two-sided support rings 45 and 46, respectively, which complement rings 43 and 44 so that seal elements 41 and 42 are surrounded on three sides by a support member thereby leaving only the sealing surface 41′ and 42′ of seal elements 41 and 42, respectively, open for contact with a nonsupporting member such as shaft 10. These support rings 43 through 46 distinguish lip seal elements 41 and 42 from conventional chevron seals and this combination of members provides a very effective dynamic seal means since, in operation, shaft 10 will be rotating at a different rate of speed than housing 23. The combination of rings 43 and 45 and the combination of rings 44 and 46 can each be considered to be a single rigid support member. Annular ring 47 is fixed to housing 23 and provides an upper stop for support member 25 and an opening 48 by which fluid from the downhole motor end of annular chamber 24 can reach support 45 and seal element 41.

Second (lower or bit end) and first (upper or downhole motor end) seal means 30 and 40, respectively, define the lower and upper ends, respectively, of inner chamber 50. Inner chamber 50 is fully contained within longer annular chamber 24 and is also of an annular configuration extending laterally from the outer surface of shaft 10 to the inner surface of housing 23. Inner chamber 50 contains at least one bearing means as represented in FIG. 1 by roller bearings 51 contained between upper and lower races 52 and 53, respectively, which in turn are fixed in place by shoulders 54 and 55, respectively, to make the roller bearings act as thrust bearings which transmit force between housing 23 and shaft 10, and vice versa. Other bearings can be employed in inner chamber 50 such as ball bearings 56 which are contained between upper and lower races 57 and 58, respectively, race 57 abutting support member 46 and race 58 abutting support member 59. The assemblage for ball bearings 56 can be a plurality of individual ball bearing units (bearings and races) serving as thrust bearings and/or lateral bearings, lateral bearings being more specifically disclosed in FIG. 8, reference numerals 110–112.

Since seal element 41 is oriented toward the downhole tool end of inner chamber 50 any fluid in zone 60 will not pass by seal element 41 and pressure $P_1$ will obtain in zone 60. Similarly, pressure $P_2$ will obtain in zone 34. Zones 34 and 60 are outside of inner chamber 50.

It has been found that lip seal elements such as those shown for first seal means 40 are superior to other unidirectional seal elements for performing a dynamic sealing function while taking a pressure drop thereacross. Thus, in FIG. 2, in accordance with a preferred embodiment of this invention, the pressure drop between $P_1$ and $P_2$ is taken across first seal means 40 so that the pressure obtaining within inner annulus 50 in FIG. 2 is $P_2$.

As a safety measure, an internal pressure regulating means can be used in inner chamber 50 to insure that pressure $P_2$ will be maintained in that inner chamber. To obtain this result a movable piston means in the form of a double-acting, annular bellows 61 is fixed to the interior of housing 23, bellows 61 having upper and lower piston means 62 and 63, respectively, which move upwardly and downwardly in response to pressure variations obtaining outside housing 23 in area 26. The annular interior 64 of bellows 61 is in open communication by way of at least one aperture 65 through housing 23 to the outside of housing 23 thereby admitting drilling fluid at pressure $P_2$ to interior 64 shown by arrow 66. Bellows 61 therefore is expandable and contractible and is operatively responsive to pressure $P_2$ acting on the outside of housing 23 thereby maintaining by way of expansion or contraction the pressure within inner chamber 50 at the same value of $P_2$ that is acting outside of housing 23 at any given time. Accordingly, the pressure above support member 45 is $P_1$ while the pressure below support member 46 is $P_2$, first seal means 40 thereby taking the pressure drop between the interior of shaft 10 and the exterior of housing 23, this pressure drop being representative of the pressure drop experienced by the drilling fluid as it passes through bit channel 27. Other movable piston means can be employed in lieu of bellows 61 as shown by FIG. 12. Bellows 61 can be operatively connected to the interior of shaft 10 as shown by FIG. 11 if the pressure differential between $P_1$ and $P_2$ is taken over the second or lower seal means (seal means 160 in FIG. 11).

It is important that first and second seal means 40 and 30 both be bidirectional acting seals. It is even more helpful if the pressure drop seal has reversed unidirectional seal elements. These statements are made because it has been discovered that in the normal situation wherein inner chamber 50 is liquid full of lubricant, upon passing tool 8 from the earth's surface to the bottom of a wellbore the temperature differential experienced by the tool as it passes to the bottom of the wellbore, the temperature at the bottom of the wellbore normally being substantially higher than the temperature at the surface of the earth, causes the fluid within inner annulus 50 to expand and, without seal elements 42 and 32, for example, some fluid is lost from inside inner chamber 50. When tool 8 reaches the bottom of the wellbore drilling is started together with commencement of circulation of drilling fluid from the earth's surface down the interior of the pipe string 6 through aperture 22 as shown by arrow 67 into the interior of shaft 10 through bit 9 and into annulus 26 between the exterior of housing 23 and the inner wall of wellbore 1. After reaching a dynamic equilibrium during drilling, the circulating drilling fluid actually cools down the remaining fluid in inner chamber 50 thereby contracting that remaining fluid and leaving inner chamber 50 less than liquid full. When inner chamber 50 is less than liquid full, first seal means 40 is no longer supported with liquid under pressure within inner chamber 50 and seal means 40 then has to support the entire hydrostatic head of drilling fluid which is formed by the column of liquid drilling fluid extending from seal means 40 to the surface of the earth, normally a length of thousands of feet. Thus, seal means 40 is ex-

posed to a tremendous weight of drilling fluid and this substantially decreases the operating life of that seal means. By employing bidirectional acting seal means **30** and **40,** fluid within inner chamber **50** is prevented from escaping when tool **8** is heated by being lowered into the wellbore. Thus, inner chamber **50** is maintained liquid full when drilling is commenced, and when dynamic equilibrium during drilling is achieved and tool **8** cooled by the circulating drilling fluid. At the same time fluid which is deleterious to the wearing life of the bearing, e.g., drilling fluid, is prevented from entering inner chamber **50.** Even better sealing is obtained if the seal means that is to take the pressure drop not only is bidirectional acting but also is that species of bidirectional acting seal means which has at least two reversed unidirectional seal elements. Inner chamber **50** is maintained liquid full of lubricant at equilibrium drilling conditions so that the main bearings in the chamber are submerged in lubricant at all times and inner chamber **50** is liquid full for hydraulic support of seal means **30** and **40** at all times. By following this teaching an extremely long life is realized for the bearings in inner chamber **50** and for seal means **30** and **40,** especially for the particular seal means that takes the pressure drop between $P_1$ and $P_2$.

Thus, it is obvious that movable piston means **61** is optional and not a necessity, although its employment is useful for insuring that inner chamber **50** is always liquid full.

Face seal **70** between shaft bit end **10'** and housing bit end **23'** is also optional since such face seals tend to leak somewhat and do not serve as perfect a sealing function as bidirectional seal means **30.** As shown in FIG. **8,** seal **70** can be eliminated.

Other optional equipment in FIG. **1** is ball bearings **71** with their races **72** and **73** between shoulders **75'** and **75,** respectively, and shoulder **76** with its face seal **77.** Besides seal **70,** bearings **71** and their associated equipment, shoulder **76,** and face seal **77** can be completely eliminated, as shown by FIG. **8,** and the advantageous results of this invention as above-described still achieved with the remaining first and second seals and the bearings within inner chamber **50.**

The lip seal elements **41** and **42** must be elastic, preferably rubber, and can contain a lubricant which can be solid and/or liquid. The lip seal elements preferably also contain a plurality of layers of fibers, at least one layer of fibers being composed of porous fibers that act as a wick for moving liquid lubricant from the interior of the seal element to the zone of contact between the seal element and shaft **10,** and at least one other layer of fibers being composed of fibers which have a substantially greater tensile strength than the porous fibers.

The unidirectional seal elements in seal means **30** and **40** can be carried by housing **23** to seal against shaft **10** as shown in FIG. **1** or can be carried by shaft **10** to seal against housing **23,** if desired.

The unidirectional seal elements in seal means **30** or **40** can be reversed in their relation to one another as shown in FIG. **10,** reference numerals **128** and **129,** and the desired bidirectional sealing of this invention still achieved.

Bellows **61** is double-acting in that piston means **62** and **63** are movable at the same time so that the movable piston means as a whole as represented by bellows **61** is movable toward both the bit end and the downhole motor end of annular chamber **24** at the same time and also movable away from both the bit end and the downhole motor end of annular chamber **24** at the same time.

FIG. **3** shows a modification of the tool of FIG. **2** wherein shoulder **76** and face seal **77** are deleted and in their place is substituted a movable piston means **80** which is composed of a movable annular ring which extends in annular chamber **24** from shaft **10** to housing **23** and which carries seal means, e.g., O-rings, **81** and **82** at the sealing interface between the housing and ring and the sealing interface between the ring and shaft, respectively. In the embodiment of FIG. **3,** should lubricant be employed below piston **80** the drilling fluid pressure above that piston will continuously force that piston downwardly. Should any lubricant leak out of the chamber between piston **80** and member **47** of FIG. **2,** that piston will move downwardly to insure that lubricant is continuously forced into the vicinity of ball bearings **71.**

FIG. **4** shows a movable piston which is composed of an annular ring **83** extending between shaft **10** and housing **23** but instead of carrying single O-rings **81** and **82** as shown in FIG. **3** carries two annular unidirectional acting seal elements **84** and **85** between housing **23** and ring **83** and two additional unidirectional acting seal elements **86** and **87** between ring **83** and shaft **10,** the seal elements **84** and **85** being oriented in opposite directions and seal elements **86** and **87** being oriented in opposite directions so that seal elements **84** and **86** are oriented toward the downhole motor end of annular chamber **24** and seal elements **85** and **87** are oriented toward the bit end of annular chamber **24.**

FIG. **5** shows a modification of FIG. **3** wherein instead of employing a movable annular ring **80** a fixed annular ring **88** with face seal **88'** is employed between shaft **10** and housing **23,** ring **88** having an aperture **89** therein through which drilling fluid can pass, as shown by arrow **90,** into the interior of an annular piston means **91** which is itself an expandable and contractible bellows.

FIG. **6** shows a modification of FIG. **5** wherein bellows **91** of FIG. **5** is eliminated and a new piston means represented by bellows **92** is employed on the upper side of fixed member **88** so that fluid below member **88** can pass through aperture **89** into the interior of bellows **92** as shown by arrow **93.** Thus, in FIG. **5** piston means **91** is operatively responsive to pressure acting above member **88** whereas in FIG. **6** piston means **92** is operatively responsive to pressure acting below member **88.**

Yet another modification of FIG. **3** is shown in FIG. **7** wherein movable ring **80** of FIG. **3** is omitted and a fixed ring **94** with face seal **94'** substituted therefor. In this modification shaft **10** contains at least one aperture **95** placed below member **94.** An annular piston means in the form of single acting bellows **96** is placed on shaft **10** around aperture or apertures **95** so that drilling fluid can pass by way of aperture **95** into the interior of bellows **96** as shown by arrow **97** thereby making piston means **96** operatively responsive to pressure acting on the inside of shaft **10.**

FIG. **8** shows a modification of the apparatus of FIG. **2** wherein first seal means **40** is retained as shown in FIG. **2** and the pressure differential between pressure $P_1$ and $P_2$ is taken across that seal means **40.** However, second seal means **30** of FIG. **2** is eliminated and substi-

tuted therefor is a movable piston means **100** which is composed of an annular ring **101** having seal elements, e.g., O-rings, **102** and **103** at the sealing interface between housing **23** and ring **101** and at the sealing interface between ring **101** and shaft **10,** respectively. At least one bearing means is contained within the inner chamber **104** defined as to its outer limits by seal means **40** and **100.** As with any embodiment of this invention, any particular combination of one or more bearing means can be employed. For example, in this particular embodiment roller bearings **105** between races **106** and **107** which in turn are between shoulders **108** and **109** are employed in combination with lateral roller bearings **110** between races **111** and **112.**

Movable piston **101** of FIG. **8** is employed as a substitute for bellows **61.** Piston **101** together with seal elements **102** and **103** is a bidirectional seal means equivalent in sealing operation to second seal means **30** of FIG. **2** especially when the pressure drop between $P_1$ and $P_2$ is taken across seal means **40** and not across seal means **100.** Thus, the bidirectional sealing effect of seal means **30** of FIG. **2** is also achieved with seal means **100** and, at the same time, the pressure-adjusting effect of bellows **61** is accomplished for the interior of inner chamber **104.**

The use of seal means **100** with the consequent elimination of bellows **61** is advantageous in that aperture or apertures **65** of FIG. **2** are eliminated together with the possibility that these apertures can become plugged with rock cuttings which are carried from the bottom of the bit upwardly past aperture **65** by the drilling fluid.

Since bit end **10'** is moving relative to bit end **23',** spacing **35** therebetween will be self-cleaning should any cuttings try to pass into and through space **35** into zone **113.** Thus, the conduit **35** by which drilling fluid passes to maintain pressure $P_2$ in inner chamber **104** in the embodiment of FIG. **8** is self-cleaning and less likely to become plugged with rock cuttings than aperture **65** of FIG. **2.** To help assure the cleaning of this conduit **35,** spaced apart fins **114** can be carried around the periphery of bit end **10'** to knock cuttings that attempt to enter conduit **35** away from that conduit and back out into zone **26** where the drilling fluid will pick up the cuttings and carry them upwardly through the annulus between the drill pipe and wellbore to the earth's surface for normal disposal.

Movable piston **101** can readily be employed in lieu of seal means **30** of FIG. **2** because seal means **100** is not taking the pressure drop between $P_1$ and $P_2$. A similar movable piston means preferably is not substituted for seal means **40** when that seal means is taking the pressure drop between $P_1$ and $P_2$. If the pressure drop between $P_1$ and $P_2$ were to be taken by the lower seal means, i.e., the seal means closest to the bit, movable piston **101** could not then be employed but rather a seal means such as seals **30** or **40** of FIG. **2,** preferably seal **40,** would then be employed. This will be discussed in greater detail with regard to FIG. **11** wherein the lower or bit end seal means is specially designed to take the pressure drop between $P_1$ and $P_2$.

Bearings **71** and shoulder **76** of FIG. **2** can be employed above member **47** in FIG. **8** if desired, these parts being optional in both FIGS. **2** and **8.** Similar reasoning applies to face seal **70** of FIG. **2.** In addition, instead of shoulder **76** of FIG. **2,** the movable pistons of FIGS. **3** through **7** could also be employed in the embodiment of FIG. **8,** if desired, although such is not required for the operation of this invention.

FIG. **9** shows a cross section of the apparatus of FIG. **8** taken through fins **114** and shows the fins to be spaced apart at about 90° intervals and of rounded configuration. Any desired spacing and configuration can be employed so long as the fins serve the function of knocking solid cuttings away from the entrance to conduit **35.**

FIG. **10** shows a modification wherein sealing surface means are employed between the sealing elements of the first and second seal means that define the extent of the inner chamber. Such sealing surface means are applicable to either or both of the first and second seal means of FIGS. **2, 10** and **11,** and are applicable to the upper seal means **40** of FIG. **8.**

More specifically, second seal means **120** of FIG. **10** employs block **31** and unidirectional seal elements **32** and **33** of FIG. **2.** However, seal elements **32** do not bear directly upon the outer surface of shaft **10** as in FIG. **2,** but rather bear upon an annular second sealing surface means **121** which is carried between upper and lower stops **122** and **123,** respectively. Thus, second sealing surface means **121** is carried by shaft **10** but spaced from shaft **10** and is additionally carried by shaft **10** in a sealed manner in that O-ring seal means **124** and **125** are fixed between shaft **10** and second sealing surface means **121.**

First seal means **126** which defines the upper end of inner chamber **127** is composed of two annular lip seal elements **128** and **129** oriented in opposite directions to one another and each having single-sided support members **130** and **131** together with complementary double-sided support members **132** and **133** thereby forming a three-sided support configuration and leaving only sealing surfaces **128'** and **129'** open to contact an outside member. In this embodiment, as with second seal means **120,** the seal elements do not actually contact shaft **10** but rather contact a first sealing surface means **134** which is carried by shaft **10** between shoulders **135** and **138.** Thus, annular first sealing surface means **134** is carried by but spaced from shaft **10.** Means **134** is carried in the same sealed manner as second sealing surface means **121** in that O-ring seal means **136** and **137** are disposed between and in contact with first sealing surface means **134** and shaft **10.**

Both the first and second sealing surface means are laterally movable in a sealed manner with respect to its carrying member, i.e., shaft **10,** so that each sealing surface maintains substantially full contact with the unidirectional seal elements **32, 33, 128,** and **129,** notwithstanding any lateral displacement of the housing **23,** shaft **10,** or both the housing and the shaft, thereby substantially increasing the effectiveness of the seal between the seal elements carried by housing **23** and shaft **10.** The use of a movable sealing surface as shown for both seal means **120** and **126** of FIG. **10** is preferably employed for the particular seal means that is used to take the pressure drop between $P_1$ and $P_2$. Thus, a movable sealing surface may be employed with only one of the sealing means defining the inner chamber, that particular sealing means being the one that is taking the pressure drop between $P_1$ and $P_2$.

If the seal means **120** and **126** of FIG. **10** are carried by shaft **10** instead of housing **23** as shown in FIG. **10,** then sealing surface means **121** and **134** will be carried

by housing 23 instead of shaft 10. Of course, if desired, in any of the FIGURES, one seal means could be carried by the shaft while the other seal means is carried by the housing.

Like FIG. 8, FIG. 10 can be modified as to additional bearing means, seal means, movable pistons, and the like, as shown in FIGS. 2 through 7, and 12.

Inner chamber 127 contains lateral ball bearings 140 between races 141 and 142 which rest upon shoulders 143 and 144, respectively. This chamber also contains thrust bearings in the form of roller bearings 145 between races 146 and 147 which are held between shoulders 148 and 149, respectively, and ball bearings 150 between races 151 and 152 which are held between shoulders 153 and 154, respectively.

FIG. 11 shows a modification wherein the second seal means denoted by bracket 160, i.e., the seal means closest to the bit end of the annular chamber, takes the pressure drop between $P_1$ and $P_2$ and therefore is composed of two lip seal elements 161 and 162 oriented in opposite directions with their complementary one-sided support means 163 and 164 and two-sided support means 165 and 166 together with stop ring 167 with its aperture 168.

The upper end of inner chamber 170 is defined by a first seal means denoted by bracket 171 which is composed of an annular ring 172 carried by housing 23 and having opposite acting unidirectional seal elements 173 and 174 at the interface between ring 172 and shaft 10, the pressure being $P_1$ on the upper and lower sides of second seal means 171. Inner chamber 170 can contain any desired arrangement of bearings such as roller bearings 175 between races 176 and 177 which are fixed between shoulders 178 and 179, respectively, and ball bearings 180 between races 181 and 182 which are fixed between shoulders 183 and 184, respectively.

Since first seal means 171 does not take the pressure drop between $P_1$ and $P_2$, inner chamber 170 can be at pressure $P_1$ so that at least one aperture 190 in shaft 10 in between seals 160 and 171 can be employed and a movable piston means 191 connected to aperture 190 and carried in inner chamber 170. Thus, drilling fluid in the interior of shaft 10 can pass through aperture 190 into the interior of piston means 191 (in the case of FIG. 11 a double-acting bellows) as shown by arrow 192 so that movable piston means 191 is operatively responsive to the pressure acting on the inside of shaft 10. The pressure in inner chamber 170 can be at pressure $P_1$ only when the pressure drop between $P_1$ and $P_2$ is taken by the lower or first seal means as shown in FIG. 11. If the pressure drop between $P_1$ and $P_2$ is taken by the upper or first seal means as shown in FIG, 2, inner chamber 170 must be at pressure $P_2$ as shown in FIGS. 2, 8 and 10.

Since first seal means 171 does not take the pressure drop between $P_1$ and $P_2$, ring 172 can readily be replaced by a movable piston means in the same manner as disclosed in FIG. 8 wherein movable piston means 101 was used to replace ring 31 of FIG. 2. As with piston 101 of FIG. 8, piston 83 of FIG. 4 could be employed as the movable piston in FIG. 11. If a movable piston is employed in lieu of ring 172, the piston means in the inner chamber (bellows 191 in inner chamber 170) can be eliminated in the same manner as shown in FIG. 8. This is so because a movable piston in place of ring 172 will be forced downwardly by drilling fluid above the piston and the pressure in inner chamber 170 will be maintained at $P_1$ without the aid of bellows 191.

FIG. 12 shows a modification of FIG. 2 wherein bellows 61 is replaced by an L-shaped annular member 200 carried on the interior of housing 23 to define an annular cylinder 201 which contains an annular movable piston 202. Piston 202 has seal means 203 and 204 at the sealing interfaces between housing 23 and the piston, and between the piston and member 200, respectively. Piston 202 is biased upwardly by a spring means 205 so that the pressure in the inner chamber is incrementally greater than the pressure outside of housing 23 and if fluid leaks in any direction it will be from the inner chamber to the area 26 outside of housing 23. Thus, drilling fluid from outside of housing 23 can enter through aperture 65 as shown by arrow 66 in the same manner as described hereinabove with respect to FIG. 2. Member 200 can be carried on shaft 10 with communication with the interior of shaft 10, in which case member 200 and its piston 202 can be used to replace bellows 191 in FIG. 11.

As can be seen from the foregoing, one, or both, or neither seal means in a given tool can contain unidirectional seal elements, but both seal means must be bidirectional acting. Also, when a particular seal means has two sealing interfaces, e.g., piston 101 of FIG. 8 having a first sealing interface between seal element 102 and housing 23 and a second sealing interface betwen seal element 103 and shaft 10, a sealing surface means as shown in FIG. 10 can be employed in one or both sealing interfaces, preferably both.

Reasonable variations and modifications are possible within the scope of this disclosure without departing from the spirit and scope of this invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In a well drilling tool whereby a drill bit is rotated in the earth to drill a wellbore, the improvement comprising a downhole motor means, a shaft means connected at one end to said motor, the other end of said shaft being adapted to carry a drill bit, a housing carried concentric with said shaft and spaced therefrom thereby providing an annular chamber between said housing and said shaft, at least one bearing means in said annular chamber, a bidirectional acting seal means in said annular chamber on one side of said at least one bearing means, another bidirectional acting seal means in said annular chamber on the opposite side of said at least one bearing means, said two spaced apart seal means thereby defining the limits of an inner chamber within said annular chamber, said inner chamber containing said at least one bearing means, whereby fluid contained within said inner chamber is prevented from passing by either of said seal means into portions of said annular chamber which are external to said inner chamber and fluid contained in said annular chamber external to said inner chamber cannot pass by either of said seal means into said inner chamber, and a movable piston means associated with said inner chamber and operatively responsive to pressure acting outside said inner chamber.

2. A tool according to claim 1 wherein a first of said two bidirectional acting seal means is adapted to take any pressure differential between the interior of said shaft and the exterior of said housing by carrying at

least two unidirectional acting seal elements at the sealing interface, at least one of said unidirectional seal elements being oriented to stop fluid which is moving in said annular chamber toward one side of said first seal means, at least one other of said unidirectional seal elements being oriented to stop fluid which is moving in said annular chamber toward the opposite side of said first seal means, said first seal means being carried by one of said housing or shaft.

**3.** A tool according to claim **2** wherein said second seal means also carries at least two unidirectional acting seal elements, at least one of said seal elements being oriented to stop fluid which is moving toward one side of said second seal means, and at least one other unidirectional seal element being oriented to stop fluid which is moving toward the opposite side of said second seal means, said second seal means being carried by one of said housing or shaft.

**4.** A tool in accordance with claim **1** wherein at least one additional seal means is carried in said annular chamber but externally of said inner chamber, and at least one additional bearing means is carried in said annular chamber between said at least one additional seal means and said inner chamber, said at least one additional bearing means also being external to said inner chamber.

**5.** A tool in accordance with claim **1** wherein said movable piston means is carried in said inner chamber and is operatively responsive to pressure acting on the outside of said inner chamber.

**6.** A tool in accordance with claim **5** wherein said movable piston means is a pressure expandable and contractible bellows means whose interior is openly connected to the exterior of said housing.

**7.** A tool in accordance with claim **6** wherein said bellows means is double acting in that it is movable toward both the bit end and the downhold motor end of said annular chamber at the same time, and movable away from both the bit end and the downhole motor end of said annular chamber at the same time.

**8.** A tool in accordance with claim **5** wherein said movable piston means is an annular ring carried in an annular cylinder, said cylinder being disposed in said inner chamber on said housing, said cylinder being open to the exterior of said housing in a first location and open to said inner chamber in a second spaced apart location and said annular ring in between said first and second locations, and seal means between said ring and cylinder and between said ring and housing.

**9.** A tool in accordance with claim **1** wherein said movable piston means is carried in said inner chamber, is operatively responsive to pressure inside said shaft, and any pressure differential between the interior of said shaft and the exterior of said housing is taken across said second seal means.

**10.** A tool in accordance with claim **9** wherein said movable piston means is a pressure expandable and contractible bellows means whose interior is openly connected to the interior of said shaft.

**11.** A tool according to claim **9** wherein said second seal means has at least two oppositely oriented unidirectional seal elements.

**12.** A tool in accordance with claim **11** wherein said seal elements in said second seal means are elastic lip seals, each lip seal being supported by a rigid support member.

**13.** A tool in accordance with claim **11** wherein a second sealing surface means carried by but spaced from the member which does not carry said second seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said second seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**14.** A tool in accordance with claim **13** wherein a first sealing surface means carried by but spaced from the member which does not carry said first seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said first seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**15.** A tool in accordance with claim **3** wherein said first seal means is nearest the downhole motor end of said annular chamber and said second seal means is nearest the bit end of said annular chamber, there is at least one additional bearing means between said first seal means and the downhole motor end of said annular chamber, a third seal means between said at least one additional bearing means and the downhole motor end of said annular chamber, at least two bearing means in said inner chamber arranged so that at least one bearing means in said inner chamber is between said second seal means and said movable piston means and so that at least one other bearing means in said inner chamber is between said first seal means and said movable piston means, a fourth seal means between said first seal means and the bit end of said annular chamber.

**16.** A tool in accordance with claim **15** wherein said first seal means seal elements are each composed of an elastic lip seal, each lip seal being supported by a rigid support member.

**17.** A tool in accordance with claim **16** wherein said lip seals are rubber and are impregnated with a solid lubricant.

**18.** A tool in accordance with claim **17** wherein said lip seals each contain a plurality of layers of fibers, at least one layer being composed of porous fibers that act as a wick for liquid lubricant, and at least one other layer being composed of fibers which have a substantially greater tensile strength than said porous fibers.

**19.** A tool in accordance with claim **16** wherein said second seal means has at least two unidirectional seal elements and at least two of said seal elements are reversed from one another, said seal elements being composed of rubber U-cup seal rings.

**20.** A tool in accordance with claim **16** wherein a first sealing surface means carried by but spaced from the member which does not carry said first seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said first seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substan-

tially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**21.** A tool in accordance with claim **20** wherein a second sealing surface means carried by but spaced from the member which does not carry said second seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said second seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**22.** A tool in accordance with claim **2** wherein said first seal means seal elements are each composed of an elastic lip seal, each lip seal being supported by a rigid support member.

**23.** A tool in accordance with claim **22** wherein a first sealing surface means carried by but spaced from the member which does not carry said first seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said first seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**24.** A tool in accordance with claim **3** wherein said second seal means seal elements are each composed of an elastic lip seal, each lip seal being supported by a rigid support member.

**25.** A tool in accordance with claim **24** wherein a second sealing surface means carried by but spaced from the member which does not carry said second seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said second seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**26.** A tool in accordance with claim **3** wherein said first seal means seal elements and said second seal means seal elements are all composed of elastic lip seals each of which are supported by a rigid support member.

**27.** A tool in accordance with claim **26** wherein both said first and second seal means employ sealing surface means.

**28.** A tool in accordance with claim **1** wherein both said first and second seal means employ sealing surface means.

**29.** A tool in accordance with claim **3** wherein a first sealing surface means is carried by but spaced from the member which does not carry said first seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said first seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**30.** A tool in accordance with claim **29** wherein a second sealing surface means carried by but spaced from the member which does not carry said second seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said second seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

**31.** A tool in accordance with claim **1** wherein the first of said seal means is nearest the downhole motor end of said annular chamber and there is at least one additional bearing means between said first seal means and the downhole motor end of said annular chamber, and said movable piston means is between said at least one additional bearing means and the downhole motor end of said annular chamber.

**32.** A tool in accordance with claim **31** wherein said movable piston means is a movable annular ring which extends in said annular chamber from said shaft to said housing and which carries seal means both between said ring and said shaft and between said ring and said housing.

**33.** A tool in accordance with claim **32** wherein said seal means between said ring and said shaft comprises two annular unidirectional acting seal elements, and said seal means between said ring and said housing comprises two annular unidirectional acting seal elements, one of said seal elements between said ring and shaft and one of said seal elements between said ring and housing each being oriented to stop fluid which is moving in said annular chamber toward said movable piston and also toward the bit end of said annular chamber and the other of said seal elements between said ring and shaft and between said ring and housing each being oriented to stop fluid which is moving in said annular chamber toward said movable piston and also toward the downhole motor end of said annular chamber.

**34.** A tool in accordance with claim **31** wherein said movable piston means is a pressure expandable and contractible bellows whose interior is openly connected to said annular chamber outside said inner chamber and between said movable piston means and the downhole motor end of said annular chamber.

**35.** A tool in accordance with claim **31** wherein said movable piston means is a pressure expandable and contractible bellows whose interior is openly connected to said inner chamber.

**36.** A tool in accordance with claim **31** wherein said movable piston means is a pressure expandable and contractible bellows whose interior is openly connected to the interior of said shaft.

**37.** A tool in accordance with claim **2** wherein said second seal means is said movable piston means and is a movable bidirectional sealing piston means.

**38.** A tool in accordance with claim **37** wherein said movable bidirectional sealing piston means is an annular ring with seal elements between said ring and said shaft and between said ring and said housing.

39. A tool in accordance with claim 38 wherein said seal means between said ring and said shaft comprises two annular unidirectional acting seal elements, and said seal means between said ring and said housing comprises two annular unidirectional acting seal elements, one of said seal elements between said ring and shaft and one of said seal elements between said ring and housing each being oriented to stop fluid which is moving in said annular chamber toward said movable piston and also toward the bit end of said annular chamber and the other of said seal elements between said ring and shaft and between said ring and housing each being oriented to stop fluid which is moving in said annular chamber toward said movable piston and also toward the downhole motor end of said annular chamber.

40. A tool in accordance with claim 37 wherein said first seal means seal elements are each composed of an elastic lip seal, each lip seal being supported by a rigid support member, and any pressure differential between the interior of said shaft and the exterior of said housing can be taken across said first seal means.

41. A tool in accordance with claim 40 wherein a first sealing surface means carried by but spaced from the member which does not carry said first seal means, said sealing surface being carried by its carrying member in a sealed manner, at least a portion of said sealing surface contacting the unidirectional seal elements of said first seal means, said sealing surface being laterally movable in a sealed manner with respect to its carrying member so that said sealing surface maintains substantially full contact with said unidirectional seal elements notwithstanding lateral displacement of the housing or shaft.

42. A tool in accordance with claim 37 wherein fin means are carried on the bit end of said shaft adjacent to but spaced from the bit end of said housing.

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