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W. F. CARR ETAL

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DIRECTIONAL DRILL WITH HYDRAULICALLY EXTENDED SHOE

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2 Sheets-Sheet 1

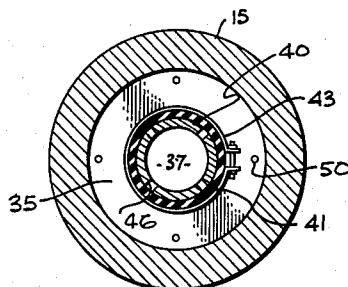
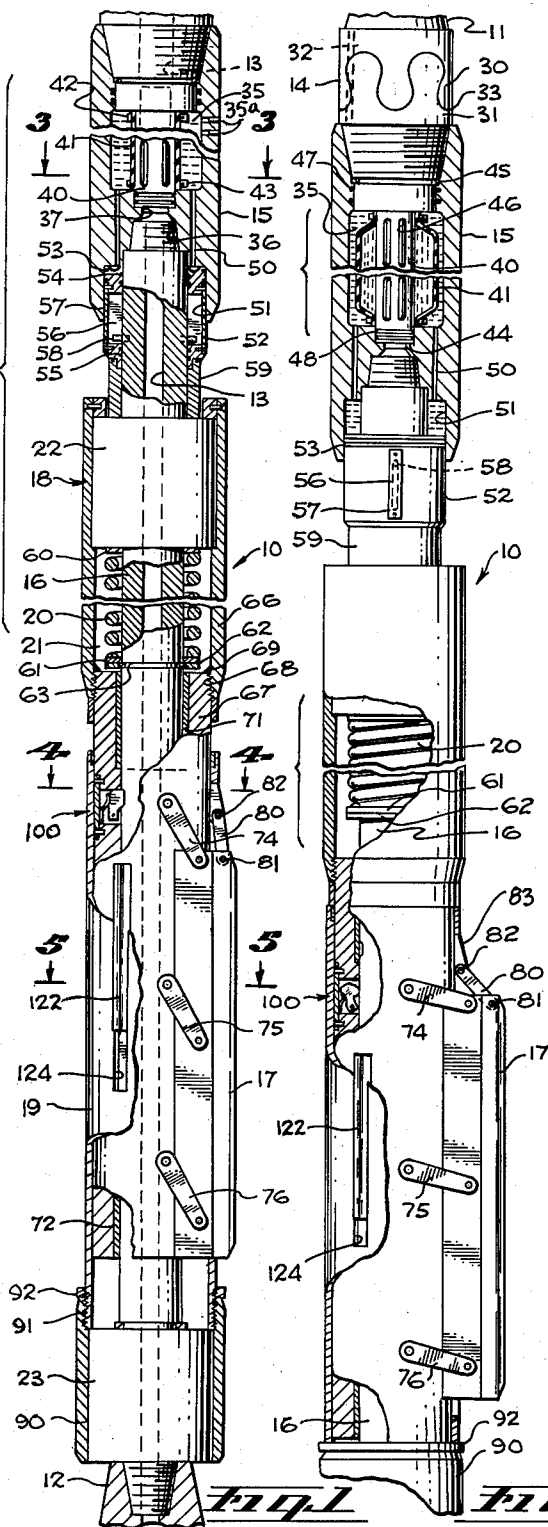


Fig. 3

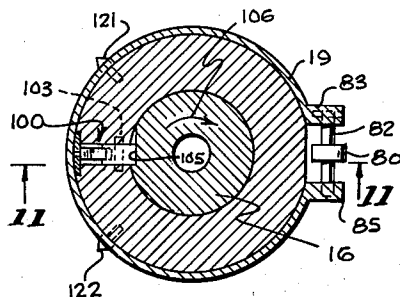
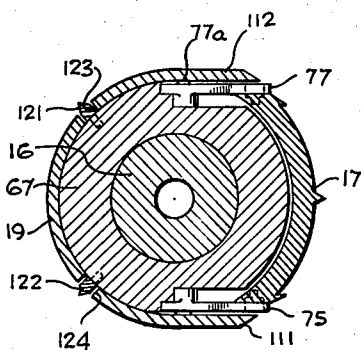


Fig. 4



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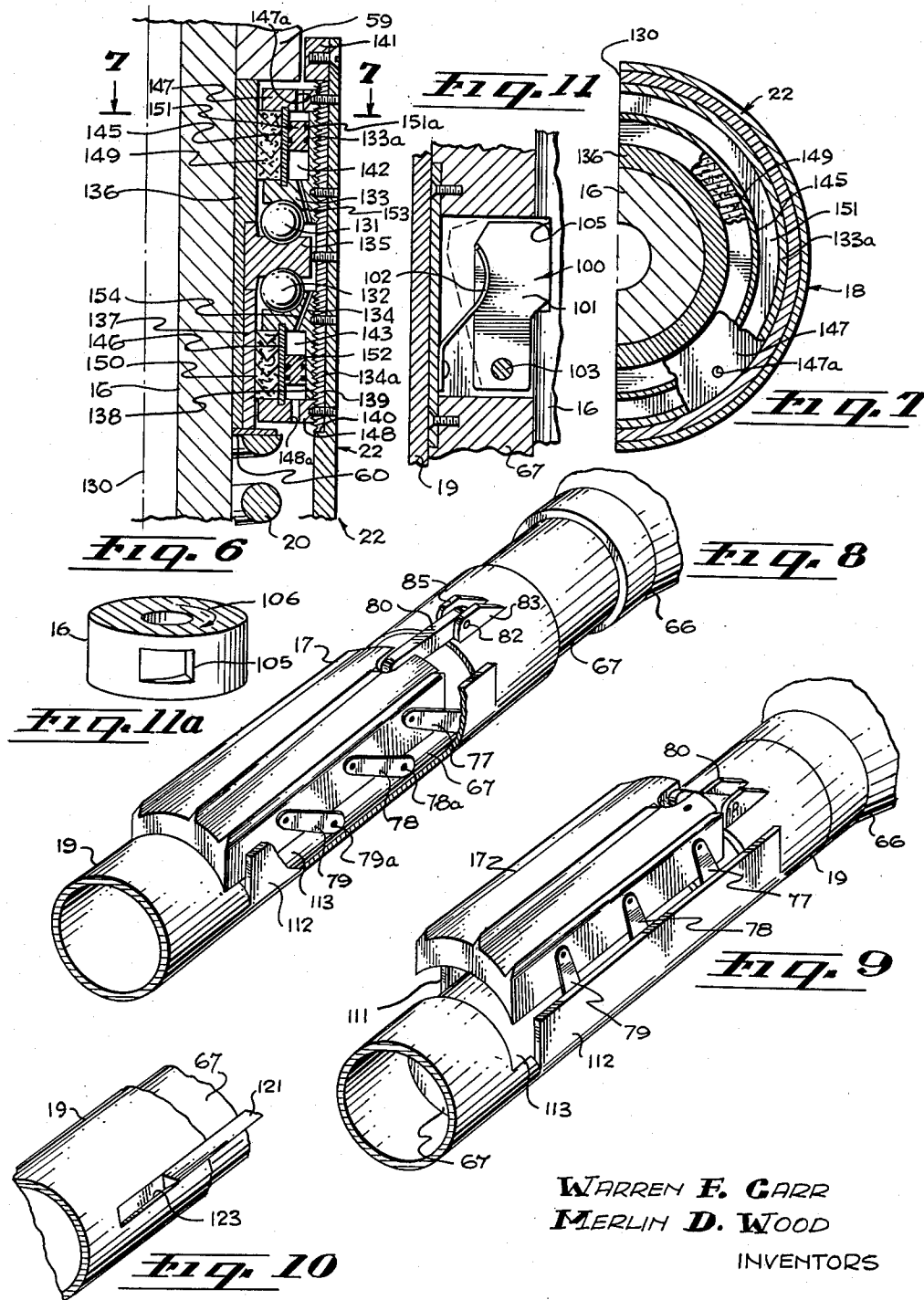
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WARREN F. CARR

MERLIN D. WOOD

INVENTORS

By *Beckler & Shanahan*
ATTORNEYS

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DIRECTIONAL DRILL WITH HYDRAULICALLY EXTENDED SHOE

Warren Farrell Carr, 227 S. Leaf Ave., West Covina, Calif., and Merlin Denver Wood, 4611 N. Riohondo Parkway, El Monte, Calif.

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9 Claims. (Cl. 175—73)

In the drilling of oil wells, a rotary bit chips away at the rock and earth at the bottom of the bore hole many thousands of feet from the surface, the bit being rotated about a vertical axis by means of a long tubular drill string. The drill string is tubular in order to provide a passage for the drilling mud which is pumped through it from the surface to the drill bit, where it serves as a drilling lubricant and as a medium to transport drilled particles from the bottom of the hole to the ground surface.

At the great depth involved, the drill string has almost no resistance to deflection by the irregularities encountered in the strata of earth being drilled.

In the past, various devices have been assembled with the drill bit, and connected with it to the lower end of the drill string to provide means for drilling straight down or for deflecting the drill in a desired direction away from the vertical as it progressed downwardly. Such devices may be referred to all-inclusively as "directional drilling systems," whether they be used for drilling on a slant away from the vertical, or for drilling straight down by using one or more directional drilling systems one below the other, or for deflecting the end of the drill string, or some intermediate part of the drill string, in a desired direction, for purposes other than drilling. It will be understood throughout the following specification and the claims that the device disclosed herein is not restricted to drilling away from the vertical only, nor is it necessarily restricted to drilling despite the name "directional drilling system," since the invention is concerned with the deflecting means and not with the rotary bit at the lower end of the drilling assembly.

The present invention belongs to a class of directional drilling systems, previously found to be one of the most practical types, in which the deflecting means is actuated by the pressure of a fluid pumped into the well from the surface, generally the drill mud passing down an axial passage in the drill string to the bit; however, it will be obvious that the device could be actuated by almost any fluid pumped down to the point of operation of the directional drilling system by any passage convenient in the well hole.

One of the major objections to mud-actuated directional drilling systems known in the past has been the tendency of the moving parts in the system to become jammed or to be worn away with excessive speed because of particles of rock and sand in the drill mud. Devices which operate perfectly under test at the ground surface with perfectly clean mud have failed to operate satisfactorily for a reasonable period of time when actually placed in use in the bottom of an oil well bore; hydraulic machinery can not be relied upon if the hydraulically operated parts are exposed to a hydraulic liquid filled with chunks of rock. In the present invention, this objectionable feature is avoided by using an oil hydraulic system, completely separate from the circulating drilling mud, and protected therefrom by liquid tight seals. Operation of the oil hydraulic system is controlled by the pressure of the drilling mud as it is transmitted through a heavy rubber-like bladder.

In previously known mud-actuated devices, some of the actuating parts were subjected to both rotational and longitudinal surface friction. It is an advantage of the

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present invention, that the important actuating parts do not experience any rotational wear, and are subjected to longitudinal surface friction only for the momentary period of actuation at the beginning of drilling, and of the actuation at the end of drilling.

In most previously known mud-actuated systems, either there have been no bearings for insulating the longitudinally reciprocable parts from the rotational movement of the drill string parts, or the bearings used have been unreliable after short period of use. The present inventors have found that even previously known pressure lubricated bearings have failed in use, and have traced the difficulty apparently to penetration of the bearing by drill mud because of extremely high pressures on the drill mud at a depth of several thousand feet in the drill hole. Thus, a bearing packed under fairly high pressure at the ground surface unavoidably contains some entrained air, and the bearing seals are penetrated and the lubricant spoiled with dirt particles at the high pressures far beneath the ground surface. It is an important object of the present invention to provide a bearing suspension for the relatively reciprocable parts, which insulates them from the rotating parts, and which includes protective sealing means adjustable to the pressure of the drilling mud so that the bearing may operate satisfactorily although exposed to the drill mud necessarily circulated through a mud-actuated system.

The drilling sub-assembly is subjected to very large longitudinal stresses of tension or compression during use. Previously known systems have generally been vulnerable to breakage because these stresses have been transmitted through complex and delicate mechanical structures, or through lateral structure which broke the direct vertical transmission of the stress, and subjected parts of the drilling sub-assembly to shear stress. It is an important object of the present invention to provide a directional drilling system in which vertical stresses are transmitted in a substantially uninterrupted vertical line through a tubular system of substantial wall thickness.

In the past, it has been considered a very objectionable feature to introduce into the drilling sub-assembly any auxiliary device which substantially increased its length. In the present invention, the separate hydraulic system necessarily introduces some additional length, but past objections to such a step have been overcome by connecting the hydraulic system housing to the lower end of the drill string by means of a simple but very strong joint having sufficient flexibility to avoid the flexing fatigue which might otherwise be encountered.

The foregoing and other objects and advantages of our invention will be understood from the following description of a preferred specific embodiment, read in view of the accompanying drawings, in which:

FIGURE 1 is a vertical sectional view of a directional drilling system constructed according to the invention, the upper end, the ball bearings, and certain other parts being shown in full elevation rather than end section, and other parts being broken away in order to reduce the vertical length of the illustration for convenient drawing size, or to reveal components of the assembly; the figure shows the different parts of the system as they appear when at rest, without mud pressure or drilling rotation, and without extension of the deflecting shoe;

FIGURE 2 is a vertical sectional view corresponding to FIGURE 1 except that the parts are shown in the positions which they assume when mud pressure is on, the drill is in rotation, and the shoe has been shifted to extended position;

FIGURE 3 is a horizontal sectional view taken transversely through the directional drilling system at the line 3—3 as indicated in FIGURE 1;

FIGURE 4 is a horizontal sectional view taken trans-

versely through the drilling system at a plane indicated by the line 4—4 in FIGURE 1, as viewed looking down at the upper ends of the latch system and the two stabilizing runners carried on a reciprocable part of the directional drilling system;

FIGURE 5 is a transverse sectional view taken at a horizontal plane indicated by the line 5—5 in FIGURE 1, looking down upon a section of the deflecting shoe and the shoe extending system, as the latter appear in their retracted position;

FIGURE 6 is a vertical sectional view taken at a diameter, of the ball-type thrust bearing which is used for upper and lower bearings in the directional drilling system; only the portion to the right of the vertical center line is illustrated, since the drawing would be identical and symmetrical as to right and left halves;

FIGURE 7 is a transverse sectional view, looking down from the horizontal plane indicated by the line 7—7 in FIGURE 6, of the bearing of FIGURE 6, only the right half being shown since the drawing would be symmetrical about the center line;

FIGURE 8 is a perspective view of the stationary and reciprocable sleeve assembly as seen in the rest position with the deflecting shoe shown retracted into the sleeve assembly;

FIGURE 9 is a perspective view of the sleeve assembly, partially broken away to reveal the interior parts, as it appears when telescoped for drilling position, with the shoe extended as in FIGURE 2;

FIGURE 10 is a fragmentary perspective view of a stabilizing runner projecting through a slotted opening in the side of the assembly;

FIGURE 11 is a vertical sectional view of a detail of an anti-rotation latch, as seen at the plane and in the direction indicated by the arrow 11 in FIGURE 4; and

FIGURE 11a is a perspective view of a section of the mandrel showing a latch recess.

The directional drilling system of the invention is illustratively presented as a whole in the vertical sectional views of FIGURES 1 and 2, and as indicated therein generally by the numeral 10. The directional drilling system is seen to be positioned at the bottom of a drill bore hole, not illustrated, between the lower end of the string of drill pipes 11, and the rotary bit 12.

The directional drilling system 10 has a vertical, axial passage 13 for the downward flow of drill mud to the drill bit 12 in the manner which is conventional in well drilling, and for the purposes well known to those familiar with the well drilling art.

The directional drilling system 10 is a continuation of the vertical column of the drill string, the vertical or longitudinal stress-carrying components being, in order from the top, a flexible joint 14, a hydraulic system housing 15, and a tubular mandrel 16. It will be seen that one of the advantages of the device of the invention is that longitudinal stress is carried directly through parts of great strength and large transverse cross-sectional area, from the end of the drill string 11 to the bit 12, without deflection of the longitudinal stress through the complicated structure sometimes found in previously known directional drilling systems.

Deflection of the drill bit 12 is produced by means of a laterally extendable shoe 17, which can be shifted from the retracted rest position of FIGURE 1 to an extended drilling position, as illustrated in FIGURE 2, when an inner reciprocable sleeve assembly, indicated generally by the numeral 18, is telescoped into an outer stationary sleeve 19 by the action of the hydraulic system in hydraulic system housing 15. It will be noted that the extension action of the hydraulic system and hydraulic system housing 15 must take place by overcoming and compressing a long, helical retraction spring 20 which occupies an annular space 21 between the mandrel 16 and the reciprocable sleeve assembly 18.

In order to understand the manner in which the direc-

tional drilling system 10 operates, it is important to note that the reciprocable sleeve assembly 18 is supported on an upper ball bearing 22, so that the reciprocable sleeve assembly does not rotate with rotating column comprised of hydraulic system housing 15 and tubular mandrel 16, both of which rotate with the drill string 11 and the bit 12 during drilling operation. Similarly, the stationary sleeve 19 is supported without rotation by means of a lower ball bearing 23, located just above the bit 12.

The detailed construction of the directional drilling system 10 will now be described in detail beginning with the flexible joint 14 at the upper end of the entire assembly. The flexible joint is not required to execute any large angle of deflection, but merely to tolerate some deflection without strain or fatigue at the point of coupling between directional drilling system 10 and drill pipe 11. One preferred form illustrated is simply comprised of two interlocking nipples 30 and 31, which are lined with a short section of neoprene hose 32, so as to make the joint 14 waterproof. The line of interlocking, 33 is curved and smooth at all points to permit a slight flexure, but at the same time, it provides for sufficient cross section of engagement so that the joint 14 has more than the minimum required longitudinal strength in compression and tension and torque.

The sectional views of FIGURES 1 and 2, and the transverse cross sectional view of FIGURE 3 reveal that the hydraulic system housing 15 has an enlarged tubular cavity 35 at its upper end, and an enlarged mandrel receiving bore 36 at its lower end, which are in communication with each other through an axial passage 37 of reduced cross section at a region intermediate the upper and lower ends of the hydraulic system housing 15. A pair of ports 35a closed by means of threaded plugs, are provided for charging hydraulic oil to the cavity 35. Hydraulic oil is forced into one port at the same time air is bled from the other, so as to have no air trapped in the hydraulic chamber 35.

Received into the upper end of the hydraulic system housing 15 is a bladder support tube 40, which passes through a tubular neoprene bladder 41 clamped to it by means of upper and lower bladder clamps 42 and 43 respectively. (See also FIGURE 3.)

The bladder support tube seats at its lower end on a shoulder 44, and is retained in position by means of a snap ring 45 located at its upper end.

Drill mud passing through the bladder support tube 40 is freely admitted to the interior of the bladder 41, or expelled therefrom into the bladder support tube interior, by means of a number of longitudinal passage slots 46.

The annular space in the reservoir chamber 35 around the exterior of the tubular bladder 41 is filled with oil or other suitable hydraulic fluid, and protected from the entry of mud by means of O-ring seals 47 and 48.

It will be seen from FIGURES 1 and 2, respectively, that the bladder is collapsed when the system is at rest and there is no drilling mud pressure, whereas it is expanded so as to expel hydraulic fluid from the reservoir 35 when the drilling operation is going on and the drilling mud is under pressure.

Under drilling conditions, with the bladder 41 in its expanded condition, as illustrated in FIGURE 2, the hydraulic fluid is expelled from the reservoir 35 under pressure downwardly through the four longitudinal hydraulic fluid passages 50, best seen in the transverse cross-sectional view of FIGURE 3. The lower ends of the four passages 50 discharge the hydraulic fluid into an enlarged bore 51 as the lower end of the hydraulic system housing which serves as a cylinder in which an annular piston 52 is reciprocable.

The vertical sectional view of the piston in FIGURE 1, and the front elevational view of FIGURE 2 reveal that the piston 52 is provided with O-ring seals 53, 54 and 55, and that it has four longitudinal slots 56, covered by cover plates 57, the slots serving to cover piston lock pins 58,

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which insure that the piston 52, although reciprocable, will also rotate with the rotating mandrel 16. The length of the slots 56 gives some idea of the length of the reciprocable movement of the vertically reciprocable parts, including reciprocable sleeve assembly 18.

However, reciprocable sleeve assembly 18 does not rotate, being supported from the outer race of the reciprocable sleeve support bearing 22. Longitudinal reciprocation action is transmitted from piston 52, through a piston extension sleeve 59 to the inner race of the ball bearing 22, the details of ball bearing 22 being described hereinafter in connection with a description of FIGURES 6 and 7.

The downward displacement of the ball bearing 22, together with the longitudinally reciprocable sleeve assembly 18, the piston 52, etc., is resisted by the powerful retraction spring 20, which seats at its upper end against an upper spring seat ring 60, which is vertically slidable on the rotating mandrel 16. Spring 20 has its lower end locked against longitudinal movement by a lower spring seat ring 61 (see FIGURE 2), which is fixed at one position relative to the rotating mandrel 16 by means of a locking ring 62 received in an annular groove 63 (see FIGURE 1) in mandrel 16.

It will be seen from FIGURES 1 and 2 that the reciprocable sleeve assembly 18 is made up principally of an upper spring enclosing tube 66 and a lower shoe-carrying tube 67 of smaller diameter, the latter being threaded into the lower opening of the former at 68 and welded in place by the fillet weld 69.

Since the reciprocable sleeve assembly 18 does not rotate whereas the mandrel 16 rotates continuously during drilling, it is desirable to line the lower shoe-carrying tube 67 with a pair of bronze bearings, one at each end, indicated by numerals 71 and 72. The shoe 17 is shown as being carried on the lower shoe-carrying tube part 67 of the reciprocable sleeve assembly 18 by means of six arms 74 to 79, which are pin-mounted at each end to permit the outwardly shifting movement of shoe 17 to the laterally extended position as illustrated in FIGURE 2 and also in the perspective view of FIGURE 9. It is obvious, however, that the number of pairs of links to shoe 17 may be more or less than the three illustrated.

The downward actuation of the vertically reciprocable sleeve assembly 18 would not produce outward extension of the shoe 17, if the shoe itself were not held from being moved downwardly by means of a holding link 80, which is pin connected by pin 81 to the upper end of the shoe 17, and is held by pin 82, at its upper end, in a manner permitting outward rotation of the holding link 80 about the axis of 82. The pin 82, seen in cross section in FIGURES 1 and 2 and vertical elevation in the horizontal sectional view of FIGURE 4, is mounted between a pair of longitudinal shoulders 83 and 85 carried on the stationary sleeve 19.

As previously mentioned, the stationary sleeve 19 neither rotates nor reciprocates, and therefore must be supported (in this case at its lower end) on the outer stationary race of the lower ball bearing 23, the inner race of ball bearing 23 being carried in rotation with the rotary mandrel 16. Since the lower ball bearing 23 is identical in construction with upper ball bearing 22, and is interchangeable therewith, its inner construction will be understood from the descriptions hereinafter of FIGURES 6 and 7. It will suffice to say at this point that the lower ball bearing 23 is held in position in a non-rotating cylindrical housing 90 threaded at 91 against a lock ring 92 on stationary sleeve 19, by the bit 12 which shoulders against the inner race of the lower ball bearing 23 as seen in FIGURE 1.

An important feature visible from FIGURES 1, 2, 4 and 11 is the mandrel latch, indicated generally by the numeral 100, and shown in FIGURE 1 and FIGURE 11 in latched position to prevent relative rotation between the mandrel 16 and the reciprocable sleeve assembly 18

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when the tool is not drilling (for example, when it is being lowered into the hole or withdrawn therefrom).

In FIGURE 2 (also seen in dashed outline in FIGURE 11) the latch 100 is shown tilted back to unlatched position, downward movement of the reciprocable sleeve assembly 18 having displaced the latch pawl 101, against the leaf spring 102 so that the pawl 101 has rotated outwardly about latch pin 103, and the surface of the latch pawl 101 merely rides on the rotating surface of the mandrel 16 during drilling.

It will be seen from FIGURE 11, that in locked position, as shown in FIGURE 1 the latch pawl 101 is received in a slot 105 machined out of the surface of the mandrel 16, but note also, in the plan view of FIGURE 4, that the left side of the slot 105 is shown removed so as to insure engagement of the right side shoulder upon rotation of the mandrel in a clockwise direction, as indicated by the arrow 106 in FIGURE 4. It is important also to note, in FIGURE 11, that the lower edge of the pawl 101, and the corresponding lower shoulder of the slot 105, form an inclined plane so that the latch 100 offers no resistance to downward displacement of the reciprocable assembly 18 with respect to mandrel 16, as illustrated in the shift from the position to FIGURE 1 to the drilling position of FIGURE 2; the pawl 101 merely rides smoothly outward to a deflected position as the lower beveled shoulder of slot 105 (see FIGURE 11) rises with respect to the pawl.

The perspective views of FIGURE 8 and FIGURE 9 show the shoe 17 in retracted, non-drilling position, and extended, drilling position, respectively, FIGURE 8 corresponding to FIGURE 1 and FIGURE 9 corresponding to FIGURE 2. FIGURES 8 and 9, taken in connection with FIGURES 1 and 2, had also in connection with the sectional view of FIGURE 5, revealed that the six arms, 74 to 79, which permit the pivoting action of the shoe 17 are pin mounted on the reciprocable shoe carrying tube 67, as indicated in FIGURES 5 and 8 at 77(a), 78(a) and 79(a).

It will be recalled that the shoe carrying tube 67 is permanently connected to the spring enclosing tube 66 (the lower end of which is visible in FIGURES 8 and 9), the two together comprising the reciprocable sleeve assembly 18.

The holding link 80, on the contrary, is connected at pin 82 to the outer stationary sleeve 19. Thus, the lower end of the shoe carrying tube 67 is not visible through the lower end of the stationary sleeve 19 in FIGURE 8, whereas it is visible at that point in FIGURE 9.

The pin connections of the arms 74 and 79 to the shoe carrying tube 67 are given some degree of protection from damaging encounters with the bore hole walls by longitudinal fenders 111 and 112, which extend from stationary sleeve 19, on each side of its shoe receiving opening 113. The upper end of the opening 113 is clearly seen in FIGURE 8, and the lower end is clearly seen in FIGURE 9.

FIGURE 10 supplements FIGURES 2, 4 and 5 in showing a pair of stabilizing runners 121 and 122 which are mounted on the shoe carrying tube 67 as an integral part thereof, and which project radially outwardly through vertical longitudinal slots 123 and 124, respectively, in the walls of the outer stationary sleeve 19. The runners 121 and 122 are freely reciprocable relative to the stationary sleeve 19, slots 123 and 124 being of sufficient length to permit the desired reciprocation, as seen in FIGURES 1, 2 and 10. Runners 121 and 122 can be selected as to size to control exact degree of deflection of the drill from the center line of the hole.

The function of the stabilizing runners 121 and 122 is to engage the walls of the bore hole opposite to the side thereof upon which the shoe 17 bears. Thus, shoe 17 can apply a deflecting pressure toward the right, as viewed in the planned sectional view of FIGURE 5, thus pushing the axis of the entire directional drill system 10 to

the left of the center of the bore hole. The runners 121 and 122 engage the walls of the bore hole permitting easier vertical descent during drilling than if the outer wall of the stationary sleeve 19 had to be pushed along the bore hole wall.

FIGURES 6 and 7 illustrate in detail the construction of the bearing 22, the internal construction of bearing 23 being identical. Only the right half of the bearing is illustrated in FIGURES 6 and 7, the part lying to the left of the vertical center line plane 130 being exactly the duplicate of the right half illustrated.

The vertical cross-sectional view of FIGURE 6 reveals that the bearing 22 has an upper and lower ring of balls 131 and 132, respectively, which roll in raceways between upper and lower race rings 133 and 134, and intermediate race ring 135.

The intermediate race ring 135 rotates integrally with the tubular mandrel 16, being mounted thereon between the piston extension sleeve 59 and the upper spring seat ring 60 by means of inner and outer race mounting sleeves 136 and 137. Upper and lower race rings 133 and 134 are immovably mounted inside the reciprocable sleeve assembly 18, which does not rotate, mounting being by threaded connection at threads 138 to an outer race ring mounting sleeve 139, which is recessed into the interior wall of the reciprocable sleeve assembly 18 at 140, being retained by an upper retaining ring 141.

An important feature of novelty of the directional drilling system of the present invention is the provision of bearings 22 and 23 which are capable of operating for prolonged periods despite the presence of abrasive drill mud, filled with rock, bits and chips, in the region surrounding the bearings. In the present invention, the pressure of the drill mud is utilized to apply lubricant directly to the ball bearings 131 and 132 under pressure. Lubricant is stored in annular chambers 142 and 143, formed between sleeve extensions 133(a) and 134(a) of race rings 133 and 134, and the packing retainer cylinders 145 and 146.

It will be seen from the sectional view of FIGURE 6 that the packing cylinder 145 is mounted between the upper race ring 133 and a packing cover ring 147; a packing ring 148 performs a similar role at the lower end of bearing 22. Between the packing cylinders 145 and 146 and the inner rings 136 and 137, packing 149 and 150 is provided to prevent drill mud from entering the bearing 22.

Within the annular space 142, the lubricant is sealed by a vertically slidable annular piston 151, in the form of a ring, seen in FIGURE 6 and in plan view in FIGURE 7. The piston 151 is provided with piston rings 151(a) for sealing drill mud from lubricant as will be explained hereafter. A similar piston 152 is provided for the lower annular lubricant chamber 143.

Lubricant from lubricant chamber 142 reaches the raceway of ball bearings 131 by means of a plurality of small bore holes 153, one of which is seen in cross section in FIGURE 6. Similar passages 154 are likewise located in the lower race ring 134. Both lubricant passages 153 and 154 are obliquely bored in the race rings 133 and 134 in order to provide clearance of the raceways of the balls 131 and 132.

Pressure is applied to the lubricant in lubricant chambers 142 and 143 by the annular pistons 151 and 152, which being freely reciprocable in a vertical direction, tend to be urged against the lubricant by the pressure of drill mud which reaches the outer surfaces of the pistons 151 and 152 by way of passages 147(a) and 148(a) through the cover rings 147 and 148. The right half horizontal sectional view of FIGURE 7 shows parts fragmentarily broken away to reveal the annular piston 151, but enough of the ring-shaped cover 147 remains to reveal one of the mud passages 147(a).

It will be seen that the drill mud itself applies the pressure to supply the bearings 22 and 23 with pressurized

lubrication during drilling. Also, the static head at the bottom of the well applies a continuous pressure to the ring-shaped pistons 151 and 152, equalizing internal and external pressure.

The operation of the directional drilling system is best seen in FIGURES 8 and 9, taken in connection with their corresponding FIGURES 1 and 2.

When the drilling system is at rest, or is being inserted or retracted without drilling mud pressure, the bladder 41 is collapsed as seen in the upper part of FIGURE 1, the reciprocable sleeve assembly 18, including spring enclosing tube 66 and shoe carrying tube 67, are upwardly retracted relative to stationary sleeve 19, under the pressure of the spring 20. Thus, as seen in FIGURE 1 and also in FIGURE 8, the shoe 17 lies retracted against the surface of shoe carrying tube 67 within the opening 113 in the stationary sleeve 19.

When drilling begins, mud pressure inflates the bladder 41 operating the hydraulic system within the housing 15 to downwardly displace the reciprocable sleeve assembly 18, overcoming the pressure of spring 20. As seen in FIGURES 2 and 9, this forces shoe 17 outwardly against the wall of the bore hole and deflects the drill string, at a point just above the drill bit 12, to an off-center position, thus producing the desired directional drilling.

It will be understood that the foregoing is a description of but one specific embodiment of the invention. Although many of the details are much preferred, they may obviously be omitted or modified by those skilled in the art, for particular applications, without departing from the general spirit and scope of the invention.

The invention is not be limited, therefore, by the great detail set forth in the specific embodiment illustrated, but only by the terms clearly set forth in the following claims.

We claim:

1. A directional drilling system for deflecting a drill bit from the center line of a bore hole by means actuated by the pressure of a drilling liquid, which system includes: a tubular mandrel forming a part of the drill string near the drilling bit, said tubular mandrel having an axial passage for conducting drilling liquid under pressure from the interior of the drill string above it to the drill bit; a hydraulic system housing enclosing a hydraulic fluid reservoir, said housing being coupled to said mandrel; a distensible bladder forming a conduit passing through said hydraulic reservoir chamber and forming part of a drilling liquid passage through said hydraulic system housing; an annular piston reciprocable on said tubular mandrel adjacent said hydraulic system housing; walls integral with said hydraulic system housing forming a cylinder enclosing one end of said annular piston, and providing an annular hydraulic actuating chamber for actuating said piston, said hydraulic actuating chamber being in open communication with said hydraulic reservoir chamber but separated from the drilling liquid passage through said hydraulic reservoir by said bladder; a bearing of the anti-friction type having its inner race reciprocable and rotatable with said annular piston, and its outer race reciprocable without rotation; a reciprocable structure mounted on the outer race of said reciprocable bearing; a helical spring encircling said tubular mandrel for a part of its length adjacent said reciprocal bearings, and urging said annular piston into said hydraulic actuating chamber by thrust transmitted through the inner race of said reciprocable bearing; anchoring means for anchoring the end of said helical spring opposite said reciprocable bearing to said tubular mandrel, to constrain said helical spring to longitudinal compression when said piston is expelled from said hydraulic cylinder; a reciprocable structure mounted on the outer race of said reciprocable bearing and reciprocable therewith; a non-reciprocating bearing mounted on said tubular mandrel at a point spaced from said reciprocable bearing, and having its inner race rotatable with said tubular mandrel, and its outer race rotationally free of mandrel rotation; a longitudinally extend-

ed shoe for engaging the sidewall of said bore hole, said shoe having a retracted rest position adjacent said tubular mandrel, and an extended drilling position spaced from said tubular mandrel toward the sidewalls of said bore hole stationary structure supported on the outer race of said non-reciprocable bearing and adapted to remain relatively free of reciprocation and rotation during rotation of said tubular mandrel; holding link means between said stationary structure and said shoe for preventing said shoe from movement longitudinal to said tubular mandrel with said reciprocable structure; and link means between said reciprocable structure and said shoe for thrusting said shoe outwards from its rest position to its bore hole wall engaging position upon displacement of said reciprocable structure by movement of said hydraulic piston partially out of said hydraulic actuating chamber.

2. A directional drilling system for deflecting a drill bit from the center line of the bore hole by means actuated by the pressure of a drilling liquid, which system includes: a tubular mandrel forming a part of the drill string near the drilling bit, said tubular mandrel having an axial passage for conducting drilling liquid under pressure from the interior of the drill string above it to the drill bit; a hydraulic system housing enclosing a hydraulic fluid reservoir, and having an axial passage for the flow of drilling liquid passing downwardly through said drill string; a distensible bladder forming a conduit passing through said hydraulic reservoir chamber and forming part of the drilling liquid passage through said hydraulic system housing; a bladder support tube disposed in said hydraulic reservoir chamber in alignment with and communicating with said drilling liquid passage through said hydraulic housing, said bladder support tube having wall openings to permit free communication between the interior of said bladder support tube and the interior of said bladder; an annular piston reciprocable on said tubular mandrel adjacent said hydraulic system housing; walls integral with said hydraulic system housing forming a cylinder enclosing one end of said annular piston, and providing an annular hydraulic actuating chamber around said mandrel for actuating said piston, said hydraulic actuating chamber being in open communication with said hydraulic reservoir chamber but separated from the drilling liquid passage through said hydraulic reservoir by said bladder; a bearing of the anti-friction type having its inner race reciprocable and rotatable with said annular piston, and its outer race reciprocable without rotation; a reciprocable structure mounted on the outer race of said reciprocable bearing; a helical spring encircling said tubular mandrel for a part of its length adjacent said reciprocable bearing, and urging said annular piston into said hydraulic cylinder, by thrust transmitted through the inner race of said reciprocable bearing; anchoring means for anchoring the end of said helical spring opposite said reciprocable bearing to said tubular mandrel, to constrain said helical spring to compression when said piston is expelled from said hydraulic cylinder; a reciprocable structure mounted on the outer race of said reciprocable bearing and reciprocable therewith; a non-reciprocating bearing mounted on said tubular mandrel at a point spaced from said reciprocable bearing, and having its inner race rotatable with said tubular mandrel, and its outer race rotationally free of mandrel rotation; a longitudinally extended shoe for engaging the sidewall of said bore hole, said shoe having a retracted rest position adjacent said tubular mandrel, and an extended drilling position spaced from said tubular mandrel toward the sidewalls of said bore hole stationary structure supported on the outer race of said non-reciprocable bearing and adapted to remain relatively free of reciprocation and rotation during rotation of said tubular mandrel; holding link means between said stationary structure and said shoe for preventing said shoe from movement longitudinal to said tubular mandrel with said reciprocable structure; link means between said reciprocable structure and said shoe for thrusting said shoe

outwards from its rest position to its bore hole wall engaging position upon displacement of said reciprocable structure by movement of said hydraulic piston partially out of said hydraulic cylinder; and longitudinal runner means extending outwardly from said reciprocable structure to bear upon bore hole sidewalls opposite said shoe.

3. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit, at the lower end of said drill string, a drill deflecting means for engaging the side wall of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing and a tubular mandrel coupled in series as part of said drill string near the lower end thereof; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a drill liquid passage for the flow of drilling liquid through said drill string to said drill bit, said tubular bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said drilling liquid passage and hydraulic fluid in an annular hydraulic fluid reservoir surrounding said bladder in said hydraulic system housing; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near said hydraulic system housing; walls extending from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated; a helical spring encircling said tubular mandrel adjacent said annular piston, said helical spring having one end vertically moveable with said annular piston and its opposite end fixed against longitudinal movement with respect to said tubular mandrel, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the displacement of said annular piston; a reciprocable sleeve enclosing said helical spring and reciprocable with the moveable end thereof, and a stationary sleeve supported on said tubular mandrel without vertical reciprocation said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings between said tubular mandrel and said sleeves to permit relative rotation of said mandrel without requiring simultaneous rotation of said telescoping sleeves; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said reciprocable sleeve, and projecting through a longitudinal opening in the wall of said stationary sleeve; a plurality of swinging links along each side of said shoe, moveably connecting said shoe to said reciprocable sleeve, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting through said shoe opening in said stationary sleeve to engage said bore hole sidewalls; and a link means moveably connecting said shoe to said stationary sleeve and restricting the movement of said shoe from said rest position to said extended position upon the telescoping of said reciprocable sleeve and said stationary sleeve by the displacement of said annular piston.

4. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit, at the lower end of said drill string, a drill deflecting means for engaging the sidewalls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing and a tubular mandrel coupled in series as part of said drill string near the lower end thereof; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a drill liquid passage for the flow of drilling liquid through said drill string to

said drill bit, said tubular bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said drilling liquid passage and hydraulic fluid in an annular hydraulic fluid reservoir surrounding said bladder in said hydraulic system housing; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near said hydraulic system housing; walls extending from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated; a helical spring encircling said tubular mandrel adjacent said annular piston, said helical spring having one end vertically moveable with said annular piston and its opposite end fixed against longitudinal movement with respect to said tubular mandrel, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the displacement of said annular piston; a reciprocable sleeve enclosing said helical spring and reciprocable with the moveable end thereof, and a stationary sleeve supported on said tubular mandrel without vertical reciprocation said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings between said tubular mandrel and said sleeves to isolate said telescoping sleeves from the rotation of said mandrel; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said reciprocable sleeve, and projecting through a longitudinal opening in the wall of said stationary sleeve; a plurality of swinging links along each side of said shoe, moveably connecting said shoe to said reciprocable sleeve, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting through said shoe opening in said stationary sleeve to engage said bore hole sidewalls; a link means moveably connecting said shoe to said stationary sleeve and restricting the movement of said shoe from said rest position to said extended position upon the telescoping of said reciprocable and stationary sleeves by the displacement of said annular piston; stabilizing runners mounted on said reciprocable sleeve and extending through longitudinal openings on said sleeve and said stationary sleeve to engage the walls of said bore hole opposite said shoe.

5. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit, at the lower end of said drill string, a drill deflecting means for engaging the sidewalls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing and a tubular mandrel coupled in series as part of said drill string near the lower end thereof; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a drill liquid passage for the flow of drilling liquid through said drill string to said drill bit, said tubular bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said drilling liquid passage and hydraulic liquid in an annular hydraulic fluid reservoir surrounding said bladder in said hydraulic system housing; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near said hydraulic system housing; walls extending from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the

passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated; a helical spring encircling said tubular mandrel adjacent said annular piston, said helical spring having one end vertically moveable with said annular piston and its opposite end fixed against longitudinal movement with respect to said tubular mandrel, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the displacement of said annular piston; a reciprocable sleeve enclosing said helical spring and reciprocable with the moveable end thereof, and a stationary sleeve supported on said tubular mandrel without vertical reciprocation said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings between said tubular mandrel and said sleeves to isolate said telescoping sleeves from the rotation of said mandrel; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said telescoping sleeves; and a plurality of swinging links moveably connecting said shoe to said telescoping sleeves, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting to engage said bore hole sidewalls in response to the action of said piston; means movably connecting said shoe to said stationary sleeve to actuate said shoe from a retracted rest position to an extended position upon the relative displacement of said stationary and reciprocable sleeves by the displacement of said annular piston and latching means for releasably locking said reciprocable sleeve to said tubular mandrel for rotation therewith when said reciprocable sleeve is upwardly retracted by said helical spring into a position corresponding to retraction of said shoe.

6. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit, at the lower end of said drill string, a drill deflecting means for engaging the side walls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing and a tubular mandrel coupled in series as part of said drill string near the lower end thereof; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a drill liquid passage for the flow of drilling liquid through said drill string to said drill bit, said tubular bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said drilling liquid passage and hydraulic fluid in an annular hydraulic fluid reservoir surrounding said bladder in said hydraulic system housing; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near said hydraulic system housing; walls extending from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated; a helical spring encircling said tubular mandrel adjacent said annular piston, said helical spring having one end vertically moveable with said annular piston and its opposite end fixed against longitudinal movement with respect to said tubular mandrel, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the displacement of said annular piston; a reciprocable sleeve enclosing said helical spring and reciprocable with the moveable end thereof, and a stationary sleeve supported on said tubular mandrel without vertical reciprocation said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings between said tubular mandrel and said sleeves to isolate said telescoping sleeves from the rotation of said

mandrel; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said telescoping sleeve; a plurality of swinging links moveably connecting said shoe to said telescoping sleeves, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting to engage said bore hole sidewalls in response to the action of said piston; and means movably connecting said shoe to said stationary sleeve to actuate said shoe from a retracted rest position to an extended position upon the relative displacement of said stationary and reciprocable sleeves by the displacement of said annular piston.

7. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit at the lower end of said drill string, a drill deflecting means for engaging the sidewalls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing forming a part of said drill string at the lower end thereof, and enclosing an annular reservoir for hydraulic liquid; a tubular mandrel coupled at its upper end to the lower end of said hydraulic system housing and at its lower end to the bit-carrying part of said drill string; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a passage for the flow of drilling liquid from said drill string through said hydraulic housing to the interior of said tubular mandrel and thence to said drill bit, said bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said axial drilling liquid passage and hydraulic fluid in said annular hydraulic fluid reservoir; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near its upper end; walls extending downwardly from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of the upper end of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated downwardly; a helical spring encircling said tubular mandrel below said annular piston, said helical spring having its lower end fixed against longitudinal movement with respect to said tubular mandrel and its upper end vertically moveable with said annular piston, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the downward displacement of said annular piston; an upper reciprocable sleeve enclosing said helical spring and reciprocable with the upper end thereof, and a lower stationary sleeve supported on said tubular mandrel without vertical reciprocation, said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings encircling said tubular mandrel, including an upper reciprocable bearing between said annular piston and said reciprocable sleeve to isolate said reciprocable sleeve from the rotation of said tubular mandrel, and a lower non-reciprocable bearing between said tubular mandrel and said stationary sleeve to isolate said stationary sleeve from the rotation of said mandrel; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said reciprocable sleeve, and projecting through a longitudinal opening in the wall of said stationary sleeve; a plurality of swinging links along each side of said shoe, moveably connecting said shoe to said reciprocable sleeve, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting through said shoe opening in said stationary sleeve to engage said bore hole sidewalls; and a link means moveably connecting said shoe

to said stationary sleeve and restricting the movement of said shoe from said rest position to said extended position upon the telescoping of said reciprocable sleeve and said stationary sleeve by the displacement of said annular piston.

8. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit at the lower end of said drill string, a drill deflecting means for engaging the sidewalls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: an elongated hydraulic system housing forming a part of said drill string at the lower end thereof, and enclosing an annular reservoir for hydraulic liquid; a tubular mandrel coupled at its upper end to the lower end of said hydraulic system housing and at its lower end to the bit-carrying part of said drill string; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a passage for the flow of drilling liquid from said drill string through said hydraulic housing to the interior of said tubular mandrel and thence to said drill bit, said bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said axial drilling liquid passage and hydraulic fluid in said annular hydraulic fluid reservoir; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near its upper end; walls extending downwardly from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of the upper end of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated downwardly; a helical spring encircling said tubular mandrel below said annular piston, said helical spring having its lower end fixed against longitudinal movement with respect to said tubular mandrel and its upper end vertically moveable with said annular piston, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the downward displacement of said annular piston; an upper reciprocable sleeve enclosing said helical spring and reciprocable with the upper end thereof, and a lower stationary sleeve supported on said tubular mandrel without vertical reciprocation, said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings encircling said tubular mandrel, including an upper reciprocable bearing between said annular piston and said reciprocable sleeve to permit relative rotation between said reciprocable sleeve and said tubular mandrel, and a lower non-reciprocable bearing between said tubular mandrel and said stationary sleeve to permit relative rotation between said stationary sleeve and said mandrel; walls in at least one of said bearings defining an annular lubricant chamber for the storage of lubricant under pressure but in communication with the bearing surfaces of said bearing; an annular ring-shaped piston reciprocable in said annular lubricant chamber longitudinally with respect to said tubular mandrel, said annular piston being in open communication with drilling mud in said bore hole on the end of said annular piston opposite the portion of said annular lubricant chamber containing lubricant; a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said reciprocable sleeve, and projecting through a longitudinal opening in the wall of said stationary sleeve; a plurality of swinging links along each side of said shoe, moveably connecting said shoe to said reciprocable sleeve, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting through said shoe opening in said stationary sleeve to engage said bore hole sidewalls; and

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a link means moveably connecting said shoe to said stationary sleeve and restricting the movement of said shoe from said rest position to said extended position upon the telescoping of said reciprocable sleeve and stationary sleeve by the displacement of said annular piston.

9. In a drilling system in which drilling liquid is conducted through an axial passage in a rotating drill string to a drill bit carried in a bit-carrying part at the lower end of said drill string, a drill deflecting means for engaging the sidewalls of a bore hole and deflecting said drill bit from straight-line drilling, which means includes: a flexible coupling comprised of two relatively deflectable parts longitudinally connected to each other, said coupling forming a part of said drill string near the lower end thereof; a flexible hose-like conduit means providing liquid-tight passage for said drilling liquid through said flexible coupling; an elongated hydraulic system housing coupled at its upper end to the lower end of said flexible coupling, and enclosing an annular reservoir for hydraulic liquid; a tubular mandrel coupled at its upper end to the lower end of said hydraulic system housing and at its lower end to said bit-carrying part of said drill string; a tubular bladder longitudinally disposed in said hydraulic system housing and forming a part of a passage for the flow of drilling liquid from said drill string through said hydraulic housing to the interior of said tubular mandrel and thence to said drill bit, said bladder serving as a flexible but impenetrable barrier between said drilling liquid passing through said axial drilling liquid passage and hydraulic fluid in said annular hydraulic fluid reservoir; an annular piston encircling said tubular mandrel and freely reciprocable on said mandrel near its upper end; walls extending downwardly from said hydraulic system housing and defining a hydraulic actuating chamber for the reception of the upper end of said annular piston, said hydraulic actuating chamber being in communication with said annular hydraulic fluid reservoir, and providing for the displacement of hydraulic fluid from said hydraulic fluid reservoir to said hydraulic actuating chamber when said bladder is distended by the passage through its interior of drilling liquid under pressure, whereby said annular piston is hydraulically actuated downwardly; a helical spring encircling said tubular mandrel below said annular piston, said helical spring having its lower end fixed against longitudinal movement

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with respect to said tubular mandrel and its upper end vertically moveable with said annular piston, whereby said spring urges said piston upwardly into said hydraulic actuating chamber and is compressed by the downward displacement of said annular piston; an upper reciprocable sleeve enclosing said helical spring and reciprocable with the upper end thereof, and a lower stationary sleeve supported on said tubular mandrel without vertical reciprocation, said reciprocable sleeve being telescopically received in said stationary sleeve; a pair of bearings encircling said tubular mandrel, including an upper reciprocable bearing between said annular piston and said reciprocable sleeve to permit relative rotation between said reciprocable sleeve and said tubular mandrel, and a lower non-reciprocable bearing between said tubular mandrel and said stationary sleeve to permit relative rotation between said stationary sleeve and said mandrel, a vertically elongated shoe for engaging the sidewalls of the bore hole disposed longitudinally on said reciprocable sleeve, and projecting through a longitudinal opening in the wall of said stationary sleeve; a plurality of swinging links along each side of said shoe, moveably connecting said shoe to said reciprocable sleeve, said connecting links permitting the movement of said shoe between a retracted position against said reciprocable sleeve and an extended position projecting through said shoe opening in said stationary sleeve to engage said bore hole sidewalls; and a link means moveably connecting said shoe to said stationary sleeve and restricting the movement of said shoe from said rest position to said extended position upon the telescoping of said reciprocable sleeve and stationary sleeve by the displacement of said annular piston.

References Cited in the file of this patent

UNITED STATES PATENTS

1,608,158	Benson	Nov. 23, 1926
2,584,705	Hornschuch	Feb. 5, 1952
2,712,434	Giles et al.	July 5, 1955
2,730,328	Brown	Jan. 10, 1956
2,743,082	Zublin	Apr. 24, 1956
2,891,769	Page et al.	June 23, 1959
2,915,286	Wright	Dec. 1, 1959
2,942,666	True et al.	June 28, 1960