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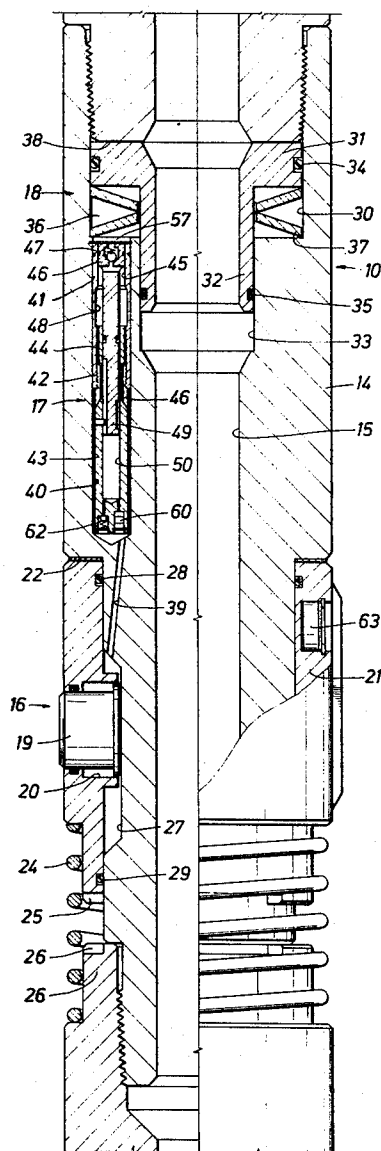
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[54] **DIRECTIONAL DRILLING APPARATUS**
13 Claims, 5 Drawing Figs.

[52] U.S. Cl. 175/73
[51] Int. Cl. E21b 7/08
[50] Field of Search 175/61, 73,
76

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ABSTRACT: As a preferred embodiment of the invention disclosed herein, a new and improved tool carrying a drill bit on its lower end is dependently coupled from a drill string and lowered into a borehole which is to be excavated along a selected axis. One or more pressure-responsive wall-engaging members are operatively arranged on the tool in such a manner that, when correctly oriented and actuated, the drill bit will be diverted in a desired lateral direction. Pressure-actuated control means are arranged on the tool for selectively extending the wall-engaging members in response to deliberate changes in the circulating pressure.



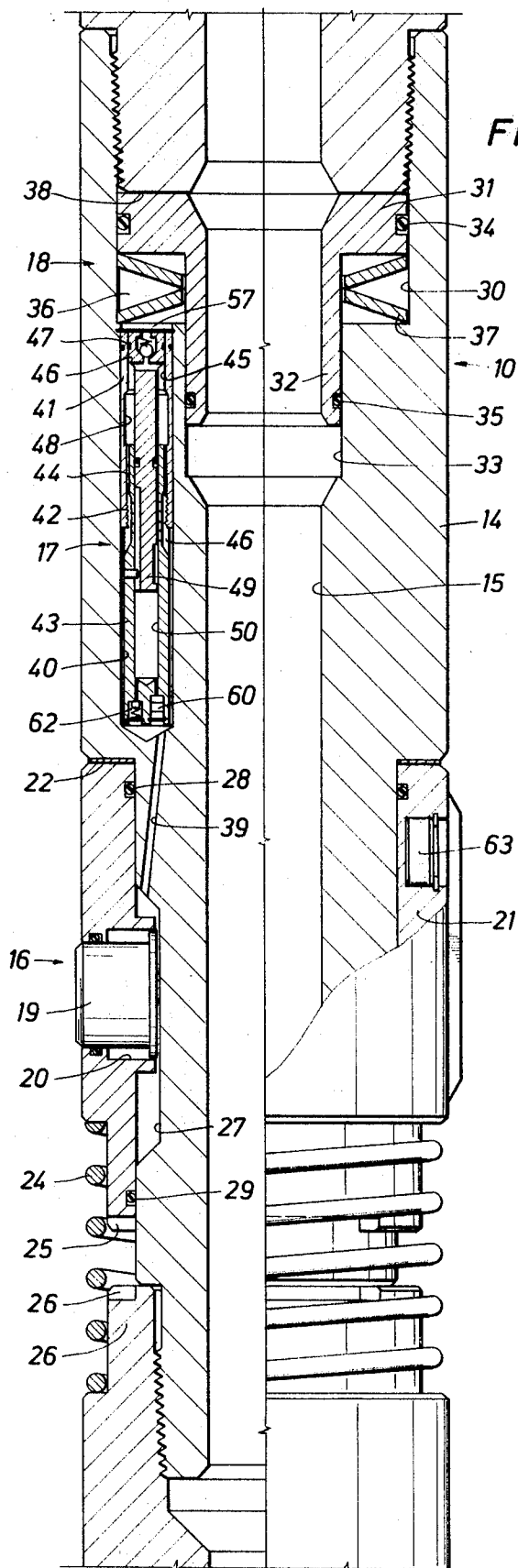


FIG. 2

FIG. 1

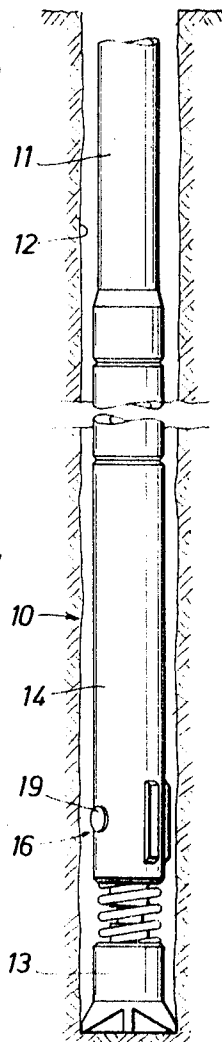
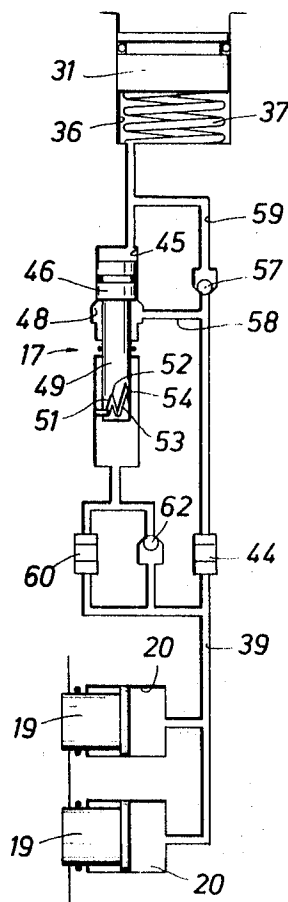


FIG. 3



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FIG. 4

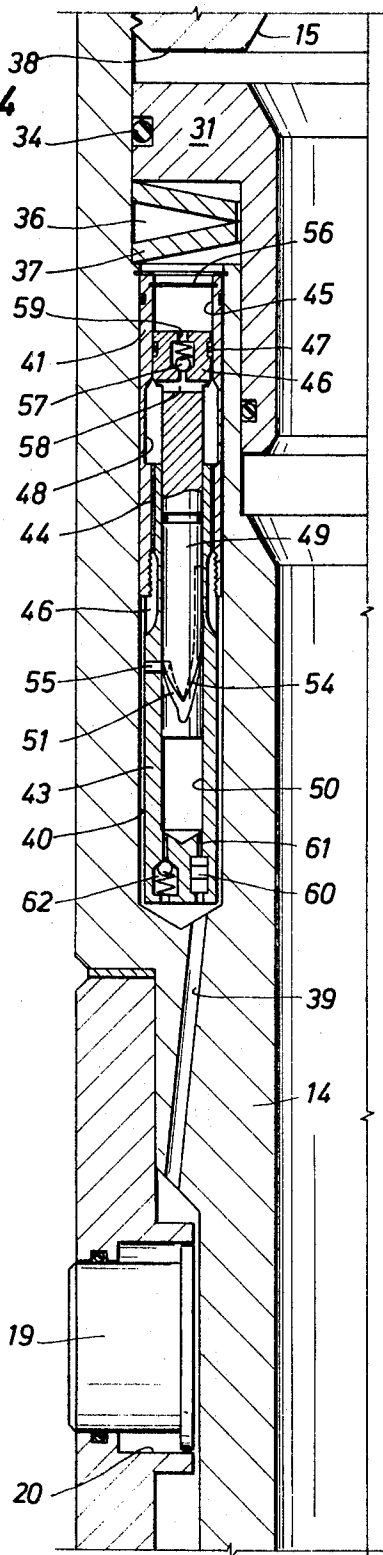
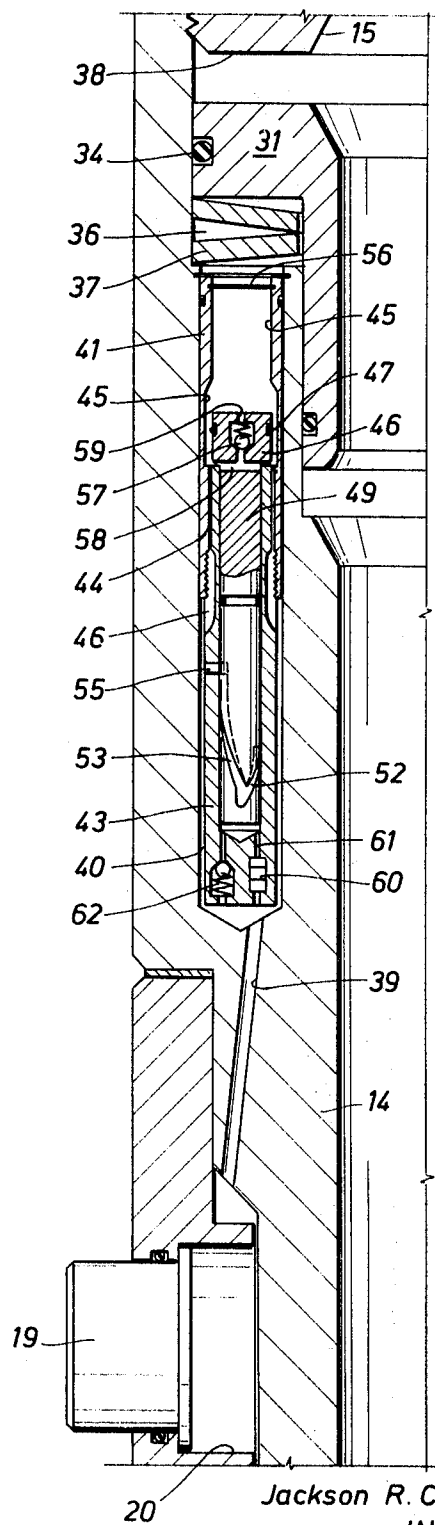


FIG. 5



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DIRECTIONAL DRILLING APPARATUS

In drilling an oil well, it is well known that variations in the weight applied to the drill bit, the rotative speed, and the rotative direction will often inadvertently deviate the borehole from its intended axis. On the other hand, in many drilling operations it may be necessary to drill a deviated borehole having a desired inclination as well as a selected azimuthal orientation. In such situations, the drill bit is deliberately diverted so as to pass a borehole obstruction or to reach a specified target area that is at a considerable depth and horizontal displacement from the drilling rig at the surface.

It has been the usual practice heretofore to employ so-called "whipstock" tools or the like for either deviating a borehole toward a desired location or returning it to an intended axis. Some typical whipstock tools include a wedgelike body that is slidably mounted on the drill string and has an inclined longitudinal face. Once this slidably mounted body is positioned in a desired orientation along one side of the borehole, a small-diameter drill bit on the drill string is advanced downwardly along the inclined face of the body and diverted accordingly in a desired direction and inclination to excavate a reduced-diameter pilot hole for some distance into the formation. The whipstock and smaller drill bit are removed from the borehole and a full-sized bit is then run in on the drill string to enlarge or ream the smaller pilot hole. This operation is repeated as many times as is necessary to accomplish the desired job.

To avoid such time-consuming whipstocking operations, other tools have also been employed which generally include an assembly having one or more manually positioned deflecting members arranged thereon. Once these deflecting members are secured in a desired configuration at the surface, the assembly is run into the borehole immediately above the drill bit. Then, once the tool assembly has been properly oriented from the surface, drilling is commenced and the fixed deflecting members will hopefully divert the drill bit along a desired axis. It will be appreciated, however, that with even such improved tools, the direction and inclination of the borehole must be frequently checked; and, if it is discovered that the borehole is not being deviated properly, the assembly must be returned to the surface for making corrective adjustments. It is readily apparent, of course, that even an infrequent return of the drill string and tool assembly to the surface for such adjustments constitutes a time-consuming and, therefore, an expensive operation.

Accordingly, it is an object of the present invention to provide new and improved apparatus for selectively guiding a drill bit as it progressively excavates a borehole without it being necessary to remove the drill string from the borehole during the course of the drilling operation for making corrective adjustments to the guiding apparatus.

This and other objects of the present invention are attained by providing a directional well-drilling tool having pressure-actuated guiding means operatively mounted above the drill bit and adapted for deflecting the drill bit along selected axes of excavation. To operate the guiding means, pressure-responsive control means are arranged on the tool in such a manner that operation of the guiding means is effectively accomplished simply by selectively varying the pressure of the drilling fluids flowing through the drill string.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. 1 depicts a preferred embodiment of a directional drilling tool arranged in accordance with the principles of the present invention as it may appear while drilling a borehole;

FIG. 2 is a cross-sectioned elevational view of the more-significant portions of the tool illustrated in FIG. 1;

FIG. 3 is a schematic view of the hydraulic system depicted in FIGS. 2; and

FIGS. 4 and 5 are views similar to FIG. 2 but respectively illustrate successive operating positions of various control elements of the directional drilling tool during the course of a typical operation.

Turning now to FIG. 1, a directional drilling tool 10 dependently coupled from the lower end of a typical tubular drill string 11 is shown as it may appear during the course of the excavation of a borehole 12. A typical drill bit 13 is operatively arranged on the lower end of the directional drilling tool 10 for operation in the usual manner upon rotation of the drill string 11 by a typical drilling rig (not shown) at the surface.

As illustrated in FIGS. 1 and 2, the directional drilling tool 10 has an elongated, thick-walled tubular body 14 with an axial bore 15 therethrough to accommodate the usual circulation of drilling fluids or so-called "mud" from the surface through the drill string 11 and appropriate discharge openings (not shown) in the drill bit 13 and back to the surface by way of the borehole 12. Pressure-actuated guiding means 16 are mounted on a lower portion of the tool body 14 and operatively connected by selectively-operable control means 17 to pressure-developing means 18 arranged thereabove on the tool and adapted for selectively developing fluid pressures for actuation of the guiding means.

As best seen in FIG. 2, the guiding means 16 preferably include one or more laterally movable pistons 19 that are respectively disposed in outwardly opening radial bores 20 arranged along one side of an annular member 21 that is movable mounted around the tool body 14 between longitudinally spaced opposed shoulders 22 and 23 thereon. To enable the annular member 21 to slide longitudinally in relation to the tool body 14, the shoulders 22 and 23 are spaced from the ends of the annular member. A compression spring 24 is, however, engaged between the lower shoulder 23 and the annular member 21 to normally position the annular member against the upper shoulder 22. For reasons that will subsequently be explained, opposed clutch members, such as one or more coengageable teeth 25 and 26, are respectively arranged on the lower end of the annular member 21 and the upwardly directed shoulder 23 therebelow for corotatively securing the annular member to the body 14 whenever the annular member and lower shoulder are brought together. It will be noted, however, that the spring 24 normally urges the upper end of the annular member 21 against the downwardly directed shoulder 22 so that the annular member is free to rotate in relation to the tool body 14.

To accommodate the lateral movements of the tool-guiding pistons 19, a circumferential recess 27 is formed around the tool body 14 and provides an adequate volumetric capacity for a suitable operating fluid such as oil or other hydraulic fluids (not shown) for properly actuating the pistons. Suitable sealing members, such as O-rings 28 and 29, are sealingly engaged between the tool body and the upper and lower ends, respectively, of the annular member to seal the annular space 27 defined between the body 14 and the movable member 21.

In the depicted preferred embodiment of the pressure-developing means 18, the internal bore 15 of the tool body 14 is substantially enlarged, as at 30, and receives an annular piston 31 having a reduced-diameter tubular guide 32 extending therebelow and slidably engaged with a slightly enlarged complementary portion 33 of the internal bore. Sealing members 34 and 35 are suitably arranged around the piston 31 and its depending guide 32, respectively, for sliding engagement with their associated portions of the tool body 14 and define an enclosed chamber 36 for containing a supply of the operating or hydraulic fluid. Spring means, such as one or more Belleville washers 37 coaxially disposed around the depending tubular portion 32, are operatively arranged in the piston chamber 36 for normally urging the piston 31 upwardly against an opposed body shoulder 38 defining the upper limit of the enlarged bore portion 30. It should be noted that the pressure of fluids in the longitudinal bore 15 will impose a cor-

responding downward force on the upper face of the piston 31.

Fluid communication is provided between the enclosed chambers 20 and 36 by suitable passage means such as a body passage 39 coupling the lower chamber to the lower end of an enlarged longitudinal bore 40 formed thereabove in the tool body 14 and having its upper end in communication with the upper chamber. As will subsequently be described in further detail, the selectively-operable control means 17 are operatively arranged in the enlarged longitudinal bore 40 and adapted for selectively communicating the pressure chambers 20 and 36 by certain operations at the surface.

It will be appreciated from FIG. 2 that the pressure-developing piston 31 will remain in its depicted position so long as the pressure of the circulating fluids in the longitudinal bore 15 through the tool body 14 is about equal to the hydrostatic pressure of the fluids in the borehole 12. It is preferred that the upwardly acting spring force of the Bellville washers 37 be selected so that at least a predetermined increase in the pressure of the circulating fluids in the longitudinal bore 15 will move the piston 31 downwardly. The operating fluids in the lower and upper piston chambers 20 and 36 will, of course, normally be at the hydrostatic pressure of the borehole fluids at whatever depth the tool 10 then occupies. Thus, since the tool-guiding pistons 19 are normally retracted, the pressure in the lower piston chamber 20 must be increased above the borehole pressure by developing an increased pressure in the upper piston chamber 36 to extend the tool-guiding pistons.

Those skilled in the art will, of course, recognize that during the course of typical drilling operations, the circulating fluids or mud must be maintained at sufficient pressures to achieve adequate fluid circulation through the drilling bit 13 for removing formation cuttings and transporting them upwardly in the borehole 12. Moreover, as the drilling bit 13 encounters varying formation conditions, the fluid pressures required to maintain sufficient mud circulation will vary in accordance with the formation conditions then being encountered.

Accordingly, the control means 17 for the tool 10 of the present invention are operatively arranged for selectively controlling communication between the piston chambers 20 and 36 without being inadvertently operated by variations in the pressure of the drilling fluids circulating through the tool. In the preferred manner of accomplishing this, a tubular valve body 41 is sealingly mounted in the upper portion of the enlarged longitudinal bore 40 and dependently carries, as by threads 42, an elongated cylindrical body 43 of a smaller diameter extending therebelow into the lower portion of the longitudinal bore. As depicted in FIG. 2, the upper end of the cylindrical body 43 is coaxially arranged within the lower end of the valve body 41 to provide an annular flow restriction 44 between the axial bore 45 of the valve body and one or more longitudinal grooves 46 formed around the exterior of the extension and opening into the lower portion of the longitudinal bore 40. An enlarged-diameter valve member 46 is operatively arranged within the axial bore 45 of the valve body 41 for sliding movement therein between the depicted elevated fluid-blocking position and a lower fluid-communicating position where the sealing member 47 mounted around the valve member is disposed within an enlarged portion 48 of the axial bore. To guide the upward and downward movements of the valve member 46, an axial control rod 49 is dependently supported below the valve member and coaxially arranged within an axial bore 50 in the cylindrical body 43 which preferably terminates just above the lower end of the body.

Accordingly, as will be appreciated from FIG. 2, the valve member 46 and the upper axial bore 45 in the tubular body 41 are operatively proportioned to block fluid communication between the piston chambers 20 and 36 until the valve member has traveled downwardly a sufficient distance to bring the sealing member 47 into the enlarged-diameter bore 48 in the tubular valve body. Once, however, the valve member 46 reaches the enlarged bore 48, communication will be established between the piston chambers 20 and 36 by way

of the reduced annular restriction 44, the annular clearance between the cylindrical body 43 and the internal wall of the enlarged-diameter bore 40, and the fluid passage 39.

It will, of course, be appreciated that upon an increased fluid pressure of the circulating fluids in the longitudinal bore 15, the resulting downward movement of the pressure-developing piston 31 will develop a correspondingly increased fluid pressure in the upper piston chamber 36 that will be effective for shifting the valve member 46 downwardly in relation to the valve body 41. Accordingly, in the preferred manner of regulating the movements of the valve member 46, cam means are provided such as four steeply inclined, alternately directed grooves 51—54 formed at uniform intervals around the depending guide rod 49 to provide a continuous alternating path around the rod in which a cam member or pin 55 projecting inwardly from the body 43 is received. Thus, by beginning at any given point in any of the grooves 51—54, an uninterrupted, upward and downward path can be traced by following the alternate changes in direction of the interconnected grooves around the rod 49 and on back to the initial starting point.

As will be noted by examination of FIGS. 2, 4 and 5, two of the grooves 51 and 52 are shorter than the other two grooves 53 and 54, and these shorter grooves are joined to one another at their upper ends with their lower ends respectively joining the lower ends of each of the longer grooves. In this manner, by confining the free end of the cam pin 55 within the labyrinthlike system of grooves 51—54, the valve member 46 will be alternately halted at an intermediate fluid-blocking position (FIG. 4) and a lower fluid-communicating position (FIG. 5) upon successive downward movements of the valve member. By arranging the lower ends of the four grooves 51—54 to be at the same elevation on the guide rod 49, the valve member 46 will be returned to its elevated fluid-blocking position (FIG. 2) each time the valve member is shifted upwardly. It will, of course, be appreciated that as the valve member 46 is successively moved upwardly and downwardly, the cam pin 55 will cooperate with the several cam grooves 51—54 to also progressively rotate the valve member about its longitudinal axis.

To better appreciate the operation of the tool 10 of the present invention, a schematic diagram is depicted in FIG. 3 of the pressure-developing piston 31, the tool-guiding pistons 19, and the control means 17. As illustrated there, so long as the pressure-developing piston 31 remains in its elevated position, the valve member 46 will remain in the reduced-diameter bore 45 so as to block fluid communication between the lower and upper piston chambers 20 and 36. On the other hand, whenever the pressure-developing piston 31 is urged downwardly by an increase in the pressure of the circulating fluids flowing through the tool 10, the resulting increase in pressure within the upper chamber 36 will shift the valve member 46 downwardly to either its intermediate fluid-blocking position or its lower fluid-communicating position depending upon whether the cam pin 55 is in the shorter groove 51 or in the longer groove 53. If, for example, the cam pin 55 is in the shorter inclined groove 51, the downward movement of the valve member 46 will be halted once the shoulder defined by the junction of the upper ends of the two shorter grooves 51 and 52 engages the cam pin. At this point, the sealing member 47 on the valve member 46 will still be sealingly engaged within the reduced-diameter bore 45 in the upper portion of the tubular valve body 41 so as to continue blocking fluid communication between the lower and upper piston chambers 20 and 36. On the other hand, whenever the cam pin 55 is confined in the longer groove 53, downward movement of the pressure-developing piston 31 will be effective for shifting the valve member 46 downwardly until the shoulder at the junction of the upper ends of the longer grooves 53 and 54 engages the cam pin. Once this occurs, the lower face of the valve member 46 will be adjacent to the lower end of the enlarged bore 48 in the valve body 41.

It will, of course, be appreciated that upward movement of the valve member 46 will be readily accomplished by simply reducing the pressure in the internal bore 15 through the tool body 14 to the hydrostatic pressure in the borehole 12 so as to allow the pressure-developing piston 31 to be returned upwardly by the Bellville washers 37. Thus, as the pressure-developing piston 31 is returned upwardly, the pressure in the lower piston chamber 20 will be reduced and the tool-guiding pistons 19 will be returned inwardly by the hydrostatic pressure in the borehole 12 acting thereon. The decreased pressure in the upper piston chamber 36 will, of course, allow the valve member 46 to be returned upwardly until it again contacts a stop member 56 at the upper end of the valve body 41.

Accordingly, by alternately raising the pressure of the circulating fluids in the tool 10 above the borehole hydrostatic pressure and then decreasing this pressure to about the borehole hydrostatic pressure, the valve member 46 will be successively moved downwardly and returned upwardly. As previously explained, on alternate increases of the circulating pressure, the valve member 46 will merely be shifted downwardly to its intermediate fluid-blocking position; and, following a reduction in the circulating pressure, the next increase in circulating pressure will be effective for shifting the valve member downwardly to its lower fluid-communicating position.

It will be appreciated that once the seal 47 on the enlarged valve member 46 begins to enter the enlarged bore 48 in the valve body 41, the increased fluid pressure thereabove will tend to decrease as fluid communication is established with the lower piston chamber 20. Thus, should the pressure be substantially equalized across the enlarged valve member 46, further downward travel of the valve member to its fluid-communicating position would usually cease. This would, however, not allow the valve member 46 to move a sufficient distance downwardly to enable the cam pin 55 to enter the next adjacent one of the cam grooves 51-54 whenever the circulating pressure is again reduced. As a result, even though the valve member 46 would be returned upwardly by a subsequent reduction of fluid pressure in the internal tool bore 15, the next increase of the circulating pressure would simply repeat the cycle so that the valve member would merely shift part way back and forth between its elevated position and its fully opened position. This would, of course, not allow the valve member 46 to be sequentially opened and closed in the desired manner of operation of the tool 10.

Accordingly, to assure that the valve member 46 will be stroked its full extent of travel each time it is moved toward its lower fluid-communicating position, a flow restriction or orifice is arranged between the enlarged bore 48 and the flow passage 39. The narrow or restricted annular clearance space 44 defined between the coaxially arranged members 41 and 43 is, therefore, the preferred manner of providing this flow restriction. It will be noted from FIG. 2 that once the pressured fluid passes from the enlarged bore 48 through the restricted annular clearance 44 and the longitudinal grooves 46, a relatively uninterrupted path is provided to the passage 39 therebelow by the annular space between the internal wall of the longitudinal bore 40 and the exterior of the cylindrical body 43. As a result, as the valve member 46 is being moved downwardly to its fluid-communicating position, the annular orifice 44 will prevent a significant increase in fluid pressure in the longitudinal bore 40 below the orifice as the sealing member 47 first enters the enlarged bore 48. Thus, the annular flow restriction 44 will maintain an effective pressure differential acting on the upper face of the valve member 46 which will be sufficient for moving the valve member completely downwardly until the cam pin 55 has come to rest on the downwardly directed shoulder formed at the upper junction of the grooves 53 and 54.

It will, of course, be appreciated that as the valve member 46 is being reclosed and reaches its intermediate fluid-blocking position, further fluid communication is blocked between the lower and upper piston chambers 20 and 36.

Thus, to provide a bypass around the valve member 46 for the hydraulic fluid in the lower piston chamber 20 to return to the upper piston chamber 36 so that the tool-guiding pistons 19 can be fully retracted, a check valve assembly 57 is mounted in the enlarged head 46 and coupled by means of suitable passages as at 58 and 59 for permitting the flow of hydraulic fluid between the enlarged bore portion 48 and the upper piston chamber 36 but preventing flow in the opposite direction.

Once the valve member 46 is in its fluid-communicating position, inward movements of the tool-guiding pistons 19 will, of course, develop corresponding increased pressures in the lower piston chamber 20 tending to reclose the valve member. Although the valve member 46 has a considerable travel span before it recloses the reduced bore 45, it is nevertheless preferred to dampen any momentary pressure differential tending to reclose the valve member. Accordingly, in the preferred manner of accomplishing this, a fluid restrictor such as one or more serially arranged orifices or chokes 60 and passages 61 are provided to permit fluid communication between the passage 39 and the internal bore 50 of the cylindrical member 43 below the lowermost position of the guide rod 49. In this manner, a momentary increase of the fluid pressure in the fluid passage 39 that would otherwise tend to elevate the valve member 46 will be at least partially dampened by the orifices 60.

It will, of course, be appreciated that to facilitate the downward movement of the valve member 46, fluids trapped in the reduced bore 50 below the lower end of the guide rod 49 should be rapidly exhausted to maintain a substantial pressure differential that is effective for moving the valve member downwardly to its fluid-communicating position before the fluid pressure across the annular orifice 44 has equalized. The orifices 60 will, however, tend to limit the rate at which these trapped fluids can be exhausted. Accordingly, a second check valve assembly 62 is mounted in the lower end of the cylindrical body 43 and operatively arranged therein in parallel with the orifices 60 for readily opening to permit fluid flow only from the bore 50 to the flow passage 39.

Return of the valve member 46 from either of its two lower positions to its uppermost position is, of course, accomplished upon reduction of the circulating pressure in the internal bore 15 of the tool 10. Thus, by simply reducing the pressure in the internal bore 15 to about the hydrostatic pressure of the fluids in the borehole 12, the pressure-developing piston 31 will be returned upwardly by the Bellville washers 37 to its position as illustrated in FIG. 2. The upward movement of the pressure-developing piston 31 will, of course, create a momentary pressure reduction within the upper piston chamber 36 so that the hydrostatic pressure acting on the tool-guiding pistons 19 will shift the valve member 46 upwardly by virtue of the increased pressure on the lowermost end of the depending guide rod 49. As previously described, although the check valve assembly 62 will not permit fluid to flow into the internal bore 50 from the passageway 39, the orifices 60 in parallel with the check valve assembly will admit fluid from the passageway into the internal bore at a sufficient rate to assure that the valve member 46 is fully reclosed and that the cam pin 55 is at the lower junction of two adjacent ones of the grooves 51-54.

To employ the tool 10 of the present invention, a drill bit, such as at 13 in FIG. 1, is coupled to the lower end of the tool and this assembly is, in turn, dependently coupled to a drill string as at 11 which is, of course, progressively assembled at the surface to lower the tool and the drill bit into the borehole 12. Once the tool 10 reaches the bottom of the borehole 12 and the drilling fluids are being circulated through the drill string 11, the pressure-developing piston 31 will be urged downwardly to develop an increased fluid pressure in the upper piston chamber 36. As previously described, however, by orienting the valve member 46 so as to position the shoulder at the upper junction of the shorter cam grooves 51 and 52 against the cam pin 55, the valve member will initially be in its intermediate fluid-blocking position (FIG. 4) and the

tool-guiding pistons 19 will remain retracted. Accordingly, continued excavation of the borehole 12 can proceed in the usual manner so long as the pistons 19 are retracted.

It will, of course, be appreciated that momentary reductions in the circulating pressure will often occur such as, for example, when the circulation of the drilling fluids is momentarily ceased to permit additional lengths of pipe to be joined to the drill string 11. As previously described, even such a momentary decrease in the circulating fluid pressure will be effective for returning the valve member 46 to its fully elevated position (FIG. 2). As a result, when the circulation is again resumed, the valve member 46 will then be moved to its fluid-communicating position (FIG. 5). To prevent the unwanted diversion of the drilling bit 13, the circulation of the drilling fluid must again be momentarily reduced or halted to return the valve member 46 to its uppermost position. Thereafter, upon resumption of the fluid circulation, the valve member 46 will be repositioned in its intermediate fluid-blocking position (FIG. 4) so that drilling can continue without the tool-guiding pistons 19 being extended.

Once it is determined that the drill bit 13 should be diverted in a selected direction in accordance with the particular circumstances, the valve member 46 is deliberately actuated so as to shift it to its fluid-communicating position. To accomplish this, since the valve member 46 is in its intermediate fluid-blocking position, the fluid circulation is again momentarily ceased to restore the valve member to its elevated position (FIG. 2). Thereafter, upon resumption of the circulation, the increased fluid pressure will be effective for shifting the valve member 46 to its fully opened position (FIG. 5) and the tool-guiding pistons 19 will be extended outwardly into contact with the walls of the borehole 12.

It will, of course, be appreciated that the angular position of the tool-guiding pistons 19 in relation to the tool body 14 will not be known since the annular member 21 is rotatably mounted on the tool body. Although other techniques can be employed to ascertain the angular position of the tool-guiding pistons 19 in relation to the tool body 14, in one manner of determining this relationship, a typical borehole-orienting device such as one of those shown on Pages 1786—1793 of the 1968—1969 Composite Catalog of Oil Field Equipment and Services can be lowered through the drill string 11 and alternately moved to one position for determining true north and then into another position adjacent to the annular member 21 for detecting the angular position of an indicator, such as, for example, a magnet 63 mounted on the annular member 21 in a known angular position in relation to the tool-guiding pistons 19. From successive readings of this nature, it will, therefore, be known how the pistons 19 are to be positioned to accomplish a desired deviation of the bit 13. With a magnet, such as at 63, the annular member 21 and at least the adjacent portions of the tool body 14 must, of course, be made of a suitable nonmagnetic material. Other means such as downhole signaling devices associated with the tool 10 can, of course, be arranged to provide the necessary signals at the surface for angularly positioning the member 21 and pistons 19.

Irrespective of the particular technique used to ascertain the angular position of the tool-guiding pistons 19 in relation to the tool body 14, once this determination has been made, the drill string 11 is raised sufficiently to coengage the opposed clutch teeth 25 and 26. It will be recalled that, at this time, the tool-guiding pistons 19 are extended to secure the annular member 21 and permit the tool body 14 to be moved upwardly in relation thereto. Once the clutch teeth 25 and 26 are coengaged, the drill string 11 is rotated as required to position the tool-guiding pistons 19 at a selected angular position on the borehole wall. Although the pistons 19 are extended, sufficient torque can be readily applied to the drill string 11 along with any necessary reduction in circulating pressure to rotate the annular member 21 as required to move the tool-guiding pistons to a desired angular position in the borehole 12. Thereafter, once the drill string 11 is lowered to disengage the clutch teeth 25 and 26, further drilling will result in

the drill bit 13 being deviated away from the wall of the borehole 12 against which the tool-guiding pistons 19 are then engaged.

It will be realized, of course, that each time the circulation of the drilling fluid is ceased such as when an additional joint of pipe is added to the drill string 11, the circulation pressure will have to be momentarily increased and then temporarily halted before again being raised to resume drilling so that the valve member 46 will again be restored to its fully open position to maintain the tool-guiding pistons 19 firmly engaged against the wall of the borehole 12. Periodic or continuous checks can, of course, be made with suitable direction-determining devices to determine the course of the drilling bit 13 and, if necessary, make further corrections to the angular position of the tool-guiding pistons 19 in relation to the tool body 14. In any event, once the borehole 12 has been deviated sufficiently, the valve member 46 can again be closed and then, if further drilling is necessary, again moved to its intermediate fluid-blocking position to enable the resumption of drilling in the usual manner.

In any event, it will be appreciated that the present invention has provided a new and improved tool which is selectively operable for guiding a drill bit as it progressively excavates the borehole, with this guidance being accomplished during the course of the drilling operation without it being necessary to remove the drill string from the borehole to make corrective adjustments. By arranging the pressure-actuated guiding means 10 above the drill bit 13 for selectively deflecting it along a selected axis, the disclosed control means 17 will permit the tool-guiding pistons 19 to be extended simply by varying the pressure of the drilling fluids circulating through the drill string 11.

While a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What I claim is:

1. Apparatus adapted for controlling the direction in which a borehole is being excavated and comprising: a body adapted for connection in a drill string including a borehole-excavating device; pressure-developing means on said body and operable for developing increased pressures in response to selected changes in the pressures of fluids being circulated through a drill string coupled to said body during the excavation of a borehole by a borehole-excavating device coupled thereto; wall-engaging means on said body and operable in response to increased pressures applied thereto for shifting said body laterally in relation to the axis of a borehole being excavated by a borehole-excavating device coupled to said body; and control means on said body and operable in response to selected changes in the pressures of such circulating fluids for selectively coupling said pressure-developing means to said wall-engaging means for operation of said wall-engaging means.

2. The apparatus of claim 1 wherein said pressure-developing means are operable in response to selected increases in the pressures of such circulating fluids.

3. The apparatus of claim 2 wherein said control means are operable in response to selected increases in the pressures of such circulating fluids.

4. The apparatus of claim 1 wherein said control means include first and second pressure conduits respectively coupled to said pressure-developing means and said guiding means, valve means adapted for movement relative to said body for selectively regulating pressure communication between said first and second conduits, and pressure-responsive actuating means coupled to said valve means and operable in response to selected increases in the pressures of such circulating fluids for selectively moving said valve means to a position for establishing pressure communication between said first and second conduits.

5. The apparatus of claim 4 wherein said valve means include a valve member adapted for opening and closing pressure communication between said first and second conduits upon movement of said valve member between selected positions; and said actuating means include a pressure-responsive actuating member operatively coupled to said pressure-developing means and adapted for moving said valve member to its said selected positions in response to predetermined changes in the pressures developed by said pressure-developing means.

6. The apparatus of claim 1 wherein said control means include first and second pressure conduits respectively coupled to said pressure-developing means and said guiding means, valve means adapted for movement relative to said body for selectively regulating pressure communication between said first and second conduits, means operatively arranged between said valve means and said body for alternately halting said valve means in a first position blocking pressure communication between said first and second conduits upon a first movement of said valve means and halting said valve means in a second position opening pressure communication between said first and second conduits upon a second movement of said valve means, and pressure-responsive actuating means coupled between said valve means and said pressure-developing means and operable in response to selected changes in the pressures developed by said pressure-developing means for moving said valve means.

7. The apparatus of claim 6 wherein said pressure-developing means are operable in response to selected increases in the pressures of such circulating fluids.

8. The apparatus of claim 7 wherein said pressure-responsive actuating means are operable in response to alternate increases and decreases in the pressures developed by said pressure-developing means.

9. A directional drilling tool comprising: an elongated body having a longitudinal circulating fluid passage therethrough and adapted for connection in a rotating drill string including a borehole-excavating device; wall-engaging means rotatably mounted on said body and including at least a first piston operatively arranged in a first chamber for lateral movement between retracted and extended positions in relation to said body; pressure-developing means on said body in communication with said longitudinal passage and including a second piston operatively arranged in a second chamber and adapted for movement from a first position to a second position in response to increases in the pressure of circulating fluids in said longitudinal passage for developing correspondingly increased pressures in a hydraulic fluid within said second chamber; control means adapted for selectively intercoupling said first and second pistons and including first and second

conduits respectively coupled to said first and second chambers, valve means movably mounted on said body for movement between spaced positions and operatively arranged for selectively regulating communication between said first and second conduits in accordance with the position of said valve means, and valve-actuating means operable in response to selected changes in the pressure of such circulating fluids for selectively moving said valve means between said spaced positions; and clutch means operatively arranged between said wall-engaging means and said body for selectively securing said wall-engaging means in selected angular positions on said body.

10. The directional drilling tool of claim 9 wherein said valve-actuating means include a pressure-responsive actuator, and a third conduit coupling said pressure-responsive actuator to said second chamber for communicating increased pressures developed therein to said pressure-responsive actuator for operating said valve means.

11. The directional drilling tool of claim 10 wherein said valve means are movable between a first and a second one of said spaced positions upon an increase of pressure in said second chamber for intercoupling said first and second chambers only when said valve means are in said second position; and said valve-actuating means further include means operatively coupled to said valve means for alternately blocking movement of said valve means to said second position and permitting movement of said valve means to said first position upon successive increases of pressure in said second chamber.

12. The directional drilling tool of claim 10 wherein said valve means include a valve member operatively arranged on said body for movement relative thereto between first, second and third ones of said spaced positions and adapted for intercoupling said first and second chambers only when said valve member is in its said third position; and said actuating means include cam means operatively arranged between said body and said valve member for progressively indexing said valve member to each of its said positions upon successive increases of pressure in said second chambers.

13. The directional drilling tool of claim 10 wherein said valve means include a valve member operatively arranged on said body for movement relative thereto between first, second and third ones of said spaced positions and adapted for intercoupling said first and second chambers only when said valve member is in its said third position; and said actuating means include cam means operatively arranged between said body and said valve member for progressively indexing said valve member to each of its said positions upon successive cycles of an increase of pressure in said second chamber followed by a decrease of pressure therein.