United States Patent

[11] 3,593,810

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[45] Patented **July 20, 1971**

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New York, N.Y.

[54] **METHODS AND APPARATUS FOR DIRECTIONAL DRILLING**
37 Claims, 28 Drawing Figs.

[52] **U.S. Cl.** **175/61,** 175/76
[51] **Int. Cl.** **E21b 7/08,** E21b 7/04
[50] **Field of Search** 175/73, 61, 74, 76

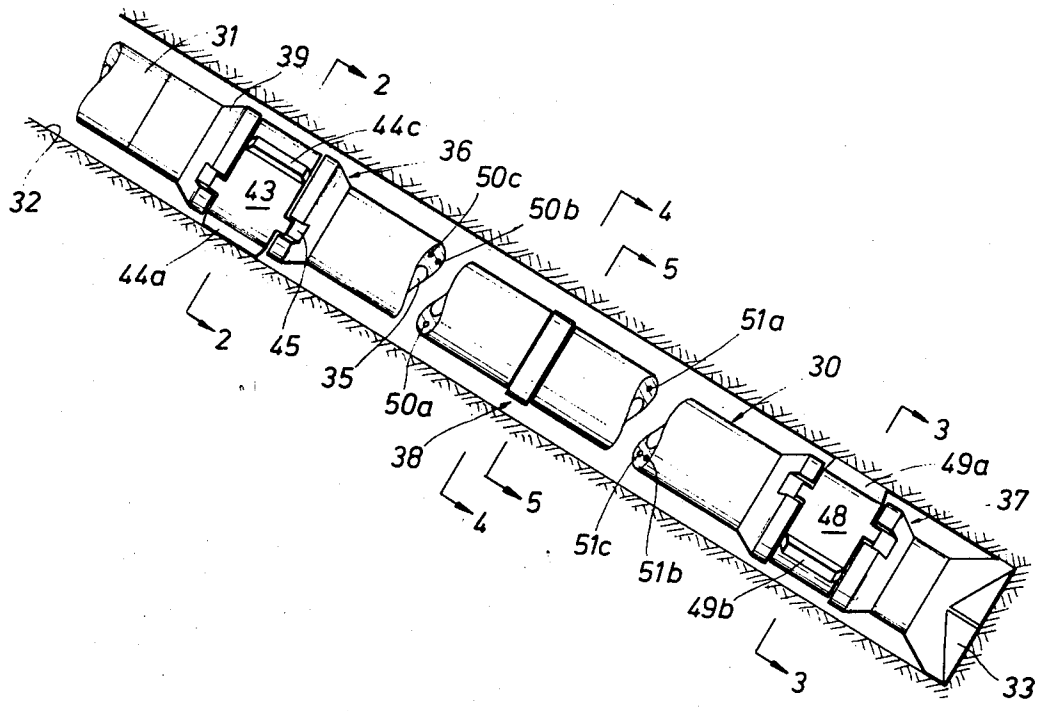
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Primary Examiner—James A. Leppink
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ABSTRACT: In each of the several embodiments of the apparatus of the invention disclosed herein, a new and improved tool carrying a drill bit is dependently coupled from a drill string and lowered into a borehole which is to be excavated in a desired direction. First and second sets of wall-engaging members are operatively arranged around the tool in such a manner that as the weight of the rotating tool is successively supported by each of the first members, commensurate outwardly directed forces will be successively imposed on each of the second members for urging the drill bit in a desired lateral direction. Various controls adapted for operation from the surface of the earth are disclosed for selectively interconnecting the first and second wall-engaging members so as to either maintain the course of the drill bit along a vertical axis or else to direct the drill bit in a selected azimuthal direction and inclination. In practicing the methods of the present invention, a tool arranged in accordance with the invention and having a drill bit connected thereto is coupled in a drill string and positioned in a borehole. Depending upon the particular tool, the controls on the directional drilling tool are then regulated from the surface to direct the drill bit along a selected source for continuing the excavation of the borehole.



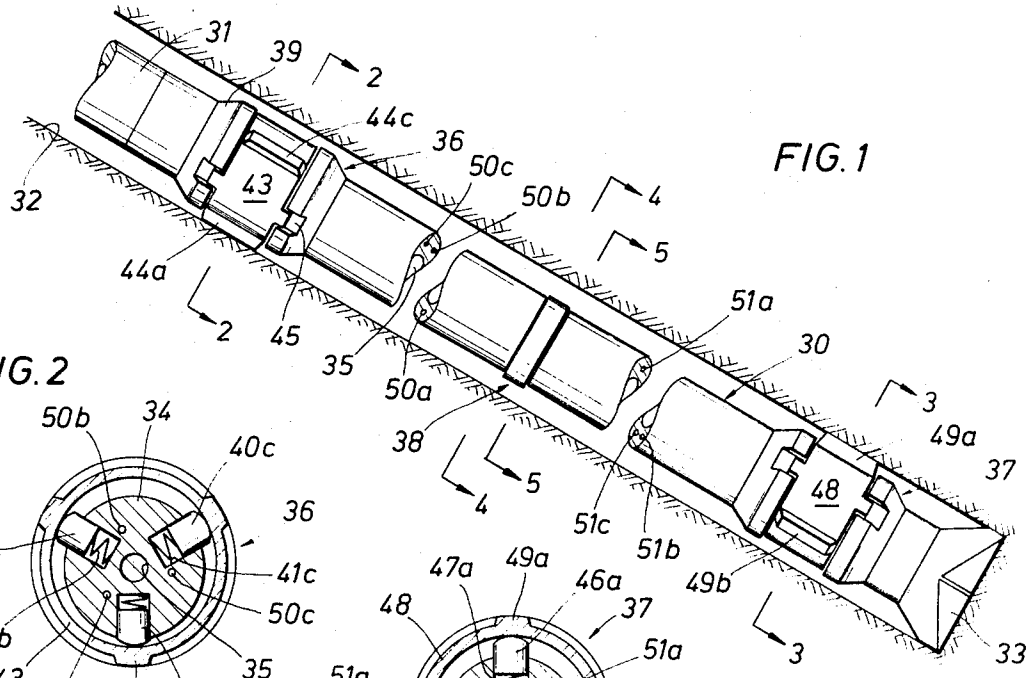


FIG. 1

FIG. 2

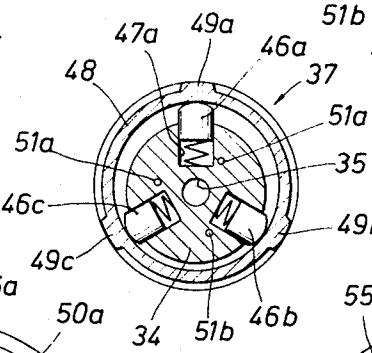
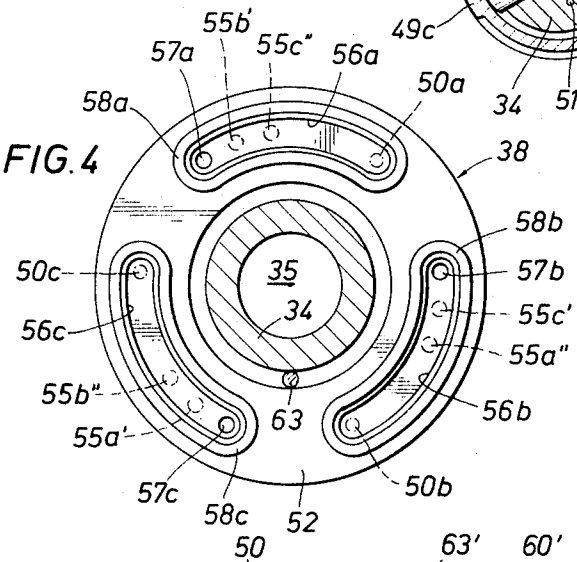


FIG. 3

FIG. 4



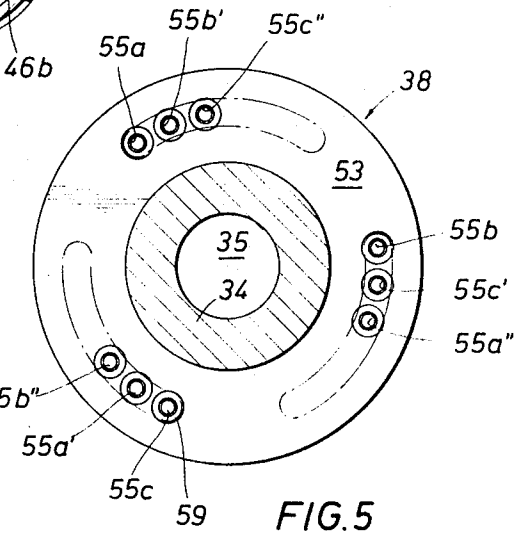


FIG. 5

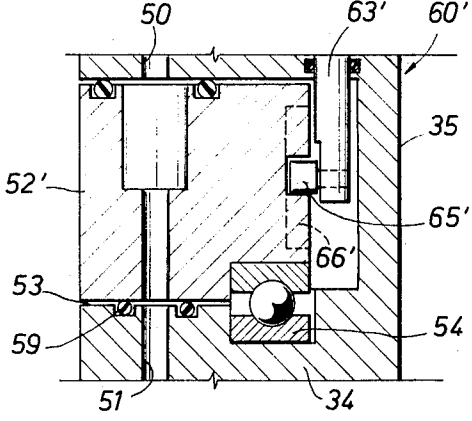


FIG. 10

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FIG. 6

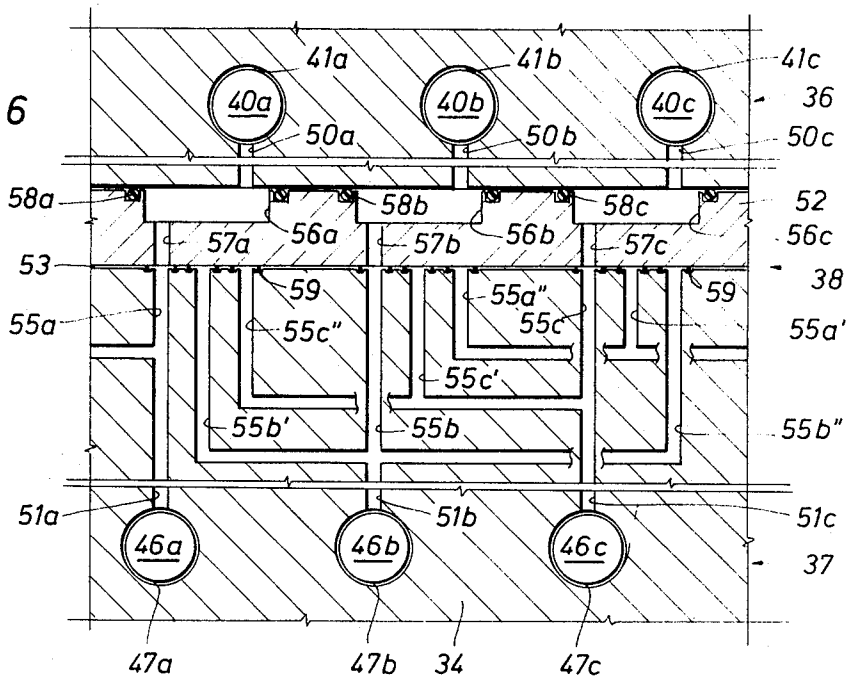


FIG. 7

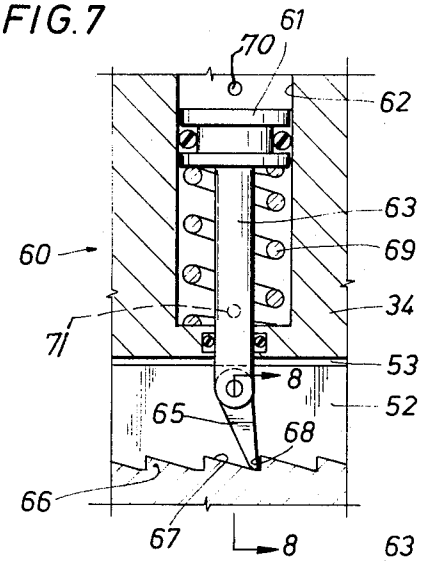


FIG. 8

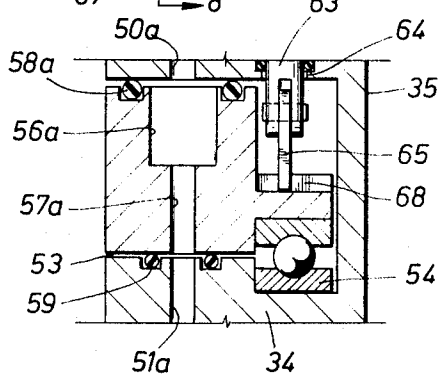
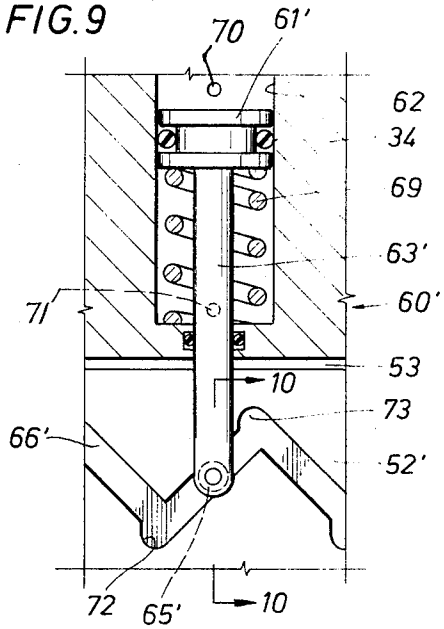


FIG. 9



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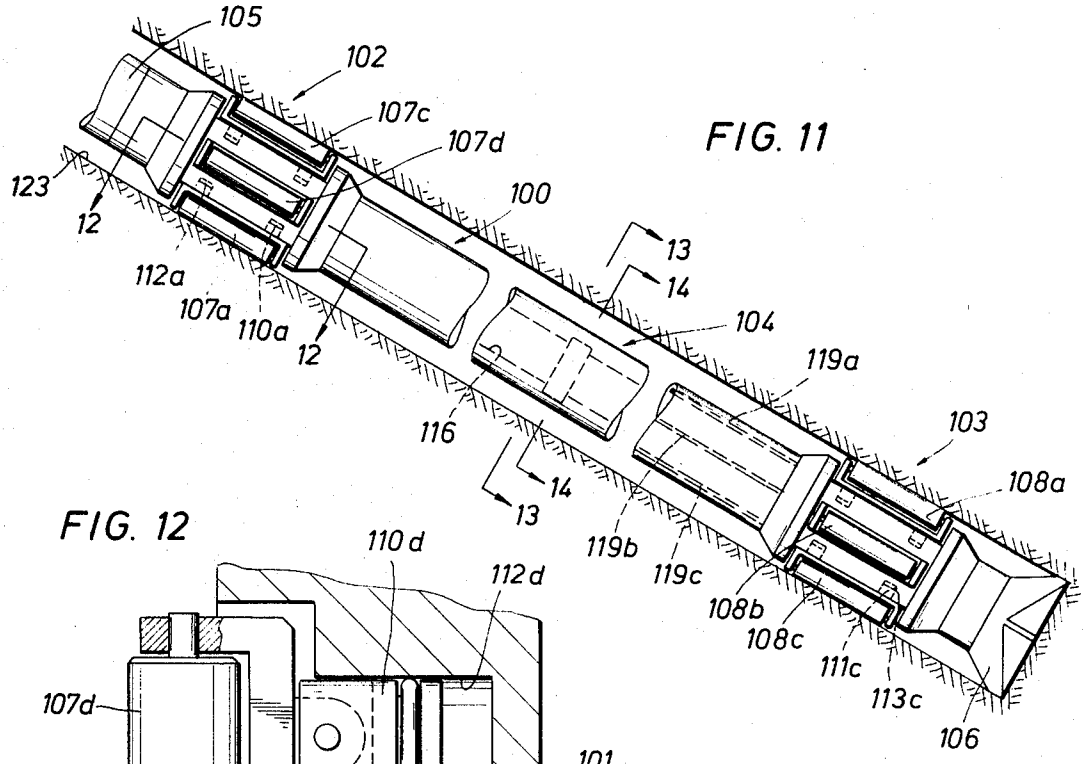
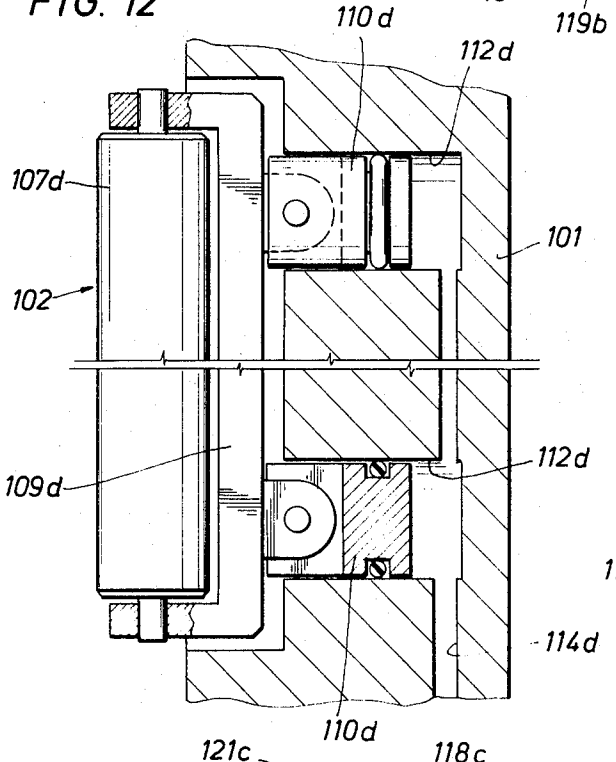


FIG. 11

FIG. 12



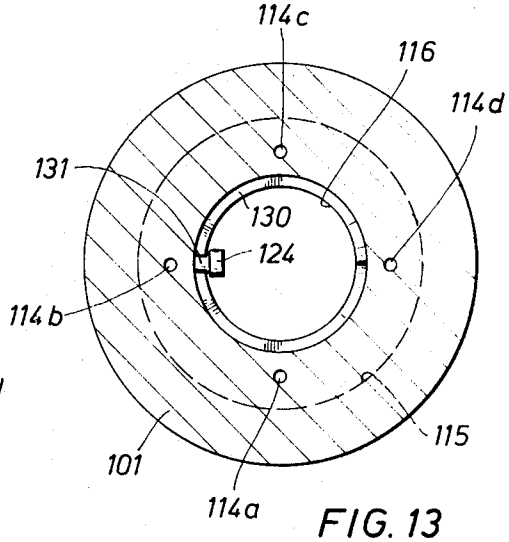


FIG. 13

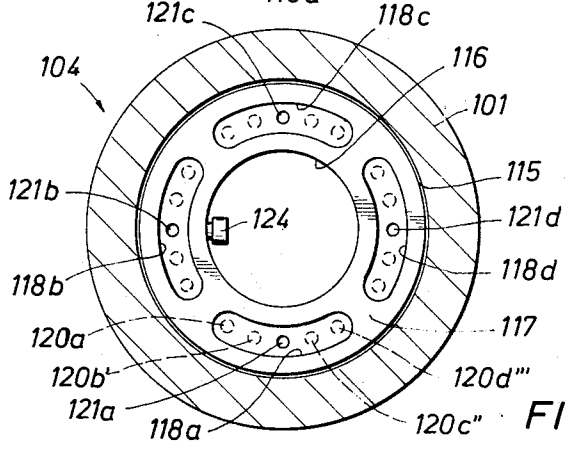


FIG. 14

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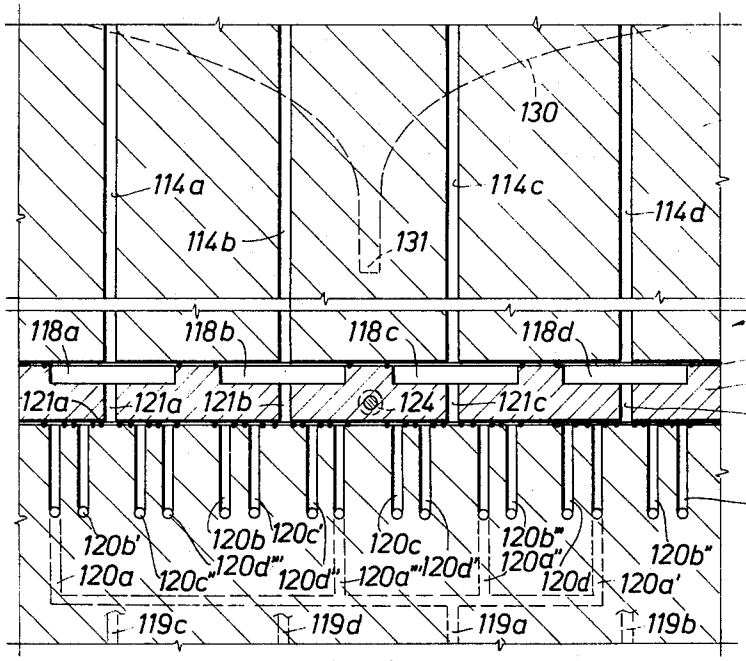


FIG. 15

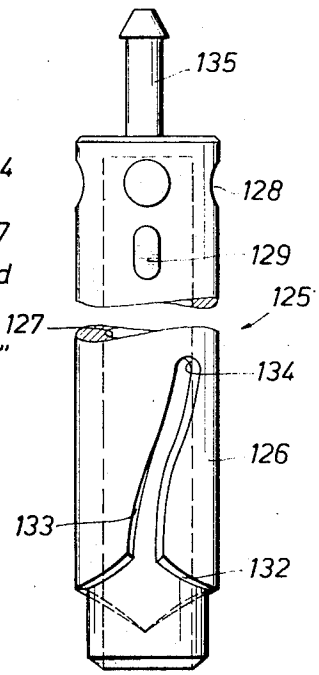


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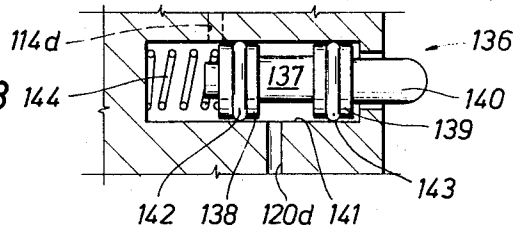


FIG. 18

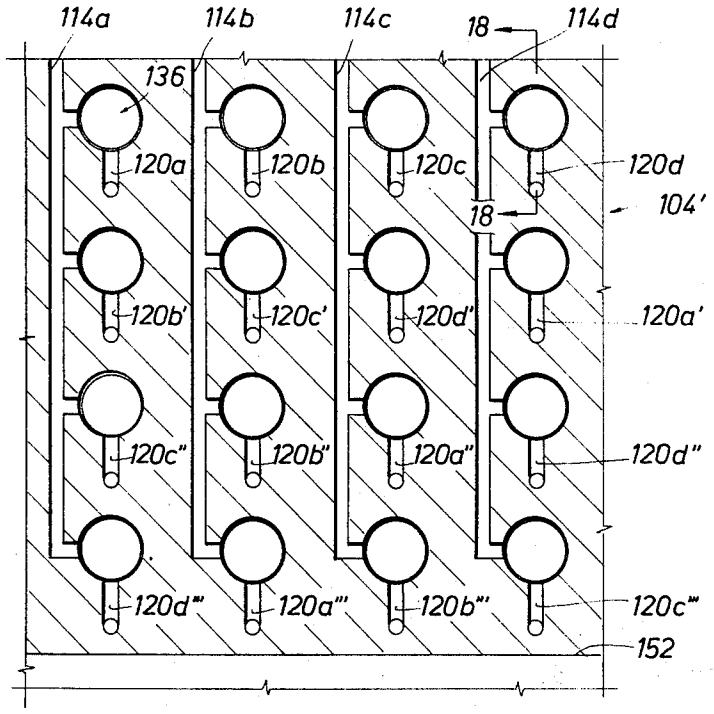


FIG. 17

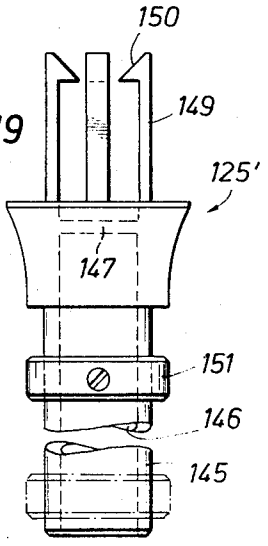


FIG. 19

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FIG. 20

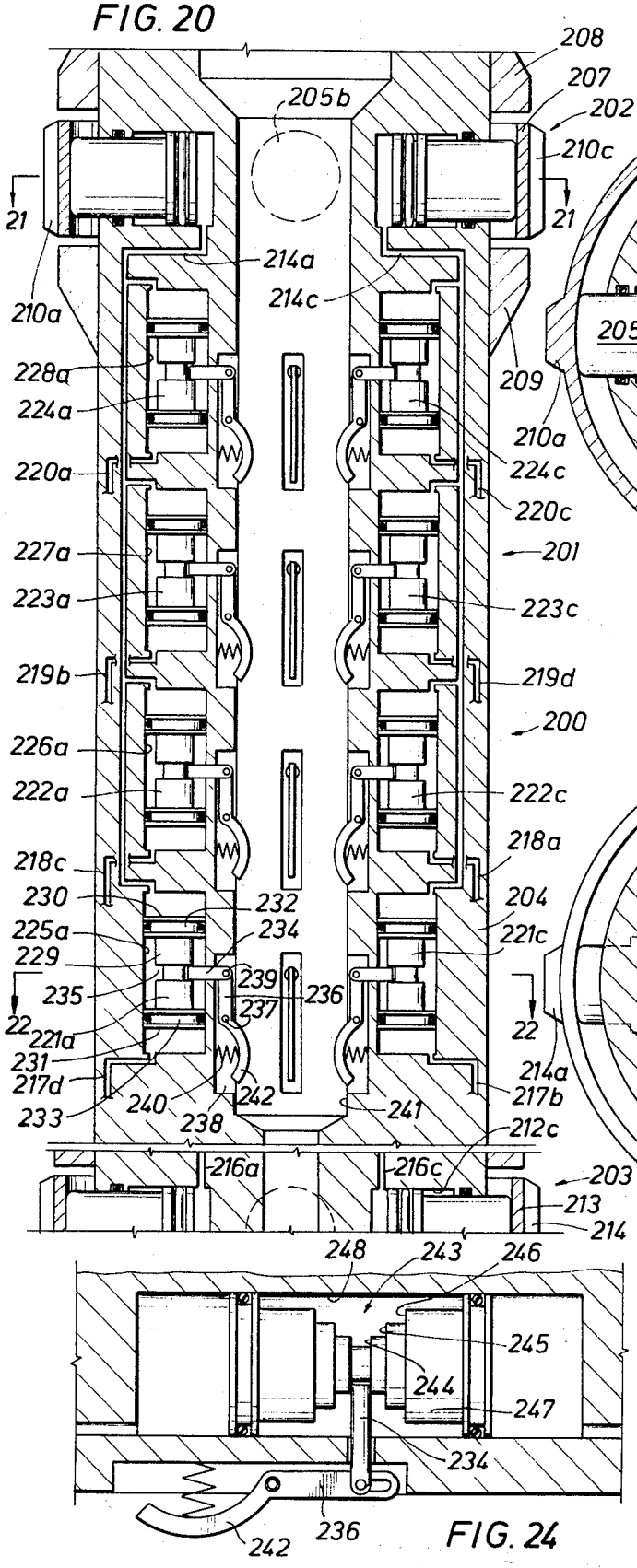


FIG. 24

FIG. 21

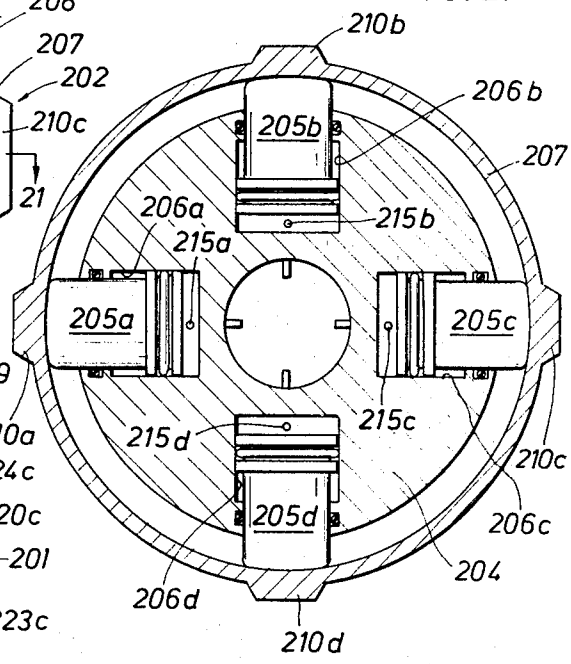
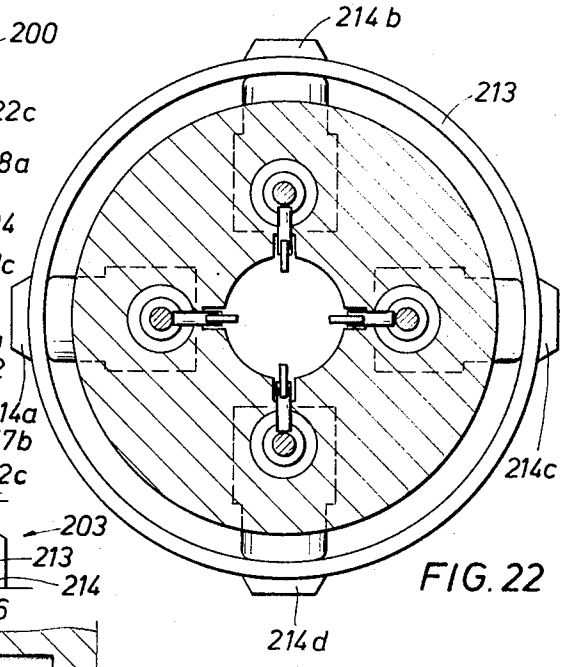
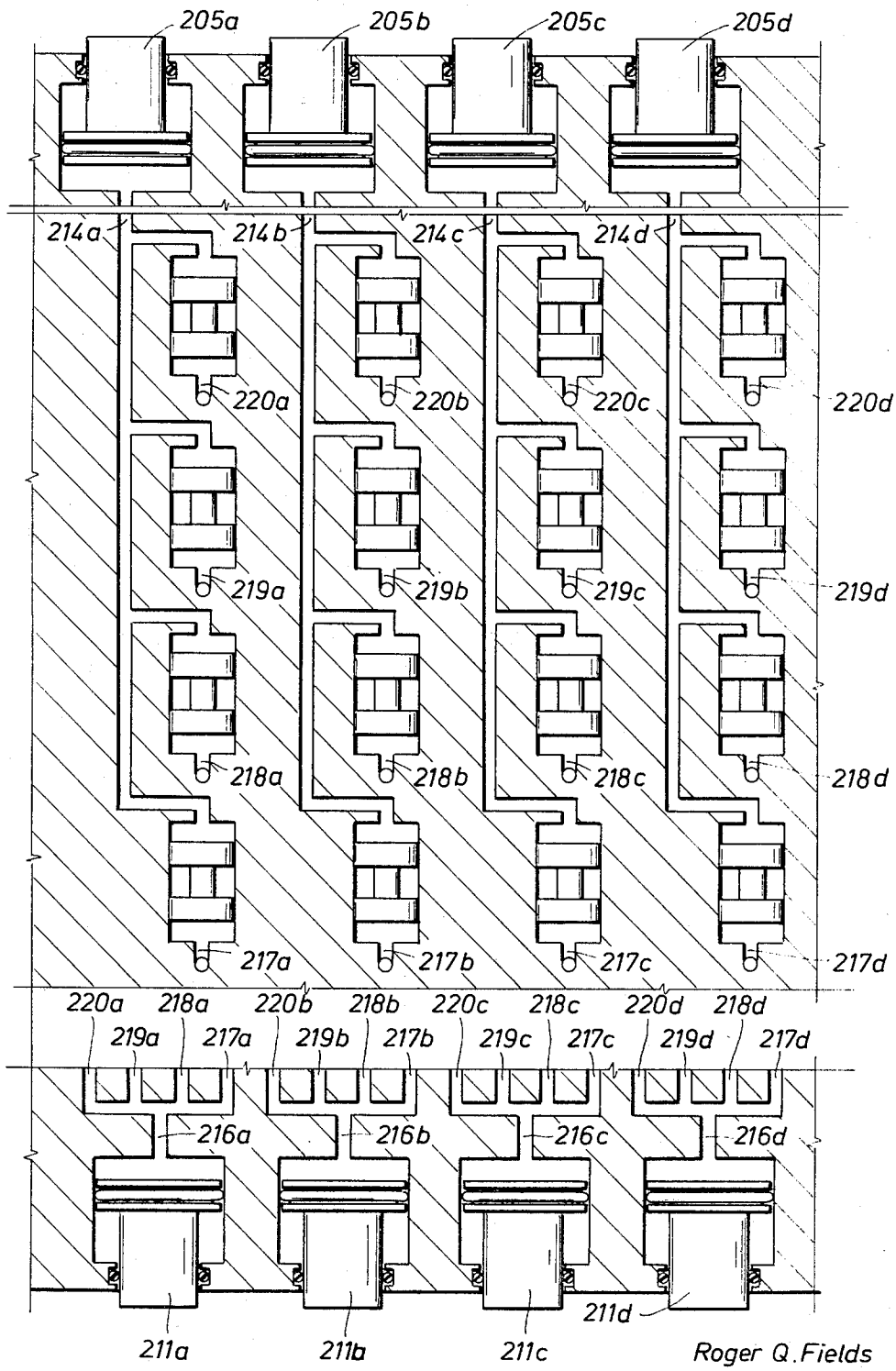


FIG. 22



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FIG. 23

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FIG. 25

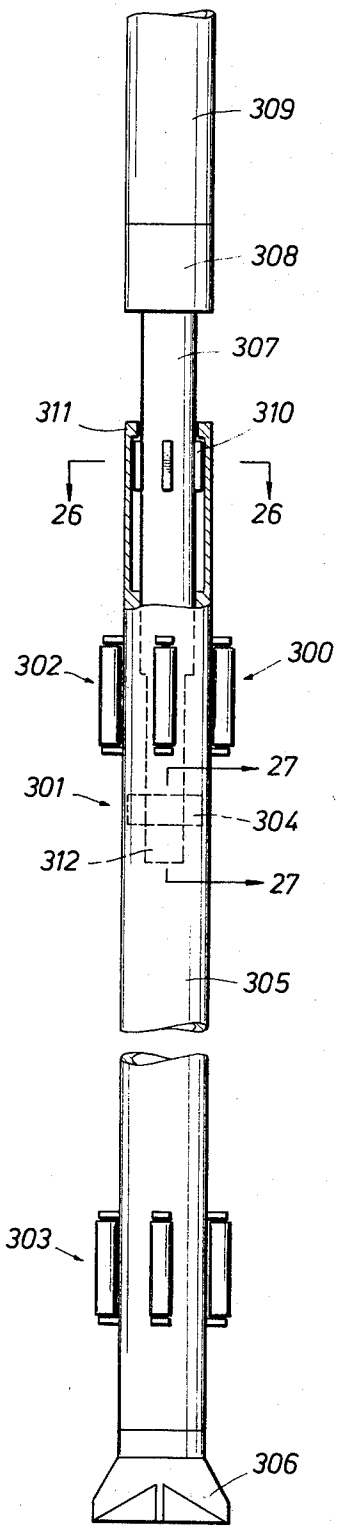


FIG. 26

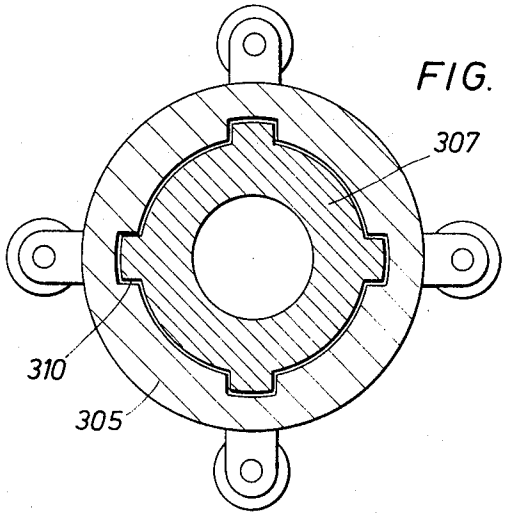
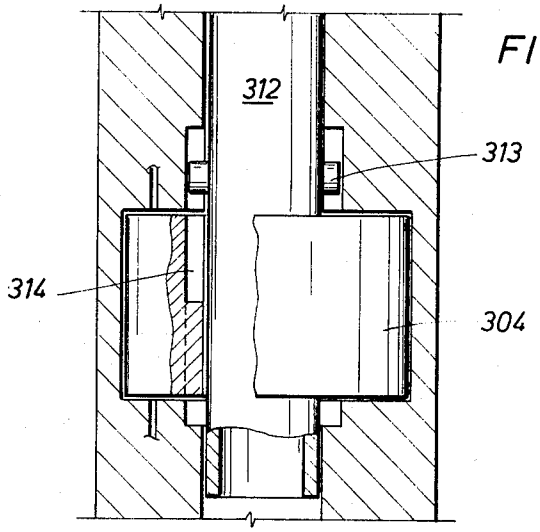


FIG. 27



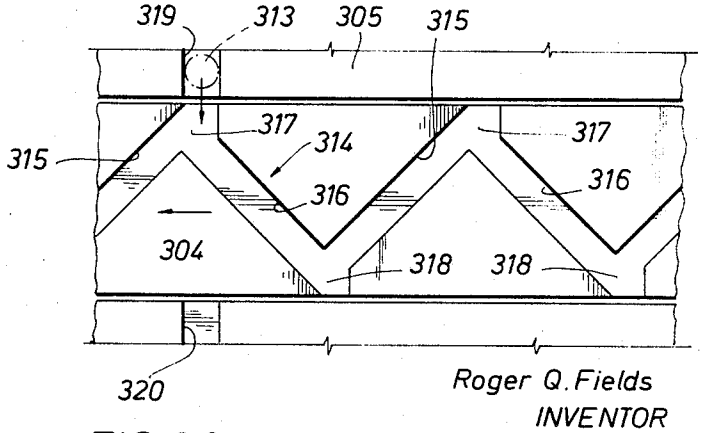


FIG. 28

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METHODS AND APPARATUS FOR DIRECTIONAL DRILLING

In drilling of 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 t4 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 methods and apparatus for selectively guiding a drill bit as it progressively excavates a borehole, with the guidance being accomplished during the course of the drilling operation without removing the drill string from the borehole for corrective adjustments.

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 a drill bit for deflecting the drill bit along selected axes of excavation in response to the lateral movements of deviation-sensing pressure-developing means arranged on the tool and selectively coupled to the guiding means by one of several embodiments of selectively operable control means carried on the tool. In some of the disclosed embodiments of the present invention, pressure-responsive control means are arranged on the tool in such a manner that by simply increasing the pressure of the drilling fluid flowing through the drill string to at least a predetermined magnitude, a selected coupling arrangement will be established between the deviation-sensing means and the guiding means. In alternate embodiments, the control means are selectively controlled by actuating members adapted to be dispatched from the surface through the drill string to the directional tool. By arranging particular surfaces of these actuating members to cooperatively engage matching surfaces on the control means, the deviation-sensing means and guiding means are selectively coupled in any one of several predetermined arrangements. Another embodiment employs control means adapted for operation in response to predetermined manipulations of the drill string to couple the deviation-sensing means and guiding means.

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 and methods employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. 1 depicts one embodiment of a directional drilling tool arranged in accordance with the principles of the present invention as it may appear while a deviated borehole is being drilled by practicing the methods of the invention;

FIGS. 2—5 are cross-sectional plan views respectively taken along the designated section lines in FIG. 1 and showing various details of the directional drilling tool illustrated there;

FIG. 6 is a somewhat schematic, developed view of a portion of the apparatus depicted in FIG. 1;

FIGS. 7 and 8 are two views showing one embodiment of a pressure-responsive actuator which may be used for controlling the directional drilling tool shown in FIG. 1;

FIGS. 9 and 10 are two views of an alternative pressure-responsive actuating mechanism that may also be used with the tool depicted in FIG. 1;

FIG. 11 illustrates an alternative embodiment of a directional drilling tool generally similar to that shown in FIG. 1 but including additional new and improved features;

FIGS. 12—14 are cross-sectional views of the directional drilling tool depicted in FIG. 11 respectively taken along the designated section lines therein;

FIG. 15 is a developed view schematically illustrating one embodiment of a mechanically actuated control for the directional drilling tool shown in FIG. 11;

FIG. 16 depicts an actuator adapted for use with the control shown in FIG. 15;

FIG. 17 is a developed view schematically representing an alternative embodiment of a mechanically actuated control for the directional drilling tool illustrated in FIG. 11;

FIG. 18 is a cross-sectional view of a portion of the control shown in FIG. 17;

FIG. 19 illustrates one embodiment of an actuator adapted for use with the control illustrated in FIGS. 17 and 18;

FIG. 20 is an elevational cross-sectional view of still another embodiment of a directional drilling tool also incorporating the principles of the present invention;

FIGS. 21 and 22 are cross-sectional plan views respectively taken along the lines 21—21 and 22—22 in FIG. 20;

FIG. 23 is a schematic representation of the control system of the directional drilling tool illustrated in FIG. 20;

FIG. 24 illustrates an alternative embodiment of a control device for the directional drilling tool shown in FIG. 20;

FIG. 25 depicts a further embodiment of a directional drilling tool also arranged in accordance with the principles of the present invention;

FIGS. 26 and 27 are cross-sectional views taken along the designated section lines in FIG. 25; and

FIG. 28 is a developed view of a portion of the tool shown in FIG. 27.

DESCRIPTION OF THE TOOL DEPICTED IN FIGS. 1—10

Turning now to FIG. 1, a directional drilling tool 30 dependently coupled from the lower end of a typical tubular drill string 31 is shown as it may appear during the course of the excavation of a deviated borehole 32. A typical drill bit 33 is operatively arranged on the lower end of a directional drilling tool 30 for operation in the usual manner upon rotation of the drill string 31 by a typical drilling rig (not shown) at the surface. As illustrated, the directional drilling tool 30 has an elon-

gated, thick-walled tubular housing **34** with an axial bore **35** therethrough to permit the usual circulation of drilling fluids or so-called "mud" from the surface through the drill string **31** and appropriate discharge openings (not shown) in the drill bit **33** and back to the surface by way of the borehole **32**. In this preferred embodiment of the tool **30**, wall-engaging deviation-sensing means **36** and direction-guiding means **37** are respectively mounted on the upper and lower ends of the tool housing **34** and operatively interconnected by selectively operable control means **38** adapted to be remotely actuated from the surface. To protect the wall-engaging means **36** and **37** as the directional drilling tool **30** is moved into and out of the borehole **31**, enlarged-diameter shoulders, as at **39**, are respectively arranged on the housing **34** immediately above and below the upper and lower wall-engaging means.

As best seen in FIG. **2**, the upper wall-engaging means **36** preferably include three laterally movable pistons **40** respectively disposed in outwardly facing radial bores **41** arranged at equal intervals around the exterior wall of the tubular housing **34** and biased outwardly by springs **42**. A circumferential band **43** encircles the tool housing **34** between the several enlarged shoulders **39** and carries on its outer face three outwardly projecting wall-contacting members **44** respectively disposed adjacent to the outer ends of each of the pistons **40**. To prevent significant rotation between the band **43** and tool housing **34**, the circumferential band is loosely keyed, as at **45**, to the shoulders **39**. As illustrated in FIG. **3**, the lower wall-engaging means **37** also include three pistons **46** arranged in uniformly spaced radial bores **47** in the housing **34** as well as a circumferential band **48** supporting three circumferentially spaced wall-contacting members **49**. Although the upper and lower wall-engaging means **36** and **37** are preferably identically arranged, it will be noted in FIGS. **1—3** that the upper and lower wall-engaging means are angularly offset 60° from one another on the tool housing **34**.

The upper piston cylinders **41** (FIG. **2**) are filled with a suitable relatively noncompressible fluid, such as a hydraulic oil, and respectively fluidly coupled by flow conduits, such as separate tubing lines or fluid passages **50** and **51** in the tool housing **34**, and the control means **38** to the fluid-filled piston chambers **47** (FIG. **3**) of the lower wall-engaging means **37**. In this manner, depending upon the particular operating position of the control means **38**, inward movement of one of the upper pistons **40** will develop an increased hydraulic pressure for producing a corresponding outward movement of a selected one of the lower piston members **46** of the direction-guiding wall-engaging means **37**. For example, assuming that the fluid conduits **50*a*** and **51*a*** are fluidly coupled to one another by the control means **38**, each time the piston **40*a*** immediately adjacent to the upper wall-contacting member **44*a*** is moved inwardly by the weight of the tool **30** and drill string **31**, the corresponding outward movement of the piston **46*a*** will in turn urge the lower wall-contacting member **49*a*** outwardly.

As illustrated in FIGS. **1** and **6**, therefore,, with the control means **38** selectively interconnecting the conduits **50*a*** and **51*a*** each time the drill string **31** is rotated so as to bring the upper wall-contacting member **44*a*** into contact with the lower surface of the borehole **32**, the corresponding outward movement of the lower wall-contacting member **49*a*** will, of course, impose a downwardly acting force on the drill bit **33** that is proportionally related, if not equal, to the inwardly acting force on the upper wall-contacting member. Similarly, with the control means **38** fluidly c4ueling the upper and lower pistons **40*b*** and **46*b***, each time the upper wall-contacting member **44*b*** is rotated into position along the lower surface of the borehole **32**, a corresponding outwardly directed force will be applied t4 the wall-contacting member **49*b*** which is at this time against the upper surface of the borehole. Then, since the third piston **40*c*** is also coupled by the control means **38** for actuation of the lower piston member **46*c***, as the drill string is rotated to bring the upper wall-contacting member **44*c*** into contact with the lower surface of the borehole **32** the lower wall-contacting member **49*c*** (which is now at the upper surface of the borehole) will in turn be u7ged upwardly against the borehole wall so as to again impose a downwardly directed force on the drill bit **33**.

Thus, it will be appreciated that as the drill string **31** is rotated, the upper wall-contacting members **44** will be successively brought into contact with the lower surface of the borehole **32** and, in turn, be moved inwardly by the weight of the tool **30**. In this manner, when the upper and lower wall-engaging means **36** and **37** are fluidly coupled in the manner just described, successive downwardly acting lateral forces will be imposed on the drilling bit **33** so as to continue to divert it generally downwardly.

In keeping with the objects of the invention, however, the control means **38** are capable of selectively interconnecting the upper and lower wall-engaging means **36** and **37** into various operative combinations for selectively guiding the drill bit **33** in other directions as may be required in a given situation without having to withdraw the directional drilling tool **30** and entire drill string **31** from the borehole **32**. As shown in FIGS. **4—6**, in one manner of accomplishing this, the control means **38** include an annular valve member **52** rotatively mounted in a complementary outwardly directed recess or opening **53** formed around an intermediate portion of the tool body **34**. To permit the rotatable valve member **52** to rotate with relative ease in relation to the tool body **34**, a suitable bearing **54** (FIG. **8**) is mounted between the rotatable valve member and the body of the tool **30**. The fluid passages **50** from the three piston chambers **41** of the upper wall-engaging means **36** are carried down the tool housing **34** and respectively terminated at equally spaced intervals around the downwardly directed upper face of the peripheral recess **53** in the tool housing. Similarly, as best seen in FIGS. **4—6**, the fluid passages **51** respectively coupled to the piston chambers **47** of the lower wall-engaging means **37** are brought up the tool body **34** and, by means of appropriately arranged branch passages **55*c***, terminated at the upwardly directed lower face of the housing recess **53** in such a manner that each of the three passages from the lower piston chambers is terminated by the branch passages at three equally spaced intervals around the circumference of the lower recess face. Generally arcuate recesses **56** are formed in the upper face of the rotatable valve member **52** and respectively disposed therearound through an arc of less than 120°. Single downwardly directed ports **57** are respectively formed in the lower surface of the arcuate recesses **56** so as to provide communication therefrom to the lower face of the rotatable valve member **52**.

Accordingly, as schematically illustrated in the developed view in FIG. **6**, by spacing the several branch passages **55** at uniform intervals around the circumference of the lower surface of the housing recess **53**, each of the ports **57** will be facing one of the branch passages in selected incremental positions of the valve member **52** in relation to the tool housing **34**. Furthermore, by virtue of the arcuate recesses **56**, the passages **50** will be respectively communicated to one of the three branch passages **55** adjacent to the ports **57** in these incremental angular positions of the rotatable valve member **52**. It will be appreciated, therefore, that by arranging the branch passages **55** in the manner illustrated, each of the upper piston chambers **41** will be sequentially connected in turn to each of the lower piston chambers **47** as the valve member **52** is successively positioned between its several incremental positions. Moreover, in other incremental positions of the rotatable valve member **52**, the fluid passages **50** and branch passages **55** will be fluidly sealed (as by the seals **58** and **59**) by the body of the valve member so as to block communication between the upper and lower piston chambers **41** and **47**. Thus, as illustrated in FIG. **6**, the valve member **52** can be selectively moved to attain any one of four operating conditions which are respectively determined by the particular incremental angular position of the valve member in relation to the t4ol housing **34**.

In the particular operating position of the valve member **52** schematically illustrated in FIG. **6**, the piston chamber **41*a*** is

connected by means of the passages 50*a*, 57*a*, 55*a* and 51*a* to the lower piston chamber 47*a*; the upper piston chamber 41*b* is connected to the lower piston chamber 47*b*; and the third piston chamber 41*c* is connected to the third piston chamber 47*c* of the lower wall-engaging means 37. Rotational movement of the valve member 52 to the right (as viewed in FIG. 6) to its next incremental position will, of course, be effective to couple the first piston chamber 41*a* to the second lower piston chamber 47*b*, with the other two upper piston chambers 41*b* and 41*c* being similarly coupled to the lower piston chambers 47*c* and 47*a* respectively. Similarly, by indexing the rotatable valve member to its next incremental position, a different combination of interconnection between the upper and lower piston chambers 41 and 47 will be accomplished. In at least the fourth incremental position of the rotatable valve member 52, no interconnection is provided between the upper direction-sensing means 36 and the lower direction-guiding means 37 such as, for example, when the port 57*a* is between the passages 55*c*'' and 55*b*.

In one manner of selectively moving the rotatable valve member to its various incremental angular positions, pressure-responsive actuating means 60 are conveniently located as seen in FIGS. 7 and 8 adjacent to the housing recess 53 and operatively arranged so that successive transmissions of an increased pressure of selected magnitude will be effective to rotatively shift the valve member 52. To accomplish this, a piston member 61 is slidably mounted for reciprocating upward and downward movement in a piston chamber 62 formed in the tool body 34 immediately above the outwardly directed annular recess 53. A depending axial projection 63 from the piston 61 is extended downwardly therefrom through an opening 64 in the upper surface of the housing recess 53 and appropriately arranged for carrying a pivotable pawl 65. A plurality of equally spaced ratchet teeth 66 are formed in a circumferential path around the upper face of the rotatable valve member 52 directly below the pawl 65.

It will be appreciated, therefore, that whenever the piston 61 is moved downwardly, the free end of the pawl 65 will be moved downwardly across the inclined face, as at 67, of one of the teeth 66 until halted by coming into engagement with an opposing upright face 68 of the next adjacent tooth. Then, upon continued downward movement of the piston 61, the pawl 65 will be effective to shift the rotatable valve member 52 to the right (as viewed in FIG. 7) until the piston has reached the lower limit of its downward travel. Upward travel of the piston 61 will, of course, retract the pawl 65 and restore it to its initial position immediately above the next adjacent tooth 66. Thus, upon successive upward and downward strokes of the piston 61, the rotatable valve member 52 will be incrementally shifted through a predetermined arc of travel.

In one manner of actuating the piston 61, a spring member 69 is arranged in the piston chamber 62 for normally urging the piston upwardly and a fluid passage 70 is provided between the upper portion of the piston chamber and the central bore 35 through the tool housing 34. A second fluid passage 71 is provided for communicating the lower portion of the piston chamber 62 with the exterior of the directional drilling tool 30. Accordingly, by imposing a higher fluid pressure above the piston 61 than that presently existing therebelow, the piston will be urged downwardly to accomplish the above-described angular indexing movement of the rotatable valve member 52.

In one manner of providing this increased fluid pressure, the fluid-circulating or mud pumps at the surface can be readily operated in such a manner as to produce a greater fluid pressure in the central housing bore 35 than that existing in the borehole 32 exterior of the housing 34. Thus, once the fluid pressure in the axial bore 35 has increased sufficiently to compress the spring 69, the piston 61 will be shifted downwardly until it is halted by the pawl 65 reaching its lower limit of travel in relation to the rotatable valve member 52. To assure that the piston 61 is not inadvertently actuated by minor variations in the pressure of the circulating fluid or mud, the spring 69 is appropriately selected so as to require a significant increase in fluid pressure over the hydrostatic pressure of the mud column in the borehole 32. Thus, so long as the circulating fluid is maintained in its usual range of pressure conditions, the operator can be certain that the directional drilling tool 30 is properly adjusted for directing the drill bit 33 in the then selected manner. Then, should it become necessary during the course of the drilling operation to make a correction such as by shifting the valve member 52 to either another operating position or to an inoperative position for interrupting the directional control of the tool 30, this can be simply accomplished by one or more brief increases of the circulating pressure. It will be appreciated that successive increases of the circulating pressure will readily index the rotatable valve member 52 through each of its several positions before it is again returned to its initial operating position.

Turning now to FIGS. 9 and 10, an alternative embodiment is shown of selectively operable pressure-responsive actuating means 60' that are generally similar to the pressure responsive actuating means 60 just described. The actuating means 60' similarly include a piston member 61' that is adapted for reciprocating vertical movement in the piston chamber 62 immediately above the rotatable valve member 52'. The pressure-communicating passage 70 is similarly provided for communicating the pressure in the axial bore 35 of the tool 30 to the upper portion of the piston chamber 62 and the other passage 71 again communicates the lower portion of the piston chamber with the borehole 32. Thus, an increase in pressure in the axial bore 35 sufficient to overcome the upwardly directed biasing force of the compression spring 69 will also shift the piston 61' downwardly toward the valve member 52'.

To selectively index the valve member 52' between its various angular positions, the depending shaft 63' of the piston 61' is provided with an outwardly directed cam which, preferably, is a laterally oriented roller 65'. The roller 65' is operatively received within a labryinthlike system of alternately inclined cam grooves 66' formed around the internal surface of the valve member 52' to provide a continuous alternating track upwardly and downwardly around the internal wall of the rotatable valve member. In this manner, each downward movement of the piston member 61', the roller 65' will be effective for camming the valve member 52' to the right as viewed in FIG. 9 until the roller reaches an upwardly facing pocket, as at 72, formed at the lower junction of two adjacent grooves 66'. Then, upon upward movement of the piston member 61', the roller 65' will cam the valve member 52' still further to the right until the piston member again reaches its normal elevated position with the roller coming to rest in a downwardly facing pocket as at 73. Thus, by arranging adjacent pairs of the grooves 66' to span a selected angular interval, each successive upward and downward movement of the piston 61' will be effective to shift the valve member 52' to its next angular position in relation to the tool housing 34.

It will be appreciated that with the directional drilling tool 30 as shown in FIGS. 1—6 having either the actuating means 60 or the actuating means 60', the valve member 52 (or 52') may be selectively indexed to successive angular positions as desired to either isolate the wall-engaging means 36 and 37 or else interconnect the upper wall-contacting members 44 with the lower wall-contacting members 49 in any of their three operating arrangements. Moreover, by virtue of the ability to selectively operate the valve member 52 (or 52') from the surface, the particular order of interconnection between the upper and lower wall-engaging means 36 and 37 may be varied as required simply by momentarily increasing the pressure of the circulating fluid or mud passing downwardly through the drill string 31 to a magnitude sufficient to at least overcome the bias of the spring 69 and shift the piston actuator 61 (or 61') downwardly so as to leave the valve member 52 (or 52') at a selected angular position whenever pressure is again restored to its usual operating value. Thus, by making periodic surveys with typical borehole-orienting devices such

as one of those shown on pages 1786—1793 of the 1968—1969 Composite Catalog of Oil Field Equipment and Services, the operator at the surface can readily determine the course of the drill bit 33 and make appropriate adjustments as required to continue excavation of the borehole 32 in any desired direction.

DESCRIPTION OF THE TOOL DEPICTED IN FIGS. 11—19

It will, of course, be appreciated that some situations may require more positive regulation for directing the course of a particular directional drilling operation. Accordingly, an alternative tool 100 is shown in FIG. 11 which is capable of being selectively controlled from the surface for movement in any one of four lateral directions. As illustrated, the directional drilling tool 100 is comprised of a thick-walled tubular housing 101 having deviation-sensing and direction-guiding wall-engaging means 102 and 103 respectively arranged at its upper and lower ends and selectively actuated control means 104 intermediately located therebetween. The lower end of a drill string 105 is coupled to the upper end of the tool 100 and a drill bit 106 is dependently coupled to its lower end. Although the upper and lower wall-engaging means 102 and 103 could be arranged as previously described with reference to FIGS. 2 and 3, in the preferred embodiment of the tool 100 four longitudinally oriented rollers 107 and 108 are circumferentially spaced at 90° intervals respectively around the upper and lower ends of the tool housing 101 as depicted in FIG. 11; and, as seen in FIG. 12, each of these rollers are respectively supported by a bifurcated bracket 109 that is operatively mounted on the outer ends of a pair of laterally movable piston members 110 (and 111) respectively mounted in vertically aligned outwardly opening radial bores 112 (and 113) in the upper and lower ends of the tool housing.

A fluid passage 114 couples each set of the upper piston chambers 112 to the selectively operable control means 104. As best seen in FIGS. 13 and 14, each of the four passages 114 is terminated by the upper surface of an inwardly directed annular recess 115 formed around the tool housing 101 and opening into the axial bore 116 therethrough. The control means 104 include an annular valve member 117 that is rotatively mounted within the complementary housing recess 115 and adapted for rotative movement in relation thereto between two angularly spaced positions on each side of a selected neutral position as illustrated. Four similar or identical arcuate recesses 118 are formed at equal intervals around the circumference of the upper face of the annular valve member 117 so as to be in alignment with the four passages 114 in all of the selective positions of the annular valve member.

As depicted in FIGS. 14 and 15, each of the piston chambers 113 of the lower wall-engaging means 103 are fluidly coupled to the control means 104 by suitable individual conduits 119 which may be provided by means of either passages drilled through the tool housing 101 of by fluid lines disposed along the axial housing bore 116. These passages 119 are then respectively branched out as shown in FIG. 15 so that each passage has four branches 120 each terminating at a selected position on the upwardly facing face of the annular housing recess 115. In this manner, in any of the four operating positions of the valve member 117, a single port 121 in each of the arcuate recesses 118 is selectively registered with one of the four branch passages 120. In the fifth or neutral position of the valve member 117 illustrated in FIG. 15, the ports 121 are displaced from the several branch passages 120 and fluidly sealed, as by seals 122, against the lower face of the recess 115.

It will be seen that with the annular valve member 117 in the neutral position depicted in FIG. 15, there is no fluid communication between the deviation-sensing means 102 and the direction-guiding means 103 so as to preclude operation of the lower wall-engaging means when, for example, the tool 100 is being lowered into the borehole 123. It will be appreciated, therefore, that to selectively intercouple individual ones of the upper wall-contacting members 107 and the lower wall-contacting members 108, the valve member 117 must be shifted to one of its four operating positions. Accordingly, to selectively shift the valve member 117, an inwardly projecting cam member 124 is arranged on the inner wall of the valve member in such a manner that any one of four actuating members 125 such as the one shown in FIG. 16 can operatively shift the valve member from its neutral position to a selected one of its four operating positions.

As illustrated, the valve actuator 125 is comprised of an elongated tubular body 126 having an axial passage 127 therein terminated at its upper end by one or more lateral ports 128 to permit free flow of the circulating fluid as the actuating tool is moving through the drill string 105. An outwardly projecting lug 129 is arranged on the upper end of the actuator body 126 for reception by an upwardly facing shoulder 130 formed around the inner wall of the tool housing 101 and defining a downwardly converging guide surface terminating in an elongated narrowed vertical channel 131 having an upwardly directed lower shoulder. Accordingly, when the actuator 125 is moved downwardly through the drill string 105 and enters the tool housing 101, the lug 129 will engage the converging guide 130 irrespective of whatever angular position the actuator body 126 may then be in relation to the tool housing. Then, further downward travel of the actuating tool 125 will cause it to be turned to a selected angular position in relation to the tool housing 101 and the valve member 117 once the lug 129 reaches the terminal shoulder of the channel 131. To selectively shift the valve member 117 to a desired operative position, a downwardly facing shoulder 132 is formed around the actuator body 126 and uniformly converged upwardly to the opposite sides of the lower end of an upwardly extending groove 133 that is spiralled upwardly part way around the tool body and terminated in a downwardly opening vertical guide groove 134 having a predetermined angular orientation in relation to the lower entrance of the curved groove.

Accordingly, as the valve actuator 125 enters the upper end of the housing bore 116, the outstanding guiding lug 129 thereon will be progressively guided by the upwardly diverging shoulder 130 within the tool housing 101 so as to bring the valve actuator in a fixed angular orientation in relation thereto once the lug is in the narrow channel 131. As the valve actuator 125 moves into its fixed angular position, the inwardly projecting cam member 124 on the valve member 117 will engage the downwardly diverging shoulders 132 on the actuator and be guided thereby into the spiralled groove 133 as the actuator moves downwardly toward its final resting position. Then, once the valve actuator 125 has reached its final position within the tool housing 101 as may be determined by the engagement of the lug 129 with the shoulder at the bottom of the channel 131, the cam member 124 will have been progressively guided by the curved walls of the spiralled groove 133 into the vertical groove 134 to rotate the valve member 117 into a corresponding operative position in relation to its initial neutral position.

It will, of course, be appreciated that the angular displacement between the lower end of the spiralled groove portion 133 and the vertical groove portion 134 will determine the degree of angular orientation of the valve member 117 in relation to the tool housing 101. Thus, by providing four individual valve actuators such as that shown at 125 in FIG. 16 with two of these having their respective vertical grooves 134 at two different angular positions to the right of the entrance groove 133 and the other two actuators having their vertical grooves in two different angular positions to the left of the entrance groove, the annular valve member 117 may be selectively moved to any one of its four operative positions.

To withdraw the valve actuator 125 from the drill string 105, an upright fishing neck 135 is provided on the upper end of the actuator body 126 for coengagement by a typical cable-suspended overshot (not shown). Thus, as the valve actuator

125 is withdrawn by means of such an overshot, the upward movement of the actuator in relation to the tool housing **101** will restore the inwardly projecting cam member **124** to its initial neutral position as shown in FIG. **15** so as to again close fluid communication between the upper and lower wall-engaging means **102** and **103**. Then, if it is desired to shift the annular valve member **117** to another of its selected positions, the appropriate valve actuator **125** can be dropped or lowered through the drill string **105** so as to reposition the valve member in a desired operating position.

Turning now to FIG. **17**, an alternative embodiment is shown of selectively operable control means **104'** which may be employed with the tool **100** for controlling fluid communication between the upper and lower wall-engaging means **102** and **103**. In this developed view of the interior wall of the tool housing **101**, the passages **114** from each of the upper piston chambers **112** are respectively extended downwardly through the tool housing at circumferentially spaced positions therearound. Four sets of valve members **136** are provided with each of these four sets having four valve members disposed in vertical alignment with one another and having their inlets coupled to the same one of the four fluid passages **114** and their outlets respectively coupled by individual branch passages **120** to a different one of the four pistons **111** of the direction-guiding means **103**. In this manner, opening of any one of the four valves **136** in a given vertical stack will selectively connect one of the four upper piston chambers **112** with a corresponding one of the four lower piston chambers **113**. Thus, by also arranging the four valves **136** in any horizontal tier with their outlets respectively connected to a different one of the passages **119** and **120**, opening of all four valves in a given horizontal tier will connect each of the four upper pistons **110** respectively to a separate one of the four lower pistons **111**. It will be appreciated, therefore, that by selecting a horizontal tier of four valves **136** which are to be opened and by leaving the remaining 12 valves closed, e8ch of the upper wall-contacting members **107** can be respectively connected to any one of the four lower wall-contacting members **108**. The order of the 16 valves **136** is, of course, arranged so as to provide for any one of the four possible connections between the upper and lower wall-engaging means **102** and **103**.

Accordingly, as shown in FIG. **17**, a specific pattern is established so that when all four valves **136** in any horizontal tier are opened, each of the upper wall-contacting members **107** will be respectively connected to a selected one of the four lower wall-contacting members **108**. Thus, if the valves **136** in the uppermost horizontal tier are all opened, for example, the upper wall-contacting member **107*a*** will be connected by way of the passage **114*a*** and passage **120*a*** to the lower wall-contacting member **108*a***. Similarly, the second upper wall-contacting member **107*b*** will be connected to the lower wall-contacting member **108*b***; and the third and fourth valves being open will respectively connect the upper wall-contacting members **107*c*** and **107*d*** to the lower wall-contacting members **108*c*** and **108*d***. It will be realized that the other 12 valves **136** in the lower three tiers will remain closed. Simultaneous opening of the valves in the second, third, or fourth tiers will, of course, change the order of connection between the upper and lower wall-engaging means **102** and **103** to one of the other three possible connection patterns.

Turning now to FIG. **18**, a cross-sectional view is shown of one of the valves **136**. As illustrated, the valve **136** is comprised of a cylindrical body **137** having longitudinally spaced enlarged-diameter shoulders **138** and **139** and a longitudinally extending forward end **140**. The valve body **137** is slidably mounted in a radial bore **141** formed in the tool housing **101** and sealingly received therein by O-rings **142** and **143** mounted around the shoulders **138** and **139**. The forward end **140** of the valve body **137** is urged into the axial housing bore **116** by a compression spring **144** arranged in the radial bore **141** and engaged with the rearward body end. In its depicted normally closed position, the passages **114*d*** and **120*d*** in the tool housing **101** are terminated within the radial bore **141** so that the rear sealing member **142** on the valve body **137** is between the entrances of these passages. Thus, so long as the valve body **137** is shifted forwardly, fluid communication is blocked between the two passages **114*d*** and **120*d***. Conversely, it will be appreciated that movement of the valve body **137** further into the radial bore **141** will shift the rearward valve seal **142** to the rear of the passage **114*d*** so as to open communication between that passage and the outlet passage **120*d***.

Accordingly, it will be appreciated from viewing FIG. **11** that as the drill string **105** is rotated, one of the upper wall-engaging members **107** will come into contact with the lower surface of the borehole **123** during each quarter of a given revolution. When this occurs, the combined weight of the drill string **105** and directional tool **100** will, for example, move the upper wall-engaging member **107*a*** inwardly and the lower wall-engaging member **108*a*** outwardly to impose a generally downwardly acting lateral force on the drill bit **106** and produce a corresponding change in its direction. Each quarter-revolution of the drill string **105** will, of course, similarly impose a downwardly acting force on the drill bit **106** so as to continue diverting the drill bit in the selected direction.

To selectively open and close the various valves **136** without requiring a specific angular orientation of an actuator (such as the actuator **125** in FIG. **16**) with the tool housing **101**, an actuator **125'** as illustrated in FIG. **19** can be employed. As depicted there, the actuator **125'** includes a tubular body **145** having an axial bore **146** which is temporarily closed near the upper end of the body **145** by a frangible transverse partition **147**. A sealing member, such as a typical swab cup **148**, is mounted around the actuator body **145** so that the actuator **125'** can be pumped downwardly through the drill string **105**. A fishing neck, such as a plurality of upright fingers **149** having inwardly turned upper ends **150**, is provided on the upper end of the actuator body **145** to permit its recovery by a typical spear-type overshot (not shown).

To actuate the valves **136**, a collar **151** is slidably mounted around the lower portion of the actuator body **145** and adapted to be releasably secured at any one of four selected longitudinal positions therealong. In this manner, whenever the valve actuator **125'** is pumped through the drill string **105**, it will pass through the array of valves **136** with its lower end coming to rest on an upwardly directed shoulder **152** formed around the internal wall of the tool housing **101** immediately below the valves. Thus, when for example, the slidable collar **151** is releasably secured in the full-line position illustrated in FIG. **19**, the four valves **136** in the uppermost horizontal tier will be open when their outer ends, as at **140**, are engaged by the outer face of the collar. The remaining 12 valves **136** in the other three horizontal tiers will, of course, still be closed by their respective biasing springs **144**.

It will be appreciated, therefore, that with the directional drilling tool **100** illustrated in FIGS. **11** and **12** and including either the control means **104** (as shown in FIGS. **13—15**) or the control means **104'** (as shown in FIGS. **17** and **18**), the deviation-sensing means **102** can be interconnected to the direction-guiding means **103** as required for accomplishing any one of four desired changes of direction of the drill bit **106**. Where the control means **104** are included with the directional drilling tool **100**, the tool is selectively operated by means of four specially arranged actuators such as illustrated at **125** in FIG. **16**. As previously described, so long as none of the actuators **125** are positioned within the directional drilling tool **100**, the annular valve member **117** will remain in its neutral position depicted in FIG. **15**. This will, of course, enable the drill bit **106** and the directional tool **100** to be lowered by the drill string **105** to a desired position in the borehole **123** without operating the wall-engaging means **102** and **103**.

Once, however, it is determined that a change of direction of the drill bit **106** is desired, the appropriate one of the four actuators **125** is selected for insertion into the drill string **105**. For example, if it is desired to urge the drill bit **106**

downwardly, the actuator **125** particularly illustrated in FIG. **16** will be dispatched through the drill string **105** and into the directional drilling tool **100**. Once the valve actuator **125** comes to rest with its outstanding guide lug **129** resting on the upwardly facing shoulder at the bottom of the groove **131**, the cam **124** will have entered the spiralled groove portion **133** to progressively cam the annular valve member **117** to the left (as viewed in FIG. **15**) of its illustrated neutral position. This will, of course, place each of the ports **121** respectively in communication with the left-hand branch passage **120** in each of the four depicted groups. For example, the valve port **121***a* will be in communication with the branch passage **120***a* and conduit **119***a* so that the inward movement of the wall-engaging member **107***a* will produce a corresponding outward movement of the lower wall-engaging member **108***a*. Similarly, inward movements of the upper wall-engaging members **107***b*—**107***d* will respectively produce corresponding outward movements of the lower-engaging members **108***b*—**108***d*.

Accordingly, it will be appreciated from viewing FIG. **11** that as the drill string **105** is rotated, one of the upper wall-engaging members **107** will come into contact with the lower surface of the borehole **123** during each quarter of a given revolution. When this occurs, the combined weight of the drill string **105** and directional tool **100** will, for example, move the upper wall-engaging member **107***a* inwardly and the lower wall-engaging member **108***a* outwardly to impose a generally downwardly acting lateral force on the drill bit **106** and produce a corresponding change in its direction. Each quarter-revolution of the drill string **105** will, of course, similarly impose a downwardly acting force on the drill bit **106** so as to continue diverting the drill bit in the selected direction.

As previously mentioned, the course of the drill bit **106** may be reliably ascertained by periodic surveys with suitable borehole-surveying devices. Thus, if it is determined that a change in direction is required, the particular valve actuator **125** that is then in the directional drilling tool **100** is withdrawn to restore the valve member **117** to its illustrated neutral position. The appropriate one of the other three valve actuators **125** is then simply dispatched through the drill string **105** by either allowing the actuator to fall free or by pumping it downwardly by the circulation of the drilling fluid. Once this second actuator **125** is in position, the valve member **117** will have been shifted to the selected operating position. On the other hand, if no further change in course is required, so long as no valve actuator **125** is positioned within the directional drilling tool **100**, the upper and lower wall-engaging means **102** and **103** will be isolated from one another by the neutrally positioned control means **104** to permit the drilling to continue in the usual manner.

The operation of the directional drilling tool **100** including the alternative control means **104'** is, of course, generally similar. It will be appreciated, however, that instead of having four distinctive valve actuators, the valve actuator **125'** is selectively adjustable for interconnecting the upper and lower wall-engaging means **102** and **103** in any one of their four possible operating arrangements. For example, if it is desired to deviate the drill string bit **106** downwardly such as previously described, the slidable collar **151** is simply left in the full-line position illustrated in FIG. **19**. In this manner, when the valve actuator **125'** comes to rest with its lower end shouldered on the internal housing shoulder **152**, the slidable collar **151** will open only the four valves **136** in the uppermost horizontal tier of valves as illustrated in FIG. **17** and leave the other 12 valves closed. Opening of these four upper valves **136** will, of course, operatively couple the upper wall-engaging member **107***a* to the lower wall-engaging member **108***a* and similarly couple the wall-engaging members **107***b*—**107***d* with the lower wall-engaging members **108***b*—**108***d* respectively. As previously described, this operating arrangement will produce the desired downwardly acting force on the drill **106** for each quarter-revolution of the drill string **105**.

If it is desired to discontinue the deviation of the drill bit **106**, removal of the valve actuator **125'** will reclose the four previously opened valves **136** so as to again block fluid communication between the upper and lower wall-engaging means **102** and **103**. Repositioning of the slidable collar **151** to any one of the three other longitudinally spaced positions on the actuator body **145** will, of course, readily provide the other three operating arrangements.

It should be noted that the easily ruptured transverse partition **147** in the actuator body **145** will allow the valve actuator **125'** to be readily pumped downwardly through the drill string **105**. Then, to be certain that the valve actuator **125'** is actually in position with its lower end abutting the inwardly directed housing shoulder **152**, the pumping pressure of the circulating mud is simply increased to rupture the transverse partition **147** and the resulting decrease in pump pressure will provide a positive indication at the surface that the valve actuator is, in fact, positioned within the directional drilling tool **100**. This transverse partition **147** is, of course, readily replaceable so that the valve actuator **125'** can be reused as necessary.

DESCRIPTION OF THE TOOL DEPICTED IN FIGS. 20—24

Turning now to FIG. **20**, an alternative embodiment is shown of a directional drilling tool **200** that is similar in many respects to the directional drilling tools **30** and **100** previously described but which incorporates selectively operable control means **201** adapted to transmit fluid pressure between wall-engaging deviation-sensing means **202** and direction-guiding means **203** respectively mounted on the upper and lower ends of the tool housing **204**. Although the upper and lower wall-engaging means **202** and **203** could also be arranged in the same manner as the wall-engaging means **102** in FIG. **12**, as best seen in FIG. **21**, the upper wall-engaging means **202** preferably include four laterally movable pistons **205** respectively disposed in outwardly facing radial bores **206** arranged at 90° intervals around the tubular housing **204**. A circumferential band **207** is loosely mounted around the housing **204** between enlarged shoulders, as at **208** and **209**, with four wall-contacting members **210** being mounted on the band respectively adjacent to the outer ends of the pistons **205**. The lower wall-engaging means **203** are similarly arranged and include four radially disposed pistons **211** that are disposed in radial bores **212** for outward movement against a loosely mounted circumferential band **213** carrying four equally spaced wall-contacting members **214**.

The upper piston cylinders **206** are filled with a suitable hydraulic fluid and respectively connected by fluid conduits such as tubing lines or fluid passages **215** through the housing **204** to the control means **201**. Similarly, the lower piston cylinders **212** are separately filled with a hydraulic fluid; and these four cylinders are connected by fluid conduits **216** which are in turn respectively connected to four branch conduits such as tubing lines or fluid passages **217**—**220** extending from the lower wall-engaging means **203** through the housing **204** to the control means **201**.

Although the control means **201** are similar in many respects to the control means **104'** illustrated in FIG. **17**, the control means **201** are arranged for transmitting fluid pressure between the upper and lower pistons **209** and **211** without there being any direct fluid communication therebetween. To accomplish this, as best seen in FIGS. **20** and **23**, the selectively operable control means **201** are comprised of a plurality of pistons **221**—**224** respectively mounted in complementary longitudinal chambers **225**—**228** in the tool housing **204**. Each of these control pistons **221**—**224** are comprised of a cylindrical body, as at **229**, having enlarged-diameter end portions **230** and **231** respectively carrying suitable fluid seals **232** and **233**. It will be appreciated, therefore, that since the fluid passages **214** and **217**—**220** respectively terminate at the opposite ends of the longitudinal bores **225**—**228**, the control pistons **221**—**224** will block fluid communication between the

upper and lower piston cylinders **206** and **212**; and whenever an increase in fluid pressure is developed by one of the upper pistons, its associated control piston will be moved correspondingly so as to transmit the increased fluid pressure to the lower piston.

Accordingly, assuming that any given one of the 16 control pistons, such as **224***a*, is free to move within its complementary chamber **228***a*, inward movement of its associated upper piston member **205***a* will develop an increased hydraulic pressure which will be immediately effective for shifting the control piston downwardly in relation to the tool body **204**. This downward movement will, of course, produce a corresponding increased hydraulic pressure in the piston cylinder **228***a* which is, in turn, transmitted to whichever one of the lower pistons **211** the piston chamber is then connected to.

To control the movement of the pistons **221—224**, the control pistons are normally retained in a neutral position by selectively operable release means which, in the preferred manner of accomplishing this, include a latch member, such as at **234**, that is cooperatively mounted in the internal wall of the tool housing **204** for radial movement inwardly and outwardly. Stop means, such as a reduced-diameter groove **235**, are provided on the control piston **221***a* for selective engagement with the free end of the movable latch member **234**. To selectively actuate the movable latch member **234**, an actuator **236** is pivotally mounted, as at **237**, to the tool housing **204** within an internal housing recess **238** and coupled as at **239** to the inner end of the latch member. To normally maintain the latch member **234** in engagement with the control piston **221***a*, a spring, as at **240**, is mounted in the recess **238** for normally urging the latch member into the reduced-diameter groove **235**.

By shaping the lower end of the actuator **236** so as to normally project inwardly a short distance into the axial housing bore **241**, inward movement of the curved end **242** of the actuator will be effective for retracting the latch member **234** form engagement with the reduced-diameter groove **235** on the piston **221***a*. Thus, once the latch member **234** is withdrawn from the groove **235**, the control piston **221***a* will be free for longitudinal movement upwardly and downwardly within its associated cylinder **225***a*. Once, however, the actuator **236** is freed for movement by the spring **240** to return the latch member **234** inwardly, the latch will reenter the groove **235** whenever the control piston **221***a* next reaches its neutral or intermediate position as illustrated.

It will be appreciated, therefore, that by arranging the selectively operable control means **201** with 16 identical control pistons as at **221—224** and their respective actuators as at **234**, each of the four upper piston cylinders **206** can be selectively coupled to each of the four lower piston cylinders **212** in any one of the four possible arrangements. Thus, by arranging the fluid passages **214**, **216** and **217—220** and the upper and lower pistons **205** and **211** as illustrated in FIG. **23**, any one of the four possible operating arrangements can be readily obtained by selectively releasing a selected group of four of the control pistons **221—224** while leaving the remaining 12 control pistons latched in their intermediate positions. In the preferred manner of accomplishing this, each vertical tier of four control pistons **221—224** is respectively coupled to one of the upper piston cylinders **206** by the fluid passages **214**. Then, each of the four piston cylinders **206** in the same horizontal tier are in turn respectively coupled by the individual fluid passages **217—220** to each of the four lower piston cylinders **212**. Thus, whenever, for example, the four control pistons **224***a—224d* in the upper horizontal tier are released for free axial movement, each of the four upper piston cylinders **206***a—206d* will be respectively coupled to one of the four lower piston cylinders **212***a—212d*.

To actuate the selectively operable control means **201**, a tool such as shown in FIG. **19** is arranged for movement into the axial housing bore **241** for selectively operating any four of the actuators **236** in a given horizontal tier. It should be noted that irrespective of which four of the 16 actuators **236** are to be depressed at a given time, passage of the actuating tool through the housing bore **241** may momentarily release some or possibly all of the other 12 control pistons **221—224** which are supposed to remain latched. This, however, will not present any particular problem inasmuch as the continued rotation of the directional-drilling tool **200** will quickly return the 12 momentarily released control pistons **221—224** to their neutral positions as the upper and lower pistons **205** and **211** respectively associated therewith are moved inwardly and outwardly by the weight of the rotating drilling tool and its associated drill string (not shown). Thus, once any one of these 12 control pistons **221—224** passes its intermediate or neutral position, the latch member **234** respectively associated therewith will be urged inwardly into the locking groove **235** to lock the piston in its neutral position. Thereafter, inasmuch as the selected four actuators **236** will be held inwardly for retracting the selected four latch members **234**, only these four control pistons **221—224** will be free to move in accordance with the successive movement of the upper pistons **205**.

It will be appreciated that since the particular arrangement illustrated in FIGS. **20—22** only enables the control pistons **221—224** to either move or not to move, there may be situations in which the corresponding movements of the lower wall-engaging means **203** should be reduced. Accordingly, to accomplish this, the control pistons **221—224** illustrated in FIG. **20** may be replaced with control pistons as illustrated at **243** in FIG. **24**. As seen there, the piston members **243** have a plurality of steps **244—246** formed around the intermediate portion of their body **247** for limiting the axial travel thereof to three progressively larger spans of travel. Thus, by forming the piston body **247** with the longitudinally spaced reduced-diameter portions **244—246**, the piston **243** may be selectively latched in its intermediate position or alternatively permitted to move axially in any one of three spans of travel.

To actuate the latch member **234**, a tool such as that illustrated in FIG. **19** is employed except that the selectively positioned annular collar (as at **151**) employed thereon is replaced with similar collars (not shown) having different external diameters so as to determine the degree of withdrawal of the latch member **234** as required. Thus, for example, if only the minimum travel of the control piston **243** is to be permitted, the collar (such as that at **151** in FIG. **19**) is selected to have a minimum external diameter so that the latch member **234** will be only partially retracted for limiting the actual travel of the piston **243** to the span of travel defined between the shoulders **245**. Similarly, by providing an annular collar (as at **151**) of slightly larger diameter, whenever this collar comes into contact with the free end **242** of the actuator **236**, the latch member **234** will be withdrawn still further so as to limit the span of travel of the piston **243** to that length defined by the longitudinal spacing between the shoulders **246**. Full retraction of the latch member **234** will, of course, permit the piston **243** to travel the full length of the cylinder **248**.

It will, of course, be appreciated that the directional-drilling tool **200** will function in the same manner as the directional-drilling tool **100** having the control means **104'** depicted in FIG. **17**. Thus, for the sake of brevity, it is believed necessary only to point out that operation of the tool **200** is conducted with an actuator such as illustrated in FIG. **19** and described immediately above.

DESCRIPTION OF THE TOOL DEPICTED IN FIGS. 25—28

It will be recognized, of course, that there may be situations in which it will be preferred to operate the directional drilling tools of the present invention by manipulation of the drill string. Accordingly, as shown in FIG. **25**, a directional drilling tool **300** is depicted in which control means **301** are adapted for selective operation from the surface to couple the upper deviation-sensing means **302** to the lower directional-guiding means **303**. Inasmuch as the upper and lower wall-engaging means **302** and **303** are similar to their counterparts previ-

ously described as, for example, in FIG. 12, it is not believed necessary to illustrate their construction in detail. Similarly, the control means 301 preferably include an annular valve member 304 arranged in generally the same manner as the valve member 52 illustrated in FIG. 6 for controlling fluid communication through various passages between the upper and lower wall-engaging means 302 and 303.

To control the annular valve member 304, the directional drilling tool 300 is arranged with an elongated tubular body 305 on which the upper and lower wall-engaging means 302 and 303 and drill bit 306 are respectively mounted. A tubular mandrel 307 is telescopically arranged in the upper portion of the tool body 305 and coupled, as by an enlarged section 308, to the lower end of the drill string 309. As seen in FIGS. 25 and 26, the mandrel 307 is corotatively secured to the tool body 305 by longitudinal splines and mating grooves as at 310 for transmitting rotation from the drill string 309 to the drill bit 306. The mandrel 307 is, however, free to move longitudinally from its elevated position depicted in FIG. 25 downwardly until the enlarged mandrel portion 308 engages the upper face of the shoulder 311 on top of the body 305. Conversely, the upper limit of travel of the mandrel 307 in relation to the tool body 305 is determined by the upper end of the splines 310 on the mandrel coming into abutment with the lower face of the shoulder 311.

It will be appreciated, therefore, that once the directional drilling tool 300 is positioned within a borehole, the mandrel 307 can be moved over a limited span of longitudinal travel in relation to the tool body 305 by simply picking-up and slacking-off the drill string 309. Accordingly, to utilize this longitudinal travel of the mandrel 307 for selectively shifting the annular valve member 304, a depending tubular extension 312 ((FIG. 27) of the mandrel is provided with one or two laterally extending cam followers or rollers 313 that are adapted for reception in a system 324 of alternating channels or grooves formed around the circumference of the internal wall of the valve member.

As best seen in FIG. 28, the groove system 314 is preferably arranged as a series of upwardly inclined grooves 315 alternately disposed between a series of downwardly inclined grooves 316. As illustrated, the junctions of the grooves 315 and 316 at the upper and lower faces of the valve member 304 are respectively arranged to provide entrance and exit openings 317 and 318 at circumferentially spaced intervals around the valve member, with the upper openings being staggered in relation to the lower openings. To accommodate the cam roller or rollers 313, vertical grooves 319 and 320 are formed in the internal wall of the tool body 305 so that the cam rollers can pass above and below the valve member 304 as the mandrel 307 is reciprocated in relation to the tool body.

Accordingly, it will be appreciated that by arranging the inclined groove system 314 as illustrated, each downward stroke of the mandrel 307 will shift the annular valve member 304 through an arc equal to the angular separation of two immediately adjacent entrance and exit openings 317 and 318; and, conversely, each upward stroke of the mandrel will be effective to index the valve member so as to bring the next-following entrance opening into alignment with the upper groove 319. Thus, in the preferred arrangement of the tool 300, an upward stroke of the mandrel 307 followed by a downward stroke is required to index the valve member 304 to its next effective position.

It will be recognized, therefore, that the angular spacing between two successive exit openings 318 should preferably correspond to the angular spacing between adjacent ports (such as those shown at 55*a* and 55*b*' in FIG. 6). Thus, to index the annular valve member 304 from one operating position to its next, a consecutive upward stroke and a single downward stroke of the mandrel 307 are required. With four sets of upper and lower wall-engaging means 302 and 303, four consecutive reciprocating strokes of the mandrel 307 will progressively index the annular valve member 304 to its four operating positions. The fifth reciprocation of the mandrel 307 will index the valve member 304 to its neutral position for blocking communication between the upper and lower wall-engaging means 302 and 303; and the sixth reciprocation of the mandrel will return the valve member to its first operating position. It will be also seen that by arranging the valve member 304 to be in one of its five positions (its four operating positions and its neutral position) when the mandrel 307 is fully telescoped into the tool body 305, the abutment of the shoulders 308 and 311 will enable the weight of the drill string 309 to be imposed on the drill bit 306 during the operation of the tool 300.

SUMMARY

With the directional tool 30 depicted in FIGS. 1—10, control of the drilling bit coupled thereto is simply accomplished by regulating the pressure of the drilling fluid or mud circulating through the system. On the other hand, the directional drilling tools 100 and 200 respectively shown in FIGS. 11—19 and FIGS. 20—24 are adapted to be controlled by special purpose actuating tools as illustrated in FIGS. 16 and 19 which are dispatched through the drill string. The directional tool 300 is adapted for selective operation by manipulating the drill string to position the control means thereof in any one of several control positions.

Accordingly, it will be appreciated that the present invention has provided new and improved methods and apparatus for guiding a drill bit as it progressively excavates a borehole. By employing any of the several directional drilling tools disclosed herein, a drill bit coupled thereto can be reliably directed in any of several selected directions during the course of a drilling operation without requiring the removal of the drill string from the borehole to make corrective adjustments to the directional drilling tool.

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; deviation-sensing means on said body and adapted for developing pressures upon lateral movements of said body toward a borehole wall during the excavation of a borehole by a borehole-excavating device coupled to said body; guiding means on said body and responsive to 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 operable from the surface for selectively coupling said deviation-sensing means to said guiding means for operation of said guiding means in response to pressures developed by said deviation-sensing means.

2. The apparatus of claim 1 wherein said deviation-sensing means and said guiding means are angularly displaced so that their respective movements are in different lateral directions.

3. The apparatus of claim 1 wherein said control means include first and second fluid conduits respectively coupled to said deviation-sensing means and said guiding means, a control member adapted for movement on said body for selectively regulating communication between said first and second fluid conduits, and actuating means operable from the surface for selectively moving said control member.

4. The apparatus of claim 3 wherein said control member is a valve member adapted for opening and closing fluid communication between said first and second fluid conduits whenever said valve member is in selected positions; and said actuating means include a pressure-responsive actuating member adapted for moving said valve member to its said selected positions in response to predetermined changes in the fluid pressure within a drill string coupled to said body.

5. The apparatus of claim 3 wherein said control member is a valve member adapted for opening and closing fluid communication between said first and second fluid conduits whenever said valve member is in selected positions; and said actuating means include an actuator adapted for passage

through a drill string coupled to said body to a predetermined position relative to said body, and means on said actuator and said valve member adapted for shifting said valve member to its said selected positions whenever said actuator is moved into and out of its said predetermined position.

6. The apparatus of claim 3 wherein said actuating means include an actuating member movably mounted on said body and adapted for connection to such a drill string, and means cooperatively arranged between said actuating member and said control member and adapted for selectively moving said control member upon movements of such a drill string.

7. The apparatus of claim 6 wherein said control member is a valve member movably mounted on said body and adapted for opening and closing fluid communication between said first and second fluid conduits as said valve member is selectively moved.

8. 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 drill bit adapted for excavating a borehole; first wall-engaging means on said body and adapted for movement inwardly in response to forces urging said body laterally against a borehole wall during the excavation of a borehole by a drill bit connected thereto; second wall-engaging means longitudinally spaced from said first wall-engaging means on said body and adapted for movement outwardly in relation thereto for shifting said body laterally in relation to the axis of a borehole being excavated by such a drill bit; and control means operable from the surface to selectively intercouple said first and second wall-engaging means for cooperatively urging said second wall-engaging means outwardly against a borehole wall in response to inward movements of said first wall-engaging means to direct such a drill bit along a selected axis of excavation.

9. The apparatus of claim 8 wherein said first wall-engaging means include pressure-developing means adapted for developing fluid pressures in response to said inward movements of said first wall-engaging means; said second wall-engaging means include pressure-actuated means adapted for moving said second wall-engaging means outwardly in response to fluid pressures developed by said pressure-developing means; and said control means include first and second fluid conduits respectively coupled to said pressure-developing means and said pressure-actuated means, a control member adapted for movement on said body for selectively regulating communication between said first and second fluid conduits, and actuating means operable from the surface for selectively moving said control member.

10. The apparatus of claim 9 wherein said pressure-developing means and said pressure-actuated means are angularly displaced so that their respective movements are in different lateral directions.

11. The apparatus of claim 9 wherein said actuating means include a pressure-responsive actuating member adapted to be coupled to said control member for moving said control member in response to predetermined changes in the fluid pressure within a drill string coupled to said body.

12. The apparatus of claim 11 wherein said control member is a valve member adapted for opening and closing fluid communication between said first and second fluid conduits whenever said valve member is in selected positions.

13. The apparatus of claim 8 wherein said first wall-engaging means include pressure-developing means adapted for developing fluid pressures in response to said inward movements of said first wall-engaging means; said second wall-engaging means include pressure-actuated means adapted for moving said second wall-engaging means outwardly in response to fluid pressures developed by said pressure-developing means; and said control means include first and second fluid conduits respectively coupled to said pressure-developing means and to said pressure-actuated means, a control member adapted for movement between spaced positions on said body for selectively regulating communication between said first and second fluid conduits, an actuator adapted for passage through a drill string coupled to said body to a predetermined position relative to said body, and means on said actuator and said control member adapted for shifting said control member between its said spaced positions whenever said actuator is moved into and out of its said predetermined position.

14. The apparatus of claim 13 wherein said control member is a valve member adapted for opening and closing fluid communication between said first and second fluid conduits whenever said valve member is in different ones of its said spaced positions.

15. The apparatus of claim 13 wherein said control member is a piston member operatively disposed in a cylinder and adapted for blocking pressure communication between said first and second fluid conduits whenever said piston member is retained in one of its said spaced positions within said cylinder and for transmitting fluid pressure between said first and second conduits whenever said said piston member is free to move between its said spaced positions within said cylinder; and further including means on said body adapted for releasably retaining said piston member in its said one position; and means adapted for cooperation with said piston-retaining means upon movement of said actuator to its said selected position for releasing said piston member for movement between its said spaced positions.

16. The apparatus of claim 8 wherein said first wall-engaging means include pressure-developing means adapted for developing fluid pressures in response to said inward movements of said first wall-engaging means; said second wall-engaging means include pressure-actuated means adapted for moving said second wall-engaging means outwardly in response to fluid pressures developed by said pressure-developing means; and said control means include first and second fluid conduits respectively coupled to said pressure-developing means and to said pressure-actuated means, a control member on said body adapted for movement between predetermined spaced positions for selectively regulating communication between said first and second fluid conduits, an actuating member movably mounted on said body and adapted for connection to such a drill string, and means cooperatively arranged between said actuating member and said control member for moving said control member between its said spaced positions in response to movements of said actuating member in relation to said body by a drill string connected to said actuating member.

17. The apparatus of claim 16 wherein said control member is a valve member adapted for opening and closing fluid communication between said first and second fluid conduits whenever said valve member is in different ones of its said spaced positions.

18. The apparatus of claim 16 wherein said first and second wall-engaging means are angularly displaced so that said first and second wall-engaging means are movable in different lateral directions.

19. A directional drilling tool comprising: an elongated body having a longitudinal passage therethrough and adapted for connection in a rotating drill string including a borehole-excavating device; first and second wall-engaging means longitudinally spaced on said body and including first and second groups of pistons operatively mounted on said body for movement respectively along first and second sets of angularly spaced lateral axes between retracted and extended positions in relation to said body; and control means adapted for selectively intercoupling said first and second wall-engaging means and including first and second conduits respectively fluidly coupled to said first and second groups of pistons, 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 actuating means operable from the surface for selectively moving said valve means between its said spaced positions while said tool is in a borehole.

20. The directional drilling tool of claim 19 wherein each of said pistons is fluidly coupled to only one of said conduits; and said valve means are movable to a sufficient number of said spaced positions to enable each of said first pistons to be fluidly coupled to each of said second pistons in successive ones of said spaced positions of said valve means.

21. The directional drilling tool of claim 20 wherein said valve means are also arranged for movement to another one of said spaced positions to isolate said first conduits from said second conduits.

22. The directional drilling tool of claim 20 wherein said valve means include a valve member operatively arranged on said body for rotation in relation thereto between angularly spaced positions; and said actuating means include a pressure-responsive actuating member adapted for movement in response to predetermined changes in the fluid pressure within a drill string coupled to said tool, and cam means operatively arranged between said members for progressively rotating said valve member to each of its said positions upon successive movements of said actuating member.

23. The directional drilling tool of claim 20 wherein said valve means include a valve member operatively arranged on said body for rotation in relation thereto between angularly spaced positions; and said actuating means include a plurality of actuator members respectively adapted for passage through a drill string coupled to said tool and to a predetermined position in relation to said body, and individually distinctive cam means on each of said actuator members and said valve member for selectively rotating said valve member to a predetermined one of each of its said positions according to which one of said actuator members is in said predetermined position.

24. The directional drilling tool of claim 20 wherein said valve means include a valve member operatively arranged on said body for rotation in relation thereto between angularly spaced positions; and said actuating means include an actuating member adapted for coupling to a drill string and operatively arranged for reciprocating movement in relation to said body upon reciprocation of such a drill string, and cam means operatively arranged between said members for progressively rotating said valve member to each of its said positions upon successive reciprocations of said actuating member.

25. A directional drilling tool comprising: an elongated body having a longitudinal passage therethrough and adapted for connection in a rotating drill string including a borehole-excavating device; first and second wall-engaging means longitudinally spaced on said body and including first and second groups of pistons operatively mounted thereon for movement respectively along first and second sets of angularly spaced lateral axes between retracted and extended positions in relation to said body; and control means adapted for selectively intercoupling said first and second wall-engaging means and including first and second conduits respectively fluidly coupled to said first and second groups of pistons with each of said pistons being fluidly coupled to only one of said conduits, a plurality of movable members operatively arranged on said body with each of said movable members being respectively coupled to one of said first conduits and one of said second conduits for selectively regulating communication between only the two conduits coupled thereto independently of the operation of the others of said movable members, and actuating means operable from the surface for selectively moving each of said movable members independently of said others so as to selectively intercouple said first and second wall-engaging means in different predetermined arrangements for directing such a borehole-excavating device along selected axes of excavation.

26. The directional drilling tool of claim 25 wherein said actuating means include an actuator member adapted for passage from the surface through a drill string coupled to said tool and to a predetermined position in relation to said body, and means cooperatively arranged on said movable members and said actuator members for moving only selected ones of said movable members to operating positions for establishing desired ones of said predetermined arrangements.

27. The directional drilling tool of claim 26 wherein said movable members are valve members respectively adapted for opening and closing fluid communication between said two conduits coupled thereto.

28. The directional drilling tool of claim 26 wherein said movable members are piston members respectively disposed in a cylinder and adapted for blocking pressure communication between said two conduits coupled thereto whenever that piston member is retained in a fixed position within its respective cylinder and for transmitting fluid pressure between said two conduits coupled thereto whenever that piston member is free to move within its respective cylinder.

29. The directional drilling tool of claim 28 wherein said actuating means include: means on said body adapted for releasably retaining said piston members in their respective said fixed positions, an actuating member adapted for passage from the surface through a drill string coupled to said tool and to a predetermined position in relation to said body, and means cooperatively arranged on said actuating member and engageable with said piston-retaining means for releasing only selected ones of said piston members for free movement within their respective cylinders for establishing desired ones of said predetermined arrangements.

30. A directional drilling tool comprising: a first tubular member having a longitudinal passage therethrough and adapted for connection to a borehole-excavating device; a second tubular member adapted for connection to a rotating drill string corotatively secured to said first member and having at least a lower portion extending into said longitudinal passage for movement between spaced positions therein upon upward and downward movements of said second member relating to said first member; first and second wall-engaging means longitudinally spaced on said first member and including first and second groups of pistons operatively mounted thereon for movement respectively along first and second sets of angularly spaced lateral axes between retracted and extended positions in relation to said first member; and control means adapted for selectively intercoupling said first and second wall-engaging means and including first and second conduits respectively fluidly coupled to said first and second groups of pistons with each of said pistons being coupled to only one of said conduits, a valve member on said first member adapted for movement relative thereto between predetermined operating positions for selectively regulating fluid communication between said first and second conduits, and means cooperatively arranged in said longitudinal passage between said valve member and said lower portion of said second member and responsive to movements thereof between its said spaced positions for moving said valve member between its said operating positions.

31. The directional drilling tool of claim 30 wherein said valve member is an annular member rotatably mounted on said first member; and said valve moving means include an alternating cam-guiding track formed around said annular valve member and defining successive angularly spaced stops, and a cam member on said lower portion of said second member received in said cam-guiding track and adapted for progressively rotating said valve member to each of its said operating positions as said cam member is moved to each of said angularly spaced stops.

32. A method for excavating a borehole along a desired course with a tool coupled to a tubular drill string extending to the surface, said tool having a drill bit coupled thereto and including first wall-engaging means thereon adapted for movement inwardly in response to forces urging said tool against a borehole wall during excavation of a borehole, second wall-engaging means thereon adapted for movement outwardly against a borehole wall for shifting said tool and drill bit laterally in relation to the axis of a borehole being excavated, and control means operable from the surface for selectively connecting said first and second wall-engaging means, com-

prising the steps of: rotating said drill string for operatively driving said drill bit to progressively excavate said borehole further; and, as said tool is rotated by said drill string, operating said control members from the surface for selectively connecting said first and second wall-engaging means to move said second wall-engaging means outwardly in response to inward movements of said first wall-engaging means for shifting said drill bit in a selected lateral direction.

33. The method of claim 32 wherein said control means are selectively operated by increasing the pressure of drilling fluids circulating through said drill string to at least a predetermined pressure.

34. The method of claim 32 wherein said control means are selectively operated by dispatching an actuating member from the surface through said drill string to said tool.

35. The method of claim 32 wherein said control means are selectively operated by predetermined movements of said drill string in relation to said tool.

36. The method of claim 32 further including the step of measuring at least one parameter indicative of the course of said borehole to determine the extent that said drill bit has been shifted.

37. The method of claim 36 further including the step of operating said control members from the surface for disconnecting said first and second wall-engaging means to discontinue further shifting of said drill bit.