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DRILL STRING STABILIZER

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FIG. 1

FIG. 2

FIG. 3

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The present invention relates to apparatus for drilling oil wells, gas wells, and similar boreholes in the earth and more particularly relates to an improved stabilizer for correcting borehole deviation during the rotary drilling of such boreholes. In still greater particularity, the invention relates to a stabilizer provided with hydraulically extensible shoes which can be individually actuated in response to pressure of the tool against the borehole wall in order to increase the pendulum force on the drill bit and thus correct deviation of the borehole as drilling progresses.

The apparatus utilized downhole during the rotary drilling of oil wells, gas wells and similar boreholes in the earth normally includes a string of drill pipe extending from the earth's surface to a point a few hundred feet above the bottom of the borehole, a series of heavy drill collars attached to the lower end of the drill pipe, and a rotary drill bit connected to the lowermost drill collar. The drill collars, which may weigh 50,000 pounds or more, supply the weight needed for effective bit penetration and at the same time keep the relatively thin-walled drill pipe in the upper part of the borehole in tension. This reduces buckling and flexing of the pipe as it is rotated in the hole and thus increases the life of the pipe. Some irregular motion of the drill bit normally takes place due to buckling and flexing of the drill collars, variations in the hardness of the formation, and differences in the effectiveness of the bit cutting elements, however. This is usually sufficient to cause some deviation of the borehole, particularly while drilling through steeply dipping, laminated formations which have an inherent tendency to deflect the bit. Boreholes which deviate as much as 30 degrees in a few thousand feet are not uncommon.

The method generally used to overcome borehole deviation problems can best be understood by considering some of the forces which act on a rotary drill bit in a sloping bore hole. The weight of the drill collars transmitted to the bit can be broken down into two components, one extending in the direction of the hole and the other extending into the formation toward the low side of the borehole. The latter of these two forces is generally referred to as the restoring force or the pendulum force acting on the bit. The magnitude of the pendulum force is in part determined by the angle of inclination of the borehole and in part governed by the distance above the bit at which the drill collars first make contact with the lower side of the borehole wall. The greater the distance between the bit and this first point of contact, the greater will be the pendulum force acting on the bit. Since the pendulum force tends to force the bit back into a vertical position, an increase in the length of the drill collar column between the bit and the point where the column first sags against the borehole wall will tend to reduce borehole deviation.

The conventional method for increasing the pendulum force on a rotary drill bit in order to counteract the forces responsible for borehole deviation involves the use of a drill collar stabilizer. The usual stabilizer is a tubular member having external ribs and provided with box and pin joints which permit it to be connected into the drill string at an intermediate point between adjacent drill collars. The ribs of the stabilizer extend radially beyond the drill collars and thus support the drill collars above the lower side of the borehole. By placing the stabilizer above the point where the drill collars would normally make contact with the lower side of the borehole wall, the length of the drill collar column between the bit and the point of contact can be increased. The resulting increase in the pendulum force acting on the bit tends to force it back towards a vertical position and correct the deviation problem as drilling progresses. The increased pendulum force thus obtained is, however, often insufficient to accomplish the desired results.

The effectiveness of a drill collar stabilizer of conventional design for straightening a crooked borehole is largely determined by the length of the drill collar column which can be suspended between the stabilizer and the bit. The longer the suspended section, the greater will be the pendulum force on the bit which serves to straighten the hole. The length of the suspended section is in part limited by the difference between the diameter of the drill collars utilized and that of the borehole itself. Even in very large diameter boreholes, this difference is seldom more than about four inches. Conventional stabilizers tend to center the string of drill collars in the hole. The maximum elevation of the drill collars above the wall of the borehole at the stabilizer is therefore one-half of the difference between the diameter of the drill collars and that of the borehole. Elevation of the drill collars in this manner usually permits the point of contact between the drill collars and the borehole wall to be moved only a short distance above the point where contact would occur if a stabilizer were not used. The increase in the pendulum force achieved by the installation of the drill collar stabilizer is thus usually small. In many formations the tendency of dipping, laminated strata to deflect the bit is so great that borehole deviation cannot be controlled even though a conventional drill collar stabilizer is used.

The present invention provides a new and improved stabilizer for correcting deviation during the rotary drilling of oil wells, gas wells, and similar boreholes in the earth. The stabilizer of the invention results in a greater increase in the pendulum force on the drill bit than can generally be obtained with conventional stabilizers and hence permits the control of deviation under conditions where the tools available heretofore have often proved ineffective. The apparatus can be employed with conventional rotary drilling equipment, does not require specialized drilling procedures, and need not be manipulated from the surface to be effective. These and other features make the stabilizer of the invention an effective tool for use in rotary drilling operations where deviation problems are encountered.

The improved stabilizer of the invention includes a tubular mandrel provided with means for connecting the stabilizer into a conventional rotary drill string. The mandrel carries an outer sleeve within which it is free to rotate. One or more ports permit the flow of drilling fluid from the mandrel to the sleeve. Hydraulically extensible shoes positioned about the sleeve communicate with the port through a series of passageways. Each shoe has associated with it a valve which controls the flow of drilling fluid into it. The valves are responsive to pressure between the tool and the borehole wall and downward movement of the tool in the hole. Opening of the valves permits drilling fluid to flow from the mandrel into the shoe, extending it. In a vertical borehole, there is not sufficient pressure against the valve mechanisms to open the valves, and hence the shoes are not extended. In a sloping hole where a deviation problem exists, however, the valve mechanism associated with one or more shoes bears against the lower side of the borehole. Friction against the borehole wall prevents the mechanism from sliding as the tool moves downwardly and thus the valve is opened. Drilling fluid pressure against the inner faces of the shoes
extends them outwardly against the formation and results in an increase in the pendulum force acting on the bit. In one specific embodiment of the invention, the valve mechanism is actuated by the shoe assembly itself. Pressure on the shoe as it bears against the lower side of the borehole holds the mechanism in a depressed position so that the tool can move downwardly with respect to it as the borehole is advanced. This downward movement opens the valve and admits drilling fluid from the mandrel to the shoe. As the shoe is extended due to the hydraulic pressure exerted by the fluid, it raises the drill string from the lower side of the borehole to the upper side of the hole. This elevates the drill string at a point above the point at which it would otherwise make contact with the borehole wall. The resulting increase in the length of the drill collar between the bit and the point of first contact with the wall increases the pendulum force acting on the bit. Since the shoe raises the drill string to the upper side of the hole instead of merely centering it in the hole as does a conventional stabilizer, the increase in the pendulum force is considerably greater than that achieved with prior art stabilizers. During drilling, the shoe slides downwardly against the borehole wall as the drill string advances. The mandrel rotates within the sleeve of the tool. The shoe can readily be returned to its original position in the sleeve by pulling upwardly on the tool from the surface. This retracts the shoe and permits the drill string to be withdrawn from the borehole without undue wear and abrasion. It also reduces the danger of damage to the borehole wall during trips into and out of the hole.

In a second, preferred embodiment of the invention, the valve mechanisms and shoes are located at opposite ends of the tool. The tool is installed in the drill string so that the shoes are positioned just above the bit. Each valve is operated by a valve rod which projects from the sleeve and makes contact with the lower side of the borehole. Pressure against the valve rod and downward movement of the tool with respect to it opens the valve. This permits drilling fluid to flow from the valve through a passage in the sleeve which spirals 180° to a corresponding shoe at the lower end of the tool. Extension of the valve in response to the fluid pressure exerts a force against the high side of the borehole just above the bit. This augments the pendulum force and results in a much greater total force toward the lower side of the borehole than can be achieved by merely lengthening the distance between the bit and the point of first contact between the drill collar and the borehole wall. As in the earlier embodiment, the mandrel turns within the sleeve and the shoe slides downwardly in contact with the borehole wall as the drill string advances.

The exact nature and objects of the invention can best be understood by referring to the following detailed description of the two embodiments mentioned above and to the accompanying drawings, in which:

FIGURE 1 is a vertical elevation, partially in section, of a drill collar stabilizer provided with hydraulically actuated shoes and valve mechanisms which are designed to lift the drill collars away from the lower side of the borehole in order to increase the pendulum force acting on the drill bit;

FIGURE 2 is a cross-sectional view of the apparatus depicted in FIGURE 1 taken along the line 2—2;

FIGURE 3 is a cross-sectional view through the apparatus represented in FIGURE 1 taken along the line 3—3;

FIGURE 4 is a small-scale elevation view of the apparatus shown in FIGURES 1 through 3 illustrating the installation of the apparatus in the bottom hole assembly of a rotary drill string in order to correct borehole deviation;

FIGURE 5 is a vertical view, partially in section, of a stabilizer having separate valve mechanisms and shoe assemblies for applying force to the upper side of a sloping borehole just above the bit in order to augment the pendulum of the stabilizer of the tool; FIGURE 6 is a cross-sectional view of the apparatus of FIGURE 5 taken along the line 6—6; FIGURE 7 is a cross-sectional view of the apparatus of FIGURE 5 taken along the line 7—7;

FIGURE 8 is a cross-sectional view of the stabilizer shown in FIGURES 5 through 8 installed in a rotary drill string with a shoe extended just above the bit in order to correct borehole deviation.

During the course of the drawing, the tool depicted therein includes a mandrel 11 which is of generally cylindrical shape and contains an axial passage 12 through which fluids may flow from one end of the tool to the other. The mandrel is provided with means at its upper and lower ends for connecting the tool at an intermediate position within a conventional rotary drill string. As shown in FIGURE 1, the mandrel includes a standard API pin 13 at its lower end and a separate API box joint 14 of larger diameter connected to its upper end by threads or equivalent means 15 in order to permit disassembly of the tool when desired. Mandrel 11 is divided into two sections, a lower section 16 and a relatively larger diameter located just above pin 13 and an upper section 17 which extends from shoulder 18 upwardly to threads 15. Fluid passage 19 extends laterally from axial passage 12 to the outer surface of the mandrel within upper section 17. Grooves 20 and 21 are located on the outer surface of the mandrel above and below the outlet of passage or port 19 for stress relief purposes. The upper edge of lower mandrel section 16 is provided with notches 22 to facilitate milling when washer operations are necessary, as will be explained in detail later.

Sleeve 23 of the tool depicted in FIGURE 1 of the drawing is a tubular member carried on upper section 17 of mandrel 11. The inner diameter of the sleeve is slightly larger than the outer diameter of the upper mandrel section in order to permit the sleeve to rotate and move axially on the mandrel. Wiper ring 24 and seal ring 25 of rubber, plastic or similar material are set in annular grooves on the inner surface of the sleeve near the upper end thereof and provide a fluid-tight seal between the sleeve and mandrel. Port 26 permits the escape of fluids entrapped between the rings. Similar rings 27 and 28 and port 29 are located near the bottom of the sleeve for like purposes. The rings shown in FIGURE 1 of the drawing are not shown in the remaining drawings between the mandrel and sleeve. Separate bearings may be provided if desired. In its lowermost position, the axially slideable sleeve 23 seats against shoulder 18 of the mandrel and is supported thereby. The lower edge of the sleeve is provided with projections 30 which mate with notches 22 in the mandrel so that the mandrel and sleeve may be locked together and rotated in a counterclockwise direction if desired. The faces of the projections are tapered to permit clockwise rotation of the mandrel independently of the sleeve. As pointed out earlier, box joint 14 extends laterally beyond the mandrel and thus serves to retain the sleeve when it is in its uppermost position on the mandrel.

The outer surface of sleeve 23 contains a plurality of elongated recesses which extend parallel to the longitudinal axis of the tool. The hydraulically extensible shoe assemblies and associated valve mechanisms utilized in this embodiment of the invention are housed within these recesses.

As can be seen from FIGURES 2 and 3 of the drawing, each of the recesses extends radially into the wall of sleeve 23 and is of substantially rectangular cross section. A port 31 in the sleeve wall near the mid point of each recess permits the passage of fluids between the recess and the space separating the sleeve and mandrel. An annular sealing member 32 of rubber or similar resilient
material is seated in a groove in the wall surrounding each port. The sealing member extends radially beyond the wall and provides a fluid-tight seal against the inner surface of valve body 33. The valve bodies are elongated members having substantially the same width as the recesses in which they are positioned. They are somewhat shorter than the recesses, however, and can therefore slide longitudinally within them. The outer face of each valve body contains a recessed intermediate section 34 within which a port 35 is located. The port extends through the body and is aligned with port 33 when the valve body comes into its uppermost position with the recess 23. A coil spring 36 in the upper end of the recess limits upward movement of the valve and holds it in a normally downward position until sufficient force to compress the spring is applied to the valve. When the valve body is in its lowermost position, ports 31 and 35 do not align with one another and hence no fluid can pass between the recess and the space separating the sleeve and mandrel.

The shoe assembly includes a plate-like supporting member 37 which contains an elongated opening near its center. The supporting member fits within the recessed intermediate section 34 of the valve body and is supported by leaf springs 38 and 39 which bear against it. Each of the leaf springs is seated in a shallow groove in the outer surface of the valve body in order to prevent its being jarred out of position. The grooves are designated by reference numerals 40 and 41 in FIGURE 1 of the drawing. Two springs are located at each end of the supporting member, although only one of these can be seen in FIGURE 1. The springs permit depression of the supporting member into recessed section 34 in the valve body. The outer face of the supporting member is provided with a projecting rim 42 which surrounds the opening therein. Annular elastic member 43 and shoe 44 occur on rim 42 and are spaced from the supporting member to rim 42 and shoe 44 and tend to hold the shoe in a retracted position within the supporting member. It should have a sufficient modulus of elasticity to permit extension of the shoe at low differential pressures and should be capable of withstanding the shoe stresses encountered at higher operating pressures. Good bonding properties to metal are desirable. Conventional bonding techniques may be utilized in forming the shoe assembly. It is preferred that the elastic member be made of neoprene or nitrile rubber having high resistance to deterioration in the presence of crude oil but other rubbers and rubber-like materials may be used. The shoes and leaves are rounded at their ends to reduce the likelihood that the elastic member will pull free from the metal under high stress. The shoes are normally made of wear-resistant alloy steel and may be surfaced with tungsten carbide or a similar material to increase their resistance to wear and abrasion.

An annular resilient member 45 is seated in a groove in the inner face of supporting member 37 and extends around elastic member 43 and shoe 44. This member protrudes beyond the face of the supporting member a distance sufficient to effect a seal between the supporting member and valve body. The inner face of the supporting member is depressed into the valve body. This prevents the escape of fluid from the space behind elastic member 43 and shoe 44 into the annular space surrounding the tool. When the supporting member is in its outermost position as shown in FIGURE 1 of the drawing, resilient member 45 and the sleeve 23 are brought into contact and the assembly is effectively vented to the annular space surrounding the tool.

A curved cover plate 46 containing an elongated opening 47 through which the shoe assembly protrudes fits over each recess and is held in place by the mandrel. The opening is somewhat longer than the shoe assembly in order to permit longitudinal movement of the assembly with respect to the recess. The cover plate contains on its inner face a shoulder 49 against which the supporting member 37 abuts when the shoe assembly is in its lowest position within the recess. In order for the supporting member to clear this shoulder, it must be depressed within the intermediate section 34 of the sliding valve. The leaf springs 38 and 39 hold it in a normally outward position against the cover plate. The tool depicted in FIGURES 1 through 3 of the drawing contains 6 identical shoe assemblies spaced at regular intervals. It will be understood, however, that the invention is not limited to the use of 6 shoes and that a greater or lesser number may be employed.

The operation of the embodiment of the improved stabilizer described in the preceding paragraphs is in some respects similar to that of a conventional stabilizer but is significantly different in other respects. When a deviation problem is encountered during a rotary drilling operation, the hole is surveyed to determine the points at which it slopes. Conventional inclinometers and other instruments can be employed for this purpose. The information thus obtained, coupled with information as to the extent to which the drill collars utilized tend to sag under their own weight, permits calculation of the distance above the bit at which the drill collar stabilizer should be placed for maximum effectiveness. Standard charts and tables giving these distances for conventional stabilizers used with drill bits and drill collars of various sizes under various deflection conditions have been prepared and have been published in the literature. References include "A Study of the Buckling of Rotary Drilling Strings," Arthur Lubinski, API Drilling and Production Practice (1950), 178; "Factors Affecting the Angle of Inclination and Dog-Logging in Rotary Bore Holes," Arthur Lubinski and H. B. Woods, API Drilling and Production Practice (1953), 222; "Practical Charts for Solving Problems in Hole Deviation," H. B. Woods and Arthur Lubinski, API Drilling and Production Practice (1954), 56; and "Use of Stabilizers in Controlling Hole Deviation," H. B. Woods and Arthur Lubinski, API Drilling and Production Practice (1955), 165. The charts and tables also generally indicate the extent to which the weight of the drill bit can be increased without increasing deviation if a conventional stabilizer is used. Such charts and tables can be readily modified to permit determination of the point at which the drill collar stabilizer of the invention should be placed for maximum effectiveness, bearing in mind that the stabilizer permits almost twice the elevation of the drill string above the lower side of the borehole that can be obtained with conventional tools. Methods for making the computations necessary for such modifications will be readily apparent to those skilled in the art.

After the proper location for the stabilizer has been determined, the drill string is withdrawn, the tool is inserted between adjacent drill collar sections, and the string is returned to the borehole. The drill collars sag against the lower side of the sloping hole as the string is lowered and thus one or more of the stabilizer shoes is forced inwardly in the recesses which houses it. This permits supporting member 37 to clear shoulder 49 on the shoe assembly cover plate. Friction between the shoe and borehole wall holds the shoe back so that the tool moves downwardly around it, aligning ports 31 and 35 so that fluid may pass from the space between the mandrel and sleeve into the shoe assembly housing. Should the shoe be relieved of pressure due to rotation of the drill string, coil spring 36 will force it back into its normal position. Another shoe will then be depressed and held by friction as the drill string moves downwardly, thus opening the corresponding valve.

The valve associated with one or more stabilizer shoes will thus be opened when the drill string reaches the bottom of the borehole. Drilling fluid is then circulated downwardly through the string and up the annulus. Fluid flowing through mandrel 11 in the stabilizer passes through port 19 into the space between the mandrel and sleeve 23. Seals 24 and 25 at the top of the sleeve and
27 and 28 at the bottom of the sleeve prevent loss of the fluid pressure. Ports 31 and 35 are aligned in the shoe housing on the lower side of the stabilizer and hence fluid pressure is exerted against the underside of the shoe bearing against the borehole wall. Resilient member 45 provides a seal between supporting member 37 and valve body 33, thus preventing escape of the fluid between the cover plate and shoe assembly. The pressure behind the shoe is essentially the same as that within the mandrel. The pressure on the face of the shoe outside the sleeve, on the other hand, is considerably lower because of the pressure drop across the nozzle of the drill bit. In response to this difference in pressure, the shoe is forced outwards against the borehole wall. This raises the stabilizer and adjacent drill collars away from the lower side of the hole. Since the shoes on the upper side of the stabilizer are not expanded, the drill string can be elevated higher than would be the case with a conventional tool. The longer column of drill collars which can thus be suspended between the stabilizer and the drill bit results in a greater increase in the restoring force acting on the bit than could be obtained with a conventional stabilizer.

After circulation of the drilling fluid has commenced, the drill string is rotated from the surface in the conventional manner. Mandrel 11 rotates within sleeve 23 in order to transmit torque through the stabilizer to the bit below. The friction between the stabilizer shoe and the borehole wall is sufficient to prevent rotation of the sleeve. Sharp inserts of tungsten carbide or a similar material may be provided on the outer surface of the shoe to increase this friction. As drilling continues and the drill string moves downwardly, pressure exerted on the sleeve by the lower end of box joint 14 forces the sleeve downwardly. The shoe in contact with the lower side of the borehole slides against the borehole wall. Wear on the outer surface of the shoe will normally be insignificant because of the slow relative motion between the shoe and the wall.

FIGURE 4 of the drawing shows the stabilizer embodiment described in the preceding paragraphs in place in the lower section of a drill string during such a drilling operation. It can be seen from the drawing that stabilizer shoes support the sleeve 23 and adjacent drill collars near the upper side of the borehole. This permits the suspension of a somewhat longer drill collar column between the stabilizer and drill bit than could be suspended if the stabilizer were merely centered in the borehole. The pendulum force or restoring force acting on the drill bit, indicated by the arrow at the lower end of the drill string, is thus greater than can normally be obtained through the use of a conventional drill collar stabilizer.

Continuous drilling of the borehole with the stabilizer in place will normally result in a continuous decrease in the inclination of the hole until it is substantially vertical. Periodic surveys of the borehole can be made during trips to the surface to replace the drill bit. When it is desired to withdraw the drill string containing the stabilizer from the hole, the drill string may be pulled upwardly upwardly the length of the kelly before the circulation of drilling fluid is halted. Friction between the outer surface of the shoe and the borehole wall results in the restoration of the shoe and valve assembly to the normal position shown in FIGURE 1 of the drawing. In this position, resilient member 45 does not provide a seal between supporting member 37 and valve body 33 because fluid behind the shoe is free to escape into the annular space surrounding the tool. The pressure on the inside and outside surfaces of the shoe equalize and the elasticity of elastic member 43 causes retraction of the shoe. The pump used to circulate the drilling fluid must then be shut off and the drill string may be pulled out of the hole in the usual manner. In some cases it may be preferred to shut down the pump before the drill string is initially moved upwardly. The resulting reduction in pressure within mandrel 11 permits retraction of the shoe even though the shoe and valve assembly is not returned to the position shown in FIGURE 1 of the drawing. In either case, the stabilizer can be withdrawn without danger of damaging the formation or sticking of the tool in the borehole.

 Pry holes 101 and 102 shown in FIGURE 5 depict a preferred embodiment of the stabilizer of the invention wherein the valve mechanisms and associated shoes are located at opposite ends of the tool in order to permit greater augmentation of the pendulum force that can normally be obtained by elevating the drill string at a point some distance above the bit. As can be seen from FIGURE 5, this embodiment includes a mandrel 105 similar to that utilized in the earlier embodiment. The mandrel contains an axial passage 106 through which fluid may be passed from the drill string above the tool to the bit below it. API box joint 103 connected to the mandrel at its upper end by threads 104 or equivalent means permits attachment of the stabilizer to the lower end of a conventional drill collar and facilitates disassembly of the tool where necessary. A standard API pin joint 105 is provided at the lower end of the mandrel. Other connecting means may be provided in lieu of those shown, for instance, for example, it is preferred to provide a box joint at the lower end of the mandrel in order to eliminate the necessity for a connecting sub between the stabilizer and the drill bit. The mandrel is divided into two integral sections, a lower section 106 of relatively large diameter which is located just above pin 105 and an upper section 107 of smaller diameter which extends from a shoulder 108 upwardly to the threads at the upper end of the mandrel. Fluid passage 109 extends laterally from axial passage 102 to the outer surface of the mandrel within upper section 107. The upper edge of the lower mandrel section 106 is provided with notches 110 to facilitate milling where washover operations become necessary, as will be described more fully hereafter. Tubular sleeve 111 is carried on the upper section 107 of the mandrel. The inner diameter of the sleeve is slightly larger than the outer diameter of the mandrel so that the sleeve is freely housed. Each valve mechanism includes a cylindrical valve body 23 containing an intermediate elongated recess 124 in its
outer surface. Positioned within this recess is a depression plate 125 to which is attached valve rod 126 by means of bolts 127. The valve rod protrudes through an elongated opening 128 in the outer surface of the sleeve. Leaf springs 129 are located between the valve body and the depression plate in order to force the plate outward. Each spring is preferably seated within a shallow groove in the valve in order to prevent its slipping out of position and yet permit compression of the spring when valve rod 126 bears against the borehole wall. The outer surface of the depression plate below the valve rod contains a notch 130 which mates with a corresponding notch in recess 125. Positioned within the recess is the valve body, depression plate and valve rod unless the rod is depressed into valve body recess 124. Coiled spring 131 in the upper part of recess 122 holds the valve assembly in a normally downward position within the housing. The coiled spring is held in place by the upper sleeve section 119. Annular seal ring 132 is set in a groove in the upper end of the valve body. Ring 133 is set in a groove in the sleeve near the lower end of the valve in order to provide a fluid-tight seal between the valve body and the housing. Port 134 extends through the inner wall of the sleeve into the housing. Valve rod 126 in the valve body is in its lowestmost position, circular seal 135 is set in a groove on the inner surface of the body opposite port 134 prevents the flow of fluids from within the sleeve past the valve. The lower end of the valve body is recessed so that it clears port 134 when the body is in its uppermost position. Movement of the valve upwardly in the housing thus uncoils the port and permits the passage of fluid past the valve. The valve body also contains vent passage 136 which communicates with vent port 137 in the sleeve when the body is in its lowermost position. Circular seal 137A is set in a groove in the outer surface of the valve body near its lower end and encircles vent port 137 when the valve body is in its uppermost position. This permits the escape of fluid from the shoe assembly and associated passageways when the valve is closed.

Sleeve section 138 is threadedly connected to valve section 120 at its lower end. Gasket 139 provides a fluid-tight seal between the two sections. A passageway 140 corresponding to each of the passageways in section 129 extends longitudinal through section 138. An alignment pin 141 is set in notches in the outer surface of the two sleeve sections to assure alignment of the passageways. The pin may be tacked welded to hold it in place after the sections have been assembled.

Sleeve section 142 is threaded to the lower end of section 138. A gasket 143 is positioned between the two to effect a seal. Passageways 144 corresponding to the passageways 140 in the section above extend through the sleeve along spiral paths. Each passageway emerges from section 142 at a point 180° away from the point at which it entered. As shown in the drawing, the spiral passageways may be fabricated by milling spiral slots in the outer surface of the sleeve section, installing a length of steel tubing 145 in each of the spiral slots, and thereafter filling in the slot around the tubing with welding metal. The apparatus is not limited to this particular fabrication technique, however, since other techniques for forming spiral passageways in a sleeve are available and will be familiar to those skilled in the art. An alignment pin 147 placed in slots in the outer surfaces of sleeve sections 138 and 142 assures proper alignment of the passageways in the two sections when the apparatus is assembled.

Threaded to the lower end of sleeve section 142 containing spiral passageways 144 is lower sleeve section 148 in which are located the hydraulically extensible shoe assemblies utilized in this embodiment of the invention. Grooves spiral between the two sections. Passageways 150 extend downwardly in the lower sleeve section and emerge within recesses in the outer surfaces of the sleeve in which the shoe assemblies are positioned. Each shoe assembly includes an outer supporting member 151 containing a central elongated opening about which a raised rim 152 extends. The supporting member is attached to the sleeve by means of bolts 153. An elastic member 154 is bonded to rim 152 and to shoe 155 centrally positioned within the elastic member. The supporting member and shoe are curved at their ends in order to permit better bonding between the elastic member and the metal making up the supporting member and shoe. Wiper and seal rings 115 and 116 are positioned in the lower sleeve section below the shoe assemblies. An alignment pin 156 is provided to show proper alignment of the passageways in sleeve sections 142 and 148.

The tool depicted in FIGURES 5 through 8 of the drawing includes six identical valve assemblies and six identical shoe assemblies spaced around the sleeve at regular intervals. A greater or lesser number of shoes and valves may be utilized.

The preferred embodiment of the invention described above is employed in a manner similar to that in which the earlier described embodiment is used, except that it is placed in the lower section of the drill string just above the bit. It is therefore unnecessary to survey the borehole to find the optimum position for the tool described herein before using it. A short sub will normally be used to connect the bit to the lower end of the stabilizer. The drill string contained in the tool is lowered into the borehole with the stabilizer valves in the normal, closed position. There is little danger of opening the valves during tripping, since this requires depression of two valve rods and movement of the stabilizer downwardly with respect to them. Upon reaching the sloping section of the hole, however, the drill string will sag against the lower side of the borehole wall. One or more of the valve rods 126 will then be depressed by the weight of the tool against the wall. As the string is lowered further, friction between the rod and the borehole wall will result in relative motion between the valve assembly and the valve housing. This opens one or more valves so that drilling fluid can pass downwardly through the conduits in sleeve 111 to the shoe assemblies.

After the drill string has been lowered into place, the circulation of drilling fluid is commenced. Fluid passes from within mandrel 101 through port 109 into the enclosed space between the mandrel and sleeve 111. The valve on the lower side of the stabilizer has been opened by the valve rod 126 and hence fluid flows through port 136 past the valve. The fluid then passes downwardly through conduits 140 and 144 to the shoe located upon the upper side of the stabilizer opposite the open valve. The pressure differential across the shoe extends it into contact with the upper side of the borehole. The restoring force thus applied to the drill string augments the normal pendulum force acting on the drill bit. Drilling is then resumed. Pressure between the shoe and the borehole wall prevents rotation of the sleeve as the mandrel is rotated within it. The increased restoring force on the drill bit causes it to drill in a more vertical direction than it would do in the absence of the stabilizer. As the drill string moves downwardly, the stabilizer shoe slides downwardly in contact with the borehole wall. The shoe may be hard surfaced with tungsten carbide or a similar material in order to reduce wear and abrasion of it during drilling.

FIGURE 9 of the drawing shows the stabilizer of FIGURES 5 through 8 in place in a borehole during a rotary drilling operation. As can be seen from the figure, the stabilizer is connected between a drill collar 157 and a short sub 158 to which the drill bit 159 is attached. Valve rod 126 has been depressed by the weight of the stabilizer and the associated valve has been opened as the tool moves downwardly. A Sleeve 125 is located on the opposite side of the stabilizer has been extended into contact with the borehole wall. The restoring force acting on the bit is indicated by the arrow at the bottom of the
figure. This restoring force is considerably greater than that which can be obtained by means of a conventional drill collar stabilizer and hence the deviation problem can be overcome more quickly than if a conventional tool were used.

The stabilizer depicted in FIGURES 5 through 9 of the drawings can readily be withdrawn from the borehole after the deviation problem has been corrected. Friction between valve rod 126 and the borehole wall as the tool is pulled upwardly restores the valve body 123 to its normal downward position within recess or valve housing 122. In this position, vent passage 156 is aligned with valve port 137. Fluid escapes through the vent port due to the difference in pressure across the shoe assembly and thus the shoe is retracted. The apparatus can then be raised in the borehole without damage to the shoes or the formation. The pump at the surface may be stopped to halt drilling fluid circulation immediately or circulation may instead be continued until the drill string is raised the length of the Kelly. In either case, the tool can readily be withdrawn from the hole.

Should the drill string become stuck in the borehole for any reason, a conventional milling tool can be lowered over the tool to mill off the valve rods and shoes and free the stabilizer. The notches and projections on the lower section of the tool permit locking of the mandrel and sleeve together during the milling operation. The valve rods and shoe assemblies can be replaced at moderate cost following such an operation without the necessity for replacing the entire stabilizer.

It will be understood that the apparatus of the invention is not restricted to the specific embodiments illustrated in the drawings and that a number of modifications may be made without departing from the inventive concept. A variety of valve mechanisms may be utilized in lieu of the specific mechanisms described. The valve assembly may be designed so that it is responsive to lateral force against the stabilizer without requiring axial movement of the tool. The shoe assemblies may be modified by substituting piston-type shoes in place of shoes bonded to an elastic member. The shoes may be provided with means for positively limiting shoe extension. The provisions for rotating the sleeve and mandrel to facilitate milling during washover operations may be omitted if desired. Wholly separate shoe assemblies and valve assemblies may be provided in a stabilizer designed to elevate a drilling string above the lower side of a sloping borehole. These and other modifications in similar vein will readily suggest themselves to those skilled in the art.

What is claimed is:

1. A drill string stabilizer comprising in combination a tubular mandrel containing a lateral port; an outer sleeve on said mandrel within which the mandrel is free to rotate, said sleeve extending above and below said port; upper sealing means between said sleeve and mandrel above said port; lower sealing means between said sleeve and mandrel below said port; a plurality of hydraulically extensible shoe assemblies mounted in recesses in the outer surface of said sleeve, said sleeve containing passageways extending from each of said recesses to the inner surface of the sleeve between said upper and lower sealing means; valves in said sleeve for controlling flow through each of said passageways individually; means for maintaining said valves in a normally closed position; and means for opening said valves individually in response to contact between said stabilizer and the lower side of a sloping borehole.

2. A stabilizer as defined by claim 1 wherein said valves are located within said recesses in said sleeve and each valve is opened in response to contact between a shoe assembly and the lower side of a sloping borehole.

3. A stabilizer as defined by claim 1 wherein said mandrel above said port includes valve members which extend outwardly beyond said sleeve and are actuated by contacting the borehole wall.

4. A stabilizer as defined by claim 1 wherein said valves are located in recesses in said sleeve near the upper end thereof and said shoe assemblies are located in recesses in said sleeve near the lower end thereof, each valve controlling flow through a passageway extending to a recess containing a shoe assembly displaced 180° from the recess in which said valve is located.

5. A drill string stabilizer comprising in combination a tubular mandrel provided with means for connecting said mandrel in a rotary drill string, said mandrel including an intermediate lateral port therein; an outer sleeve mounted upon said mandrel within which the mandrel is free to rotate, said sleeve extending above and below said lateral port in said mandrel and including a plurality of recesses spaced about the outer surface of the sleeve; upper sealing means between said sleeve and mandrel above said lateral port; lower sealing means between said sleeve and mandrel below said lateral port; a hydraulically-extensible shoe assembly positioned in each of said recesses in said sleeve, each of said assemblies including a rigid shoe and means for biasing said shoe in a normally inward position in said recess and said sleeve containing internal passageways extending from each of said recesses to the inner surface of the sleeve between said upper and lower sealing means; a valve in each of said recesses for controlling flow through the passageway communicating therewith; means for maintaining each of said valves in a normally closed position; and means for opening said valves individually in response to contact between said stabilizer and the lower side of a sloping borehole to permit fluid entry through said passageway to said recesses.

6. A stabilizer as defined by claim 5 wherein each of said sleeve assemblies includes an outer supporting member containing an opening within which said rigid shoe is positioned, and said means for biasing said shoe in a normally inward position comprises an elastic member bonded between said supporting member and the mandrel, said biasing means thereby said shoe may move outwardly with respect to said supporting member in response to differential pressure across said assembly.

7. A stabilizer as defined by claim 5 wherein said valve comprises a valve body provided with a recess within which said shoe assembly is disposed, said valve body being longitudinally slidable in said sleeve recess and containing a port which is aligned with said sleeve passageway when said body is in an upward position in said sleeve recess and means normally biasing said valve body in a downward position within said sleeve recess.

8. A stabilizer as defined by claim 5 wherein said said mandrel is rotated in a counterclockwise direction.

9. A drill string stabilizer comprising in combination a tubular mandrel provided with means for connecting said mandrel within a rotary drill string, said mandrel including an intermediate lateral port therein; an outer sleeve mounted upon said mandrel within which the mandrel is free to rotate, said sleeve extending above and below said port in said mandrel and including a plurality of valve recesses in the outer surface near the upper end of said sleeve and a plurality of shoe assembly recesses in the outer surface near the lower end of said sleeve; upper sealing means between said sleeve and mandrel above said lateral port; lower sealing means between said sleeve and mandrel below said lateral port; a hydraulically-extensible shoe assembly positioned in each of said shoe assembly recesses, each of said assemblies including a rigid shoe and means for biasing said shoe in an inward position in said shoe assembly recess; and a valve means in each of said valve recesses, said valve means including a valve rod extending outwardly beyond the outer surface of said sleeve whereby said valve means is moved from a normally closed position into an open position in response to opening said valve means and valve members which extend outwardly beyond said sleeve and are actuated by contacting the borehole wall.
cesses to a corresponding valve recess displaced 180° from said shoe assembly recess and from each of said valve recesses to the inner surface of said sleeve between said upper and lower sealing means.

10. A stabilizer as defined by claim 9 wherein said valve means includes a valve body longitudinally slideable in said valve recess in response to contact between said valve rod and the lower side of a sloping borehole wall, said valve body being normally biased downwardly in said valve recess to close said passageway between said inner surface of said sleeve and said shoe assembly recess.

11. A stabilizer as defined by claim 9 wherein said sleeve is axially slideable on said mandrel and said sleeve and mandrel include mating serrations for rotating said sleeve counterclockwise with said mandrel.

12. A stabilizer as defined by claim 9 wherein said means for biasing said shoe in a normally inward position comprises an elastic member bonded to said rigid shoe.

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