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Description

Adjustable Stabilizer for Directional Drilling

Technical Field

The present invention relates generally to apparatus for use in drilling directional boreholes. More specifically, the present invention is related to stabilizer assemblies carried by a drillstring for altering the direction of drilling from vertical.

Background Art

The earliest efforts to drill directionally for petroleum hydrocarbons employed mechanical whipstocks, which were used to deflect a rotating drillstring from vertical in a previously vertical wellbore. The chief drawback to the use of whipstocks is that directional control of the bit and drillstring is lost once the drillstring is kicked off or deflected by the whipstock. Additionally, whipstock operations are time-consuming and therefore expensive.

Another method of directional drilling employs the use of a bent or bendable sub in connection with a downhole motor or turbine. The bent sub has a bend formed therein to position the drill bit a few degrees from the vertical axis of the remainder of the drillstring. A downhole motor is coupled between the bent sub and drill bit or is incorporated in the bent sub itself. The drillstring and downhole motor may be rotated to cause the bit to disintegrate formation and drill straight ahead at the same angle and azimuth of the existing borehole. When it is desirable to alter the direction of drilling, rotation of the drillstring is stopped and the bit is rotated by the drilling motor. This mode of operation is known as the

"sliding" mode, because the drillstring is sliding rather than rotating with respect to the sidewall of the borehole. In the deviated portion of the borehole, the drillstring experiences sufficient frictional contact with the sidewall of the borehole to make it difficult to apply significant weight to the bit, resulting in reduced rates of penetration compared to rotary drilling. Examples of bent sub or motor directional drilling systems and method are disclosed in U.S. Patent Nos. 5,311,953, May 17, 1994 to Walker; 5,139,094, August 18, 1992 to Prevedel et al; and 5,050,692, September 24, 1991 to Beimgraben.

In another directional drilling system and method, a pair of stabilizers are provided in the drillstring and are spaced-apart above the drill bit. The difference in diameter between the upper stabilizer and the near-bit stabilizer, whether adjustable or fixed, and the spacing between the stabilizers, provide lateral forces that assist in deflecting the bit from the vertical axis of the borehole. Such stabilizer arrangements are employed in both rotary drilling and downhole motor arrangements. If the stabilizers are adjustable and employed in surface rotation drilling, each stabilizer blade must extend from the stabilizer body the same distance to maintain symmetry and avoid eccentricity and associated rough running. If drilling is accomplished with a drilling motor, no such limitation is imposed on upper stabilizer, above the drilling motor, because it is not rotated. Examples of stabilizer arrangements are found in U.S. Patent No. 5,332,048, July 26, 1994 to Underwood et al; 5,293,945, March 15, 1994, to Rosenhauch et al.; 5,181,576,

January 26, 1993 to Askew et al.; and 4,754,821, July 1, 1988 to Swietlik.

A variation on the adjustable stabilizer theme is to provide stabilizer bodies having fixed stabilizer blades, but having pistons acting between the drillstring or stabilizer sub and the fixed stabilizer bodies to introduce eccentricities between the upper and lower stabilizers and resulting lateral deflection forces. These arrangements require multiple piston actuations per revolution of the drillstring and thus present mechanical and reliability disadvantages. Examples of such arrangements can be found in U.S. Patent Nos. 5,038,872, August 13, 1991 to Shirley and 3,593,810, July 20, 1971 to Fields.

A needs exists, therefore, for a directional drilling assembly or system for use with an efficient rotating drillstring that permits the driller to control precisely the trajectory of the bit during drilling operation.

Disclosure of Invention

It is a general object of the present invention to provide an improved assembly for steering a rotating drillstring in a borehole.

This and other objects of the present invention are accomplished by providing a stabilizer sub for attachment into a drillstring proximal to a drill bit. A stabilizer body is rotatably carried by the stabilizer sub, wherein the stabilizer body remains substantially stationary relative to the borehole as the drillstring rotates. At least one stabilizer blade

is carried by the stabilizer body, the stabilizer blade being radially extendable from the stabilizer body and into engagement with the sidewall of the borehole.

According to the preferred embodiment of the present invention, at least three stabilizer blades are spaced apart on the circumference of the stabilizer body. Each stabilizer blade is selectively extendable and retractable independently of the others.

According to the preferred embodiment of the present invention, each stabilizer blade is carried in a longitudinal slot in the stabilizer body, the slot having an inclined bottom such that relative longitudinal movement between the stabilizer blade and stabilizer body causes extension or retraction of the stabilizer blade. A motor is coupled between each stabilizer blade and the stabilizer body to cause relative longitudinal movement therebetween.

According to the preferred embodiment of the present invention, the stabilizer sub includes a fixed stabilizer at an end opposite the drill bit. A lead screw couples the motor to the stabilizer blade, wherein rotation of the lead screw by the motor cause the relative longitudinal movement.

Description of the Drawings

Figure 1 is a longitudinal section view of a borehole illustrating the steering assembly according to the present invention.

Figure 2 is an elevation view of the stabilizer portion of the improved steering assembly of Figure 1.

Figure 3 is a longitudinal section view of the stabilizer portion of Figure 2.

Figures 4A-4D are cross section view of the borehole and steering assembly, taken along section lines 4--4 of Figure 1.

Figure 5 is a flowchart depicting the operation and control of the adjustable stabilizer of the steering assembly of Figure 1.

Description of the Preferred Embodiment

Referring now to the Figures, and specifically to Figure 1, a longitudinal section view of a borehole 1 having a steering assembly disposed therein is depicted. Steering assembly includes a stabilizer sub 3, which is conventionally connected by a threaded tool joint into a conventional rotary drillstring (not shown). A drill bit 5, of either the fixed or rolling cutter variety, is secured to the lowermost end of stabilizer sub 3. A fixed stabilizer 7 is carried by stabilizer sub 3 and spaced apart from bit 5. An adjustable stabilizer 9, including a plurality of stabilizer blades 11, is carried by stabilizer sub 3 at its lower end, near drill bit 5. Alternatively, upper stabilizer 7 can be an adjustable stabilizer, as well, further increasing the versatility of the steering assembly according to the present invention.

Figures 2 and 3 are elevation and longitudinal section views, respectively, of adjustable stabilizer 9 of the steering assembly according to the present invention. A generally cylindrical stabilizer body 13 is coupled to the exterior of generally cylindrical

stabilizer sub 3 by bearings and seals 15, which permit stabilizer body 13 to rotate relative to stabilizer sub 3 and retain lubricant in the annular gap therebetween.

According to the preferred embodiment of the present invention, at least four stabilizer blades 11A, 11B, 11C, 11D are received in longitudinal slots 17 in stabilizer body 13 and are retained therein by a tongue-and-groove arrangement. Each longitudinal slot 17 has an inclined bottom 17A, which defines a ramp wherein relative longitudinal movement between the stabilizer blades 11A-11D and ramp 17A causes radial expansion or retraction of stabilizer blades 11A-11D from stabilizer body 13. Associated with each slot 17 is a one-half horsepower electric motor 19. Motor 19 rotates a lead screw 21, which engages a ball nut (not shown) carried in each stabilizer blade 11A-11D to cause the relative longitudinal movement.

According to the preferred embodiment of the present invention, each lead screw 21 is designed to yield when stabilizer 9 is subjected to axial sticking loads of 10,000 pounds per stabilizer blade to prevent adjustable stabilizer 9 from causing the drillstring to stick in the borehole. Because each stabilizer blade 11A-11D is provided with its own actuator, in the form of motor 19 and lead screw 21, the stabilizer blades are independently extendable and retractable with respect to stabilizer body 13. Motors 19 preferably are stepper or servo motors adapted to control precisely the rotation of lead screws 21 and the extension of each stabilizer blade 11A-11D from stabilizer body 13.

A microprocessor or control unit 23 is coupled to each motor 19 to control the rotation of motor 19 and lead screw 21, and thus the extension of stabilizer blades 11A-11D from stabilizer body 13. Microprocessor 23 carried in stabilizer body 13 contains conventional means for reading position data from encoders associated with each motor 19 to ascertain the extension of each stabilizer blade 11A-11D. Microprocessor or controller 23 and motors 19 are powered by a battery 25 carried in stabilizer body 13. Battery 25 preferably is charged by inductive coupling with a plurality of charging coils 27 circumferentially spaced in stabilizer sub 3. Charging coils 27 preferably are energized by a conventional drilling-fluid-powered generator carried by stabilizer sub 3 or a separate measurement-while-drilling (MWD) apparatus elsewhere in the drillstring.

Figures 4A-4D are cross section views of borehole 1 and stabilizer body 13 and blades 11A-11D, taken along section line 4--4 of Figure 1, depicting various configurations of stabilizer blades 11A-11D having varying effects on the trajectory of drill bit 5. For convenience, upper stabilizer blade is labeled 11A, right stabilizer blade is labeled 11B, bottom stabilizer blade is labeled 11C, and left stabilizer blade is labeled 11D.

In Figure 4A, stabilizer assembly 9 is configured to drop angle, or reduce the amount of deviation or deflection from vertical. In this configuration, upper stabilizer blade 11A is extended beyond stabilizer body 13 and into contact or engagement with the sidewall of borehole 1, while bottom stabilizer blade 11C is near

fully retracted. According to the preferred embodiment of the present invention, opposing stabilizer blades 11A, 11C are extendable to a diameter larger than the gage of the bit 5 or borehole 1. Of course, opposing stabilizer blades 11A, 11C are never simultaneously fully extended to avoid sticking in borehole 1. The same applies for opposing stabilizer blades 11B, 11D, which, in the drop angle configuration, are extended to an intermediate degree less than the gage of bit 5 and borehole 1.

In Figure 4B, stabilizer 9 is depicted in a configuration to build angle, or increase the amount of deviation or deflection from vertical in borehole 1. In this configuration, bottom stabilizer blade 11C is near fully extended and upper stabilizer blade 11A is near fully retracted. Again, right and left stabilizer blades 11B, 11D are extended to an intermediate degree less than the gage of bit 5 and borehole 1.

Figure 4C illustrates stabilizer 9 in a configuration for turning bit 5 to the left in which right stabilizer 11B is near fully extended and left stabilizer blade 11D is retracted, permitting changes in the azimuth of bit 5. Upper and lower stabilizer blades 11A, 11C are extended to an intermediate degree less than the gage of bit 5 and borehole 1 to hold angle.

Similarly, Figure 4D depicts stabilizer 9 in a configuration to turn bit 5 left in which right stabilizer blade 11D is near fully extended and right stabilizer blade 11B is near fully retracted, while

upper and lower stabilizer blades 11A, 11C are extended to an intermediate degree to hold angle.

While Figures 4A-4D depict only four of the configurations of stabilizer 9 of the steering assembly according to the present invention, because each stabilizer blade 11A-11D is extendable independently of the others, a virtually infinite variety of stabilizer configurations and bit trajectories are possible. Of course, the virtually infinite adjustability of stabilizer 9 is made possible by coupling stabilizer body 13 for rotation to stabilizer sub 3, wherein it remains substantially stationary relative to borehole 1 as the drillstring rotates. This permits the differential or asymmetric extension of stabilizer blades 11A-11D, which, in turn, permits the wide range of trajectories achieved by the various configurations of stabilizer 9.

Of course, stabilizer body 13 cannot be expected to remain entirely stationary with respect to the sidewall of the borehole. Friction encountered between the inner diameter of stabilizer body 13 and the outer diameter of stabilizer sub 3 is less than that between stabilizer blades 11A-11D and the sidewall of the borehole such that stabilizer body 13 makes approximately one revolution for each 100 to 500 feet drilled. As this slow rotation occurs, upper stabilizer 11A will tend to move toward the orientation of right stabilizer 11B and the same is true of stabilizer blades 11C and 11D. As the orientation of stabilizer blades 11A-11D changes with respect to the sidewall of borehole 1, corrections must be made to

maintain the trajectory of bit 5 on the desired course.

A three-axis accelerometer with each accelerometer aligned on orthogonal axes is carried by stabilizer body 13 and coupled to microprocessor 23 to permit measurement of the inclination angle of stabilizer body 13 and the rotational orientation of stabilizer body 13 and blades 11A-11D. Microprocessor 23 is programmed to correct for changes in orientation of stabilizer sub 13 automatically, or can, through MWD apparatus, communicate this information to the surface for appropriate response. If MWD apparatus is employed, an AM radio transceiver (not shown) is carried by stabilizer body 13 to provide two-way radio communication between microprocessor 23 and the telemetry section of the MWD apparatus, which in turn may be in communication with the surface through one of several conventional telemetry or hardwire techniques.

Similarly, it is frequently advantageous to purposefully alter the configuration of stabilizer 9 to correct for unanticipated alterations in bit trajectory due to unexpected changes in the formation material, the drilling characteristics of bit 5 and the like. Thus, the appropriate configuration for stabilizer 9 is determined at the surface or is pre-programmed into microprocessor 23 or an MWD apparatus in the drillstring that is in communication with microprocessor 23. Motors 19, lead screws 21, and stabilizer blades 11A-11D then are adjusted appropriately for the desired trajectory or trajectory correction.

Figure 5 is a flowchart depicting the control sequence and operation of the steering assembly according to the present invention. With reference to Figures 1-5, the operation of the steering assembly according to the present invention will be described. First, a bit is made up into a drillstring to drill an interval of vertical borehole to the kick-off or deflection point at which it is desired to commence directional drilling. If the kick-off point is sufficiently shallow so as not to deplete the life of the drill bit prior to or shortly after kick-off, the vertical drillstring can include stabilizer sub 3, along with fixed and adjustable stabilizers 7, 9. In the vertical section of the borehole, stabilizer blades 11A-11D are fully retracted or positioned at an extension less than the gage of bit 5 and borehole 1, wherein stabilizers 7, 9 simply function as centralizers.

At the kick-off point, stabilizer 9 and stabilizer blades 11A-11D are set in the configuration adapted for the kick-off trajectory, as reflected at step 101 of Figure 5. The controlled misalignment caused by spaced-apart stabilizers 7, 9 causes deflection of stabilizer sub 3 and bit 5 from the vertical axis of borehole 1, and directional drilling is commenced.

As reflected at step 103 of Figure 5, stabilizer body 13 is monitored by microprocessor 23 alone or together with MWD apparatus, which may be in communication with the surface, for rotation relative to borehole 1. If rotation of stabilizer body 13 is detected, this information is communicated to or through microprocessor 23, which takes corrective

action to readjust the configuration of stabilizer blades 11A-11D to compensate for rotation of stabilizer body 13 in borehole 1.

If no rotation of stabilizer body 13 is detected, at step 105 in Figure 5, it is determined whether a change of trajectory is desired. Such a change in trajectory is programmed in microprocessor 23 and triggered by measurements from the accelerometers carried by stabilizer body 13, or by survey data from an MWD apparatus that indicates a change in trajectory is appropriate, or may be communicated to microprocessor 23 via telemetry from the surface when there is a surface-detected or monitored indication that a change in trajectory is warranted.

As reflected by the flowchart of Figure 5, if neither rotation of stabilizer body 13 is detected nor is a trajectory charge or correction warranted, microprocessor 23 continues to monitor both conditions for appropriate response in the event of the occurrence of either condition.

The present invention provides a number of advantages over prior-art steering assemblies and systems. A principal advantage is that the steering system is adapted for use with efficient surface-rotation drilling techniques and their associated high rates of penetration. The steering assembly according to the present invention does not require complex hydraulic and mechanical systems to effect deflection of the bit or changes in its trajectory during drilling operation.

The invention has been described with reference to a preferred embodiment thereof. It is thus not limited, but is susceptible to variation and modification without departure from the scope and spirit of the invention.

Claims

1. An improved assembly for steering a rotating drillstring in a borehole, the assembly comprising:

a stabilizer sub for attachment into a drillstring;

a stabilizer body rotatably carried by the stabilizer sub, wherein the stabilizer body remains substantially stationary relative to the borehole as the drillstring rotates;

at least one stabilizer blade carried by the stabilizer body, the stabilizer blade being radially extendable from the stabilizer body and into engagement with the sidewall of the borehole.

2. The assembly according to claim 1 further comprising:

at least three stabilizer blades spaced apart on the circumference of the stabilizer body.

3. The assembly according to claim 1 wherein each stabilizer blade is carried in a longitudinal slot in the stabilizer body, the slot having an inclined bottom and relative longitudinal movement between the stabilizer blade and stabilizer body causes extension or retraction of the stabilizer blade.

4. The assembly according to claim 3 further comprising:

a motor coupled between each stabilizer blade and the stabilizer body to cause relative longitudinal movement therebetween.

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5. The assembly according to claim 1 wherein the stabilizer sub includes a fixed stabilizer at an end opposite the drill bit.

6. An improved assembly for steering a rotating drillstring in a borehole, the assembly comprising:

a stabilizer sub for attachment into the drillstring adjacent a drill bit;

a stabilizer body rotatably carried by the stabilizer sub, wherein the stabilizer body remains substantially stationary relative to the borehole as the drillstring rotates;

at least a pair of generally opposed stabilizer blades carried by the stabilizer body, the stabilizer blades being independently radially extendable from the stabilizer body and into engagement with the sidewall of the borehole.

7. The assembly according to claim 6 further comprising:

four stabilizer blades spaced apart on the circumference of the stabilizer body.

8. The assembly according to claim 6 wherein each stabilizer blade is carried in a longitudinal slot in the stabilizer body, the slot having an inclined bottom and relative longitudinal movement between the stabilizer blade and stabilizer body causes extension or retraction of the stabilizer blade.

9. The assembly according to claim 7 further comprising:

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a motor coupled between each stabilizer blade and the stabilizer body to cause relative longitudinal movement therebetween.

10. The assembly according to claim 7 wherein the stabilizer sub includes a fixed stabilizer at an end opposite the drill bit.

11. An improved assembly for steering a rotating drillstring in a borehole, the assembly comprising:

a stabilizer sub for attachment into the drillstring adjacent a drill bit;

a stabilizer body rotatably carried by the stabilizer sub, wherein the stabilizer body remains substantially stationary relative to the borehole as the drillstring rotates, at least one longitudinal slot formed in the exterior of the stabilizer, the slot having an inclined bottom;

at one stabilizer blade carried in the slot in the stabilizer body, the stabilizer blade being independently radially extendable from the stabilizer body and into engagement with the sidewall of the borehole by longitudinal movement in the slot having the inclined bottom;

a motor carried by the stabilizer body and coupled to the stabilizer blade to cause longitudinal movement of the stabilizer blade in the slot;

a source of electrical power carried by the stabilizer sub and in electrical communication with the motor.

12. The assembly according to claim 11 further comprising:

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four stabilizer blades spaced apart in four longitudinal slots in the circumference of the stabilizer body; and

four motors carried by the stabilizer body.

13. The assembly according to claim 11 wherein a lead screw couples the motor to the stabilizer blade, rotation of the lead screw by the motor causing longitudinal movement of the stabilizer blade in the slot.

14. The assembly according to claim 7 wherein the stabilizer sub includes a fixed stabilizer at an end opposite the drill bit.

15. A method of steering a drillstring in a borehole, the method comprising the steps of:

making a stabilizer sub into a drillstring above a drill bit, the stabilizer sub including:

a stabilizer body rotatably carried by the stabilizer sub, wherein the stabilizer body remains substantially stationary relative to the borehole as the drillstring rotates;

at least a pair of stabilizer blades carried by the stabilizer body, the stabilizer blades being independently radially extendable from the stabilizer body and into engagement with the sidewall of the borehole;

running the drill string into the borehole;

rotating the drillstring; and

selectively and independently extending and retracting each of the stabilizer blades into and out of engagement with the sidewall of the borehole to alter the direction of drilling of the drill bit.

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16. The method according to claim 15 further wherein the step of independently extending and retracting the stabilizer blades is controlled from the surface via telemetry.

17. The method according to claim 15 further wherein the step of independently extending and retracting the stabilizer blades is controlled by measurement-while-drilling apparatus carried in the drillstring.

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