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(54) DOWNHOLE CLOSED LOOP CONTROL OF DRILLING TRAJECTORY

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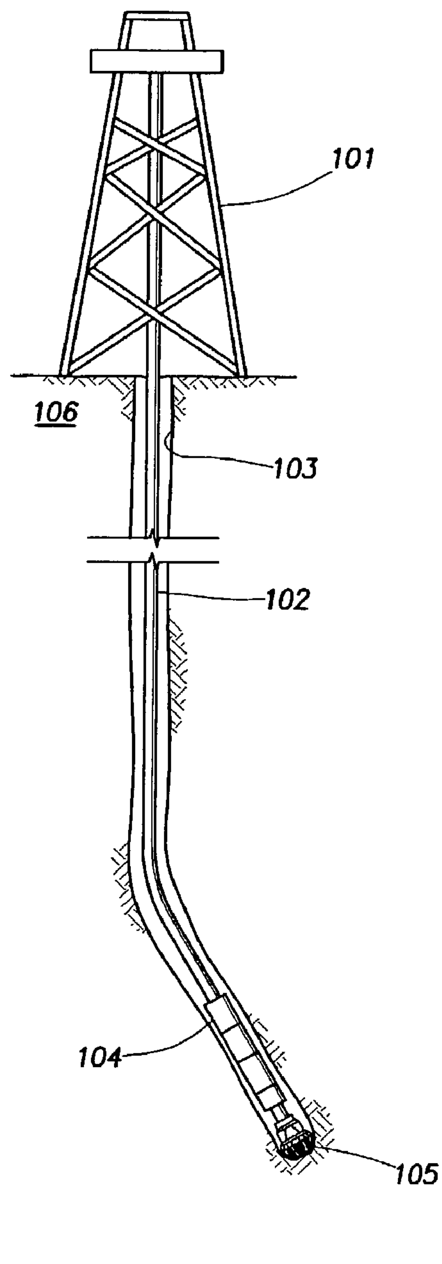
(57) ABSTRACT

A method for drilling a borehole, comprising transmitting a directional signal to a downhole processor, and maintaining the desired drill bit azimuthal direction by using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the desired drill bit azimuthal direction, and using the downhole processor to adjust the actual drill bit azimuthal direction by controlling the directional drilling device.



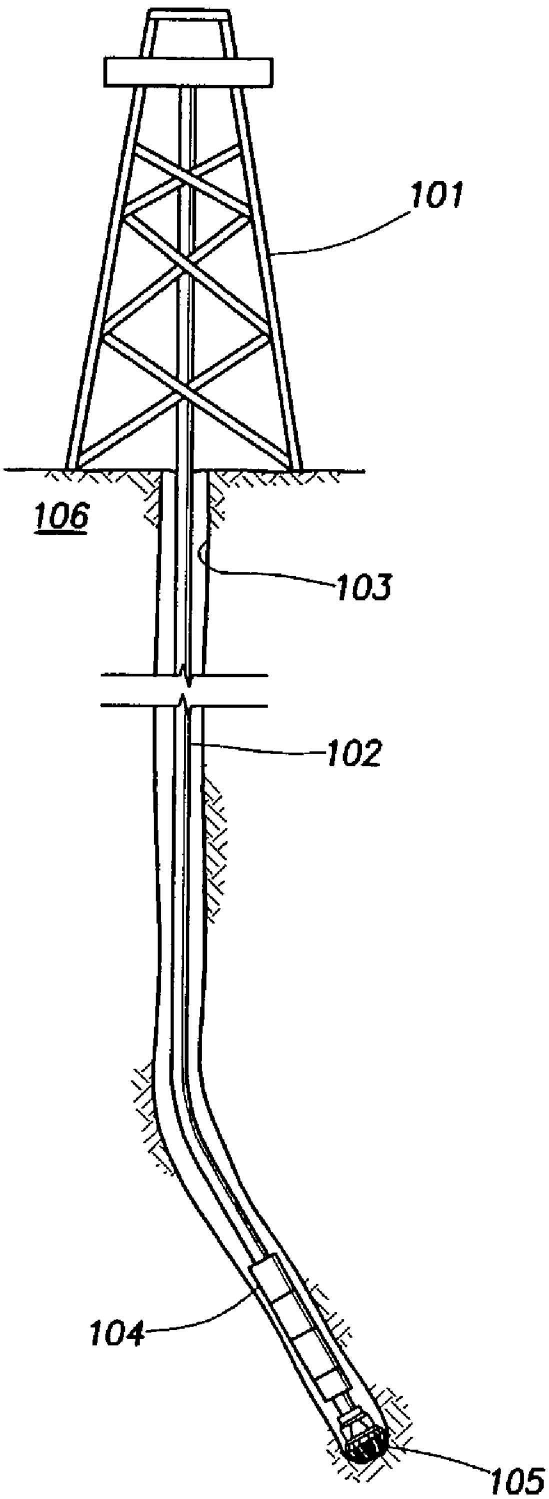

101
106
103
102
104
105

FIG. 1

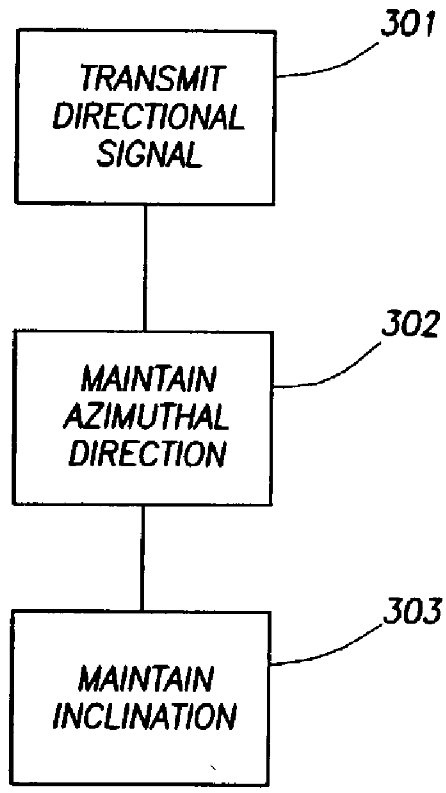

TRANSMIT DIRECTIONAL SIGNAL
301
MAINTAIN AZIMUTHAL DIRECTION
302
MAINTAIN INCLINATION
303

FIG. 3

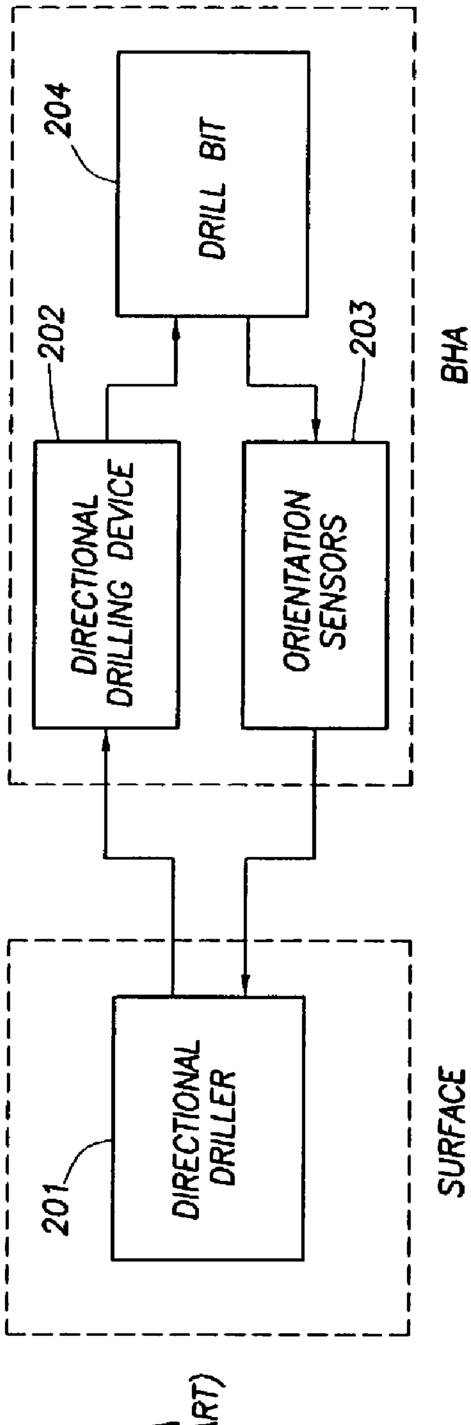


FIG.2A
(PRIOR ART)

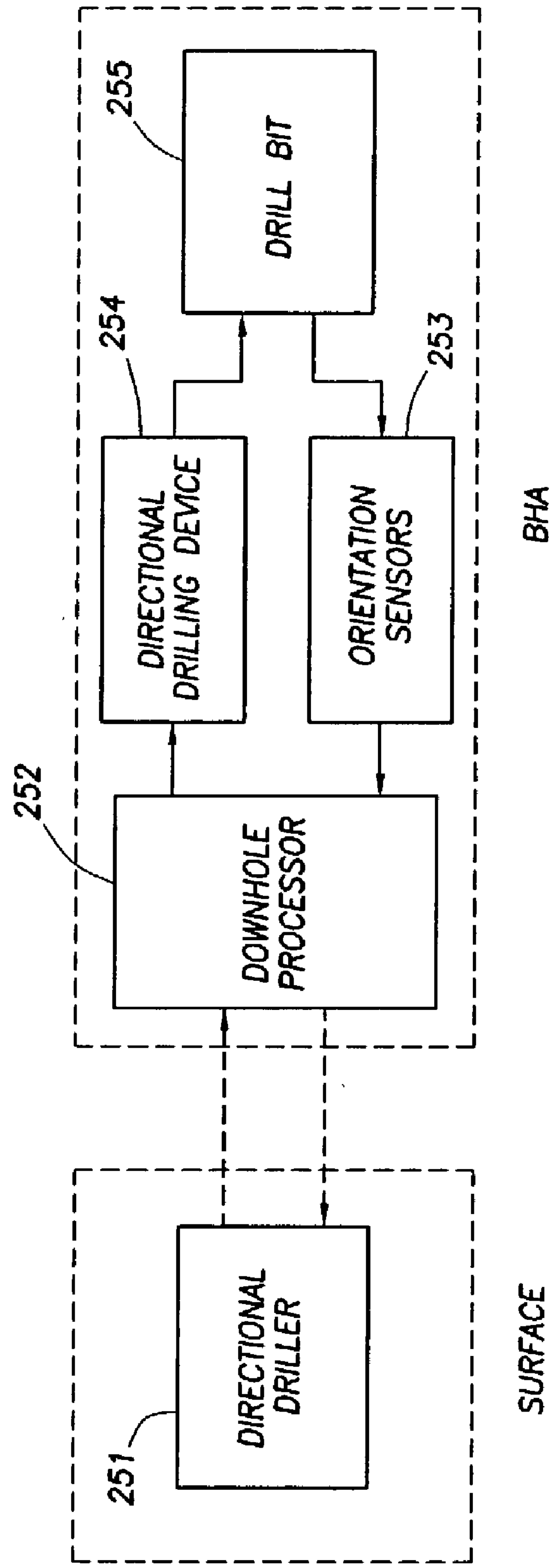


FIG.2B

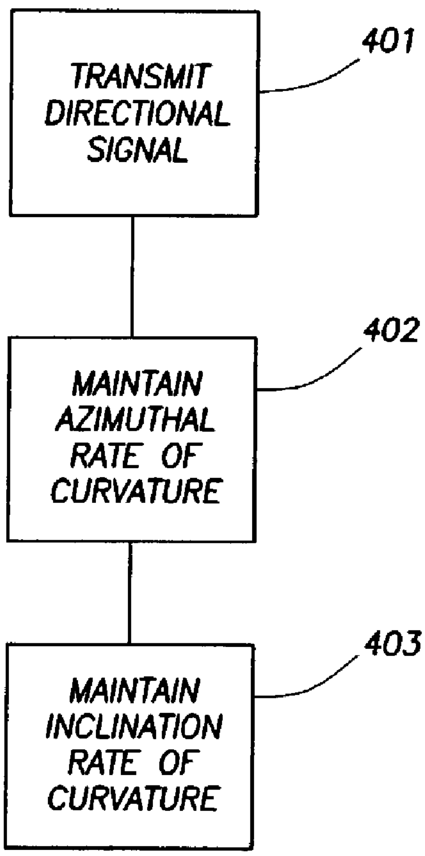

TRANSMIT DIRECTIONAL SIGNAL
401
MAINTAIN AZIMUTHAL RATE OF CURVATURE
402
MAINTAIN INCLINATION RATE OF CURVATURE
403

FIG.4

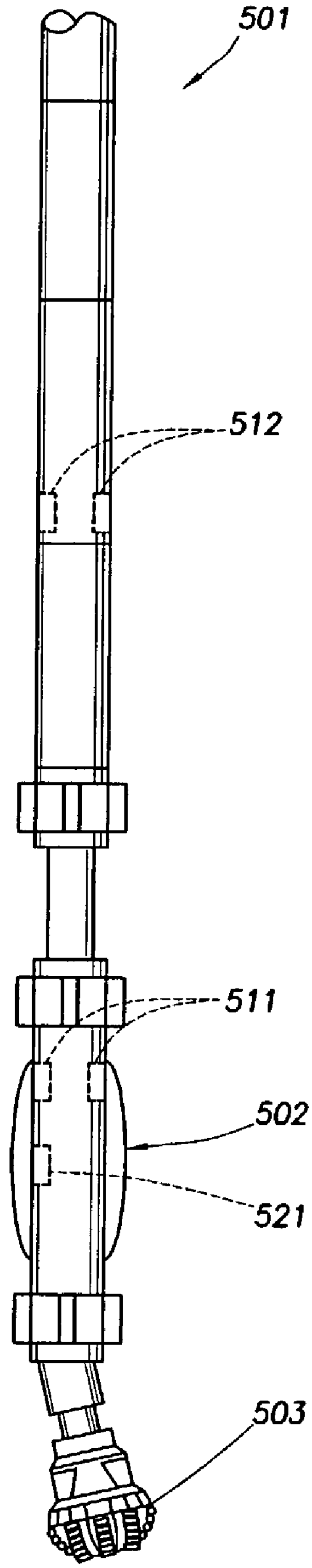

501
512
511
502
521
503

FIG.5

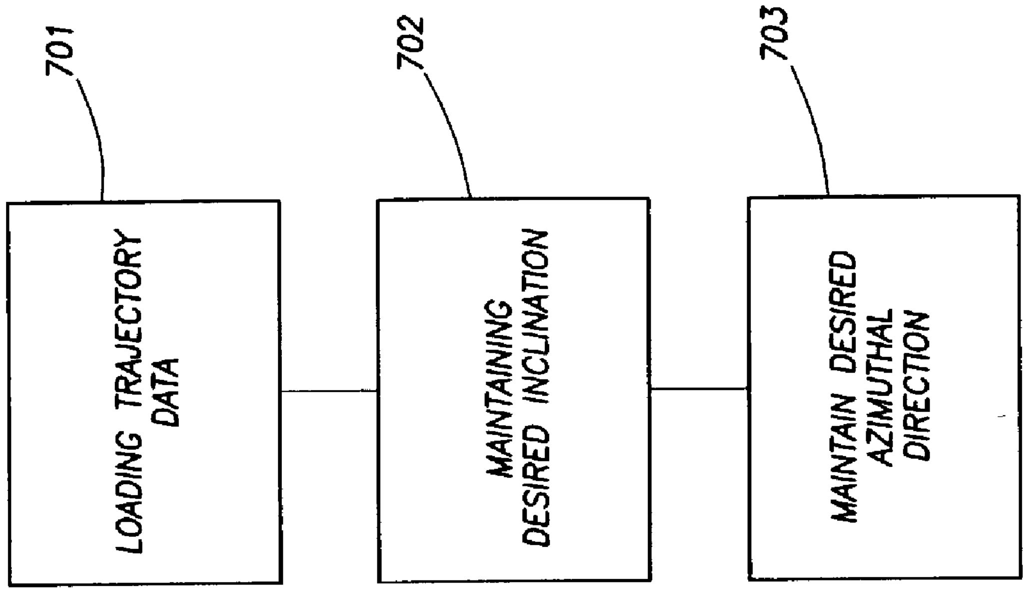

701
LOADING TRAJECTORY DATA
702
MAINTAINING DESIRED INCLINATION
703
MAINTAIN DESIRED AZIMUTHAL DIRECTION

FIG. 7

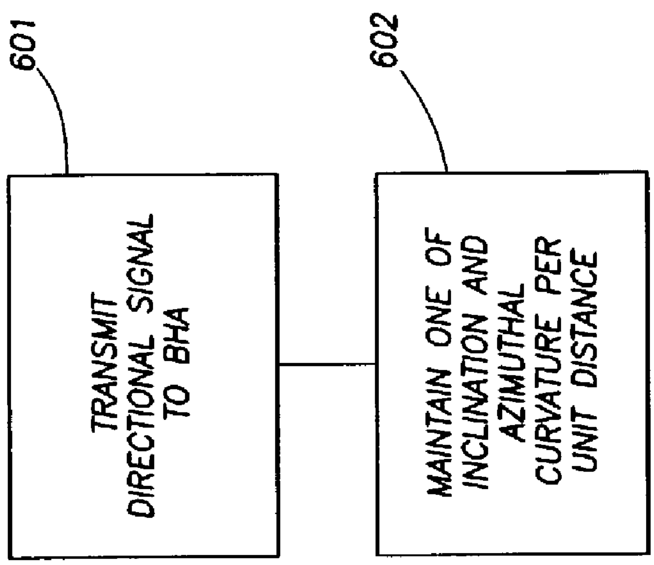

601
TRANSMIT DIRECTIONAL SIGNAL TO BHA
602
MAINTAIN ONE OF INCLINATION AND AZIMUTHAL CURVATURE PER UNIT DISTANCE

FIG. 6

DOWNHOLE CLOSED LOOP CONTROL OF DRILLING TRAJECTORY

BACKGROUND OF INVENTION

[0001] In underground drilling, a drill bit is used to drill a borehole into underground earth formations. Typically, the drill bit is attached to sections of pipe that stretch back to the surface. The attached sections of pipe are called the "drill string." The section of the drill string that is located near the bottom of the bore hole is called the "bottom hole assembly" ("BHA"). The BHA typically includes the drill bit, sensors, batteries, telemetry devices, and various other equipment located near the drill bit. A drilling fluid, called "mud," is pumped from the surface to the drill bit through the pipe that forms the drill string. The primary functions of the mud are to cool the drill bit and carry drill cuttings away from the bottom of the borehole and up through the annulus between the drill pipe and the borehole.

[0002] Because of the high cost of setting up drilling rigs and equipment, it is desirable to be able to explore formations other than those located directly below the drilling rig, without having to move the rig or set up another rig. In off-shore drilling applications, the expense of drilling platforms makes directional drilling even more desirable. "Directional drilling" refers to the intentional deviation of a wellbore from a vertical path. A driller can drill to an underground target by pointing the drill bit in a desired drilling direction.

[0003] Directional drilling can be accomplished with several types of equipment. One type is a bent housing and a steerable mud motor. A "bent housing" is a coupling in the drill string that has a natural bend in it, so that the end of the drill string bends away from the axis of the rest of the drill string. The bent housing typically is located just above the drill bit in the BHA. A "mud motor" is a positive displacement motor disposed in the BHA that uses the hydraulic power of the drilling mud to rotate the drill bit.

[0004] The combination of a bent housing and a mud motor can be used to steer the drill bit. The bent housing is positioned so that it points in the desired drilling direction, and the mud motor drives the drill bit. The drill string does not rotate during drilling. So long as the drill string remains stationary, the bent housing will cause the drill bit to drill in the direction of the bend in the bent housing. Straight drilling can be accomplished by rotating the entire drill string, including the BHA. The bent housing will rotate along with the drill string, and the drill bit will drill a straight, but oversized, borehole. An example of a bent housing drilling device is disclosed in U.S. Pat. No. 6,047,784 issued to Dorel, which is assigned to the assignee of the present invention.

[0005] Another directional drilling device is a rotary steerable system ("RSS"). An RSS is a tool designed to steer the drill bit while the entire drill string is rotated. There are several types of RSS devices that use various methods to steer the drill bit. One type of RSS device uses pads to push the drill string in the desired direction. Another type of RSS device has a section that rotates in an opposite direction from the drill string so that the section is stationary relative to the borehole. The stationary section can cause the drill string to bend in the desired direction. Because it continuously rotates, an RSS device drills a smoother, less tortuous borehole than a mud motor/bent housing arrangement. An example of an RSS is disclosed in U.S. Pat. No. 6,092,610 issued to Kosmala et al., which is assigned to the assignee of the present invention.

[0006] A directional driller needs information about the orientation and position of the drill bit to make decisions and corrections during the drilling process. This information includes the depth of the dill bit, and its inclination and azimuthal direction. "Inclination" refers to the drill bit's angle of offset, or deviation, from the vertical, irrespective of the bit's compass direction. At zero degrees, the drill bit points straight down, and at 90° the drill bit is horizontal. The "azimuthal direction" is the rotational angle around the axis of the borehole/BHA with reference to a particular direction, such as the magnetic pole of the Earth or any direction relative to the Earth's coordinate.

[0007] The inclination may be measured with accelerometers disposed in the BHA. Accelerometers measure the direction of the Earth's gravity and determine the drill bit's deviation from that direction. Accelerometers typically are disposed in a measurement-while-drilling ("MWD") or logging-while-drilling ("LWD") collar that forms part of the BHA. An MWD or LWD collar typically includes other sensors for formation evaluation and drill bit health evaluation.

[0008] The azimuthal direction of the drill bit can be measured with magnetometers or gyroscopes. Magnetometers measure the direction of the Earth's magnetic field relative to the drill bit. The accuracy of a magnetometer, however, is affected by the presence of ferrous materials near the drill bit. Gyroscopes are rotating devices that measure the direction of the Earth's rotation about its axis. The azimuthal direction of the drill bit can then be determined from the gyroscopic measurement. Magnetometers and gyroscopes may also be disposed in an MWD or LWD collar.

[0009] Other information that a directional driller uses when orienting a drill bit includes the drill bit depth. Knowing the drill bit depth enables the driller to know when the well plan requires a change of direction. This information is not measured by sensors in the BHA, but is determined at the surface based on the length of the drill string that has been inserted into the well head.

[0010] The orientation and position information measured by the downhole sensors is transmitted, via any method known in the art, to a directional driller at the surface. A directional driller uses information about the inclination, azimuthal direction, and depth of a drill bit to guide a drill bit to the desired target. The sensors provide information so that the driller knows whether the drill bit is following the planned well path or not. In those cases where the drill bit is not following the planned path, the driller can make corrections to get the drill bit back on course.

[0011] These directional drilling methods rely on communications between the driller on the surface and the BHA downhole. In a typical drill string, the bandwidth for communication is limited. Surface-to-BHA communications are further complicated by the distance between the surface and the BHA, which can exceed several miles. Therefore, it is desirable to have methods for directional drilling that are less dependent on such communications.

SUMMARY OF INVENTION

[0012] One aspect of the invention relates to methods for drilling a borehole comprising transmitting a directional signal to a downhole processor and maintaining a desired drill bit azimuthal direction by using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the desired drill bit azimuthal direction, and using the downhole processor to adjust the actual drill bit azimuthal direction by controlling the directional drilling device. In some embodiments, the downhole processor may be used to maintain a drill bit inclination.

[0013] Another aspect of the invention relates to methods for drilling a borehole comprising transmitting a directional signal to a downhole processor, and maintaining a desired drill bit azimuthal rate of curvature per unit time by using the downhole processor to evaluate an actual drill bit azimuthal rate of curvature per unit time relative to the desired azimuthal rate of curvature per unit time and using the downhole processor to adjust the drill bit azimuthal rate of curvature per unit time by controlling the directional drilling device. In some embodiments, the method includes maintaining an inclination rate of curvature per unit time by using the downhole processor to control a directional drilling device.

[0014] Another aspect of the invention relates to methods for drilling a borehole comprising transmitting a directional signal to a downhole processor, and maintaining a desired drill bit azimuthal rate of curvature per unit distance by using the downhole processor to evaluate an actual drill bit azimuthal rate of curvature per unit distance relative to the desired azimuthal rate of curvature per unit distance and using the downhole processor to adjust the drill bit azimuthal rate of curvature per unit distance by controlling the directional drilling device. In some embodiments, the method includes maintaining an inclination rate of curvature per unit distance by using the downhole processor to control a directional drilling device.

[0015] Yet another aspect of the invention relates to a bottom hole assembly comprising a drill bit, a directional drilling device operatively coupled to the drill bit, a first orientation sensor set disposed proximate to the drill bit, and a second sensor set disposed at a known axial distance from the first orientation sensor set.

[0016] In another aspect, the invention relates to methods for drilling a borehole, comprising transmitting a directional signal to a downhole processor operatively coupled to a bottom hole assembly, the bottom hole assembly comprising a plurality of sensors spaced by a known axial distance and a directional drilling device, maintaining an at least one of an inclination rate of curvature per unit distance and an azimuthal rate of curvature per unit distance by using the downhole processor to control the at least one of the inclination rate of curvature per unit distance and an azimuthal rate of curvature per unit distance.

[0017] Still another aspect of the invention relates to methods for drilling a borehole comprising loading trajectory data for each of a plurality of drilling segments into a downhole processor, maintaining a desired drill bit inclination by using the downhole processor to evaluate an actual drill bit inclination relative to the trajectory for each of the plurality of drilling segments and by using the downhole processor to control a directional drilling device, and maintaining a desired azimuthal direction by using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the trajectory data for each of the plurality of drilling segments and using the downhole processor to control the directional drilling device.

[0018] Other aspects and advantages of the invention will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0019] **FIG. 1** shows an drilling rig and a borehole through an Earth formation.

[0020] **FIG. 2A** shows a prior art drilling trajectory control loop.

[0021] **FIG. 2B** shows a downhole closed loop trajectory control according to an embodiment of the invention.

[0022] **FIG. 3** shows a method for drilling a borehole according to one aspect of the invention.

[0023] **FIG. 4** shows a method for drilling a borehole according to another aspect of the invention.

[0024] **FIG. 5** shows a perspective view of a bottom hole assembly according to one embodiment of the invention.

[0025] **FIG. 6** shows a method for drilling a borehole according to another aspect of the invention.

[0026] **FIG. 7** shows a method for drilling a borehole according to another aspect of the invention.

DETAILED DESCRIPTION

[0027] The present invention relates to downhole closed loop systems and methods that control the trajectory of drill bits. In certain embodiments, the invention relates to a method for drilling a borehole by transmitting a signal to a downhole processor that controls the drill bit trajectory. In certain other embodiments, the invention relates to a BHA that includes two sensor sets and enables the determination of the rate of curvature per unit distance.

[0028] **FIG. 1** shows a rig and drill string assembly. A rig **101** is located at the surface and a drill string **102** is suspended from the rig **101**. A drill bit **105** disposed on a BHA **104** drills a borehole **103** through an Earth formation **106**. Using directional drilling, the borehole **103** can be made to deviate from the vertical direction.

[0029] **FIG. 2A** shows a block diagram of a prior art drilling control process. A directional driller **201** at the surface controls the drilling process. The driller **201** selects a "well plan," which represents the desired path that the drill bit will bore through the Earth to the planned target. The driller **201** controls the drill bit **204** so that the drill bit **204** will drill along the well plan.

[0030] In order to steer the drill bit **204** along the well plan, the driller **201** needs information about the drill bit's position and orientation. The driller **201** can estimate the depth of the drill bit **204** based on the length of drillpipe or coiled tubing that has been sent downhole. Information about the orientation, that is, the inclination and the azimuthal direction, of the drill bit **204** can be acquired from the orientation sensors **203** on the BHA. Thus, continuous communication between the orientation sensors **203** and the surface is required. Once the depth and orientation of the drill bit **204** are known, the driller **201** selects a drill bit inclination and azimuthal direction that will result in the drill bit **204** drilling along the well plan. The driller **201** transmits the desired inclination and azimuth to the directional drilling device **202**, which controls the orientation of the drill bit **204**. The driller **201** monitors the orientation of the drill bit **204** and sends new orientation instructions any time the drill bit **204** strays from the well plan or when the well plan requires a different orientation. This requires frequent communication between the driller and the directional drilling device.

[**0031**] **FIG. 2B** shows a block diagram of a downhole closed loop trajectory control according to one aspect of the invention. The directional driller **251** determines the well plan and ultimately controls the drilling process, but the primary drill bit trajectory control is performed by a downhole processor **252**.

[**0032**] The driller **251** transmits a directional instruction to a processor **252** disposed in the BHA. The processor **252** receives the directional signal, and from that point on, the processor **252** controls the trajectory of the drill bit **255** through a downhole closed loop, with minimal or no further input from the driller **251**. The processor **252** acquires drill bit **255** orientation information from the orientation sensors **253**, such as the drill bit's inclination and azimuthal direction. Based on the directional instruction and the orientation information, the processor **252** determines how the drill bit **255** should be oriented during drilling so that it will drill along the desired path. The processor **252** transmits instructions to the directional drilling device **254**, which, in turn, steers the drill bit **255**.

[**0033**] In some embodiments, the processor **252** also transmits a signal back to the surface so that the driller **251** can monitor drilling progress. The rate of communication may be at a much slower rate than is required in open-loop methods where the driller **251** controls the drill bit **255**.

[**0034**] The lines representing communications between the driller **251** and the processor **252** are shown as dashed lines because they are not continuous communications. A downhole closed-loop trajectory control according to the invention enables the processor **252** disposed down hole to control the drill bit **255** with minimal communication between the processor **252** and the driller **251**.

[**0035**] In some embodiments, a directional signal comprises a simple instruction to drill along a straight path by maintaining the present orientation. In other embodiments, the directional signal comprises a desired inclination and azimuthal direction. In still other embodiments, the directional signal comprises a instruction to follow a curved path. A curved path directional signal may comprise a curvature rate per unit time, or it may comprise a curvature rate per unit distance. Various directional signals are described in more detail in the description of different embodiments that follow.

[**0036**] The directional drilling device can be any device used to control the direction of a drill bit. Many such devices are known in the art. For example, a bent housing and a mud motor could be used as a directional drilling device. Also, a rotary steerable system could be used as a directional drilling device. The invention is not limited by the exact directional drilling device used.

[**0037**] The processor **252** in **FIG. 2B** may be any device adapted to interpret sensor set data or control the directional drilling device **254**. The processor **252** may also be a more complex computer that is also adapted to interpret and store data from MWD or LWD sensors on the BHA that investigate formation properties or drill bit health status.

[**0038**] Advantages of the present invention include the elimination of human error from the drilling process. The processor uses objective criteria to evaluate the position to the drill bit in relation to a desired position. The downhole closed loop does not include subjective evaluation by a driller, thereby reducing the human error in the drilling process.

[**0039**] Further, the present invention reduces the effect of off trajectory drilling. Because the trajectory control is a downhole closed loop, the processor can make adjustments based on orientation data in real time. Orientation data is analyzed downhole, and the processor makes correction as soon as a deviation from the desired path is detected. There is no need to transmit orientation data to the surface and await a response from the driller. Even in embodiments where orientation data are transmitted back to the surface for monitoring, it is only so that the driller can monitor the process. The processor does not need to await a response. The result is a more accurately drilled well path that is less tortuous than open loop methods.

[**0040**] Other advantages of a downhole closed loop trajectory control according to the present invention include a substantial reduction in the amount of data that must be transmitted between the driller and the BHA. Any telemetry devices may then be used to transmit other data, such as formation data collected by MWD or LWD sensors.

[**0041**] **FIG. 3** shows a method of drilling a borehole according to one embodiment of the invention. The method first includes transmitting (shown as **301**) a directional signal to a downhole processor. In some embodiments, the directional signal comprises a signal that instructs the processor to maintain the present drill bit inclination and azimuthal direction. In other embodiments, the signal may comprise a desired inclination and azimuthal direction of the drill bit. Those having skill in the art will realize that there are many types of signals that may constitute a directional signal.

[**0042**] In some embodiments, the directional signal is transmitted to the downhole processor before the processor is placed in a borehole. That is, the directional signal is pre-loaded into the processor at the surface, and then the BHA is lowered into the borehole.

[**0043**] The method next includes maintaining (shown as **302**) a desired drill bit azimuthal direction. The processor acquires azimuthal direction data from the orientation sensors and evaluates the drill bit azimuthal direction in relation to the desired azimuthal direction, determined from the directional signal. The processor controls the directional drilling device to make any necessary corrections to the drill bit azimuthal direction.

[**0044**] In some embodiments, the method also includes maintaining (shown as **303**) the desired drill bit inclination.

Once the processor has received a directional signal from the driller, the processor acquires inclination data from orientation sensors and evaluates the drill bit's actual inclination relative to the desired inclination. The processor then makes any necessary corrections to the drill bit's inclination by controlling the directional drilling device.

[0045] The method is not limited by the order of maintaining the azimuthal direction and maintaining the inclination. The maintaining the azimuthal direction may be a continuous process, or a process that is repeated at relatively small time intervals. Maintaining the inclination is a similar process.

[0046] **FIG. 4** shows a method of maintaining a curve according to another aspect of the invention. The method includes transmitting a directional signal to a downhole processor (shown at **401**). The directional signal according to this aspect of the invention comprises a rate of curvature per unit time. In some embodiments, the signal comprises both an azimuthal rate of curvature per unit time, expressed as degrees per hour, and an inclination rate of curvature per unit time, also expressed as degrees per hour. Note that the units of degrees per hour are used merely as a matter of convention. Any units of curvature per unit time may be used, for example, radians per day, without departing from the scope of the invention.

[0047] The method next includes maintaining an azimuthal rate of curvature (shown as **402**). The directional signal, which may include a desired azimuthal rate of curvature, enables the processor to determine a desired azimuthal direction as a function of time. The actual azimuthal rate of curvature, determined using orientation data from the orientation sensors, is compared with the desired azimuthal rate of curvature. The processor controls the directional drilling device to maintain the drill bit azimuthal rate of curvature.

[0048] The method may also include maintaining an inclination rate of curvature (shown as **403**). The directional signal, which may include a desired inclination rate of curvature per unit time, enables the processor to determine the desired inclination as a function of time. The actual inclination rate of curvature, determined from the orientation sensors, is compared with the desired inclination at that particular time, and the processor controls the directional drilling device to make corrections to the actual drill bit inclination.

[0049] As an example, a driller may transmit a directional signal to a drill bit comprising an inclination curvature of +3°/hour and an azimuthal direction curvature of −1°/hour. If the drill bit's initial position, that is, the drill bit's orientation when the signal was received, was at an inclination of 3° and an azimuthal direction of 0°, the processor can compute the desired orientation at any future time. Thus, after 3 hours have elapsed, the processor will have maintained the curved path and the orientation of the drill bit will be an inclination of 12° and an azimuthal direction of 3° (in a counter-clockwise direction, looking down the borehole).

[0050] Even though control of the drill bit trajectory is transferred downhole, it is not necessary that the downhole processor knows the drill bit depth to maintain a constant curve. Using a downhole closed loop to maintain a rate of curvature per unit time enables the driller to monitor only the rate-of-penetration ("ROP") of the drill bit. If the driller maintains a constant ROP, the curvature of the drilled wellbore will be constant over the length of the curve and will closely match the well plan.

[0051] **FIG. 5** shows another aspect of the invention. A BHA **501** comprises a drill bit **503**, a directional drilling device **502**, and two sets of orientation sensors **511** and **512**. The first set of orientation sensors **511** is disposed proximate to the drill bit and enables the determination of the drill bit's orientation. The second set of orientation sensors **512** is located farther up the drill string, at a known axial distance from the first set of orientation sensors **511**.

[0052] The two sets of orientation sensors separated by a known axial distance enables the determination of the curvature per unit distance by acquiring orientation data from each set of sensors. Along a curved well path, the axially spaced orientation sensors will detect different orientations at their respective axial locations. By dividing the difference between similar orientation measurements at each sensor set location by the distance between the sensor sets, a rate of curvature per unit distance is determined.

[0053] A sensor set is a plurality of sensors that are able to determine the inclination and azimuthal direction of the BHA at that axial position. A sensor set may include accelerometers, magnetometers, or gyroscopes. In some embodiments, a sensor set comprises three accelerometers and three magnetometers. In other embodiments, a sensor set may comprise three accelerometers and a combination of magnetometers and gyroscopes. U.S. Pat. No. 6,405,808 issued to Edwards et al. discloses a method for improving the quality of data from orientation sensors.

[0054] In some embodiments, the BHA **501** may include a processor **521** to enable a downhole closed loop trajectory control. The directional drilling device **502** can be any suitable device known in the art, including a rotary steerable system or a bent housing with a mud motor. In some other embodiments, the BHA **501** includes a short-hop telemetry system (not shown). The short-hop telemetry system enables communication between the processor **521** and the sensor sets **511** and **512**. Many short-hop telemetry devices are known in the art.

[0055] As an example, if the first sensor set **511** indicates an inclination of 15° and the second set of orientation sensors **512** indicates an inclination of 10°, the difference would be 5°. When that difference is divided by the axial distance between the first sensor set **511** and the second sensor set **512**, for example, 100 feet, an inclination curvature rate of 1°/20 feet would be determined.

[0056] **FIG. 6** shows a method according to another aspect of the invention. The method first transmits (shown as **601**) a directional signal to the BHA. The BHA may comprise a processor and a plurality of orientation sensor sets spaced apart by a known axial distance. The directional signal may comprise a desired rate of curvature per unit distance. The desired rate of curvature may include an desired inclination rate of curvature and a desired azimuthal rate of curvature.

[0057] The processor controls the directional drilling device so as to maintain (shown as **602**) at least one of the inclination rate of curvature per unit distance and the azimuthal rate of curvature per unit distance. In some embodiments, the processor acquires orientation data from the orientation sensors and evaluates the actual inclination rate of curvature relative to the desired rate of curvature. The processor makes corrections to the inclination rate of curvature by controlling the directional drilling device.

[0058] In other embodiments, the processor also acquires orientation data from the orientation sensors and evaluates the actual azimuthal rate of curvature relative to the desired rate of curvature. The processor makes any necessary corrections to the actual azimuthal rate of curvature by controlling the directional drilling device.

[0059] **FIG. 7** shows an embodiment according to another embodiment of the invention. The method includes loading (shown as **701**) trajectory data for a plurality of drilling segments into a downhole processor. The trajectory data may include data for straight line segments of a well path as well as data for curved segments of a well path. For example, a driller may desire to drill straight down for certain distance, then change the inclination by 15°, then drill another straight path, and finally change the azimuth by 25°. Each of these segments could be programmed into the downhole processor so that the processor could control drilling to the target without any further instructions.

[0060] The straight line segments may be represented by trajectory data indicating a desired inclination and the azimuthal direction, as well as the time required to drill the straight line segment. The driller regulates the ROP so that the drill bit would drill the desired distance in the specified time.

[0061] Curved segments may be specified by either a curvature rate per unit time or a curvature rate per unit distance. In either case, the trajectory data for a curved segment may include a final orientation. Once the final orientation is achieved, the processor begins drilling the next segment. In some embodiments, the trajectory data do not include a time duration, but the driller transmits a short signal instructing the processor to drill the next segment.

[0062] The method next includes maintaining (shown at **702**) a desired drill bit inclination using a downhole processor to evaluate an actual drill bit inclination relative to the trajectory data for each segment. The actual drill bit inclination is determined using data from orientation sensors, and the trajectory data for each segment enable the processor to determine a desired inclination.

[0063] The method also includes maintaining (shown at **703**) a desired azimuthal direction using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the trajectory data for each segment. Similarly, the actual drill bit azimuthal direction is determined using data from the orientation sensors, and it is compared to the trajectory data.

[0064] While the invention has been described with respect to a limited number of embodiments, those skilled in the art, having benefit of this disclosure, will appreciate that other embodiments can be devised which do not depart from the scope of the invention as disclosed herein. Accordingly, the scope of the invention should be limited only by the attached claims.

What is claimed is:

1. A method for drilling a borehole, comprising:

transmitting a directional signal to a downhole processor; and

maintaining the desired drill bit azimuthal direction by using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the desired drill bit azimuthal direction, and using the downhole processor to adjust the actual drill bit azimuthal direction by controlling a directional drilling device.

2. The method of claim 1, further comprising maintaining the desired drill bit inclination by using the downhole processor to evaluate an actual drill bit inclination relative to the desired drill bit inclination, and using the downhole processor to adjust the actual drill bit inclination by controlling the directional drilling device.

3. The method of claim 2, wherein the directional signal comprises a desired drill bit inclination and a desired drill bit azimuthal direction.

4. The method of claim 2, wherein the directional signal is transmitted to the downhole processor before the downhole processor is placed in the borehole.

5. A method for drilling a borehole, comprising:

transmitting a directional signal to a downhole processor; and

maintaining the desired drill bit azimuthal rate of curvature per unit time by using the downhole processor to evaluate an actual drill bit azimuthal rate of curvature per unit time relative to the desired azimuthal rate of curvature per unit time and using the downhole processor to adjust the actual drill bit azimuthal rate of curvature per unit time by controlling a directional drilling device.

6. The method of claim 5, further comprising maintaining the desired drill bit inclination rate of curvature per unit time by using the downhole processor to evaluate an actual drill bit inclination rate of curvature per unit time relative to the desired inclination rate of curvature per unit time and using the downhole processor to adjust the actual drill bit inclination rate of curvature per unit time by controlling the directional drilling device.

7. The method of claim 6, wherein the directional signal comprises a desired drill bit inclination rate of curvature per unit time and a desired drill bit azimuthal rate of curvature per unit time.

8. The method of claim 6, wherein the directional signal is transmitted to the downhole processor before the downhole processor is placed in a borehole.

9. A bottom hole assembly, comprising:

a drill bit;

a directional drilling device operatively coupled to the drill bit;

a first orientation sensor set disposed proximate to the drill bit; and

a second orientation sensor set disposed at a known axial distance from the first orientation sensor set.

10. The bottom hole assembly of claim 11, further comprising a processor operatively coupled to the directional drilling device, the first orientation sensor set, and the second orientation sensor set, and adapted to control the directional drilling device.

11. The bottom hole assembly of claim 12, wherein the processor is operatively coupled to at least one of the first orientation sensor set and the second orientation sensor set by a short-hop telemetry device.

12. The bottom hole assembly of claim 11, wherein the directional drilling device comprises a bent housing and a mud motor.

13. The bottom hole assembly of claim 11, wherein the directional drilling device comprises a rotary steerable system.

14. A method for drilling a curved well path, comprising:

transmitting a directional signal to a downhole processor operatively coupled to a bottom hole assembly, the bottom hole assembly comprising a plurality of sensors spaced by a known axial distance and a directional drilling device; and

maintaining an at least one of an inclination rate of curvature per unit distance and an azimuthal rate of curvature per unit distance by using the downhole processor to control the at least one of the inclination rate of curvature per unit distance and an azimuthal rate of curvature per unit distance.

15. The method of claim 14, wherein the directional signal comprises a desired drill bit inclination rate of curvature per unit distance and a desired drill bit azimuthal rate of curvature per unit distance.

16. The method of claim 14, wherein the directional signal is transmitted to the downhole processor before the processor is placed in a borehole.

17. The method of claim 14, wherein the directional drilling device comprises a bent housing and a mud motor.

18. The method of claim 14, wherein the directional drilling device comprises a rotary steerable system.

19. The method of claim 14, wherein maintaining at least one of the inclination rate of curvature per unit distance and the azimuthal curvature per unit distance comprises using the downhole processor to evaluate an actual drill bit inclination rate of curvature per unit distance relative to the desired inclination rate of curvature per unit distance and using the downhole processor to adjust the actual drill bit inclination rate of curvature per unit distance by controlling the directional drilling device.

20. The method of claim 14, wherein maintaining at least one of the inclination rate of curvature per unit distance and the azimuthal curvature per unit distance comprises using the downhole processor to evaluate an actual drill bit azimuthal rate of curvature per unit distance relative to the desired azimuthal rate of curvature per unit distance and using the downhole processor to adjust the actual drill bit azimuthal rate of curvature per unit distance by controlling the directional drilling device.

21. A method for drilling a borehole, comprising:

loading trajectory data for each of a plurality of drilling segments into a downhole processor;

maintaining a desired drill bit inclination by using the downhole processor to evaluate an actual drill bit inclination relative to the trajectory data for each of the plurality of drilling segments and by using the downhole processor to control a directional drilling device; and

maintaining a desired drill bit azimuthal direction by using the downhole processor to evaluate an actual drill bit azimuthal direction relative to the trajectory data for each of the plurality of drilling segments and using the downhole processor to control the directional drilling device.

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