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DRILLING A BOREHOLE IN AN EARTH
FORMATION***E21B 47/02* (2006.01)*E21B 7/08* (2006.01)*E21B 44/00* (2006.01)*E21B 47/04* (2012.01)(76) Inventor: **Douwe Johannes Runia**, Rijswijk
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Publication Classification(51) **Int. Cl.***E21B 7/04* (2006.01)*E21B 47/12* (2012.01)*E21B 47/26* (2012.01)(57) **ABSTRACT**

A method of drilling a borehole in an earth formation using a drill string including a control system for controlling the borehole trajectory. The control system is operable to receive a selected signal, to determine the borehole depth from at least one length increment and the number of times the selected signal is received, and to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with a desired borehole trajectory. While drilling, for each length increment that the drill string is lowered into the borehole, transmitting the selected signal to the control system; inducing the control system to determine the borehole depth from said length increment and the number of times the selected signal is received; and operating the control system to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with the desired borehole trajectory.

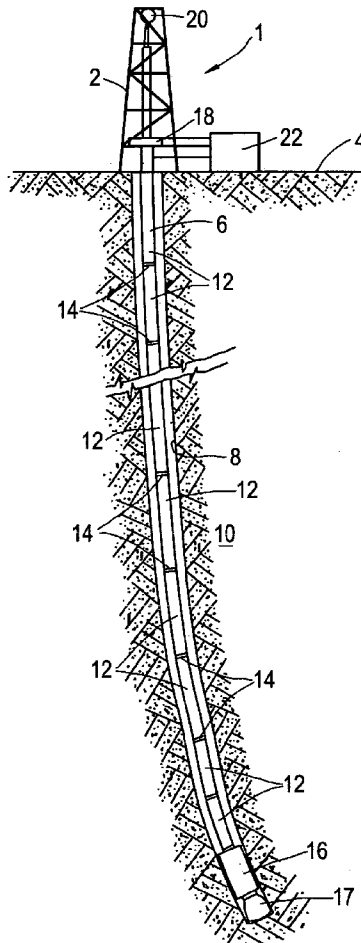


Fig.1

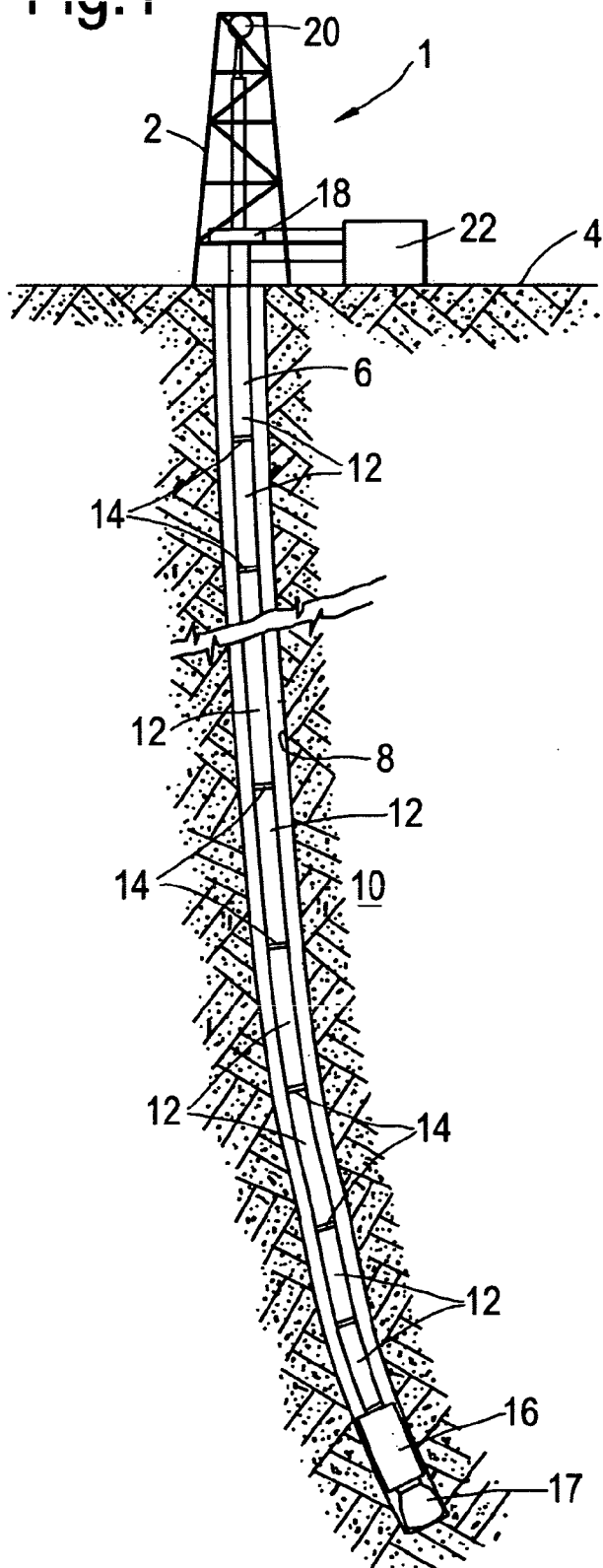


Fig.2

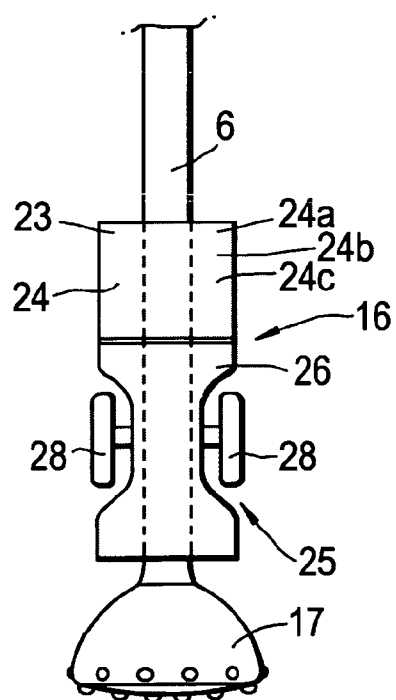
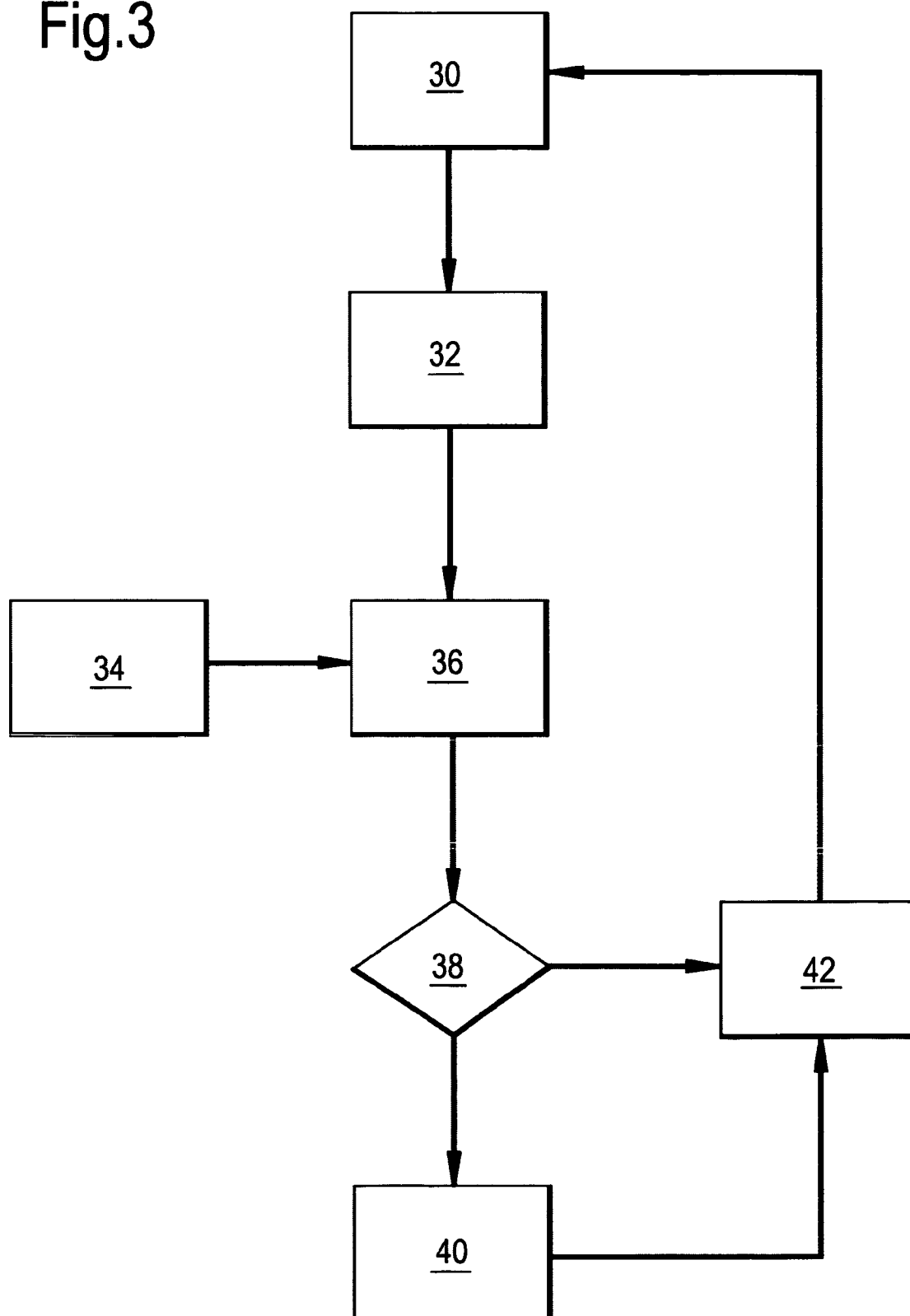


Fig.3



METHOD AND STEERING ASSEMBLY FOR DRILLING A BOREHOLE IN AN EARTH FORMATION

[0001] The present invention relates to a method of drilling a borehole in an earth formation using a drill string including a control system for controlling the borehole trajectory, and to a steering assembly for steering the direction of drilling into an earth formation.

[0002] In the industry of the production of hydrocarbon fluid from a subterranean reservoir zone, several systems and methods are used to steer the drill string such that the wellbore is drilled along a desired wellbore trajectory. One steerable drilling system includes a downhole drilling motor with a bent housing and a measuring while drilling tool (MWD) for receiving/transmitting signals between surface and the bottom hole assembly to orient the bent housing in the borehole. During drilling of a straight borehole section, the drill string including the bent housing rotates whereby the drill bit orbits slightly in the borehole. The drill bit is driven in rotation either by rotation of the drill string only, or by rotation of the drill string and simultaneously by the downhole motor. To drill a curved section, the MWD tool is used to transmit information regarding the orientation of the bent housing in the borehole to the operator at surface. After orienting the bent housing in the desired direction, the downhole motor is operated to drill the curved section whereby the drill string is kept stationary.

[0003] Another steerable drilling system includes a rotating drill string having a lower portion provided with a sleeve that is stationary relative to the drill string by virtue of bearings arranged between the sleeve and the drill string. The sleeve has a number of circumferentially spaced force application members, such as pads or ribs that are radially extendable against the borehole wall. This system is generally referred to as a rotary steerable system (RSS). The drill string is rotated at surface to drive the drill bit while the sleeve remains stationary or rotates slowly while the drill string progresses in the borehole. In some applications the drill string is additionally provided with a downhole motor, whereby the drill bit is either driven by the rotating drill string only, or simultaneously by the rotating drill string and the downhole motor. In such applications, the sleeve suitably extends around the bearing assembly of the downhole motor. When it is desired to drill a curved section, one or more of the force application members is (are) radially extended against the borehole wall so as to push or point the drill bit in the desired direction. The system is controlled from surface using a down link, which is a system for transferring measurement or control signals between the operator at surface and the bottom hole assembly, such as a mud pulse device or an electromagnetic device. The detailed design and operational methodology of the various devices available in the industry are very diverse.

[0004] US2004/0050590 discloses a method for drilling a borehole comprising transmitting a directional signal to a downhole processor, and maintaining the desired drill bit direction using the downhole processor to adjust the actual drill bit azimuthal direction, and also drill bit inclination, by controlling the directional drilling device. In the known system and method, the downhole processor does not use actual depth as input parameter for the control loop, and depth

information is not transmitted downhole. Rather, the rate-of-penetration (ROP) is maintained constant by the driller on surface.

[0005] SU903565 discloses a logging tool recording borehole trajectory parameters. The tool is lowered into a drill string extending in a borehole that was drilled. The logging tool is lifted together with the drill string, and data is recorded each time a drill pipe element is detached.

[0006] U.S. Pat. No. 2,987,822 discloses several drill string depth measuring systems for indicating at surface the depth of a drill string in a borehole.

[0007] US2006/0006000-A1 discloses a drilling system and method whereby a MWD survey tool is positioned above a rotary steerable tool in the bottom hole assembly, the MWD survey tool comprising magnetometers and inclinometers to provide data regarding azimuth and inclination of the borehole. The system includes an automated guidance system using closed loop control whereby the computational control system is arranged in the bottom hole assembly, and whereby information regarding the length of the borehole path is transmitted from surface and combined with measurement data of borehole azimuth and inclination. In the known system and method, the MWD tool must be capable of receiving and processing signals representing the borehole depth, which signals vary continuously with borehole depth.

[0008] It is to be understood that, in the context of this specification, the term "borehole depth" refers to the along-hole-depth, which corresponds to the length of the borehole measured along its central longitudinal axis.

[0009] It is therefore an object of the invention to provide an improved method of drilling a borehole in an earth formation using a drill string including a control system for controlling the borehole trajectory.

[0010] In accordance with the invention there is provided a method of drilling a borehole in an earth formation using a drill string including a control system for controlling the borehole trajectory, wherein the control system is operable to receive a selected signal, to determine the borehole depth from at least one length increment and the number of times the selected signal is received, and to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with a desired borehole trajectory, the method comprising:

[0011] a) operating the drill string to drill the borehole thereby lowering the drill string into the borehole;

[0012] b) for each length increment that the drill string is lowered into the borehole in step (a), transmitting the selected signal to the control system;

[0013] c) inducing the control system to determine the borehole depth from said at least one length increment and the number of times the selected signal is received by the control system;

[0014] d) operating the control system to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with the desired borehole trajectory.

[0015] In this manner it is achieved that information regarding the borehole depth is transmitted to the control system in a single type of signal that is repeated for each length increment the drill string progresses into the borehole. The control system therefore needs to be adapted to receive a single type of signal only, as opposed to the known system in which the MWD tool must be capable of receiving and processing con-

tinuously varying signals representing the borehole depth. The transmission of the control signal is suitably induced at surface.

[0016] Suitably the signal is transmitted to the control system each time the length of the drill string in the borehole increases by a respective one of said at least one length increment. If the drill string is assembled from a plurality of drill string sections, it is preferred that each length increment corresponds to the length of a respective drill string section.

[0017] Preferably the selected signal includes a variation of a drilling parameter detectable by the control system. As in most drilling operations a stream of fluid is pumped through the drill string during drilling, the drilling parameter to be varied suitably comprises a flow rate of the stream of fluid.

[0018] Alternatively, in applications whereby the drill string is rotated during drilling, the drilling parameter to be varied advantageously is the rotary speed of the drill string.

[0019] Furthermore, in applications whereby the drill string rests on the borehole bottom during drilling, the drilling parameter to be varied suitably comprises a compressive force exerted by the drill string to the borehole bottom. For example, the drill string can be lifted from the borehole bottom to induce a variation of the compressive force between the drill string and the borehole bottom.

[0020] The invention further provides a steering assembly for steering the direction of drilling into an earth formation, the steering assembly being adapted to form part of a drill string extending into a borehole into the earth formation, the steering assembly comprising a steering system for setting the direction of drilling in response to a control signal, and a control system for providing the control signal to the steering system, the control system comprising

[0021] memory means for storing a desired borehole trajectory;

[0022] one or more directional sensors for determining azimuth and inclination;

[0023] means for obtaining a borehole depth;

[0024] means for determining an actual borehole trajectory using the borehole depth, azimuth and inclination as input parameters;

[0025] means for determining a deviation between the desired borehole trajectory and the actual borehole trajectory, and for determining the control signal from the deviation, wherein the means for obtaining a borehole depth comprises

[0026] receiver means for receiving a selected signal characteristic for a length increment that the drill string is lowered into the borehole;

[0027] a counter for determining the number of times the selected signal was received; and

[0028] calculation means adapted to determine the borehole depth from at least one length increment and the number of times the selected signal is received.

[0029] The memory means can be a computer memory. Suitably the memory means is adapted to store the at least one length increment. The directional sensor(s) can be conventional sensors as known from e.g. MWD tools. The means for determining an actual borehole trajectory using the borehole depth, azimuth and inclination as input parameters can be a data processing means such as a computer module. The data processing means can also be used for determining the deviation between the desired borehole trajectory and the actual borehole trajectory, and/or for determining the control signal from the deviation, and/or for as the calculation means for determining the borehole depth.

[0030] The steering assembly can further comprise a power supply such as a battery or a turbine power supply driven by drilling fluid, so that it can operate without electrical connection to surface. The power supply can supply electric power to one or more or all components of the control system, such as to a computer module, receiver means, directional sensor, counter, and/or to the steering system. The steering system can also be provided with hydraulic power, such as to operate hydraulic actuators of pads against the borehole wall.

[0031] The steering assembly suitably forms part of a drill string including a drill bit. It is suitably arranged during operation in a downhole position, preferably close to the drill bit that is located at the lower end of the drill string, such as at a distance of 100 m or less, preferably 50 m or less, more preferably 25 m or less, from the drill bit. The steering assembly, including the control system, can in particular form part of the bottom hole assembly.

[0032] The invention will be described hereinafter in more detail and by way of example, with reference to the accompanying drawing in which:

[0033] FIG. 1 schematically shows an embodiment of a drilling assembly for use with the method of the invention; and

[0034] FIG. 2 schematically shows a lower portion of the drilling assembly of FIG. 1; and

[0035] FIG. 3 schematically shows a flow chart of various steps during drilling of a borehole with the drilling assembly 1.

[0036] Referring to FIG. 1 there is shown a drilling assembly 1 comprising a drilling rig 2 at surface 4 and a drill string 6 extending from the drilling rig 2 into a borehole 8 formed in an earth formation 10. The drill string 6 is assembled from a plurality of drill string sections 12 (also referred to as "drill pipe stands") interconnected by threaded or welded connections 14. In conventional drilling applications, a drill pipe stand generally consists of three interconnected drill pipe joints, each drill pipe joint being approximately 9 meters in length.

[0037] A lower portion of the drill string 6 includes a steering assembly 16 for steering the drill string 6 in accordance with a desired borehole trajectory. A drill bit 17 is arranged at the lower end of the drill string 6. The steering assembly 16 is shown just above the drill bit, forming part of the bottom hole assembly. The drilling rig 2 comprises a rotary table 18 for rotating the drill string 6 and a hoisting system 20 for lifting the drill string 6. A pump 22 is provided at surface 4 for pumping a stream of drilling fluid via the drill string 6 and the drill bit 17 to the borehole bottom from where the stream flows through the annular space between the drill string 6 and the borehole wall 8 to a shale shaker (not shown) at surface. The steering assembly 16 includes a power supply 23.

[0038] In FIG. 2 is shown the steering assembly 16 of the drill string 6 in more detail. The steering assembly 16 comprises a control system 24 and steering system 25. The steering system 25 of this embodiment comprises a sleeve 26 that is rotatable relative to the drill string 6 about its central longitudinal axis by virtue of bearings (not shown) between the sleeve 26 and the drill string 6. The sleeve 26 is provided with a series of pads 28 spaced in circumferential direction of the sleeve. Each pad 28 is movable relative to the sleeve 26 between a radially retracted position in which the pad is retracted from the borehole wall 8, and a radially extended position in which the pad 28 is pushed against the borehole wall 8 in order to position the drill string 6 eccentrically in the

borehole 8. Each pad 28 is provided with a hydraulic actuator (not shown) for moving the pad between the radially retracted position and the radially extended position, whereby the control system 24 controls operation of each hydraulic actuator.

[0039] The control system 24 is adapted to receive a selected signal transmitted from surface to the control system, and includes receiver means 24a to this end. It also suitably includes a counter for determining the number of times the selected signal was received. This can be an electronic circuit or computer counter. In the present example, the selected signal is a predetermined change of the velocity of the stream of drilling fluid flowing in the drill string 6. Suitably the predetermined change of velocity results from stopping and then again starting the pump 22 so that the flow rate of the stream temporarily reduces to substantially zero. Further, the control system 24 includes calculation means 24b such as a computer module, adapted to determine the borehole depth from at least one length increment, that is suitably stored in a memory 24c, and the number of times the selected signal is received. The control system in this example is programmed to calculate the borehole depth as the product of a predetermined length increment (L) and the number of times (N) that the signal is transmitted to the control system. In operation, the signal is transmitted to the control system 24 each time that the drill string progresses into the borehole a distance equal to the length increment (L). This information, in combination with borehole azimuth and inclination data, is used by the control system 24 as input data for calculating, in computer module 24b, a deviation (D) of the actual borehole trajectory from a desired borehole trajectory stored in memory 24c of the control system 24. The deviation (D) is compared to a threshold deviation (T) stored in memory 24c of the control system 24, in order to determine whether or not the hydraulic actuators of the pads 28 need to be activated to correct the borehole path.

[0040] Normal operation during drilling with the drilling assembly 1 is explained hereinafter with reference to FIG. 3.

[0041] In a first step 30, the selected signal is transmitted from surface to the control system 24 by switching the pump 22 off, and then again on, so that the flow rate of the stream temporarily reduces to substantially zero. This is done each time the drill string progresses into the borehole 8 a distance equal to the predetermined length increment (L). In a suitable embodiment, the drill string 6 is assembled from drill string sections 12 of standard length in the form of drill pipe stands whereby a suitable length increment (L) is the length of one such drill pipe, or drill pipe stand, or a number of drill pipe stands assembled together. The signal is received by the receiver means 24a, which can be e.g. a pressure or flow sensor to detect pump rate changes. For other types of signals, other types of sensors can be used, e.g. magnetometer or accelerometer sensors to detect rate-of-penetration changes or off-bottom lifting of the drill string.

[0042] In a second step 32, the control system 24 calculates the borehole depth as the product of the predetermined length increment (L), which can be stored in the memory means of the control system, and the number of times (N) that the signal is transmitted to the control system, i.e. the borehole depth is $N \times L$. The calculation means can be a computer module.

[0043] In a third step 34, the azimuth and inclination of the borehole are determined using directional sensors (not shown) arranged in the control system 24. It will be understood that the second and third steps can be carried out in any order, or simultaneously.

[0044] In a fourth step 36, the control system 24 determines the actual borehole trajectory using the borehole depth, azimuth and inclination as input parameters. The actual borehole trajectory is then compared to a desired borehole trajectory stored in the internal memory of the control system 24, in order to determine a deviation (D) of the actual borehole trajectory from the desired borehole trajectory.

[0045] In a fifth step 38, the deviation (D) (if any) is compared to a threshold deviation (T). If the deviation is larger than the threshold deviation, a sixth step 40 is performed followed by a seventh step 42. If the deviation is smaller than the threshold deviation, the sixth step is skipped and the seventh step 42 is performed. The fourth and fifth step can also be done in a calculation means like a computer module.

[0046] In the sixth step 40, the control system 24 controls the hydraulic actuators of the pads 28 to steer the drill string 6 during further drilling, thereby setting the drilling direction so as to reduce the deviation from the desired borehole trajectory to below the threshold deviation.

[0047] In the seventh step 42, drilling proceeds until the length of drill string that has moved into the borehole 8 as a result of drilling, has increased by the predetermined length increment (L). Then the steps 30, 32, 34, 36, 38, 40, 42 are repeated until the borehole 8 has reached its target depth.

[0048] Thus, in summary, the control system is pre-programmed to follow a planned borehole trajectory and to correct for deviation from that trajectory. Information regarding the borehole depth is transmitted to the control system by a selected signal indicating that the drill string has made an incremental progress in the borehole, for example 9m, 27m, 30m, or another convenient length increment. A suitable signal comprises a certain pattern of on/off switching of the pump(s), which the internal logic of the control system recognizes as representing the incremental depth information. Using this depth information, the control system calculates its exact location from which the drift component is calculated. With this information, the control system calculates a corrective direction in order to steer the drilling assembly back to the originally planned trajectory. The control system also can be programmed to build up expertise on the drift, so that the drift can be pre-corrected thereby minimizing correction drilling runs and related borehole tortuosity.

[0049] The method and steering assembly of the invention allow a robust operation of an autonomous rotary steering system, which can guide the drilling to a predetermined location in the earth formation without the need for complex signal transmission from surface downhole. Transmitting an actual depth would require a complex signal transmission. Instead, merely selected signals triggering the inclusion of another length increment in the depth calculation performed downhole are required.

[0050] The invention has been illustrated at the hand of a steering system including a sleeve and pads for setting the direction of drilling. It will be understood that the invention can be used with a large variety of steering systems as part of the steering assembly, using different ways to direct the drilling into a desired direction, e.g. point-the-bit, push-the-bit, or other methods. The control system of the invention can be used to generate suitable control signals control the operation the respective steering system. Reference is made for example to the methods and devices disclosed in U.S. Pat. Nos. 5,168,941, 5,520,255, 5,857,531, 5,875,859, 6,092,610, US2007/0163810, or WO-A-2005/005767.

[0051] If the drill string sections 12 vary in length, for example due to manufacturing tolerances of the drill pipe joints, it is preferred that the lengths of the drill string sections 12 are stored in the internal logic of the control system 24 as a plurality of length increments. Furthermore, the order in which the sections 12 are assembled into the drill string 6 is stored in the internal logic of the control system 24. The control system 24 then calculates the borehole depth from the number of times (N) that the signal is transmitted to the control system, the stored length increments, and the order in which the sections 12 are assembled into the drill string. The calculated borehole depth is the sum of the lengths of the drill string sections 12 that have been lowered into the borehole.

[0052] Instead of operating the force application members hydraulically, the force application members can be operated electrically. Further, instead of using radially extendable force application members, the sleeve can be provided with a mechanism that positions the sleeve eccentrically in the borehole.

[0053] In order to check the ongoing steering progress while drilling, a conventional directional MWD tool can be positioned above the tool. The MWD tool can be one of a number of commercial systems, which signals the progress to surface using mud pulse or EM technology. If the RSS tool were to fail and thus no longer follow the desired trajectory, the MWD readings will indicate this and the drill string can be pulled and the RSS tool replaced.

1. A method of drilling a borehole in an earth formation using a drill string including a control system for controlling the borehole trajectory, wherein the control system is operable to receive a selected signal, to determine the borehole depth from at least one length increment and the number of times the selected signal is received, and to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with a desired borehole trajectory, the method comprising:

- a) operating the drill string to drill the borehole, thereby lowering the drill string into the borehole;
- b) for each length increment that the drill string is lowered into the borehole in step (a), transmitting the selected signal to the control system;
- c) inducing the control system to determine the borehole depth from said at least one length increment and the number of times the selected signal is received by the control system;
- d) operating the control system to use the borehole depth as input parameter for controlling the borehole trajectory in correspondence with the desired borehole trajectory.

2. The method of claim 1, wherein the signal is transmitted to the control system each time the drill string is lowered into the borehole a respective one of said at least one length increment.

3. The method of claim 1 wherein the drill string is assembled from a plurality of drill string sections, and wherein each length increment corresponds to the length of a respective drill string section.

4. The method of claim 1 wherein the selected signal includes a variation of a drilling parameter detectable by the control system.

5. The method of claim 4, wherein a stream of fluid is pumped through the drill string during drilling, and wherein said drilling parameter comprises a flow rate of the stream of fluid.

6. The method of claim 4 wherein the drill string is rotated during drilling, and wherein said drilling parameter comprises a rotary speed of the drill string.

7. The method of claim 1 wherein the drill string rests on the borehole bottom during drilling, and wherein said drilling parameter comprises a compressive force exerted by the drill string to the borehole bottom.

8. The method of claim 7, wherein the drill string is lifted from the borehole bottom to induce a variation of said compressive force exerted by the drill string to the borehole bottom.

9. The method of claim 1 further comprising operating the control system to use at least one of borehole azimuth and borehole inclination as input parameter for controlling the borehole trajectory in correspondence with the desired borehole trajectory.

10. The method of claim 1 wherein the control system forms part of a bottom hole assembly of the drill string, which bottom hole assembly is lowered into the borehole.

11. A steering assembly for steering the direction of drilling into an earth formation, the steering assembly being adapted to form part of a drill string extending into a borehole into the earth formation, the steering assembly comprising a steering system for setting the direction of drilling in response to a control signal, and a control system for providing the control signal to the steering system, the control system comprising

memory means for storing a desired borehole trajectory;
one or more directional sensors for determining azimuth and inclination;

means for obtaining a borehole depth;

means for determining an actual borehole trajectory using the borehole depth, azimuth and inclination as input parameters;

means for determining a deviation between the desired borehole trajectory and the actual borehole trajectory, and for determining the control signal from the deviation, wherein the means for obtaining a borehole depth comprises

receiver means for receiving a selected signal characteristic for a length increment that the drill string is lowered into the borehole;

a counter for determining the number of times the selected signal was received; and

calculation means adapted to determine the borehole depth from at least one length increment and the number of times the selected signal is received.

12. The steering assembly according to claim 11, wherein the memory means is adapted to store the at least one length increment.

13. The steering assembly according to claim 11 further comprising a power supply.

14. The steering assembly according to claim 1 wherein the steering assembly forms part of a drill string including a drill bit.

15. The steering assembly according to claim 14, wherein the steering assembly is arranged at a distance of 100 m or less from the drill bit.