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(54) **ROTARY STEERABLE DRILLING APPARATUS AND METHOD**

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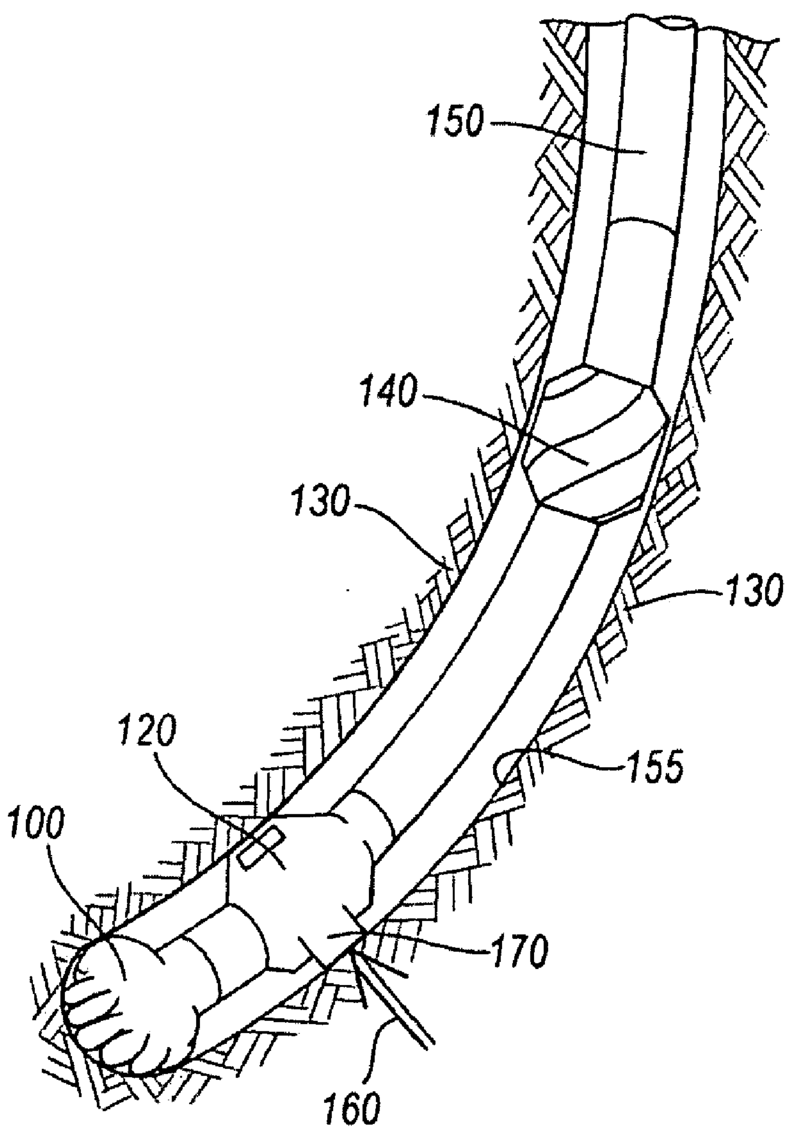
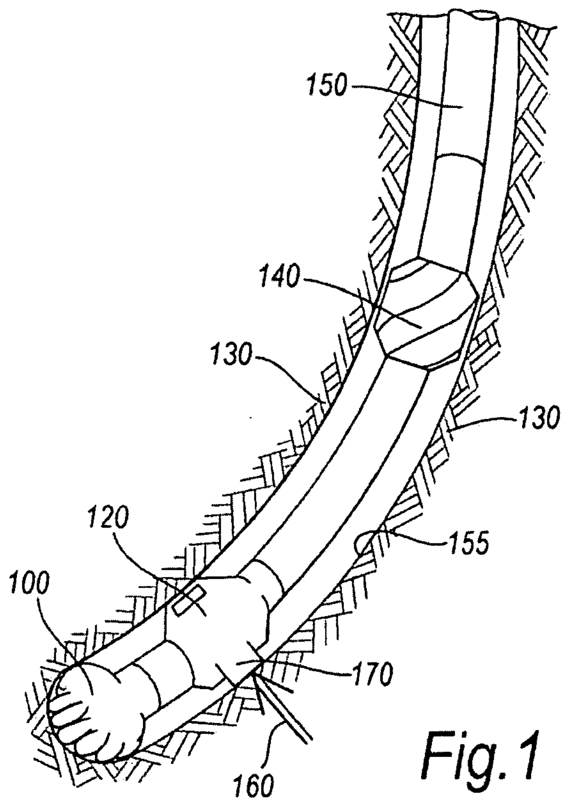
(57) **ABSTRACT**

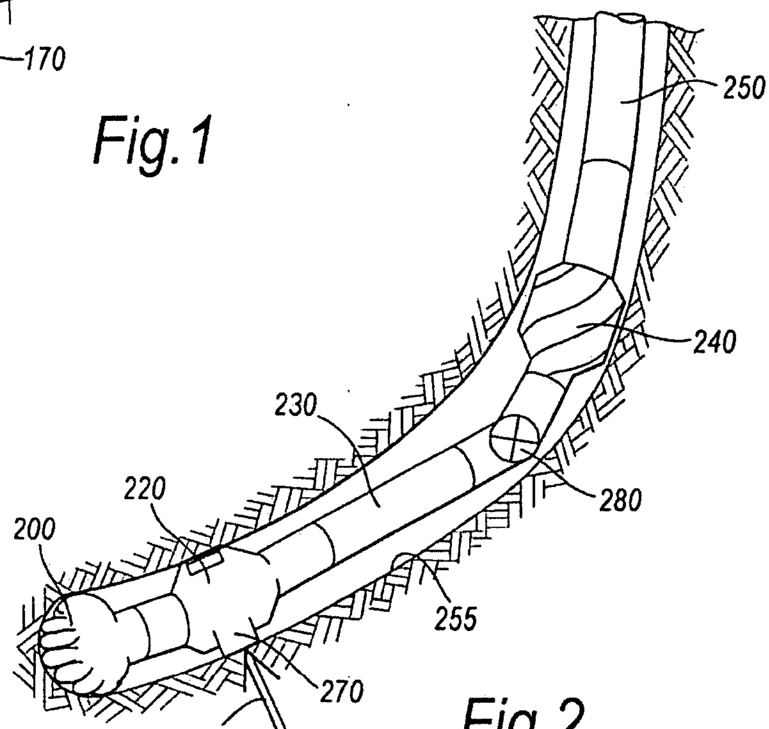
The present invention relates to drilling apparatus which includes a steerable bottom hole assembly for use in a well bore. The steerable bottom hole assembly includes a bent sub assembly connectable to a distal end of a drill string. It also has a control bias unit connected to the bent sub assembly and a drill bit connected to the control bias unit. The bent sub assembly may have an adjustable angle.





150
140
130
130
120
155
100
170
160

Fig.1



250
240
230
280
220
200
255
270
290

Fig.2

ROTARY STEERABLE DRILLING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

[0001] This invention relates generally to oilfield downhole tools and more particularly to a rotary steerable drilling apparatus utilizing a bent sub assembly to increase the dogleg capability achieved by a rotary steerable drilling system in pushing the bit in the preferred dill path. To obtain hydrocarbons such as oil and gas or other materials, boreholes or wellbores are drilled by rotating a drill bit attached to the bottom of a bottom hole assembly ("BHA"). In other circumstances the borehole or wellbore may be used to sequester material such as carbon dioxide.

[0002] One aspect of drilling is called"directional drilling." Directional drilling is the intentional deviation of the wellbore from the path it would naturally take. In other words, directional drilling is the steering of the drill string so that it travels in a desired direction.

[0003] Directional drilling is advantageous offshore because it enables many wells to be drilled from a single platform. Directional drilling also enables horizontal drilling through a reservoir. Horizontal drilling enables a longer length of the wellbore to traverse the reservoir, which increases the production rate from the well.

[0004] A directional drilling system may also be used in vertical drilling operation as well. Often the drill bit will veer off of a planned drilling trajectory because of the unpredictable nature of the formations being penetrated or the varying forces that the drill bit experiences. When such a deviation occurs, a directional drilling system may be used to put the drill bit back on course. Known methods of directional drilling include the use of a rotary steerable system ("RSS"). In an RSS, the drill string is rotated from the surface, and downhole devices cause the drill bit to drill in the desired direction. Rotating the drill string greatly reduces the occurrences of the drill string getting hung up or stuck during drilling.

[0005] Rotary steerable drilling systems for drilling deviated boreholes into the earth may be generally classified as either "point-the-bit" systems or "push-the-bit" systems. In the point-the-bit system, the axis of rotation of the drill bit is deviated from the local axis of the bottom hole assembly (BHA) in the general direction of the new hole. The hole is propagated in accordance with the customary three-point geometry defined by upper and lower stabilizer touch points and the drill bit. The angle of deviation of the drill bit axis coupled with a finite distance between the drill bit and lower stabilizer results in the non-collinear condition required for a curve to be generated. There are many ways in which this may be achieved including a fixed bend at a point in the BHA close to the lower stabilizer of a flexure of the drill bit drive shaft distributed between the upper and lower stabilizer. In its idealized forms, the drill bit is not required to cut sideways because the bit axis is continually rotated in the direction of the curved hole. Examples of point-the-bit type rotary steerable systems, and how they operate are described in U.S. Patent Application Publication Nos. 2002/0011359; 2001/0052428 and U.S. Pat. Nos. 6,394,193; 6,364,034; 6,244,361; 6,158,529; 6,092,610; and 5,113,953 all herein incorporated by reference.

[0006] In a push-the-bit rotary steerable, the requisite non-collinear condition is achieved by causing either or both of the upper or lower stabilizers or another mechanism to apply an eccentric force or displacement in a direction that is preferentially orientated with respect to the direction of hole propagation. Again, there are many ways in which this may be achieved, including non-rotating (with respect to the hole) eccentric stabilizers (displacement based approaches) and eccentric actuators that apply force to the drill bit in the desired steering direction. Again, steering is achieved by creating non co-linearity between the drill bit and at least two other touch points. In its idealized form the drill bit is required to cut side ways in order to generate a curved hole. Examples of push-the-bit type rotary steerable systems, and how they operate the described in U.S. Pat. Nos. 5,265,682; 5,553,678; 5,803,185; 6,089,332; 5,695,015; 5,685,379; 5,706,905; 5,553,679; 5,673,763; 5,520,255; 5,603,385; 5,582,259; 5,778,992; 5,971,085 all herein incorporated by reference.

[0007] Known forms of RSS are provided with a "counter rotating" mechanism which rotates in the opposite direction of the drill string rotation. Typically, the counter rotation occurs at the same speed as the drill string rotation so that the counter rotating section maintains the same angular position relative to the inside of the borehole. Because the counter rotating section does not rotate with respect to the borehole, it is often called "geo-stationary" by those skilled in the art. In this disclosure, no distinction is made between the terms "counter rotating" and "geo-stationary".

[0008] A push-the-bit system typically uses either an internal or an external counter-rotation stabilizer. The counter-rotation stabilizer remains at a fixed angle (or geo-stationary) with respect to the borehole wall. When the borehole is to be deviated, an actuator presses a pad against the borehole wall in the opposite direction from the desired deviation. The result is that the drill bit is pushed in the desired direction.

[0009] A drilling assembly may be attached to the distal end of a drill string comprised of a plurality of tubular or a relatively flexible spoolable tubing string commonly referred to as "coiled tubing." The section comprising the tubing and the drilling assembly is generally referred to as the "drill string." When a jointed pipe is used as the tubing, the drill bit is rotated by rotating the jointed pipe from the surface or by a mud motor attached to the tubing proximate the drill bit, or preferably both rotation and continuous directional drilling with the BHA. In the case of coiled tubing, the drill bit is rotated by a mud motor. Coiled tubing or flexible tubing may not withstand the rotational torque required in drilling. As referred to herein "drilling" includes coil tubing drilling and also casing drilling in which the casing or tube used to line the production well is used as the drillstring. As drilling occurs, a drilling fluid can be pumped to the drill bit discharging through jets in the drill bit to lubricate and cool the bit and to move rock crushed by the drill bit to the surface. The mud motor uses the hydraulic power of this drilling fluid to power the drill bit.

[0010] A substantial portion of current drilling activity involves drilling of directionally deviated wells to fully exploit a given set of geological formations from a single drilling platforms. This is especially true of offshore drilling platforms which have high daily operating costs. Current drilling programs can provide any number of proposed drill paths to exploit the reservoir from a single location. Such boreholes can provide very complex well profiles. To drill such profiles, bottom hole assemblies are normally provided with a plurality of independently operable force application members to apply force on the wellbore wall during drilling to move the drill bit along a prescribed path.

[0011] A sub assembly or ("Sub") is any small component of the drill pipe or drillstring, such as a short drill collar or a thread crossover. A bent sub assembly ("bent sub") refers to a piece of drill pipe or drillstring that is made or produced with a small bend angle between upper and lower portions thereof. Bent sub assemblies are used to change the direction in which a drilling bit cuts the borehole. The bent sub assembly has a transverse bend at a point along its length. The assembly is commonly positioned between the power section of a downhole motor and a bearing assembly to which the bit is connected. At its upper end, the bent sub assembly is coaxial with the longitudinal axis of drill string, but beneath the bend the longitudinal axis of the lower end of the bent sub assembly is offset at a slight angle (typically up to 3"). Before rotary steerable drilling systems, in order to change the inclination in which a borehole is being drilled, it has been common practice to place in the mud motor assembly a "bent sub". The bent sub usually is connected to the top of the downhole motor which drives the bit in response to circulation of drilling fluids, or it can be a part of the assembly between the mud motor and its bearing section. The presence of a bent angle causes gradual change in the inclination of the bottom portion of the borehole as the bit drills ahead, with the result that the borehole is formed along a curved path until a desired new inclination is achieved. The presence of a bend angle also allows torque that is applied to the drill string at the surface to be used to steer the bit to the right or to the left to achieve a change in the azimuth of the borehole.

[0012] Adjustable bent subs are available in this form so the bend angle can be adjusted, usually on the surface. Known adjustable bent subs use splines to provide for an adjusted angle. Other bent subs that have an adjustable bend angle have been proposed, for example, devices such as those shown in U.S. Pat. Nos. 4,745,982, 4,813,497, 4,836,303, 4,220,214, 4,240,512, and 4,303,135 have to be removed from the well for adjustment of the bend angle, which necessitates a round trip of the drill string. Another adjustable bent sub is described in U.S. Pat. No. 4,077,657, this also must be hoisted up to the surface for adjustment. Other proposals for downhole adjustable bent subs are shown in U.S. Pat. Nos. 4,655,299, 4,895,214 and 4,596,294, these systems require surface manipulation of flow rates of the drilling fluids to achieve different downhole states of the bent sub. Others downhole adjustable systems are illustrated in U.S. Pat. Nos. 4,884,643 and 4,374,547, these devices may include ratchets and continuous jay slots and pin arrangements. Other surface and non-surface adjustable bent subs are known.

[0013] Slide drilling occurs when drilling with a mud motor rotating the bit downhole without rotation of the drillstring from the surface. Slide drilling was required when directional drilling was principally accomplished with bent subs or a bent sub mud motor or some combinations of those devices.

[0014] Rotary steerable drilling systems are often classified as either "point-the-bit" or "push-the-bit" systems. In point-the-bit systems, the rotational axis of the drill bit is deviated from the longitudinal axis of the drill string in the direction sought by the drilling program. In push-the-bit drilling programs, the required directionality is achieved by causing a stabilizer located adjacent the drill bit or remotely from the drill bit top apply an eccentric force on the BHA to move the drill bit in the desired path. Generally, the drill bit is moved into engagement with the borehole face by selective eccentric movement at two other stabilizer locations in the BHA. Progressive cavity pumps or motors, also referred to as a profiled cavity pumps or motors, typically include a power section consisting of a rotor with a profiled helical outer surface disposed within a stator with a profiled helical inner surface. The rotor and stator of a progressive cavity apparatus operate according to the Moineau principle, originally disclosed in U.S. Pat. No. 1,892,217.

[0015] In use as a pump, relative rotation is provided between the stator and rotor by any means known in the art, and a portion of the profiled helical outer surface of the rotor engages the profiled helical inner surface of the stator to from a sealed chamber or cavity. As the rotor turns eccentrically within the stator, the cavity progresses axially to move any fluid present in the cavity.

[0016] In use as a motor, a fluid source is provided to the cavities formed between the rotor and stator. The pressure of the fluid causes the cavity to progress and a relative rotation between the stator and rotor. In this manner fluidic energy can be converted into mechanical energy. Herein the motor or mud motor converts hydraulic energy from the flow of drilling fluid or drilling mud to rotation which may be used to rotate the bit. The mud motor may be also referred to as a drilling motor and the progressive cavity known referred to as a power section.

[0017] As progressive cavity pumps or motors rely on a seal between the stator and rotor surfaces, one of or both of these surfaces preferably includes a resilient or dimensionally forgiving material. Typically, the resilient material has been a relatively thin layer of elastomer disposed in the interior surface of the stator. A stator with a thin elastomeric layer is typically referred to as thin wall or even wall design.

[0018] An elastomeric lined stator with a uniform or even thickness elastomeric layer has previously been disclosed in U.S. Pat. No. 3,084,631 on "Helical Gear Pump with Stator Compression". The prior art has evolved around the principle of injecting an elastomer into a relatively narrow void between a stator body with a profiled helical bore and a core, or mandrel, with a profiled helical outer surface. The core is then removed after curing of the elastomer and the remaining assembly forms the elastomeric lined stator. The elastomer layer is essentially the last component formed.

[0019] The stator bodies mentioned above have a preformed profiled helical bore. The profiled helical bore is generally manufactured by methods such as rolling, swaging, or spray forming, as described in U.S. Pat. No. 6,543,132 on "Methods of Making Mud Motors", incorporated by reference herein. Similarly, a profiled helical bore can be formed by metal extrusion, as described in U.S. Pat. No. 6,568,076 on "Internally Profiled Stator Tube", incorporated by reference herein. Further, various hot or cold metal forming techniques, such as pilgering, flow forming, or hydraulic forming, as described in P.C.T. Pub. No. WO 2004/036043 A1 on "Stators of a Moineau-Pump", incorporated by reference herein, can be used to form a stator body with a profiled helical bore.

[0020] A stator body can also be formed by creating a profiled helical bore in relatively thin metal tubing. This formed metal tube can then be used as the stator body by itself, with an injected inner elastomeric layer, or the formed metal tube can be inserted inside into a second body with a longitudinal bore to form the stator body. A stator body with a profiled helical bore can also be formed through other process such as sintering or hot isostatic pressing of powdered materials, for example, a metal, or the profiled helical bore can be machined directly into a body.

[0021] As previously noted, rotary steerable drilling apparatus have been developed and are well known in this art for using the flow of drilling fluid to the drill bit to selectively actuate pads or pistons which urge the drill bit along a desired path at the borehole face. These pads may be activated by either hydraulic forces or electromotive forces to move into engagement with the well bore to thereby move or urge the drill bit in a given direction. The force that may be asserted against the pads is generally limited by both the available pressure difference and the piston diameter. Often, the hydraulic force available to push the pad into engagement with the well bore wall is insufficient to both lift the BHA and affixed drill string from the well bore wall and bend the BHA in the desired direction.

[0022] If slide drilling is performed and bent sub assembly is strategically placed in the BHA above the rotary steerable drilling apparatus, the force to push the BHA in the desired direction can be increased thus improving the dogleg capability of the BHA. If the bent sub assembly is properly oriented with the wellbore by using a conventional Measuring While Drilling ("MWD") tool, then the bent sub assembly well better fit the curved hole, thus the bending stiffness of the drill string can be significantly reduced and with the same force output, the performance of the rotary steerable drilling apparatus can be dramatically increased.

[0023] MWD is and MWD tools provide the evaluation of physical properties, usually including pressure, temperature and wellbore trajectory in three-dimensional space, while extending a wellbore. The measurements are made downhole, may be sorted in solid-state memory for some time and later transmitted to the surface. Data transmission methods vary but known methods involve digitally encoding data and transmitting to the surface as pressure pluses in the mud system. These pressures may be positive, negative or continuous sine waves. Some MWD tools have the ability to store the measurements for later retrieval with wireline or when the tool is tripped out of the hole if the data transmission link fails.

SUMMARY OF INVENTION

[0024] The present invention is a steerable bottom hole assembly for use in a well bore made up, at a minimum, with a bent sub assembly connected to a drill string; a control bias unit connected to the bent sub assembly; and, a drill bit connected to the control bias unit. The bent sub assembly is believed to minimize the energy required by the bias pads to move the BHA from the well bore wall. Furthermore, in another embodiment, the bent sub can be places on a mud motor, which is commonly used to rotate the BHA. After it has first been properly oriented using a conventional or known MWD tool, the inclusion of the bent sub will lower the bending stiffness relative to the control bias unit and the drill string to which is attached. In forms of the invention the control bias unit may comprise separate units or modules, that is, it may take the form of a control unit and a bias unit. In other forms of the invention the control and bias unit may be integral. In the form of the invention herein described the bias unit and control unit are referred to separately, this is intended to be an example only and not limiting.

[0025] As may be readily appreciated by one skilled in the art to which the invention relates, in conventional rotary steerable systems, the control bias unit comprises a control unit for receiving signals from sensors and transmitting a signal to the bias unit and a bias unit for converting such signal into movements of one or more bias pads against an adjacent face of the well bore. In a highly deviated well, the drill string must be moved in unison with the bottom hole assembly upon actuation of the bias pads into the desired path. The force required to move the BHA and the attached drill string is often too great to accomplish either goal efficiently, thereby forcing the drill path into a larger than desired turning radius, exhibiting less dogleg severity.

[0026] The presence of a bent angle in the bent sub assembly causes gradual change in the inclination of the bottom portion of the borehole as the bit drills ahead in slide or sliding drilling, with the result that the borehole is formed along a curved path until a desired new inclination is achieve. The presence of a bent sub assembly also allows torque that is applied to the drill string at the surface to be used to steer the bit, or BHA, or rotary steerable drilling system, to the right or to the left to achieve change in the azimuth of the borehole.

[0027] Using the method of drilling a well bore with the current invention requires attaching a drill bit to a bias unit; attaching the bias unit to a control unit; attaching the control unit to the bent sub assembly; attaching the bent sub assembly to a drill string.

DETAILED DESCRIPTION OF THE DRAWINGS

[0028] For a detailed understanding of the present invention, reference should be made to the following detailed description of a preferred embodiment, taken in conjunction with the accompanying drawings, in which like elements have been given like numerals.

[0029] FIG. **1** is a schematic drawing of the prior art steerable bottom hole assembly.

[0030] FIG. **2** is a schematic drawing of the steerable bottom hole assembly with a bent sub mud motor placed between the drill string and the bottom hole assembly.

DETAILED DESCRIPTION OF THE INVENTION

[0031] FIG. **1** shows a typical steerable BHA consisting of a drill bit **100** connected to a bias unit **120**. Bias until **120** operates during rotational drilling by moving actuator pads or pistons **170** into engagement with a bore hole wall **155** at a point or fulcrum **160** to move the drill bit **100** and bias unit **120** in a preferred direction as determined by the sensors located in control unit **130**. The method of controlling a deviated well by activating a rotary steerable bias unit is more fully described in U.S. patent application 10/248,053, filed Dec. 13, 2002, and the patents cited therein, all of which are incorporated herein by reference.

[0032] As may be readily appreciated, when the unit is in the position shown in FIG. **1**, the bias unit **120** can be required to lift the entire weight of the drill string and BHA off of the well bore wall. This can be a problem in unconsolidated and/or soft formations. Additionally, the bias unit **120** can be required to overcoming the flexural rigidity of the drill string **150** and BHA to accomplish the change in direction sought. The dogleg severity or build angle is limited by the relative stiffness of the drill string and BHA subassembly.

[0033] In contrast, FIG. **2** shows the arrangement of the bias unit to the bent sub mud motor that has been properly oriented by a conventional MWD tool so that it is drilling ahead in a desired direction to allow the bottom hole assembly to sit freely in a curved hole section without the need to move the remaining portion of the drill string adjacent the BHA. The force necessary to direct the bit in the desired direction is substantially less than the force necessary to direct the bit in the conventional arrangement shown in FIG. **1**. A drill bit **200**, in FIG. **2**, is connected to a bias unit **220** in the conventional manner well known to those skilled in this art. Bias unit **220** is actuated by a signal received from a control unit **230** adjacent the bias unit. Control unit **230**, in the present embodiment, is connected to a bent sub mud motor which is driven by the mud motor. During slide or sliding drilling, the BHA below the bent sub mad motor turns at the same speed as the mud motor drive shaft. By properly orienting the bent sub with a conventional or known MWD tool, bias unit **220** need only move drill bit **200** and control unit **230** off the well bore wall **255** by selectively extending pads, such as pad **270**, with sufficient force reflected at location **290** into the correct position to drill in that desired path. The bent sub assembly can have a conduit for fluid communication with the drillstring and bit, while keeping separate the flow of fluid outside the drillstring. The bent sub assembly can be constructed to withstand the forces of drilling.

[0034] Bent sub assemblies have many variances. Some examples of bent sub assemblies are more fully described in U.S. patent application Nos. 3,586,116, 4,077,657, 4,220, 214, 4,745,982, 4,813,497, 4,817,740, 4,884,643, 4,932,482, and 5,050,692. Other variance of the bent sub assembly have been developed, such as a downhole adjustable bent sub assemblies. Some examples of downhole adjustable bent sub assemblies are more fully described in U.S. patent application No. 6,394,193, and 5,117,927, the full content of which are hereby incorporated by way of reference. In the co-owned U.S. Pat. No. 5,117,927 the bent sub apparatus comprising an upper inner member and a lower outer member, with a lower section of said upper member being telescopically disposed with respect to an upper section of said lower member. The lower section of said upper member has an axis that is inclined at a small angle with respect to the axis of the upper portion thereof, and such lower section extends down into the upper section of the lower member which has a bore axis that is inclined at the same angle as said lower section. When said lower and upper sections are rotated relative to one another, such angles are additive so that at a first relative position the angles cancel one another and the assembly is essentially straight. At a second relative position that is at 180° to the first relative position the bend angle is twice such angle. When the members are rotated back to the original or 0° reference position, the bend angle disappears by cancellation. Relative rotation is achieved downhole by stopping the pumps to release a hydraulic lock, and them lowering the pipe string to release a clutch. Then the pipe string is rotated slowly to the right to cause the upper member to rotate relative to the lower member until a stop engages, tat which point preferably about 180° of relative rotation will have occurred to establish a bend angle, for example, of 1°. Other angles can be established, depending upon the geometry of the tool. Then the upper member is raised, and the mud pumps restarted to operate the downhole motor and reengage the hydraulic lock. The bit now tends to drill at a different inclination, and will gradually drill along a curved path so long as the bend angle is present. To remove the bend angle so that further drilling will be straight-ahead, the same procedure is employed to rotate the upper member on around to its initial, or zero, position where the lower section of the lower member is realigned with the longitudinal axis of the drilling motor. Other bent sub assemblies and adjustable bent sub assemblies my be suitable for use in the present invention.

[0035] By providing the bent sub assembly **280** at this location in the BHA, the dogleg severity can be greatly increased, thereby allowing substantially greater build angle to be achieved during slide drilling. The bias unit can assert less force on a formation, so the formation will receive less damage from the bias unit.

[0036] The use of the bent sub assembly **280** combines the benefits of the steerable directional drilling systems with slide drilling thereby permitting better dogleg severities than previously experienced with slide drilling or steerable directional drilling systems. Hole spiraling, a feature of drilling completions encountered in bore holes using mud motors and slide drilling, is reduced or minimized by the steerable directional drilling system, thereby permitting larger casing to be set deeper in the hole. As shown in FIG. **2** the bent sub assembly may be provided with a mud motor having a drive shaft **300** and a bearing **310**.

[0037] When the present invention is used in rotary drilling, either the bent sub assembly must be rotated, or if a downhole adjustable bent sub assembly is used, then it may be straightened before rotary drilling is performed.

[0038] Although only a few exemplary embodiments of this invention have been described in detail above, those skilled in the art can readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the following claims. While the above disclosure includes the best mode belief in carrying out the invention as contemplated by the named inventors, not all possible alternatives have been disclosed. For that reason, the scope and limitation of the present invention is not to be restricted to the above disclosure, but is instead to be defined and constructed by the appended claims.

[0039] In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. It is the express intention of the applicants not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words "means for" together with an associated function.

What is claimed is:

1. A steerable bottom hole assembly for use in a well bore comprising:

a bent sub assembly connectable to a distal end of a drill string;

a control bias unit connected to the bent sub assembly; and,

a drill bit connected to the control bias unit.

2. The steerable bottom hole assembly of claim **1** wherein the bent sub assembly provides a low bending stiffness relative to the control bias unit.

3. The steerable bottom hole assembly of claim **1** wherein the bent sub assembly has an adjustable angle.

4. The steerable bottom hole assembly of claim **1** wherein the control bias unit comprises a control unit providing a signal output to steer the bit along a given path in the well and a bias unit for converting such signal into movements of one or more bias pads against an adjacent face of the well bore.

5. A rotary steerable bottom hole assembly comprising:

a drill bit;

means for biasing the drill bit in a particular direction in response to signals received from a control unit; and, means for coupling to a drill string allowing rotation in three planes.

6. A method of drilling a well bore comprising the steps of:

attaching a bent sub assembly to a drill string;

attaching a control bias unit to the bent sub assembly;

attaching a drill bit to the control bias unit; and,

rotating the drill bit while actuating the control bias unit to move the drill bit in a desired direction.

7. The method of claim **5** wherein the drill member is a drill string.

7. The method of claim **5** wherein the bent sub assembly is mounted above the top of a downhole motor.

8. The method of claim **7** wherein the bent sub assembly is part of the assembly between the mud motor and its bearing section.

9. The method of claim **5** wherein the bent sub assembly may be adjusted while down hole.

* * * * *