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(54) **STEERABLE DRILLING TOOL**

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(57) **ABSTRACT**

A downhole steering tool will steer the angle of the drill bit for drilling directional wells. The steering tool includes a steering housing which is mounted on the drill string above the drill bit. The steering housing can be held against rotation while the drill string rotates to cause the bit to drill in a desired direction. Guide members are mounted on the steering housing. The guide members may engage the borehole. The guide members can be turned about an axis which is perpendicular to the longitudinal axis of the steering housing. Turning the guide members causes the steering housing to rotate relative to the borehole in one direction or the other as the housing slides downward in the borehole. Reorienting the steering housing allows steering of the drill bit.

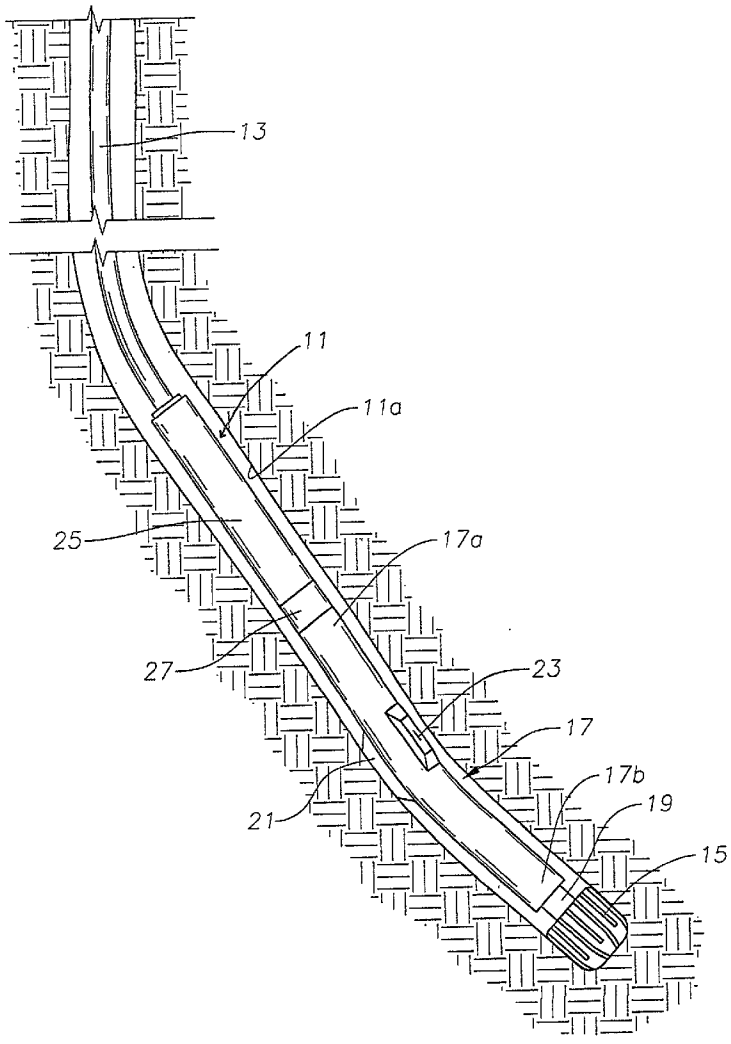
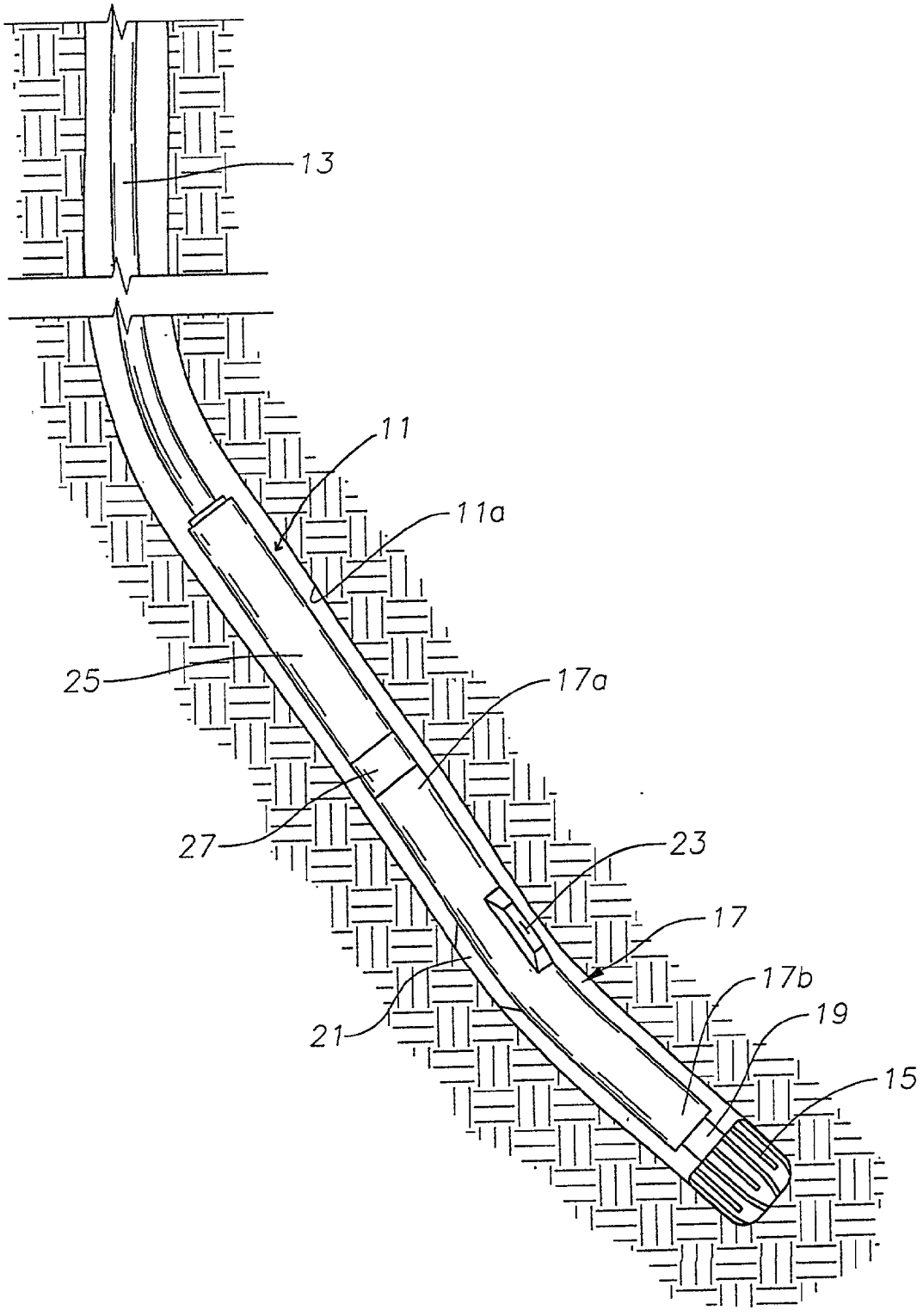


Fig. 1



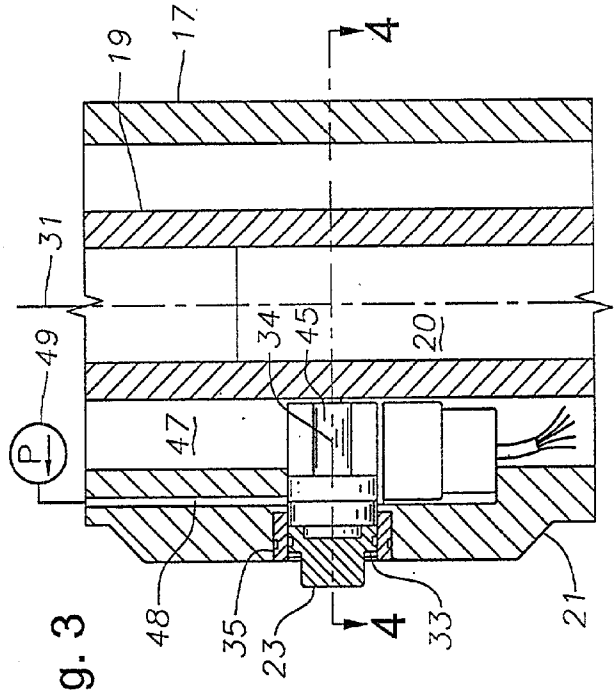



Fig. 3

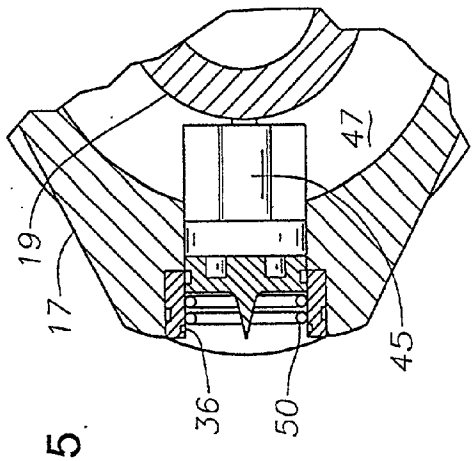



Fig. 5

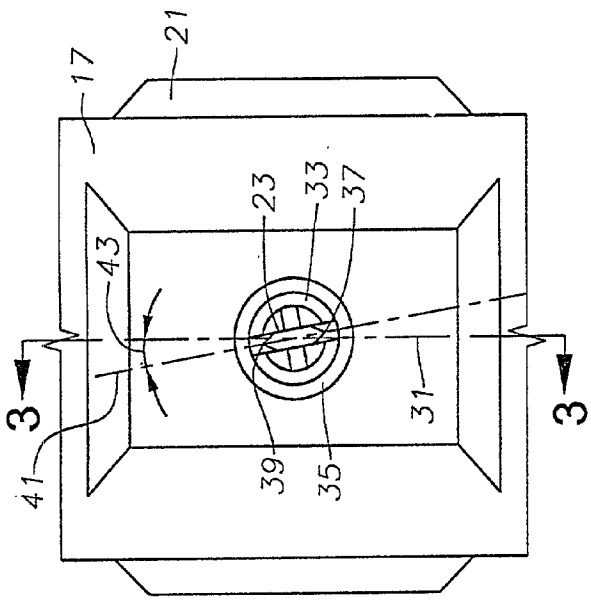



Fig. 2

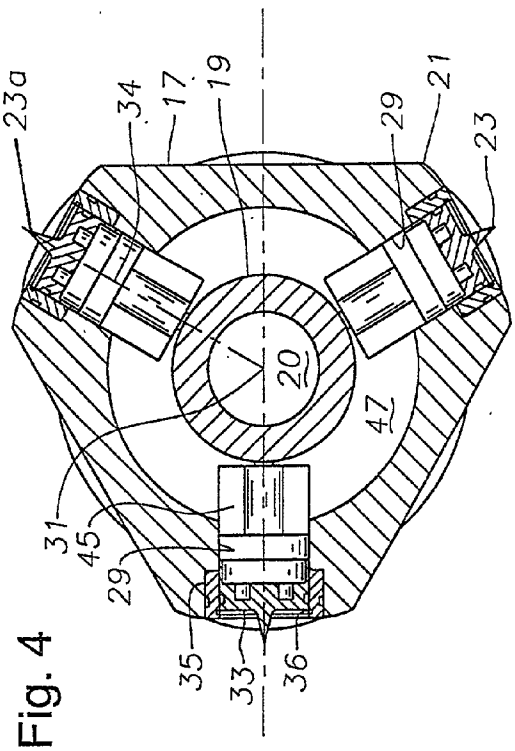



Fig. 4

Fig. 6

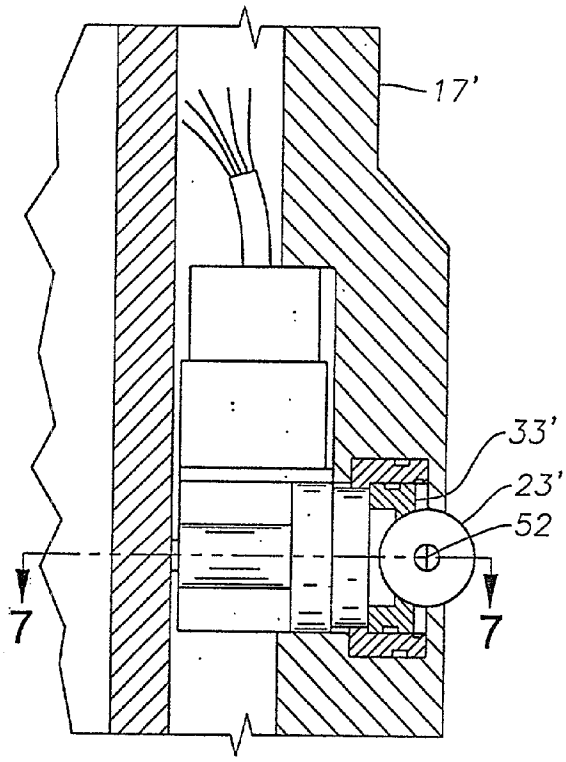



Fig. 7

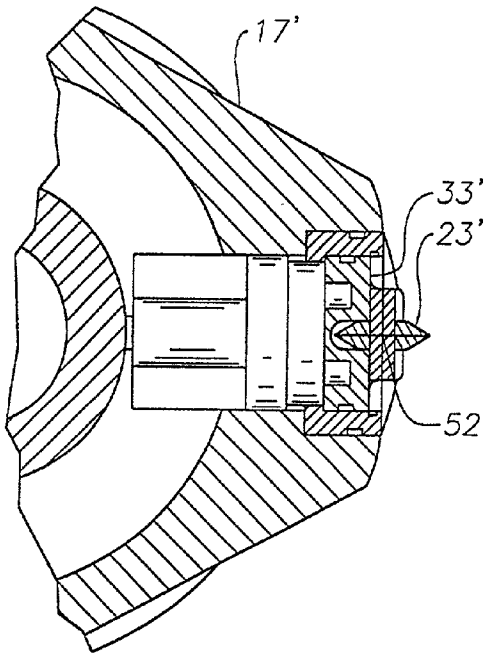



Fig. 8

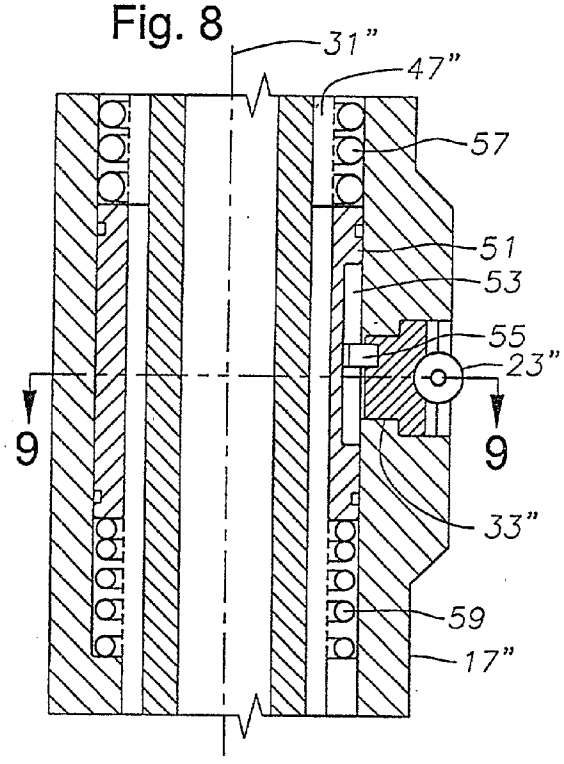



Fig. 9

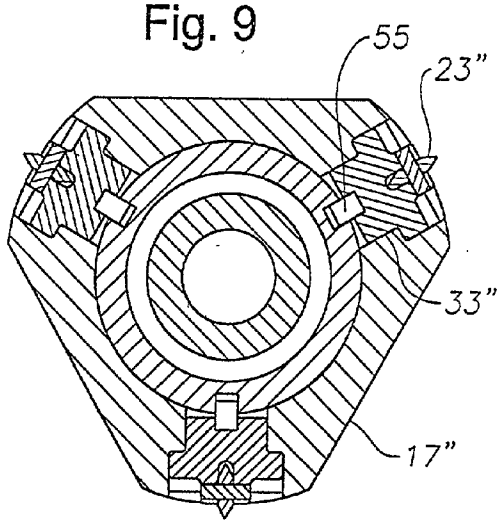


Fig. 10

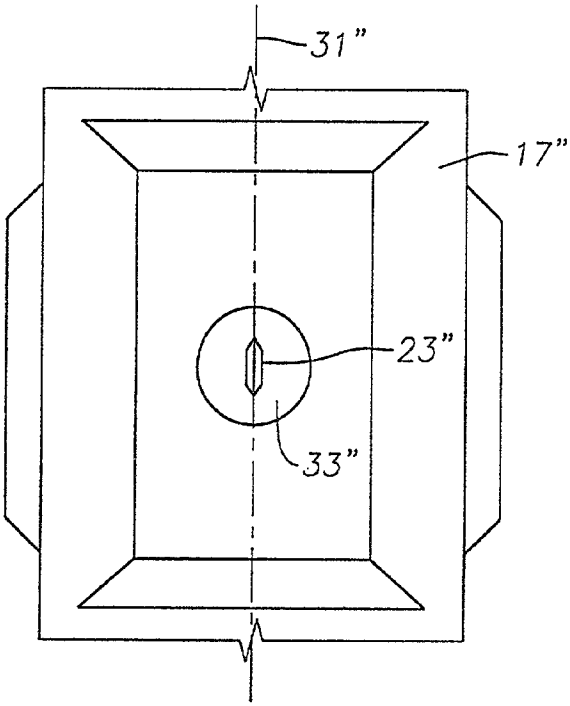



Fig. 11

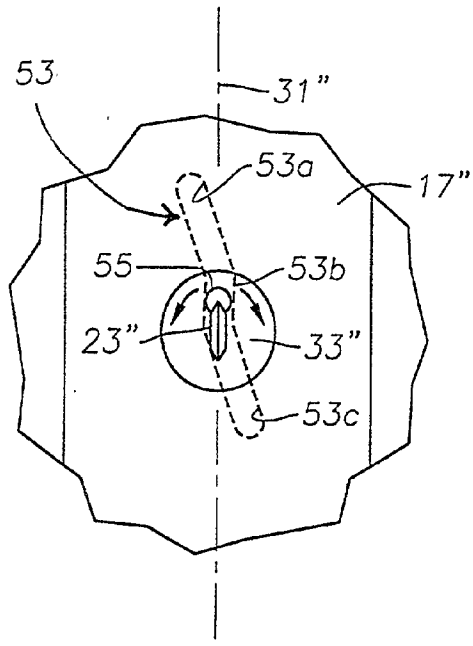



Fig. 12

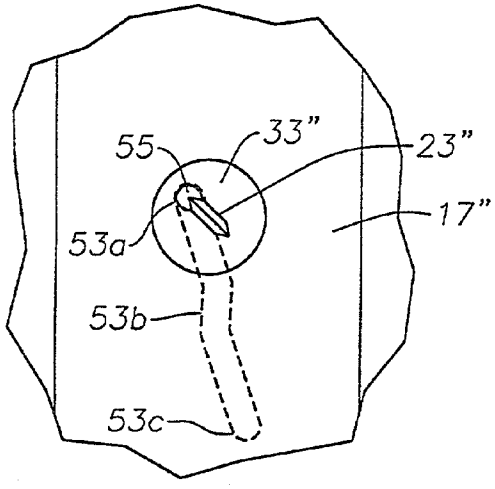
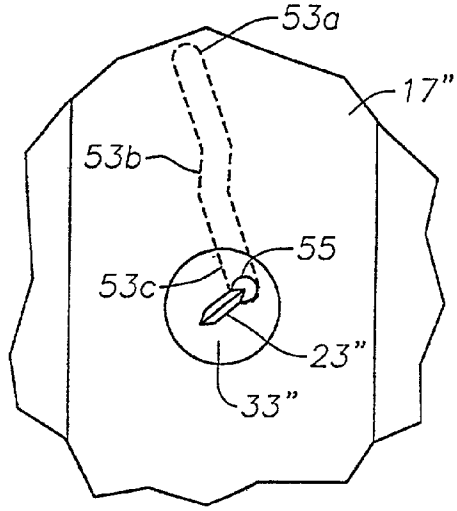



Fig. 13



# STEERABLE DRILLING TOOL

[0001] This application is based upon and claims the priority of U.S. provisional application No. 60/211817 filed Jun. 15, 2000.

## BACKGROUND OF INVENTION

[0002] This invention relates in general to downhole steerable drilling tools for drilling directional wells.

[0003] Directional wells have curved or inclined portions. A variety of types of tools have been used in the past for drilling wells at a desired inclination and in the desired direction. One type, used particularly for highly deviated wells, utilizes a downhole drill or mud motor. While drilling a curved portion of the well, the downhole drill motor rotates the drill bit in response to the mud flow pressure being delivered from the surface. The drill string is not rotated, but slides downward while the drill bit extends the well in the desired direction and at the desired angle.

[0004] In one technique, the mud operated drill motor steers the drill string with the assistance of a bent housing. The lower portion of the housing is "bent" at an angle of a few degrees relative to the upper portion of the housing, typically about 0.4 to 2.5 degrees. Sensors above the housing sense the orientation of the housing and provide a signal to instruments at the surface. Typically, the orientation is sensed and signals sent by a measuring while drilling tool (MWD), which provides mud pulses or uses some other type of telemetry. When the operator wishes to change the direction, the operator stops rotating the drill pipe and orients the drill pipe so that the lower part of the bent housing and bit are pointed in the desired direction. The operator then operates the drill motor by pumping drilling fluid down the drill pipe while holding the bent housing and drill pipe stationary. Once a sufficient curve has been built, the operator then begins drilling straight by rotating the drill pipe. The bent housing, which always rotates with the drill pipe, causes the bit to orbit slightly. However, because the origin of the orbital path is coincident or almost coincident with the center of the hole, straight drilling can be performed. While this technique is satisfactory, there are disadvantages associated with using this technique. For example, the operator is unable to rotate the upper section of the drill string while building an angle. This reduces the efficiency of hole cleaning. Also, the mud operated drill motor is inefficient in energy consumption.

[0005] In another type of directional drilling tool, a straight housing is used. The axis of rotation of the drill bit can be changed relative to the housing because of articulated joints located within the housing. This type of tool also operates with a downhole drill motor. In still another type, a downhole drill motor is not utilized. Rather, eccentric cam sleeves and weights are employed in the housing. The eccentric cam sleeves can be selectively rotated to change the angle of the axis of rotation of the drill bit relative to the housing. The housing is held against rotation by stabilizer blades, in type wheels, while the drill string and drill bit rotate. This type of tool has its advantages, however it is expensive and complex. Also, it is difficult to completely restrain the housing from rotation while the drill pipe and drill bit are rotating.

## SUMMARY OF INVENTION

[0006] In this invention, the drill pipe and drill bit can rotate relative to the steering housing. A downhole drill motor is typically not utilized, but may be used above the assembly. Preferably, the steering housing is of a bent housing type, with a lower portion at a slight angle relative to the upper portion. Alternately, the steering housing could be straight, with articulated connecting joints within it to vary the axis of rotation of the drill bit relative to the housing.

[0007] The steering housing has at least one guide member mounted to it. The guide member protrudes laterally from the steering housing for engaging the borehole wall while the drill pipe and drill bit are rotating relative to the steering housing. The guide member is mounted for selective turning movement about a steering axis. The steering axis is transverse to the length of the steering housing. Turning the guide member causes the steering housing to rotate about its longitudinal axis relative to the borehole as the housing slides downward in the borehole. Changing the orientation of the steering housing relative to the borehole changes the direction of the drill bit. As an analogy, the guide member operates similar to a short section of a screw thread of a self-tapping screw. The change in the angle of the protruding guide member behaves like a variable pitch screw thread.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0008] **FIG. 1** is a schematic view of a drill string and steerable drilling tool constructed in accordance with this invention.

[0009] **FIG. 2** is an enlarged side elevational view of an upper portion of the steering housing of the steerable drilling tool of **FIG. 1**.

[0010] **FIG. 3** is a sectional view of an upper portion of the housing of **FIG. 2**, taken along the line **3-3** of **FIG. 2**.

[0011] **FIG. 4** is a sectional view of the steering housing of **FIG. 2**, taken along the line **4-4** of **FIG. 3**.

[0012] **FIG. 5** is a partial sectional view similar to **FIG. 4**, but enlarged and showing one of the guide members in a retracted position.

[0013] **FIG. 6** is a sectional view of an alternate embodiment of a guide member for the steering housing of **FIG. 2**.

[0014] **FIG. 7** is a sectional view of the guide member of **FIG. 6**, taken along the line **7-7** of **FIG. 6**.

[0015] **FIG. 8** is a sectional view of another alternate embodiment of the steering housing for the steering tool of **FIG. 1**.

[0016] **FIG. 9** is a sectional view of the housing of **FIG. 8**, taken along the line **9-9** of **FIG. 8**.

[0017] **FIG. 10** is an elevational view of a portion of the steering housing of **FIG. 8**.

[0018] **FIG. 11** is an enlarged partial view of the guide member for the steering housing of **FIG. 10**, illustrating the cam slot which controls turning of the guide member.

[0019] **FIG. 12** is a view of the guide member similar to **FIG. 11**, but showing the guide member rotated in one direction.

[0020] **FIG. 13** is a view of the guide member similar to **FIG. 12**, but showing the guide member rotated in an opposite direction.

## DETAILED DESCRIPTION OF THE INVENTION

[0021] Referring to **FIG. 1, a** deviated borehole **11** is shown schematically. A string **13** of drill pipe extends into borehole **11**, terminating in a drill bit **15** at the lower end. A steering housing **17** is located a short distance above drill bit **15**. Steering housing **17** in this embodiment is of a type referred to as a "bent housing", suggesting it has an upper portion **17***a* and a lower portion **17***b* which are inclined a few degrees relative to each other. The angle of inclination in the drawing is exaggerated. A mandrel **19** extends rotatably through steering housing **17**, being supported within steering housing **17** by bearings (not shown). Mandrel **19** may be considered a part of drill string **13** because it always rotates with drill string **13**. Mandrel **19** has a passage **20 (FIG. 3)** within it for the passage of drilling fluid being pumped down drill string **13** to bit **15**. The axis of rotation of bit **15** will be at a slight angle relative to the upper portion **17***a* because of the bend in steering housing **17**. Consequently, by first orienting steering housing **17** in a particular direction and position in borehole **11**, and then holding it stationary, bit **15** will drill in a desired direction. Alternately, a straight housing with articulated joints between bit **15** and drill string **13** could be used, such as shown and described in U.S. Pat. No. 4,895,214, which is intended to be incorporated herein by reference.

[0022] A plurality of stabilizer blades **21** assist in allowing drill string **13**, mandrel **19** and drill bit **15** to rotate relative to steering housing **17**. Stabilizer blades **21** are longitudinally extending blades on upper portion **17***a* or lower portion **17***b*, or both, for engaging the sidewall **11***a* defining borehole **11**. In the preferred embodiment, each stabilizer blade **21** has a guide member **23** mounted to it, although a single guide member **23** could suffice. As shown more clearly in FIGS. **2-4**, each guide member **23** has a protuberance **23***a* which may be a sharp thin disk or blade for engaging the sidewall **11***a* of borehole **11**. Guide members **23** are "angulatable" which, for purposes of this application, means the guide member(s) **23** can be rotated, moved or turned relative to the longitudinal axis of steering housing **17** to cause housing **17** to rotate slightly or for orientation in a desired direction. The turning movement of guide members **23**, coupled with the downhole sliding movement of steering housing **17**, is similar in effect to varying the pitch of a short section of a screw thread of a self-tapping screw.

[0023] Referring still to **FIG. 1**, the downhole assembly also includes a measuring while drilling (MWD) tool **25**, which may be of conventional design. MWD tool **25** will sense various characteristics of the well, including the direction or bearing, referred to as the tool face, of drill bit **15** and the inclination of the borehole **11**. MWD tool **25** provides signals to surface equipment by mud pulse telemetry (or alternate methods of telemetry) through the drilling mud flowing back through the annulus surrounding drill string **13**. Also, the system preferably has bi-directional communication abilities between surface equipment and MWD tool **25**, allowing commands to be sent by the operator at the surface to MWD tool **25**. One method of communicating with MWD tool **25** is by manipulating mud pump pressure as explained in U.S. Pat. No. 5,979,570. For example, shutting off the mud pump (not shown) for a period of time may be sensed by the MWD tool **25**, which interprets this event as an indication to move from straight drilling to curved drilling.

[0024] A clutch **27** is preferably mounted between steering housing **17** and MWD tool **25**, which rotates with drill string **13**. MWD tool **25** preferably always rotates with drill string **13**, however, housing **17** may be disengaged from rotation with drill string **13**. Clutch **27** may be of a generally conventional design which operates to selectively cause steering housing **17** to rotate with drill string **13** and, alternately, to allow drill string **13** and drill bit **15** to rotate relative to steering housing **17**. For example, clutch **27** may include an actuator which is powered by a battery or generator in MWD tool **25**. A signal may be provided from the surface to MWD tool **25**, which sends an electrical signal to an actuator to cause clutch **27** to move between engaged and disengaged positions. Alternately, clutch **27** may be shifted between its positions by manipulating mud pump pressure, generally as shown in U.S. Pat. No. 4,895,214, which material is hereby incorporated by reference.

[0025] Referring now to FIGS. **2-4**, in this embodiment each guide member **23** is located in a hole **29** extending through the sidewall of steering housing **17** and one of the stabilizer blades **21**. Guide member **23** in this embodiment is a flat, thin blade **23***a* with a sharpened outer edge for engaging the sidewall of borehole **11**. Guide member **23** is secured to and protrudes outward from a rotary member **33**. Rotary member **33** is a cylindrical disk which is rotatable relative to steering housing **17** about a steering axis **34**. Steering axis **34** is perpendicular to longitudinal axis **31** and intersects it in the preferred embodiment, as shown in **FIG. 4**. Rotary member **33** may be located within a retainer sleeve **35**, which in turn is sealingly secured within housing sidewall hole **29**. Rotary member **33** has seals on its sidewall which slidingly engage the inner diameter of retainer sleeve **35**. A snap ring type retainer **36** fits within the inner diameter of retainer sleeve **35** to retain rotary member **33** within retainer sleeve **35**.

[0026] Referring to **FIG. 2**, guide member **23** has a leading edge **37** and a trailing edge **39**, considering the forward or downward movement of steering housing **17** during drilling. Leading edge **37** refers to the lower or forward edge, which is the edge of guide member **23** closest to drill bit **15**. An imaginary line extending between leading edge **37** and trailing edge **39** may be referred to as a track **41**. In the position shown in **FIG. 2**, track **41** is at a track angle **43** of about ten degrees negative relative to longitudinal axis **31**. If steering housing **17** is moving downward while guide member **23** is in the position shown in **FIG. 2**, its engagement with the sidewall **11***a* of borehole **11** will tend to cause steering housing **17** to rotate counterclockwise, as viewed from above. On the other hand, if rotary member **33** is rotated clockwise about steering axis **34** to a position wherein track angle **43** is positive, or located on the opposite side of longitudinal axis **31**, guide member **23** would tend to cause steering housing **17** to rotate clockwise in the borehole **11** as seen from above. Presently, a track angle **43** within the range of from negative fifteen degrees to positive fifteen degrees is a preferred working range for the track angle **43**.

[0027] Various actuators may be employed to cause each of the guide members **23** to turn about its steering axis **34**. Preferably, each of the guide members **23** are synchronized to turn in unison. One type of actuator comprises a plurality of stepper motors **45**, shown in **FIG. 4**. A separate stepper motor **45** is coupled to each rotary member **33** by a right angle drive. Stepper motors **45** are located inside steering housing **17**, preferably in an annulus **47** located between mandrel **19** and the sidewall of steering housing **17**. Stepper motors **45** may be electrically powered by a battery or

generator (not shown) located within MWD tool **25** (**FIG. 1**). Annulus **47** is filled with a dielectric fluid, such as oil. A pressure compensator (not shown) will equalize the pressure of the dielectric fluid with that of the drilling fluid pressure in the drill string **13** or alternately in the annulus of borehole **11**.

[**0028**] Also, preferably, each guide member **23** is retractable along its steering axis **34** from a retracted position shown in **FIG. 5** to an extended position, shown in **FIGS. 3 and 4**. In the retracted position, the outer edge of guide member **23** will be recessed within hole **29**. Retraction and extension may be accomplished in a variety of manners. Preferably it is handled by a telescoping device which is biased to a retracted position. For example, this may include a hydraulic passage **48** leading to a hydraulic pump **49** incorporated within steering housing **17** and driven by an electrical motor supplied with power from MWD tool **25** (**FIG. 1**). Hydraulic pump **49** (**FIG. 3**) supplies pressure to a chamber on the interior side of rotary member **33**, causing it to move to the extended position. A spring **50** (**FIG. 5**) urges guide member **23** to the retracted position when hydraulic pressure from hydraulic pump **49** is removed.

[**0029**] In the operation of the embodiment of FIGS. **1-5**, the upper end of mandrel **19** will be connected to MWD tool **25** and the lower end to drill bit **15**. Clutch **27** will be located on the upper end **17***a* of steering housing **17**. MWD tool **25** will be secured to a string **13** of drill pipe. The entire assembly is lowered into the well. The default position for clutch **27** will be in an engaged position, locking steering housing **17** to drill string **13** for rotation therewith, and the default position for guide members **23** will be a retracted position. While in the default position, which is for drilling in a straight line, MWD tool **25** and housing **17** rotate in unison with drill string **13** and mandrel **19**. Although bit **15** will orbit slightly relative to upper housing portion **17***a*, it will drill straight portions of borehole **11**.

[**0030**] When it is desired to begin a curve to establish a new direction, the operator provides a signal to actuate clutch **27** to the released position and to move guide members **23** to the extended position shown in **FIGS. 3 and 4**. Guide members **23** will engage the side of borehole **11**. The default orientation for guide members **23** may be in a neutral position, generally shown in **FIG. 10**, although a small track angle **43** (**FIG. 2**) may exist in the default position to accommodate for normal bit walk due to rotation of drill bit **15**. MWD tool **25** will sense the angle of the tool face of steering housing **17** and signal stepper motors **45** to turn guide members **23** to a desired track angle **43**, such as illustrated in **FIG. 2**, which is either preprogrammed in MWD tool **25** or signaled from the surface. Drill string **13** continues to rotate, which rotates MWD tool **25** and drill bit **15** through mandrel **19**. Housing **17** will not rotate in unison with drill pipe **13** because of stabilizer blades **21** and guide members **23**, however steering housing **17** will rotate slowly or turn about its longitudinal axis **31** due to seal and bearing friction between mandrel **19** and steering housing **17** and the track angle **43** (**FIG. 2**) set by guide members **23**. As drill bit **15** drills forward, steering housing **17** slides forwardly or downwardly. The track angle **43** selected by guide members **23** will force steering housing **17** to rotate to a different orientation relative to borehole **11**. Signals from MWD tool **25** will control stepper motor **45** to turn guide members **23** to various tracks **41**. Guide members **23** will thus be able to rotate steering housing **17** clockwise or counterclockwise as desired to maintain a desired heading or bearing of drill bit **15** which is either preprogrammed or signaled from the surface. When a sufficient amount of the curve has been built, the operator again provides a signal to cause clutch **27** to actuate, placing steering housing **17** in an engaged mode with drill pipe **13** and retracting guide members **23**. Signaling clutch **27** to engage and disengage could be automatic.

[**0031**] **FIGS. 6 and 7** illustrate an alternate embodiment with similar components to those in the first embodiment being shown with a prime symbol. The only difference between the embodiment shown in **FIG. 6** and the first embodiment is that rather than a stationary flat, thin blade for guide member **23**, the embodiment of **FIG. 6** has a circular guide member **23'** rotatably mounted to axle **52**. Axle **52** is rigidly mounted to rotary member **33'** perpendicular to steering axis **34** (**FIGS. 3 & 4**). Guide member **23'** is thus a sharp circular disk which rolls as it engages the sidewall of borehole **11**.

[**0032**] In the embodiment of **FIGS. 8 and 9**, guide member **23"** could be either a circular rolling disk/blade as in **FIGS. 6 and 7** or a non-rotating blade as in FIGS. **1-5**. The embodiment of FIGS. **8-12**, however, utilizes a different mechanism for turning guide members **23** about the steerable axis. In this embodiment, similar components are shown with a double prime symbol. A cam sleeve **51** is mounted within annulus **47"** for axial movement along longitudinal axis **31"**. Cam sleeve **51** has a cam slot **53** formed in its outer sidewall. A pin **55** is eccentrically mounted in rotary member **33"**. Pin **55** engages slot **53**, and slot **53** is curved to cause rotation of rotary member **33"** when cam sleeve **51** moves axially. An actuator (not shown), which may be of a variety of types, will engage cam sleeve **51** to cause it to move axially. The actuator may be a linear motor supplied by power from MWD tool **25**. Alternately, the actuator might be a hydraulically driven piston supplied with hydraulic pressure from a hydraulic pump located within housing **17"**. Preferably coil springs **57** and **59** urge cam sleeve **51** to a neutral position.

[**0033**] The neutral position is illustrated in **FIG. 10-11**. In this position, guide member **23"** is substantially aligned on longitudinal axis **31"**, however, it may be at a slight angle to resist normal bit walk. In the neutral position, guide member **23"** will thus resist any rotation of housing **17"** relative to the borehole. As shown in **FIG. 11**, cam slot **53** has an upper portion **53***a* which is inclined relative to axis **31"** and a central portion **53***b* which is parallel with axis **31"**. A lower portion **53***c* joins central portion **53***b* and is inclined relative to axis **31"** at the same angle as upper portion **53***a*. When cam sleeve **51** has moved downward to the position shown in **FIG. 12**, pin **55** rotates rotary member **33"** counterclockwise to orient steering housing **17"** for clockwise movement when viewed from above. When the actuator moves cam sleeve **51** upward to the position shown in **FIG. 13**, it will cause pin **55** to rotate rotary member **33"** clockwise. This results in steering housing **17"** rotating counterclockwise when viewed from above.

[**0034**] The invention has significant advantages. It allows substantially real time steering by monitoring the angle of the tool face and orienting the steering housing relative to the borehole by use of the guide members. It is less complex than an eccentric cam tool. It does not require the use of a downhole drill motor. Drilling continues with the drill string rotating at all times.

[**0035**] While it has been shown in only a few of its forms, it should be apparent to those skilled in the art that it is not so limited, but susceptible to various changes without departing from the scope of the invention.

What is claimed is:

1. A steering apparatus for use in directional drilling a borehole with a drill string and a drill bit, comprising:

a steering housing mounted on the drill string above the drill bit;

a clutch connected between the drill string and the steering housing; and

at least one angulatable guide member mounted to the steering housing, and having a protuberance from the steering housing.

2. The apparatus according to claim 1, wherein said protuberance comprises a blade for engaging a sidewall of the borehole.

3. The apparatus according to claim 1, wherein said at least one angulatable guide member includes a rotary member defining a steering axis which is approximately perpendicular to a longitudinal axis of the steering housing.

4. The apparatus according to claim 3, wherein said protuberance comprises a blade for engaging a sidewall of the borehole.

5. The apparatus according to claim 1, further comprising a motor mounted in the steering housing and coupled to said at least one angulatable guide member.

6. The apparatus according to claim 1, wherein said at least one angulatable guide member comprises an extensible and retractable, angulatable guide member.

7. The apparatus according to claim 1, further comprising at least one stabilizer blade connected to the steering housing having an outer diameter which is greater than an outer diameter of the steering housing and less than an outer diameter of said protuberance.

8. The apparatus according to claim 1, further comprising:

an annular cam member mounted in the steering housing, said annular cam member having a cam slot; and

a pin extending eccentrically from said at least one angulatable guide member into engagement with the cam slot.

9. The apparatus according to claim 1, wherein said at least one angulatable guide member comprises a plurality of angulatable guide members evenly spaced around a circumference of the steering housing.

10. The apparatus according to claim 1, wherein the steering housing has an upper portion and a lower portion, and the lower portion has a longitudinal axis which is at angle relative to a longitudinal axis of the upper portion.

11. A steering apparatus for use in directional drilling a borehole with a drill string and a drill bit, comprising:

a steering housing mounted on the drill string above the drill bit;

a means for allowing rotation of the drill string relative to the steering housing connected between the drill string and the steering housing; and

a means for engaging a sidewall of the borehole mounted in the steering housing including a means for independently turning said means for engaging the sidewall of the borehole.

12. The apparatus according to claim 11, wherein said means for engaging a sidewall of the borehole comprises a plurality of blades.

13. The apparatus according to claim 11, wherein said means for independently turning comprises an angulatable guide member.

14. The apparatus according to claim 13, wherein said means for engaging a sidewall of the borehole comprises a plurality of blades.

15. The apparatus according to claim 11, wherein said means for independently turning comprises a plurality of motors mounted in the steering housing and operationally coupled to said means for engaging a sidewall of the borehole.

16. The apparatus according to claim 11, wherein said means for engaging the sidewall of the borehole comprises a plurality of extensible and retractable blades.

17. The apparatus according to claim 11, wherein said means for allowing rotation of the drill string relative to the steering housing comprises a clutch.

18. The apparatus according to claim 11, wherein the actuator compnses:

an annular cam member mounted in the steering housing, said annular cam member having a cam slot; and

a pin extending eccentrically from said means for independently turning into engagement with the cam slot.

19. The apparatus according to claim 11, wherein the steering housing has a lower portion and an upper portion, and the lower portion has a longitudinal axis which is inclined relative to a longitudinal axis of the upper portion.

20. The apparatus according to claim 19, wherein said means for engaging a sidewall of the borehole is located on the upper portion of the steering housing.

21. A method of steering a drill bit for directional drilling a well wherein the drill bit forms a borehole with a sidewall, comprising:

(a) penetrating the sidewall of the borehole with a guide member;

(b) rotating the drill string and the drill bit independent from the guide member; and

(c) selectively angulating the guide member to change an orientation relative to the borehole.

22. The method according to claim 21, further comprising:

retracting the guide member away from the sidewall of the borehole.

23. The method according to claim 22, further comprising selectively rotating the drill string and the drill bit together with the guide member.

24. The method according to claim 21, wherein said step of angulating the guide member in one direction causes the drill bit to rotate relative to the borehole in a counterclockwise direction, and angulating the guide member sufficiently in an opposite direction causes the drill bit to rotate relative to the borehole in a clockwise direction.

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