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RU 002109908 C1
US 5941323 A
US 4694914 A
US 20030034178 A1
US 6244361 B1
US 5467834 A
US 4319649 A

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INT CL[7] **E21B**
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(54) Abstract Title: **A steering apparatus for a steerable drilling tool**

(57) An apparatus is described for steering the drill bit of a borehole drilling tool. The apparatus comprises an outer sleeve 30 having an eccentrically located bore 34 which houses a rotatable cam 36. The cam also has an eccentrically located bore 42 housing a mandrel connected to a drill shaft. The eccentricity of the bores in the cam and the outer sleeve are the same, such that by rotation of the cam within the sleeve, the axis of rotation for the mandrel can be moved from the central axis 100 of the borehole being drilled to a position displaced from it 102. In the displaced position, rotation of the mandrel and the drill shaft cause the borehole to curve. Rotation of the cam with respect to the sleeve is arranged by providing a stop 52 in the mandrel which picks up ratchets 46 or 48 of the cam depending on the direction of rotation. Stop 40 and stop 52 limit the rotation of the cam so that straight ahead drilling and deviated drilling can be performed.

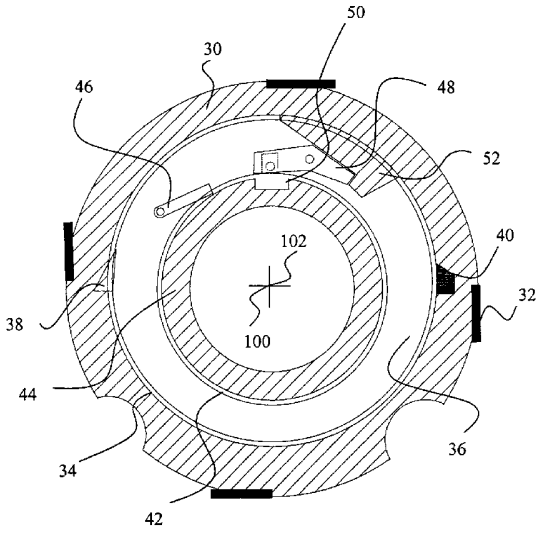

Figure 4

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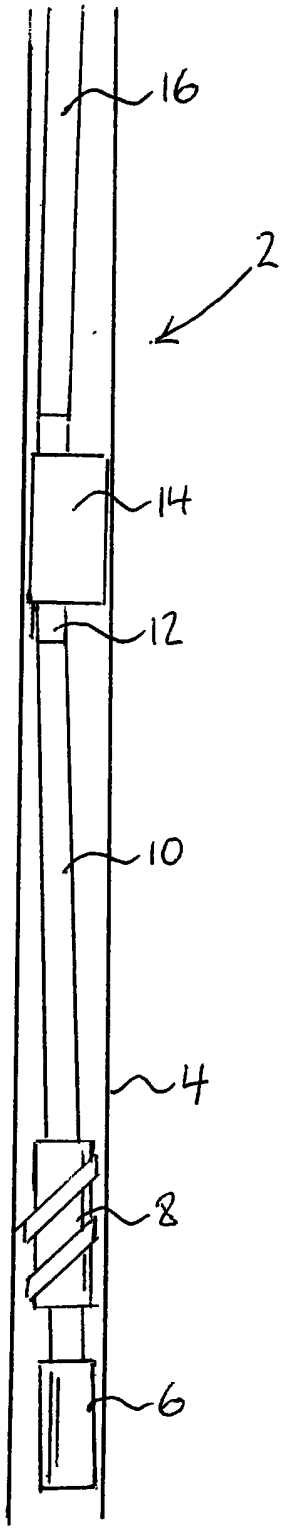


Figure 1

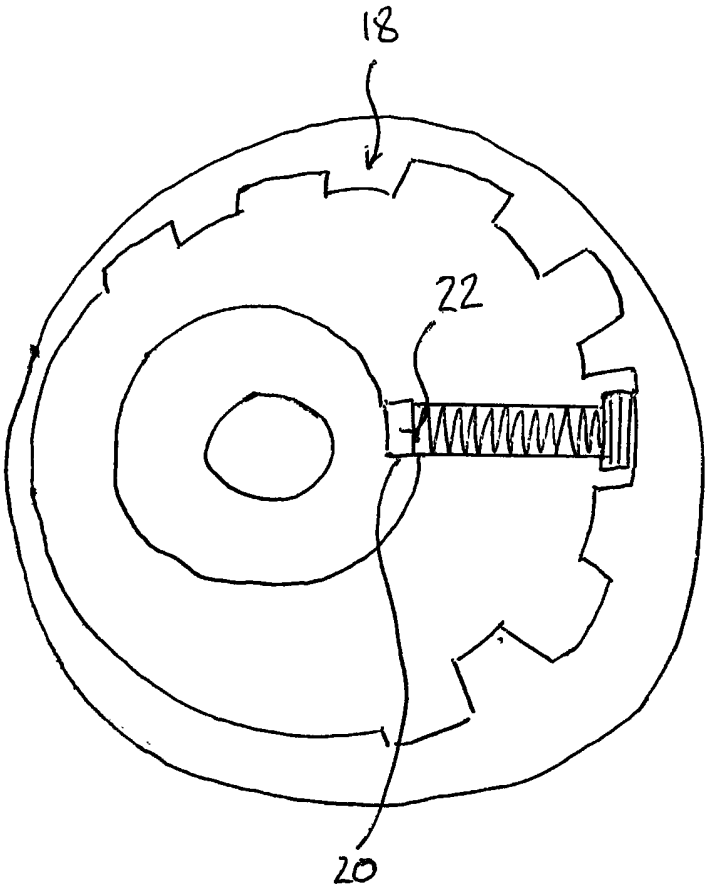


Figure 2

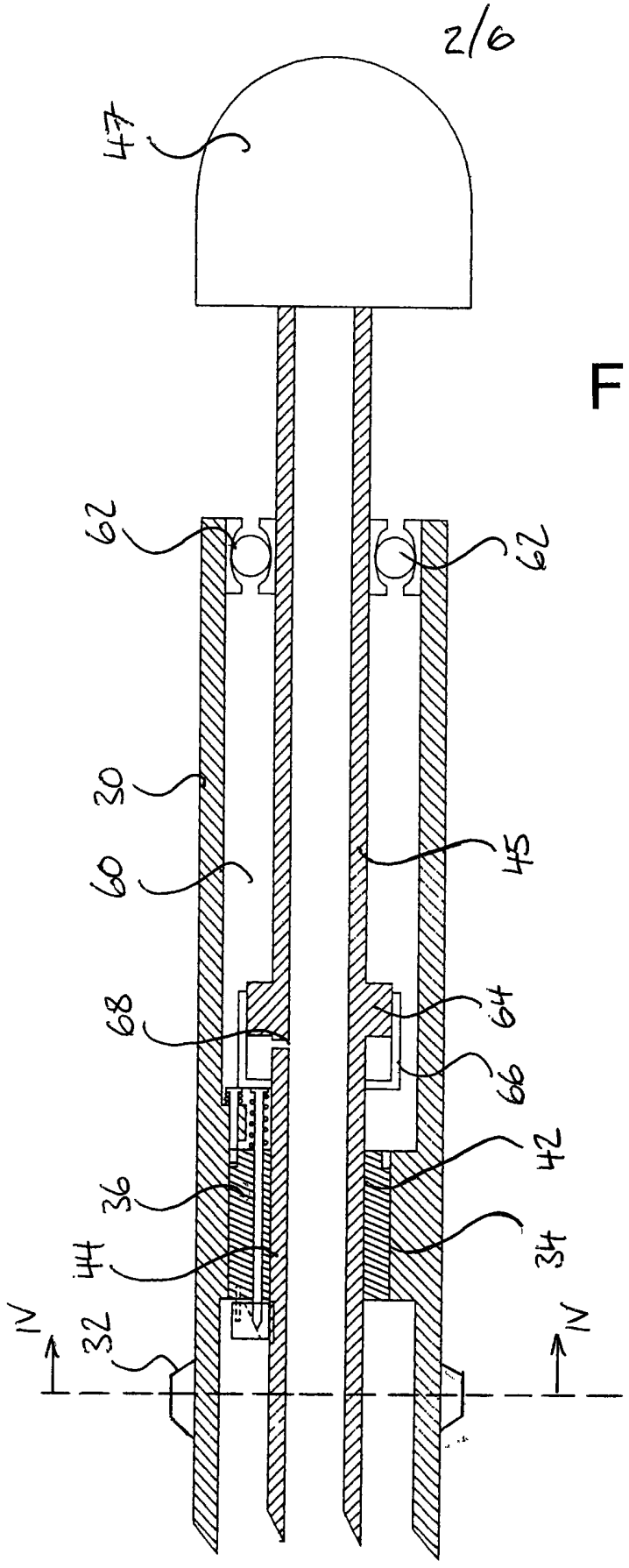


Figure 3

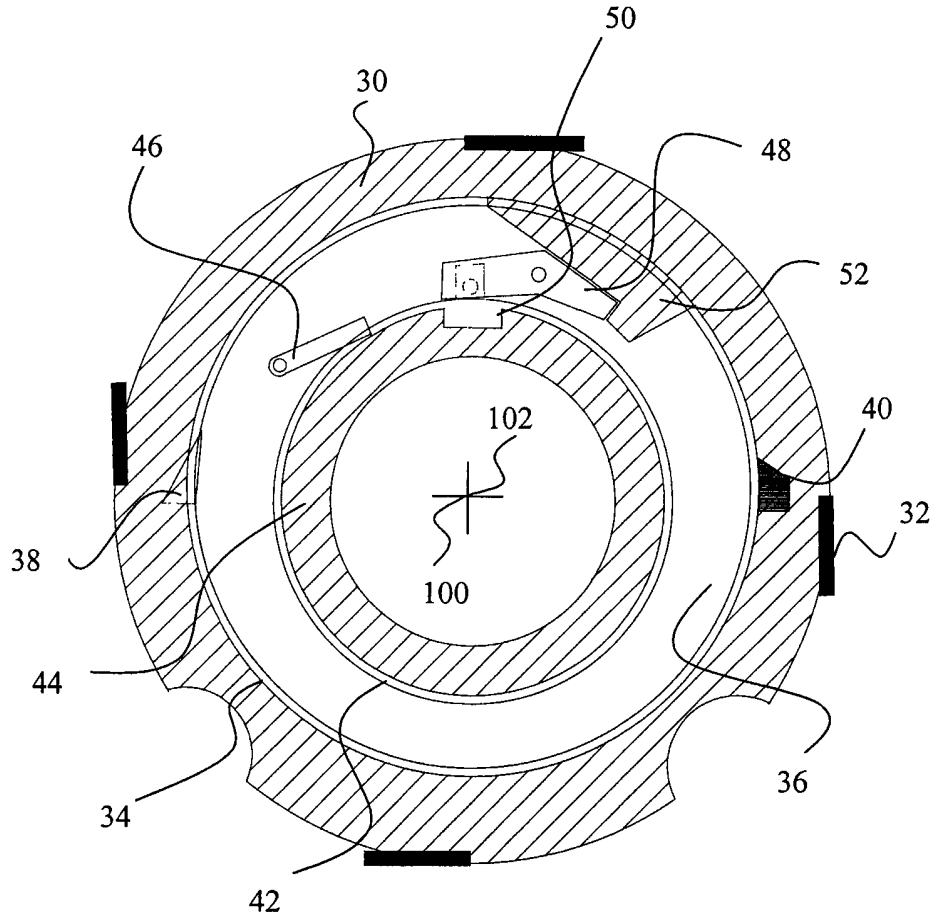
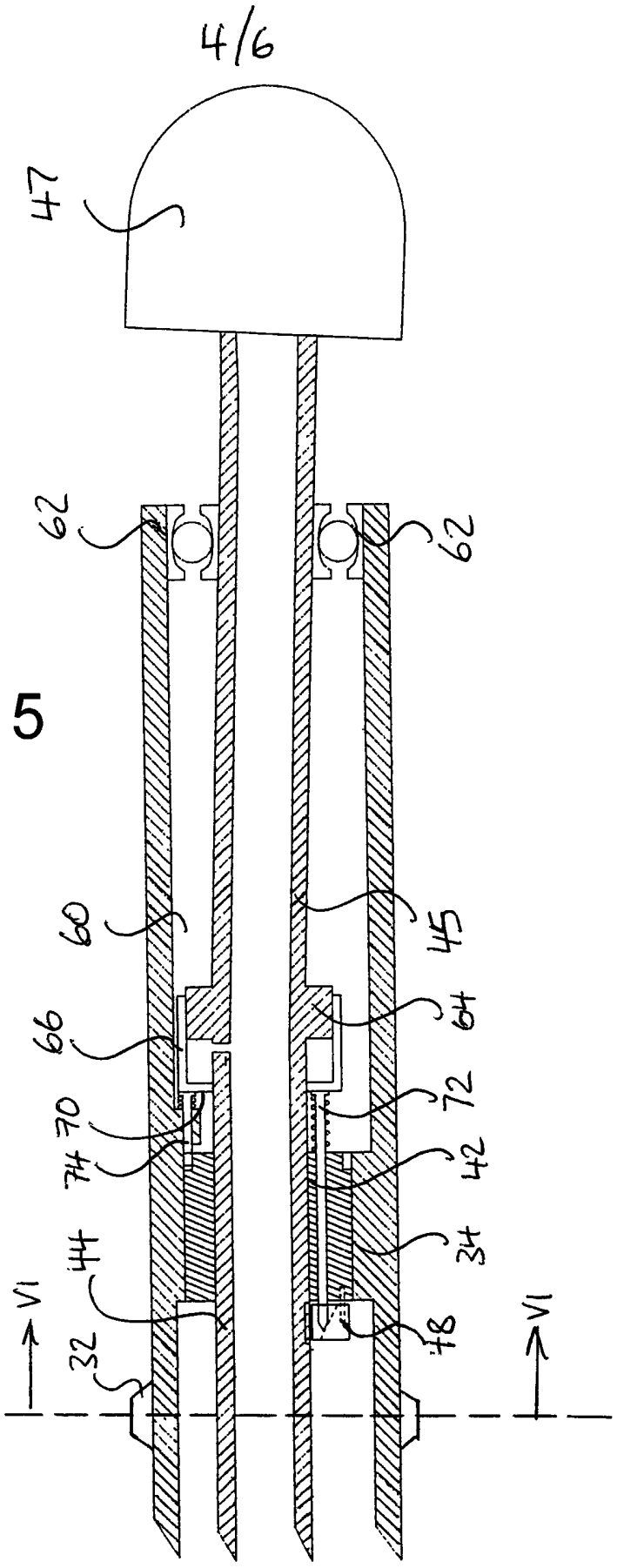


Figure 4

Figure 5



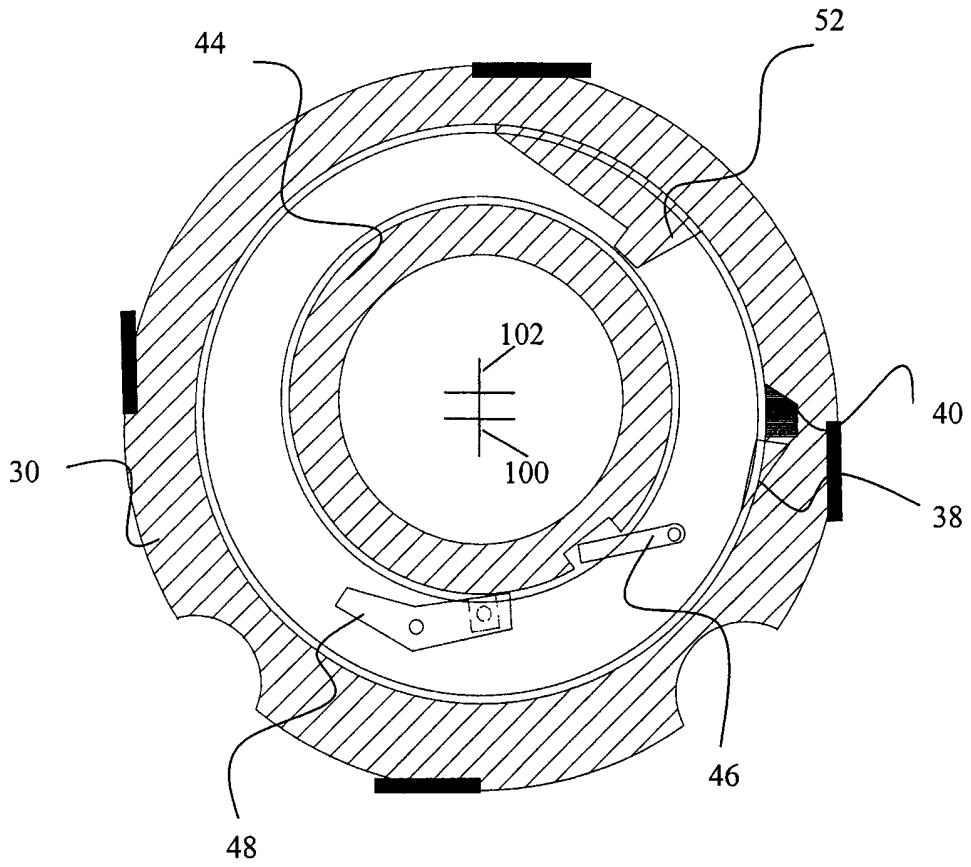


Figure 6

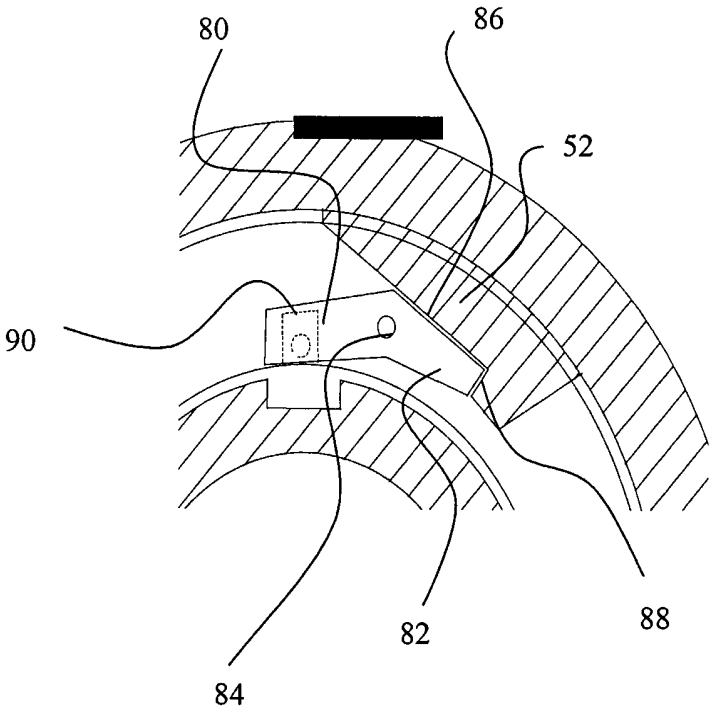


Figure 7

A Steering Apparatus for a Steerable Drilling Tool

The present invention relates to a steering apparatus for a steerable drilling tool, such as those used in borehole formation.

Deposits of natural resources, such as hydrocarbons, gas, water and steam for example, often exist at significant depths underground, and it is known that in order to extract them a well or borehole must be drilled from the surface to the location of the deposit. The underground layer in which the deposit is located is often relatively thin, having a height of only a few meters in comparison to lateral or longitudinal dimensions of much greater magnitude. Thus, while a borehole or well will typically have a vertical configuration near the surface, it is desirable to curve or angle the borehole in the vicinity of the deposit in order to increase the area of the borehole surface that lies within the deposit and from which extraction of the natural resource can then take place.

Steerable drilling tools have therefore been developed such that having drilled a substantially straight section of borehole, the angle in which the drilling tool is proceeding can be changed.

One such device is described in detail in US 2712434. This device is shown schematically in Figure 1, and will next be explained by way of background.

Figure 1 shows a known steerable drilling tool 2 located in a borehole 4. The tool comprises a drill bit 6, connected to a reamer or bit stabilizer 8. Above the stabiliser is a drill collar 10, which is connected to a mandrel 12 housed inside an eccentric bushing 14 or steering element. The mandrel passes through the steering element 14 and connects with a drill pipe 16 which in turn extends to the surface of the borehole. A rotary table at the surface (not shown) rotates the drill pipe, mandrel, collar and bit in order to drill the borehole.

As can be seen from Figure 2, the steering element has a circumference slightly smaller than the borehole 4 in which it is housed. Cut-out sections 18 provided in the circumference allow mud and other fluid generated in the vicinity of the drill bit to pass along the borehole, past the steering element and to the surface, where it may be removed. As can be seen from Figures 1 and 2, the mandrel is housed

inside the steering element in an off-centre position. The relative displacement of the mandrel, and the drill pipe and collar within the borehole causes angling of the drill bit at the borehole head and therefore causes the borehole to gradually curve.

In practice, with this device, a straight borehole is first drilled without the steering element in place. The steering element is then inserted between the drill collar and drill pipe and the direction of curvature chosen by rotating the steering element about the longitudinal axis of the borehole. By arranging the steering element so that the mandrel and drill pipe are displaced away from the centre axis of the borehole, deviation in the opposite direction is achieved. See Figure 1.

The steering element itself is rotated in the borehole by means of an anti-clockwise facing shoulder 20 on the mandrel. When the mandrel is rotated in an anti-clockwise direction, the shoulder engages with a spring-actuated detent 22 in the steering element, causing the steering element to rotate. Once the steering element is in the desired position, drilling is resumed by rotating the drill pipe, mandrel, drill collar and bit in a clockwise direction. In this direction, the mandrel rotates freely in the steering element.

In the example shown in Figures 1 and 2, assuming that the drill bit has a 27cm gauge diameter, the steering element has a 27cm gauge diameter, the respective geometrical centres of the steering element and mandrel are 3.5cms apart and the drill collar is nearly 6m in length, then the borehole will deviate by approximately 1° from the direction of the straight hole previously drilled. As the drill pipe and steering element move down the borehole further, the deviation will be maintained, causing the borehole to gradually curve.

Measurement While Drilling (MWD) systems are known, and provide means of detecting the orientation of the steering element within the borehole. One such system has a 'signal' ring connected to the steering element. The 'signal' ring has an aperture, which corresponds to a similar aperture on the mandrel. Thus, as the mandrel rotates, mud or other borehole fluid pulses through the apertures when they are in alignment, producing a "mud pulse" signal which can be detected at the surface and used to indicate the orientation of the steering element.

A further known device, described in US 5,941,323 uses the above principle in a similarly constructed drilling tool. The steering element has a cam sleeve supported on the mandrel between two extension pads. The sleeve has two cam surfaces that are positioned adjacent the pads, such that rotation of the sleeve causes one pad to extend the other pad to contract. In this way, the centre line of the rotating mandrel is displaced from the centre line of the borehole. The sleeve is rotated by means of a piston which can be controlled by adjusting the pressure of the fluid or drilling mud in the borehole. By turning on a mud pump, fluid pressure in the borehole is made great enough for the piston to move against a return spring, while the axial movement of the piston is conveyed into rotational movement of the sleeve by a linkage. Turning the mud pump on allows the piston and cam to move into a deviated drilling position, while turning it off allows the piston and cam to return to the normal drilling position. The piston is normally locked in place by an annular locking mechanism. The locking mechanism is unlocked by selecting counter clockwise rotation of the mandrel. In doing so, the deviated drilling position can then be reached by turning on the mud pump.

It will be appreciated that systems, such as that described above, allow straight line or deviated drilling to be selected without the need for changing over parts of the apparatus. However, such systems can be complicated, and in the extreme conditions of the downhole environment this can lead to problems of maintenance, repair and associated expense.

For example, the above device relies on a catch mechanism secure the elements in place for straight line drilling. Should the catch break the device will default to the deviated drilling position making it difficult to retrieve the device for repair or later use. Additionally, as the selection mechanism is spring operated, there can be problems associated with friction overcoming the biasing force of the spring. Such devices also typically tend to be relatively long in terms of the space that they take up in the borehole.

We have appreciated therefore that there is a need for an improved steering device for a drill bit.

Summary of the Invention

The invention is defined in the independent claims to which reference should be made. Advantageous features are set forth in the appendent claims.

Brief Description of the Drawings

Preferred embodiments of the invention will now be described in more detail, by way of example, and with reference to the drawings in which:

Figure 1 illustrates a known deflection apparatus;

Figure 2 is a cross section through the steering element of the deflection apparatus;

Figure 3 is a longitudinal cross-section through the preferred embodiment of the invention in an undeviated drilling position;

Figure 4 is a lateral cross section through the embodiment of figure 3 along line IV-IV, showing the steering element in a neutral or zero deflection position;

Figure 5 is a longitudinal cross-section through the preferred embodiment of the invention in an deviated drilling position;

Figure 6 is a lateral cross section through the embodiment of Figure 5 along line VI-VI, showing an eccentric or deflection position; and

Figure 7 which is a lateral cross-section showing the tapered stop and ratchet in more detail.

Detailed Description of the Preferred Embodiments

Reference will now be made to Figures 3 and 4, which show a preferred embodiment of a drilling tool comprising a steering apparatus for a drill bit. Figure 4 is a lateral cross-section through Figure 3 along line IV-IV. As shown in Figures 3 and 4, the steering element comprises a substantially cylindrical steering

element housing or outer sleeve 30. On the surface of the sleeve, a number of anti-rotation blades 32 are provided, that limit rotation of the outer sleeve to just one of the clockwise or anti-clockwise directions. The diameter of the outer sleeve and the blades combined is therefore approximately the diameter of the borehole under construction. Preferably, and as illustrated in Figure 4, the blades prevent rotation in the clockwise direction, but permit anti- or counter clockwise movement.

The outer sleeve has an eccentric central bore 34, in which a cylindrical cam 36 is located. The cylindrical cam is arranged to rotate in the bore between the first position shown in Figures 3 and 4, and the second position shown in Figures 5 and 6. The cam therefore forms an inner member, which is rotatable relative to the outer sleeve. A stop 38 provided on the cam (not shown in Figure 3) makes contact with a corresponding stop 40 on the outer sleeve to limit anticlockwise rotation of the cam within the bore of the outer sleeve, thereby defining the second position shown more clearly in Figure 6. The first position is reached by clockwise rotation of the cam, from the orientation in Figure 6, back to that shown in Figure 4. The mechanism for preventing further clockwise rotation of the cam beyond the first position will be in more detail described later.

The cam 36 also has an eccentric bore 42 in which mandrel 44 is located. The mandrel is connected at one end to the drill collar 45 and drill bit 47, and at the other to the drill pipe or shaft (not shown), which drives rotation of the drill bit in the borehole. Instead of the mandrel, it may be possible to have the drill pipe extend through the cam and connect directly to the collar or drill bit. The principle of operation will be the same.

As mentioned above, the bore 34 of the outer sleeve or housing is eccentrically located. That is the central axis of the bore 34 is offset from the central axis of the outer sleeve, and consequently as the outer sleeve has a substantially circular cross section, from the central axis 100 of the borehole. Similarly, the central axis of the eccentric bore 42 of the cam is offset or displaced laterally from the central axis of the cam. The eccentricity of the bore of the outer sleeve and the bore of the cam are the same, such that the eccentricity of the cam and outer sleeve combination can be enhanced or cancelled by the relative rotational position of the cam to the sleeve.

In the first position, shown in Figure 4, the outer sleeve and cam are arranged in opposing relative rotational positions, such that the cam compensates for the eccentricity or offset of the outer sleeve. As a result, the central axis 102 of the bore 42 in the cam and the central axis of the borehole 100 substantially coincide. Thus, as the mandrel and drill shaft rotate, they do so around the central axis of the borehole causing undeviated or straight line drilling.

However, in the second position, shown in Figure 5, the cam and the outer sleeve are located in complementary positions such that the lateral displacements provided by the offset of the bore 34 within the outer sleeve and the offset of the bore 42 of the cam combine. As a result, the central axis 102 of the cam bore 42 around which the mandrel 44 rotates is displaced laterally from the centre of the borehole. This displacement of the mandrel within the borehole causes angling of the drill bit, and therefore results in a curved or deviated path being drilled.

In the first position therefore the steering apparatus causes the drill string to drill a substantially straight path, and in the second position causes the path drilled top deviate from a straight line, in a direction chosen by rotation of the outer sleeve.

The device will typically have a diameter between 5cm and 25cm, and a length between 1 and 4 meters. These dimensions are not intended to be limiting.

The preferred embodiment advantageously allows selection of either the first or second position to be achieved entirely by selecting the direction of rotation of the mandrel. Thus, straight line or deviated, curved drilling can be selected in a straight forward manner from the surface.

As shown in Figure 4, the cam 36 has first and second ratchets or pins 46 and 48, which are biased so that they open outwards against the exterior surface of the mandrel 42. The first pin 46 is orientated so that it faces in the clockwise direction, while the second pin is disposed to face in the anticlockwise direction. A rotation slot 50 or cut out is disposed in the exterior of the mandrel to engage with either of the first or second pins, depending on the direction of rotation.

In the preferred embodiment, the direction of rotation of the mandrel for drilling is in the clockwise direction. Although, the rotation slot 50 will pick up the second

ratchet 48 when rotating in this direction, a claw or tapered stop 52 mounted on the outer sleeve is arranged to restrain the ratchet in a position where it is held back from the mandrel, preventing engagement with the slot 50 when the cam is in the first position. Thus, when the cam is in the first position, the mandrel can rotate clockwise independently and in an unrestricted fashion allowing drilling to proceed. The anti-rotation blades 32 prevent the outer sleeve from rotating clockwise so that the correct drilling angle is maintained.

The interaction of the second ratchet and the tapered stop will now be described briefly with reference to Figure 7 to which reference should be made. Preferably, the second ratchet 48 has an irregular shape, comprising a tooth portion 80, for engagement with the rotation slot, and a stop portion 82 either side of a pivot 84, which attaches the ratchet to the cam 36. The tapered stop or claw 52, which is attached to the housing, has an angled surface 86 which is arranged to engage one side of the deviated portion 82. The angled surface 86 also terminates in a shoulder 88 which is arranged to support the end of the deviated portion and prevent further clockwise motion of the ratchet and cam. The angled surface of the tapered stop, causes the ratchet to adopt an orientation around the pivot in which the straight section is lifted away from the rotation slot 50 allowing the mandrel to rotate freely.

When a curved borehole is to be drilled however, the direction of rotation of the drill shaft connected to the mandrel is changed to anti-clockwise. In doing so, the rotation slot 50 moves anti-clockwise until it engages the first ratchet 46. The biasing of the ratchet to open outwards ensures that it drops into the slot provided in the mandrel to make a good connection. Once the first ratchet has been picked up by the rotation slot 50, further anti-clockwise motion of the mandrel causes corresponding rotation of the cam within the borehole of the outer sleeve. The cam is therefore turned through approximately 180° into the second position where stop 38 and stop 40 engage and prevent any further relative rotation of the cam to the outer sleeve.

In travelling through 180°, the central axis of rotation of the mandrel is displaced away from the central axis of the borehole so that any further drilling will cause the borehole to deviate from the previous direction.

Subsequent further anti-clockwise rotation of the mandrel causes the outer sleeve itself to rotate within the borehole. The slot 50 acts on the first ratchet 46 of the cam 36, which by means of the stops 38 and 40, transmits that force to the outer sleeve. In the anti-clockwise direction, the anti-rotation blades provide small resistance to the rotation.

As the cam and outer sleeve turn together, the central axis of rotation 102 of the mandrel traces a circular path around the central axis 100. Drilling mud is then pumped down the drill string using a mud pump, so that using known MWD telemetry techniques, the rotational position of the outer sleeve and cam, and therefore the rotational centre of the mandrel can be detected and adjusted. Once a particular orientation of the mandrel centre with respect to the centre of the borehole is selected, the borehole can be made to deviate in the diametrically opposed direction by resuming clockwise rotation of the mandrel to operate the drill bit. Before clockwise rotation begins however, the mud pressure in the bore hole (resulting from the activation of the mud pump) is used to operate a locking mechanism that locks the cam and the outer sleeve to each other, and an actuator which retracts the second ratchet so that it cannot engage with the rotation slot. This holds the cam and outer sleeve in the second, deviated, position, and prevents the apparatus inadvertently adopting the first position when deviated drilling is commenced. The operation of the locking mechanism and actuator will be described in more detail below.

Thus, when the mandrel centre 102 is in the required position, clockwise rotation of the drill shaft is selected and normal drilling resumes at an angle.

The speed of rotation of the mandrel in the anti-clockwise direction is preferably significantly smaller than the speed of rotation for normal drilling, so that the orientation of the steering element can be easily controlled.

When it is once again desired to drill in a straight line, the cam 36 can be returned to the first position by turning off the mud pump to release the actuator, and selecting clockwise rotation of the drill shaft and mandrel. Again, this rotation is preferably carried out at a much lower speed than for normal drilling, at least for the first revolution of the mandrel, so that the cam, sleeve and ratchets can return smoothly to their normal operation positions.

Referring to Figure 6, it will be appreciated that clockwise rotation of the mandrel causes the rotation slot 50 to engage with the second ratchet 48. Further rotation of the mandrel causes the cam to turn from the second position towards the first position. This continues until eventually the claw or tapered stop 52 unlatches the ratchet from the slot so that the rotation of the cam is separated from the rotation of the mandrel. Thus, the action of the stop on the second ratchet 48 limits the rotation of the cam and thereby defines the first position. In the first position normal drilling in the straight-ahead direction can be resumed.

The stops 38 and 40 have been shown in Figures 4 and 6 in a schematic fashion. They can be implemented in practice in a number of ways. Stop 38 may for example be a protrusion on cam 34 which is constrained to move in a channel cut into the interior face of the outer sleeve. Stop 40 may then be formed by the end of the channel. In moving from the first to the second position, the stop 38 would then perhaps move from one end of the channel to the other.

As the operation of the steering element has been now described in detail, the locking mechanism and actuator, and the cooperation of the steering element and the drilling apparatus itself will now be considered with reference to Figures 3 and 5. As can be seen from Figures 3 and 5, the steering element of the drilling apparatus need only take up a relatively small percentage of the length of the drilling apparatus in which it is located. Between the steering element and the end of the drilling apparatus however is located a chamber 60, into which the mandrel 44 or drill collar 45 extends. At the end of the chamber is a spherical bearing 62 through which the mandrel passes; the drill bit 47 is mounted on the end of the mandrel outside of the chamber 60. The bearing allows the movement of the mandrel from the straight to the deviated position.

Inside the chamber 60, the mandrel has an enlarged collar portion 64 which is received in a piston sleeve 66. The mandrel may be made to flex or may be provided with one or more lateral joints within the sleeve 30.

A port 68 provided adjacent the collar 64, allows communication of the drilling mud pressure with the cavity formed by the collar 64 and sleeve 66. As a result of the pressure from the drilling mud, the bearing surface 70 of the sleeve 66 is caused to act on the actuator 72 and the locking mechanism 74. The actuator is a

spring loaded pin received in the cam 36. When the bearing surface of the sleeve acts on the actuator, the actuator engages the ratchet 48 to disable it and prevent it from engaging with the rotation slot 50 in the mandrel. In this way, the mandrel can be rotated clockwise for drilling in a deviated direction, without the ratchet or cam mechanism being damaged or hindering drilling.

The effect of the actuator on the ratchet 48 can be understood from Figure 5. The ratchet has an angled surface against which the actuator bears. When the actuator is pushed through the cam by the mud pressure it acts against the angled surface causing the ratchet to rise or otherwise move out of the way of the rotation slot. The point of engagement between the actuator 72 and the ratchet is shown as angled bearing surface 90 in Figure 7. Additionally, locking mechanism 74 is acted upon by bearing surface 70 such that it engages with a recess in the cam 36, to locking the cam in place with respect to the housing.

When the mud pump is turned off, bias springs on both the actuator and locking mechanism cause the actuator and locking mechanism to disengage. Thus, the cam 36 is once again free to rotate with respect to the housing, and the second ratchet can pick up the rotation slot, when the mandrel is rotating in the clockwise position, to restore the device to a position for straight line drilling.

As the deviated drilling position is selected by anti-clockwise rotation of the mandrel, and drilling is normally preformed by clockwise rotation, the operation of the device ensures that the device always defaults to straight line drilling. It is therefore preferable if the deviated drilling selection is provided by rotation in the opposite direction to the normal drilling operation.

Claims

1. A steering apparatus for controlling a drill string to drill straight and deviating paths, comprising: a housing, and a rotatable mandrel disposed axially within the housing for connection with a drill pipe, the mandrel having a first position for straight line drilling, and a second position laterally displaced from the first, for deviated drilling, such that rotation of the drill pipe in opposite directions moves the drill pipe between the first and second position.

2. Apparatus according to claim 1, comprising an inner member disposed between the drill pipe and the housing, such that rotation of the mandrel in one direction causes rotation of the housing, but in the other direction the mandrel can rotate freely.

3. Apparatus according to claim 1 or 2, wherein the housing comprises an outer sleeve having an eccentrically located internal bore; the apparatus further comprising:

an inner member rotatably mounted within the internal bore of the outer sleeve, having an eccentrically located internal bore in which the mandrel is disposed, wherein the inner member is rotatable between a first position for straight line drilling, and a second position for deviated drilling; and

a linkage between the mandrel and the inner member such that rotation of the mandrel causes rotation of the inner member with respect to the outer sleeve, and movement of the mandrel between the first and the second position.

4. Apparatus according to claim 3, wherein the outer sleeve has a central longitudinal axis which in use in a borehole is arranged to lie substantially at the central longitudinal axis of the borehole, and wherein in the first position the bores of the inner member and outer sleeve are arranged such that the mandrel is located co-axially with the longitudinal axis at the centre of the borehole, and wherein in the second position the bores of the inner member and outer sleeve are arranged such that the mandrel is offset from the longitudinal axis at the centre of the borehole.

5. Apparatus according to any preceding claim, wherein the inner member and outer sleeve comprise a stop such that the inner member cannot rotate beyond the second position, and such that in the second position further rotation of the mandrel causes rotation of the outer sleeve.

6. Apparatus according to any of claims 3, 4 or 5, wherein the linkage comprises a recess on the mandrel and a first ratchet on the inner sleeve, the recess being arranged to engage the ratchet when rotating in the first of a clockwise or anticlockwise direction to move the inner member from the first to the second position.

7. Apparatus according to any of claims 3, 4 or 5, wherein the linkage further comprises a second ratchet on the inner member, the recess engaging the second ratchet when rotating in the other of a clockwise or anticlockwise direction to move the inner sleeve from the second position to the first position.

8. Apparatus according to claim 7, comprising a pawl for disengaging the second ratchet from the recess when the inner sleeve is in the first position, so that the mandrel can rotate freely within the inner sleeve in at least one of clockwise or anti-clockwise directions.

9. Apparatus according to any preceding claim wherein the housing comprises anti-rotation blades, limiting the rotation of the housing to one of the clockwise or anti-clockwise directions.

10. Apparatus according to any preceding claim wherein the outer sleeve and the inner member are cylindrical.

11. Apparatus substantially as described herein and with reference to Figures 3 to 6 of the drawings.

Application No:	GB 0509316.6	**Examiner:**	Steffen Lorentzen
Claims searched:	1-11	**Date of search:**	15 September 2005

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X, Y	X: 1, 3, 4, 10 Y: 2, 5, 9	US 4319649 A	(JETER), See figures and abstract and column 1, line 36-47 and column 2, line 65-68 and column 4, line 1-5
X	1	US 6244361 B1	(COMEAU et al.) See figure 5 and abstract and column 36, line 24-37 and column 37, line 1-8
X	1	US 4694914 A	(OBRECHT) See figures and abstract and column 4, line 50-68
Y	2, 5, 9	US 5941323 A	(WARREN) See figures and column 2, line 31-42 and column 5, line 22-32
A	-	US 5467834 A	(HUGHES et al.) See especially figure 3 and abstract
A	-	US 2003/0034178 A1	(CARGILL et al.) See figure 6(a)-6(d) and abstract
A	-	RU 2109908 C1	(PREDPRIJATIE) See figures and abstracts (EPO and WPI)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC[X]:

Worldwide search of patent documents classified in the following areas of the IPC[7]:

E21B

The following online and other databases have been used in the preparation of this search report:

Application No:	GB 0509316.6	**Examiner:**	Steffen Lorentzen
Claims searched:	1-11	**Date of search:**	15 September 2005

EPODOC, WPI