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Richter, Jr. et al.

[11] **3,789,510**

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[54] **BOREHOLE DEVIATION MEASUREMENT WHILE DRILLING**

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[52] **U.S. Cl.** **33/306**, 33/304, 33/366, 33/379

[51] **Int. Cl.** ... **E21b 47/022**, G01c 9/06, G01c 9/20

[58] **Field of Search** 33/304, 306, 309, 312, 313, 33/314, 366, 379, 396, 282, 283

[56] **References Cited**

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[57] **ABSTRACT**

Disclosed is a downhole deviation-sensing system for enclosure in a drilling string during the drilling operation. The system produces a control signal representative of the deviation of a drilling collar of a drilling string relative to a vertical. The system employs a hollow lens enclosure with a concave configuration, the enclosure being partially filled with an opaque, antifoaming liquid so that a bubble is formed within the lens enclosure, and an area is exposed on a concave inner surface of the enclosure, the area being bounded by an imaginary cylinder at right angles to the inner surface. A collimated light source and a photocell are aligned with the central axis of the imaginary cylinder, with the photocell having a surface area similar in size to the area defined by the cylinder. Dependent upon the degree of tilt with respect to a vertical, the area formed by the bubble on the lens controls the amount of light transmitted to the photocell. The photocell output is calibrated so that it is a function of the angle of deviation. The system is adapted for downhole operation in a drilling string, and series-connected switches for controlling the conditions of operation, i.e., when not drilling, are employed.

11 Claims, 2 Drawing Figures

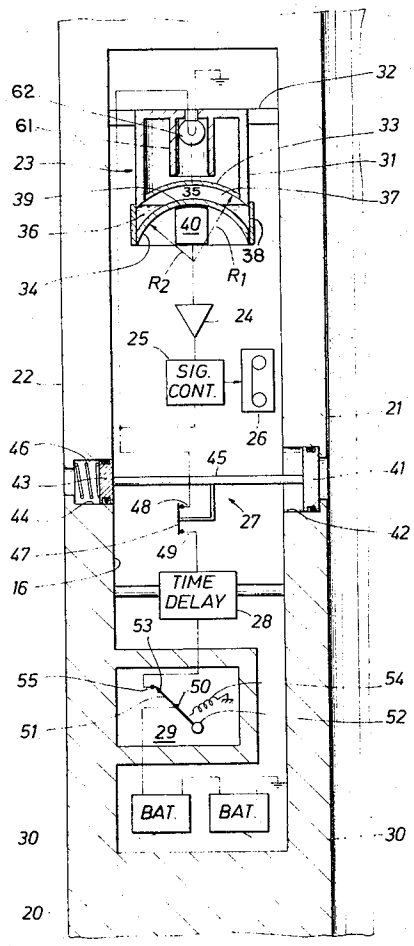
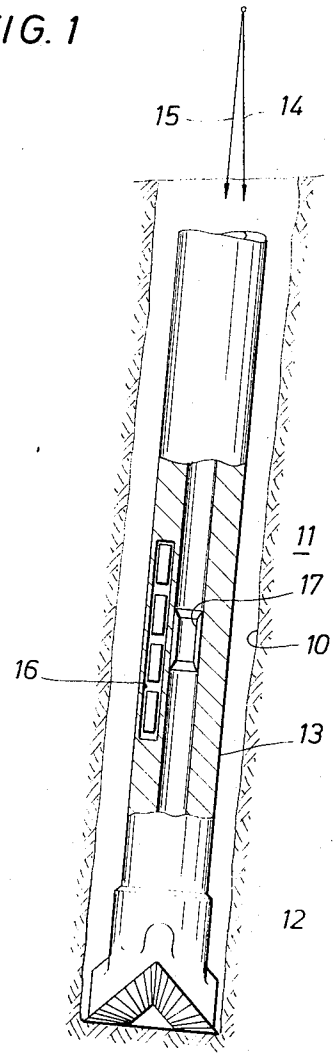


FIG. 1


15
14
11
17
10
16
13
12

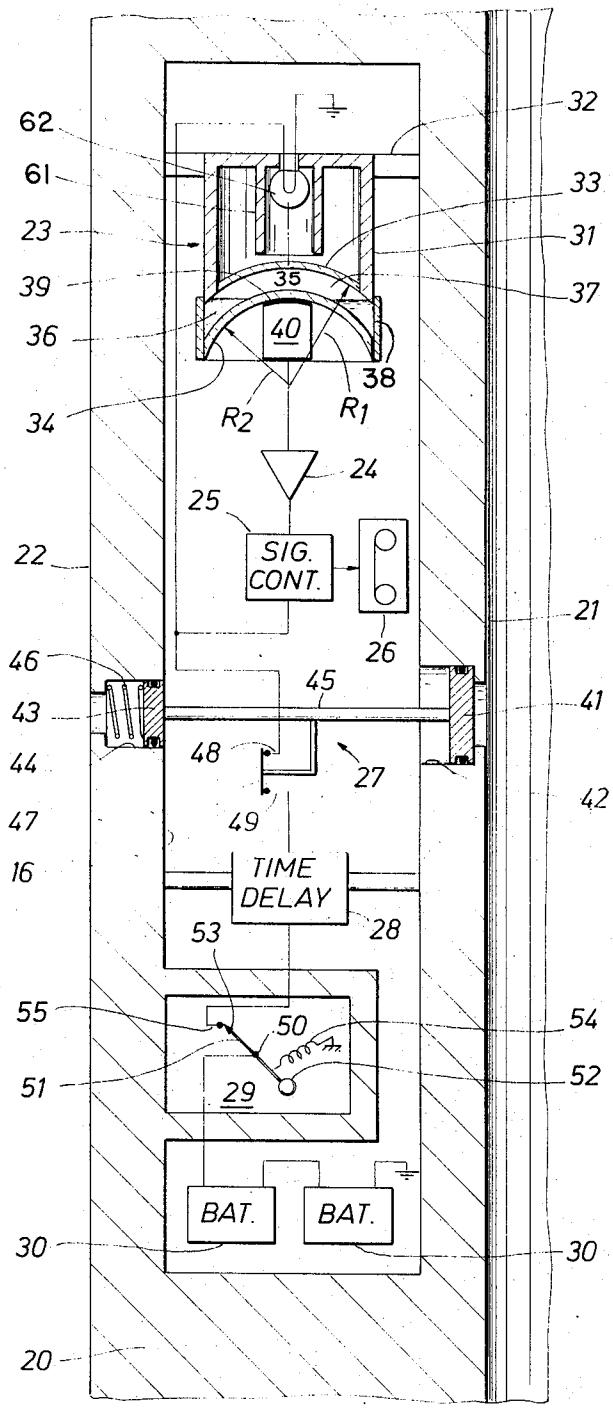

62
61
23
39
36
34
35
40
38
R2
R1
24
25
SIG. CONT.
26
22
21
46
43
44
47
16
45
41
48
27
49
42
TIME DELAY
28
53
55
50
54
51
52
29
BAT.
BAT.
30
30
20
32
33
31
37

FIG. 2

BOREHOLE DEVIATION MEASUREMENT WHILE DRILLING

BACKGROUND OF THE INVENTION

This invention relates to a drilling system and, more particularly, to a system for determining, while the drilling string is in the borehole, what the angle of deviation of the drilling string is relative to a vertical. This is accomplished during the drilling operation without requiring a separate run of another tool.

It is important to know what angle of deviation that the drilling bit takes during the drilling operation so that the operator can get some idea where the drilling bit is located horizontally relative to the drilling location. As the drilling bit drills into earth formations, their character and bedding planes can and do alter the direction that the drilling bit takes. As a consequence, the bottom of the borehole can be displaced horizontally at great distances relative to the surface opening. Many regulating agencies control the degree of horizontal offset that the bottom of the hole can bear relative to the surface opening. Often times, the deviation may be such that it is necessary to drill an offset hole.

Present operations for determining deviation involve stopping the drilling operation, pulling the drilling string and running a wire line tool. It is also possible to run a deviation tool on a piano line through the drilling string while the string is in the borehole. However, in either case, time is involved in obtaining the measurement, and thus it is not performed any oftener than is deemed absolutely necessary. If the borehole requires straightening, the general procedure is to decrease the weight on the bit and increase the RPM. This procedure usually results in decreased penetration rate and lost time, and it is preferable to have as little deviation as possible to straighten.

If it is possible to have a deviation-detecting system near the drill bit as an intergral part of the drill string, more frequent checks of the deviation will result in less lost time for deviation surveys and hole straightening as well as provide a straighter borehole.

It is accordingly an object of the present invention to provide a new and improved system for determining downhole deviation during the drilling operation.

The present invention involves a downhole deviation-sensing device which is receivable within a cavity formed in a drilling collar. The system is immersed in a shock-absorbing material, and the deviation-sensing device will produce an electrical control signal proportional to the degree of deviation of the drilling string relative to a vertical. Series-connected switches are included in the system to operate the deviation-detectng device only under preselected conditions. The deviation-sensing device includes a collimated light source which is directed toward a photoelectric cell having a defined surface area. The axis for the path of light is aligned parallel to the axis for the drilling collar. The light path is intersected by a light filter which varies the amount of light received by the photocell as a function of deviation of the light path relative to a vertical. In the present embodiment, this filter is constituted by a spherical lens system which encloses an opaque liquid and an air bubble. In a vertical position, the bubble is centrally located in the lens system such that the output of the photocell is a function of the light transmitted to the defined surface area on the photocell along a central axis through the photocell and light source.

As the axis for the light path is tilted, the liquid continues to center the bubble relative to the lens curvature and, in so doing, causes the opaque liquid to cover a portion of the surface area of the photocell and the degree of coverage is porportional to the degree of tilt or deviation. The resultant porportional signal from the photocell is calibrated and produces a proportional response for a signal-indicating mechanism.

The system is dependent for operation upon event switches which include a pressure-sensing switch operative during the drilling operation to disconnect the system from operation, a time delay mechanism which establishes a waiting period before initiating operation of the mechanism and a rotation-sensing switch which, during rotation of the drilling bit, disconnects the device from operation. Thus, when the mud pumps are shut down and the rotation stopped, the switches, after a predetermined waiting period, will operate the deviation detector which can then provide a control signal in response to the inclination detected.

The objects of the present invention will be understood from the foregoing description and the description to follow when taken in connection with the accompanying drawings in which:

FIG. 1 illustrates a portion of a drilled borehole and drilling bit, and

FIG. 2 represents a schematic cross-sectional view through a wall of a drilling collar.

Referring now to FIG. **1**, a borehole **10** extends through earth formations **11** and is formed by a drilling bit **12** attached to the lower end of a drilling string **13**. As illustrated in FIG. **1**, it is the purpose of the system of the present invention to determine the angle of deviation between the vertical line illustrated by numeral **14** and the axis of the drilling string indicated by line **15**. In the drilling string **13** adjacent to the drilling bit **12** is a hollow cavity **16** which may extend circumferentially around the drilling collar and lengthwise of the collar. The design of such cavity is well known in the art. Enclosed within the cavity **16** are a number of components which will be more specifically described with respect to FIG. **2** hereinafter, which components, however, are immersed in a shock-absorbing material such as Dow-Corning "Sylgard" 184. The system is intended to provide an output response which is functionally related to the angle of deviation, and this output signal can be transmitted to the surface in a variety of modes. One such mode is illustrated by numeral **17** in FIG. **1** as a variable orifice means which can, by changing size, alter the pressure on the mud which can be detected at the surface. Other known systems include transmission of electrical or acoustic signals. Alternatively, the device can use a downhole recording mechanism so that the deviation measurement is derived upon examination of the recording mechanism when the drilling bit is pulled for replacement. In this procedure, there is no lost time as the record can be examined while a different mechanism is being run in the hole with the pipe.

Referring now to FIG. **2**, a wall **20** of the drilling collar of the drilling string is illustrated where the internal wall surface (which defines the bore through the collar) is designated by the numeral **21** and the external surface is designated by the numeral **22**. Between the internal and external surfaces **21** and **22** is the hollow cavity **16**, and suitably disposed in cavity **16** are the deviation-detecting device **23**, an output amplifier **24**,

a signal control device **25** and a recorder **26.** Associated with the deviation detector **23** is an electrical control circuit which includes a pressure sensing system **27,** an electric time delay **28** and a rotation-sensing switch **29,** as well as electrical power supplies such as batteries **30.**

The deviation-sensing device **23** includes a hollow case member **31** which is supported relative to the drill pipe by struts or braces **32.** The case at its lower end receives a spherically shaped, light-transparent, upper lens **33** which has a radius of curvature R_1. A second spherically shaped, light-transparent lens **34** having a similar radius of curvature is disposed below the upper lens **33.** The lenses **33** and **34** are equidistantly spaced from one another and have a cylindrically shaped interconnecting wall **38.** The surfaces of lenses **33** and **34** define an enclosure **35** which has upper and lower concave surfaces. Within the cavity or enclosure **35** is an opaque anti-foaming liquid **36,** and the enclosure is incompletely filled so that an air bubble **37** is also within the cavity. The central point for the lenses **33** and **34** lies on an axis which intersects the center of a photocell **40** and conicides with the central axis for a tubular, light collimating cylinder **61.** The collimating cylinder **61** has a light means **62** disposed therein, and when the light means is illuminated, light is directed or collimated along the axis, through the lens system, to the surface area **39** of the photocell. Liquid **36** is included in an amount sufficient so that the bubble exposes substantially all of the surface area of the photocell.

If the central axis of the light system is inclined relative to a vertical, the shifting of the liquid will move the bubble in the lens system off of the center axis, and, because of the curved lens system, the liquid will cover a portion of the surface of the photocell. The amount of surface area of the photocell covered by the liquid will increase proportionally to the relative angle of deviation. Thus, the amount of light transmission along the central axis to the photocell is a function of the angle of deviation. The output of the photocell is therefore functionally dependent upon the angle of deviation and can be calibrated in terms of the deviation angle relative to a vertical. It will be appreciated that the radius of curvature of the lens and the surface area of the photocell can be varied to provide any selected range of angles or resolution.

The electrical output from the photocell is appropriately amplified by an amplifier **24** and can be converted from an analog signal to a digital control signal or other significant, discrete control signal by the signal control device **25.** In the embodiment illustrated, the device **25** would convert the signal to a digital signal which is appropriately recorded on a tape recorder **26.** A suitable downhole tape recorder system is found, for example, in U. S. Pat. No. 3,566,597.

Because of the severe environment of vibration, temperature and pressure at the drill bit, it is desirable to have a minimum number of moving parts. In this regard, it should be noted that the above described system consists of a solid state photocell, a lens system which is filled with an anti-foaming liquid, and that the deviation is a function of light. For further ruggedizing of this system, it is immersed in the shock-absorbing material such as the Dow-Corning "Sylgard".

To conserve the power requirements for the system and to obtain operation on a selective basis, control switches can be employed. As illustrated in FIG. **2,** a pressure-responsive device **27** can be provided. Device **27** includes a piston **41** slidably and sealingly received within a cylinder **42** which is responsive to the pressure of the mud within the drilling pipe and a piston **43** slidably and sealingly received in a cylinder **44.** Pistons **41** and **43** are coupled together by a rod **45** and are responsive to mud pressure within the pipe. By sizing the piston **41** which is exposed to the internal pressure of the drill pipe with a larger area than the area of the piston exposed to the external pressure, the connecting coupling **45** can be shifted when the mud pumps are operated such that the pumping of mud produces higher pressures within the drill pipe than the pressure exterior to the drill pipe. A spring **46** may be provided between the piston **43** and a wall surface to obtain a shifting of the pistons **41** and **43** whenever the pressures are equalized — that is, when the mud pumps are shut down. By attachment of an electrical switch contact member **47** to the rod **45,** open contacts **48** and **49** for the electrical circuit from the power supply may be opened whenever the pressure on the interior exceeds the exterior pressure and the contacts closed whenever the pressure is equalized.

Batteries **30** may, of course, be any sort of well-known, direct current devices which can be connected to a motion-responsive switch **29.** The switch **29** may, for example, be a mercury type switch which is operated under the centrifugal action of the bit rotation or can be a mechanically operated switch. As illustrated, a rotationally mounted pin **50** supports a transverse, electrical switch contact **51** which has a mass **52** at one end or to one side of the pivot pin and a switch contact **53** to the other side of the pivot pin. A spring **54** is attached to the contact **53** at a location between the pivot pin and the mass **52.** In operation, rotation of the drilling collar causes the mass **52** to rotate the contact arm **53** by virtue of the pivot pin and disconnect the movable contact relative to a stationary contact **55.** When rotation is discontinued, the spring **54** will move the movable contact **53** into electrical contact with the stationary contact **55.**

In the electrical system between the centrifugal switch **29** and the pressure switch **27** is a time delay switch **28.** Switch **28** functions upon the closing of switch **29** to close a pair of electrical contacts after a predetermined time delay and retain the contacts in a closed position for a preselected time period.

In the operation of the foregoing system, during the drilling operation, whenever a measurement is desired, the pumps are stopped and the bit rotation is stopped. Switches **27** and **29** will close when the pumps and pipe rotation are stopped, and shortly thereafter time delay switch **28** will close. The closing of the switches applies power to the lamp **62** as well as the signal control circuit **25** and recorder **26.** The angle of deviation is therefore recorded. It is, of course, not necessary to record the signal control output **25** as this control can be applied to a transmission circuit for transmission to the earth's surface.

While particular embodiments of the present invention have been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A system for detecting deviation relative to a vertical in a borehole comprising:

a tubular member adapted for coupling in a drilling string, said tubular member having a cavity formed therein,

deviation detecting means in said cavity including means for providing a collimated light beam,

means responsive to the light beam for producing an electrical output which is functionally related to the intensity of the light received, and

variable filter means disposed in the path of said light beam, said filter means including a concave lens shaped enclosure containing an opaque liquid and gas bubble where the amount of liquid intersecting said light beam is a function of deviation relative to a vertical.

2. The apparatus of claim 1 wherein said detecting means is surrounded by a shock absorbing material.

3. The apparatus of claim 1 and further including means for conditioning said deviation detecting means for operation only when the drilling fluid pressure internal and external to the said tubular member has a predetermined relationship.

4. The apparatus of claim 1 and further including means for conditioning said deviation detecting means for operation only when the tubular member is not being rotated.

5. The apparatus of claim 3 and further including means for delaying the operation of said deviation detecting means for a predetermined time after said conditioning means is operated.

6. The apparatus of claim 3 and further including second means for conditioning said deviation detecting means for operation only when the tubular member is not being rotated, and means for delaying the operation of said deviation detecting means for a predetermined time after both of said conditioning means are operated.

7. The apparatus of claim 1 and further including means responsive to the electrical output of said light response means for producing a discreet signal.

8. The apparatus of claim 1 wherein said variable filter means includes a pair of spaced apart, light transparent, concave lenses defining an enclosure, an opaque liquid in said enclosure and partially filling said enclosure so as to form a bubble which exposes an area on the lower lens, said light responsive means having a light sensitive area aligned with the area on said lower, lens in a vertical position, whereby tilting of said tubular member will cause said bubble to move and alter the light transmissibility to said light sensitive area.

9. The apparatus of claim 8 where said light responsive means is a photocell.

10. A system for determining deviation of a pipe string while it is in the borehole comprising:

a tubular drilling member having a hollow chamber between its inner and outer wall surfaces,

deviation-sensing means disposed in said hollow chamber and including means for transmitting and receiving a collimated light beam along a first axis aligned relative to the central axis of said drilling member,

means defining an enclosure in the path of said light beam and having a pair of equidistantly spaced, light transparent, concave lenses disposed so that their centers intersect said first axis, said enclosure means enclosing a gas bubble and an opaque liquid, said bubble being centered relative to said axis when said axis is in a vertical position, and exposing an area of said lenses in juxtaposition to said light receiving means, and

means responsive to said light receiving means for producing an output signal which is a function of the position of the bubble with respect to said light receiving means.

11. The apparatus of claim 10 wherein said light receiving means is a photocell having a face with an area substantially equal to the area of said lenses exposed by said bubble.

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