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(54) Detecting roll angle of a borehole tool

(57) First and second sensors 2, 3 fixed in relation to each other by a housing 1 are attachable to a borehole tool by means of a connection 4 and to a drill string by means of a second connection 5. The tool is advanced into the borehole in a series of steps, each step being equal in length to the spacing between the sensors 2, 3 and at each step the sensors are used to detect a vector field having a component transverse to the longitudinal axis of the borehole. By comparing each reading of the uppermost sensor with the preceding reading of the lower sensor, the angle through which the tool has rotated during each insertion step can be found and by integrating these angles the total angular displacement of the tool from its initial position can be determined. The sensors may detect a natural magnetic, electrical or gravitational field or an artificially produced magnetic or electrical field. A third sensor may be provided with the three sensors in a linear array and with adjacent pairs equally spaced.

The depth of a borehole may be determined by withdrawing the tool and continuously recording the readings from the first and second sensors. Comparison of the two real-time recordings allows determination of the speed of the tool through the borehole, and integration of the instantaneous speed measurements provides a determination of the depth of the borehole.

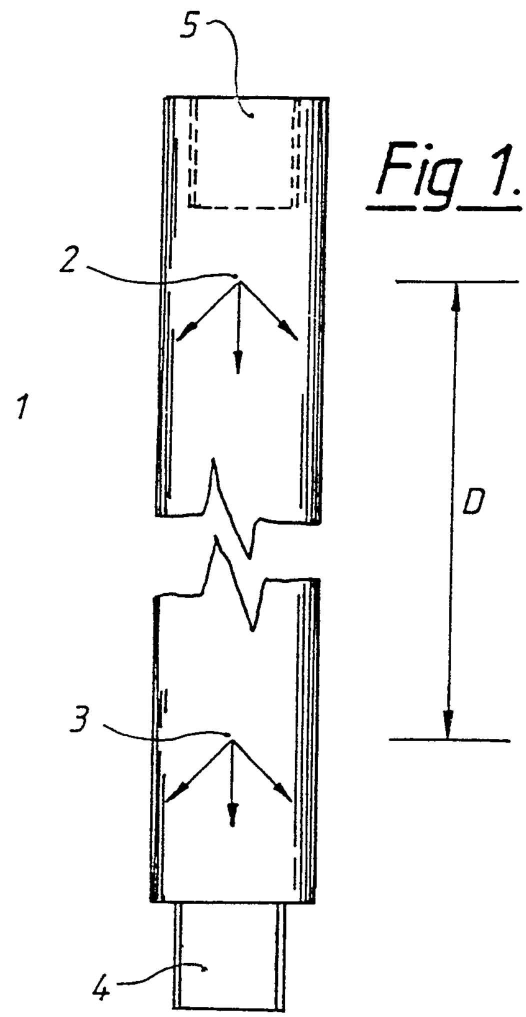

Fig 1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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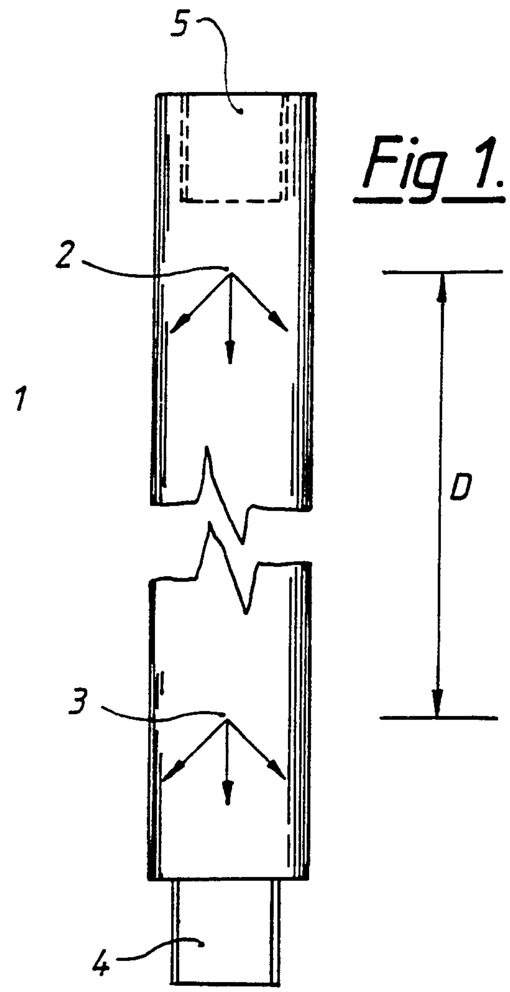

Fig 1.

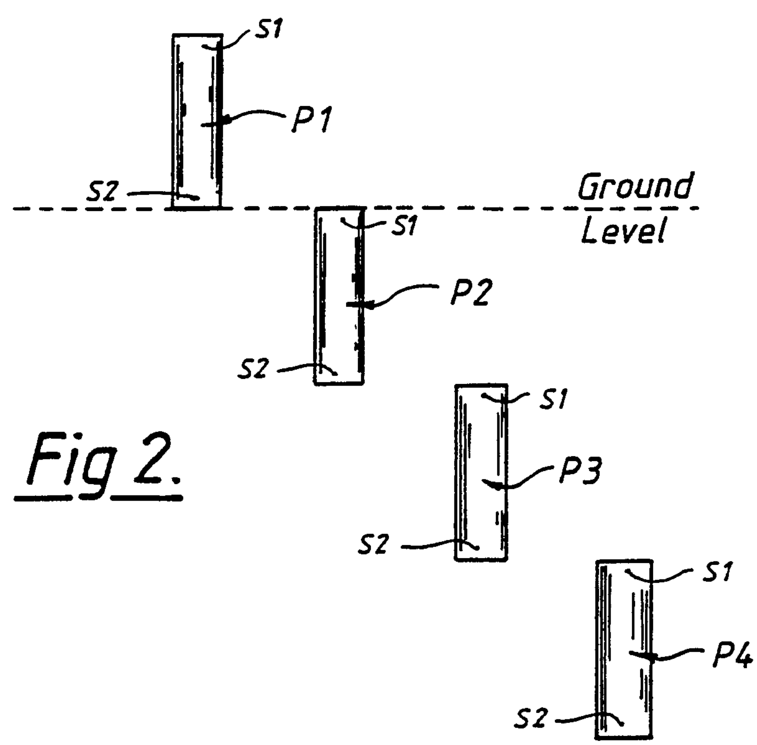

Fig 2.

IMPROVEMENTS IN REMOTE SENSING

The present invention relates to remote sensing, and is particularly concerned with methods and apparatus for determining tool orientation and position in boreholes. The apparatus may also be used for depth measurement in boreholes.

When taking core samples from boreholes, it is advantageous to ascertain the correct directional orientation of the core sample, so that the inclination of strata in the core sample may be accurately determined. In order to do this, the orientation of the core sampling tool relative to a fixed radial direction in the borehole must be ascertained. This orientation, referred to as the 'roll angle' of the tool, is generally measured relative to the gravity vector in boreholes inclined to the vertical, but its reliable determination in vertical or near vertical boreholes has so far not been achieved.

While it is possible to mount a magnetometer in the tool to indicate the tool's orientation relative to the local magnetic field, distortion of the earth's field either by subterranean magnetic masses or by metallic borehole casings render this determination pointless, since the direction of the local field is unknown.

The present invention has as its primary objective the provision of an apparatus and method capable of measuring tool roll angle in boreholes irrespective of their inclination, and providing a continuous indication of the roll angle of the tool at any point in the borehole.

A secondary objective is to provide a method of depth measurement in boreholes, using the apparatus.

According to a first aspect of the invention, a method of sensing the roll angle of a borehole tool comprises the steps of:

a) providing a first sensor adjacent the tool

b) providing a second sensor spaced above the first sensor by a predetermined distance and held against rotation relative to the first sensor about the drill string axis, the sensors adapted to detect a parameter having a component transverse to the longitudinal axis of the borehole

c) positioning the tool in the borehole entrance with the first sensor aligned in a reference direction and taking and recording a first reading of the first sensor

d) advancing the tool into the borehole by a series of steps each substantially equal to the distance between the first and second sensors, and taking and recording readings of the first and second sensors at each step

e) comparing each reading of the second sensor with the previous reading of the first sensor, taken at the same axial location in the borehole, to determine the difference in the roll angle during each advancing step

f) integrating the resultant differences to arrive at a total roll angle for the tool in its movement into the borehole.

The sensors are preferably biaxial magnetometers sensitive to the local magnetic field, and capable of resolving the earth's magnetic field in the direction perpendicular to the longitudinal axis of the tool, and measuring the angle between the resolved field component and a reference datum. The reference datums of the sensors in the apparatus are preferably aligned, or a calibration measurement must be performed to determine the (fixed) angular difference between the reference datums. By relying on the component of the local field transverse to the borehole axis, the method may be used in boreholes irrespective of their inclination to the vertical, provided that the borehole axis does not coincide with the direction of the local field.

In boreholes which are non-vertical it may be possible to use sensors responsive to gravity. A further alternative is to use sensors which detect an electric field, and to establish a static electric field in the area of the borehole by passing a current through a pair of electrodes placed on either side of the borehole.

The apparatus for use in the method essentially consists of a tool carrying two sensors, detecting either the earth's magnetic field, its gravity vector, or an artificially produced static field, the sensors fixed in an elongate body or frame so as to be incapable of relative movement or rotation. Each of the sensors may be a biaxial or triaxial array of sensors, so that the parameter measured may be resolved either into two orthogonal components perpendicular to the tool axis, or into three orthogonal components with one coinciding with the tool axis.

As an alternative to providing a preassembled tool having two sensors, the tool may be assembled on site by fixing first and second sensor modules to the respective ends of a standard drill pipe section. By arranging for the sensor separation to be equal to a standard length of drill pipe, the action of advancing the tool into the borehole at the end of a string of drill pipe sections will then automatically ensure the correct step length, as the drill string is held to add each successive drill string section at the wellhead.

In an advantageous development of the method and apparatus, three or more sensors may be provided, the separation between adjacent pairs of sensors being equal. Using such an arrangement, at each position in the borehole three or more readings are taken, thus providing two or more pairs of readings from each of which a roll angle difference may be calculated. This provides a back up check to the calculation of total roll angle.

An example of the method and apparatus of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic side view of a roll angle measuring tool; and

Figure 2 is a schematic diagram showing four positions of the tool down a borehole.

Referring now to the drawings, Figure 1 illustrates a tool for roll angle sensing. The tool comprises a body 1, within which are housed upper and lower sensors 2 and 3 respectively. The sensors are preferably magnetometers, and are capable of resolving magnetic fields in three orthogonal planes, so as to give an output measuring the direction of the local magnetic field relative to a reference radial direction fixed in relation to the tool. The tool may however also function if the sensors are biaxial, and do not take account of the component of the field in the axial direction of the tool, but merely give an indication of the radial (relative to the tool) field component direction relative to a reference radial datum.

Alternatively, the sensors may be adopted to detect fields other than the earth's magnetic field, such as an electric or magnetic field generated locally by conductors buried adjacent the borehole, or may be substituted or supplemented by sensors dependant on the earth's gravity for use in boreholes inclined to the local vertical.

The axial spacing D between the sensors 2 and 3 is a predetermined value, and may correspond to the length of a standard drill pipe section, for reasons to be described below. The tool is formed, at its axial ends, with male and female connectors 4 and 5 of standard form for connecting to conventional drill string components. The tool may be attached anywhere in the drill string, but is preferably inserted directly behind the tool whose roll angle is to be measured. Alternatively, sensors may be attached directly to, or built into, the tool whose roll angle is to be detected.

As an alternative to the sensors 2 and 3 being fixedly mounted in a single tool 1, it is possible for each sensor to be separately packaged in a housing adapted to be connected between two drill string sections. In such an arrangement, a first sensor is mounted between the drill string tip and the first drill pipe section, and the second sensor is placed between the first and second drill pipe sections.

The roll angle determination method of the present invention will now be described, using the tool of Figure 1 to place in a borehole a well accessory whose angular orientation is required to be known.

First, the well accessory is placed at the wellhead in position P1 in a known manner, and its roll angle relative to a reference datum DW at the wellhead is noted. The roll angle sensing tool is fixed to the well accessory by conventional coupling, and the sensors are read to indicate the angle between the tool reference datum DT and the local azimuth direction of the earth's field MN. The tool and well accessory are advanced into the borehole from the wellhead by a distance D, equal to the spacing between the sensors in the tool, to a position P2 and again the angle between the local azimuth of the earth's field and the tool reference datum DT is measured by both sensors 2 and 3. This procedure is continued through positions P3, P4, etc. until the well accessory is at the correct depth in the borehole for installation.

The results of the sensor readings for each position P1, P2, P3, P4, etc. of the tool in the borehole are tabulated in Table I for the example illustrated in Figure 2, and will be explained below. The sensor readings are the angles between local magnetic north and the tool radial datum direction. The reading is measured clockwise from the tool datum direction.

TABLE I

Tool Position	Sensor Readings (Degrees)	
	S1	S2
P1	0	0
P2	+2	+2
P3	+8	+6
P4	+6	+5

Referring to Figure 2, it is clear that as the tool is advanced into the borehole in a stepwise fashion, sensor readings are taken at substantially the same point in space by the two sensors. In other words, the position of sensor S1 when the tool is in position P1 is the same point in space as the position of sensor S2 when the tool is in position P2. The difference in these readings of the sensors will then be equal to the angle through which the tool has rotated during its descent from position 1 to position 2.

In the example, the reading of sensor 1 at position 1 (S1P1) is 0, indicating that the tool radial datum direction coincides with magnetic north at that point. Likewise, the reading of sensor 2 at position 2 (S2P2) is +2, indicating that magnetic north is 2° clockwise from the tool radial datum. In the descent from position 1 to position 2, the tool has thus rotated 2° in the anti-clockwise sense (seen from above).

Sensor 1 in position 2 (S1P2) indicates that magnetic north at this depth is now 2° clockwise from the tool radial datum; by comparing this measurement with the reading of sensor 2 at tool position 3 (S2P3=8) after the next stepwise descent, it becomes clear that the tool has rotated by 4° clockwise during the descent from position P2 to position P3.

Similarly, comparing the readings S1P3 and S2P4 it is clear that the tool has rotated by 3° anti-clockwise during the movement from position P3 to position P4.

By adding the rotation calculated for each advance, the total roll angle of the tool is found to be 3° clockwise from the datum position noted at the wellhead.

Since the tool roll angle at position P4 can be determined, the reading of sensor 1 at position 4 may be used to determine the local direction of the magnetic field at the depth of sensor 1; comparing S1P4 with the accumulated tool roll angle of 3°, it is seen that magnetic north at the depth D4 is 2° to the east (clockwise) from magnetic north at ground level. Clearly this calculation may be performed at each step during the descent to construct a 'map' of the local field direction at the measurement points in the borehole.

While the tool can be used to find the local magnetic north (or south, as the case may be) at any depth, it is stressed that the calculation of tool roll angle requires no actual calculation of the local field direction whatsoever, since roll angle calculation relies on the difference between successive readings taken at the same point in space relative to the tool radial datum. The method is thus particularly useful in that even a magnetic field distorted by local anomalies such as underground magnetic rock formations, or a field attenuated and distorted by a metallic borehole casing can still be used to calculate tool roll angle. The only requirement is that the field should remain constant. The method is not limited to magnetic fields, but can be used in connection with any measurable vector parameter in any constant field, even though the vector parameter measured may not itself be aligned in the same direction throughout the field, and may vary in magnitude.

The use of the tool for accurate depth measurement of a borehole is achieved by placing the tool at an end of the borehole (either the wellhead or the bottom of the hole) and moving the tool through the hole while continuously recording the readings from the two sensors. Preferably in this application of the tool triaxial sensing is performed, to obtain continuous real-time records from each sensor of the magnitude and direction of a vector parameter throughout the time of passage of the tool through the hole. However, sensing may alternatively be of a scalar parameter such as temperature.

By comparing the two real-time records, points in time when the respective sensors passed through the same point in space may be determined and by knowing the distance separating the two sensors the instantaneous speed of the tool may be found. Integration of the thus calculated instantaneous speeds of the tool can provide a measurement of the distance travelled by the tool and thus the depth of the borehole.

The depth measuring feature may advantageously be used when retrieving the tool from the borehole, after stepwise descent of the borehole to place a roll-angle sensitive well accessory or to take a core sample.

CLAIMS

1. A method of sensing the roll angle of a borehole tool comprising the steps of:

a) providing a first sensor adjacent the tool

b) providing a second sensor spaced above the first sensor by a predetermined distance and held against rotation relative to the first sensor about the drill string axis, the sensors adapted to detect a parameter having a component transverse to the longitudinal axis of the borehole

c) positioning the tool in the borehole entrance with the first sensor aligned in a reference direction and taking and recording a first reading of the first sensor

d) advancing the tool into the borehole by a series of steps each substantially equal to the distance between the first and second sensors, and taking and recording readings of the first and second sensors at each step

e) comparing each reading of the second sensor with the previous reading of the first sensor, taken at the same axial location in the borehole, to determine the difference in the roll angle during each advancing step

f) integrating the resultant differences to arrive at a total roll angle for the tool in its movement into the borehole.

2. A method according to Claim 1, wherein the parameter sensed by the sensors is a natural magnetic, electrical, or gravitational field.

3. A method according to Claim 1, wherein the parameter sensed by the sensors is an artificially produced magnetic or electrical field.

4. A method according to any preceding Claim, wherein the first and second sensors are mounted directly in the tool whose angle is to be determined.

5. A method according to any of Claims 1 to 3, wherein the first and second sensors are mounted in a housing which is attached to the tool whose angle is to be determined.

6. A method according to Claim 1, 2 or 3, wherein the first sensor is mounted within a first housing attached to the tool, and the second sensor is mounted in a second housing connected to the first housing by a rigid connection.

7. A method according to any preceding Claim, wherein a third sensor is provided in addition to the first and second sensors, the first, second and third sensors being arranged in a linear array with equal spacing between respective adjacent pairs of sensors.

8. A method according to any preceding Claim, wherein the sensors are magnetometers.

9. A method according to any of Claims 1 to 7, wherein the sensors are gravity sensors.

10. Apparatus for use in a method according to any preceding Claim, comprising first and second sensors rigidly fixable in relation to each other, and attachable to a borehole tool.

Patents Act 1977
Examiner's report to the Comptroller under Section 17 (The Search Report)

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Relevant Technical fields

(i) UK Cl (Edition K) G1N (NAAJ, NACN)

(ii) Int CL (Edition 5) E21B

Search Examiner

D J MOBBS

Databases (see over)

(i) UK Patent Office

(ii) ONLINE DATABASES: WPI

Date of Search

13 APRIL 1992

Documents considered relevant following a search in respect of claims 1-10

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
X	GB 1552863 (TELECO INC)	10
X	US 4351116 (BJ-HUGHES INC)	10

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

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