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(54) Title: MAGNETIC RANGING SYSTEM FOR CONTROLLING A DRILLING PROCESS
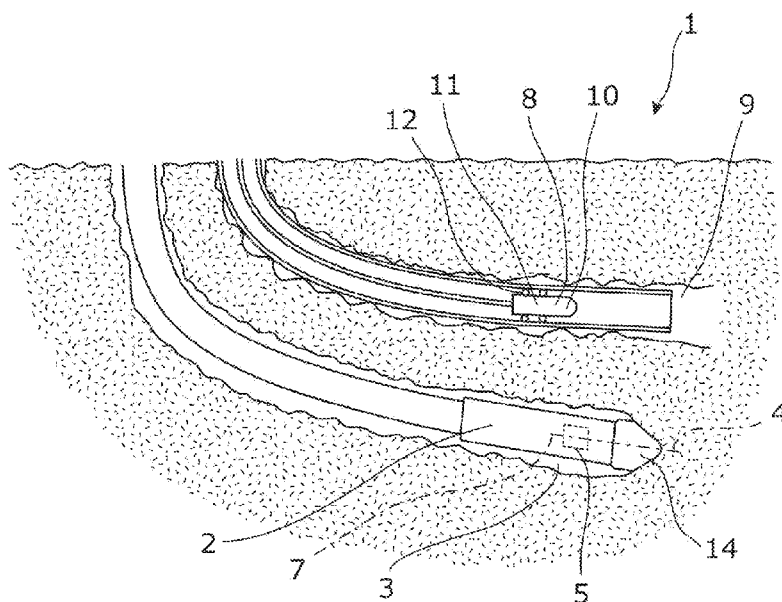

Fig. 1

(57) **Abstract**: The invention relates to a ranging system (1) for controlling a drilling process downhole. The ranging system has a longitudinal direction and comprises a drilling tool (2) for drilling a first borehole (3), the drilling tool having a tool axis (4) and comprising a magnetic field source (5) in the form of an electromagnet generating a magnetic field (6) and having a magnetic field source axis (7) which is substantially parallel to the tool axis. Moreover, the ranging system comprises a sensing tool (8) arranged in a second borehole (9) for measuring the magnetic field by means of at least two sensor units (10), which sensor units are arranged at a distance (D) from each other along an axis of the sensing tool.

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—   *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

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MAGNETIC RANGING SYSTEM FOR CONTROLLING A DRILLING PROCESS

Technical field

The present invention relates to a ranging system for controlling a drilling process downhole. The ranging system has a longitudinal direction and comprises a drilling tool for drilling a first borehole, the drilling tool having a tool axis and comprising a magnetic field source in the form of an electromagnet generating a magnetic field and having a magnetic field source axis. In addition, the ranging system comprises a sensing tool arranged in a second borehole for measuring the magnetic field by means of a sensor unit.

Background

When drilling into the formation of an existing well or borehole, it is very important to know the distance to the existing well or borehole while drilling. In some cases, the purpose is to meet the existing well or borehole at a certain position and, in other cases, the purpose is to drill a new borehole at an exact distance to the existing borehole or well, while ensuring that the distance between the two is substantially the same along a certain stretch.

Known tools comprise different solutions to determine this distance. The tools are used to detect magnetic fields for the purpose of determining the distance. Some tools use current in a wire in the existing borehole while others use a magnet rotating in the drilling head.

In prior art tools, such as the one described in US 2008/0041626, the magnet in the drilling head needs to rotate in order for the sensor to be able to detect the magnetic field and thus the distance of the drilling head in relation to a known position. Sometimes, however, the drilling heads stops, making it impossible to detect the magnetic field and thus determine the distance and the drilling direction of the drilling head. Furthermore, in order to conduct measurements, the drilling process has to be stopped to allow the magnet to be rotated and the tool to be slid back and forth further than the interwell separation, i.e. further than 5-10 meters.

In regard to these tools and tools using current in a wire in an existing borehole, the magnetic field sensing device is positioned in the drilling tool. Since the drilling

head of the drilling tool is driven by high-pressurised fluid delivered through the drill string, transmission of data from the measurements conducted by the sensing device is very difficult. These tools produce waves in the fluid as a means of communicating data, which is a very slow means of communication and may moreover inhibit the drilling process.

Description of the invention

It is an object of the present invention to wholly or partly overcome the above disadvantages and drawbacks of the prior art and provide an alternative ranging system able to determine the distance between the drilling tool and an existing well or borehole and even the three-dimensional position and orientation of the drilling head in order to control the drilling tool while drilling.

It is an additional object to provide an improved ranging system capable of determining the distance to an existing borehole or well, even when the drilling tool or the drilling string is not rotating.

The above objects, together with numerous other objects, advantages, and features, which will become evident from the below description, are accomplished by a solution in accordance with the present invention by a ranging system for controlling a drilling process downhole, the ranging system having a longitudinal direction and comprising:
- a drilling tool for drilling a first borehole, the drilling tool having a tool axis and comprising a magnetic field source which is an electromagnet generating a magnetic field and having a magnetic field source axis, and
- a sensing tool arranged in a second borehole for measuring the magnetic field by means of at least two sensor units,
wherein the sensor units are arranged at a distance from each other along an axis of the sensing tool.

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When the sensor units are arranged at a distance from each other along an axis of the sensing tool, the electromagnet does not have to move in order to make sufficient measurements to be able to calculate the position of the magnet relative to the sensing tool. When it is necessary to move the magnet, an imprecise distance between two sets of measurements may occur as a result; however, this is not the case when two sensor units are arranged at a fixed mutual distance. Furthermore, when having an electromagnet in relation to a permanent magnet, it is not necessary to rotate the magnet. Consequently, the calculation of the position of the magnet and thus the drilling tool is simplified, since the magnetic field is the same in relation to a rotating permanent magnet, rotating to change the field.

In one embodiment, the magnetic field source axis may be substantially parallel to the tool axis.

The magnetic field source axis may also be substantially coincident with the tool axis.

The sensor units may each comprise a three axis magnetometer for measuring the magnitude and direction of the magnetic field.

Moreover, the magnetometers may be arranged in the same plane in the sensor unit.

According to one embodiment, the second borehole may be an existing borehole.

In another embodiment, the sensor unit and/or the drilling tool may be driven by a driving unit.

The ranging system may further comprise a positioning tool for determining the position of the sensing tool in the second borehole or the position of the drilling tool in the first borehole.

This sensing tool may also have means for controlling and/or measuring the position of the sensing tool.

The magnetic field source may have a through hole, allowing fluid for driving a drilling head of the drilling tool to pass through the magnetic field source.

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The ranging system may also comprise a calculation unit for processing magnitude and direction measurements of the magnetic field measured by the sensing tool.

In addition, the ranging system may comprise a second drilling tool, and the sensing tool may be arranged in or in connection with the second drilling tool so that the first drilling tool comprises the magnetic field source and the second drilling tool comprises the sensing tool.

The invention further relates to a method for using the ranging system according to the invention, comprising the steps of:
- drilling the first borehole in one drilling direction,
- inserting the sensing tool into the second borehole,
- measuring the magnitude and direction of the magnetic field, and
- calculating a position of the drilling tool relative to the sensing tool,
wherein the steps of measuring and calculating occur while drilling the first borehole.

In one embodiment, the steps of measuring and calculating are performed simultaneously with drilling the first borehole, meaning that the steps of measuring and calculating are performed at least once an hour, preferably at least once every 0.5 hour, more preferably at least once every 10 minutes.

Furthermore, the method may comprise the step of calculating the direction of the drilling head.

In addition, the method may comprise the step of adjusting the drilling direction based on the calculated relative position of the drilling tool in relation to the sensing tool.

In addition, the method may comprise the step of adjusting the drilling direction based on the calculated direction and relative position of the drilling tool.

Finally, the invention relates to any use of the ranging system according to the invention.

Brief description of the drawings

The invention and its many advantages will be described in more detail below with reference to the accompanying schematic drawings, which for the purpose of illustration show some non-limiting embodiments and in which

Fig. 1 shows a cross-sectional view of a ranging system according to the invention arranged in two boreholes downhole,

Fig. 2 shows a partly cross-sectional view of the drilling tool,

Fig. 3 shows the magnetic field source in perspective, and

Fig. 4 shows the sensing unit.

All the figures are highly schematic and not necessarily to scale, and they show only those parts which are necessary in order to elucidate the invention, other parts being omitted or merely suggested.

Detailed description of the invention

The present invention relates to a ranging system 1 for controlling a drilling process downhole, the ranging system having a longitudinal direction. When drilling a borehole, it is very important to be able to control the drilling direction and to know the orientation of the drilling head to ensure that the borehole is positioned at the predetermined position. When using steam assisted gravity drainage (SAGD) to extract the oil out from the ground, two boreholes must be drilled being substantially parallel, along almost all of their horizontal extension to ensure that the steam penetrates the formation along almost the entire horizontal extension of the boreholes.

The ranging system comprises a drilling tool 2 for drilling a new borehole near an existing borehole as shown in Fig. 1. The drilling tool 2 comprises a drilling head 14 for drilling a first borehole into the formation, and it further comprises a magnetic field source 5 generating a magnetic field 6, which can be detected by a sensing tool 8 arranged in a second borehole in order to determine the distance between the drilling tool 2 and the sensing tool 8 while drilling and to determine the orientation of the drilling head.

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The ranging system 1 may also be used while drilling two new boreholes. When drilling two boreholes at substantially the same time, the magnetic field source 5 is arranged in one drilling tool 2 and a sensor unit 10 of the sensing tool 8 is arranged in, or in connection with, another drilling tool 2. By processing the measurements

5   conducted by the sensor unit 10, the drilling direction of the drilling tools 2 can be adjusted to ensure that the distance between the two boreholes remains substantially the same. In order to ensure that the boreholes are positioned in the predetermined position, one of the drilling tools 2 may comprise a positioning tool which is able to determine the position of the drilling tools in relation to the starting

10   point or another known position.

In Figs. 1 and 2, the drilling tool 2 has a tool axis 4 and the magnetic field source 5 has a magnetic field source axis 7 which is substantially coincident with the tool axis 4. The magnetic field source 5 may be any suitable electromagnet. By using an

15   electromagnet, the poles can switch, and the sensor units 10 are thereby able to conduct measurements where the contribution from the earth magnetic field is effectively cancelled out.

Furthermore, rotating the drilling string, and thereby the magnetic field source,

20   does not have any substantial effect on the measurements, which means that useful measurements can be made while drilling and even when the drilling tool is not rotating. As shown in Fig. 4, the sensing tool comprises at least two sensor units 10 arranged at a distance D from each other along an axis of the sensing tool. This means that independent measurements of the magnetic field can be made

25   simultaneously, i.e. there is no need for moving the magnet along the tool axis and thus stop drilling while conducting the measurements. In prior art tools, the conducting of measurements is dependent on the magnetic field source rotating and sliding while conducting the measurements. Thus, in prior art tools, measurements can only be performed when the drilling process is stopped.

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If the drilling tool 2 and thereby the drilling process stops, for instance if the drilling tool 2 has broken down, the sensing tool 8 of the present invention is still capable of sensing the magnetic field 6 and thus of continuing to conduct measurements.

35   As shown in Fig. 4, the sensing tool 8 comprises at least two sensor units 10. Thus, the sensor tool 8 comprises at least two magnetometers, enabling it to calculate the exact position of the drilling head 14 in relation to the sensing tool as well as the direction in which the drilling head 14 is drilling. Each magnetometer measures

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the local magnitude and direction of the magnetic field 6 and thus provides independent vector measurements without having to move the magnet in relation to the sensors, as is the case in the prior art. When having several sensor units 10, sufficient measurements can be conducted to calculate the position of the drilling

5   tool in relation to the sensing tool 8 without having to stop the drilling process. The first vector corresponding to the magnitude and direction of the magnetic field 6 measured in a first sensor unit and the second vector corresponding to the magnitude and direction of the magnetic field 6 measured in a second sensor unit are used to calculate the position of the magnet in the drilling tool. The

10   measurements in the two sensor units 10 are conducted at the same time and, as the distance between the sensor units is known, the position of the magnet can be calculated.

When the sensing unit has detected that the distance from the drilling tool to the

15   sensing tool is increased or decreased, the drilling direction of the drilling head 14 can be adjusted so that the direction is the intended direction or so that the distance to a second borehole is the same as the predetermined distance, meaning that the first and second boreholes thus become parallel again.

20   The sensing tool may comprise even more sensing units. Having three or even four sensor units instead of only the two mentioned above will increase the accuracy of the calculated position as well as the direction of the magnetic source and thus the drilling tool. The method described above still applies when using more than two sensor units.

25
When having an electromagnet as the magnetic field source, the magnet does not have to rotate in order to produce useful measurements as the electromagnet is instead pulsed. The direction of the magnetic field is thus the same relative to the rest of the drill string, simplifying the calculation of the position of the magnet

30   substantially. Even though the electromagnet is rotated, its rotational axis can be coincident with the rotational axis of the drilling tool, thus not affecting the direction of the magnetic field.

In Fig. 1, the sensing tool 8 comprises a driving unit 11 for driving the tool in the

35   longitudinal direction of the second borehole 9. The sensing tool 8 may comprise means 12 for adjusting the position of the sensing tool, enabling the sensing tool to move back and forth in the borehole to be within the desired range of the drilling tool. The desired range is the range within which the sensing tool 8 has a distance

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to the magnet of the drilling tool 2, enabling measurements of good enough quality to accurately and precisely calculate the position of the drilling tool in relation to the sensing tool.

5   The drilling tool 2 may also comprise a driving tool if the drilling process is not performed by means of coiled tubing or drill pipes.

In Fig. 1, the first borehole 3 is the borehole to be drilled, and the second borehole 9 is an existing borehole, but the second borehole may also be a well or another
10   kind of hole in the formation. The second borehole 9 may be a vertical part of a well which the drilling tool drilling the first borehole deliberately is to collide with or deliberately is to avoid while drilling.

The drilling tool 2 typically runs on a high-pressurized fluid. As can be seen in Figs.
15   2 and 3, the magnetic field source 5 has a through hole 13, allowing the fluid to pass through the magnetic field source 5 without losing energy. This is especially convenient when the drilling tool 2 is driven by pressurised fluid through drill pipes or coiled tubing.

20   In order to calculate the distance between the drilling head 14 and the sensing tool 8 and the orientation of the drilling head based on the measurements, the ranging system 1 comprises a calculation unit 15 for processing magnitude and direction measurements of the magnetic field 6 measured by the sensor unit 10. The calculation unit 15 is placed in the sensor unit 10.
25

Detailed description of the calculation method

The position, r, of the magnet relative to the sensor is calculated as the solution to a minimisation problem. The expression for the field, B, of a magnetic dipole in
30   vector notation is:

$$B = \frac{\mu}{4\pi}\left(\frac{3(d \cdot r)r}{r^5} - \frac{d}{r^3}\right)$$

where μ is the permeability, d is the dipole vector being substantially coincident
35   with the magnetic field source axis 7, r is the position vector, and r is the distance, i.e. the length of the position vector. This can be rearranged into:

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$$-\frac{\mu}{4\pi}d = r^3\left(B - \frac{3}{2r^2}(r \cdot B)r\right).$$

If two field-vector measurements, B_1 and B_2, are made at the same time in two different places, r and $r+s$, the dipole vector, being the same for both measurements, can be eliminated from the above equation and the following expression emerges:

$$\|r\|^3\left(B_1 - \frac{3}{2\|r\|^2}(r \cdot B_1)r\right) = \|r + s\|^3\left(B_2 - \frac{3}{2\|r + s\|^2}((r + s) \cdot B_2)(r + s)\right)$$

where r is the only variable and s is the relative position between the two measurements. The position of the magnet with respect to the sensor unit, r, can be found by minimisation of a residual based on the equation above, the expression being:

$$r = \arg\min_r\|d_1 - d_2\|,$$

where

$$d_1 = \|r\|^3\left(B_1 - \frac{3}{2\|r\|^2}(r \cdot B_1)r\right)$$

and

$$d_2 = \|r + s\|^3\left(B_2 - \frac{3}{2\|r + s\|^2}((r + s) \cdot B_2)(r + s)\right).$$

After finding the relative position of the magnet, the dipole vector can be calculated directly by insertion into the equation for d.

All of the calculations described above are performed by the processing unit 15 situated in the sensor tool 8 immediately after the measurements are available, and are subsequently transmitted to the surface. Thus, the information about direction and relative position of the drilling head 14 is available to the drilling operator almost instantly, and any needed actions can be performed without further delay.

Thus, there is no heavy data communication or time-consuming post-processing involving personnel for making interpretations of the data.

The method using the ranging system comprises the steps of:

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- drilling the first borehole in one drilling direction,

- inserting the sensing tool into the second borehole,

- measuring the magnitude and direction of the magnetic field, and

- calculating a position of the drilling tool relative to the sensing tool,

5   wherein the steps of measuring and calculating are performed while drilling the first borehole.

The steps of measuring and calculating are performed simultaneously with drilling the first borehole, meaning that the steps of measuring and calculating are 10   performed at least once an hour, preferably at least once every 0.5 hours, more preferably at least once every 10 minutes. It is also possible to do this more often, such as several times per second.

In order to ensure that the borehole is drilled in the predetermined position, either 15   the drilling tool 2 or the sensing tool 8 may also have a positioning tool.

By fluid or well fluid is meant any kind of fluid which may be present in oil or gas wells downhole, such as natural gas, oil, oil mud, crude oil, water, etc. By gas is meant any kind of gas composition present in a well, completion, or open hole, and 20   by oil is meant any kind of oil composition, such as crude oil, an oil-containing fluid, etc. Gas, oil, and water fluids may thus all comprise other elements or substances than gas, oil, and/or water, respectively.

By a casing is meant any kind of pipe, tubing, tubular, liner, string, etc. used 25   downhole in relation to oil or natural gas production.

In the event that the tools are not submergible all the way into the casing, a downhole tractor can be used to push the tools all the way into position in the well. A downhole tractor is any kind of driving tool capable of pushing or pulling tools in 30   a well downhole, such as a Well Tractor®.

Although the invention has been described in the above in connection with preferred embodiments of the invention, it will be evident for a person skilled in the art that several modifications are conceivable without departing from the invention 35   as defined by the following claims.

Claims

1.   A ranging system (1) for controlling a drilling process downhole, the ranging system having a longitudinal direction and comprising:

5   - a drilling tool (2) for drilling a first borehole (3), the drilling tool having a tool axis (4) and comprising a magnetic field source (5) in the form of an electromagnet generating a magnetic field (6) and having a magnetic field source axis (7) which is substantially parallel to the tool axis, and

    - a sensing tool (8) arranged in a second borehole (9) for measuring the magnetic
10   field by means of at least two sensor units (10) wherein the sensor units are arranged at a distance (D) from each other along an axis of the sensing tool.

2.   A ranging system according to claim 1, wherein each sensor unit comprises at least one magnetometer (20).

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3.   A ranging system according to claim 1 or 2, wherein the magnetic field source axis is substantially coincident with the tool axis.

4.   A ranging system according to any of the preceding claims, wherein the
20   sensing tool is submerged into the well by a wireline.

5.   A ranging system according to any of the preceding claims, wherein the magnetometers are arranged in the same plane in the sensor unit.

25   6.   A ranging system according to claim 5, wherein the magnetometers measure the magnitude and direction of the magnetic field, such as the magnitude and direction of a local magnetic field vector.

7.   A ranging system according to any of the preceding claims, wherein the
30   second borehole is an existing borehole.

8.   A ranging system according to any of the preceding claims, wherein the sensor unit and/or the drilling tool is driven by a driving unit (11).

35   9.   A ranging system according to any of the preceding claims, further comprising a positioning tool for determining the position of the sensing tool in the second borehole or the position of the drilling tool in the first borehole.

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10. A ranging system according to any of the preceding claims, wherein the sensing tool has means (12) for controlling and/or measuring the velocity or position of the sensing tool.

5   11. A ranging system according to any of the preceding claims, wherein the magnetic field source has a through hole (13), allowing fluid for driving a drilling head (14) of the drilling tool to pass through the magnetic field source.

12. A ranging system according to any of the preceding claims, further comprising
10   a downhole calculation unit (15) for processing magnitude and direction measurements of the magnetic field measured by the sensing tool.

13. A ranging system according to any of the preceding claims, further comprising a second drilling tool, the sensing tool being arranged in or in connection with the
15   second drilling tool so that the first drilling tool comprises the magnetic field source and the second drilling tool comprises the sensing tool.

14. A method for using the ranging system according to any of the preceding claims, comprising the steps of:
20   - drilling the first borehole in one drilling direction,
      - inserting the sensing tool into the second borehole,
      - measuring the magnitude and direction of the magnetic field while drilling,
      - calculating a position of the drilling tool relative to the sensing tool while drilling, and
25   - calculating the direction of the drilling head,

15. A method according to claim 14, further comprising the step of:
      - adjusting the drilling direction based on the calculated direction and relative position of the drilling tool.
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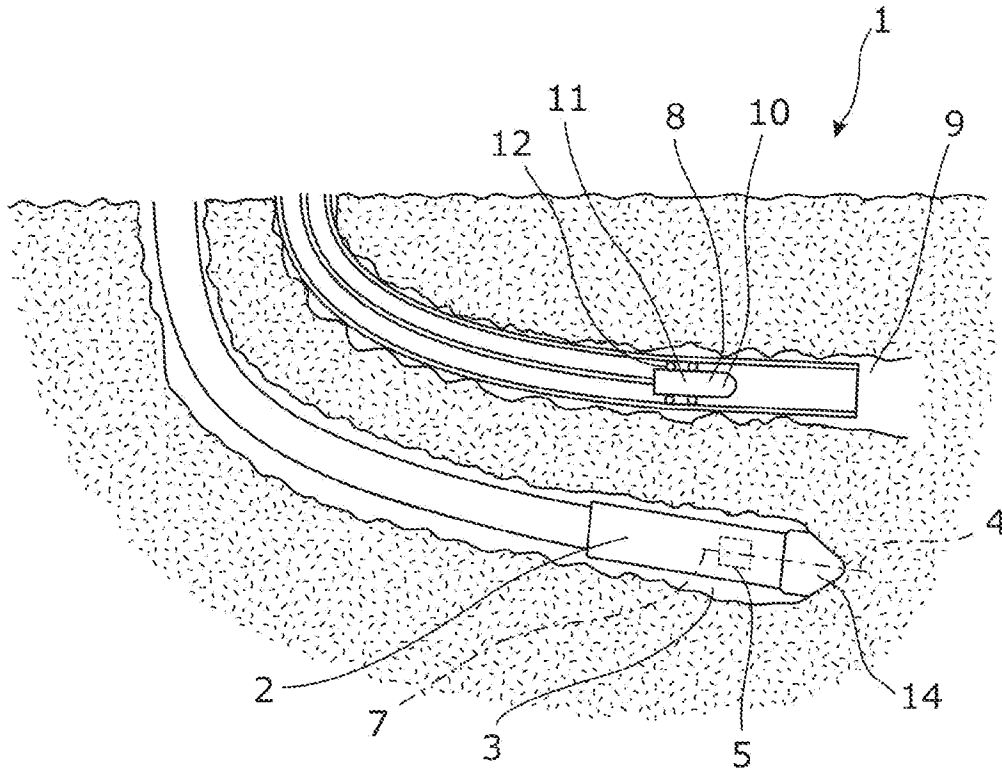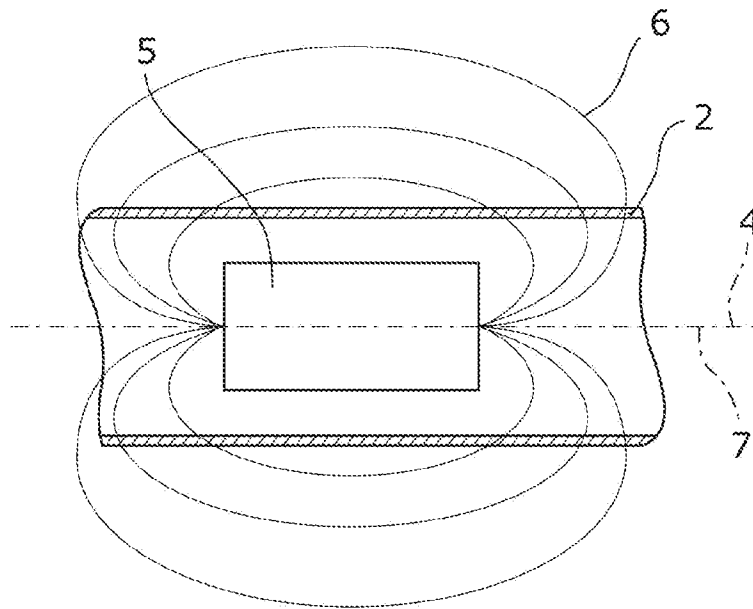   16. Use of the ranging system according to any of the claims 1-13 downhole.
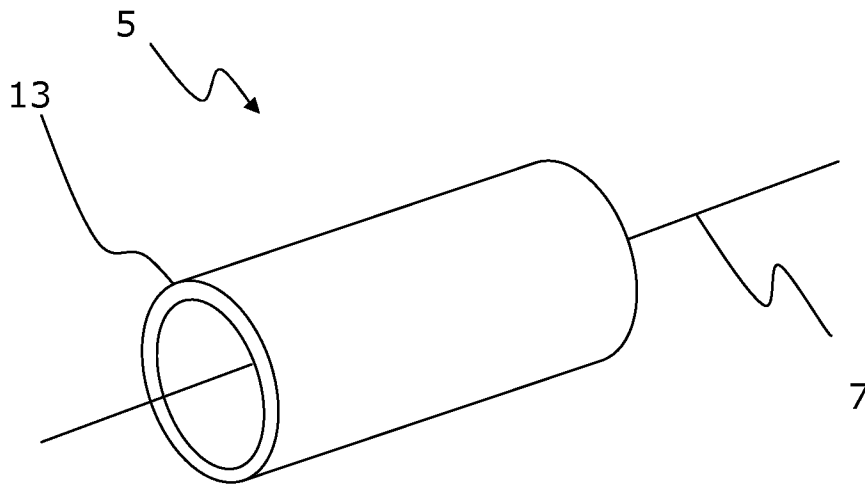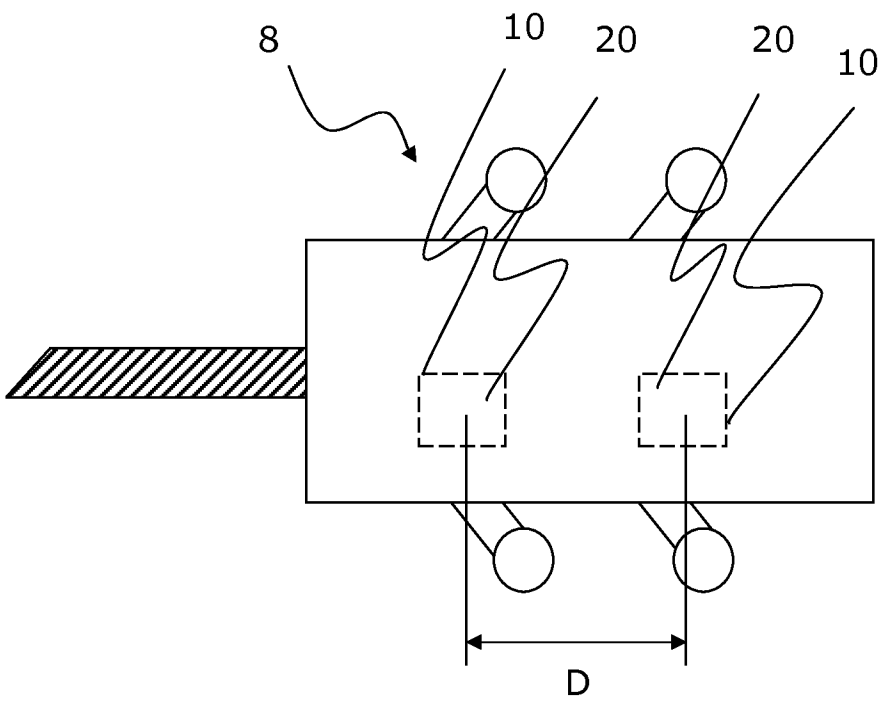
1/2

Fig. 1

Fig. 2

Fig. 3

Fig. 4

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B47/022   G01V3/26
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21B   G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X,P	WO 2010/008634 A1 (SCHLUMBERGER CA LTD [CA]; SCHMLUMBERGER TECHNOLOGY B V [NL]; PRAD RES) 21 January 2010 (2010-01-21) page 11, paragraph 1 page 14, paragraph 1 -----	1-16
A	US 2008/041626 A1 (CLARK BRIAN [US]) 21 February 2008 (2008-02-21) paragraphs [0032] - [0036], [0047] - [0053] -----	1-16
A	US 2009/260879 A1 (CLARK BRIAN [US] ET AL) 22 October 2009 (2009-10-22) paragraphs [0033], [0034] -----	1-16
A	US 5 589 775 A (KUCKES ARTHUR F [US]) 31 December 1996 (1996-12-31) column 3, line 7 - column 4, line 15 -----	1-16

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[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 March 2011	17/03/2011

| Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016 | Authorized officer Garrido Garcia, M |

1

C(Continuation).	DOCUMENTS CONSIDERED TO BE RELEVANT	
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2008/275648 A1 (ILLFELDER HERBERT M J [US]) 6 November 2008 (2008-11-06) paragraphs [0010] - [0011] -----	1-16
A	US 4 933 640 A (KUCKES ARTHUR F [US]) 12 June 1990 (1990-06-12) column 5, lines 6-24 column 6, lines 7-27 -----	1-16
A	US 2008/018334 A1 (REIDERMAN ARCADY [US]) 24 January 2008 (2008-01-24) paragraph [0041] -----	1-16
A	US 2009/260878 A1 (MORLEY JAN S [US] ET AL) 22 October 2009 (2009-10-22) * abstract -----	1-16

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INTERNATIONAL SEARCH REPORT
Information on patent family members

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