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3,406,766

METHOD AND DEVICES FOR INTERCONNECTING SUBTERRANEAN BOREHOLES

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3 Sheets-Sheet 1

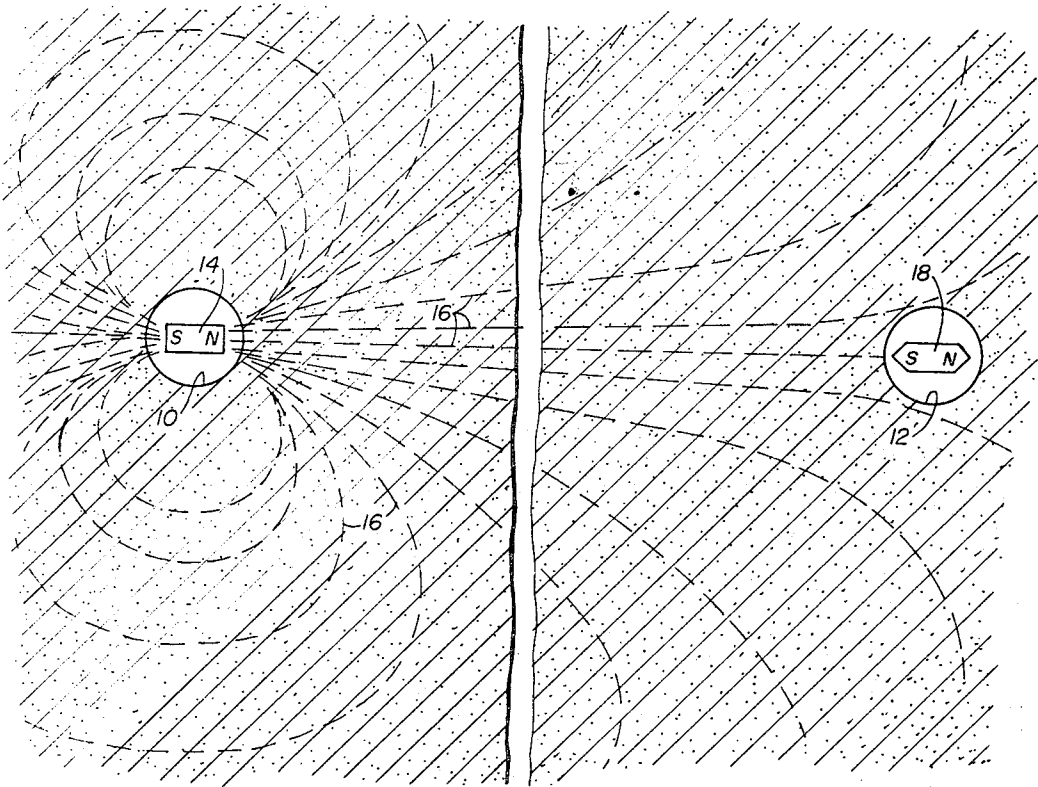


Fig. 1.

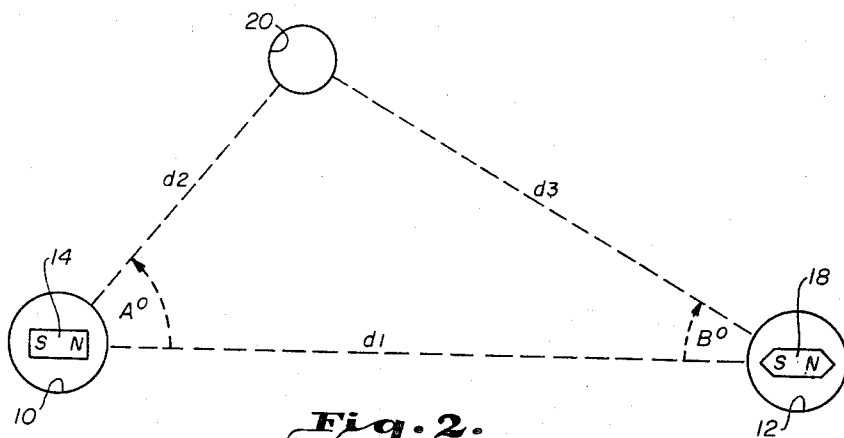


Fig. 2.

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3 Sheets-Sheet 2

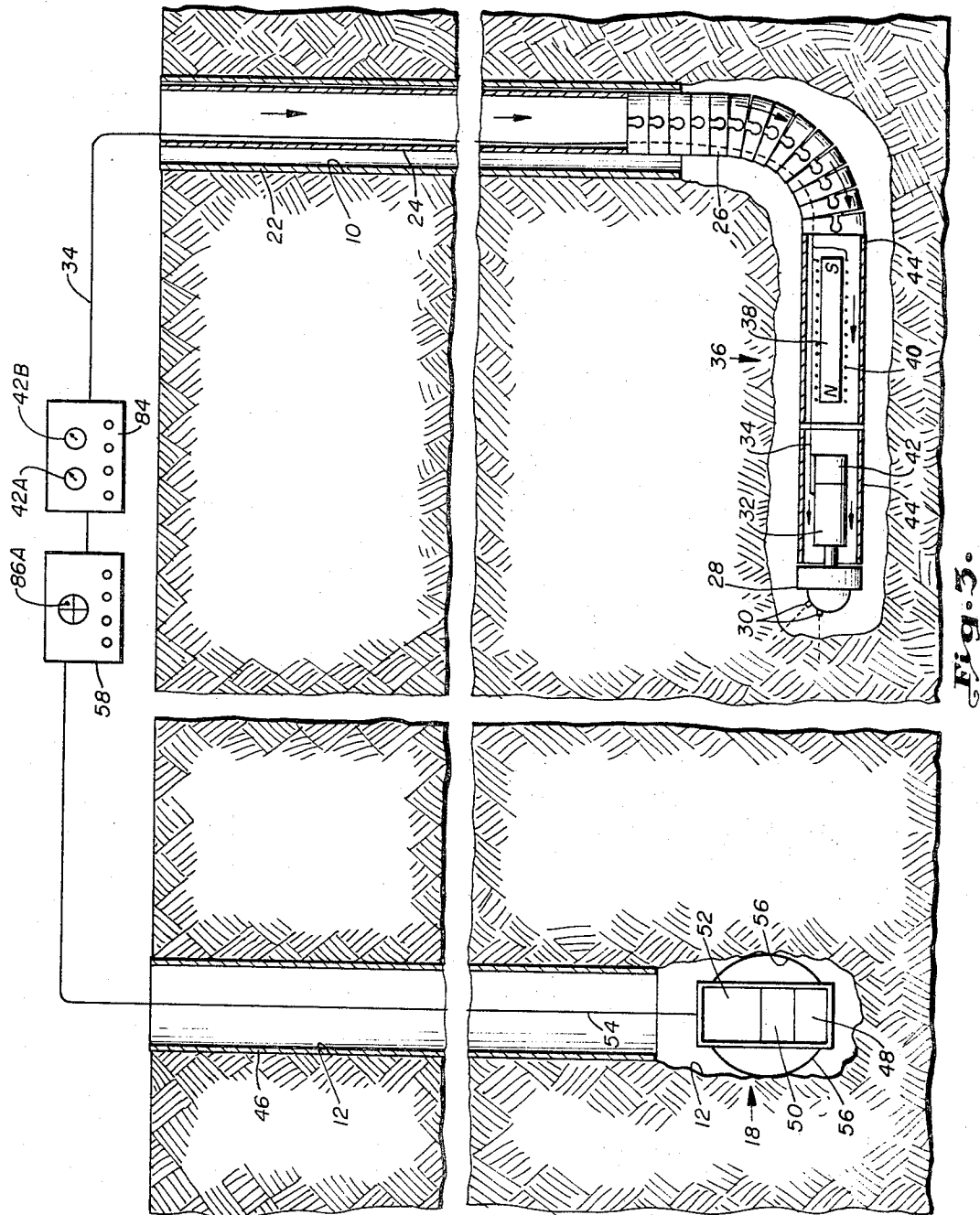


Fig. 3.

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3 Sheets-Sheet 3

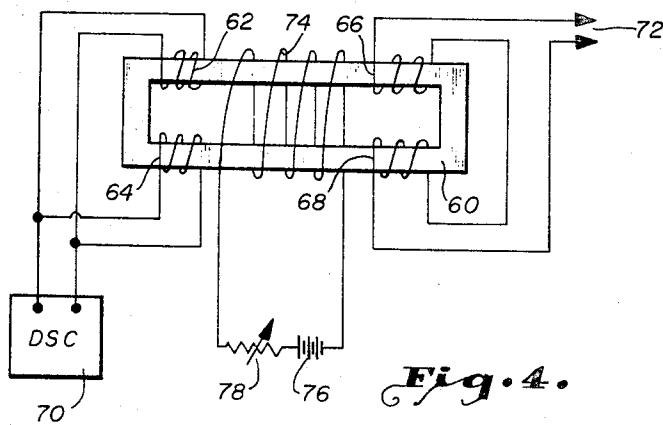


Fig. 4.

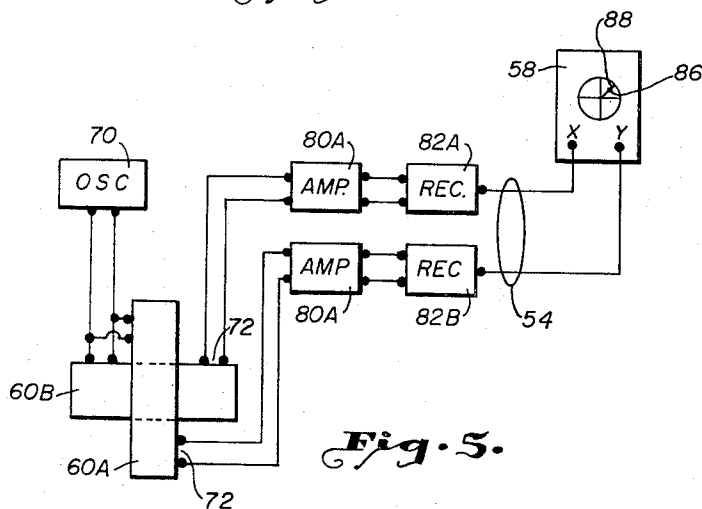


Fig. 5.

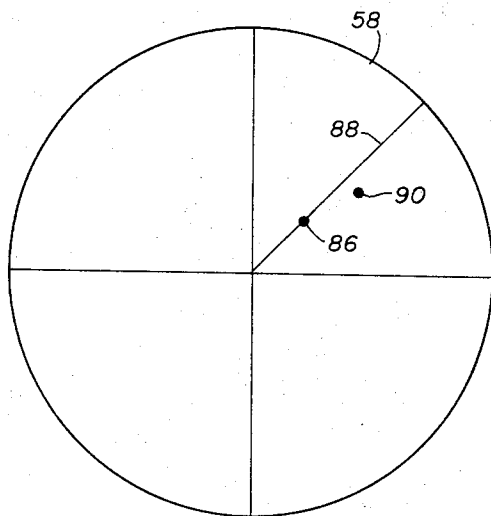


Fig. 6.

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METHOD AND DEVICES FOR INTERCONNECTING SUBTERRANEAN BOREHOLES

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Continuation-in-part of application Ser. No. 362,100,
Apr. 23, 1964. This application July 7, 1966, Ser.
No. 563,555

14 Claims. (Cl. 175-61)

This application is a continuation-in-part of S.N. 362,100, filed Apr. 23, 1964, now Patent No. 3,285,350, issued Nov. 15, 1966, for a Method and Apparatus for Controllably Drilling Off-Vertical Holes. In S.N. 362,100 is described a method of drilling a hole from a first subterranean point to a second subterranean point. The method disclosed consists essentially of the steps, in drilling from one borehole to another, of positioning a drilling device in the first borehole, positioning a signal generating device in one of the boreholes, positioning a signal receiving device in the other of the boreholes, one of the signal generating device or signal receiving device being attached to the drilling device for advancement with it, drilling with the drilling device in an off-vertical direction towards the first borehole and correcting the direction of drilling as indicated by the character of signal received by the signal receiving device from the signal generating device to continually drill towards the second borehole until the drilling device reaches the second borehole. This invention has for its principal object the provision of methods and devices accomplishing the principles of the above-identified application in an arrangement wherein the signal generating means is in the form of a magnetic field generating means and wherein the signal receiving means is in the form of a magnetic field direction sensing means.

It is therefore an object of this invention to provide methods and apparatus for interconnecting a first subterranean point with a second subterranean point by means of a directionally controllable drill and including means wherein the drill is controlled in direction in response to a magnetic field created by a magnetic field generating means in the first or second point to be interconnected and a magnetic field direction sensing means positioned in the other of the said points to be interconnected, one of the magnetic field generating means and the magnetic field sensing means being carried by said direction controllable drill.

Another and more specific object of this invention is to provide methods and devices for controllably drilling from a first subterranean point to intersect a second subterranean point including means of generating a magnetic field carried by a drilling means and means of receiving and directionally sensing the magnetic field positioned at the subterranean point to be intersected.

Another object of this invention is to provide methods and devices for directionally drilling a first well to intersect a subterranean point displaced from a second well.

These and other objects of the invention will be fulfilled and a better understanding had by referring to the following description and claims taken in conjunction with the attached drawings in which:

FIGURE 1 is a diagrammatic representation of the principals of this invention showing, in horizontal cross-section, two spaced subterranean wells wherein a magnetic field is created in one well and the direction of the origination of such magnetic field is indicated in the other well as a means of indicating the direction for controllably drilling one of the wells to intersect the other.

FIGURE 2 is a diagrammatic view showing the arrangement of this invention wherein a magnetic field is created in a first subterranean well and the direction of the origination of the magnetic field sensed in a second sub-

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terranean well and the detected direction utilized for controllably drilling the first subterranean well to a preselected point displaced from the second subterranean well.

FIGURE 3 is a vertical cross-sectional view showing the application of the methods and devices of this invention wherein a first subterranean well is being interconnected with a second subterranean well by means of a directionally controllable drill in the first well in an arrangement including a source of magnetic field carried by the directionally controllable drill and a magnetic field direction sensing means positioned in the second well.

FIGURE 4 is a schematic representation of a flux gate magnetometer illustrated as one embodiment of the invention for detecting the direction of emanation of a magnetic field.

FIGURE 5 is a schematic block diagram of a magnetic direction sensing device as utilized to practice the methods of the invention for detecting the direction of emanation of a magnetic field.

FIGURE 6 is a representation of the screen of an oscilloscope illustrating the use of an oscilloscope as an indicator in the practice of the methods of this invention.

Referring now to the drawings and first to FIGURE 1, a first subterranean well 10 formed in the earth is illustrated spaced from a second subterranean well 12. This invention provides methods and devices for controllably drilling from the first well 10 to the second well 12, that is, interconnecting wells 10 and 12. According to the principles of this invention, a magnetic field is established in one of the wells, illustrated in FIGURE 1 as being established in first well 10. The magnetic field is illustrated as being established by a magnet 14 which may be in the form of a permanent magnet or an electromagnet. The lines of flux forming the magnetic field extend out in a manner substantially as illustrated, the lines of flux being illustrated as those formed in a horizontal plane of the magnet, a part of which lines of force pass through the second well 12. In the second well 12 a magnetic field direction sensing device is positioned, illustrated in the form of a compass. By means of the magnetic field direction sensing device 18 the direction of emanation of the magnetic field is indicated and from this indication the direction required to drill from well 10 to well 12, or vice versa, can be established.

While normally, in most petroleum producing and mining operations, the practice of the methods of this invention will be utilized to drill a subterranean interconnection between a first and a second well, the principles of this invention can equally be applied to drill an interconnecting passage from a first well to a preselected point displaced from a second well. This method is illustrated diagrammatically in FIGURE 2. A magnetic field generating means 14 is positioned in first well 10. In second well 12 the magnetic field direction indicating device 18 is positioned which is effective to detect the direction of emanation of the magnetic field originating from well 10. If it is desired to drill a subterranean connection between second well 12 and a subterranean point 20 displaced from the first well 10, such can be accomplished by incorporating the principles of this invention. Since the distances between the wells and subterranean point 20 are known, illustrated by d_1 , d_2 and d_3 , and since angles A and B are known, the direction of drilling can be controlled in response to the detected direction of emanation of the magnetic field from first well 10. By application of trigonometric principles second well 12 can be drilled to intersect the subterranean point 20.

Referring to FIGURE 3, devices exemplifying means of accomplishing the methods of the invention are illustrated. First well 10, which may have inserted in the upper portion thereof a casing 22, includes a drill pipe 24 having at the lower end thereof a flexible portion 26.

The outer end of the drill pipe 24 is provided with a directionally controllable drill head 28. Drilling may be accomplished in a variety of ways but the illustration is that of the use of a jet stream for producing drilling, the drill head 28 accomplishing drillable direction by means of varying the attitude of the drilling jets 30, and the attitude of drill head 28 being, in turn, determined by a jet head positioner 32 which is electrically controlled from the earth's surface by means of signals supplied through multiconductor cables 34.

Adjacent the drill head 28 and its positioner 32 is a magnetic assembly generally indicated by the numeral 36, which is essentially formed of a core 38 and an encompassing coil 40. Electrical energy to the magnetic assembly is supplied from the surface by multiconductor cables 34.

The drilling device includes a roll and level sensor 42 by which signals indicative of the direction of drilling of drill head 28 are conveyed through multiconductor cables 34 to the earth's surface.

The magnetic assembly 36, the jet head positioner 32 and roll and level sensor 42 are so arranged to permit drilling fluid to pass therearound within their housing 44. The housing 44 may be of stainless steel or other metal which does not interfere with the magnetic field created by the magnetic assembly.

A direct current voltage applied to coil 40 creates a magnetic field within the core 38. The lines of force (or magnetic flux) of the field created thereby extend for a distance in the subterranean area surrounding the magnetic structure, as illustrated in FIGURE 1.

Second well 12 (of FIGURE 3) is illustrated as typically including a casing 46. Positioned in the lower end of the well borehole 12 is a magnetic field direction sensing device, generally indicated by the numeral 18. The magnetic field direction indicating device may consist of any arrangement for detecting the direction of the magnetic field within which the device is positioned. As an exemplification, such a device is illustrated as including a first fluxgate 48, a second fluxgate 50 positioned adjacent thereto and oriented perpendicular to the first, and an electronic package 52 in which the electronic devices for actuating the fluxgates 48 and 50 and receiving and amplifying the signals therefrom are included. A multiconductor cable 54 is affixed to the device 18 and extends to the surface. The cable 54 includes not only electrical signal carrying portions but strength imparting portions whereby the device 18 may be lowered into and retrieved from the well borehole 12. To fix the device 18 in a single position within the borehole 12, that is, to prevent its rotation while in use, flexible bows 56 extend from the exterior thereof which engage the sides of the borehole 12.

Conductor cable 54 extends to the surface and connects to a magnetic field direction indicating device 58 which may be in the form of an x-y recorder such as a typical oscilloscope.

Referring to FIGURES 4 and 5, the arrangement of the magnetic field direction indicating device is shown, it being understood that such illustrations are exemplary only as one embodiment by which the invention may be practiced. FIGURE 4 illustrates the basic elements of a fluxgate magnetometer. A low reluctance elongated magnetically directionally sensitive loop 60 is the basis of the device. On opposing legs of the loop drive coils 62 and 64 are wound, the drive coils being wound in opposite directions. Spaced from the drive coils are oppositely wound sense coils 66 and 68. An oscillator 70 imparts an AC current flow in the paralleled drive coils 62 and 64 which in turn impart alternating magnetic forces in opposite direction in the loop 60. The drive coils 62 and 64 drive the loop 60 beyond saturation. When the loop 60 is not subject to any ambient magnetic field the voltage imparted in sense coils 66 and 68 are equal and opposite so that no voltage is obtained at the output points 72. When the mag-

netic loop 60 is subjected to an ambient magnetic field having lines of force including a vector component paralleling the length of the loop 60, the level at which saturation of the loop is obtained is altered thereby, altering the voltage induced in sense coils 66 and 68, disturbing the voltage balance and producing an AC voltage at output points 72.

The magnetic field direction indicating device 18 will be subject to the earth's magnetic field so, in order to eliminate the effect of the earth's magnetic field, a neutralizing coil 74 is formed around the magnetic loop 60. By means of a DC voltage force 76, the plurality of which can be reversed, a magnetic field can be induced in loop 60 opposite that induced by the earth's magnetic field. Rheostat 78 controls current flow through the neutralizing coil 74 so that the magnetic field induced can be adjusted to be that exactly opposite the component of the earth's magnetic field.

The fluxgate magnetometer of FIGURE 4 is sensitive only to magnetic fields having a vector component parallel the length of the loop 60 and is therefore not sensitive to magnetic fields perpendicular the length of the loop. In order to establish the direction of emanation of a magnetic field two of such fluxgate magnetometers are required positioned adjacent to and perpendicular to each other. This arrangement is illustrated in FIGURE 5, the loop being designated by the numerals 60A and 60B, the coils not being shown, it being understood that they are included in the assembly. The same oscillator 70 may be utilized to drive each of the fluxgate magnetometers. The output points 72 are each connected to amplifiers 80A and 80B which amplify the AC signals output from each of the magnetometers. This AC signal output is then converted to a DC voltage by rectifiers 82A and 82B. The output of the rectifiers is fed through conductor 54 to the x-y recorder 58 located at the earth's surface.

The oscillator 70, amplifiers 80A and 80B, and rectifiers 82A and 82B may be positioned in the electronic package 52 adjacent the magnetometers 48 and 50 as illustrated in FIGURE 3. The voltage source 76 and rheostat 78 for each of the magnetometers may be located at the surface of the earth.

The roll and level sensors 42 of the drilling device (see FIGURE 3) are connected to a programmer 84 positioned at the earth's surface, the roll and level positions of the drill head 28 being indicated by roll and level position instruments 42A and 42B. Control means with the programmer enable the operator to select the roll and level attitude of drill head 28.

Operation

After a first borehole 10 and a second borehole 12 are formed in the earth and it is desired to interconnect the boreholes at the lower end thereof, the drilling device as shown in FIGURE 3 is lowered into the first borehole 10. By means of a whipstock or other devices well known in the industry the direction of drilling can be deflected horizontally towards the second borehole 12 to an accuracy of within ten degrees of the direction necessary to intersect the second borehole. That is, by means well known in the petroleum industry the direction of drilling of the first borehole 10 can be initiated towards the second borehole 12 to within ten degrees. This invention provides means of correcting the direction of drilling continually or at intervals, as required, so that the direction of drilling will proceed to intersect the second borehole 12 or to intersect some preselected point displaced from the second borehole as illustrated in the diagram of FIGURE 2.

After horizontal direction drilling has been initiated at the first borehole 10, the magnetic field direction indicating device 18 is lowered into second borehole 12. The oscillators portion 70 of the instrument is initiated producing an x-y DC voltage output. The effect of the magnetic field will provide a spot 60 on the x-y recorder 58

(in this illustration being an oscilloscope) representative of the direction of the earth's magnetic field. By means of voltage sources 76 and rheostat 78 the direction and polarity of current flow through coils 74 can be adjusted to neutralize the magnetic fields in each of the perpendicularly positioned magnetometers which will have the effect of eliminating voltage outputs from rectifiers 82A and 82B bringing the spot 86 back to the center. With the earth's magnetic field neutralized, magnetic structure 36 positioned in the second borehole may be energized. This will create a magnetic field which effects the magnetometers 48 and 50, the extent of the effect being determined by the vector component of the field perpendicular to the magnetic loop 60 in each of the magnetometers. This will produce x and y voltage moving the oscillograph spot 86 (see FIGURE 6) from its center position and indicating the direction of emanation of the field created by magnetic structure 36 positioned in borehole 10. A line 87 drawn from the axis of the scope passing through the spot 86 will then represent the direction of drilling required to intersect second borehole 12. Drilling can then be commenced. As the magnetic structure 36 approaches the direction of indicating device 18, the x and y voltages will increase causing the dot 86 to move away from the center axis of the scope. As long as the drilling is directly towards the direction indicating device 18 the dot 86 will move on the straight line 87. If the direction of drilling departs from the direction necessary to intersect the second borehole 12, dot 86 will move away from line 88, as an example, to the position of dot 90. The operator will know that the drilling is not proceeding towards the second borehole 12 and can, by means of the rotation of the drill head 28, correct the direction of drilling to bring it back in the line of direction which will result in the intersection of the second borehole 12.

In this description the magnetic structure 36 has been illustrated as being positioned with the drilling structure to be advanced with the drill and the direction indicating device 18 is illustrated as being positioned in the second or target borehole. It is understood that the reverse can equally well be utilized, that is, the direction indicating device 18 may be carried with the drilling attachments and the magnetic structure 36 positioned in the target borehole.

The utilization of juxtaposed perpendicular fluxgate magnetometers and an oscillograph as an x-y recorder are merely exemplary of one embodiment of the invention and other devices which detect the direction of a magnetic field may be employed in practicing the methods of the invention. As an example, a compass or any simple device effected by a magnetic field may be utilized as the direction indicating means in conjunction with photoelectric devices responsive to convey the direction the compass points to the earth's surface. Another example of a magnetic field direction indicating device includes the use of a compass to point the direction of the magnetic field and a television picture transmitting system positioned adjacent the compass to transmit the picture indicating the direction the compass is pointing to the surface. Many other devices to indicate the direction of the magnetic field will be suggested to those skilled in the art.

While drilling from a first to a second borehole has been described as being in the nature of horizontal drilling, it is understood that "horizontal" is used in a relative way and that the interconnection of one borehole with another or one borehole with a preselected point spaced from a second borehole may be made practicing the invention wherein the interconnecting drilling is conducted at an angle relative to the horizontal. The expression "borehole" is used in the broadest sense. For example, the methods and devices of this invention may be used to drill a hole from one mine shaft or cavern to another and therefore "borehole" includes any underground excavation.

While this invention has been described with a certain degree of particularity, it is manifest that many changes may be made in the details of construction and the arrangement of components without departing from the spirit and scope of this disclosure.

What is claimed:

1. A method of directionally drilling a first well to intersect a second well comprising the steps of:

establishing a magnetic field in one of said first and second wells with a magnetic field generating means; detecting the direction of emanation of said magnetic field with a magnetic field direction sensing means, and

orienting the course of drilling of a directionally controllable drilling means in said first well in response to said detected direction of said magnetic field.

2. A method of directionally drilling a well to intersect a second well according to claim 1 including advancing the one of said magnetic field generating means and said magnetic field direction sensing means at said first well with said drilling means.

3. A method of directionally drilling a well to intersect a second well according to claim 1 including the step of nulling out extraneous magnetic fields before detecting the direction of said magnetic field established by said magnetic field generating means.

4. A method of directionally drilling a well to intersect a second well according to claim 1 including the steps of periodically interrupting the drilling of said drilling means, detecting the direction of emanation of said magnetic field and reorienting the direction of drilling of said drilling means, and sequentially repeating the steps until said first well intersects said second well.

5. A method of directionally drilling a well to intersect a second well according to claim 1 wherein the steps of detecting the direction of emanation of said magnetic field and orienting the course of drilling are continuously carried on until said first well intersects said second well.

6. A method of directionally drilling a first well to intersect a subterranean point displaced from a second well comprising the steps of:

establishing a magnetic field in one of said first and said second wells with a magnetic field generating means;

detecting the direction of emanation of said magnetic field with a magnetic field direction sensing means at the other of said first and said second wells, and

orienting the course of drilling of a directionally controllable drilling means at said first well towards intersection with said subterranean point in response to said detected direction of said magnetic field.

7. A method of directionally drilling a first well to intersect a subterranean point displaced from a second well according to claim 6 including advancing the one of said magnetic field generating means and said magnetic field direction sensing means at said first well with said drilling means.

8. A method of directionally drilling a first well to intersect a subterranean point displaced from a second well according to claim 6 including the step of nulling out extraneous magnetic fields before detecting the direction of said magnetic field established by said magnetic field generating means.

9. A method of directionally drilling a well to intersect a subterranean point displaced from a second well according to claim 6 including the steps of periodically interrupting the drilling of said drilling means, detecting the direction of emanation of said magnetic field and reorienting the direction of drilling of said drilling means and sequentially repeating the steps until said first well intersects said subterranean point.

10. A method of directionally drilling a well to intersect a subterranean point displaced from a second well according to claim 6 wherein the steps of detecting the direction of emanation of said magnetic field and orient-

ing the course of drilling are continuously carried on until said first well intersects said subterranean point.

11. Apparatus for directionally drilling a first well to intersect a second well comprising:

- a directionally controllable hole drilling device positioned in said first well; 5
- means for advancing said drilling device;
- a magnetic field generating means positioned in one of said first and second holes;
- a magnetic field direction sensing means positioned in the other of said boreholes, the one of said magnetic field generating means and said magnetic field direction sensing means positioned in said first hole being advanced with said directionally controllable hole drilling device; 10
- an indicator at the earth's surface having communication with said magnetic field direction sensing means, and 15
- means for changing the direction of drilling of said drilling device towards said second well in response to the detected direction of emanation of said magnetic field as indicated by said indicator. 20

12. An apparatus according to claim 11 wherein said magnetic field generating means includes an electromagnetic means in tandem with and advanced with said directionally controllable drilling device. 25

13. An apparatus according to claim 11 wherein said magnetic field direction sensing means includes earth's magnetic field neutralizing means.

14. An apparatus according to claim 11 wherein said magnetic field direction sensing means includes .

- a first fluxgate magnetometer providing a DC voltage output in response to a magnetic field having a vector component in one direction relative thereto;
- a second fluxgate magnetometer providing a DC voltage output in response to a magnetic field having a vector component in one direction relative thereto, said first and second fluxgate magnetometers being arranged in juxtaposed relation to each other in a borehole and in 90° magnetic field direction response relationship; and
- a cable for conducting the DC voltage output of each of said fluxgate magnetometers to the earth's surface.

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