June 19, 1951 J. J. ARPS ET AL 2,557,168

CONTINUOUS ELECTRIC LOGGING WHILE DRILLING

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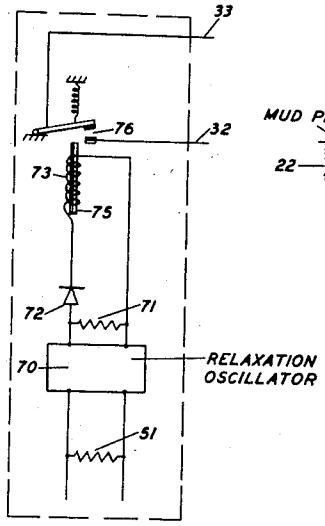


FIG. 2

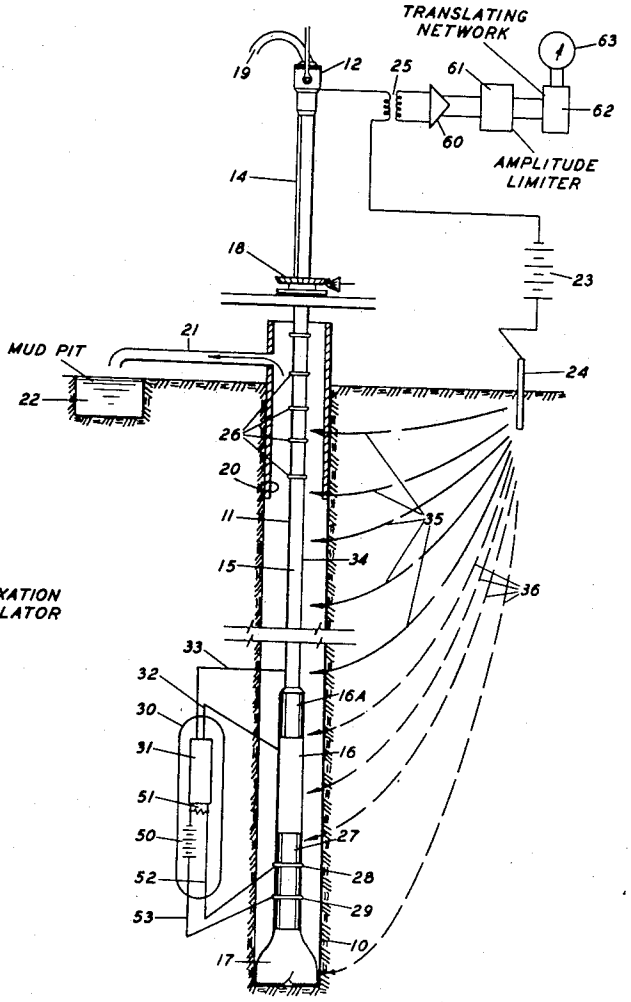


FIG. 1

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CONTINUOUS ELECTRIC LOGGING WHILE DRILLING

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6 Claims. (Cl. 175—182)

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This invention relates to electrical exploration of geological strata traversed by bore holes. Heretofore, in the practice of electrical well-logging, a source of electric current has been located on the surface of the earth and current has been applied to the geological strata to be explored through the medium of an insulated conductor. The provision of such insulated conductor is a difficult matter, particularly when it is desired to perform the electrical logging along with the drilling operation.

An object of this invention is a new method or an apparatus for the electrical exploration of geological strata traversed by bore holes wherein is avoided the necessity of using an insulated conductor in the drill hole.

The method and apparatus of the present invention are equally applicable to the exploration of bore holes simultaneously with the drilling operation or to the exploration of bore holes in which the drilling either has been completed or suspended.

A number of efforts were made in the prior art to use the method of continuous electric logging while drilling whereby a current is sent down from the surface through the drill pipe to the bit and returns to a grounded electrode nearby. It was believed that the slight changes in conductivity, due to the bit opening more formation, would cause corresponding changes in the total conductance of the circuit, thereby making it possible to obtain from the changes in total current a continuous log of the resistance changes due to the penetration of the bit. This proves impractical because the slight changes in overall resistance due to the changing resistance at bottom are too small to be measured against a background of normal fluctuation encountered during drilling, when the position of the drill pipe and its contact with the wall of the hole is constantly changing.

The proposed method overcomes the above difficulty by converting an actual measurement of the resistance or any other characteristic near the bottom of the hole into a frequency-modulated signal which is used to alternately cut in and out the conductivity of the drill collar section and the bit from the total conductive circuit formed by the drill pipe and the surrounding formation. Thus the total resistance of the drill string is varied periodically by a small amount which causes a corresponding small periodic change in the total current output of the system. This frequency-modulated current can be measured at the surface and recorded against depth,

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thereby producing a log of the characteristic of the formation while drilling.

Various novel features and advantages of this invention will become apparent from the following specification and accompanying drawing, wherein:

Fig. 1 is a vertical section through a bore hole in which is provided one form of apparatus for practicing the invention.

Fig. 2 shows diagrammatically one of the elements of the arrangement of Fig. 1.

As shown in Fig. 1, the bore hole 10 is being drilled by means of conventional drilling apparatus 11. This consists of swivel 12 supported from the derrick, to which is attached Kelly 14, supporting drill string 15, drill collars 16 and bit 17. The string is rotated by means of conventional rotary table 18. Cuttings are being removed by mud entering the swivel goose-neck 19, flowing down the drill string and up from the bit through the annular space to the surface where it leaves surface casing 20 through flow line 21, and is deposited in mud pit 22, to be recirculated by mud pumps, not shown, to swivel goose-neck 19.

A source of electric power, such as a battery 23, is located at the surface and has its positive terminal grounded by means of a suitable ground electrode 24, located at a considerable distance away from the bore hole. The negative terminal is connected through the winding of a transformer 25 with swivel 12. The top part of the drill pipe within the surface casing 20 is provided with rubber drill pipe protectors 26 which prevent electrical contact between drill pipe and casing. All other parts of the surface equipment connected with the top part of the drill string are insulated in a corresponding manner, by suitable means, from grounding. The drill collar section 16 is insulated from the drill pipe above by means of insulating drill collar joint 16A. The bottom section of the drill collar 27 is provided with an outside insulating sleeve, which is equipped with electrode rings 28 and 29.

Within the drill collar is positioned a suitable container schematically designated by 30, comprising a battery 50, having one of its terminals connected through a resistor 51 to a lead 52 and having the other terminal connected to the lead 53. The leads 52 and 53 are respectively connected to the electrodes 28 and 29, thus forming a closed circuit through the formation in the neighborhood of the electrodes. Consequently, the current passing in this circuit will be sub-

stantially proportional to the formation conductivity in the vicinity of these electrodes.

The output terminals of the resistor 51 are connected to a transducer comprised within the block 31 and provided with output leads 32 and 33, said output lead 32 being grounded to the drill collar metal, while the output lead 33 is attached to the drill pipe above the insulating drill collar joint 16A. The transducer 31 is shown schematically in Fig. 2 and is adapted to produce a frequency-modulated signal which alternately makes and breaks the connection between leads 32 and 33.

It is obvious that when leads 32 and 33 are not connected, the drill collar section is electrically separated from the drill string above, so that the current from electric power source 23 and ground electrode 24 will have to find its way predominantly through the earth to drill pipe section 34, as indicated by arrows 35. When, however, contact is made between leads 32 and 33, the drill collar section and the bit are included in the conductance of the drilling string, thereby causing part of the current from power source 23 to flow from ground electrode 24, as indicated by dashed arrows 36. It will be obvious that the increased conductance of the circuit in the latter case will cause a corresponding increase in the current through the entire circuit. A corresponding decrease will occur when leads 32 and 33 are disconnected. Consequently, the conductance of the electrical circuit energized by the source 23 will alternately increase and decrease, and the number of alternations per second i. e. the frequency of alternation will be equal at any instant of time to the frequency of the signal supplied by the transducer 31 for making and breaking the connection between leads 32 and 33.

It is apparent, therefore, that the current passing through the primary winding of the transformer 25 consists of a direct current (with some slight low frequency modulations because of the drill pipe rotation) plus a high frequency alternating current caused by the frequency modulation effected by the transducer 31. We obtain thus across the output of the transformer 25 a frequency-modulated current which passes through an amplifier 60 to an amplitude limiter 61. The amplitude limiter is well known in the art and has as a purpose the elimination of any amplitude modulation of the input voltage, since such amplitude modulations do not carry any useful information. The output of the limiter 61 is in turn applied to a translating network 62 which transforms the frequency-modulated voltage applied to its input into a corresponding amplitude-modulated output signal.

It is apparent that the amplitude of the voltage at the output of the translating network 62 corresponds at any instance to the number of alternate "in" and "out" connections per unit of time produced by the transducer mechanism 31 and represents, therefore, the conductivity of the formation traversed by the drill hole. Consequently, the ampere meter 63 applied to the output of the translating circuit 62 provides us with the desired index of the conductivity of the formation in the vicinity of the electrode rings 28 and 29.

Consider now Fig. 2 showing schematically the transducer 31. The transducer comprises a relaxation oscillator 70 having its input terminals connected to the resistor 51 and output terminals connected to another resistor 71. The relaxation oscillator is well known in the art and is adapted to produce across the resistor 71 an alternating

voltage, the frequency of which is proportional to the D. C. voltage derived from the resistor 51. Consequently this frequency represents at any instant the conductivity of the formation drilled. The resistor 71 is in series with a rectifier 72 and solenoid 73, said solenoid being adapted to activate a plunger and to close contact 76 whenever a current passes through its windings. The current through the windings pulsates at a frequency representing the conductivity of the formation and provides, therefore, a mechanism to connect and disconnect the leads 32 and 33 in a manner hereinbefore described.

It is apparent that the principles of this invention can be applied to other measurements, such as the self-potential, the weight of the bit on bottom, or the bottom hole temperature. When two signals are required, interrupted frequency modulation can be used, the frequency measuring one variable and the length of silence period the other. When a third variable is desired, it may be represented by the length of the signal period. Additional variables, such as a gamma ray or neutron log measurement may be transmitted and recorded by means of other frequencies sufficiently different from the ones mentioned previously to be separated by conventional electronic means.

We claim:

1. Apparatus for determining a characteristic of a formation traversed by a drill hole, which extends from the earth's surface into the earth, comprising in combination with a drill stem and a drill bit in said drill hole a tubular insulated container dividing said drill stem into an upper and a lower portion electrically insulated one from the other, a detector in the lower part of said drill stem adapted to produce a signal representing said formation characteristic, means for electrically connecting said two insulated portions and for varying said connection in response to said signal, an electrical generator at the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which varies in accordance with variation of said connection, whereby the electric current supplied by said generator correspondingly varies and a measuring means positioned at the earth's surface for measuring said current, thereby producing an index representing said formation characteristic.

2. Apparatus for determining a characteristic of a formation traversed by a drill hole, which extends from the earth's surface into the earth, comprising in combination with a drill stem and a drill bit in said drill hole a tubular insulated container dividing said drill stem into an upper and a lower portion electrically insulated one from the other, a detector in the lower part of said drill stem adapted to produce a signal representing said formation characteristic, a switch for electrically connecting or disconnecting said two insulated portions, a control mechanism responsive to said signal for alternately connecting and disconnecting said two portions in accordance with a program determined by the magnitude of said signal, an electrical generator at the the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which varies in accordance with said program, whereby the electric current supplied by said generator correspondingly varies

and a measuring means positioned at the earth's surface for measuring said current, thereby producing an index representing said formation characteristic.

3. Apparatus for determining a characteristic of a formation traversed by a drill hole, which extends from the earth's surface into the earth, comprising in combination with a drill stem and a drill bit in said drill hole a tubular insulated container dividing said drill stem into an upper and a lower portion electrically insulated one from the other, a detector in the lower part of said drill stem adapted to produce a signal representing said formation characteristic, a controllable switch mechanism actuated by said signal for alternately connecting and disconnecting said two portions at a rate that represents the magnitude of said signal, an electrical generator at the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which varies in accordance with said rate, whereby the electric current supplied by said generator has a frequency that represents said rate, and a measuring means positioned at the earth's surface and responsive to the output of said generator, for measuring said rate, thereby producing an index representing said formation characteristic.

4. Apparatus for determining a characteristic of a formation traversed by a drill hole, which extends from the earth's surface into the earth, comprising in combination with a drill stem and a drill bit in said drill hole a tubular insulated container dividing said drill stem into an upper and a lower portion electrically insulated one from the other, a detector in the lower part of said drill stem adapted to produce a signal representing said formation characteristic, a switch for electrically connecting or disconnecting said two insulated portions, a control mechanism responsive to said signal for actuating said switch at determined intervals in order to alternately connect and disconnect said two portions, the time interval separating said instants representing the magnitude of said signal, an electrical generator at the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which undergoes variation at said instants, whereby the electric current supplied by said generator correspondingly undergoes variation at said instants, and a measuring means positioned at the earth's surface and responsive to said current, thereby producing an index representing said intervals.

5. Apparatus for determining resistance of a

formation traversed by a drill hole, which extends from the earth's surface into the earth, comprising in combination with a drill stem and a drill bit in said drill hole a tubular insulated container dividing said drill stem into an upper and a lower portion electrically insulated one from the other, means encased in the lower part of said drill stem for transmitting electrical current into said formation, another means encased in the drill collar responsive to the current traversing said formation for producing a signal, a switch responsive to said signal for alternately connecting and disconnecting said two insulated portions at a rate that represents the magnitude of said signal, an electrical generator at the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which varies in accordance with said rate, whereby the electric current supplied by said generator correspondingly varies, and a measuring means positioned at the earth's surface for measuring said rate, thereby producing an index representing said formation characteristic.

6. Apparatus for determining a physical condition at a determined depth in a drill hole, comprising in combination with a drill stem and a drill collar in said drill hole a tubular insulated container dividing said drill collar into an upper and a lower portion electrically insulated one from the other, means encased in said drill collar for electrically connecting said two insulated portions and for varying said connection in accordance with said physical condition, an electrical generator at the earth's surface, said generator having one terminal grounded and the other connected to the upper portion of the drill stem thus forming an electrical circuit, the resistance of which varies in accordance with variation of said connection, whereby the electric current supplied by said generator correspondingly varies, and a measuring means positioned at the earth's surface for measuring said current, thereby producing an index representing said physical condition.

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