OR 3,103,625 SEARCH ROOM

Sept. 10, 1963 F. M. MAYES 3,103,625

BORE HOLE LOGGING APPARATUS PROVIDING A PULSE SPACE MODULATED RECORD

Filed Oct. 21, 1959 3 Sheets-Sheet 1

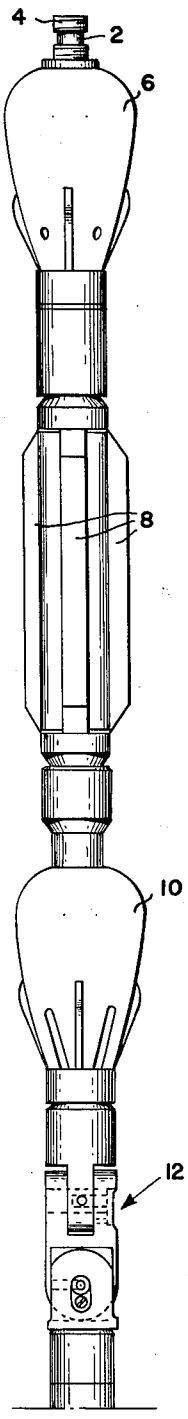


FIG. IA.

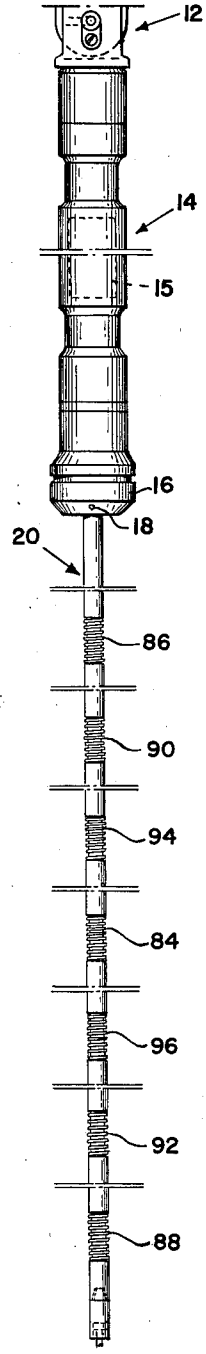


FIG. IB.



FIG. IC.

INVENTOR.
FRED M. MAYES
BY
Brisco, Smith & Hawley
ATTORNEYS

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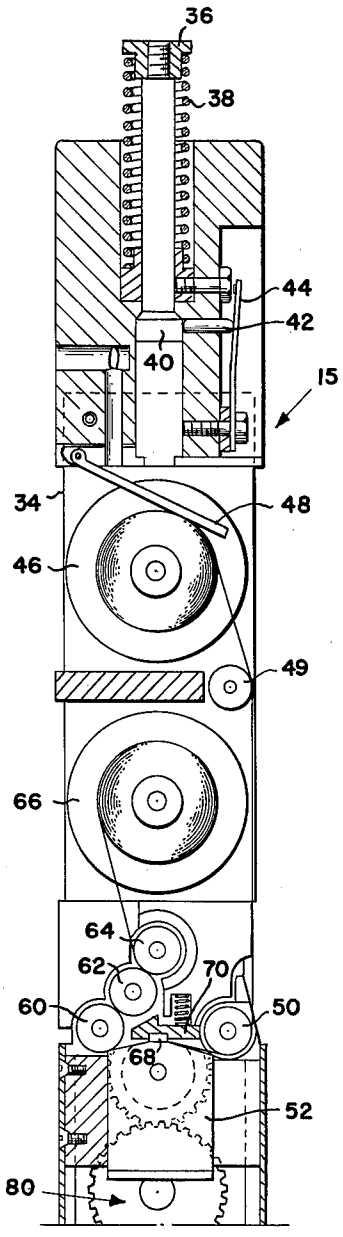


FIG. 2A.

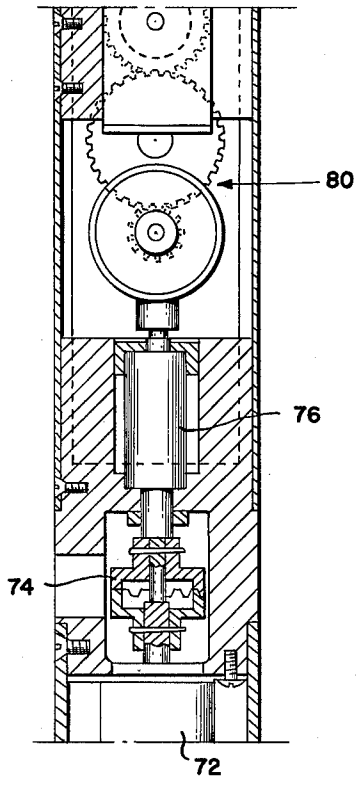


FIG. 2B.

INVENTOR.

FRED M. MAYES

BY

Brumm, Smith & Harding

ATTORNEYS

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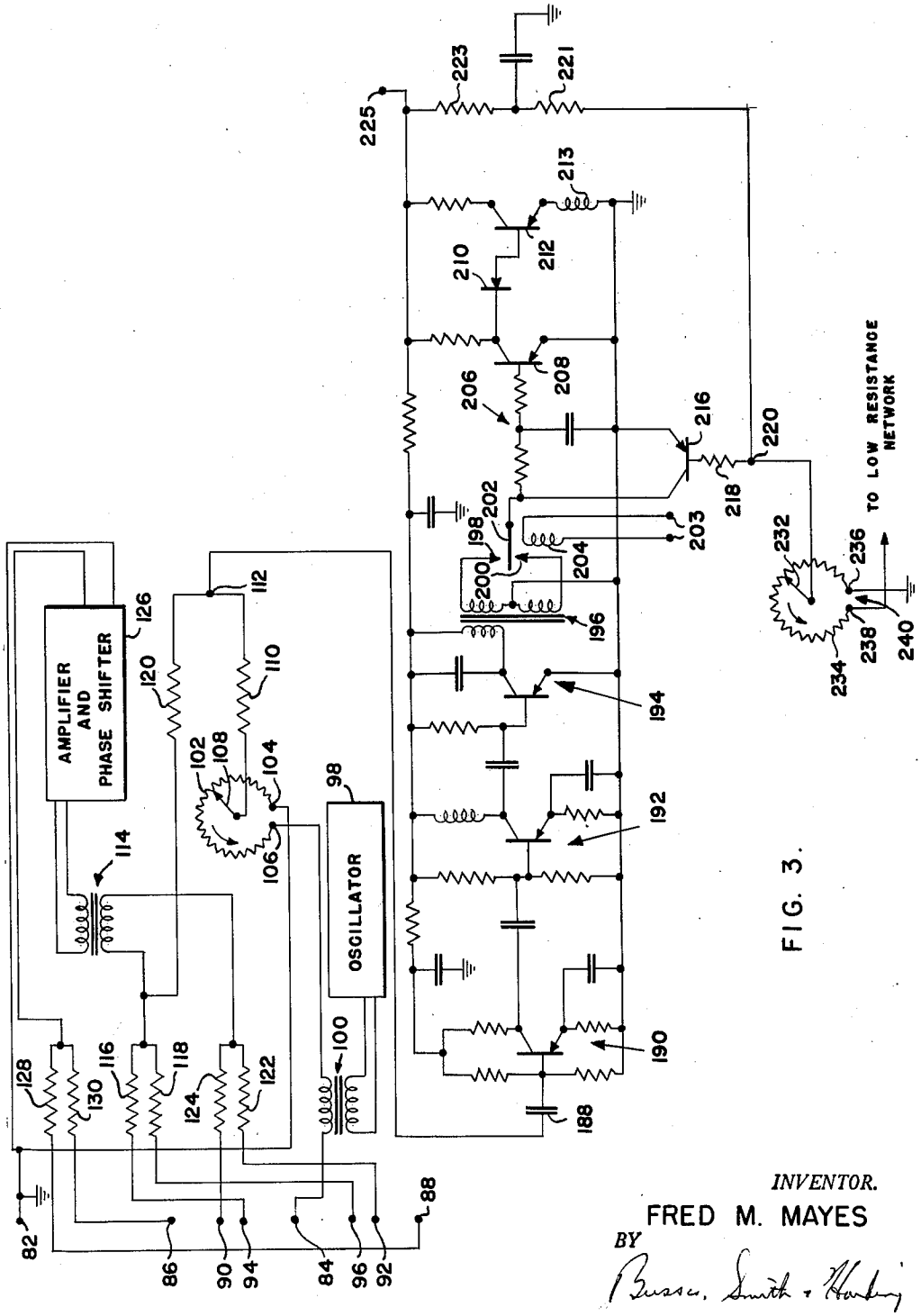


FIG. 3.

INVENTOR.

FRED M. MAYES

BY

Bussey, Smith & Hawley

ATTORNEYS

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BORE HOLE LOGGING APPARATUS PROVIDING A PULSE SPACE MODULATED RECORD

Fred M. Mayes, Richardson, Tex., assignor to Sun Oil Company, Philadelphia, Pa., a corporation of New Jersey

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6 Claims. (Cl. 324—1)

This invention relates to bore hole logging apparatus and particularly to apparatus involving the location of recording apparatus within a hole.

In the applications of Mayes and Jones, Serial Nos. 683,027, now U.S. Patent No. 3,065,404, issued November 20, 1962, and 818,066, filed, respectively, September 10, 1957, and June 4, 1959, logging methods and apparatus are provided which overcome the disadvantages of conventional logging apparatus which involves the recording of information at the surface. In accordance with the disclosures of said applications, logging methods and apparatus are provided which may be used when a drill string is in a bore hole and may be used at any time with a minimum of interruption in drilling. Not only may the logging be accomplished just prior to removal of the drill string for the purpose of changing a bit, but the logging may be carried out to be promptly followed by a continuation of drilling. A self-contained energizing and recording apparatus may be dropped through a drill string in go-devil fashion or may be pumped down therethrough when the drill string has been lifted to only a limited extent from the bottom of the hole to provide a region for reception of an electrode or other logging assembly. The apparatus particularly includes an assembly of a type suitable to pass through the mud flow openings of a jet bit which may be of any of the conventional popular types. Such bits are presently widely used since they effect the carrying away of cuttings and avoid their reworking by the drill. These jet openings are generally at relatively small angles with respect to the drill stem axis, and a flexible assembly may, accordingly, be projected therethrough to extend beneath the bit.

The self-contained assembly lowered to the vicinity of the bit contains, for electrical logging, not only means for supplying current to the earth, but also means for recording various potentials at the electrodes of the assembly.

Recording in a self-contained instrument within a drill stem within a bore hole has always presented substantial difficulties because of the limited diametral space afforded. Without the possibiilty of reference to some standard frequency supply line, there is difficulty in providing constant speed of transport of the recording medium. Furthermore, since the apparatus used must be kept to a minimum, stability of measuring circuits is difficult to maintain.

According to the disclosures of said applications, exciting and recording apparatus are provided which are self-contained and sufficiently simple in construction to be housed in an apparatus which may pass through a drill stem. A pulse width modulation recording system was used which was essentially independent of supply voltage changes and of the transport speed of the recording medium, specifically, a magnetic tape.

Also avoided in accordance with said disclosures was the difficulty of maintaining constant current to the current electrode or electrodes. The record was dependent solely on the ratios of potentials to the current introduced into the earth, and, consequently, valid and interpretable results were secured in view of the fact that the electrical configuration presented by the earth is linear.

In said applications the disclosure relates to apparatus involved particularly in the use of an electrode assembly

for electrical logging to provide records of the so-called short normal, long normal and self-potential types.

It is the general object of the present invention to provide apparatus for securing records similar to those produced in accordance with said applications but from a different type of electrode arrangement which does not lend itself directly to recording in accordance with the disclosures of said applications. The invention particularly relates to the recording of logs produced by an array of electrodes which effects beaming or focussing of current into the formation with associated potential pickup at one or more current-controlling electrodes.

The general object of the invention as well as subsidiary objects particularly relating to details of construction and operation will become apparent from the following description, read in conjunction with the accompanying drawings, in which:

FIGURES 1A, 1B and 1C illustrate a typical physical assembly of the apparatus which may be used, FIGURE 1B being a continuation of the lower portion of FIGURE 1A, and FIGURE 1C being a continuation of the lower portion of FIGURE 1B;

FIGURES 2A, and 2B jointly constitute a fragmentary longitudinal section showing a portion of a recording assembly, FIGURE 2B providing a continuation of the lower portion of FIGURE 2A; and

FIGURE 3 is a wiring diagram showing the electrical aspects of the recording apparatus.

The mechanical aspects of the apparatus are shown only in sufficient detail to indicate the general assembly, the assembly being described in full in the application of Mayes and Jones, Serial No. 818,066, referred to above, and in the application of Bennett, Chaney, Jones and Mayes, Serial No. 818,162, filed June 4, 1959. The apparatus particularly shown is that which is used by being freely dropped within a drill string without surface connection. It comprises a stem **2** threaded at **4** for the reception of a spearhead or other device depending upon the fashion in which operation is to occur. A parachute element **6** in the form of a bulb-like structure of flexible wear-resisting rubber is provided at the upper end of the assembly, its diameter being desirably normally slightly greater than of the major portion of the bore of the drill stem so that it acts to slow down the relative velocity of the assembly with respect to the velocity of downflow of the drilling fluid. Below this are the elongated shoes **8** which are spring urged outwardly to a position in which the outer diameter to which the shoes move is restricted so as to be less than the internal diameter of the drill stem but greater than the smaller internal diameter of the drill collar. Thus, during the major portion of the descent and until the shoes enter the drill collar they perform no function in effectual retarding of the descent of the assembly. However, the shoes enter the drill collar shortly before the lower end of the electrode assembly reaches the position of entrance to a jet opening of a bit.

Below the shoes **8** there is another parachute element **10** which functions similarly to the parachute element **6**. A universal joint indicated at **12** connects the foregoing to a protective housing **14** within which the recording apparatus is located together with power supply timing means. This assembly is generally indicated at **15**. At the lower end of the housing is a connecting and adaptor arrangement indicated at **16** providing an electrical ground for the apparatus and in particular having sharp projecting conducting pointed elements **18** to dip into a seat in the lower end of the drill string above a bit to extend the electrical ground to the drill string itself.

Extending downwardly from the arrangement at **18** is the flexible electrode assembly **20** which carries the electrodes described as to their arrangement later. Below the electrodes are weighting elements **22** and a flexible

strip 24 of leather or plastic which facilitates entrainment of the flexible assembly in the mud flow to effect guidance of the electrode assembly into and through a jet opening in the bit. The weighted electrode assembly is of the type shown in said Mayes and Jones application, Serial No. 818,066 and constitutes the subject matter of an application of Bennett, Chaney and Mayes, Serial No. 818,189, filed June 4, 1959.

The foregoing apparatus functions as is described in detail in the aforementioned applications, and is, as shown, particularly designed for a logging arrangement in which the apparatus as lowered is free of surface connection, the logging being accomplished by movement of the drill stem through the desired length of hole either upwardly or downwardly. In an alternative method of logging in which, during logging, the drill stem is stationary and the recording apparatus and the electrode assembly supported thereby are moved vertically by the use of a wire line, the parachutes and shoe elements 8 may be omitted, since in such case lowering may be effected under surface control through the wire line. In such case the electrode assembly may be of very considerable length so as to traverse the portion of a bore hole between its bottom and the considerably raised bit.

Reference may next be made particularly to FIGURES 2A and 2B showing the mechanical arrangement of parts of the current-supplying and recording assembly 15 located within the protective housing 14.

A frame 34, which need not be described in detail, is formed of an assembly of parts and provides mountings for the mechanical and electrical elements of the recorder. At its upper end it mounts a plunger 36 normally extended outwardly by a spring 38 and, when in such position, locating a cam 40 so as to act upon the pin 42 to open a switch 44 which constitutes a master switch disconnecting the power-supplying battery from the apparatus. When the plunger is pushed inwardly this switch is closed, the inward movement of the plunger taking place as the top plug is inserted into the protective housing.

A magnetic tape supply reel is indicated at 46, and resting on the tape is a spring-urged arm 48 which constitutes a second switch element grounded to the hub of the tape supply reel when the tape is exhausted. The tape from the supply reel 46 passes over a guide roller 49 and about an idler 50 and thence over the curved face of a multiple channel recording head 52. From this it winds about the successive capstan rollers 60, 62 and 64 which are geared together to provide a positive and uniform drive, thence passing to the takeup roller 66. In its passage over the head 52 the tape is pressed thereagainst by a pad 68 carried by a spring-urged lever 70. The capstan rollers are driven by means of gearing indicated at 80 from connections to a battery-powered drive motor indicated at 72. In order to take care of alignment the motor drives through a clutch 74 the shaft of a dual potentiometer 76 to the shaft of which the gearing 80 is connected. It may be here noted that as a result of the drive of the potentiometers at 176 in synchronism with the drive of the tape, the potentiometers at 176 which will be referred to in more detail hereafter, complete single revolutions of their wiping contacts during predetermined advancements of the tape. The recording is thus made independent of maintenance of constant speed of the motor 72.

The foregoing mechanical arrangement is illustrated and described in the application of Mayes and Jones, Serial No. 818,066. This also describes a timing and control mechanism which is advantageously used in connection with the present invention but forms no direct part thereof and hence is not further described.

An item of auxiliary equipment which is desirably provided is a detector of motion, either longitudinal or rotary, of the drill stem to provide markings on a channel of the tape indicative of initiations or interruptions of logging intervals. Such detectors form the subject matter of an application of Bennett, Chaney and Mayes, Serial No. 818,163.

In Mayes and Jones application, Serial No. 818,066, the electrical portions of the apparatus are described as units, and such units are desirably employed in the present apparatus. However, since, with the exception of one unit, they form no essential part of the present invention, the desirable units may be merely referred to briefly with reference to said Mayes and Jones application for details. One such unit is provided for the purpose of initiating and terminating control automatically, and comprises the battery which is used for furnishing power. So far as the present invention is concerned it may be considered merely that some switching unit provides power at the desired time after the electrode assembly has been projected through a bit opening.

Another unit described in detail in said Mayes and Jones application is an oscillator. Desirably this oscillator is as described therein of a type consuming a minimum of power, such as a transistor oscillator, but the oscillator involved may be of any desired type furnishing current at a desired frequency which may typically be in the audio frequency range and about four-hundred cycles per second. The frequency is quite arbitrary and so far as frequency relationships are involved it need only be stated that the frequency is desirably considerably greater than that of a cycle of the potentiometers at 76.

The electrode configuration for the logging referred to herein is illustrated in FIGURE 3. The drill pipe, electrically connected to the housing of the recording instrument and serving as ground for the apparatus therein, constitutes the electrode 82 when the logging is carried out by movement of the drill stem with the recording apparatus seated above the bit and the electrode assembly occupying a fixed relationship relative to the bit. If the logging is carried out by movement of the logging apparatus utilizing a wire line, the drill stem being stationary and raised from the bottom of the hole, the reference or ground electrode at 82 is supplied by a separate electrode in the assembly. Below the electrode 82, however provided, there is an arrangement of electrodes comprising a central current electrode 84, a pair of current electrodes 86 and 88, desirably symmetrically arranged on opposite sides of the electrode 84, and two pairs of potential electrodes 90 and 92, and 94 and 96. The electrodes of these pairs are also symmetrically arranged with respect to the electrode 84, that electrode desirably constituting the center of symmetry of all of the electrodes 84 to 96, inclusive. However, only two of potential electrodes, e.g. 90 and 94, one of each of said pairs, might be used on the assumption of equal current components up and down the hole.

Current is supplied by an oscillator 98 which feeds the primary of a transformer 100. One terminal of the secondary of this transformer is connected directly to the electrode 84, while the other terminal is connected to one end 106 of a circular linear potentiometer 102, the other end of which, 104, is connected to the electrode 82. This potentiometer is one of those included in the arrangement previously indicated at 76. There is a gap between the ends 104 and 106 of the potentiometer resistance. The wiper 108 of this potentiometer is connected through the adding resistance 110 to a terminal 112.

A transformer 114 has a primary having one of its ends connected through resistors 116 and 118 respectively to the potential electrodes 94 and 96 and also through adding resistor 120 to the terminal 112. The resistance of 120 may be large in comparison with 116 and 118 to avoid loading the circuit. The other terminal of the primary of the transformer 114 is connected through the respective resistors 122 and 124 to the potential electrodes 92 and 90.

The secondary of the transformer 114 feeds an amplifier and phase shifter, which may be of any conventional construction, indicated at 126, the output thereof being fed

through resistors 128 and 130 to the respective current electrodes 88 and 86.

An output from terminal 112 is provided through capacitor 188.

Considering only the portion of the circuitry so far described, it may be noted that through the adding resistors 116 and 118, the average potentials of the symmetrically located potential electrodes 94 and 96 are averaged at one terminal of transformer 114, while the same is true for the electrodes 90 and 92 for the opposite terminal, averaging being through the resistors 122 and 124, the pairs of these resistors being desirably equal. If no current is flowing in the direction of the axis of the bore hole in the vicinity of the current electrode 84, there should be a zero signal impressed on the primary of transformer 114. If this signal is other than zero, the amplifier and phase shifter 126 will provide current to the electrodes 86 and 88 to rectify this condition, connections being so polarized as to produce a feedback nulling the net flow in the direction of the bore hole axis. By automatic adjustment, therefore, the current emanating from the electrode 84 may be considered to have only a component transverse to the axis of the hole. Under these conditions the ratio of potential at any of the potential electrodes to the current introduced at electrode 84 is a measure of the resistivity of the formation immediately opposite this last electrode. The potential undergoing measurement, therefore, is the average of the potentials at the electrodes 94 and 96, this being delivered through the resistor 120 to the terminal 112. The purpose of the averaging resistors involved is to minimize difference in electrode resistances at the individual electrodes. It may be here noted that the input to resistor 120 could be from a separate electrode rather than from one or more of the controlling potential electrodes.

As will be evident, connections are such that with proper choice of adding resistors with respect to other resistances in the circuit, the potential at 112 will vary through a zero value for some position of the wiper 108, the signals delivered to resistors 110 and 120 being 180° out of phase with each other. The position of wiper 108 at which a zero signal occurs is a measure of the resistivity of the formation which at any time is being logged.

The input provided through the capacitor 188 is delivered to an amplifier comprising the three transistor stages 190, 192 and 194, the last of which delivers its output through the transformer 196.

A synchronous rectification system is desirable in view of the relatively small signals which are picked up, particularly because a correspondingly large quadrature signal may accompany these. Synchronous rectification of the signal which contains possibly a large quadrature component gives the maximum rejection of this component and consequently passes only the signals in proper phase relation with the oscillator. Furthermore, as will become apparent, synchronous rectification gives rise to a simple system for incorporating on the record the indication of zero time for the recording cycle.

The centrally grounded secondary of transformer 196 has its end terminals connected to contact points 198 and 200 of a chopper which has a vibrating contact 202 driven synchronously by the coil 204 which is energized from the terminals 203 connected to the oscillator output. The phasing of the synchronous rectification is so made that operation is effected as will become apparent. The chopper contact 202 is connected through the filter 206 to the base of the transistor 208. This is followed by the Zener diode connection 210 to the transistor 212 which serves to provide recording current through a coil 213 of one channel of the recording head 52 previously mentioned. In the operation of the circuit there is involved the transistor 216 having its collector connected to the chopper element 202, its emitter grounded, and its base connected through resistor 218 to a terminal 220 and also through the series arrangement of resistors 221 and 223 to a positive supply terminal 225. The terminal 220 is connected to the wiper 232 of the potentiometer 234 which has terminals 238 and 236, the latter being grounded. There is a gap between the two terminals as indicated at 240. The terminal 238 is connected to a low resistance network having at all times low potential relative to ground. Further remarks with respect to this network will be made hereafter, though so far as operation in accordance with the present invention is concerned this may be treated as merely a low potential source.

The operation of what has been described is as follows:

First, let it be assumed that the transistor 216 is absent. Considering a start with the wiper 108 at the position of the grounded terminal of its resistance, and moving counterclockwise, the potential appearing at the capacitor 188 due to the potential pickup will exceed, but will be 180° out of phase with, that derived from the potentiometer, and the resultant potential will be amplified through the amplifier stages and delivered to the synchronous rectifier. A direct potential will then result at the base of the transistor 208 which, due to proper phasing of the synchronous rectifier will at this time be positive so that the transistor 208 is conducting. It may be noted that the saturation of the last amplifier stage is not of particular significance, a sufficiently positive signal being provided to the base of transistor 208 to maintain it conducting even though the picked up signals are relatively weak. So long as transistor 208 is conducting, the transistor 212 is non-conducting and consequently recorded current does not pass through the recording head winding 213. As the potentiometer wiper continues to move, the potential introduced from the potentiometer rises until a point is reached where the in-phase component of the potential at the input to capacitor 188 becomes zero by reason of the balancing of the electrode signal. As operation passes through this point, the phase of input to the synchronous rectifier is changed through 180° and the signal delivered to the base of transistor 208 becomes negative. Transistor 208 accordingly becomes non-conducting, and transistor 212 conducts to supply recording current to the winding 213. As further movement of the potentiometer contact continues, the recording signal likewise continues.

Assuming that transistor 216 was absent, the last described condition would terminate as the potentiometer wiper reached the end terminal of its resistance and passed into the gap. On entering the gap the earth signal alone would be presented at the amplifier input, and as a consequence a positive signal would be delivered to the base of transistor 208, terminating the recording. It is desirable, however, to present a signal of zero time at the instant that the wiper 232 engages the ground terminal 236 of the potentiometer 234 (this being particularly desirable if multiple channel reading is to be effected), and for this reason a control is effected under the action of transistor 216 as follows:

Prior to passage of the contact 232 into the gap 240, the potential introduced at terminal 220, considering the resistors 221 and 223 to be of high value, is relatively low in magnitude and immaterial, the potential at 238 being low and the resistance 234 being small. However, when the wiper or contact 232 enters the gap 240, the potential of terminal 220 rises to the high positive potential of the supply terminal 225, rendering the transistor 216 highly conductive. The result is, effectively, grounding of the synchronous rectifier contact 202, so that, even though the signals introduced to this rectifier would otherwise produce a positive potential at the base of transistor 208, the base is actually held substantially at ground potential with the result that the transistor 208 remains non-conducting, and transistor 212 continues to conduct and provide a recording signal. This condition continues until the wiper 232 reaches ground potential, whereupon the transistor 216 is cut off, and the

transistor **208** immediately becomes conducting since, at this same time, a positive signal is the response of the synchronous rectifier to the earth signals. Transistor **212** is then cut off.

Summarizing the foregoing, the signal recorded by the head starts with the balancing of the inphase component of the potential applied to capacitor **188** at a zero value and continues until the wiper **232** reaches its ground contact at **236**, the latter time representing the zero reference time for the potentiometer cycle. The record, accordingly, consists of a series of "dashes," the extent of which along the tape measure the logging signals picked up. It may be noted that since the potentiometer **102** carries the current introduced to the earth, the recorded resistivity measurement is independent of the earth current, there being secured a record corresponding to the ratio of the picked up potential to the earth current.

In the foregoing discussion the potentiometer **234** was treated merely from the standpoint of its function in maintaining the recording current by reason of effective grounding of the terminal **220** except when the wiper **232** was in the gap **240**. Actually, and as described in the Mayes and Jones application, Serial No. 818,066, this potentiometer may be that used in effecting self-potential records, for which purpose the direct or slowly varying input signal from one of the electrodes may be utilized as described in that Mayes and Jones application. Such recording, though it changes the potential at **238**, does not effect the operation described since the potential at **238** is always low.

In this art it is usually desirable to have multiple records made simultaneously, and it will be evident that other potentials may be picked up and recorded by the use of suitable auxiliary circuitry in conjunction with that described as effecting the special recording due to the use of the electrode arrangement shown herein.

The correlation of the single or multiple records with the depths at which they are produced may be carried out in various fashions. Theoretically simple but not too practical is a system in which the motor **76** is accurately controlled as to speed (so that the zeros of the recording cycles occur at regular intervals) or in which timing marks are produced on the recording tape at clock-controlled equal intervals. The former of these systems requires rather elaborate electrical controls when batteries are used as power sources because of isolation of the apparatus from a surface, fixed frequency, alternating current supply. The later requires a clock synchronized with a surface clock. In both systems elaborate records are necessary at the surface giving a record of depth against time.

It is simpler to permit the tape to advance at a speed corresponding to that of the motor which, though desirably designed for reasonably constant speed despite drain on the driving battery as logging proceeds, may have a speed substantially variable over a long period of time. Using a well built and sufficiently powerful motor, it is found justifiable to assume a constant speed throughout any period of drill stem movement between stoppages for removal of drill stem sections. Furthermore, measurements have shown that it is possible to assume validly that the rate of movement of a drill stem during lifting (or lowering) periods is constant. Accordingly, it is possible to use only the logging records above described to correlate the records with depth since absences of changes of the records define those portions made during fixed vertical positions of the drill stem occurring as sections are removed or added. Accordingly by keeping records at the surface of depths corresponding to cessations of vertical movement of the drill stem and by making the assumption of substantially constant speed of tape advance throughout individual vertical movement periods and of uniform lifting or lowering movements (these assumptions permitting interpolation) complete correlations of records with depth may be secured. Doubts which may sometimes exist as to the precise points on records at which vertical movements began or ended, for example because of variations in the records due to disturbances of the electrodes caused by mud flow, may generally be resolved by quite valid assumptions that the tape speed was substantially constant throughout several successive periods of vertical movement.

However, it is desirable to provide independent records on the tape of drill stem motions, rotary or vertical, in accordance with the disclosure of the Bennett, Chaney and Mayes application, Serial Number 818,173, now U.S. Patent No. 3,017,035, issued January 16, 1962, referred to above.

In the case of control of movement of an electrode assembly through a portion of the hole below the bit under wire line control rather than by drill stem movements markers may be produced by stopping or starting the motion of the wire line, or the motion of the wire line may be continuous and uniform from beginning to end of the logging with assumption of uniform tape speed if the logging interval is not too long.

It will be evident that various details of construction and operation may be modified without departing from the invention as defined in the following claims.

What is claimed is:

1. Bore hole logging apparatus comprising a housing adapted to be moved lengthwise in a bore hole, electrode means secured to said housing to be lowered therewith, means providing a ground connection to the earth surrounding the hole being logged, said electrode means including first and second current electrodes and including potential electrodes responsive to the potential difference between predetermined points in the bore hole, means within said housing providing current to the earth through said first current electrode and said means providing a ground connection, means within said housing responsive to said potential difference to provide current flow to said second current electrode to reduce approximately to zero said potential difference, means in said housing advancing a record member at a rate independent of the rate of movement of the housing in a bore hole, and means in said housing responsive to the potential of at least one of said potential electrodes to provide within said housing a pulse space modulated record of that potential on said record member, the cycles of which record have a substantially constant length along the record member.

2. Logging apparatus according to claim 1 in which said housing is adapted to be moved through a drill stem and in which said electrode means is flexible so as to pass through a non-axial opening in a bit carried by the drill stem.

3. Logging apparatus according to claim 2 in which each potential electrode has associated with it another potential electrode connected thereto by a resistance network.

4. Logging apparatus according to claim 1 in which each potential electrode has associated with it another potential electrode connected thereto by a resistance network.

5. Bore hole logging apparatus comprising a housing adapted to be moved lengthwise in a bore hole, electrode means secured to said housing to be lowered therewith, means providing a ground connection to the earth surrounding the hole being logged, said electrode means including first and second current electrodes and including potential electrodes responsive to the potential difference between predetermined points in the bore hole, means within said housing providing current to the earth through said first current electrode and said means providing a ground connection, means within said housing responsive to said potential difference to provide current flow to said second current electrode to reduce approximately to zero said potential difference, and means in

said housing responsive to the potential of at least one of said potential electrodes to provide within said housing a pulse space modulated record of that potential, said means including means providing a cyclically varying potential having a predetermined waveform proportional in amplitude to said current provided to the earth through the first electrode, means sensitive to a predetermined relationship between said picked up potential and said cyclically varying waveform, and means recording the phase relationship of said predetermined relationship to a cycle of said cyclically varying potential.

6. Logging apparatus according to claim 5 in which said housing is adapted to be moved through a drill stem and in which said electrode means is flexible so as to pass through a non-axial opening in a bit carried by the drill stem.

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