

June 9, 1959

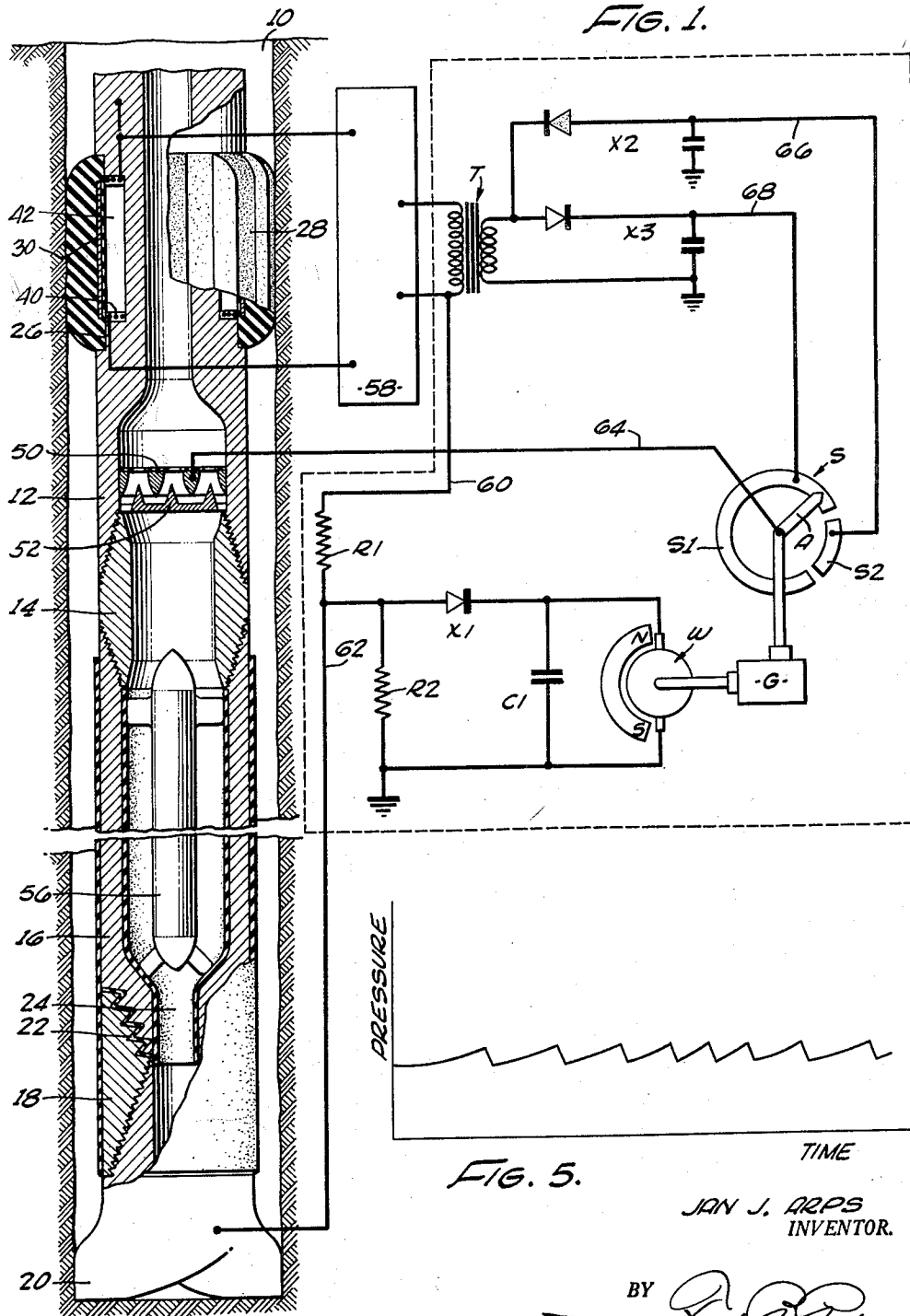
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2,890,019

EARTH BOREHOLE LOGGING SYSTEM

Filed March 26, 1956

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FIG. 2.

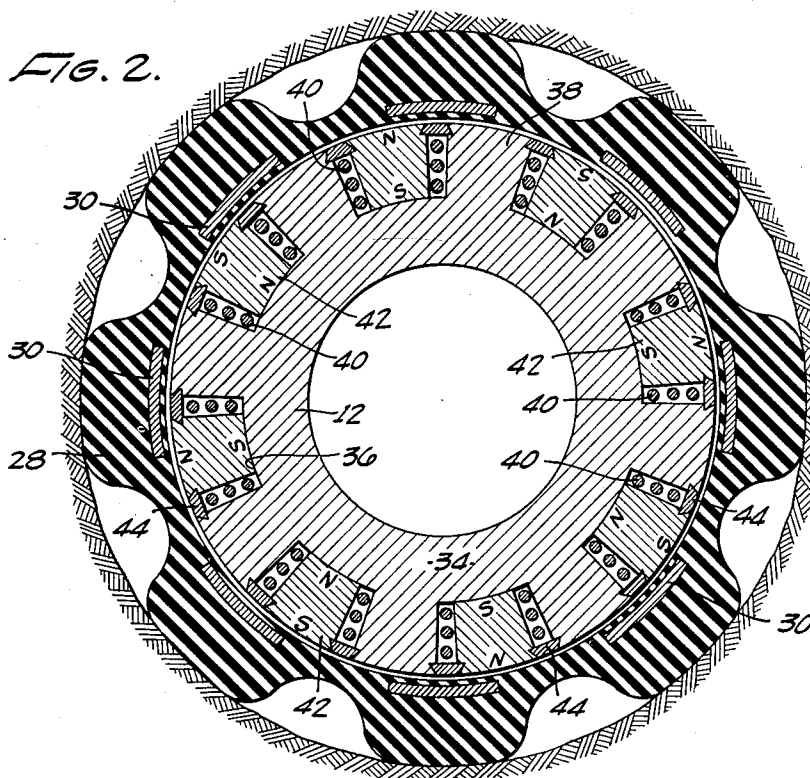


FIG. 4.

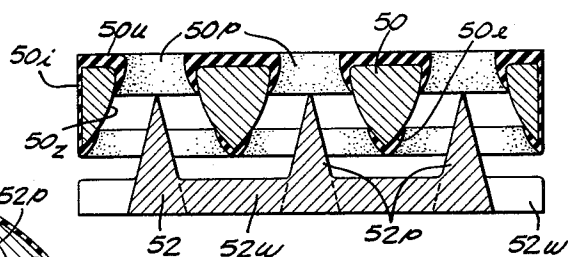
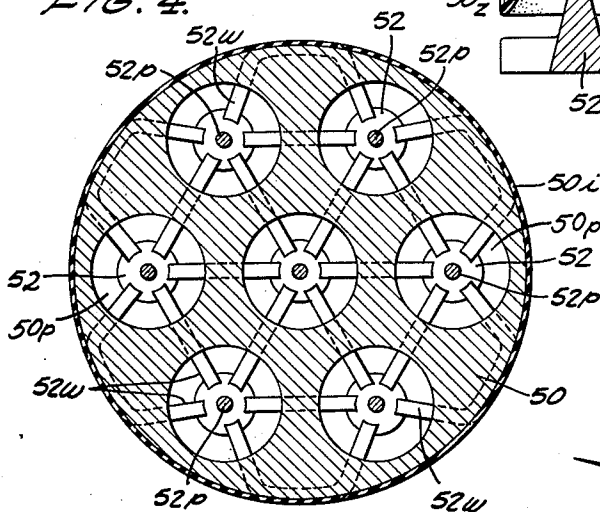


FIG. 3.

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EARTH BOREHOLE LOGGING SYSTEM

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13 Claims. (Cl. 255—1)

This invention relates to a mode and means for "logging" or investigating one or more physical characteristics at a relatively inaccessible location in an oil well or like earth borehole.

Previously proposed borehole logging systems of the type to which the present invention is generally directed have suffered the disadvantages of having in the subsurface equipment delicate parts, such as electron tubes, batteries, relays, and the like, or having complex instrumentation or relatively vulnerable parts exposed to the abrasive fluid normally present in earth boreholes. The present invention aims to provide a means and mode for investigating, within a borehole, a physical characteristic or quantity such as, for example, the resistivity of the rock or formation encircling the borehole, in which the stated objectionable features of previously proposed systems are minimized or non-existent. In general, the invention contemplates utilization of the rotation of a drill string relative to a stabilizer mounted thereon, for generation of necessary electrical power; and utilization of the generated power in apparatus employing electrophoresis phenomena to produce pressure-change signals in the drilling fluid in response to measurements or other indications of the characteristic or quantity under investigation. By such mode and means, information such as is generally recorded on a graph or "log," may be secured as drilling of a borehole proceeds, and during periods of suspension of drilling if circulation of drilling fluid and rotation of the drill pipe is maintained, the signals being transmitted to the surface of the earth and there detected in known manner.

With the aforesaid considerations in view, it is a primary object of the present invention to provide an electrical investigating system and power generator, for use adjacent the lower end of a drill string and deriving electrical power from rotation of the drill string relative to the earth and utilizing power thus derived to produce informative pressure-change signals in a body or stream of drilling fluid flowing through the drill string.

Other objects and advantages of the invention will become apparent from consideration of the following description of a preferred illustrative embodiment of apparatus of the type contemplated by the inventive concept, and the accompanying drawings to which reference is made in the description, and in which:

Figure 1 is a schematic drawing illustrating an earth borehole, lower end portions of a drill string immersed in drilling fluid therein, and apparatus according to the invention, with portions of the apparatus depicted in circuit diagram form;

Figure 2 is a view on enlarged scale indicating by cross-section the principal features of construction of the electric generator part of the apparatus.

Figure 3 is a view in section through a drilling fluid flow-controlling means which is shown on a smaller scale and in less detail in Figure 1;

Figure 4 is another view, in horizontal section, of the

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flow-controlling means, to the same scale as in Figure 3; and

Figure 5 is a graph illustrating the pressure changes produced in a drilling fluid stream flowing under pressure past the flow-controlling means of the invention.

Referring now to the drawings and to Figure 1 in particular, sections of an earth borehole 10 are indicated in somewhat diagrammatic vertical section, and lower end portions of a drill string are illustrated immersed in drilling fluid in the borehole. The drill string portions include a collar 12, a sub 14, a collar 16, and a sub 18 carrying a bit 20, sub 18 and bit 20 being insulated from the remainder of the string by insulation 22 in any suitable manner as known in the art or as disclosed in copending applications Serial Nos. 431,734, filed May 24, 1954, and 346,457, filed April 2, 1953, the latter now abandoned. The shaped bore 24 of collar 16 is insulated, and similarly the exteriors of collar 16 and sub 18 may be, and preferably are, insulated with insulating jackets, as may be well known in the art. The several collars and subs and the drill bit are intercalated by otherwise conventional threaded joints to constitute a relatively rigid lower end portion of a rotatable drill string means which extends upwardly through the entire extent of the borehole. Drilling fluid, usually in the form of a slurry or mud, is forced downwardly under pressure through the interior or bores of the drill string elements, from which it exits through jet orifices in the bit and returns upwardly in the borehole annulus encircling the drill string, carrying with it the chips and debris removed by the bit during drilling.

As has heretofore been proposed, it is feasible to utilize the downwardly flowing stream of drilling fluid as a signal transmission medium on which to transmit signals from the lower end of the drill string to an operating location outside the borehole at the surface of the earth. The signals are in the form of temporary changes in pressure induced in the drilling fluid stream by suitable means located adjacent the lower end of the drill string and transmitted very rapidly to detecting transducer means outside of the borehole. A variety of types of information may be thus conveyed from investigating apparatus at the lower end of the drill string to an operating location outside the borehole, without the inconvenience of electrical connections between the two places and with the enormous advantage of permitting investigations to be conducted during drilling, that is, during removal of rock and extension of the borehole by the bit as the latter is rotated. The investigative procedure and signaling may of course also be carried on during suspension of actual drilling, as long as the drilling fluid is circulated and the drill pipe is rotated.

The present invention enhances and improves the previously proposed mode, wherein batteries or a turbine driven generator furnished power and wherein movable valve structures interposed in the drilling fluid stream were employed to produce the signaling pressure changes, by utilizing power obtained from the rotating drill string for electrical energy, and by employing electrical energy to produce the pressure changes without employment of moving valve parts. To secure power from the rotating drill string, a specially constructed ribbed stabilizer having paramagnetic inserts is rotatably mounted on a specially constructed drill collar comprising magnetic and conductor means; and relative rotation between the collar and the stabilizer as the latter engages the borehole wall is utilized to cause relative movement of the conductor means and the field of the magnetic means to generate electrical potential and power. To produce pressure changes in the drilling fluid stream, the latter is caused to flow through restricted spaces between anode and cathode electrophoresis electrodes to which D.C. potentials are intermittently applied to cause by electro-

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phoresis alternate accumulation and erosion of solids upon and from the anode electrode in such manner as to alternately impede and free the flow of fluid past the electrodes. As the impediment to flow is created and increased during accumulation of clay solids on the anode, the stream pressure thereabove is increased; and when the potential is reversed, the accumulated solids are repelled and quickly washed away to free the stream and cause a return to normal pressure.

Again referring to Figures 1 and 2, drill collar 12 is provided with a peripheral recess 26 of sufficient longitudinal extent to accommodate therein the inner bearing portion of an externally corrugated or ribbed stabilizer unit 28. The stabilizer may be constructed principally of rubber or other tough non-magnetic material, and may be provided with longitudinally extending grooves and ribs, as indicated in section in Figure 2. The ribs are adapted to engage the borehole wall and slowly slip downwardly therealong as drilling proceeds; and the grooves permit upward flow of the chip-carrying drilling fluid past the stabilizer in the borehole annulus. Embedded in the interior portion of stabilizer 28 are magnetic-field modifying elements 30 preferably of soft iron and of suitable cross-sectional configuration such as that indicated in Figure 2. The recessed portion of collar 12 covered by the stabilizer is provided with a circumferential series of longitudinally extending interconnected grooves and intervening lands, either by attachment of spaced-apart iron pole pieces to a central tubular iron portion 34 or by milling longitudinally extending slots 36 of the type indicated in Figure 2 in the collar 12. The recesses or grooves thus provided are interconnected by annular recesses of like depth at their ends, whereby the lands or poles 38 may have wrapped therearound insulated conductor means 40 such as one or more insulated electrical conductors, in a manner well known in the electric generator art. Secured to the central cylindrical portion of collar 12, each within a respective groove 36, are several bar-type permanent magnets 42, the magnets being disposed as indicated in Figure 2 and between the reaches of the conductor means wound on the pole pieces. The magnets may be attached to collar 12 by any suitable means, such as screws (not shown). Conductor means 40 may be held in place in the slot-like spaces between poles 38 and magnets 42 by wedge means 44 as shown. Preferably there are provided a like number of poles, magnets, and members 30.

The soft iron magnetic shunts 30, embedded in the rubber stabilizer unit 28, control the magnetic flux from the permanent magnets 42, so that the flux through the poles 38 alternately reverses when collar 12 rotates relative to the encircling stabilizer. Thus an alternating current is generated in the insulated conductor means 40. The latter may comprise a single conductor, or a plurality of conductors suitably interconnected in a manner well known in the electrical generator art, terminals or connections to the conductor means being provided whereby the generated energy may be utilized. The several parts just described form a magneto electric generator means capable of supplying large amounts of energy.

Referring now to Figures 1, 3 and 4, there is mounted in the drilling fluid flow passage in collar 12, by suitable means such as internal lock rings (not shown) engaging in annular grooves formed in the interior of the collar, upper and lower electrophoresis electrode means 50 and 52, respectively. These electrodes may be of any of numerous suitable complementary forms, but as shown are in the form of plate-like elements the upper of which is insulated from the collar by a peripheral coating of insulation 50i and has a plurality of perforations 50p of downwardly increasing diameter, and the lower of which has a plurality of upstanding projections 52p of generally circular cone-shaped form each of which enters

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and is substantial coaxial with a respective one of the perforations 50p of the upper plate-like element. The projections 52p are interconnected by web portions 52w which at peripheral sections form the supporting base of the lower electrode. The configurations of the web portions are best indicated in Figure 4. Thus there is provided a plurality of fluid flow paths of restricted thickness, through the electrodes. The lower portion and the upper portion of the anode (upper) electrode are insulated with adherent layers of electrical insulation 50e and 50u as indicated in Figure 3, thus leaving zones 50z of exposed active anode facing the exposed conical surfaces of the cathode (lower) electrode. The drilling fluid normally flows downwardly through the passages thus provided by the electrodes without appreciable impediment, the total passage cross-section being of the order of that provided in the upper reaches of the drill string.

When a direct current potential is applied between the upper and lower electrodes with the upper electrode of positive polarity, electrophoretic action causes an accumulation or coating of clay or like solids on the exposed zones 50z of the upper electrode, the negatively charged clay particles being attracted from the colloidal drilling fluid and the released water flowing toward the lower electrode. The accumulation or deposit increases at a rate dependent upon the magnitudes of the applied potential and current flow, and, occurring in the most restricted part of the drilling fluid flow path through the electrodes, impedes the flow of drilling fluid therepast and creates an increase of pressure in the fluid thereabove. Upon removal or reversal of the potential, the deposit of clay solids is instantaneously repelled and rapidly washed away from the inter-electrode space, and the stream pressure returns to normal value. Means for utilizing the energy generated in conductor means 40 for investigating a physical characteristic (in the illustrated embodiment, the resistivity of the earth adjacent the drill bit) and for producing pressure changes in the drilling fluid stream as a function of the investigation, will now be described.

Referring to Figure 1, there is mounted in the fluid passage of drill collar 16 an apparatus housing 56 which preferably is insulated from the collar, and which contains apparatus indicated diagrammatically within the dash-line enclosure in Figure 1. Electrical connections, indicated only diagrammatically in Figure 1, extend from the apparatus housed in housing 56 to the aforementioned upper electrode 50, to the drill-bit 20, and to a voltage regulator device 53 which may be mounted in an internal recess in collar 12. The manner in which these connections are insulated and protected may be as desired, or as disclosed in general in the aforementioned depending applications. Regulator 53, whose use is optional, is employed to smooth out variations in the alternating voltage generated by the electric generating means, incident to variations in the relative rotational speed of stabilizer 28 and collar 12.

Electric current supplied by the generator means energizes the primary of a transformer T, and feeds a circuit including a current path through the earth adjacent bit 20. The upper terminals of the generator, regulator 53, and transformer T are grounded by being connected to drill collar 12. The lower terminal of the transformer primary is connected by way of conductor 60, resistor R1 and conductor 62, to bit 20, which is insulated from collar 12. Conductor 62 is connected to collar 12 (ground) by way of a resistor R2, which thus is in parallel with the resistance of the earth path from bit 20 to collar 12. R1 is large, compared to the earth path from bit 20 to collar 12, hence the current through R1 may be considered to be constant. If desired, R1 may be replaced by a constant current device. The current through R1 divides into two smaller currents, one

through resistor R2 and the other through the earth path from bit 20 to collar 12. This division is such that the currents are inversely proportional in magnitude to the values of the respective resistances through which they flow. Accordingly the voltage applied to a rectifier unit comprising rectifier XI and capacitor C1 is proportional to the formation resistance between bit 20 and collar 12. The output of this rectifier unit is applied to a motor W of the watt-hour meter type, whose shaft is connected to drive the sweeparm A of a rotary switch S through a gear box G. By this mode and means, switch arm A is rotated at a rate proportional to the resistance of the formation current path.

Successive currents of different polarities are supplied to electrode 50 from switch arm A by a conductor 64 which is connected alternately to switch segments S1 and S2 as arm A rotates. The segments are supplied potential of opposite polarities through respective leads 66 and 68 which are connected to rectifying nets X2 and X3. These rectifying nets are energized from the secondary of transformer T in the manner indicated in Figure 1. Thus potential of positive polarity is applied to anode 50 through S1, followed by application of negative potential through S2. During the longer period arm A contacts S1, a deposit of clay particles having negative charges accumulates on anode 50 and increasingly restricts fluid flow therepast. During the shorter interval arm A is on S2, the clay deposit is repelled and washed away.

From the preceding description of the apparatus and its operation, it is evident that as the drill string rotates and drilling fluid is circulated therethrough, the generator comprising conductor means 40 produces electrical energy which is employed to furnish power for investigating a physical characteristic (the resistance of an earth path) and for producing repetitive signal changes in pressure in the drilling fluid at a rate proportional to the magnitude of the physical characteristic. Such changes in pressure are indicated in the graph of Figure 5, wherein it will be noted that the pressure rises somewhat gradually and drops relatively quickly, the cycle being repeated but at a variable rate depending upon change in earth path resistance.

It will be understood that the pressure changes produced in the drilling fluid constitute logging signals which are to be received and translated by portions of the logging system apparatus located outside the borehole. Those portions of the apparatus may be of any suitable type, or like the corresponding apparatus disclosed in the previously mentioned applications, and are not herein further described since per se they are not of the present invention.

It will be evident from a consideration of the disclosure made that variations in the mode and apparatus according to the invention will occur to those skilled in the art; and it is therefore not desired to limit the invention to the specific illustrative apparatus depicted and described, but what is claimed is:

1. A logging system for oil well and like earth boreholes, comprising, in combination: drill string means having a drilling fluid passage therethrough; relatively rotatable magneto electric means mounted on the exterior of said drill string and arranged to generate electric energy incident to relative rotation, between the drill string and the earth and including means for inducing such relative rotation incident to rotation of the drill string means in an earth borehole; electrical investigation means carried by said drill string means for investigating the magnitude of a physical characteristic at a location in such earth borehole, connected to be energized by said magneto electric means; and means energized from said magneto electric means and controlled by said electrical investigating means, for controlling the fluid flow characteristics of said passage,

whereby, incident to rotation of said drill string means and flow of drilling fluid through said passage, signals representing the magnitude of the physical characteristic being investigated are produced in the drilling fluid stream.

2. A logging system for oil well and like earth boreholes, comprising, in combination: drill string means; borehole wall engaging means encircling and rotatably mounted on said drill string means and comprising a plurality of circumferentially spaced-apart paramagnetic members; magnetic means and insulated conductor means mounted on said drill string means and rotatable therewith in proximity to said borehole wall engaging means and arranged to cooperate with said paramagnetic members to generate electric potential in the conductor means incident to relative rotation between the drill string and the borehole wall engaging means; drilling fluid flow controlling signaling means within said drill string means, arranged for connection to said conductor means for energization therefrom; and electrical controlling means connected to said conductor means and to said signaling means for controlling the signaling means to produce drilling fluid flow change signals.

3. In a logging system for oil well and like earth boreholes, apparatus for obtaining and signaling logging information at the lower end of a drill string conveying drilling fluid under pressure, comprising, in combination: drill collar means adapted to form part of the lower end portion of a rotary drill string; stabilizer means encircling said drill collar means and rotatable with respect to the latter; cooperating electric generator means comprised in part in said stabilizer means and said collar means for generating an electric potential upon relative rotation of said collar means and said stabilizer means; and means including electrical connections to said generator means, for energization thereby, for obtaining and signaling logging information from said drill collar means.

4. In an investigation system for oil well and like earth boreholes, apparatus comprising: a drill collar; a longitudinally ribbed stabilizer encircling at least a portion of said collar and rotatable relatively thereto; electric generator means including pole pieces, at least one conductor and at least one permanent magnet, arranged on said stabilizer and said collar to provide a variable magnetic field at least partially linking said conductor whereby upon relative rotation of said collar and stabilizer a potential is induced in said conductor; means including investigation means connected to said conductor to be energized therefrom; and signaling means controlled by said investigation means and connected to be energized by said conductor to provide signals under control of said investigation means.

5. An earth borehole investigation system comprising in combination: a drill collar adapted to be comprised in the lower end portion of a drill string; a stabilizer encircling and rotatably mounted on said drill collar; magnet means mounted on said drill collar to provide a magnetic field; conductor means mounted on said collar and linked by at least a portion of such magnetic field; a paramagnetic means mounted in said stabilizer to vary the magnetic field linked by said conductor means during relative rotation of said stabilizer and said drill collar whereby electric potential is induced in said conductor means incident to relative rotation between said drill collar and said stabilizer; investigation means housed at least in part in said drill collar connected to be energized from said conductor means; and signaling means in said drill collar, controlled by said investigation means and connected to be energized by potential generated in said conductor means to provide signals representing operations of said investigation means.

6. In a logging system for oil well and like earth boreholes, apparatus for obtaining and signaling logging information at a relatively inaccessible location within

a borehole, comprising, in combination: a drill string having a drilling mud passage therethrough; magneto-electric generating means supported by said drill string for generating electric power incident to drill string rotation in a borehole; a plurality of electrophoresis electrodes positioned in said drilling mud passage; electric formation-investigating means carried by said drill string and connected to be energized by said magneto-electric generating means, for determining the magnitude of a physical characteristic of an earth formation penetrating an earth borehole; and means controlled by said investigating means for intermittently energizing said electrodes from said generating means at a rate indicative of the magnitude of the physical characteristic being investigated.

7. A logging system for oil wells and like earth boreholes, comprising, in combination: a drill string having a drilling mud passage therethrough; a ribbed drill string stabilizer rotatably mounted on said drill string and adapted for normal engagement with a borehole wall; electric generator means mounted in part on said stabilizer and in part on said drill string for generating electric energy incident to relative rotation of said stabilizer and said drill string; electric investigation means carried by said drill string for investigating the magnitude of a physical characteristic, connected to be energized by said generator means; electrophoresis electrodes mounted in said drilling mud passage and connected to said generating means and controlled by said investigating means, for varying a mud-flow characteristic of said electrodes as a function of the magnitude of said physical characteristic.

8. In an earth borehole investigation system including a rotatable elongated drill member and a stabilizer rotatably mounted thereon, electric power generating means comprising: relatively movable magnetic circuit means partly on said stabilizer and partly on said drill member and comprising permanent magnet means and adapted to produce a varying magnetic field incident to relative rotation of said stabilizer and drill member, and insulated electric conductor means arranged in said magnetic field for generation of electric power incident to relative rotation between said stabilizer and drill member.

9. In a system for use in conjunction with means for drilling oil well and like earth boreholes, apparatus comprising: a drill collar; a longitudinally ribbed stabilizer encircling at least a portion of said drill collar and rotatably mounted thereon; electric generator means including pole pieces, conductor means, and permanent magnet means, arranged on said collar and said stabilizer to provide a magnetic field variably linking said conductor upon relative movement of said collar and said stabilizer, whereby to generate an electric potential in said conductor means incident to relative rotary motion between said collar and stabilizer, to provide useful electric power in said drill collar.

10. In an earth borehole drilling system including a rotary drill string and stabilizer means rotatably mounted thereon near the lower end thereof and adapted to engage a borehole wall and stabilize the lower end of the drill string, electric power generating means mounted in said drill string and stabilizer means, and means in the drill string for using electric power and connected to said generating means to be supplied thereby, said electric power generating means comprising: permanent magnet means, insulated conductor means, and magnetic circuit means, constructed and arranged to produce a varying magnetic field linking said conductor means incident to relative rotation between said drill string and said stabilizer, to produce electric power.

11. In an investigation system for oil well and like earth boreholes, apparatus for selectively restricting and freeing the flow of drilling mud through a restricted path within a borehole, comprising, in combination with a drill string having a passage therethrough through which drilling mud is adapted to flow: upper and lower electrophoresis electrodes arranged in said passage and means for electrically insulating one of said electrodes from the other; and means for applying an electric potential between said electrodes for causing electrophoretic deposition of drilling mud solids on one of said electrodes for restricting the flow of drilling mud through said passage.

12. A system as defined by claim 11, including means to periodically reverse the polarity of the potential applied between said electrodes, whereby deposits of drilling mud solids are alternately formed upon and removed from said electrodes during flow of drilling mud through said passage.

13. In a logging system for oil well and like earth boreholes, apparatus for establishing and signaling logging information at the lower end of the drill string, comprising, in combination: drill collar means adapted to form part of the lower end portion of a rotary drill string; stabilizer means encircling said drill collar means and rotatable with respect to the latter; cooperating electric generator means comprised in part in said stabilizer means and said collar means for generating an electric potential upon relative rotation of said drill means and said stabilizer means; and means energized by said generator means for signaling logging information from said drill collar means.

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