

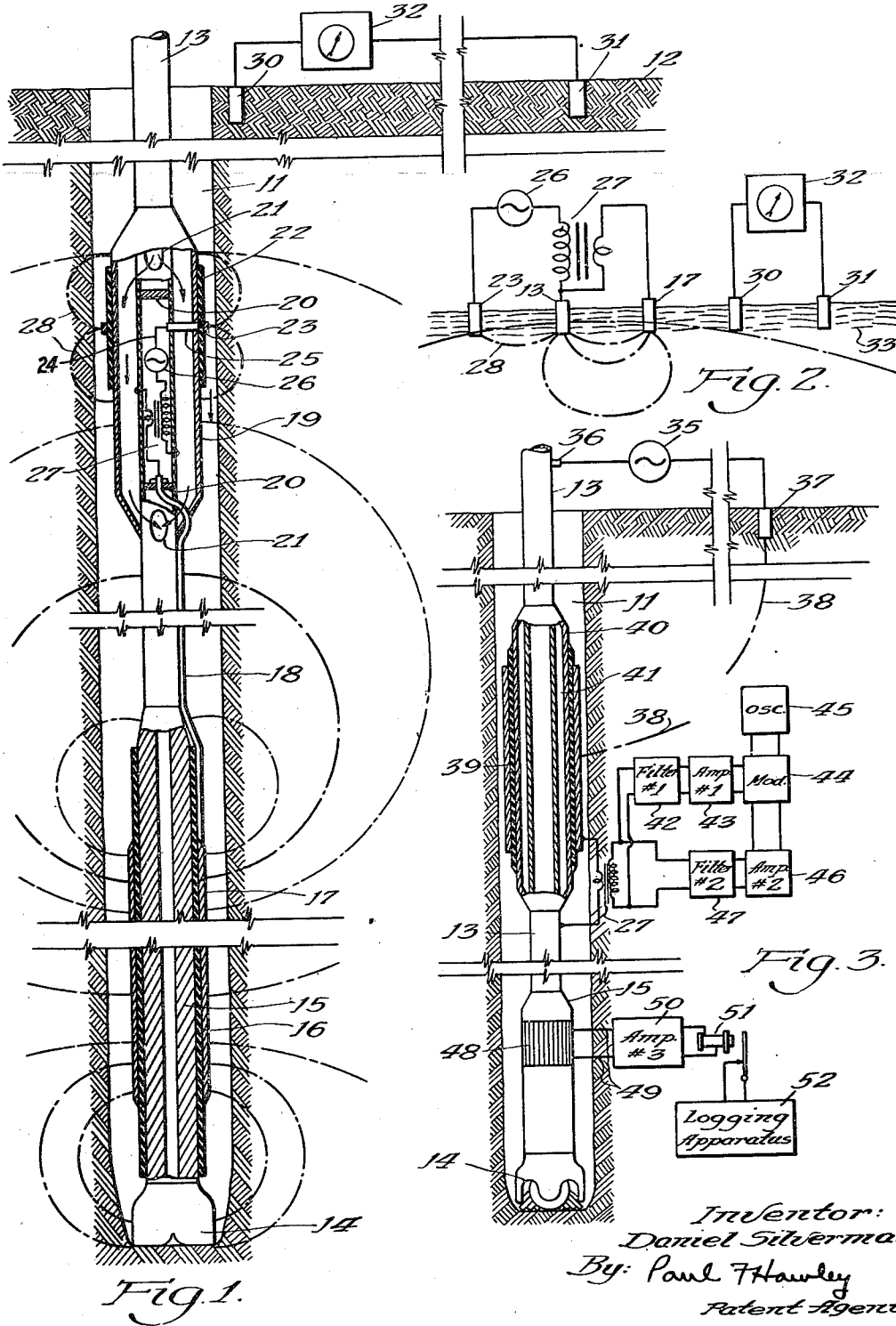
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WELL LOGGING

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## WELL LOGGING

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This invention pertains to the art of well signalling and has particular application to systems for well logging during the course of drilling a well.

One of the main difficulties encountered in the development of a satisfactory system of logging a well during the course of drilling is the provision of a system by means of which signals of pulsating electric current can be transmitted from the region where the logging measurements of some earth characteristic are made, to the surface of the earth. Early systems required the maintenance of a jointed system of insulated conductors extending up through the similarly jointed string of drill pipe. Such systems were found to be extremely expensive to maintain, due to mechanical difficulties inherent in such a system in the presence of a moving stream of abrading well fluid.

One means for applying a pulsating electric signal directly between the drill pipe or similar conductor extending into the well, by means of which a portion of the signal flows adjacent the surface of the earth, producing voltage drops approximately radially away from the well, has been described in United States Patent 2,354,887 dated August 1, 1944, issued jointly to me and Robert E. Fearon. This system involved the use of the so-called toroidal transformer. This provided not only an impedance matching device between the logging oscillator and a circuit including the conductor and a portion of the earth through which the pulsating currents flowed, but it also provided a very strong mechanical system; namely, one in which the drill pipe itself was unbroken and there was no section of insulated material in the drill pipe, through which the torque of this pipe must be transmitted.

The invention forming the subject matter of the present specification is an alternative system to that involving the toroidal transformer, and provides a well signalling system in which a drill pipe or similar conductor is employed which may be mechanically unbroken by any insulated section from top to bottom. This system provides a very easily constructed and cheap signalling system involving the advantages obtained by the use of the toroidal transformer signalling system.

It is an object of this invention to provide a system of well signalling by means of which pulsating electric currents are transmitted through the earth between bottom and top of a well, and in which the means of coupling the transmitter in such system to the earth circuit is electrically

highly efficient, while providing at the same time for a strong mechanical arrangement of drill pipe or the like, so that drilling can be accomplished during the time that the signalling is carried on. Another object of this invention is to provide a well logging system capable for use during drilling operations, by means of which it is possible to log a characteristic of the formations shortly after they have been exposed by the drill and before there is substantial contamination by penetration of the drilling fluids. This system is characterized by the absence of any electrical conductors running from the logging region to the surface of the earth, and yet provides adequate signalling facilities so that it is possible to determine the earth characteristics while the well is being drilled although the well may be several thousand feet deep. Another object of this invention is to provide a signalling system by means of which electrical apparatus located near the drill bit may be turned on or off at will from the surface of the ground. Still another object of this invention is to provide a coupling system between an earth circuit and a relatively high impedance detector circuit by means of which pulsating electric currents flowing in the earth are caused to produce voltages in the detector system with relatively high efficiency, i. e. with fairly effective impedance matching. Other objects of this invention will be apparent upon perusal of the specification.

Certain drawings have been added to this specification as a part thereof and are to be read therewith, showing various embodiments of the invention. Since these drawings are for illustrative purposes only, it is not to be considered that the invention is limited to the embodiments shown and described. In these drawings the same reference numerals refer to the same or a corresponding part. In these drawings:

Figure 1 represents in diagrammatic form a cross section of the earth penetrated by a well and one form of apparatus useful in carrying out the invention.

Figure 2 represents the electrical circuit of Figure 1 in somewhat greater detail.

Figure 3 represents an alternative signalling system, by means of which a signal applied at the surface of the ground is transmitted to logging apparatus located near the drill bit in a well penetrating the earth.

Briefly what I propose to do is to use a string of drill pipe or the like as a conductor extending into the well from the surface, at least one section of which is covered with a layer of electrically

insulated material, over which is applied an electrode which is thereby insulated from the conductor. A signalling voltage is applied between the electrode and the conductor. This voltage is applied across the low turns winding of a step-down transformer, the high turns winding of which is connected to a high impedance electric circuit. This system is a very effective means of coupling the relatively low impedance "earth circuit" comprising the conductor and the surrounding formations, and a high impedance electrical circuit disposed adjacent or within the conductor in the vicinity of the electrode.

Such a signalling system is shown in Figure 1. Here a well 11 has been bored through the earth from the surface 12 by means of a string of drill pipe 13. This well has been drilled in the customary manner using the conventional rotary drilling system with a bit 14 at the lower end of the drill string 13, and employing drilling fluid which is circulated through the pipe and the annular space between the pipe and the walls of the well. It is desired to log a characteristic of the earth formations, for example, the resistance of the formations adjacent the well as the drilling proceeds. This should be accomplished as soon as possible after this drilling, so that there is a relatively small amount of penetration of water filtering out of the well fluids. The lower portion of the drill string is customarily made up of a drill collar 15 which is composed of one or more sections of drill pipe with increased wall thickness, in order to give additional weight at the bit and to decrease the whipping action which would otherwise cause the hole to deviate from a straight line. A considerable portion of this lower section of drill pipe is covered with a wrapping or covering of insulating material 16. Any reasonably flexible insulating material may be employed for this purpose. Alternatively, relatively unflexible insulating material, such as Bakelite, may be made in the form of a cylindrical casing which is securely fixed in place on the outside of this drill collar 16. A major part of the outer surface of this insulation is effectively covered by an electrically conducting electrode 17. This may be a solid cylindrical structure firmly fastened about the insulation 16, or may be made up of smaller conductors wound or woven together to give a large effective contact surface area. For example, this electrode may be made up of wire mesh or netting, or can be made up of a spirally wrapped metallic ribbon. The chief characteristic of this electrode is that it has a large contact area. As will be discussed subsequently, when this electrode is used as part of a transmitting system, a difference of potential is applied between it and the drill string 13. In order that a substantial amount of current will flow, it is necessary that the resistance between the electrode and the conducting liquid in contact therewith should be quite small. This can be achieved only if the area of this electrode is quite large. I have found that such an electrode should have an effective length substantially greater than its diameter, and I prefer to use electrodes with a ratio of effective length to diameter of at least 5 and more desirably 8 or more. There appears to be no upper limit to this ratio other than that imposed by the cost of preparation. By effective length I mean the greatest distance between the ends of the electrode exposed to well fluid. The insulator 16 should project beyond the ends of the electrode, both above and below, a substantial distance

which can be, for example, of the order of the diameter of the electrode but which is preferably several times this amount at least. A conductor in a cable 18 is securely attached to the surface of the electrode.

The actual logging apparatus itself is preferably located near the signalling electrode. One such arrangement of apparatus is shown in Figure 1. In this particular embodiment a tubular shell 19 with conical ends has been welded over one section of the drill pipe. The drill pipe itself has been plugged by two plugs 20. Suitable openings 21 have been cut in the drill pipe above the top plug 20 and below the bottom plug 20 so that the flow of drill mud through the drill string in this region is through the annular space between the drill string and the tubular shell 19, as shown by the arrows. The space within the plugged-off portion of the drill pipe is occupied by the logging apparatus. In this figure a very simplified type of apparatus is shown. A section of the tubular shell 19 has been covered with a wide insulating sleeve 22. At or near the middle of this sleeve there is a ring electrode 23 of conducting material. A conductor 24 is connected to this ring electrode and passes into the center portion of the drill pipe through a hollow insulator 25. The conductor 24 is connected to an oscillator or alternator 26 which produces pulsating electric signals, for example a relatively constant voltage alternating potential. The other terminal of this oscillator or alternator 26 is connected to one side of the high turns winding of a step-down transformer 27, the other side of which is grounded to the drill string 13. The voltage drop through the high turns winding of this transformer therefore depends upon the current flowing between the drill string 13 and the electrode 23 which in turn depends upon the resistance of the earth formations adjacent the electrode 23. The paths of current flow to this electrode are shown roughly by the dot-dash lines 28. The voltage across the high side of this transformer is therefore a direct indication of a characteristic of the formations adjacent the well at this point.

The secondary of this step-down transformer, or the low turns winding, is connected between the drill string 13 and the conductor of cable 18, so that the signal voltage proportional to the resistance being logged is stepped down by means of the transformer, and the low voltage-high current signal is applied between the low resistance circuit made up of the drill pipe 13 and the electrode 17 on the outside of the insulation. This causes currents to flow in one direction in the drill pipe and through the earth in the other direction to form an infinite number of complete electric "earth circuits." Portions of the lower end of the drill pipe, i. e. the bit 14 and nearby parts, are also exposed to this flow of current and therefore there is a shunt path between electrode 17 and the drill string 13 which tends to reduce somewhat the efficiency of transmission. However, because of the limited area of pipe and bit exposed below the electrode, the proportion of power lost by this means is quite small. Some of the paths of current flow from the electrode 17 to the drill string 13 are shown by the dashed lines in Figure 1. A portion of this current flow from the earth to the drill string 13 and back occurs in the region just below the surface of the earth 12. This produces a drop of potential between two grounded electrodes at different radial distances from the axis of conductor 13. This

difference in potential can be picked up between electrodes 30 and 31 and detected (that is, amplified, filtered if desired, and indicated) by the detector 32. These two electrodes 30 and 31, with their associated wiring, form one example of a circuit coupled to the earth near the head of the well, capable of causing current to flow in the earth upon application of pulsating electromotive force to this circuit. Any such means is useful either to detect or to transmit earth signals. It is desirable that the electrodes 30 and 31 be spaced a substantial distance apart, for example of the order of 50 to several hundred feet, and electrode 30 may be either connected to ground, as shown, immersed in the drill fluid at the well head, or connected directly by means of a brush to the drill string 13 itself. It is apparent that all such connections are substantially equivalent.

The electrical system is shown in a slightly different form for ease in explanation in Figure 2. Here the electrodes are arranged as if they were buried at the surface of a conducting medium 33. This conducting medium is, of course, the earth itself. The voltage drop between electrodes 23 and 13 due to the impressed voltage set up by the oscillator or alternator 26 varies with the electrical properties of this medium. A corresponding voltage drop occurs across the primary or high turns winding of the step-down transformer 27. The secondary of this transformer is connected between electrodes 13 and 17, causing current to flow through the medium 33 as shown by the dashed lines in this figure. Electrode 13 represents the drill string 13 shown in Figure 1. Part of this current flow between electrodes 13 and 17 occurs across the region of medium 33 in which electrodes 30 and 31 are placed, thereby producing a voltage drop between these electrodes which is amplified and indicated by the detector 32. Many such detecting arrangements have already been shown in the prior art and since any such detecting apparatus may be used, no detailed discussion of such device is given.

While in Figure 1 the electrode 23 for measuring the properties of the formations is shown mounted at some distance above the bit, it will be understood that this positioning of the electrode 23 is illustrative only. In many instances it will be desirable to measure the properties of the formations as soon as possible after they have been exposed by the bit, and in such cases the electrode 23 may be mounted just above the bit, for example, on the insulating sleeve 16 below the electrode 17. Electrode 23 could then be connected to the logging apparatus by an insulated lead passing through the interior of drill collar 15.

Further, it will be understood that the system of measuring the earth's properties and subsequent modulation of the output of the oscillator 26 as shown in Figures 1 and 2 is only by way of example. Any other suitable type of modulation can be used, such as one where the measurement is made by currents of one frequency which then modulate currents of a different frequency for signalling.

It is apparent that the signalling system shown in Figures 1 and 2 can be employed to signal from the surface to the region near the drill bit, rather than in the opposite direction. In this case a source of alternating current is used instead of detector 32 and a detector of alternating current is used instead of the oscillator or

alternator source 26. Such a system is shown in Figure 3.

In Figure 3 is shown a system in which the signalling is from the surface down to the bottom of the well. The particular application given is one in which the signalling apparatus is used to turn off or on a logging apparatus located near the drill bit. This is only one example of many which could be given. In this figure an alternator 35 or other source of pulsating electric signals is applied between a region adjacent the well head of the well 11 and a point removed a considerable distance from the axis of the drill string 13. In Figure 3 this is accomplished by applying the voltage output of the source 35 between a brush 36 bearing on the drill string 13, and an electrode 37 buried at some distance from the well head. This produces current flow through the earth between electrode 37 and drill string 13, some of the current flowing between electrode 37 and the bit 14 in the bottom of the apparatus, and more current flowing to the drill string in the region above this bit. For further discussion of this matter, reference is made to the specification in United States Patent 2,354,887 referred to above. Part of this current follows a path shown by the dashed line 38 in Figure 3. This current path ends on the drill string 13 and produces a difference of potential between this drill string and an electrode 39 which is mounted on but insulated from the drill string 13. This electrode is of the type of electrode 17 shown in Figure 1, that is to say, this electrode is a conducting electrode which is effectively a cylinder the length of which is at least 5 times its diameter and preferably 8 to 10 times this diameter or more. It is to be noted that the drill string 13 has welded to it at this point a tubular shell 40 with conical ends, which provides a sealed annular space 41 between the outside of the drill pipe and the inside of this shell. In this space is mounted the electrical apparatus to be described. This electrical apparatus includes a step-up transformer 27, the low turns winding of which is connected between the insulated electrode 39 and the drill string 13, the high turns winding of which is connected to a first filter 42 which is tuned to the frequency band of the output of the alternator or oscillator 35. The filtered output of the first filter 42 is applied to a first amplifier 43 which may contain a demodulator. The output of this amplifier is applied to a modulator 44, which is also supplied with the output of oscillator 45. The modulated output of modulator 44 is applied to a second amplifier 46, the output of which is applied in turn to a second filter 47 tuned to the frequency band of the output of modulator 44. The output of this second filter is applied across the high turns winding of transformer 27. The oscillator 45 is arranged to oscillate in a different frequency range than that of alternator or oscillator 35.

It is apparent from this description that the electrical apparatus shown acts as a repeater station, picking up a portion of the voltage output or signal due to the pulsating electromotive force of oscillator or alternator 35, and produces a signal varying in accordance therewith but in a different frequency band, between the electrode 39 and drill string 13. This causes current to flow in the earth between the drill string and the earth formations in a manner discussed in connection with Figure 1. A part of this current flows to the drill bit 14 and the drill collar 15 below toroidal transformer 48. The construction and operation

of this toroidal transformer is fully described in United States Patent No. 2,354,887 to which reference has been made. It is sufficient to say here that it is made up of a core of magnetic material surrounding the drill string, and a coil of insulated wire wrapped around the core so that currents flowing through the drill string, i. e. through the core of the toroidal transformer, produce a voltage output across the winding wrapped around the core. Therefore a portion of the signals applied between electrode 39 and drill string 13 appear across the output leads 49 of this transformer. This output is amplified by an amplifier 50 which, although shown outside the drill string, is actually enclosed in a sealed chamber (not shown) within the walls of this drill string. The output of this amplifier is applied to the coil of a relay 51. Therefore, when current flows through the earth due to a pulsating electromotive force applied between brush 36 and electrode 37, the coil of relay 51 is energized, closing the contacts thereof, which actuate the electrical logging apparatus 52. Since this electrical logging apparatus forms no part of the invention per se and since several types of such enclosed logging apparatus have been previously described, further description of this piece of equipment is unnecessary.

While I have described my invention in connection with certain embodiments thereof, it is understood that these are by way of illustration rather than by way of limitation, and that I do not mean to be restricted thereby, but only to the invention defined in the appended claims.

I claim:

1. Well signalling apparatus including an uninsulated conductor extending into said well, an electrode surrounding said conductor but insulated therefrom, the effective length of said electrode being substantially greater than its diameter, a step-down transformer the low turns winding of which is connected between said conductor and said electrode, a source of pulsating electromotive force, a detector of pulsating electric signals, and means coupled to the earth near the head of said well capable of causing current to flow in the earth upon application of pulsating electromotive force to said means, one of said source and said detector being connected to the high turns winding of said transformer and the other of said source and said detector being connected at the surface of the earth to said means.

2. Apparatus according to claim 1 in which said electrode is made up of conducting mesh and in which said insulation is a wrapping of a thin layer of insulating material on said conductor, extending a substantial distance above and below the ends of said electrode.

3. Well signalling apparatus including an uninsulated conductor extending into said well, an electrode surrounding said conductor, the ratio of effective length of said electrode to its diameter being at least 5, a layer of insulation interposed between said conductor and said electrode, and extending a substantial distance above and below the ends of said electrode, a step-down transformer the low turns winding of which is connected between said conductor and said electrode, a source of pulsating electromotive force connected to the high turns winding of said transformer, and means coupled to the earth near the head of said well for detecting the flow of pulsating current to said conductor and for producing a visual indication of a characteristic of said detected current.

4. In well signalling apparatus including an uninsulated conductor extending into said well, the combination including an electrode surrounding said conductor, the ratio of effective length of said electrode to its diameter being at least 8, a layer of insulation interposed between said conductor and said electrode and extending a substantial distance above and below the ends of said electrode, a step-down transformer the low turns winding of which is connected between said conductor and said electrode, a source of pulsating electromotive force connected to the high turns winding of said transformer, and means coupled to the earth near the head of said well for detecting the flow of pulsating current to said conductor and for producing a visual indication of a characteristic of said detected current.

5. Well logging apparatus including an uninsulated drill pipe extending into said well, said pipe being surrounded for the major portion of its length in said well by a conducting fluid, a thin wrapping of insulating material surrounding said pipe near the lower end thereof, an electrode surrounding the major part of said insulating material, said electrode having a ratio of length to diameter of at least 8 and said material extending a substantial distance above and below the ends of said electrode, a step-down coupling transformer the low turns winding of which is connected between said pipe and said electrode, means for measuring an electrical characteristic associated with the earth formations surrounding said well, a source of alternating potential, means for varying a characteristic of said potential in proportion to the magnitude of said measurement, means for connecting said varying potential across the high turns winding of said transformer, and means responsive to alternating current flow in the earth adjacent the head of said well due to said source for producing a visual indication varying with the variations in said characteristic of said potential.

6. Well signalling apparatus including an uninsulated conductor extending into said well, an electrode surrounding said conductor, the ratio of effective length of said electrode to its diameter being at least 5, a layer of insulation interposed between said conductor and said electrode and extending a substantial distance above and below the ends of said electrode, a step-down transformer, the low turns winding of which is connected between said conductor and said electrode, means coupled to the earth near the head of said well capable of causing current to flow in the earth upon application of pulsating electromotive force thereto, a source of pulsating electromotive force connected to said means, means connected to the high turns winding of said transformer for detecting the flow of pulsating current.

7. In well signalling apparatus including an uninsulated conductor extending into said well, the combination including an electrode surrounding said conductor, the ratio of effective length of said electrode to its diameter being at least 8, a layer of insulation interposed between said conductor and said electrode and extending a substantial distance above and below the ends of said electrode, a step-down transformer the low turns winding of which is connected between said conductor and said electrode, means coupled to the earth near the head of said well capable of causing current to flow in the earth upon application of pulsating electromotive force thereto, a source of pulsating electromotive force connected to said means, and means connected to

the high turns winding of said transformer for detecting the flow of pulsating current.

8. Well signalling apparatus including an un-insulated drill pipe extending into said well, said pipe being surrounded for the major portion of its length in said well by a conducting fluid, a thin wrapping of insulating material surrounding said pipe near the lower end thereof, an electrode surrounding the major part of said insulating material, said electrode having a ratio of length to diameter of at least 8 and said material extending a substantial distance above and below the ends of said electrode, a step-down coupling

transformer the low turns winding of which is connected between said pipe and said electrode, means including a source of alternating potential coupled to the earth near the head of said well and causing current to flow in the earth, means connected to the high turns winding of said transformer for detecting the flow of alternating potential which is picked up by said electrode, an electrically operated switch, and means responsive to said detecting means for actuating said switch.

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