

Oct. 3, 1933.

N. JOHNSTON

1,928,970

WELL SURVEY INSTRUMENT

Filed Oct. 15, 1930

8 Sheets-Sheet 1

Fig. 2.

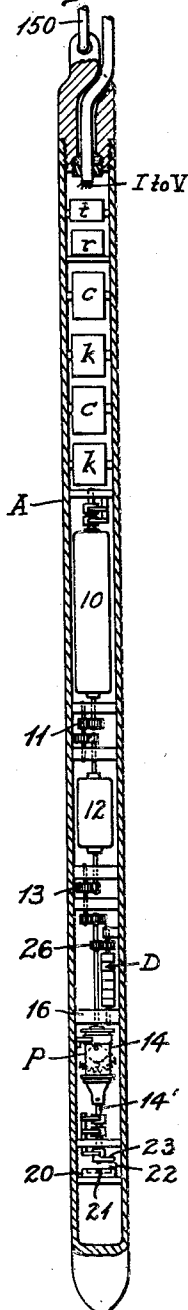


Fig. 3.

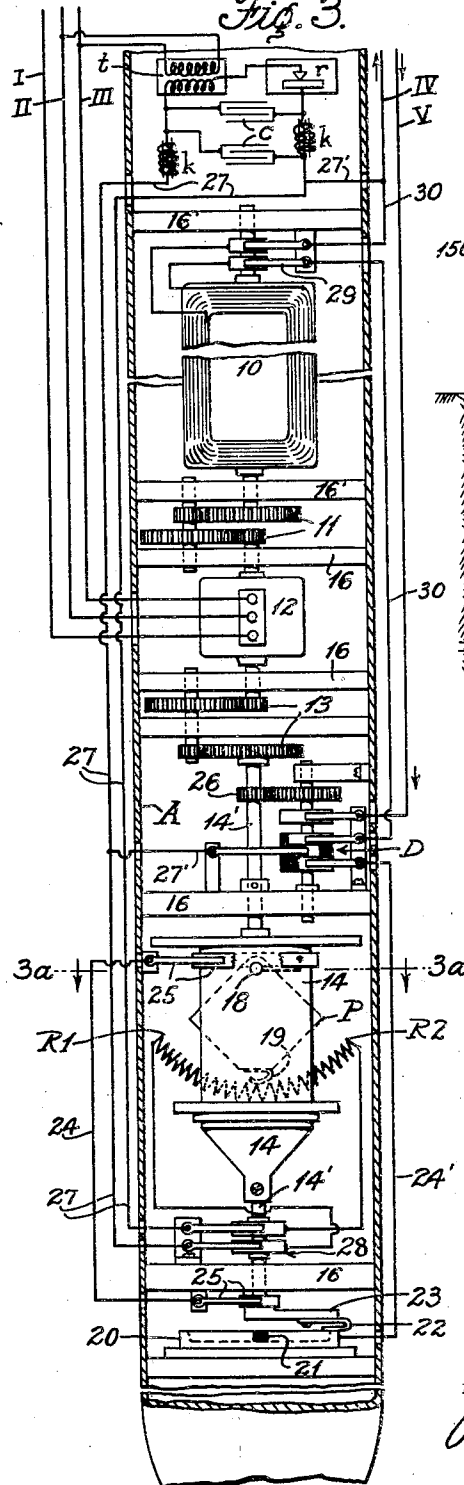


Fig. 1.

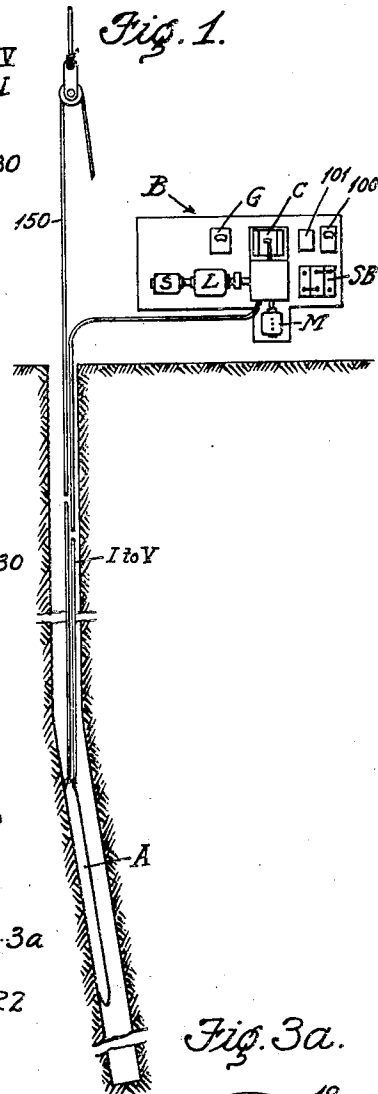
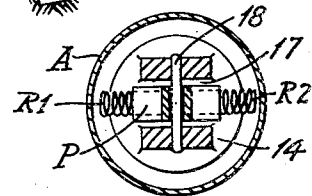


Fig. 3a.



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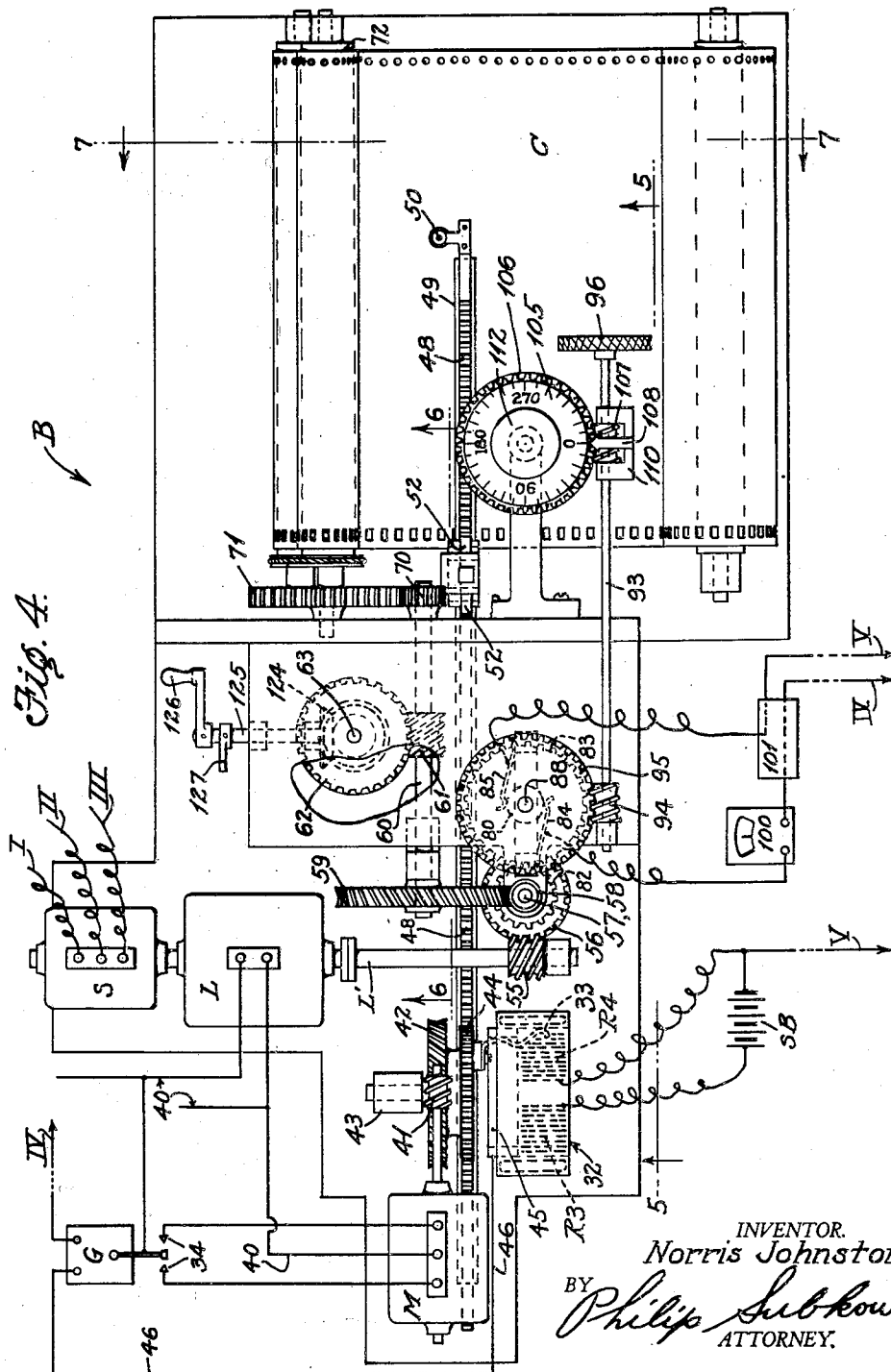
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Oct. 3, 1933.

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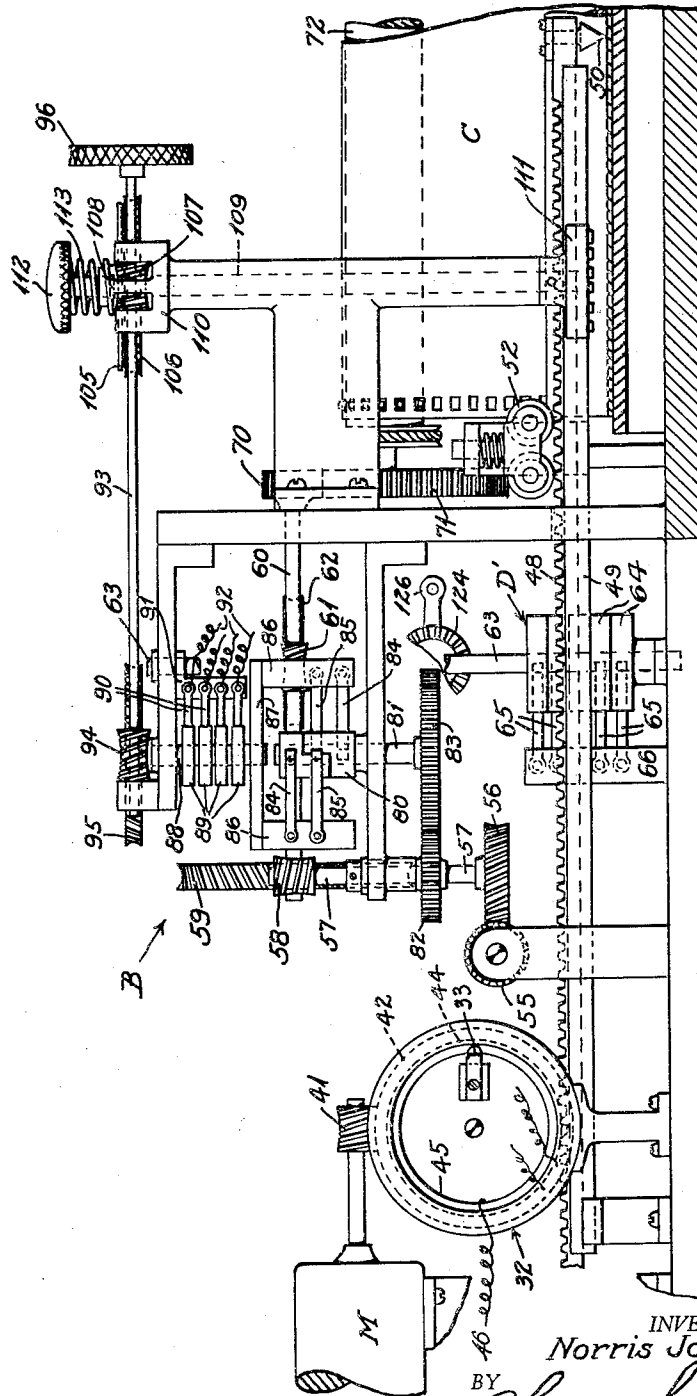
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8 Sheets-Sheet 3

Fig. 5.



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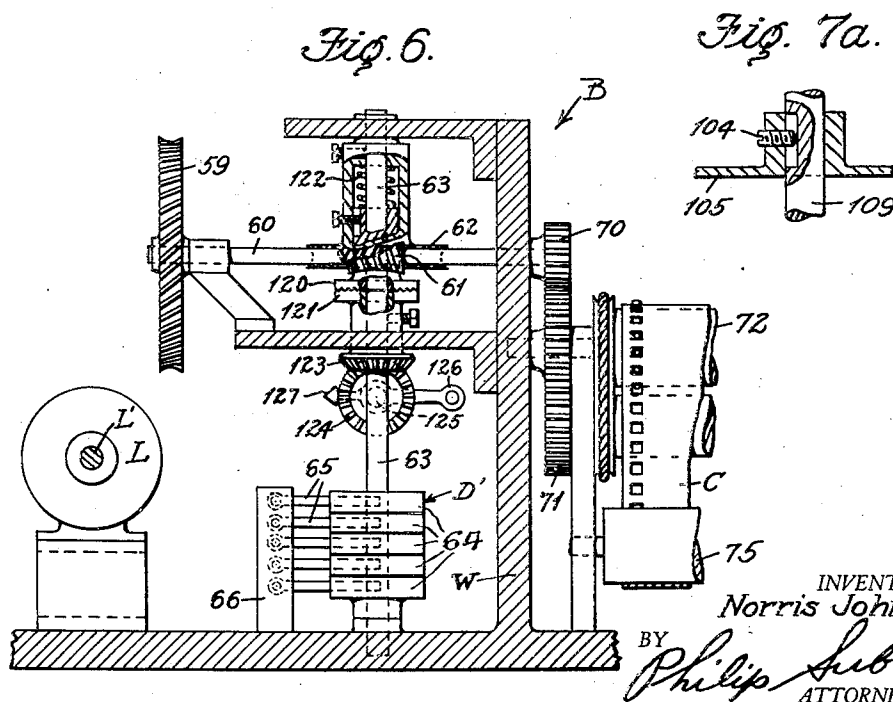
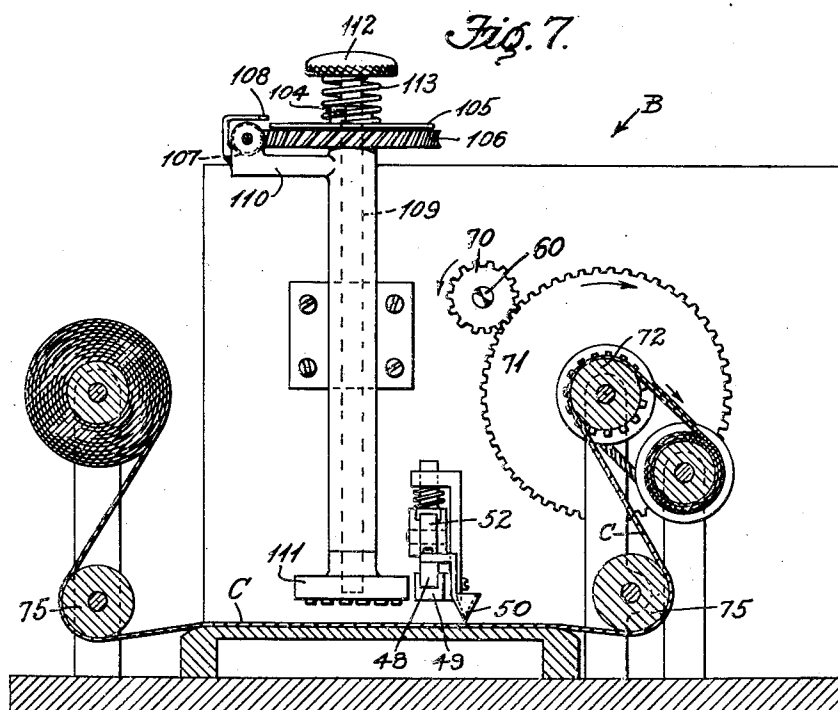
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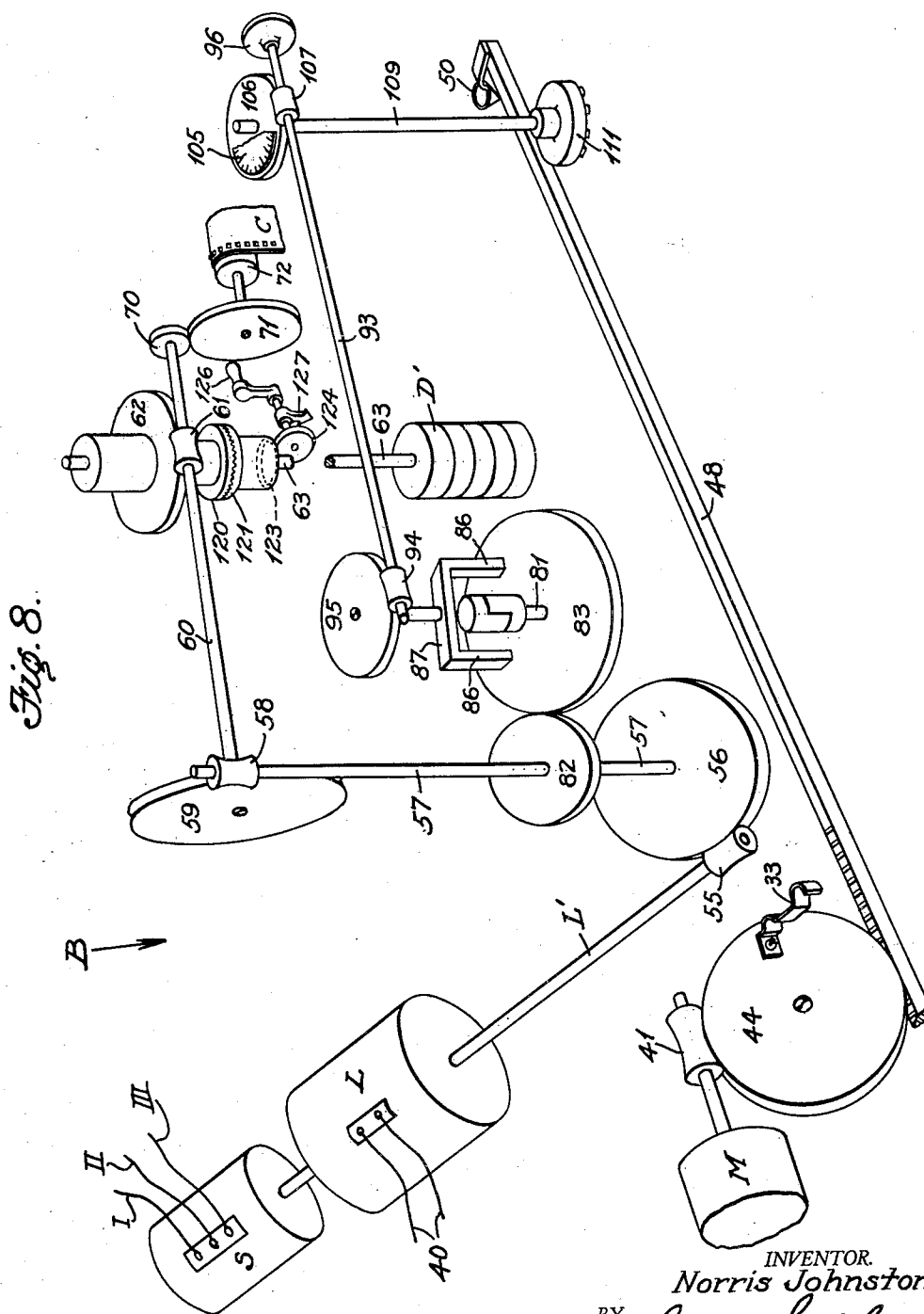
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WELL SURVEY INSTRUMENT

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8 Sheets-Sheet 5



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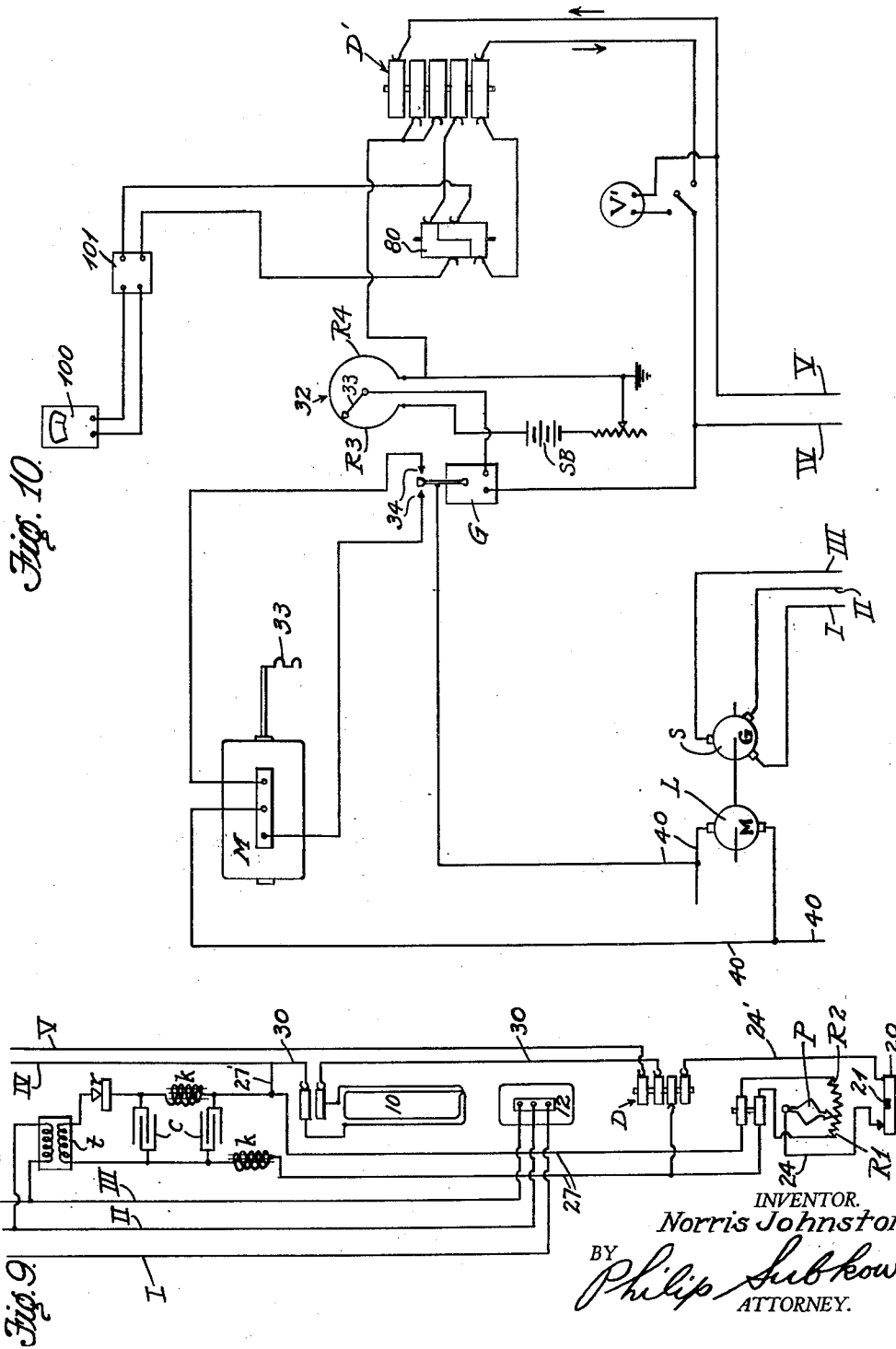
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WELL SURVEY INSTRUMENT

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Fig. 14.

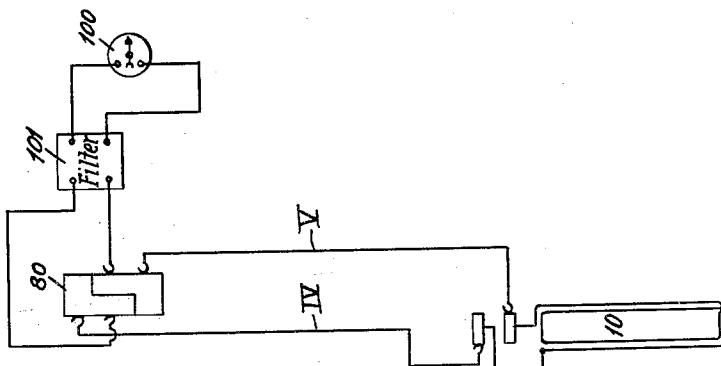


Fig. 13.

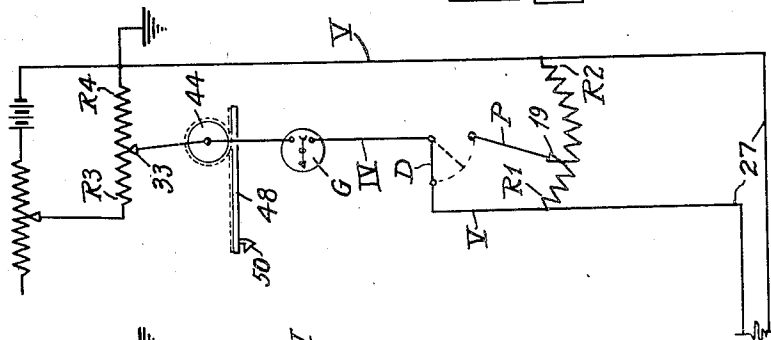


Fig. 12.

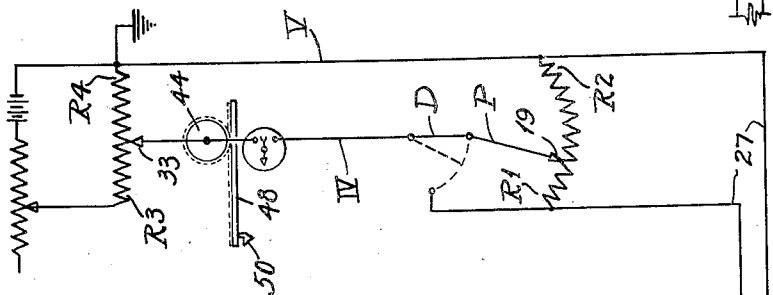
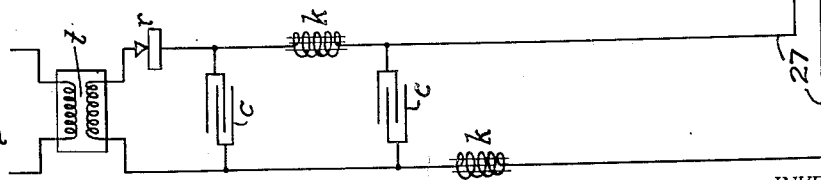


Fig. 11.



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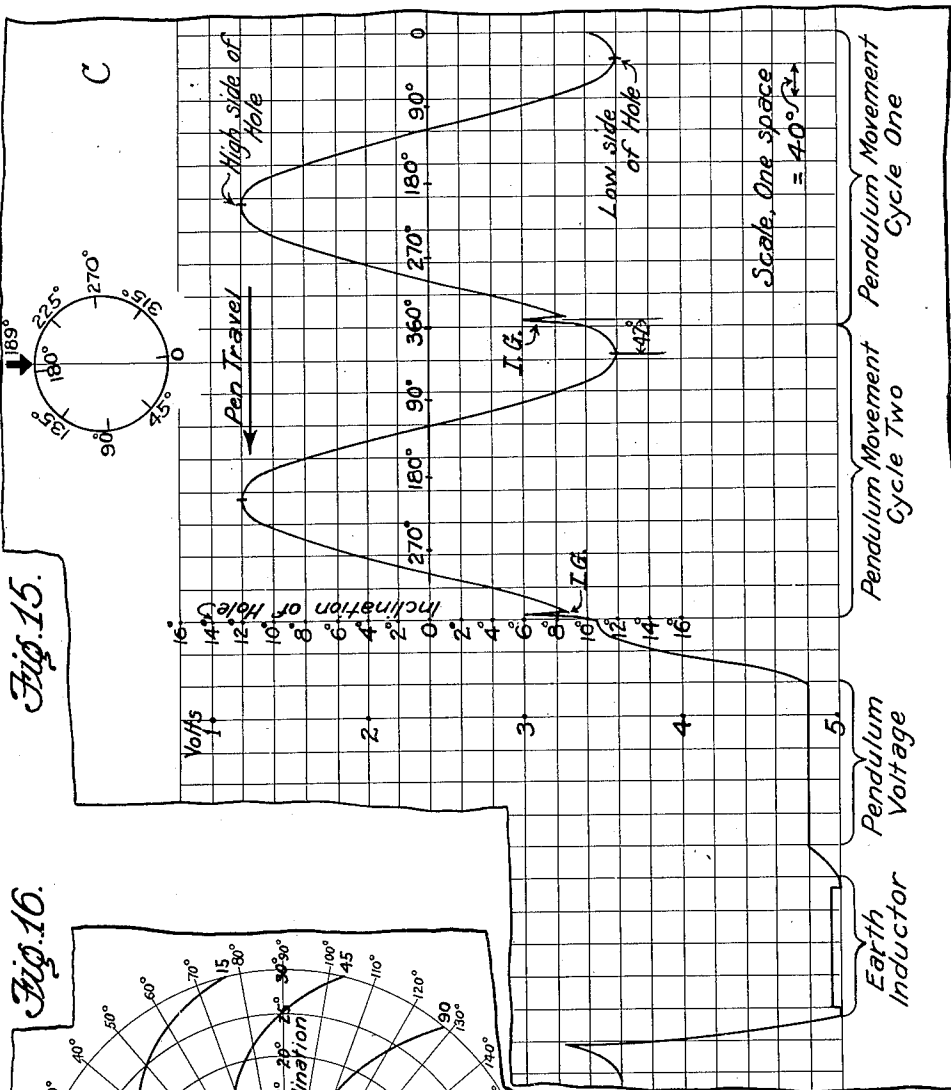
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WELL SURVEY INSTRUMENT

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8 Sheets-Sheet 8



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UNITED STATES PATENT OFFICE

1,928,970

WELL SURVEY INSTRUMENT

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Application October 15, 1930. Serial No. 488,844

22 Claims. (Cl. 234—5.3)

This invention relates to devices for surveying the trend of bore holes especially of the type produced in deep well drilling, wherein as is well known a departure from the straight and vertical

5 Fundamentally the object of the invention is to provide apparatus by means of which both the inclination and the direction of inclination of a bore hole may be measured and progressively indicated at the surface as a device is lowered in the hole successively from one position to another. Primarily all measurements are made electrically and are then successively conducted to the surface and transformed into mechanical energy whereby curves are continuously recorded for each position in which the device is placed in the well, in order that the record of the well conditions may be observed substantially at the time that the measurements are made.

10 Briefly stated the apparatus of the present invention comprises surface mechanism and an instrument adapted to be lowered into a well bore. The well instrument contains an earth inductor compass, a rotatable mounting carrying a pendulum free to swing in a plane parallel to the axis of the mounting and across a resistance element, a synchronous motor for driving the compass and the pendulum mounting, and a rotary arm driven in unison with the pendulum mounting and in contact with a conducting ring connected in electrical series with the pendulum and its resistance, said ring having an interruption gap in the form of a segment of insulation for interrupting the current during each revolution. The surface mechanism comprises a synchronous motor generator for energizing the synchronous motor in the well instrument, a commutator for the earth inductor current, means for adjusting for the phase angle between the synchronous drive and the earth inductor current, means to record said angle, and means for transforming electrical energy into mechanical energy and for continuously recording curves showing the current changes and indicative of conditions in the well instrument. In a preferred embodiment the transforming means is in the form of a galvanometer relay and a reversible motor controlled by the relay and actuating the recording means.

50 The invention may be broadly stated as comprising the employment of an instrument adapted to be lowered into a bore hole, the instrument including an earth inductor compass for indicating and determining directional relations, in combination with a rotated pendulum which is

free to swing across a resistance into the plane of maximum inclination during each rotation period of the pendulum for correspondingly modifying an electric current. The invention also includes means, such as the interrupter device, to modify a pendulum current for orienting pendulum position with respect to a point having a known or determinable position, particularly a fixed point on the instrument housing. The invention may be otherwise stated as covering a well survey instrument adapted to be lowered into a well comprising a rotating shaft, a gravity operated member movable into the plane of maximum inclination, a rotating member driven by said shaft for orientation of pendulum position, a circuit in which said members are connected, and an interruption element cooperating with one of said members to produce indicative breaks in current flowing in the circuit. The employment of multiple switches to shift the measuring circuits with proper relation to the pendulum and compass movements for separately indicating these movements at the surface, also is of this invention. The invention may further be said to reside in the method of generating curves representative of the electric currents, in modifying these curves in accordance with the inclination of the bore holes at any given point under measurement, and in further modifying these curves with respect to a magnetic north for proper orientation of the direction of inclination.

In the accompanying drawings, wherein one embodiment of the broad invention is disclosed simply by way of illustration:

Fig. 1 indicates the measuring instrument per se in operative position within a well, the surface mechanism for supplying power to the surveying instrument, and for receiving the modified current impulses from the instrument and for transforming said impulses into mechanical energy and producing a record, being indicated diagrammatically;

Fig. 2 is a vertical section through the casing and containing mechanism constituting the surveying instrument;

Fig. 3 is an enlarged sectional detail showing in elevation the major parts of the survey instrument and the electric connections;

Fig. 3a is a cross section on line 3a—3a of Fig. 3;

Fig. 4 is a plan of the surface mechanism;

Fig. 5 is chiefly a side elevation taken from the line 5—5 of Fig. 4;

Fig. 6 is a vertical sectional detail taken from the line 6—6 of Fig. 4;

Fig. 7 is a front end elevation taken from line 7-7 of Fig. 4;

Fig. 7a is a detail in section of parts shown in Fig. 7.

Fig. 8 is a diagrammatic representation of the complete system of mechanical drives contained in the surface mechanism;

Fig. 9 is a wiring diagram of the well instrument;

Fig. 10 is a wiring diagram for the surface mechanism;

Fig. 11 is a wiring diagram of the power circuit for the pendulum and resistance elements of the well instrument;

Fig. 12 is a wiring diagram for the pendulum-movement circuit;

Fig. 13 is a wiring diagram for the pendulum-voltage circuit;

Fig. 14 is a wiring diagram for the earth inductor compass;

Fig. 15 is a record of a complete cycle produced by the present apparatus; and

Fig. 16 is illustrative of calibrating charts required to be used to correct errors due to the sharp angle to the horizontal of the earth's magnetic lines in the various localities.

Before considering the structure in detail and in its logical order it will be helpful first to consider the general construction broadly in order that the general relation of the primary parts and their functions may be better understood when taking up the detailed narrative.

Briefly described, the preferred construction herein disclosed employs a Wheatstone bridge, of which two arms R_1 and R_2 are located in the well and two arms R_3 and R_4 are provided at the surface. The two arms R_1 and R_2 within the well are in the form of a resistance coil or the like across which a pendulum P is adapted to swing, the pendulum and said resistor together with a housing in which they are carried being continuously rotated so that during each cycle the pendulum swings in the plane of maximum inclination across the opposite arms R_1 , R_2 of the bridge to the extent of such maximum inclination, whereby a sine curve of voltage intercepted by the pendulum may be recorded at the surface whose amplitude will be a direct measure of the inclination of the axis of the instrument from the vertical. At the surface a galvanometer relay G is employed in conjunction with the two upper arms R_3 , R_4 of the Wheatstone bridge, whereby current variations through the bridge circuit will cause actuation of the galvanometer needle. This galvanometer relay, whose construction and operation are well understood, actually amounts to a galvanometer-operated automatic switch. This switch controls current to a reversible motor M . This motor performs two functions:

a. To shift a contact 33 across the arms R_3 and R_4 (which are in the form of a toroid coil) thereby balancing the circuit; and

b. To drive a mechanical recording rack 48 and pen 50 in exact proportion to the amount of adjustment of the contact 33.

The driving mechanism for the entire apparatus is in the form of a primary motor L provided at the surface and connected to drive a synchronous generator S .

The synchronous generator S furnishes electric power to a synchronous motor 12 disposed within the instrument casing A which is adapted to be lowered into the well. This casing A , which is of sufficient length to assume parallelism with the axis of that portion of the hole in which it is

positioned, contains the pendulum P which together with its housing and resistance R_1 , R_2 is adapted to be constantly rotated by the synchronous motor 12.

The important parts of the surface mechanism, which is generally indicated at B , are the synchronous drive motor L , the synchronous generator S which actuates the synchronous well motor 12, a toroidal coil 32 composed of the arms R_3 , R_4 , which together with adjustable contact 33 constitute the upper half of the Wheatstone bridge, a multiple switch such as a drum switch D' for the various circuits, the reversible motor M , the recording rack 48 and pen 50, a record chart C , and an adjustable synchronous commutator 80 for an earth inductor current received from an earth inductor coil 10 in the well instrument A presently to be described, said commutator being adapted to adjust for the phase angle between its position and the earth inductor voltage.

The important parts contained in the well instrument A , are the pendulum P , the synchronous motor 12, an interruptor 21, 22, 23, an earth inductor coil 10, and a multiple switch such as a drum switch D . The interruptor is located in the pendulum circuit and has its interruptor gap 21 fixed with relation to the casing A , such gap being passed by a contact 22 rotated in unison with the rotation of the pendulum and its housing. The position of this gap is definitely located, for example in the magnetic north, before the instrument is lowered into the well. The earth inductor coil 10 which is rotated at high speed from the synchronous motor 12 is connected with the synchronous commutator 80 at the surface. Before the instrument is lowered into the well, the parts being in operation, said synchronous commutator is adjusted to show a zero phase angle between the earth inductor current from coil 10 and the position of said commutator 80. Thus the amount of any future adjustment of said synchronous commutator 80 will be a measure of rotation of the casing A within the well, of consequent and corresponding rotation of the interruptor gap 21, and of consequent and corresponding rotation of the field of the synchronous motor 12 which has resulted in the phase angle change requiring the adjustment of the synchronous commutator 80. A recorder such as a stamp working opposite a fixed reference point may be used to indicate the amount of adjustment, thereby serving to orient the instrument housing A in the well with respect to its interruptor gap 21 and magnetic north.

The drum switches D and D' operate in unison and serve to cut the various circuits in and out both in the surface mechanism B and in the well mechanism A in order that a single pair of lead lines IV and V may serve for several measuring circuits. This makes it necessary then to employ in addition only those wires I , II , III which serve to drive the synchronous well motor 12 from the synchronous generator S at the surface. Current for the pendulum circuit is conveniently taken through a transformer, rectifier and filter from the power line supplying the synchronous motor 12.

DETAIL DESCRIPTION

The surveying instrument

The survey instrument which is adapted to be lowered into the well is contained in a casing A of sufficient length that when positioned within any portion of the hole being measured its axis will assume a position substantially parallel with the

axis of the hole somewhat as indicated in Fig. 1. This housing A contains an earth inductor coil 10 which is merely an elongated flat open coil mounted for high speed rotation about its longitudinal axis. It is driven through a suitable gear reduction 11 by a synchronous motor 12 supplied with electrical energy from a motor-generator set L, S of the surface mechanism B through the medium of appropriate power lines I, II, III. By means of a second gear reduction 13, the motor 12 drives a pendulum housing 14 at a comparatively low rate, for example 2 R. P. M. Both the motor 12 and the pendulum housing 14 are journaled in suitable partitions or brackets 16 within the casing A. Said housing 14 is provided with a transverse vertical slot 17 in which a flat diamond-shaped pendulum P is adapted to swing, said pendulum being pivoted within the housing as indicated at 18 and being mounted in such manner that a circuit may be completed through it to a contact 19 on its lower corner. This contact is adapted to travel along an arcuate resistance coil or other suitable resistor which may be considered to have two arms R₁ and R₂ at the opposite sides of said contact 19. Thus, when the device is inclined to the vertical and as the pendulum housing 14 is rotated, the contact 19 will travel into the plane of maximum inclination increasing R₁ and decreasing R₂ when the one side of said housing 14 is on the low side, and again into the plane of maximum inclination decreasing R₁ and increasing R₂ when the opposite side of said housing 14 is on the low side. Below the pendulum housing 14 the casing A has fixed thereto a ring 20 in which is embedded a spot or insert of insulation 21 adapted to be traversed by a contact 22 which is caused to travel around the ring 20 by reason of the rotation of the housing 14 whose shaft 14' carries on its lower end a contact arm 23 provided with said contact 22. By means of the lead wire 24 and suitable slip rings and brushes 25, said ring 20, contact 22 and arm 23 are placed in circuit with the pendulum P and the resistance arms R₁ and R₂. This circuit however is broken when the contact 22 passes across the interruption gap formed by the insulation 21. Thus said contact 22 and the arm 23 working in conjunction with the interruption gap 21 constitute an interrupter for the pendulum circuit; this term "interrupter" will be used hereafter in referring to this part of the structure. A lead line 24' extends from the ring 20 to a multiple drum switch D driven by the motor 12 through the medium of the shaft 14' and a suitable gear reduction 26. The top ring of the drum switch is connected with the measuring line V whereby the line 24' serves at the proper interval to lead the pendulum-movement circuits to the surface. The period of rotation of the drum switch D is that of a complete cycle of the apparatus, for example two minutes, and it serves to connect at proper intervals the various circuits to be measured with two measuring lines IV and V leading to the surface equipment.

In order that the opposite ends of the two resistance arms R₁ and R₂ which constitute the lower half of the Wheatstone bridge, may have a suitable voltage impressed thereon, lead lines 27 and corresponding slip rings and brushes 28 lead from the ends of said resistance arms to a source of low voltage current (for example five volts), which may be supplied either by a battery contained within the housing A or by means such as indicated comprising a transformer *t*, rectifier *r*, condenser *c*, and choke coils *k*. Connections

27' lead to the measuring line IV and to the drum switch D to which the measuring line V is connected as above indicated, whereby the total pendulum voltage may be received at the surface.

The earth inductor coil 10, which is suitably journaled in partitions or brackets 16' above the synchronous motor 12, is in turn connected through the medium of slip rings and brushes 29 with the measuring line IV and with the drum switch D through leads 30 so that the earth inductor current may be received at the surface at the proper intervals.

Thus as the drum switch D slowly rotates it successively cuts in and out the pendulum-movement circuit 24, 24', 27, the pendulum voltage circuit 27, 27', and the earth inductor circuit 29, 30.

The surface equipment

The currents carried by the measuring lines IV and V are conducted to the surface and led into a drum switch D' which is the counterpart of the drum switch D of the well instrument A. Thus, the pendulum currents are passed from the drum switch D through galvanometer relay G to the arms R₃ and R₄ of a circular or toroidal potentiometer coil 32 across which a contact 33 is adapted to be moved through the direct influence of a reversible motor M. Arms R₃ and R₄ of the toroidal coil 32 cooperate with arms R₁ and R₂ of the pendulum resistance in the well to constitute the Wheatstone bridge in which the contact 33 and the pendulum contact 19 are movable to vary the resistance of the four arms, the galvanometer relay G being connected in circuit between said contacts. A storage battery SB is provided to impress upon the arms R₃ and R₄ exactly the same potential (e. g. 5 volts) as that impressed upon arms R₁ and R₂ in the well by the transformer *t*. The needle of said galvanometer relay G swings between two contacts 34 to control a fixed voltage to a reversible motor M which is supplied from power lines 40 also supplying a main drive motor L presently to be described. Motor M is thus energized for forward or reverse movement according to the control of the galvanometer relay G and serves to adjust the contact 33 correspondingly along the arms R₃ and R₄ of the toroidal coil 32. The mechanical movement of the contact 33 by the motor M is obtained by means of a worm 41 on the motor shaft, said worm meshing with a worm gear 42 journaled at 43 and having a geared hub 44 near the periphery of which the contact 33 is mounted. The contact 33 serves to connect the bare portions of the coil 32 which it engages with a slip ring 45 carried by and insulated from coil 32, said slip ring being connected by a lead 46 with the galvanometer relay G.

In this manner the current supplied to the galvanometer G from the pendulum circuit within the well acts to control the reversible motor M to shift the contact 33 between the arms R₃ and R₄ of the toroidal coil 32 to balance the Wheatstone bridge. In this fashion the amount of rotation of the motor M forward and reverse constitutes a measure of the movement of the pendulum P across the arms R₁ and R₂. A record of this motion is obtained by causing the geared hub 44 to drive a gear rack 48 which extends along a guide 49 to the opposite side of the apparatus and carries at its end a recording pen 50. The pen 50 is thus moved across a record chart C which is slowly advanced simultaneously as hereinafter developed. Spring pressed rollers 52

serve to retain rack 48 in its guide and thereby maintain recording engagement of the pen.

The main drive motor L is direct connected to drive a synchronous generator S, thus forming a motor generator set which as previously indicated is connected through the power lines I, II, and III with the synchronous motor 12 located within the well instrument housing A, whereby the motor 12 necessarily operates in synchronism with generator S. The motor shaft L' of said motor L is provided with a spiral gear 55 engaging a second spiral gear 56 which drives a shaft 57 having on its upper end a worm 58 driving a worm gear 59 mounted on a horizontal shaft 60 known as the drum-switch drive shaft since it carries a worm 61 driving a worm gear 62 on a drum shaft 63 provided with a plurality of contact rings 64 constituting the drum switch D'. This drum switch D' is rotated at the same rate as the drum switch D in the well instrument A, and serves through the medium of a plurality of spring contact fingers 65 mounted on an insulating post 66 to connect the various circuits at proper intervals. An extension of the drum-switch drive shaft 60 beyond a vertical partition wall W carries a gear 70 meshing with other suitable gearing 71 having proper speed reduction values and connected to drive a paper roll 72 for moving a record sheet C with its record chart across a suitable platform beneath guide rolls 75. Thus as the recording pen 50 on rack 48 is reciprocated through the agency of the reversible motor M a record curve of the operations within the well is recorded upon the slowly moving chart C.

In order that the earth inductor current furnished from the earth inductor coil 10 in the well instrument A may be commutated, a synchronous commutator 80 is provided. This commutator is mounted upon a rotating shaft 81 driven at identically the same speed as the earth inductor 10 from the shaft 57 by a gear train 82, 83. Spring feed brushes 84 and take-off brushes 85 are mounted on adjustable insulating arms 86 arranged parallel with the axis of the commutator drive shaft 81, said arms being carried on a head 87 which in turn is carried by a depending shaft 88 journaled in the super-structure. Said shaft 88 is provided with slip rings 89 connected with the brushes 84 and 85, these slip rings being engaged by spring brushes 90 carried on an insulating post 91 and connected to suitable leads 92. The commutator brushes 84 and 85 are adapted to be adjusted to correct for any phase angle which may develop, as at starting, between the earth inductor current and the position of the synchronous generator S and synchronous motor 12. The phase position of the generator S and motor 12 is represented by the position of said commutator 80 with respect to its brushes 84, 85, since said commutator 80 is driven directly from the drive motor L. Adjustment of the commutator brushes 84 and 85 is accomplished through the medium of an adjusting shaft 93 carrying a worm 94 engaging a worm gear 95 on shaft 81, said adjustment shaft 93 being actuated manually by a hand wheel 96 conveniently positioned above the chart C.

In order that this commutator adjustment may be accurately made and may be measured and recorded, a galvanometer 100 and a filter 101 (Fig. 10) are connected in circuit with the commutator 80, and the hand wheel 96 is employed to cause the shaft 93 and its worm 94 to move the shaft 81 and the brushes 84 and 85 until the

galvanometer 100 reads zero. The earth inductor circuit and the commutator are now in phase, and the angle through which the brushes 84 and 85 have been moved represents the amount of angular displacement of the instrument housing A, and consequently of the interruption gap 21 in the well instrument A from the magnetic north, assuming that the original or zero position of said gap was in the magnetic north. For the purpose of indicating and recording the degree of this angular displacement a graduated circular scale is provided on a disc 105 frictionally mounted upon a worm gear 106 which is driven by worm 107 carried by the adjusting shaft 93. Assuming a zero setting of the scale 105 opposite some fixed indicator such as a pointer 108, the gear 106 and disc 105 operate through a key and groove driving connection at 104 to drive a vertical shaft 109 mounted in a supporting bracket 110. Shaft 109 has secured on its lower end a recording element 111 such as a graduated printing head or stamp whose reading will be taken from some fixed reference point or zero position such as the vertical diameter of its impression when made on the record chart C. Thus when the wheel 96 and shaft 93 are adjusted, the worm gear 106, the graduated disc 105 and stamp 111 are correspondingly adjusted. To take the reading of the stamp 111, a knob 112 on the upper end of the shaft 109 is depressed so that the position of the stamp is recorded on the chart. A spring 113 normally maintains the knob 112 and the stamp 111 in elevated position. The spring 113 also serves to maintain a sufficiently firm friction engagement between the disc 105 and the gear 106 to insure that the latter will drive the disc without slippage.

The reason for providing this friction drive between gear 106 and disc 105 is that when starting up the apparatus and preparing to lower the instrument A into the well with the interruption gap 21 in zero position, i. e. in the magnetic north, the brushes 84 and 85 must be adjusted by means of the wheel 96 to synchronize the earth inductor coil 10 with the generator S and the well motor 12. This therefore is the zero setting of the brushes, and it is necessary that the scale 105 and stamp 111 also be set at zero. The latter adjustment is accomplished simply by forcibly rotating the knob 112 and shaft 109 to move the disc 105 against its frictional engagement with gear 106 and to bring "0" opposite the pointer 108. The worm connection between gear 106 and worm 107 locks the shaft 93 against any such movement as might affect the adjustment of the brushes 84 and 85. It is to be understood that this adjustment is made only when first placing the mechanism in operation preparatory to lowering the instrument A into a well.

It is also necessary to provide for an initial adjustment of the drum switch D' of the surface mechanism B in order to bring said switch into synchronism with the drum switch D in the well instrument A. Such provision is shown in Fig. 6 where the worm gear 62 on drum shaft 63 is provided with one element 120 of a clutch whose other element 121 is fixed on the lower portion of said shaft 63, the latter being divided as indicated in order to provide for adjustment of the lower portion with respect to the upper portion. A spring 122 serves normally to maintain clutch engagement. In order that the clutch part 121 and the lower portion of shaft 63 may be independently rotated to adjust the drum switch D', the lower clutch part 121 (whose hub is jour-

naled in an adjacent bracket) is provided with a beveled gear 123 to be driven by a beveled gear 124 fixed on a shaft 125 journaled in any suitable bracket and provided with a hand crank 126 for rotation thereof. Thus, by rotating crank 126 and gears 123 and 124 the clutch part 121 will slip on the clutch part 120, the latter yielding sufficiently against the tension of spring 122. In this manner the drum switch D' can be adjusted as much as required to bring it into synchronism with drum switch D in the well instrument A. A pointer 127 on the gear shaft 125 may be employed if desired to present a visual indication of the position of said drum switch D', the gears 123 and 124 having equal diameters to synchronize the movements of pointer 127 and drum D'. It is understood of course that, as in the case of brushes 84 and 85, this adjustment is employed only when placing the mechanism in operation and preparing to lower the instrument A into the well.

Operation

In placing the mechanism in operation, the main drive or line motor L of the surface mechanism B (Fig. 4) is started, thereby rotating its shaft L' and the various gear trains connected therewith, and at the same time driving the synchronous generator S which thus supplies current to the synchronous motor 12 in the well instrument A. The motor 12 rotates the earth inductor coil 10, the pendulum housing 14, and the drum switch D. The instrument A is then turned to bring the interruption gap 21 into the magnetic north. Next, the adjusting crank 126 for the drum switch D' of the surface mechanism is then rotated to bring the rotation of said drum switch D' into synchronism with the rotation of the drum switch D in the well instrument A. The attainment of such synchronism is indicated by visual observation of a voltmeter V' (Fig. 10). When the voltmeter V' indicates a high, steady voltage (approximately 5 volts) the drum switch D in the instrument A is on the segment known as "Pendulum voltage", to give a check reading of the D. C. voltage supplied to the pendulum. When this steady 5 volt reading drops to zero, the "Pendulum voltage" segment of the drum switch D has just passed. A circular dial behind the pointer 127 is marked to show the exact position of drum switch D' at all times. When the voltmeter V' shows its sudden drop in voltage, the crank 126 is quickly turned so the pointer 127 indicates the appropriate position of drum switch D'. A single pole, double throw switch is used to connect well cables IV and V to the voltmeter for this preliminary synchronizing, and the connection to the recorder is restored immediately for normal operation after this synchronizing is completed.

The next step is to adjust the hand wheel 96, shaft 93, and worm 94 to rotate the worm gear 95 and shaft 81 to so adjust the commutator brushes 84 and 85 with respect to the commutator 80 that the galvanometer 100 shall read zero. The knob 112 on the angle recording shaft 109 is then rotated to move the graduated disc 105 against its frictional engagement with the worm gear 106 to bring "0" opposite the pointer 108. These parts are now in zero position so that there is a zero phase angle between the current supplied by the earth inductor coil 10 and the position of the synchronous commutator 80.

The instrument A is then lowered into the well as by means of any suitable cable 150 attached

to the upper end thereof. So long as the well hole is absolutely vertical, the contact 19 and the pendulum P will maintain a middle position on the pendulum resistance, making R_1 equal to R_2 , and the contact 33 on the toroidal coil 32 will maintain a middle position making the arms R_3 and R_4 of said coil 32 equal. The Wheatstone bridge represented by said arms R_1 , R_2 , R_3 and R_4 thus will be balanced and the needle of relay galvanometer G will be in zero position. Therefore as the record paper carrying the chart C advances, the recording pen 50 will inscribe a straight line upon said chart during that period when the drum switches D and D' are in position to connect the arms R_1 , R_2 , R_3 and R_4 with the measuring lines IV and V. Similarly if there has been no rotation of the instrument casing A to carry the interruption gap 21 out of the magnetic north, the galvanometer 100 will continue to read zero when the earth inductor current is cut in by switches D and D' and no adjustment of the wheel 96 will be required. However when the drum switches D and D' cut in the pendulum voltage by way of lines 27 and 27', the relay galvanometer G will be operated to bring its needle into engagement with one of the contacts 34, thereby supplying current for corresponding operation of the reversible motor M which then operates through its worm 41, worm gear 42, and hub gear 44 to drive the rack 48 and the recording pen 50 to inscribe upon the chart C a corresponding record of the pendulum voltage, as indicated in Fig. 15.

Assume now that the portion of the well hole into which the instrument A is next lowered is at an angle from the vertical as in Fig. 1. As the pendulum housing 14 and the pendulum P are rotated the pendulum contact 19 travels slowly to and fro along the pendulum resistance R_1 and R_2 according as one side or the other is at the low side of the hole. When the drum switches D and D' cut this pendulum-movement circuit in with the measuring lines IV and V, the needle of the galvanometer relay G moves into engagement with one of the contacts 34, thereby correspondingly supplying current to the reversible motor M which then drives its worm 41, the worm gear 42 and the hub gear 44 to move the contact 33 along the toroidal coil 32 until the arms R_3 and R_4 of the latter are in balance with the arms R_1 and R_2 in the well. Simultaneously the hub gear 44 moves the rack 48 to cause the pen 50 to inscribe a corresponding curve on the chart C, this curve approximating a sine curve as indicated in Fig. 15. The amplitude of this curve on opposite sides of the zero or base line represents the degree of inclination. In practice two cycles of the pendulum motion are recorded, each cycle being for example of one-half minute duration and a complete rotation of the drum switches D, D' requiring two minutes.

Assume next that, before the taking of the inclination reading as just outlined, the interruption gap 21 had rotated an appreciable number of degrees around from the magnetic north. When the interrupter contact 22 on the interruption arm 23 passes over the interruption gap 21 during each cycle in which the pendulum-movement circuit is operative, an interruption in the current flow will occur and a correspondingly sharp gap will be disclosed in each cycle of the sine curve as indicated at the points I, G, of the record of Fig. 15. Now, when the drum switches D and D' cut in the current from the earth inductor coil 10, the galvanometer 100 in

circuit with the synchronous commutator 80 will show a reading other than zero, thus indicating that the synchronous commutator 80 is out of phase with the earth inductor coil 10. The wheel 96 is therefore turned to adjust the commutator brushes 84, 85 by way of the shaft 93, worm 94 and worm gear 95, until the galvanometer 100 reads zero. This adjustment will at the same time be imparted by the worm 107 to the worm gear 106 and thence to the graduated disc 105, and the number of degrees read opposite the pointer 108 will indicate the angular adjustment, thereby showing exactly how far the interruption gap 21 had rotated from the magnetic north at the time the reading was taken. This reading is directly recorded on the chart C by striking the knob 112 to impress the printing head or stamp 111 upon the paper. The stamp 111 may be so positioned that the zero reading and all subsequent readings are taken from the impressed graduated circles at their extreme tops adjacent the upper edge of the sheet as indicated in Fig. 15, that point at the top cut by a vertical line passing through the center of each circle thus being the desired reading for the respective impression.

By correlating the interruption gaps I. G. of the sine curve with the orientation reading of the circular stamp 111 the exact direction of inclination of the hole is readily calculated, as will now be shown by reference to the record on the chart of Fig. 15. In preparing this record the paper sheet was moved to the right so that the effective pen travel was to the left as indicated. Also, the lines IV and V were connected so that the top side of the sine curve represented the top side of the inclined hole. The sine curve represents two complete cycles of the movement of the pendulum P across the resistance arms R_1 and R_2 . Two cycles are recorded as a check and to insure a complete record of the interruption gap in case such gap should be either at the beginning or at the end of the cycle. Each space as considered in the direction of the movement of the paper represents 40° of each 360° cycle of pendulum rotation, and each space considered vertically of the paper from the zero or base line represents 2° of inclination of the well hole. Thus the amplitude of the sine curve indicates an inclination of 12° , this measurement being duplicated on each side of the base line by reason of the fact that the pendulum moves symmetrically, to the maximum first shortening the arm R_1 and then to the maximum shortening the arm R_2 during the rotation of its housing 14. The interruption gap I. G. in each instance was about 42° to the right of the bottom side of the hole, or as represented by the record about 138° clockwise from the high toward the low side. But the reading of the orientation stamp 111 was 189° , showing that the interruption gap (and therefore the casing A and parts thereon) had moved in the hole to a position 189° clockwise from magnetic north. Since the interruption gap I. G. was 138° clockwise from the high side of the hole, and was also 189° clockwise from magnetic north, a direct subtraction of the former from the latter figure will show that the high side of the hole is apparently 51° clockwise from magnetic north.

However, since the earth inductor coil 10 generates a voltage whose phase relative to a synchronous reference rotor such as the synchronous commutator 80 is dependent on the azimuthal direction of the component of the earth's field

normal to the axis of coil 10, rather than on the fixed horizontal component as used by needle compasses, it then becomes obvious that when the axis of the instrument A, and consequently of the coil 10, is in some oblique plane, the phase position of the generated voltage will differ from that to be expected from the actual azimuthal direction of the instrument axis. This is particularly noticeable in case the axis of the instrument comes near the actual direction of the earth's field. In fact when the instrument is inclined at an angle greater than the angle between the direction of the earth's field and the vertical, in a northerly direction, the earth inductor indication is southerly, due to the reversal of the direction of cutting of the magnetic lines of force.

Consequently for a locality with a certain angle of dip, the record of orientation must be interpreted with the help of a calibration chart empirically determined for that locality. For small changes in dip angle, such as occur in a locality of the size of Southern California, a single calibration will be sufficient. Such a chart is shown in Fig. 16.

Thus in connection with the example, when reading the record of Fig. 15 and using the calibration chart of Fig. 16, the procedure is as follows:

1. Read record sheet, obtaining 12° inclination, 189° orientation circle, 138° I. G. position as above outlined.
2. Subtract 180° from 189° for apparent I. G. orientation.
3. On calibration chart locate inclination of 12° , at an azimuth of $189 - 138 = 51^\circ$ (shown by dot).
4. Read this off from the heavy curved lines of corrected azimuth, as 12° at N 37° E.
5. Take final reading as inclination of 12° in plane 37° E of magnetic north.

It should be noted that care must be taken to avoid ambiguity in the zero adjustment of the galvanometer 100 of the earth inductor circuit, in view of the fact that two diametrically opposite positions of brushes 84 and 85 will give zero readings. The identity of these zero readings may be detected by noting the direction of approach to zero of the galvanometer when the hand wheel 96 is turned in a given constant direction, as clockwise. A convention must be adopted as to which zero will be used, and the same zero must always be used during a given set of measurements; otherwise N may register as S, or E as W.

It is obvious that such incidental equipment as may be required to obtain desired readings and make desired adjustments can be employed without departing from the spirit of the invention. For example, since the storage battery S B is employed for the purpose of impressing the potential upon the surface arms R_3 and R_4 of the Wheatstone bridge exactly equal to the potential imposed upon the arms R_1 and R_2 in the well, it is convenient to employ the voltmeter on the measuring lines IV and V at the surface in order to visually check the voltage and make the required adjustment at the surface to avoid having to correct the amplitude on the chart due to unbalanced voltages, as indicated by chart C and voltmeter V'. Similarly if it be required to cut in a ground for the needle of the galvanometer relay G at certain times an additional ring may be employed at the lower end of the drum switch D'.

It is to be understood that the disclosures herein are to be considered merely as illustrative and not as limiting, since many modifications within the scope hereof may be made by those skilled in the art.

I claim:

1. A well survey instrument comprising a rotating shaft, a pendulum cooperating therewith and movable into planes of maximum inclination, an orienting member rotated by said shaft for orientation of said plane, and an earth inductor compass having a rotatable element connected with and driven by said shaft.

2. A well survey instrument comprising a rotating shaft, a pendulum cooperating therewith and rotatably driven with the shaft and movable into the plane of maximum inclination, orienting means including a member rotated by said shaft for orientation of said plane, an electric circuit in which the pendulum and orienting member are connected for corresponding modification of current flowing there-through, and a compass indicative of relative direction.

3. A structure according to claim 2 wherein the orienting means includes an interrupter for the current.

4. A structure according to claim 2 wherein the compass is an earth inductor compass.

5. A well survey instrument comprising a rotating shaft, a pendulum cooperating therewith and movable into the plane of maximum inclination, an orienting member rotated by said shaft for orientation of said plane, an electric circuit in which the pendulum and orienting member are connected for corresponding modification of current flowing therethrough, and an earth inductor compass having a rotatable element and a driving connection between said element and the rotating shaft.

6. A well survey instrument adapted to be lowered into a well comprising a rotating shaft, a gravity operated member movable into the plane of maximum inclination, a rotating member driven by said shaft for orientation of pendulum position, a circuit in which said members are connected, and an interruption element cooperating with the rotating orienting member to produce indicative breaks in current flowing in the circuit for purposes of orientation.

7. An instrument according to claim 6 wherein the orienting member is an earth inductor compass.

8. A well survey instrument comprising a rotating shaft, an orienting member constantly rotated thereby, a gravity member cooperating with said orienting member and movable into a plane of maximum inclination, an electric circuit in which said members are connected, an interrupter cooperating with one of said members to produce indicative breaks in a current flowing in said circuit, and a second member also rotated by said shaft to indicate relative direction.

9. A structure according to claim 8 wherein the interrupter includes an interruption gap positioned to cooperate with the orienting member for the purpose of indicating a directional position of the gravity member.

10. A structure for surveying deep wells comprising an instrument adapted to be lowered into a well, devices in said instrument electrically sensitive to deviation from the vertical and to rotational displacement of the instrument housing, a circuit in which said devices are connected,

certain of said devices being adapted to modify the current in accordance with maximum deviation of the instrument from the vertical, and certain of said devices being adapted to modify said current further for indication of the plane of maximum inclination with respect to the rotational position of said housing.

11. A structure according to claim 10 including a compass indicative of relative direction.

12. A structure according to claim 10 including an earth inductor compass and means to correlate the compass reading with the position of the instrument housing.

13. A structure for surveying deep wells comprising an instrument adapted to be lowered into a well, devices in said instrument electrically sensitive to deviation from the vertical and to rotational displacement of the instrument housing, a circuit in which said devices are connected, certain of said devices being adapted to modify the current in accordance with maximum deviation of the instrument from the vertical, and certain of said devices being adapted to modify said current further for indication of the plane of maximum inclination with respect to the rotational position of said housing, an earth inductor compass carried in said housing, means for commutating the earth inductor current, means for synchronously driving said electrically sensitive devices, and means for adjusting the phase angle between said driving means and the earth inductor current to determine directional changes.

14. A well survey means comprising surface mechanism and an instrument adapted to be lowered into a well, a synchronous motor-generator in said surface mechanism, a synchronous driven motor in said instrument, devices in said instrument electrically sensitive to deviations from the vertical and to rotational displacement of the instrument, said devices being adapted to modify a current passed through said devices in accordance with deviation and rotational displacement respectively, means to receive said current modifications, an earth inductor compass in said instrument, means to commutate the earth inductor current, and means to adjust for the phase angle between the synchronous drive and the earth inductor current.

15. A structure according to claim 14 in combination with means in the surface mechanism controlled by the receiving means for producing a record curve showing the modifications in the current from the electrically sensitive devices, and means for indicating and recording the phase angle adjustment for the earth inductor current.

16. A structure according to claim 14 including a single set of conducting lines between the surface mechanism and the well instrument, and automatic switching means for selectively switching the earth inductor circuit and the sensitive-devices circuit in and out of connection with said lines.

17. A well survey instrument adapted to be lowered into a bore hole, comprising a pendulum, a mounting for said pendulum, means for positively driving said mounting through a cycle, and a resistance across which said pendulum swings during rotation of said mounting when the axis of the mounting is inclined.

18. A structure according to claim 17 including an earth inductor compass for orienting the plane of maximum inclination of the pendulum, in combination with surface mechanism for recording the inclination and orientation.

19. A well survey instrument comprising a pen-

dulum, a rotatable mounting for said pendulum, and a resistance across which said pendulum swings during rotation of said mounting when the axis of the mounting is inclined, a synchronous motor for driving the pendulum mounting, means for orienting the pendulum position and surface mechanism including a synchronous motor-generator for energizing said synchronous motor, and means at the surface for recording pendulum movement and orientation.

20. A well survey mechanism comprising means for indicating inclination of the hole, and an earth inductor compass for orienting said indicating means.

21. A well survey mechanism comprising means for detecting an inclination of the hole, an earth inductor compass for orientation of said inclination detecting means, a synchronous motor for driving the earth inductor compass, and means for adjusting for a phase angle relation between the earth inductor current and the synchronous motor drive current and means to record said phase angle relationship.

22. Well survey mechanism including a surface

structure and an instrument adapted to be lowered into a bore hole, said instrument comprising a housing containing a pendulum, a rotatable mounting for said pendulum, a resistance across which said pendulum swings during rotation of said mounting if the axis of the mounting is inclined, a synchronous motor for driving the pendulum mounting, orienting means including an earth inductor coil connected for rotation by the synchronous motor, means in the pendulum circuit for interrupting a flow of electric current through said resistance as an indication of the relative position of the pendulum with respect to the instrument housing, and said surface structure comprising means to commutate the earth inductor current, means to adjust the commutator, means to indicate phase angle adjustment of the commutating means with respect to the synchronous drive, means for receiving the electrical energy representing pendulum movement and converting it into mechanical energy, means operated by the last mentioned means for producing a record indicative of pendulum movement.

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