

June 7, 1960

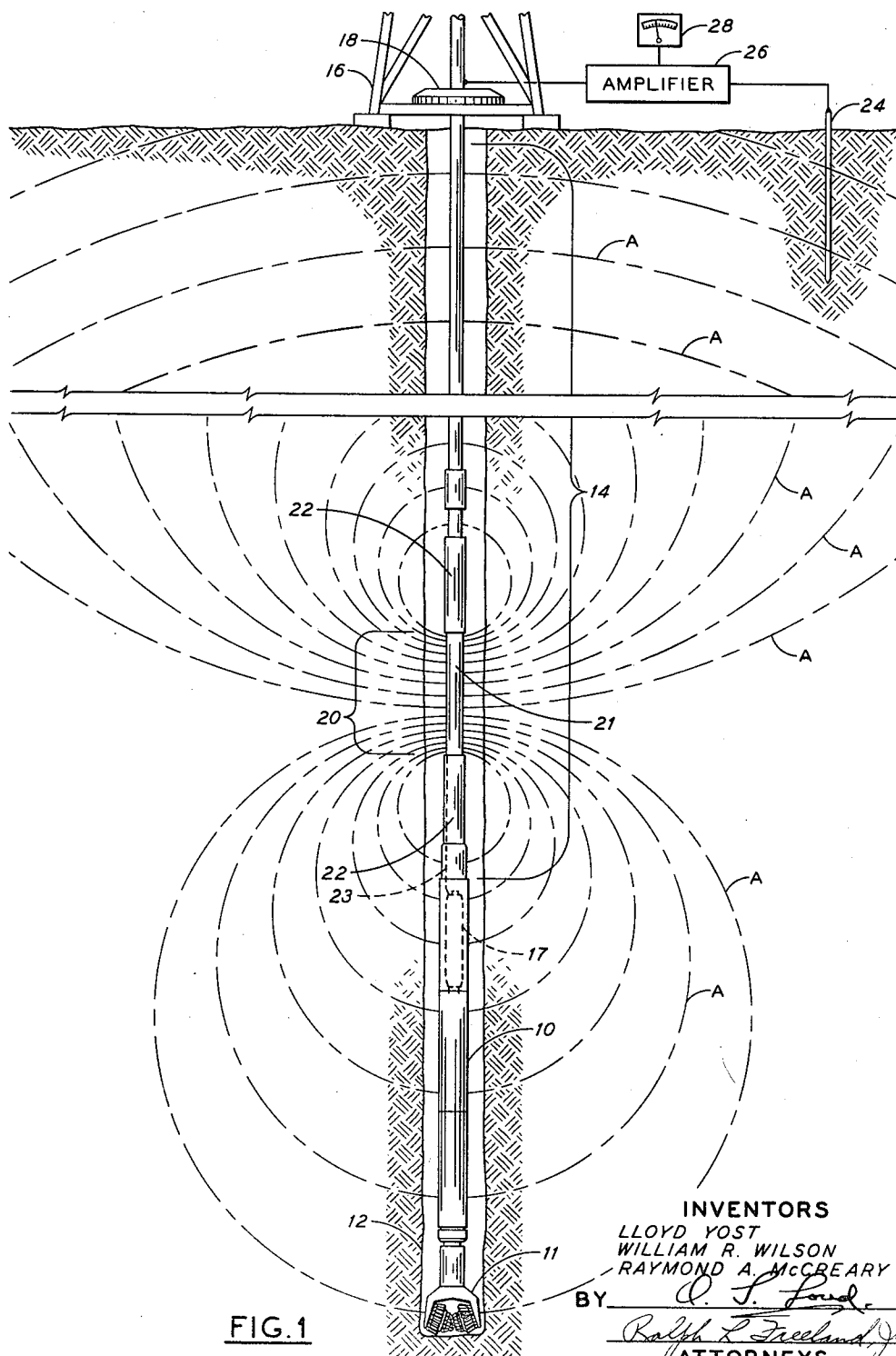
L. YOST ET AL

2,940,039

WELL BORE ELECTRICAL GENERATOR

Filed June 10, 1957

3 Sheets-Sheet 1



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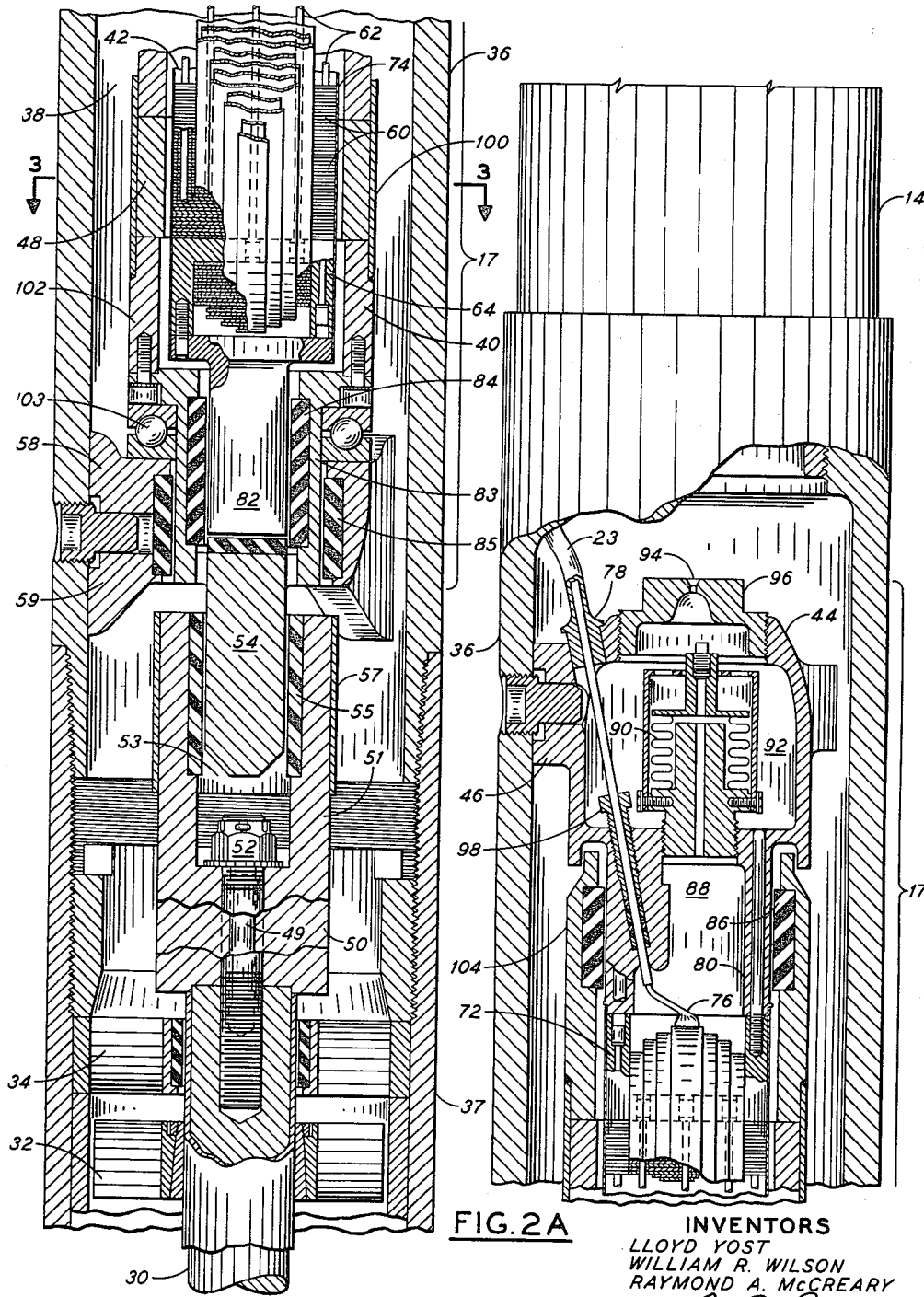


FIG. 2A

FIG. 2B

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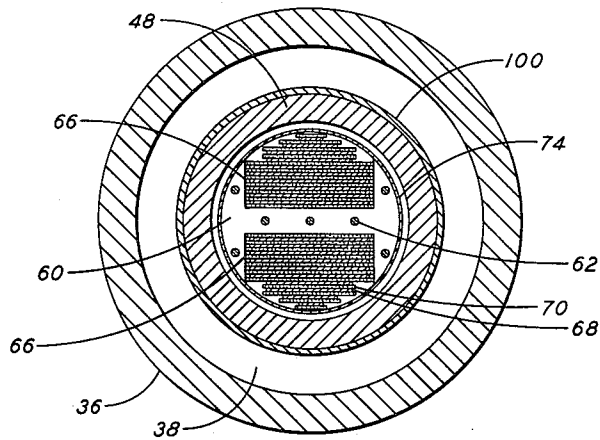


FIG. 3

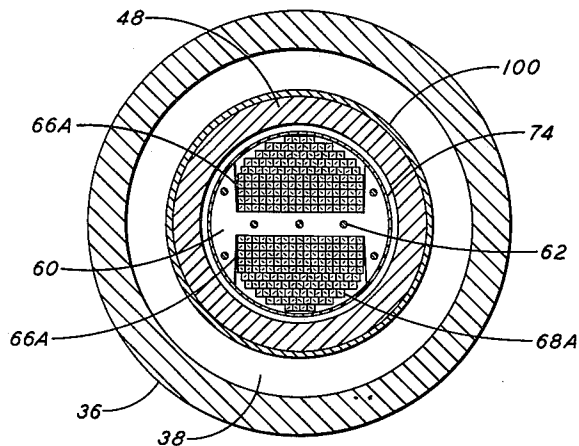


FIG. 4

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2,940,039

WELL BORE ELECTRICAL GENERATOR

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5 Claims. (Cl. 324—70)

The present invention relates to turbo drill speed indicating devices and more particularly to tachometer generator apparatus for measuring the speed of rotation of a hydraulic turbine coupled to a drilling bit.

The present invention has for an object the provision of a compact speed indicator of the tachometer generator type that may be directly coupled to the drive shaft of a borehole hydraulic turbine wherein the rotor comprises an annular permanent magnet member directly coupled to the turbine drive shaft, the magnet member being rotatable about a cylindrical stator member isolated from the drilling fluid used to drive the hydraulic turbine.

In the drilling of an earth bore with a drill rotated by a hydraulic turbine supported on the lower end of a drill pipe, the combination known in the art as a turbo drill, the motive fluid is a conventional formulation of drilling fluid supplied under high pressure to drive the turbine unit. In the preferred form of such turbo drill units, the drill bit is coupled directly to the drive shaft of the turbine unit and the turbine itself includes a plurality of stator and motor stages that use the high pressure drilling fluid to turn the turbine shaft and the drill bit. In such drilling, it is common to rotate the drill pipe at a low speed either in the same direction as the drill bit is turning, or the drill pipe is allowed to rotate slowly in the reverse direction due to reaction torque between the turbine rotor and the turbine housing supported on the drill pipe. This rotation prevents sticking of the drill pipe. However, such rotation of the drill pipe is in general substantially independent of the speed of rotation of the turbine shaft. While it has been suggested that such reaction torque between the drill bit and the drill pipe be used as a measure of the speed of rotation of the drill bit, any resistance such as that produced by drag between the drill pipe and the side of the well bore prevents the resultant reaction force from being a true measure of the rotational torque between the drill bit and the supporting drill pipe.

Another proposal has been to use apparatus for varying the flow of drilling fluid between the earth's surface and the turbine unit in accordance with the speed of rotation of the turbine shaft. Such apparatus of course requires some type of restricting mechanism such as an orifice that is opened and closed to change the pressure of the drilling fluid. The resulting flow variations create pulses, but these must be of sufficient amplitude and duration as to be distinguishable from minor pressure variations normally present where conventional high pressure reciprocating mud pumps supply the drilling fluid to the turbine. Such apparatus, of course, requires sensitive pressure measuring apparatus to be used within the drill pipe or connected thereto at the earth's surface. This type of system inherently transmits information only periodically and slowly. Well bore signalling systems using electrical current transmission have been proposed for transmission of other data, but, unfortunately, such systems have not had efficient signal generating systems capable of generating maximum current in the confined

2

space available in a drill pipe of conventional diameter.

In accordance with the present invention there is provided a system for efficiently generating an electrical signal of varying frequency corresponding to variations in the speed of rotation of the turbine drill shaft, which can be transmitted by any of several different electrical transmission systems, to permit detection of the speed of rotation at the earth's surface on a continuous and instantaneous basis. The speed of rotation can thus be indicated to the driller, for example by a frequency meter connected to the signal receiving system.

While electrical signal generators have been proposed heretofore in various well-signalling or well-surveying operations, the present invention permits maximum signal current to be generated in a minimum of space and with minimum problems in insulating the electrically conducting portions of the generator. In accordance with the invention, the electrical winding is compacted into an elongated cylindrical stator member of sufficiently small diameter that it can be positioned in the central portion of the drill pipe supplying drilling fluid to the turbine. In one embodiment, the winding comprises an elongated flat strip of conducting material, wound in a generally elliptical form around a laminated magnetic core wherein the elongated axis of said ellipse is substantially coaxial with the drill pipe. Each turn of the strip conductor is insulated so that said winding is continuous over the stator laminations, and said stator laminations are stacked so that their faces are substantially perpendicular to the axis of the drill pipe. Said stator assembly is desirably "potted" in a pressure-sealed cylindrical can member, so that said stator may withstand hydraulic pressure of the drilling fluid wherein it is located. Further, in accordance with the invention, the rotor of the tachometer generator is coupled directly to an upward extension of the turbine drive shaft and includes a permanent magnet member of substantially annular form, having two or more poles, with the permanent magnet member of said rotor positioned so that upon rotation of said annular rotor in the drilling fluid and around the cylindrical stator, there is generated an alternating current whose frequency is proportional to the speed of rotation of the rotor member and, consequently, of the turbine shaft.

In an alternative form of the invention, the continuous conductor forming the winding of the generator is a generally square or rectangular wire insulated so that the rectangular spaces formed on opposite sides of the laminations are efficiently filled and the volume above said spaces that completes the cylinder can also be filled more completely.

Further objects and advantages of the present invention will become apparent from the following detailed specification, taken in conjunction with the accompanying drawings, which form an integral part of the present application.

Fig. 1 is a vertical schematic view, illustrating one method of transmitting the electrical signal generated in response to the rotation of the turbine by the electrical generator of the present invention;

Fig. 2A is a longitudinal view, partially in section, through the upper part of the electrical generator of the present invention;

Fig. 2B is a similar longitudinal view, also partially in section, showing the lower part of the electrical generator of the present invention and illustrating its drive connection to the turbine;

Fig. 3 is a cross-sectional plan view taken in the direction of arrows 3—3 in Fig. 2B;

Fig. 4 is a view similar to Fig. 3 illustrating an alternative construction of the winding using a conductor of square cross-section.

Referring now to the drawings, and in particular to

Fig. 1, there is illustrated a turbo drill unit for drilling well bores wherein the turbine 10 drives the drill bit 11 to advance borehole 12 in the earth. Turbine unit 10 is supported at the lower end of drill pipe 14 which in turn is supported from the derrick indicated schematically as 16. In general, the drill pipe 14 is held stationary, is rotated slowly in forward direction by auxiliary power supplied through rotary table 18, or is allowed to rotate slowly backward due to turbine reaction. The purpose of such rotation, of course, is to prevent sticking of drill pipe 14 and to resist the reaction torque from turbine unit 10 applied to the pipe through the housing. Motive power for turbine 10 is supplied by drilling fluid pumped under high pressure from the earth's surface through drill pipe 14. The drilling fluid desirably is conventional in formulation with a base of water, oil, or an emulsion. The drilling fluid not only supplies power for the turbine unit 10, but also acts to cool and lubricate drill bit 11, flush cuttings from the bottom of well bore 12, and provide a hydrostatic pressure in the well bore that will exceed normal fluid pressures in earth formations penetrated by the well bore. The drilling fluid is normally desanded, that is, the chips of rock, sand and other granular materials are removed from the drilling fluid after it is returned from the borehole, but even with the best of commercial desanding equipment, the drilling fluid contains a considerable amount of granular material. Additionally, the drilling fluid may contain lost-circulation-remedial material to prevent loss of drilling fluid to low pressure formations along the well bore. This material is generally fibrous or flake-like. Thus, the drilling fluid contains a considerable amount of particulate material of various sorts, when circulating in the drilling operation.

The particulate material in the drilling fluid can easily stop circulation through the drill pipe as well as in the well bore, if small passages of unduly restricted flow paths are present in the circulation system. Excessive contact pressure between drill bit 11 and the earth formation being drilled may also stall the turbine, as might also other conditions. Therefore, one of the primary problems in drilling with a turbo drill of the type shown in Fig. 1, lies in the necessity for knowing instantaneously and continuously the speed of rotation of the turbine rotor and the drill bit 11 on bottom. When the turbine and the drill bit reach a depth of greater than 1000 to 2000 feet, the method of transmitting a signal from the drill bit to the earth's surface using either a sonic generator, pressure-varying or other similar systems, results either in slow transmission of the signal or virtually no signal at all to the earth's surface.

In the present invention, there is provided apparatus for generating a substantial electrical signal that can be transmitted and received from depths greatly in excess of the lower limitation of previously known methods. As indicated schematically in the arrangement of Fig. 1, an electrical signal generated by tachometer generator 17 is connected to a borehole antenna system, including an elongated transmission or antenna section 20 that surrounds drill pipe 14 and is insulated therefrom by a sleeve member 22 which also extends a substantial distance both above and below the antenna section 20. Desirably sleeve member 22 is made of a durable insulating material, such as rubber vulcanized to one or more sections of a heavy-walled pipe known in the art as drill collar. In this way, section 22 can be included in drill string 14 directly above turbine unit 10 to provide the required weight on drill bit 11. As illustrated in Fig. 1, antenna section 20 may be somewhat reduced in diameter where a metallic shell 21 overlies the bonded rubber portion. The interconnection between antenna shell 21 and generator 17 is through wire 23.

Electrical contact with earth is substantially proportional to the axial length of antenna section 20. Ideally, this section would extend to the earth's surface, but

such construction can be achieved only with great difficulty. However, current will leave the electrode 21 in a direction perpendicular to its surface, and follow a cured (not necessarily circular) path back to drill pipe 14, as indicated by lines of current flow A. The longer the insulated section above and below shell 21, the greater will be the resistance of the conducting paths shunting the generated signal. The only useful signal current is that which runs near the earth's surface as indicated by lines of current flow A, and is intercepted between ground electrode 24 and drill pipe 14. Thus, the electrical potential appearing between drill pipe 14 and ground electrode 24, includes the signal from the tachometer generator. This potential is amplified and filtered, thus separating the signal from other potentials. The frequency of the signal is indicated by the combination of amplifier 26 and frequency meter 28, so that there is presented at the earth's surface a direct indication, not only that drill bit 11 is rotating, but the speed at which it is rotating. Frequency meter 28 will of course be calibrated in revolutions per minute so that a driller is continuously given an indication of the speed of the drill bit.

The arrangement of Fig. 1 illustrates one method of transmitting information generated by the tachometer generator. However, several other methods of transmitting the electrical signal itself will be discussed hereinafter.

Figs. 2A and 2B illustrate one embodiment of the tachometer generator and reference is now made to these figures for a complete description thereof. As indicated in the lower part of Fig. 2B, turbine drive shaft 30 has mounted thereon a plurality of rotor vanes 32, each of which cooperates with a set of stator vanes 34 mounted in and secured to housing 37. Housing 37 in turn is supported from the lower end of drill pipe 14 by generator housing 36.

In order to reduce any hydraulic friction as much as possible, it is desirable that the speed detecting device be as compact as possible to assure maximum flow area through the conductor pipe. In accordance with the present invention, a maximum flow area around tachometer generator 17 is preserved by forming the unit in a compact form within the center of, and substantially coaxial with, the turbine housing and drill pipe. In this way, the annular flow passageway, indicated as 38, around the outside of annular rotor 40, can be made sufficiently large so that there is minimum pressure drop due to flow through said passageway. Further, in accordance with the invention, the stator element 42 is positioned as the innermost portion of the tachometer generator and is supported concentrically with the housing 36 by a head supporting member 44 mounted on a plurality of fin members 46 forming an upper spider means. The lower end of stator 42 is supported by stationary journal 82 that supports rotor 40 in bearing member 59 mounted in the center of housing 36 on fin members 58.

As indicated generally in Fig. 2B, rotor element 40 comprises an annular permanent magnet element 48, and is mounted for direct rotation by turbine shaft 30 through a pair of drive pins 49 passing from coupling member 50 into the upper end of shaft 30. Shaft 30 and coupling 50 are secured together by stud and nut arrangement 52. Coupling 50 is formed as an upturned cup member 51 having a slot 53 milled therein that forms a vertically flexible drive connection with the drive key 54 directly connected to rotor member 40. The inner surface of slot 53 has rubber covered surfacing 55 to absorb vibration in the drive mechanism. A circular shell 57 holds the sides of slot 53 against outward flexure.

Referring now to the specific construction of stator member 42 of our "inside-out" generator, it will be noted that the stator comprises a plurality of laminations 60 stacked so that their faces are perpendicular to the axis of the generator housing, turbine, and drill pipe. These

5

laminations are secured together by a plurality of rods 62 running lengthwise and clamping the laminations to annular head piece 64.

As indicated in Fig. 3, laminations 60 are provided with deep slots on opposite sides thereof identified as 66 through which the winding, electromagnetically coupled to the laminations, is wound. As indicated both in Fig. 3 and further in Figs. 2A and 2B, said winding is a continuous loop of flat strip material wound in the generally elliptical shape with the elongated axis of the ellipse substantially co-axial with the center of the stator and tachometer generator. Preferably, the flat strip winding extends from side-to-side in the slots 66 and the winding is continuous with insulation material therebetween throughout its continuous wrapping in the elliptical form. Insulation, of course, sufficiently overlaps the edges of the windings so that the electrical current generated in the individual turns is not short-circuited by the metal of the laminations 60. As more particularly illustrated in Figs. 2A and 2B, the outer windings of the continuous loops are somewhat narrowed in a stair-step fashion so that the outer turns generally conform to the diameter of the circle circumscribing the laminations 60. The outer turns are correspondingly thickened to maintain substantially constant the cross-sectional area of each turn. The continuous winding is indicated generally by the numeral 68 and the insulation therebetween by 70. The entire assembly of head sections 72 and 64, as well as stacked laminations 60 and the winding 68, are enclosed in a non-magnetic covering 74, such as stainless steel, that extends above and below the head sections. While not shown in the drawings, the inner end of the winding 68 is brazed to one of the head pieces so that the entire case forms a ground connection and only a single terminal, indicated as 76, passes to the exterior of pressure head section 44 through a conduit 78.

For the purpose of centering stator assembly 42, relative to rotor member 40, the upper end of stator 42, or specifically, the head section 72, is secured to pressure head 44 through an elongated journal bearing section identified as 80. The bottom portion of the stator includes a journal portion 82 that is secured to the lower head 64 which in turn forms a bearing member for the lower part of rotor 40. For the purpose of preventing undue wear on both the journal 82 and the bearing 80, the rotating parts of rotor member 40 are provided with rubber bushings respectively identified as 84 and 86. In the arrangement shown in Fig. 2A, the stator member is subjected to a hydrostatic pressure equal to that of the drilling fluid in the annular space 38 surrounding the tachometer generator 17. As there shown, the interior of the stator member includes a head space 88 that is filled with an insulating oil and the pressure thereon is maintained equal to ambient pressure through the bellows arrangement 90, which in turn is immersed in the drilling fluid in the outer chamber identified as 92. The pressure in said outer chamber is maintained substantially the same as that of the drilling fluid by the orifice 94 formed in the closure cap 96 for pressure head 44. The chamber 92 will be filled with drilling mud, or a mixture of mud and oil, as it will happen, and the orifice 94 is to prevent rapid movement, or interchange of pressure in or out of space 92. The device is essentially a balancing of hydrostatic pressures, plus allowance for thermal expansion of the oil in the generator stator when heated by current flow or by absorbing heat from the borehole environment. As indicated in Fig. 2A, insulated electrical conductor 76 passes through a bushing member 98 and conduit 78.

Referring to the illustrated construction of the rotor element 40 of the tachometer generator, it is to be observed that said rotor element 40 is substantially immersed in the drilling fluid so that tight seals to exclude the drilling fluid are not required. As mentioned above, the rotor comprises an annular permanent magnet mem-

6

ber 48, formed, for example, of one or more paralleled rings of Alnico, and held in vertical and annular alignment by an outer nonmagnetic member 100, which in turn is brazed to a lower spacing element 102 and an upper bearing element 104. Desirably, annular rotor 40 is formed of a single annular magnet element but in practice the magnet elements are more easily obtainable commercially as smaller rings. Thus, to obtain the desired length, the rings are paralleled.

In practice, it has been found desirable to assemble the magnets without polarization thereof until the rotor is assembled in relation to the stator. At that time, a large direct current is passed through winding 68 by a D.C. source, thus polarizing the annular Alnico magnets.

Rotor member 40 is driven by the jaw coupling or key member 54, which is coupled to turbine shaft 30 by slot 53 in bushing 51. A thrust bearing, such as ball bearing 103, carries the weight of rotor 40 and as shown in Fig. 2B, the inner and outer axial surfaces of drive collar 83 are respectively guided in rubber bearings. The inner surface of collar 83 has a rubber sleeve insert 84 that bears on journal 82, while the outer surface of said collar is guided by insert 85 in support member 59.

As mentioned above, shaft 30 directly drives drill bit 11. Thus, upon rotation of the polarized permanent magnet element 48, there is established flow of current within the single elongated winding 68 which will be an A.C. signal whose frequency is directly proportional to the speed of rotation of the permanent magnet field. The strength of such A.C. signal is of course determined by the total magnetic flux of the permanent magnets, the spacing between the pole faces and the stator, and the number and size of conductor turns on the stator. In the present arrangement, the internal impedance of the stator itself is designed to have a very low value to match as nearly as possible the earth impedance, to obtain maximum power in the signal actually transmitted.

With the foregoing construction of our "inside-out" generator, there is provided a maximum length of flux path within the annular permanent magnet rotor in a minimum of cylindrical volume, resulting in greater magnetic stability of the rotor. Further, the cylindrical solid stator provides a construction that can be more readily sealed against hydraulic pressure and an electrical winding that can be readily connected to a transmission line through a stationary contact, rather than through a slip ring connection.

The central construction of the stator permits the winding to have a maximum amount of copper with a minimum length so that the internal impedance is kept low. This arrangement also furnishes a short and therefore low-reluctance magnetic path through the stator.

Referring now to Fig. 4, there is shown an alternative method of winding stator 42. This view is similar to Fig. 3 but shows the use of square, or rectangular, insulated wire laid in the slots 66A. By this arrangement, there is made possible a greater number of turns in the same winding space and a somewhat more efficient use of the slot space and that portion of the winding that fills the subtended arc completing the circle of the stator cylinder. As indicated in exaggerated form for clearer understanding, the sides of slots 66A may be slightly tapered outwardly so that each layer of turns can be more readily fed into the slots without danger of breaking the insulation covering the wire. Alternatively, four bare, square wires may be bundled together, in contact with each other. This bundle is then wrapped with a tape, or sleeved with insulating material to form a single flexible conductor that forms the continuous winding of the coil.

From the foregoing description, it will be apparent that the inside-out construction of the generator is also

useful in generating electrical signals within a long narrow borehole containing liquid to indicate physical conditions, other than turbine speed. For example, an impeller can be secured to the annular rotor to detect direction or speed of fluid flow. Other uses include the generation of an electrical signal by said generator in response to changes in temperature, pressure, or electrical quantities indicative of a characteristic of the earth formations through which the borehole passes.

While only a few exemplifications of the present invention have been shown and described, various modifications and changes therein will become apparent to those skilled in the art. All such changes falling within the scope of the appended claims are intended to be included therein.

We claim:

1. Generator apparatus for measuring the speed of rotation of a turbo drill unit while rotating at the bottom of a well bore wherein the drill bit is rotated by a multi-stage hydraulic turbine directly connected to said drill bit and the hydraulic turbine is adapted to be rotated by drilling fluid supplied through an elongated drill pipe extending from the earth's surface comprising a rotatable element directly coupled to the upper end of a drive shaft of a hydraulic turbine, said rotatable element being drivably coupled to an annular permanent magnet rotor member extending a substantial distance upwardly into a fluid supplying drill pipe from the upper end of said drive shaft, a cylindrical stator member centrally disposed within and circumferentially surrounded by said annular permanent magnet rotor member, means for maintaining said cylindrical stator member under hydraulic pressure sufficient to counterbalance the pressure of a drilling fluid driving said turbine, electrical winding means within said stator member and electromagnetically coupled with said permanent magnet rotor member, and means for interconnecting an electrical transmission line with one end of said electrical winding means within said stator member to transmit to the earth's surface an electrical signal corresponding to the speed of rotation of said turbine and a drill bit secured to the opposite end of said drive shaft.

2. Apparatus for generating an alternating current in response to a physical condition measured at the bottom of a well bore while said well bore is being drilled, comprising a rotor element mounted within a drill pipe extending to the surface of the earth and adapted to be driven in response to a physical condition to be detected, said rotor element including a drive connection secured to an annular permanent magnet rotor member extending a substantial distance axially within said drill pipe, said drill pipe supplying drilling fluid under pressure to a drill bit at the bottom of said well bore, a cylindrical

stator member positioned substantially centrally in said drill pipe and within said annular permanent magnet rotor member, means including a cylindrical casing surrounding said stator member for automatically maintaining said stator member under hydraulic pressure sufficient to counterbalance the pressure of said drilling fluid in said drill pipe, an insulating fluid within said cylindrical casing, said stator member comprising a plurality of parallel laminations positioned transversely to the longitudinal axis of said stator member and extending substantially coextensively in the direction of said longitudinal axis with the permanent magnets of said annular rotor member, a continuous electrical coil winding positioned in slots formed in said laminations of said stator member and electromagnetically coupled with said annular permanent magnet rotor member, said coil winding comprising a plurality of turns of an electrical conductor of rectangular cross section wound axially around the said laminations of said stator member with an electrical insulator between each turn of said electrical conductor, a single electrical terminal interconnecting one end of said continuous electrical coil winding and an antenna electrode located outside of said stator member casing to transmit to recording means positioned at the surface of the earth a signal generated in said stator member by rotation of said rotor member.

3. Apparatus in accordance with claim 2 wherein said conductor is a flat strip of conductive material, each turn of a substantial portion of said winding extending laterally throughout the width of said slots in said laminations forming said stator.

4. Apparatus in accordance with claim 2 wherein said conductor is formed of square wire insulated throughout its length and said wire includes a plurality of turns forming successive layers in said slots of said laminations forming said stator member.

5. Apparatus in accordance with claim 1 wherein the stator member includes an upper axial extension supported by spider means secured to the drill pipe and a lower axial extension toward the driven end of said annular rotor member, said lower extension forming a radial bearing for maintaining said annular rotor member radially aligned with said stator member, and said annular rotor member includes annular bearing means adjacent its upper end for engaging an outer circumference of said stator member below said spider means, and a lower spider means secured to the drill pipe supporting a radial guide bearing and an axial thrust bearing for said annular rotor member.

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