Nov. 1, 1960 G. H. PFEFFERLE 2,958,511

EARTH BOREHOLE DRILLING APPARATUS AND SYSTEM

Filed June 10, 1957 2 Sheets-Sheet 1

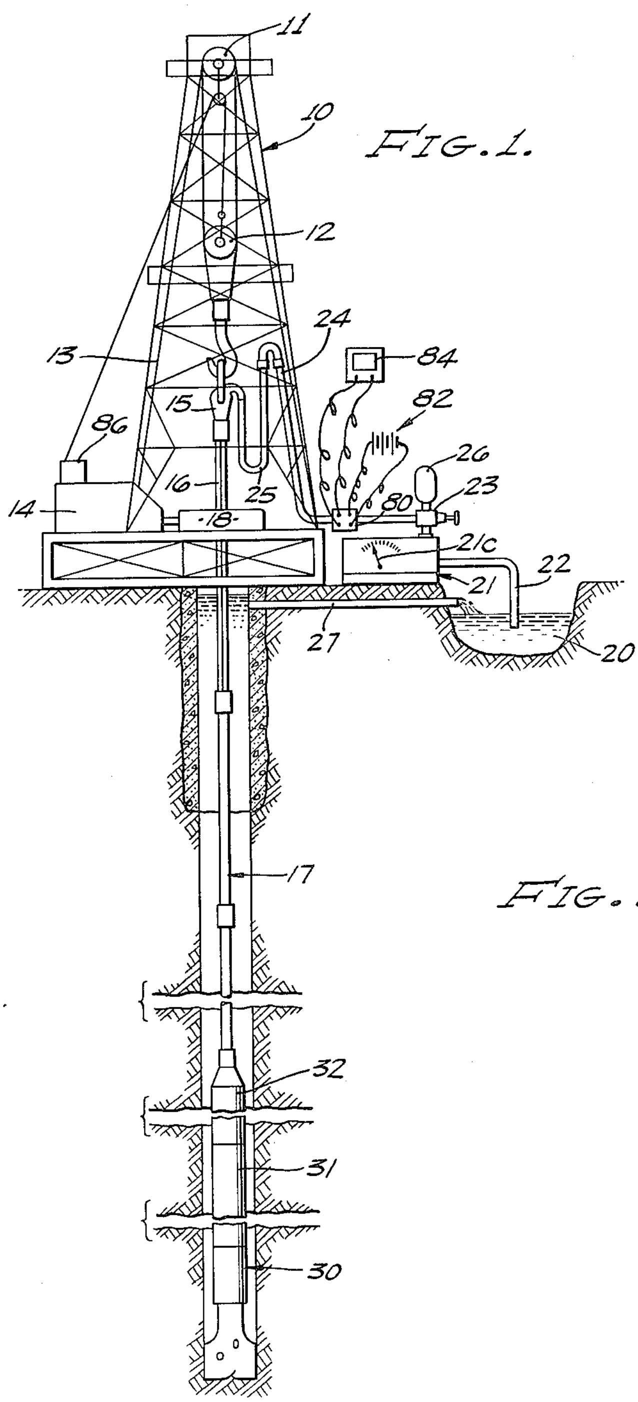

FIG. 1.

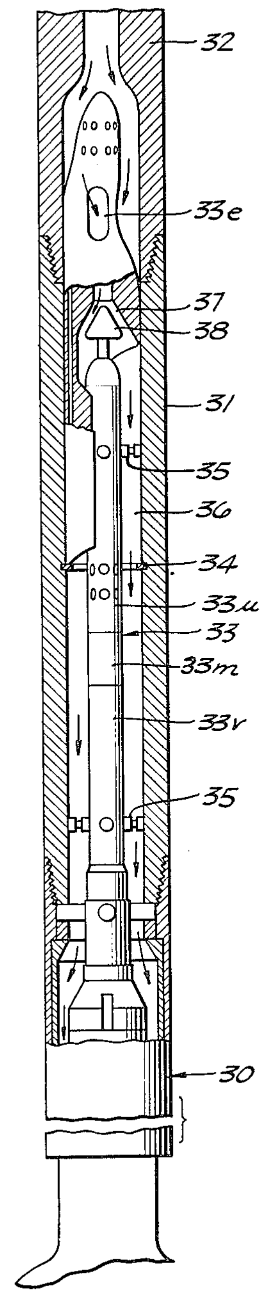

FIG. 2.

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EARTH BOREHOLE DRILLING APPARATUS AND SYSTEM

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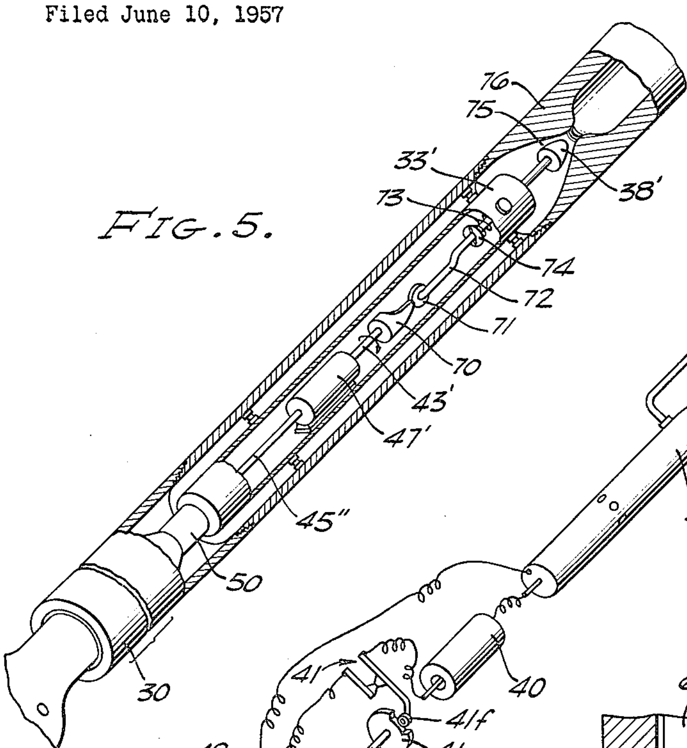
FIG. 5.



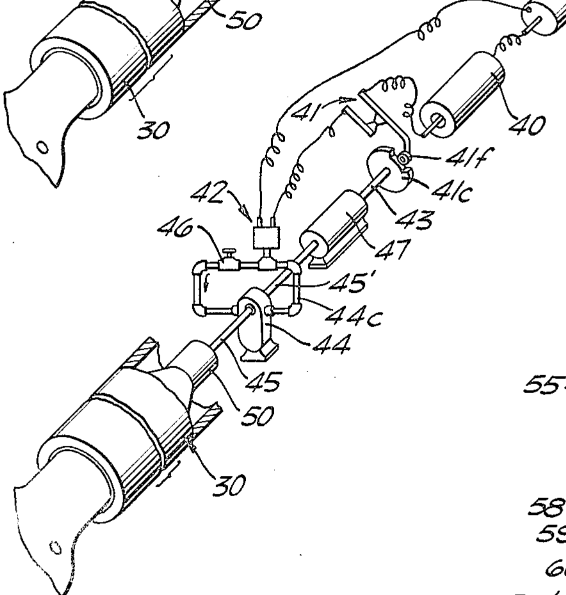


FIG. 3.

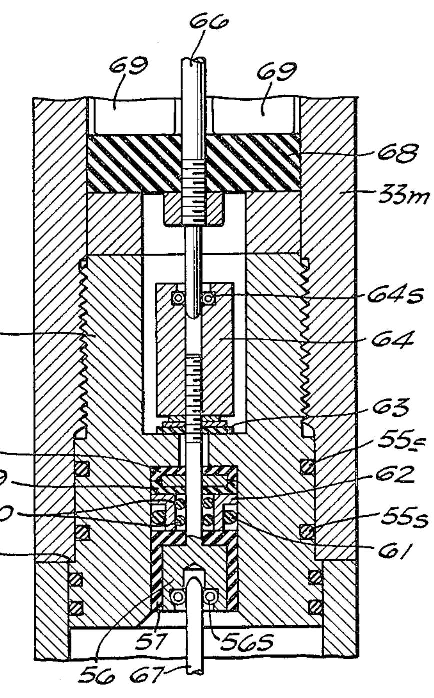


FIG. 4.

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EARTH BOREHOLE DRILLING APPARATUS AND SYSTEM

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12 Claims. (Cl. 255—4)

The present invention relates to a system and apparatus for drilling an earth borehole such as an oil well; and more particularly relates to a system and means whereby optimum drilling operations may be attained in extending a borehole with a turbine-driven drill attached to a non-rotary tubular drill string.

Deep earth boreholes or wells are commonly drilled by means including a drill bit which is secured to and rotated by an interconnected series of tubular sections or pipes and known to those versed in the art as a drill string. The tubular drill string is both suspended by and rotated by means at the surface of the earth, and consequently both the weight on the bit and its speed of rotation may readily be ascertained and easily regulated to operate at optimum economic drilling rate. It has been proposed to drill or extend earth boreholes by a drill attached to the lower end of a non-rotating tubular drill string and rotated by a turbine driven by the forced downward flow of drilling fluid. Although many types of turbodrill units have been proposed during the long period over which deep well drilling has been practiced, apparently none of the units has gone into extensive usage nor become a commercial success. One of the principal reasons for the failure of turbodrilling to successfully compete with rotary drilling and cable drilling has been the lack of control of the speed of the bit and lack of knowledge of bit speed and weight on the bit during turbodrilling. It is known that excessive bit speed results in exorbitantly reduced bit life and grossly reduced over-all drilling efficiency; and that continuous knowledge of such factors as bit speed, penetration rate, weight on the bit, etc., is necessary for the attainment of the optimum practical economic drilling rate. With present day turbodrill designs, an optimum drilling operation including proper weight on the bit may be attained by drilling fluid flow and pressure control if the rate of rotation of the bit is known.

One of the principal objects of the present invention is, therefore, to provide in a turbodrilling system a means for presenting to the driller a continuing indication of bit speed, whereby the bit speed may be regulated to an optimum or desired value by variation of the drilling fluid flow rate and pressure.

Another object of the invention is to provide means which can be interposed between a turbodrill and the tubular drill string supplying the turbine, for recurrently signaling indications of the rotative speed of the drill bit, using the confined column of drilling fluid in the drill string as a signal transmission medium.

A broad object of the invention is to provide a turbodrilling system which during operation repetitively apprises the driller of the rotational speed of the drill bit.

Other objects and advantages of the invention will hereinafter become apparent from consideration of the appended claims and disclosure of a preferred form of structural system as illustrated in the accompanying drawings, in which:

Fig. 1 is a schematic diagram of apparatus in borehole drilling attitude in an extended earth borehole, illustrating a system according to the invention in its normal operational environment;

Fig. 2 is view of a portion of a form of apparatus according to the invention and positioned above the drill bit, parts being broken away and certain parts being shown in section;

Fig. 3 is a diagram of components of apparatus according to Fig. 2, schematically illustrated to facilitate explanation of the invention;

Fig. 4 is a longitudinal sectional view of a small portion of the structure shown in Fig. 2 and illustrating sealing and electrical connection of a battery case or housing; and

Fig. 5 is a diagram similar to Fig. 3, schematically illustrating a modified form of signal-producing means according to the invention.

Referring now to the drawings and to Fig. 1 in particular, there is depicted in diagrammatic style a drilling derrick and associated equipment, situated over an earth borehole in which drilling equipment is in operating position. The derrick **10** supports a crown block **11** from which is suspended a traveling block **12**. The traveling block is traversed vertically by movements of a cable **13** which courses around the pulleys of the two blocks and is taken in or payed out by draw works **14**. Carried by the traveling block is a swivel **15** which rotatably supports a kelly **16** which forms the upper element of a tubular drill string indicated generally at **17**. The kelly is adapted to be rotated, or, alternatively, to be held fast from rotation, by a rotary table **18** which may be driven and braked through gearing from the draw works **14**. The drill string may comprise joined lengths of drill pipe and structures attached thereto and terminated by a drill bit, as is well understood in the deep-well drilling art.

Drilling fluid or mud is drawn from a mud pit **20** by power-operated pump means **21** through an intake pipe **22**, and is forced under pressure into the upper end of the drill string through a pipe **24**, a hose **25** and swivel **15**. A surge chamber or pulsation dampener **26** may be connected at a suitable point in the pump discharge line, as at valve **23** as indicated, to reduce or dampen pressure fluctuations caused by the pump. The drilling fluid, under high pressure, flows downwardly in a stream confined in the tubular drill string, through one or more drill collars and a turbine, and exits through orifices formed in the drill bit. The fluid or mud then returns to the top of the borehole by way of the annular space around the drill string, carrying the material removed by the drill bit, and may return to the mud pit **20** through a return pipe **27**.

The structures described generally in the preceding paragraph are or may be of known construction, and operate in known manner to extend a borehole in conventional turbodrilling procedure. The turbodrill unit, which includes a turbine and detachable drill bit, may be of the known type described on pages B–39 to B–44 of the October 1956 issue of "The Petroleum Engineer," or of other known type. The turbine rotates the drill bit and serves to apply downwardly directed force to the bit to load the latter. The "weight" or force applied to the bit is derived from reaction thrust of the turbine rotor blades, and selectively also some of the weight of the drill string elements above the turbine, and may be regulated by regulation of the flow rate and pressure of the drilling fluid supplied to the turbine and by adjustment of the force exerted on swivel **15** by traveling block **12**. Except as hereinafter made evident, the previously described structures and their operation are not per se of applicant's invention.

In accomplishing the objects of the invention, there are interposed in the drill string between the turbodrill unit **30** and the lowermost length of drill pipe, apparatus including drill collars of special construction, indicated in Fig. 1 at **31** and **32**. In these specially constructed drill collars are disposed means for deriving indications of the speed or rotations of the drill bit, and means for transmitting signals representing the derived information to a point outside the borehole. The information about the speed or revolutions of the bit is secured by suitable means, such as a mechanical connection to the upper end of the rotor shaft of the turbine; and the signals representing the derived information are produced by suitable means and preferably are formed and transmitted by producing recurrent pressure changes in the drilling fluid stream in the drill string. Pressure changes produced in the downwardly flowing drilling fluid in one of the drill collars are readily detectable at the upper end of the drill string by simple pressure transducer means. The changes may be produced by throttling the drilling fluid stream by valve means operated by automatic apparatus of known construction, that apparatus being controlled by means including counting or "timing" means connected to the aforementioned mechanical connection driven by the turbine.

Specifically, and exemplifying apparatus according to the concept of the invention, an apparatus case or housing **33** (see Fig. 2) is fixedly mounted in the interior bore of drill collars **31** and **32** and supports and protects principal components of the information deriving and signalling instrumentalities. The case or housing may be of any suitable configuration, such as that indicated, and may be fixed in the drill collar bore **36** by suitable means such as lock ring means **34** and radially disposed adjustable spider supports **35**. The housing is of construction such that drilling fluid may flow in part therethrough and therepast without undue restriction, along flow lines indicated by downwardly directed arrows. The housing depicted comprises upper and lower separable sections, **33***u* and **33***v*, and an intermediate section **33***m*, respectively, joined by threaded joints. The lower section may extend down into an upper end part of the turbodrill unit **30**, from which it may derive vertical support. The bore through drill collar **31**, and the lower end of the bore through collar **32**, are of relatively large diameter, to provide space for case **33** and for free passage of the drilling fluid stream. The upper specially shaped end of case **33** is disposed in the enlarged portion of the bore in collar **32**, and has formed therein openings **33***e* and connecting passages for flow of drilling fluid into a formed flow passage **37** in which a valve plunger or head **38** is adapted to operate to create pressure changes in the drilling fluid stream. The drilling fluid flows into the openings **33***e* in casing section **33***u* and on through passage **37** and around and past head **38**. The latter cooperates with the flared wall of passage **37** to produce the mentioned pressure changes. For example, when head **38** is moved upwardly as viewed in Fig. 2, well into the flared part of passage **37**, it restricts the flow of drilling fluid and hence creates an increased pressure-drop past the head and an effective increase in pressure thereabove. Subsequent return of head **38** downwardly to normal position permits the pressure to fall to normal value.

Means for moving valve head **38** to and from flow restricting position may within the scope of the invention be of any suitable type, such as known previously disclosed electromagnetic or hydraulic actuator systems, or a direct mechanical actuator system such as the cam and follower system hereinafter explained. The actuator system may, for example, be of the electromagnetic or hydraulic types disclosed in co-pending U.S. patent applications Serial No. 413,347, filed March 1, 1954, Serial No. 511,381, filed May 25, 1955, and Serial No. 568,634, filed February 29, 1956, to which reference may be had for detailed disclosures of the several types of systems. Alternatively, if elimination of electrical components is desirable, the actuator system may be entirely mechanical

in nature. Such an actuator system is hereinafter more fully explained in connection with Fig. 5.

Referring now to Fig. 3 which depicts largely in diagrammatic style one operable combination of structures for performing the information-deriving and signal-producing functions, valve head **38** is adapted to be axially shifted to and from flow restricting position by hydraulic actuator means of the type fully disclosed in the aforementioned application. The actuator means includes apparatus housed in part in a shell **39** which may if desired be a detachable part of casing **33** as indicated in Fig. 2. Operation of the valve actuating apparatus in the system of Fig. 3 is initiated by closure of an electric circuit which includes a control solenoid or magnet and a source of power, all as set forth in detail in one or more of the aforementioned co-pending applications. The control solenoid, not herein illustrated in detail, is accommodated in shell **39**, from which circuit leads extend as shown. One circuit lead makes connection with a power supply means of suitable type and here shown as a battery pack **40**, and the other solenoid circuit lead is connected to the other terminal of the battery pack through switches **42** and **41** as indicated. Switch **41** is recurrently opened and closed by operation of a cam **41***c* affixed to a shaft **43**; and the switch, cam configuration and cam follower **41***f* are such that the circuit through the switch is open when the follower is on the rise of the cam and closed when the follower rides in the fall of the cam. Switch **42** is a conventional pressure-responsive switch which functions to open the circuit through the power supply means whenever the turbine of the turbodrill is not operating, to conserve battery power during idle periods. During operation of the drill, pressure is applied to the switch actuator piston through tubing and means such as a pump **44** which is rotated through mechanical connections to the turbodrill. The arrangement illustrated is such that a shaft **45**, which is driven by connections to the rotor of turbodrill unit **30**, operates pump **44** while the turbodrill is operating. The pump, when thus operated, pumps liquid through a closed hydraulic circuit including suitable conduits **44***c* and a restrictor means such as an adjustable valve **46**, as indicated. Thus switch **42**, whose actuator is hydraulically connected to the tubing or conduit upstream from valve **46**, is closed when shaft **45** is rotating, and opens automatically when that shaft is not rotating.

A speed reducer or reduction gear means **47** is interposed between cam **41***c* and shaft **45** so the cam will operate switch **41** at a cyclic rate that is within the feasible operating rate ranges of the signal-producing means and the signal receiving means. The reduction gear ratio may for example be such as to cause one revolution of cam **41***c* for each 100 revolutions of shaft **45**. However, any other suitable ratio may be employed. The reduction gear means is driven by an extension **45'** of shaft **45** as indicated.

Shaft **45** is rotated by turbodrill unit **30** through suitable connections, such as a clutch unit **50** which may be of any satisfactory commercially available type but preferably is of the automatically engaging type having one rotatable part secured to shaft **45** and a mating rotatable part secured to the turbine rotor shaft or an extension thereof.

Since batteries will not tolerate high pressures, it is necessary to maintain battery pack **40** protected from the pressure exerted by the fluid in a well; and to maintain the battery pack at substantially surface atmospheric pressure it is enclosed in a sealed section of apparatus case **33**. This section, **33***m* (Fig. 2), comprises at each end a sealing plug-connector of the type shown in section in Fig. 4. The connector devices function to provide insulated electrical plug-type connections through sealed members into the battery pack chamber at each end of the latter. The conductive instrument case conveniently serves as a ground conductor, and the live or ungrounded conductor is established in part through the center of the connector by appropriate conductive elements. The lower end of housing section **33m** and the associated lower plug connector are shown in Fig. 4. It will be understood that a similar plug connector in inverted attitude is disposed in the upper end of section **33m**. A bored metallic plug body **55** has a threaded end portion which fits in a complementarily threaded part of section **33m**, and has a shoulder **55b** on the opposite end portion which is brought up tightly against the end of section **33m** by the threads. O-ring seals **55s** disposed as indicated seal the exterior of the plug against passage of fluid into the battery case. In the bore of body **55** there is mounted a conductive contact screw **56** which is insulated from the body **55** by insulating thimble **57** and insulating washers **58** and **59**. O-ring seals **60, 61** fitted inside and outside a seal ring **62** seal against inward (upward) leakage of fluid through the bore of the body. Screw **56** is held in position by a conductive contact nut **64** bearing against washers including insulating washer **63**, as indicated. Both nut **64** and the head of screw **56** have recessed ends in which are held captive respective garter springs **64s** and **56s** which are arranged for automatic mechanical engagement of, and electrical connection with, respective axially positioned conductive rods **66, 67** when the apparatus case sections are assembled. For example, spring **56s** is adapted to engage a tapered conductive rod **67** when the latter is moved upwardly. Likewise, spring **64s** is adapted to engage and close circuit with a conductive rod **66** whose lower end is mounted as indicated in an insulative plate **68** on which a battery pack comprising cells **69** bears. Rod **66** may be similarly terminated at the upper end of section **33m** in a similar insulative plate, and may serve as a tie rod to maintain in compression the pack of battery cells arranged peripherally around the rod inside the casing section. By the structure described and illustrated in Fig. 4, the battery case is made fluid-tight and pressure-resistant and provided with conductive connections to the remainder of the electrical apparatus.

In Fig. 5 there is illustrated a simplified form of apparatus according to the invention, in which form the necessity for electrical apparatus is obviated. As there illustrated, a drive shaft **45''**, similar to shaft **45** of Fig. 3, is connected to be driven through the clutch or motion transmitter **50** from the rotor shaft of turbodrill unit **30**. Rod **45''** drives a speed reducing gear box **47'** similar to gear box **47**, and the output shaft **43'** of the gear box rotates a cylindrical thrust cam **70** affixed to the shaft. A cam follower **71**, mounted on an offset end of a reciprocatory valve plunger rod **72** is adapted to follow cam **70** and receive rising motion therefrom. A compression spring **73** acts to maintain the follower in engagement with the cam. The spring acts against a washer **74** mounted on rod **72** in any suitable manner such as by means of a through-pin as indicated. Rod **72** is mounted for reciprocation in suitable guides (not shown) including a sealed opening in the upper end of an apparatus case **33'** which serves to enclose the moving parts and protect them from drilling fluid. A valve head **38'** is mounted on the upper end of rod **72**, outside case **33'**, and cooperates with a complementary part of the shaped bore **75** of a special drill collar **76**. Head **38'**, when raised by action of cam **70**, restricts the flow passage of the drilling fluid through bore **75** and causes a pressure increase thereabove; and when lowered by spring **73** (aided by fluid pressure on head **38'**) as follower **71** travels down the fall of cam **70**, permits the pressure above head **38'** to drop to normal value. Thus each revolution of cam **70** causes transmission of one pressure-change signal (the pressure increase, or the subsequent pressure decrease, or both) to the transducer means outside the borehole.

The recurrent pressure-change signals, each produced in the downwardly flowing drilling fluid stream by a cycle of movement of the valve head (**38** or **38'**), are transmitted up through the drilling fluid at substantially the speed of sound, and are detected at a suitable location outside the borehole. See Fig. 1. For the purpose of signal detection, a suitable conventional electrical pressure-transducer unit **80** is connected in hydraulic communication with the interior of pipe **24** to translate the pressure changes in the drilling fluid stream into corresponding electric potential changes. Power may be supplied to the transducer unit (which may comprise an amplifier) from a power supply **82**, as indicated. The output of the transducer unit is applied to a suitable conventional signal indicator such as a recorder **84** having a clockwork-driven record medium on which a series of record marks is produced, one for each pressure-change signal. By provision of suitable ruling marks along the record medium and uniform movement of the medium past the recording point, the marks corresponding to the pressure-change signals (each of which indicates a predetermined number of revolutions of the turbodrill) will indicate the time intervals elapsing between succeeding signals. Thus the time between any two signals may readily be determined; and the turbine speed may be computed using the equation

$$S=\frac{R}{T}$$

wherein S=turbine speed in r.p.m., R=number of turbine revolutions between successive signals, and T is the elapsed time in minutes indicated by successive marks on the record chart. In this equation R is determined by the gearing ratio in the gearbox.

Alternatively, by providing gearing to produce one signal per 100 turbodrill revolutions, and provision of ruling marks on the record medium indicating units of time along its length and moving the medium past the recording pen at a uniform speed of one time unit or ruling mark per unit of time, then the record marks will indicate the elapsed time intervals between successive signals, and also the number of hundreds of revolutions of the turbodrill per unit of time may be scaled directly from the record medium.

By observing the recorder **84** and manipulating valve **23** and/or pump speed controller **21c** of the fluid pump, the driller may control the speed of the turbodrill. The effective force or weight on the drill bit, composed of the downward thrust of the turbine plus the algebraic value of the force exerted upon the turbine bearings, is regulated in part by regulation of the drilling fluid pressure and flow rate, and in part by manipulation of the traveling block to add to or subtract from the drill string weight applied through the turbine bearings. The drilling rate may be determined by timed observation of a conventional depth meter **86** which indicates the change in borehole length (or depth) as time passes. Since with indications of the turbodrill bit speed available the driller is presented with data concerning all of the factors involved, determination of the maximum economic rate of drilling may be made.

From the foregoing it is evident that changes and modifications of the system and structures disclosed may occur to those skilled in the art; and accordingly I do not wish to be limited to the details illustrated and described, but what I claim is:

1. An earth well drilling system comprising, in combination: a turbodrill unit including a turbine having a rotor and a drill bit driven by the rotor, and means for supporting and supplying fluid under pressure to the turbine of said unit; a controllable valve through which said fluid passes enroute to said turbine; means including a speed reducer and cam and follower means, connected to and driven by the rotor of said turbine; means operatively connecting said cam and follower means to said valve for recurrently operating said valve to recurrently temporarily resist the flow of fluid toward said turbine once for each of a selected plural number of revolutions of said rotor; whereby there is created in the fluid passing

through said valve, recurrent pressure-change signals each indicative of the rotation of said rotor through said selected number of revolutions.

2. An earth well drilling system comprising, in combination: a turbodrill unit and means for supporting and supplying fluid under pressure to the turbodrill unit, said unit including a turbine having a rotor and a drill bit driven by the rotor; a valve means through which said fluid passes enroute to said turbine; and means controlled by said turbine for recurrently operating said valve means to alternately resist and free the flow of said fluid at a rate indicative of the speed of said turbine, said last-named means including a speed-reducer connected to be driven by said turbine, cam and follower means operated by said speed-reducer, and means connecting said follower means to said valve means to operate the latter.

3. An earth borehole drilling system comprising, in combination: a turbodrill unit including a turbine having a rotor and a drill bit driven by the rotor, and means for supporting and supplying fluid under pressure to drive the turbine of said unit; a controllable valve means through which said fluid passes enroute to said turbine; a solenoid adapted to control said valve means; a self-contained electrical power source positioned to be lowered into a borehole with said turbodrill unit; switch means for making and breaking electrical contact between said power source and said solenoid; a shaft driven by said rotor; and means driven by said shaft to actuate said switch means recurrently whereby said valve means is operated to create recurrent pressure-change signals in fluid passing through the valve means with each signal indicative of the rotation of said rotor through a predetermined plural number of revolutions.

4. An earth borehole drilling system comprising, in combination: a turbodrill unit including a turbine having a rotor and a drill bit driven by the rotor, and means for supporting and supplying fluid under pressure to drive the turbine of said unit; reciprocally movable closure means for a valve means through which said fluid passes enroute to said turbine; a plunger extending from said closure means and operable to move said closure means to control said valve means to resist flow of fluid toward said turbine; a speed reducer connected to and driven by said rotor; a shaft connected to and driven by said speed reducer; a cam on said shaft; and a cam follower on one end of said plunger and bearing against said cam whereby said closure means is actuated to actuate said valve means to create pressure change signals in said fluid by rotation of said shaft, with each of said signals being indicative of the rotation of said rotor through a predetermined plural number of revolutions.

5. An apparatus for making continuous measurements of the rotational speed of a fluid-driven turbine mounted on the lower end portion of a drill stem and while positioned adjacent the bottom of a borehole, said drill stem having a fluid circulating duct therethrough for circulating fluid down through said duct to drive said turbine, the combination comprising: flow restriction means adjacent said turbine actuatable for effecting a variable resistance to said flow of fluid through said ducts; means on said turbine for actuating said flow restriction means periodically at a frequency bearing a substantially continuous, predetermined relation to the rotational speed of said turbine; sensing means adjacent the upper end of said drill stem for sensing the thus produced periodic variations of the resistance to flow of said fluid and producing therefrom a periodically pulsating signal bearing a continuous, predetermined relation to the frequency of actuation of said flow restriction means; and means responsive to said signal for producing a continuous manifestation of the said rotational speed of said turbine.

6. In a well borehole apparatus for making continuous measurements while drilling, including a drill, a drill stem having a fluid circulation passage therethrough, a turbine positioned at the lower end thereof and adapted to be driven by fluid flow through said passage, and a drill bit drivingly coupled to said turbine, the combination comprising: flow restriction means in said drill stem in the vicinity of the lower end thereof actuatable for effecting a variable resistance to flow of fluid through said passage; means drivingly coupled to said turbine for actuating said flow restricting means periodically at a frequency bearing a continuous, predetermined relationship to the instant rotational speed of said turbine whereby to produce continuous pulsations of corresponding frequency in the fluid flowing in said passage; and means adjacent the upper end of said drill stem responsive to said fluid pulsations for producing a continuous signal bearing a continuous, predetermined relation to such frequency which in turn bears a continuous, predetermined relation to the concurrent rotational speed of said turbine.

7. In a well borehole apparatus including a drill stem having a fluid circulation passage therethrough, a drill bit at the lower end, a turbine in the vicinity in the lower end thereof coupled for driving said drill bit, said turbine being arranged to be driven by fluid flow through said passage, apparatus for continuously measuring the rotational speed of such turbine comprising: flow restriction means in said drill stem in the vicinity of the lower end thereof actuatable for effecting a variable resistance to flow of fluid through said passage; means intercoupling said flow restriction means and said turbine for actuating said flow restricting means periodically at a frequency bearing a substantially simultaneous, predetermined relation to the rotational speed of said turbine, thereby to produce continuous pulsations of corresponding frequency in fluid flowing in said passage; and means in the vicinity of the upper end of the drill stem, responsive to such pulsations to produce a continuous signal bearing a substantially simultaneous, predetermined relation to such frequency, which signal therefore bears a substantially continuous predetermined relation to the rotational speed of the turbine.

8. Apparatus according to claim 7 in which said means intercoupling said flow restricting means and said turbine includes means to actuate said flow restriction means at a frequency which is in the same order of magnitude as the rotational speed of said turbine.

9. Apparatus according to claim 7 in which said means intercoupling said flow restriction and said turbine includes means to actuate said flow restriction means at a frequency which is in the same order of magnitude as but less than the rotational speed of said turbine.

10. Apparatus for making continuous measurements of the rotational speed of a turbine driven by drilling fluid circulated down a drill pipe while said turbine is located adjacent the bottom of a drill hole on the lower portion of said drill pipe which comprises: means operated by the turbine for periodically constricting the flow of drilling fluid at a point adjacent the turbine to generate pressure pulses in the flowing drilling fluid at a frequency which bears a predetermined relation to the rotational speed of the turbine and which pulses are transmitted through the flowing drilling fluid to a point adjacent the top of the drill pipe; and means for intercepting said pressure pulses at said point to provide a signal bearing a substantially simultaneous predetermined relationship to the frequency of said pressure pulses.

11. Apparatus as recited in claim 10 further comprising means for amplifying the said signal as intercepted at said point.

12. Apparatus as recited in claim 10 in which said means for periodically constricting the flow of drilling fluid is operated by the turbine to generate pressure pulses of a frequency which is a fractional function less than one of the rotational speed of the turbine whereby said signal intercepted at said point is a pulsating signal having

a frequency which is a fractional function less than one of the rotational speed of the turbine.

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