

[72] Inventor **Henry Hobhouse**
Bottom Barn, Castle Cary, England
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 [33] **Great Britain**
 [31] **Nos. 18513/66, 37119/66 and 38920/66**

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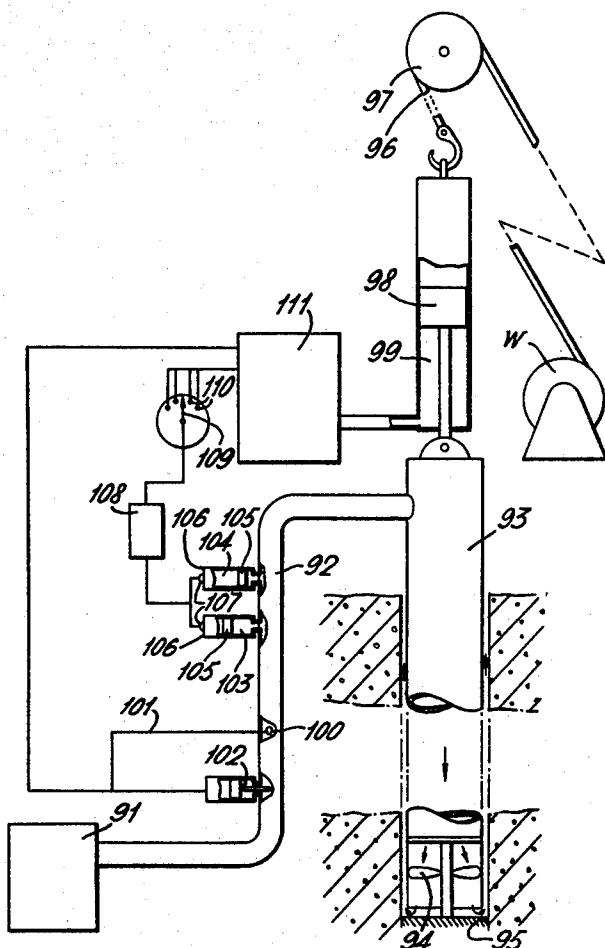
Primary Examiner—Marvin A. Champion
Assistant Examiner—Richard E. Favreau
Attorney—Woodhams, Blanchard and Flynn

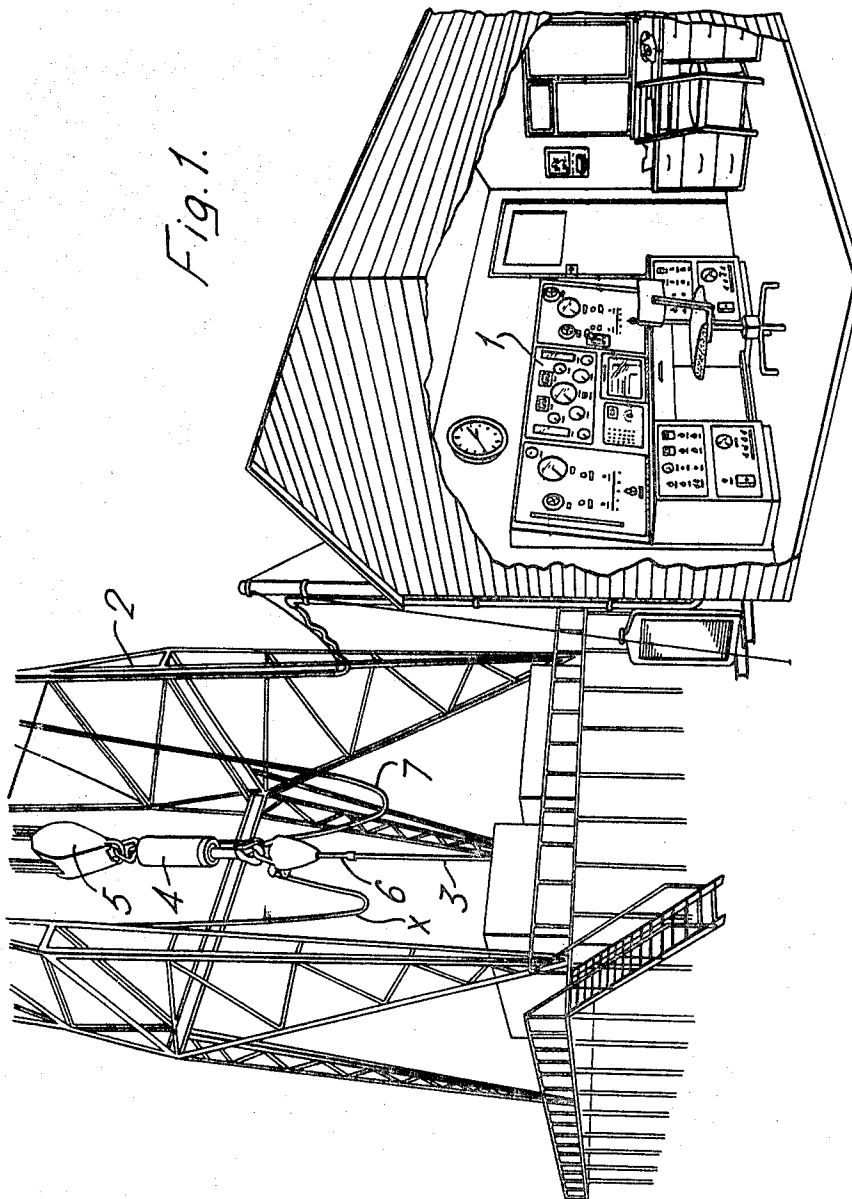
[54] **DRILLING CONDITION RESPONSIVE DRIVE CONTROL**
28 Claims, 9 Drawing Figs.

[52] U.S. Cl..... **175/26,**
173/8, 173/9; 299/12
 [51] Int. Cl..... **E21c 5/00**
 [50] Field of Search..... **175/24, 26,**
27; 173/5—10; 73/151, 151.5; 173/5, 6, 7; 175/24,
26, 27, 38

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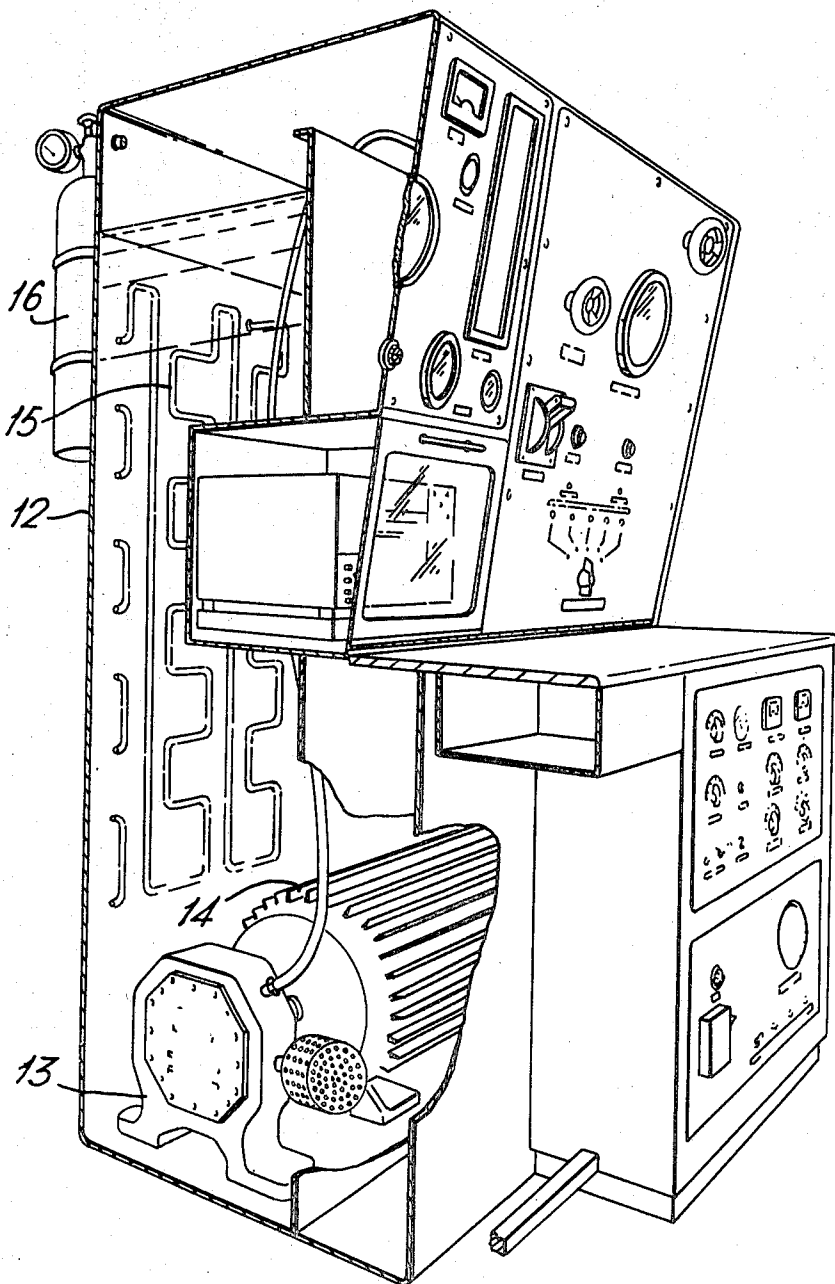
ABSTRACT: A drilling apparatus having hydraulic means operable on the drill string of an earth-boring drill whereby to maintain optimum drill speed, drilling fluid conditions, torque and weight-on-bit. The hydraulic means is controlled by a signal derived directly from the drill string upon changes in drilling conditions encountered during a drilling operation. The signal controls weight-on-bit and drilling fluid flow and pressure in order to maintain optimum torque.





INVENTOR
HENRY HOBHOUSE
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

Fig. 2.



INVENTOR
HENRY HOBHOUSE
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

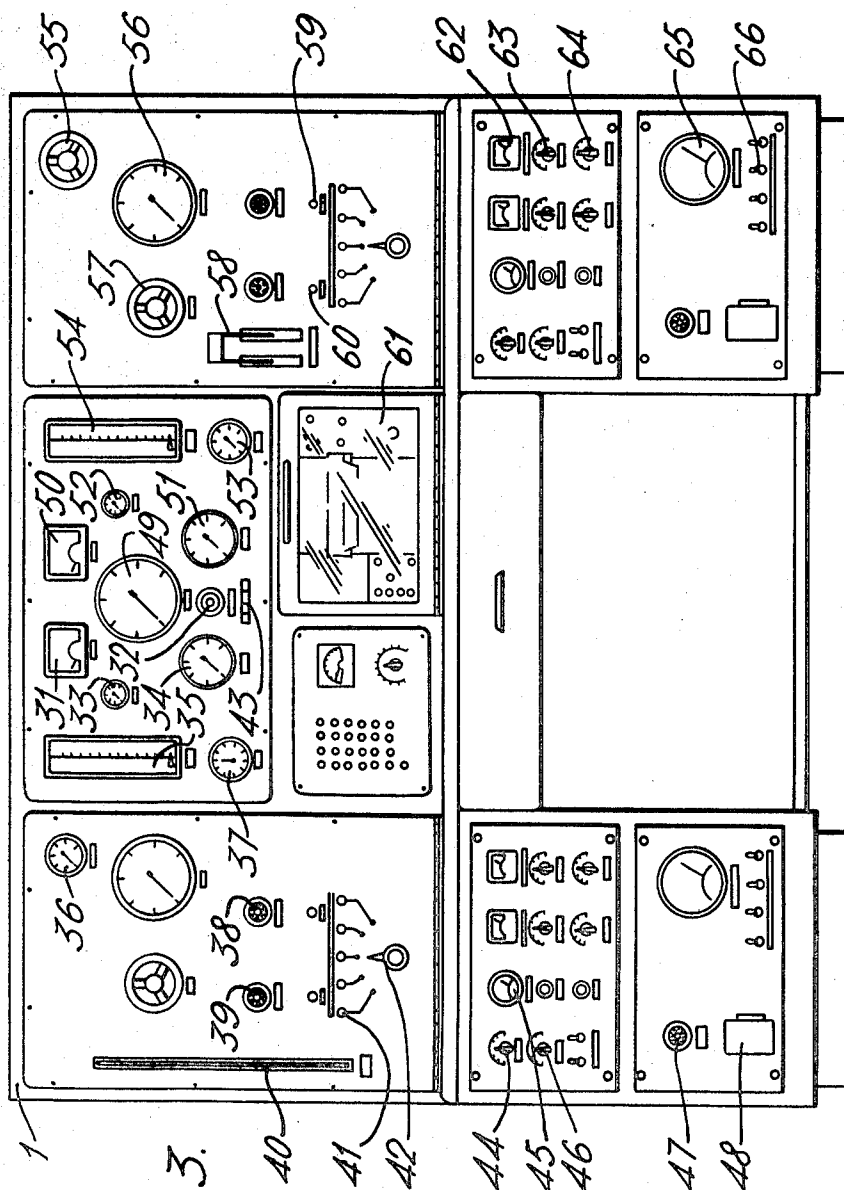
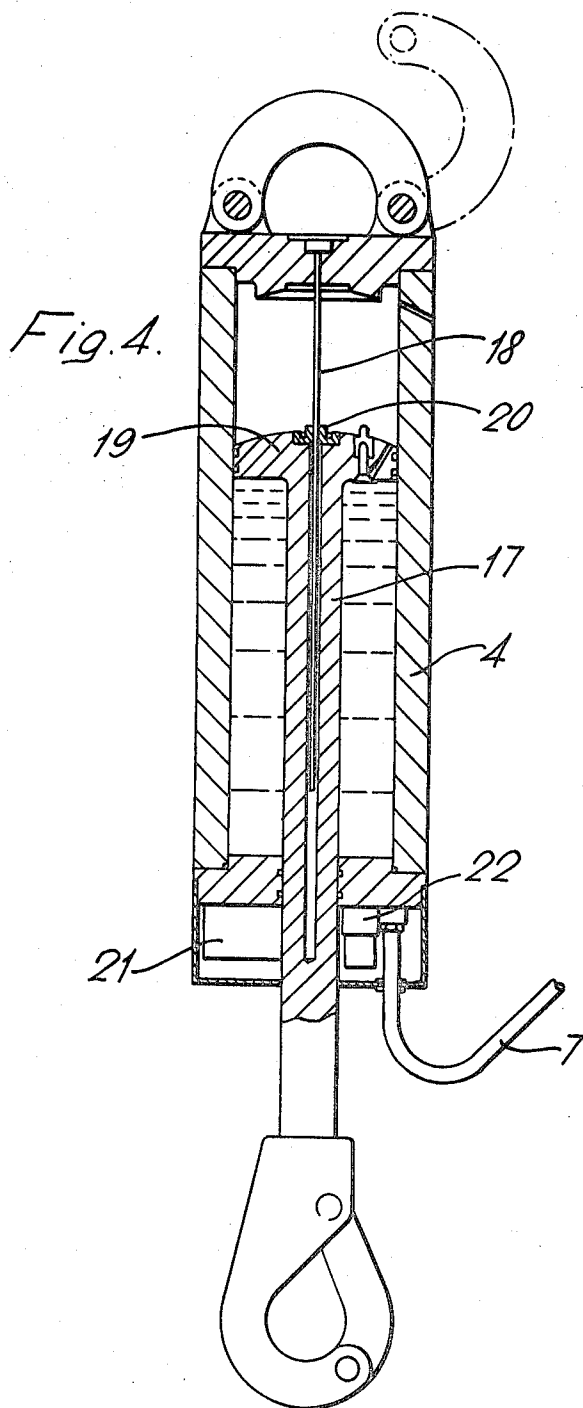


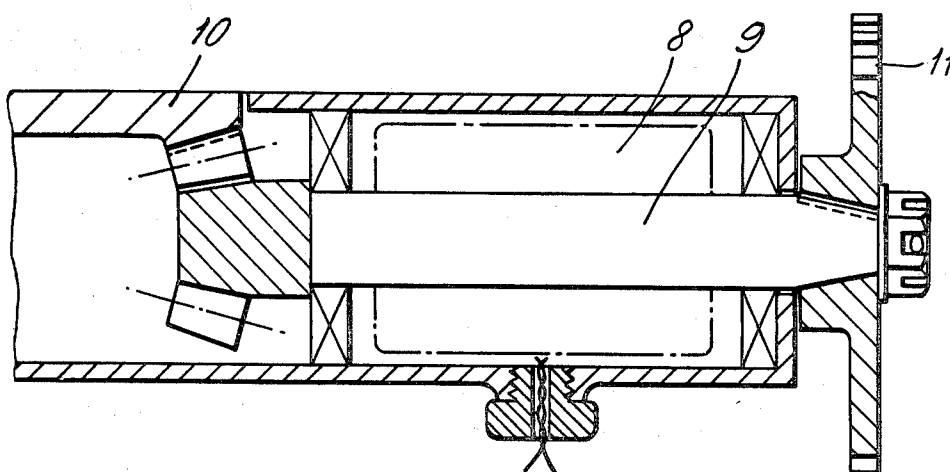
Fig. 3.

INVENTOR
HENRY HOBHOUSE
BY
Woodward, Blanchard & Flynn
ATTORNEYS



INVENTOR
HENRY HOBHOUSE
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

Fig. 5.



INVENTOR
HENRY HOBHOUSE
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

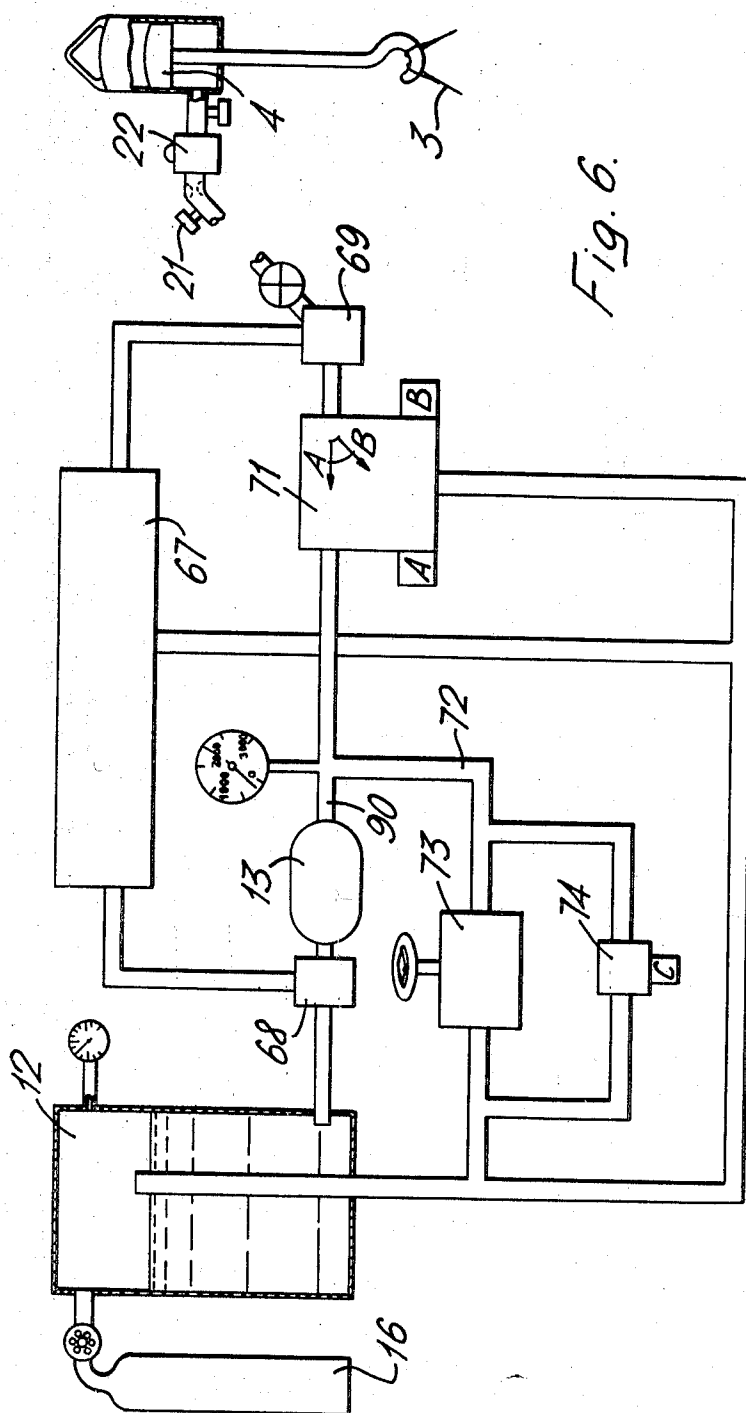
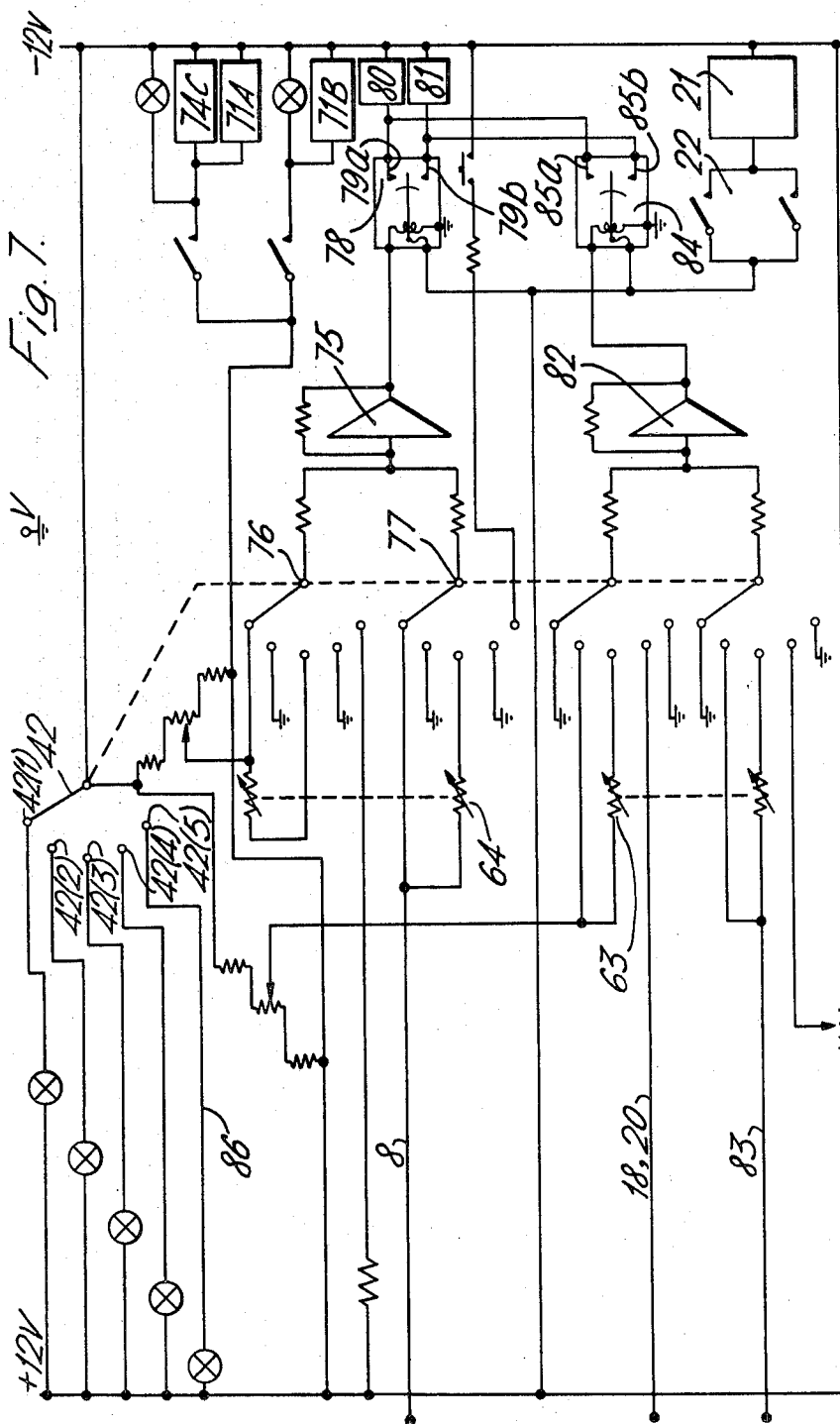
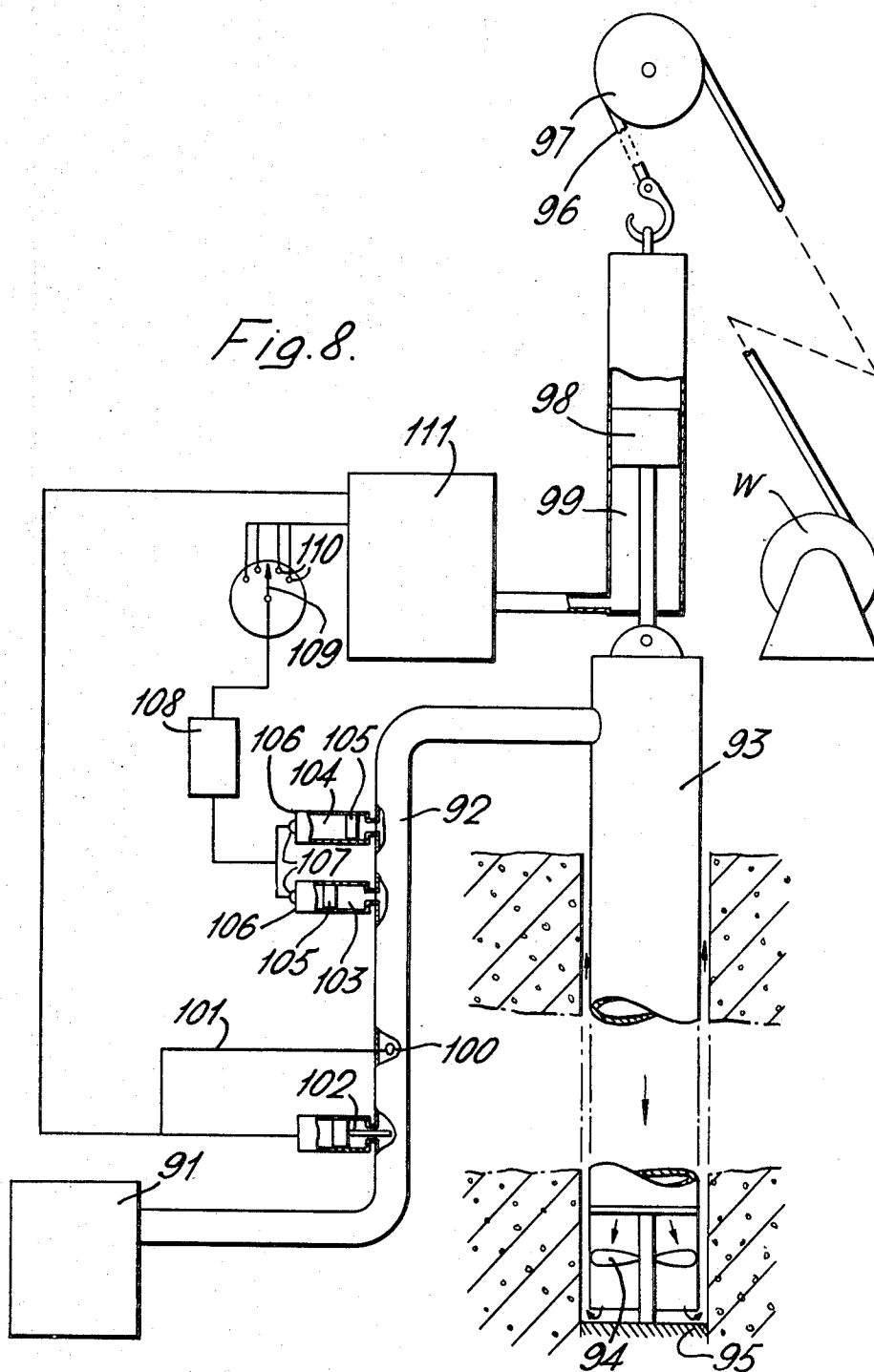


Fig. 6.

INVENTOR
HENRY HOBHOUSE
BY
Woodhouse, Blanchard & Flynn
ATTORNEYS

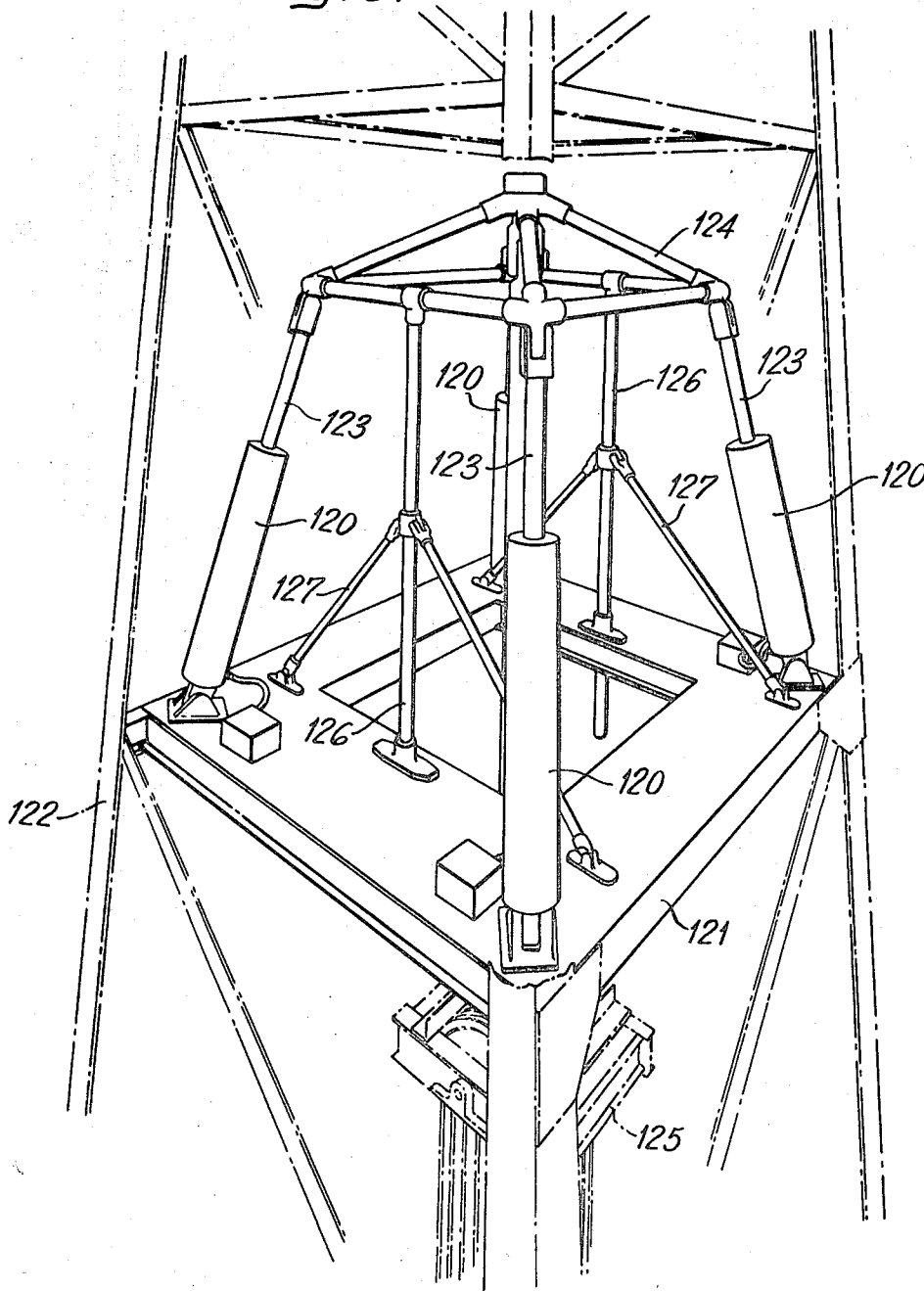


INVENTOR
 HENRY HOBHOUSE
 BY
 Woodhams, Blanchard & Flynn
 ATTORNEYS



INVENTOR
HENRY HOBHOUSE
BY
Woodhams, Blanchard & Flynn
ATTORNEYS

Fig. 9.



INVENTOR
HENRY HOBHOUSE
BY
Woodhouse, Blanchard & Flynn
ATTORNEYS

DRILLING CONDITION RESPONSIVE DRIVE CONTROL

The invention relates to means for controlling the weight applied to a drill bit on the basis of one of the drilling parameters.

Known means of controlling this factor in oil rigs are extremely unreliable and generally comprise the driller following a surface weight measurement device and/or listening to the beat of the diesel rotating the drill string and relieving the weight on the bit, by stopping the downward feed of the drill string, when the diesel beat slows due to an applied overload.

As the drill experiences changes in strata as it moves downwardly, different and difficult correlative conditions are required for the speed of rotation, weight-on-bit and bit lubrication.

Moreover there are two conditions of change in the condition of the drill bit, one change is a "chronic" change which is relatively gradual and extends from a new bit to a wornout bit and it is important to extend the time taken for this metamorphosis to the most economic period; the other change in the drill bit is "acute" and due to violent bit damage through an unexpected factor.

The main factors affecting the "chronic" change in the drill bit and the decision to replace the bit are, cost of a round trip, the existing penetration rate, the penetration rate to be expected from the new bit, the daily cost of running the rig and the cost of a new bit. Most of these factors are variables and they must be computed each one against the others to determine the most economical drilling conditions on the rig.

One disadvantage of existing methods is that this cannot be done as the full operating conditions at the drill bit are not known, thus the bit may be underloaded and thus uneconomical or overloaded causing extensive delays while broken bits and other parts are removed and replaced.

The main variables when controlling a deep hole drill are:

1. Changes in strata being drilled.
2. Changes in bit condition.

The invention has among its objects to mitigate the above mentioned disadvantage and to provide a control system for drilling rigs.

According to the invention means are provided connected in or to the drill string of an earth-boring drill whereby the weight-on-bit of the drill can be rapidly varied.

Advantageously the means comprise an hydraulic cylinder, having a piston, the cylinder being fed at one end from a pump outlet and the pump outlet being controlled by a signal derived from measurements taken of the drilling conditions and/or from empirical calculation, to move the piston within the cylinder to relieve or to increase the weight-on-bit applied to the weight of the drill string.

The means in response to a signal derived from or indicative of the torque at a rotary table of a drill and/or the torque adjacent the drill bit may be utilized to vary the weight-on-bit, by accepting a higher proportion of the weight of the drill string, or by applying a higher proportion of the weight of the drill string to the bit, to ensure that a substantially optimum torque is applied to the drill string at all times during drilling.

Thus the measurement may be taken at the pinion shaft of the rotary table with a torsion meter and transmitted to a control console as an electric signal. At the console the signal is amplified and by means of relays, and solenoid valves, is adapted to control the supply of pressure fluid to the cylinder, which cylinder may be interposed between a wire from a winch and the top of the drill string, or provided at the top of the drill string, or provided at the top of a derrick and supporting a top block of a pulley system powered by the winch for raising the drill string.

Advantageously the cylinder has limit stops at one or both of its ends, which limit stops are effective, upon full compression or expansion of the cylinder to override the winch control to allow the piston to move in the cylinder to a central position so that it can maintain control upon the weight-on-bit.

If preferred a reversible winch, advantageously an hydraulic winch, may be provided instead of the cylinder, whereby the

weight-on-bit can be controlled in dependence upon the signal received from the torsion meter on the pinion, to maintain a constant torque on the drill string.

A dash pot cylinder may be incorporated in a bail and/or hook on the cylinder to compensate for the elasticity of the wire rope between the winch and the bottom block of the pulley system.

Where the drill bit is rotated by a turbine positioned adjacent the bit and driven by a forced flow of mud-flush, air or other fluid, used to cool and lubricate the bit and extract the cuttings, the flow of mud-flush, air or other fluid, to the drill may be measured and regulated to a required value at any time and the pressure and/or flow of the mud-flush, air or other fluid be employed to control the hydraulic lift cylinder.

Thus for example a flow control formed as a gate valve or the like may be movable by means of a hydraulic control cylinder in accordance with data extracted from further measurement means, whereby the flow of mud-flush, air or other fluid may be maintained at one of a plurality of constant levels or may be regulated to give a particular drilling characteristic. The pressure of the mud-flush, air or other fluid may be employed to control the weight on bit, by means of overpressure and underpressure control devices each advantageously comprising a so called "dirty" end, separated by a movable piston from a "clean" end, the movable piston cooperating with a pressure source of hydraulic fluid, operating through strain gauges and electrical means to supply a control signal to the control console.

The console controls the position of the piston in the lift cylinder, which supports the drill string of pipes, the turbine and the bit, a supply of pressure fluid to the lift cylinder being effective to move the piston therein to regulate the weight applied to the bit of the turbodrill. The control console advantageously also controls the piston-operated gate valve controlling the flow of mud-flush.

The invention thus provides sufficient control whereby the flow of mud-flush, air or other fluid, and thus the turbine speed, the pressure of mud-flush, air or other fluid, and thus the torque, and the weight on the bit, can be controlled. The three features, speed, torque and weight-on-bit, are interrelated in drilling and any change in one causes a change in at least one of the other two when operating under constant drill conditions or allows at least one or the other two to remain constant when drilling in varying drilling conditions.

The control console may be provided with recording means and with means whereby the speed-torque-weight equation may be established initially, subsequent changes indicating strata alterations when compensated for change in depth of drilling, or change in bit characteristic due to wear.

Pressure sensing and indicating means may be provided spaced apart on the pipe supplying mud-flush air or other fluid whereby the pressure drop over a given distance can be determined and thus the pressure drop between source and turbodrill calculated. Particularly when working with mud-flush the pressure drop is dependent upon the consistency of the mud-flush which is likely to vary and also upon the volume and pressure of the mud-flush.

Advantageously means are provided on the lift cylinder whereby the rate of movement of the piston in the lift cylinder may be accurately determined. Such means may comprise a rod of determined resistance secured to the lift cylinder and extending into an aperture in the piston, pickup brushes being provided to contact the rod, whereby the extent of the rod not contained within the piston can be determined at any time.

A signal obtained from the pickup brushes, which signal during normal drilling in consistent material, with the payout winch stopped, will be substantially linear, may be fed to an integrating circuit to be integrated to give its rate of change, advantageously on the basis of a supply frequency or the frequency of a crystal oscillator. The rate of change can then be simply converted to give the drill bit penetration in equivalent feet per hour of drilling. By using the apparatus of the invention at different torques and obtaining the measure-

ment of penetration the optimum torque for drilling any particular kind of strata can be determined. The signal from the brushes may if required be used to give an indication of the cylinder approaching an end position instead of providing limit stops.

The rate of penetration can be calibrated with torque at any time, within a very short time. Thus with a new bit a determined penetration rate will necessitate a determined torque and a determined speed, whereas a few feet deeper the bit will be worn so as to require the torque and speed values to be changed to maintain the same penetration. A simple computer can be used, suitably programmed from bit deterioration curves, to link these quantities in a known relationship for every requirement.

The object of controlling the weight on the drill bit to maintain the torque within limits is:

1. To reduce the risk of damage to the bit and undue twisting of the drill pipe;
2. To equate, by means of torque measurement, optimum weight-on-bit, rotational speed and supply of mud-flush;
3. To take account of changes in strata or in bit condition so that bit damage does not occur and the driller is instantaneously aware of such changes;
4. To prevent damage in the case of extreme changes in torque;
5. To provide facilities for recording continuously the speed and torque of the drill pipe, the mud-flush volume and pressure and the weight-on-bit;
6. By analysis of the records taken under (5) to permit recommendations for various conditions to be made for future use;
7. To iron out the difference between a good and a bad shift of men by simplifying the technique of drilling so that the labor employed need be less skilled or conscientious than at present;
8. To give a greater bit life and therefore fewer round trips to change the bit;
9. To allow reduction in the normal amounts of mud-flush supplied, and thus the power required to pump it, by reason of the ability of the apparatus instantaneously to increase the supply when necessary.

The outlet of the hydraulic pump controlled by the signal is coupled to the lower end of the cylinder and under the control applied to solenoid valves by the signal, either forces hydraulic fluid into the lower end of the cylinder, in which case the weight-on-bit is relieved, or allows fluid to be drawn outwardly from the lower end of the cylinder, in which case the weight-on-bit is increased. When drilling by rotating the entire drill string a bypass around a flow control valve in a feed line (see feed line X in FIG. 2) between a mud-flush pump and the top of the drill tube is provided to be under the control of the signal.

The control imparted by the signal is as follows:

1. Upon torque rise the flow of mud-flush is increased by opening the bypass;
2. As torque continues to rise, feed is stopped by operating a solenoid controlled brake on the drum of the winch providing the downward feed of the drill bit, whereby the downward feed is checked;
3. As torque continues to rise the weight of the drill tube is lifted off the bit by pressurizing the lower end of the hydraulic cylinder;
4. As torque rises above a predetermined level the drill rotation is stopped and downward feed is stopped but the mud-flush supply is continued.

In the case where the torque falls the signal operates as follows:

1. As torque begins to fall the mud-flush supply is increased by opening the bypass;
2. As torque continues to fall the weight on the bit is increased by relieving pressure at the lower end of the cylinder;
3. As torque falls below a predetermined level rotation, feed and mud-flush supply are stopped.

The invention is diagrammatically illustrated by way of example in the accompanying drawings, in which:

FIG. 1 shows a general layout of one embodiment of apparatus according to the invention;

FIG. 2 shows a section through a control console;

FIG. 3 is a corresponding elevation;

FIG. 4 is a section through a lift cylinder;

FIG. 5 shows a torque measurement transducer;

fig. 6 is an hydraulic circuit of apparatus according to the invention;

FIG. 7 shows an electrical control circuit for apparatus according to the invention;

FIG. 8 shows a further embodiment of the invention using a drill motor formed as a turbine driven by the flow of mud-flush, and

FIG. 9 shows an embodiment with the lift cylinder mounted above the top (fixed) block.

Referring to the drawings and in particular to FIG. 1 there is shown an electrohydraulic control system provided in a console 1, to be used as an accessory to an existing drilling rig 2, to control the weight-on-bit whereby the torque at the top of a drill string 3 is maintained constant by automatic adjustment of the weight-on-bit.

This is achieved by interposing a hydraulic lift cylinder 4 between a travelling block 5 and a Kelly 6 in the drill string 3. The console 1 and cylinder 4 are interconnected by a combined hose and cable 7 which is long enough to allow the cylinder sufficient movement to allow addition of extra drill pipes as drilling proceeds. The weight-on-bit is then varied by controlling the pressure in the cylinder 4 in response to signals from a torque transducer 8 mounted in the drive shaft 9 (FIG. 5) of the rotary table 10.

The transducer 8 comprises a series of strain gauges measuring torsional resistance of the shaft 9 which extends from a drive sprocket 11 to the rotary table 10 to rotate the table and thus the drill string 3 and the drill bit. The strain gauges are connected to the console by means of slip rings and an electromagnetic pickup is included to give an accurate measurement of the speed of the shaft 9.

The torque required in the drill string 3 is selected at the console 1, which produces a varying hydraulic pressure in response to electric signals from the torque transducer 8. This hydraulic pressure is felt under the piston of the lift cylinder 4 and thus the weight on the bit is adjusted to establish the torque value dictated by the console 1. The winch operator merely prevents the piston of the cylinder 4 from reaching its end stops, and does not, as hitherto, control the drilling operation by dictating the weight on the bit. Alternatively, a winch override control may replace the operator. In either case the lift cylinder 4 is dominant.

The console 1 also provides signals which, when fed to a suitable adapter, control mud-flush pressure and flow, and rotary table speed.

As shown in FIG. 2 the control console includes a tank 12, of rigid construction, within which are mounted a hydraulic pump 13 and an electric motor 14 driving the pump 13. This construction keeps the ambient noise at a tolerable level and the hydraulic fluid surrounding the pump 13 and motor 14 acts as a heat exchanger for the high power moving parts.

Electric switch-gear and fuses for the motor 14 are mounted on the front of the tank 12 and a coil 15 may be provided through which coolant may be circulated, to control the hydraulic fluid temperature when working in unfavorable ambient temperatures.

The tank 12 and console 1 are filled with nitrogen at a pressure of 10 p.s.i. from a bottle 16. This serves the dual purpose of minimizing fire risk and obviating boost pumps.

The electric and hydraulic power supplies, and the electric control circuits, are all duplicated in the console 1. Thus, in the event of a failure in any one of these, an immediate changeover may be made and operations continued.

Advantageously the cylinder 4 is 18 inches O.D., 12 inches I.D. with a 3-inch diameter piston rod 17 and has a working range of almost 3 feet. Under normal working conditions the

maximum hydraulic pressure will be 3,000 p.s.i. (giving 317,400 lbs. pull.).

Within the cylinder 4 there is an electric transducer which signals the position of the piston 19 back to the console 1 and to a winch repeater. The transducer comprises a rod 18 secured to the cylinder head and passing through the center of the piston 19 and rod 17. The rod 18 has a resistance track thereon which cooperates with brushes 20 in the piston 19 to produce a signal dependent upon the position of the piston 19 in the cylinder 4.

Built into the base of the cylinder 4 are a fail-safe solenoid valve 21 and a pressure switch 22 which will close and thus prevent oil from leaking out of the cylinder, and therefore "bottoming" the drill string 3, in the event of a hose fracture, or failure of the electric or hydraulic supplies.

As shown in FIG. 3 the console 1, in addition to having the control equipment for the hydraulic cylinder 4 is also used as a central instrument panel, where other functions of the drilling rig are monitored and recorded.

The instruments and controls appearing on the console are:

Cylinder pressure gauge 31 fed from a pressure transducer on the cylinder 4 supplying cylinder pressure voltage to the meter.

Command indicator lamp 32 showing that the console is in command and not a winch repeater station.

Oil temperature indicator 33 from a mercury bulb gauge measuring the temperature of the hydraulic oil in the tank 12.

Weight-on-bit meter 34 including a "Calibrate" circuit. This is set by raising the drill string 3 just off the bottom. The cylinder pressure voltage is connected to the weight meter and the deflection backed off to zero by the "Calibrate" control. The polarity of the meter is then reversed and drilling proceeds. The reading on the meter is then the weight-on-bit.

Cylinder position repeater 35 as an "Edgewise" meter on the console operated by the resistance track 18.

Nitrogen pressure gauge 36.

Rotary table speed motor 37, pulses arriving from a torque transducer assembly in the rotary table main shaft, are integrated and the voltage thus obtained fed to the meter, which reads in r.p.m.

Raising and lowering, colored indicator lamps 38 and 39, connected to a two-way solenoid valve showing the direction of movement of the cylinder 4.

Level sight glass 40 showing the level of hydraulic fluid in the tank 12.

Indicator lamps 41 show selections of a control selector 42. The control selector can make any one of five selections 42(1) to 42(5) comprising:

42(1) Torque Control

The desired torque is set, the weight on the bit is varied by the cylinder 4 until this value is reached, thereafter adjustments to the weight are automatically made to keep the torque substantially constant.

42(2) Weight Control

The desired weight-on-bit is set and the length of the cylinder 4 varied to raise or lower the drill string 3, until this is reached. Subsequent automatic adjustments are made, as drilling proceeds, to keep the weight-on-bit substantially constant.

42(3) Weight/Torque Combination

Maximum and minimum values for weight-on-bit are selected and also maximum and minimum values for torque. If the preferable conditions are within these four limits, no adjustment is made to the cylinder 4 should any limit be extended, the appropriate adjustment is made.

42(4) Hold

The cylinder 4 is held in any selected position and variations of torque, weight or leakage do not affect it.

42(5) Pull

The cylinder 4 can be used to "pull" stuck pipe by manual operation from the winch repeater station.

If controls 42(1), 42(2) or 42(3) are selected, there is a preset safety limit, beyond which the system shuts down and locks the cylinder 4.

This safety limit is based on an unacceptable change in a different parameter to that selected for control purposes.

Thus, if control 42(1) were selected, torque would be dominant, but weight limits would be set, which would provide complete safety as well as indicating a need to change programming.

Also provided on the console are:

A drill string length indicator 43.

Torque value selector 44.

DC control circuit voltage indicator 45.

Weight-on-bit selector 46.

Mains supply lamp indicator 47.

Mains fuse switch 48.

Mud-flush flow gauge 49, reading differential pressure across a calibrated orifice in a mud-flush pipe at the rig.

Mud-flush pressure gauge 50 from a pressure transducer at the rig.

Torque-on-bit gauge 51 with a "Calibrated" circuit. The drill string is lifted just off the bottom of the hole and rotated, the reading on the torque meter is then backed off to zero with the calibrated control. Thereafter when drilling proceeds, the reading is the torque-on-bit to the first approximation.

Coolant temperature indicator 52 from a mercury bulb gauge measuring the temperature of the coolant in the heat exchanger 15.

Rotary table torque meter 53 showing the output from the torque transducer at the rotary table.

Rate of penetration meter 54 measuring time taken for the ram piston to travel a determined distance. The winch is stopped during this time and the meter indicates penetration in feet/hour directly.

Shutoff valve 55 to prevent leakage of oil when the hose 7 is disconnected.

Pump delivery pressure gauge 56 as a Bourden tube measuring the output pressure of the pump 13.

Pump delivery valve 57 as a manually adjusted bypass valve to set the system pressure.

Two-way change over valve 58 to change from one hydraulic circuit to the other in the event of a failure. An electrical switch is also fitted to change over the electric circuits at the same time.

Hydraulic power "on" indicator lamp 59 showing that the pump 13 is running.

Electric power "on" indicator lamp 60 showing that power is supplied to the electric circuits.

Chart recorder 61 formed as a six channel galvanometer or pen recorder, for dynamic measurements of drilling conditions.

Moving coil relays 62, these relays for torque and weight control are described under references 78 and 84 in the circuit of fig. 7.

Upper and lower weight limit controls 63 to select weight limits for combination control 42(3).

Upper and lower torque limit controls 64 to select torque limits for combination control 42(3).

Advantageously, the penetration rate of the bit is measured by the meter 54 at intervals during drilling and the rig reprogrammed to take account of the deterioration in the state of the bit.

As shown in FIG. 6, the hydraulic control circuit is duplicated by a circuit indicated at 67 and two position changeover valves 68 and 69 select whichever is to be used.

The drive motors for the pumps 13 are also controlled by the changeover valves 68 and 69. The pump 13 of the selected circuit is continually running, at its nominal speed and its outlet 90 connected to a two-way solenoid valve 71, which, in turn, connects it to the hydraulic cylinder 4, when solenoid 71A is energized.

The outlet 90 is also connected to a bypass circuit 72 consisting of a manually adjustable valve 73 to set maximum system pressure, and a normally open solenoid valve 74C which is energized closed at the same time as solenoid valve 71A is energized open.

Therefore, when it is required to raise the piston in the cylinder 4, solenoid 71A and 74C are energized, opening the two-way valve 71 and closing the bypass 72 allowing oil to be pumped into the cylinder 4.

To lower the piston in the cylinder 4, solenoid 71B is operated, and the load on the piston pumps oil through the return ports of the two-way valve 71 and back to the tank 12.

The fail-safe solenoid valve 21 is energized by the associated pressure switch 22. Therefore should a failure occur in the hose 7 or associated couplings, the pressure fails and the switch 22 deenergizes the solenoid valve 21, which traps the oil in the cylinder 4 preventing a catastrophic lowering of the drill string 4.

This fail-safe circuit is overridden by the energization of solenoid 71B, otherwise it would prevent the controlled lowering of the piston in the cylinder 4.

Stabilizing components, while included are not shown.

The function and operation of the electrical control circuit of FIG. 7 is described having regard to the control imparted by the different settings of the control selector 42, thus:

42(1) Torque control

When the selector switch 42 is set to position 42(1) an amplifier 75, receives the torque demand signal via a wafer 76 and the actual torque signal from the transducer via a wafer 77. These signals are subtracted in the amplifier 75 and the difference fed to a torque center zero moving coil relay 78. The gain of the amplifier 75 determines the hysteresis of the circuit; the moving coil relay 78 has a dead range when the pointer is between contacts 79a and 79b. If there is an excessive error, the relay 78 energizes either relay 80 or 81, which in turn energizes the hydraulic two-way solenoid valve 71 (FIG. 6) to raise or lower the piston in the cylinder 4 and correct the error.

42(2) Weight Control

In a similar way to the operation of amplifier 75, the circuit of an amplifier 82 controls weight-on-bit by comparing a demanded signal with the output from a pressure transducer 63 (not shown, but mounted adjacent the pressure switch 22 in the cylinder 4) and energizing the relays 80, 81 through a weight center zero moving coil relay 84 having contacts 85a, 85b.

42(3) Weight/Torque Combination

Use is made of hysteresis in the moving coil relays 78, 84. When the control switch is at position 42(3) the torque limits are set by varying the gain of the amplifier 75. Thus it is possible to set maximum and minimum values and the torque signals only cause the cylinder to move if these limits are exceeded.

Similarly, weight limits are set on amplifier 76. The resulting combinations allows the system to roam freely within the specified limits and only adjusts the cylinder 4 when they are exceeded.

42(4) Hold

A reference signal is compared with the position of the transducer 18, 20 by amplifier 82. Error signals are used to correct the position of the piston in the cylinder 4 via the moving coil relay 84 and relays 80, 81.

42(5) Pull

The cylinder 4 is fully extended by a positive signal on lead 86 to contact 42(5). When a "pull" is required, operation of a push button reverses the moving coil relay 78 to energize relay 80, and thus contact the cylinder 4.

The pressure switch 22 operates each time that pressure builds up in the hose 7. The solenoid valve 21 opens, allowing oil to enter the cylinder 4. When lowering, the pressure switch, contact 22 is bypassed by relay 81.

FIG. 8 illustrates the invention when used for drilling with a turbodriven bit operated by mud-flush. A mud-flush pump 91

driven by a prime mover (not shown) supplies mud-flush under pressure by means of a pipe 92 to the drill pipe 93 of a drilling rig. The drill pipe 93 supports at its lower end a turbine 94 which, when rotated by flow therethrough of mud-flush under pressure, causes rotation of a drill bit 95 to drill a hole in the ground. The drill string, formed by the drill pipe section 93, turbine 94 and drill bit 95, is supported by a rope 96, pulley 97 and a winch W, with a piston 98 in a cylinder 99, interposed between the drill pipe 93 and the rope 96.

A flow-sensing device 100 of known kind is provided in the pipe 92 to measure the flow of mud-flush therethrough and has a connection 101 whereby the flow through pipe 92 can be regulated by means of an hydraulic piston controlled gate valve 102.

Downstream of the measurement device 100 and flow control 102, control devices 103 and 104 are provided. The underside of the piston 105 in each valve is in communication with the mud-flush in the pipe 92 so as to be acted upon by the pressure thereof and the upper side of each piston 105 is in communication by hydraulic fluid with a diaphragm 106 bearing a strain gauge 107. Changes in mud-flush pressure beyond determined limits produce a change in pressure in the hydraulic fluid and generate an electrical signal from the strain gauges 107. The electrical signal is amplified by an amplifier 108 and used to deflect a needle 109 above or below a norm to make contact with graduated reference contacts 110. Contact with contacts 110 supplies a signal to a linear accelerator contained in a control console 111.

The control console 111 also obtains an indication from the flow sensor 100 of the mud-flush flow, and separately or in conjunction with the pressure sensor 109 may supply pressure fluid to the underside of the piston 98 in the cylinder 99, to regulate the sinkage of the drill string and thus the weight applied to the bit 95. A predetermined relationship between speed, resistance to rotation and the weight applied to the drill bit may thus be maintained.

The following sequence of control is advantageous upon torque rise in the bit causing an increase in mud-flush pressure in pipe 92 detected by the control device 104, for example due to the drill bit striking a harder strata than previously being drilled:

1. increase mud-flush flow by opening valve 102;
2. stop sinkage by pressurizing underside of piston 98;
3. lift weight off bit 95; (4) stop drilling.

The following sequence upon torque fall at the drill bit 95 sensed by a pressure drop detected at control device 103 for example due to the drill breaking through into a softer strata:

1. increase sinkage by releasing pressure beneath piston 98;
2. increase volume of mud-flush flow by opening valve 102;
3. stop drilling.

FIG. 9 shows an alternative construction wherein four hydraulic lift cylinders 120 are mounted one adjacent each corner of a support platform 121 on a drill derrick 122. The upper ends of pistons 123 are coupled to a gantry 124 which carries a pulley block 125. The gantry is provided with support members 126 slideable in brace members 127 mounted on the platform 121. Ingress and egress of hydraulic fluid in the cylinders 120 respectively relieves and increases the weight-on-bit. The flow of hydraulic fluid is controlled by a signal as hereinbefore described.

I claim:

1. A drilling apparatus for controlling and driving a drill string in dependence upon changes in drilling conditions as indicated by variations in drill torque, including:

- a drill string and a drill bit connected to said drill string;
- first means including a reversible hydraulic motor means connected to the drill string for varying the drill load thereon;
- second means for supplying drilling fluid to said drill bit;
- third means for generating a signal indicative of the drilling conditions;
- fourth means responsive to the generated signal for controlling the supply of hydraulic fluid to said hydraulic motor means; and

fifth means responsive to the generated signal for controlling the pressure and flow of drilling fluid to the drill bit.

2. A drilling apparatus according to claim 1, wherein said third means generates the signal in direct response to the pressure of the drill fluid.

3. A drilling apparatus according to claim 1, wherein said reversible hydraulic motor means comprises a hydraulic cylinder means having a cylinder housing and a piston positioned within the cylinder housing for movement relative thereto.

4. A drilling apparatus according to claim 3, wherein said first means includes a winch and a cable from the winch to the drill string, the hydraulic cylinder means being connected between said cable and the top of said drill string.

5. A drilling apparatus according to claim 3, further including a drilling console; and said fourth means including amplifier means, relay means and solenoid valve means carried by the console and operable to vary the supply of hydraulic fluid to said cylinder means upon receipt of the signal.

6. A drilling apparatus according to claim 3, wherein said reversible hydraulic motor means comprises a hydraulic cylinder means having a cylinder housing and a piston positioned within the cylinder housing for movement relative thereto, and the hydraulic cylinder means including a resistance track and cooperating bushes therein for indicating the position of the piston.

7. A drilling apparatus according to claim 3, wherein said first means including turbine means at the drill bit and driven by drilling fluid to rotate the drill bit, said fifth means varying the flow of drilling fluid to the bit upon changes in drilling conditions, and said third means including means for detecting changes in drilling fluid flow to initiate said signal to actuate said cylinder means.

8. A drilling apparatus according to claim 7, wherein said second means includes a drilling fluid pump and pipe means for conveying drilling fluid from the pump to the drill bit, said fifth means including means for measuring the flow of drilling fluid through the pipe means and valve means under the control of the measuring means to regulate the flow of drilling fluid to the bit, and said fourth means controlling the supply of hydraulic fluid to said hydraulic cylinder means in response to a signal from the measuring means.

9. A drilling apparatus according to claim 8, wherein said third means includes pressure-sensitive control means located on the pipe means downstream of the flow measuring means and means for transmitting a signal from the pressure-sensitive control means to actuate the supply of hydraulic fluid to the hydraulic cylinder means, said pressure-sensitive control means comprising transducer means for producing an electrical signal upon changes in pressure in the drilling lubricant; and said fourth means including amplifier means for amplifying the electrical signal and means responsive to the amplified signal to control the supply of fluid to the hydraulic cylinder means.

10. In a drilling apparatus having a drill string and drill bit, the improvement comprising an electrohydraulic control system to maintain torque in the drill string substantially constant, the system including first means having a reversible hydraulic motor means connected to the drill string for varying the weight-on-bit, second means for generating a signal indicative of a torque change, and third means responsive to the signal for controlling a supply of hydraulic fluid to the hydraulic motor means whereby to vary the weight-on-bit to compensate for said torque change.

11. A drilling apparatus according to claim 10, wherein said first means includes a traveling pulley block, a Kelly and a swivel joint at the upper end of the Kelly, the hydraulic motor means being coupled between the block and the swivel joint.

12. In a drilling apparatus according to claim 10, further including a fourth means for supplying drilling fluid to the drill bit.

13. In a drilling apparatus according to claim 12, further including fifth means responsive to said signal for controlling the

pressure and flow of drilling fluid to the drill bit, said third and fifth means together compensating for said torque change to return the torque to an initial predetermined value.

14. A drilling apparatus according to claim 10, wherein said first means including a rotary table for driving the drill string, a drive sprocket and a drive pinion shaft connecting the sprocket to the table; and said second means including transducer means mounted on the pinion shaft to sense changes in torque applied to the drill string and to generate the signal for controlling the supply of fluid to the hydraulic motor means.

15. A drilling apparatus according to claim 14, further including a drilling console; and said second means including amplifier means, relay means and solenoid valve means carried by the console and operable to vary the supply of hydraulic fluid to said hydraulic motor means upon receipt of the signal.

16. A drilling apparatus according to claim 14, wherein said reversible hydraulic motor means comprises a hydraulic cylinder means having a cylinder housing and a piston positioned within the cylinder housing for movement relative thereto; said first means including a tank filled with hydraulic fluid, motor-driven hydraulic pump provided internally of the tank, means for increasing pressure in the tank above atmospheric pressure, and means for cooling the hydraulic fluid; said third means including amplifier means, relay means and solenoid-operated valve means for receiving the signal and a selector switch effective to vary the stroke of the hydraulic cylinder means.

17. A drilling apparatus according to claim 16, wherein the selector switch is effective to cause the hydraulic cylinder means to maintain a desired torque at the drill string.

18. A drilling apparatus according to claim 16, wherein the selector switch is effective to cause the hydraulic cylinder means to maintain a desired weight on the drill string.

19. A drilling apparatus according to claim 16, wherein the selector switch is effective to cause the hydraulic cylinder means to maintain each of the torque and weight on the drill string between determined limits.

20. A drilling apparatus according to claim 16, wherein the selector switch is effective to hold the hydraulic cylinder means in a determined position.

21. A drilling apparatus according to claim 16, wherein the selector switch is effective to cause the cylinder means to pull on the drill string.

22. A method of controlling the feed rate of the drill string of a drilling apparatus, said drilling apparatus having a drill bit secured to the end of said drill string and motor means connected to said drill string for controlling the weight-on-bit, said method comprising the steps of:

generating a signal from said drill string with said generated signal representing the magnitude of the weight-on-bit; comparing the generated signal with a predetermined signal representative of a desired value of the weight-on-bit; and energizing said motor means to vary the weight imposed on the bit until the weight-on-bit signal generated from said drill string corresponds to said predetermined signal so as to indicate that the weight-on-bit of the drill string is substantially equal to the desired predetermined value.

23. A method of controlling the feed rate of the drill string of a drilling apparatus, said drilling apparatus having a drill bit secured to the end of said drill string, and motor means connected to said drill string for controlling the torque imposed thereon, said method comprising the steps of:

generating a signal from said drill string with said generated signal representing the magnitude of the torque imposed on the drill string; comparing the generated signal with a predetermined signal representative of the desired torque which is to be imposed on the drill string; and varying the torque imposed on said drill string by energization of said motor means until the signal generated by said drill string corresponds with said predetermined signal so as to indicate that the actual torque imposed on the drill

string is substantially equal to the desired predetermined torque.

24. A method of controlling the feed rate of the drill string of a drilling apparatus, said drilling apparatus having a drill bit secured to said drill string and motor means for controlling drill string torque and weight-on-bit, said method comprising the steps of:

generating a first signal from said drill string with said first signal being representative of the magnitude of the torque imposed on said drill string;

generating a second signal from said drill string with said second signal being representative of the magnitude of the weight-on-bit;

comparing said first generated signal with a first pair of predetermined signals representative of desired maximum and minimum torque values;

comparing said second generated signal with a second pair of predetermined signals representative of desired maximum and minimum weight-on-bit values; and

energizing said motor means so as to actuate said drill string until said first and second generated signals lie within the range determined by said first and second pairs of predetermined signals, respectively, whereby the torque imposed on the drill string and the weight-on-bit then lie within the desired minimum and maximum values.

25. In a drilling apparatus having a drill string and drill bit, the improvement comprising an electrohydraulic control system to maintain torque in the drill string substantially constant, the system including first means for supplying drilling fluid to the drill bit, second means for generating a signal indicative of a torque change, and third means responsive to the signal for controlling the supply of drilling fluid to the drill bit whereby to compensate for said torque change.

26. A method of controlling the feed rate of a drill string in a drilling apparatus, said apparatus having a drill bit secured to the end of said drill string and means for driving the same, the method comprising the steps of maintaining the torque ap-

plied to the drill string at a substantially constant predetermined value by generating a signal directly from said drill string with said signal representing the torque applied to the drill string, comparing the generated signal with a predetermined signal representative of a desired predetermined value and utilizing a difference between said generated signal and said predetermined signal to control hydraulic system to vary the weight imposed on the bit until the signal generated by said drill string corresponds with said predetermined signal so as to indicate that the actual torque imposed on the drill string is substantially equal to the desired predetermined torque.

27. A method of controlling the feed rate of a drill string in a drilling apparatus, said apparatus having a drill bit secured to the end of said drill string and means for driving the same, the method comprising the steps of maintaining the torque applied to the drill string at a substantially constant predetermined value by generating a signal directly from said drill string with said signal representing the torque applied to the drill string, comparing the generated signal with a predetermined signal representative of a desired predetermined value and utilizing a difference between said generated signal and said predetermined signal to control a flow of drilling fluid supplied to said drill bit until the signal generated by said drill string corresponds with said predetermined signal so as to indicate that the actual torque imposed on the drill string is substantially equal to the desired predetermined torque.

28. A method according to claim 27, further including the step of utilizing the difference between said generated signal and said predetermined signal to control concurrently a hydraulic system to vary the weight imposed on the bit and the flow of drilling fluid supplied to the bit until the signal generated by said drill string corresponds with said predetermined signal so as to indicate that the actual torque imposed on the drill string is substantially equal to the desired predetermined torque.