May 24, 1955 F. W. HILD 2,709,071

HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

Filed Dec. 3, 1949

7 Sheets-Sheet 1

FIG. VII

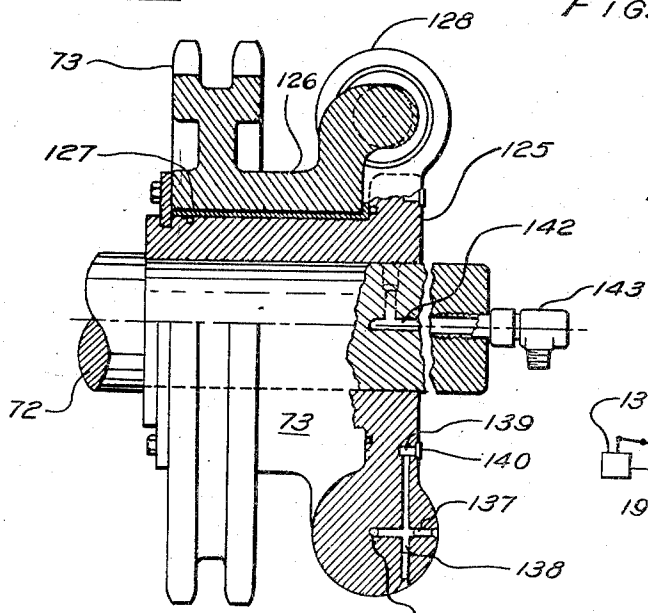


FIG. I

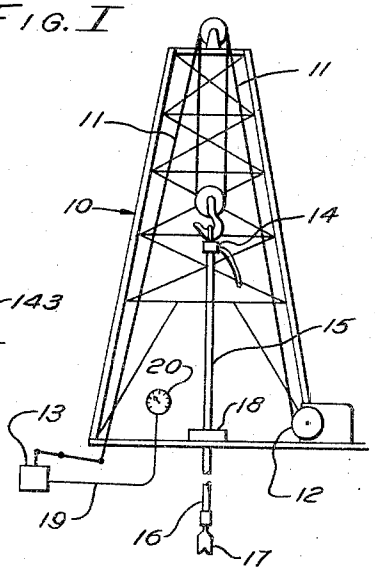


FIG. VIII

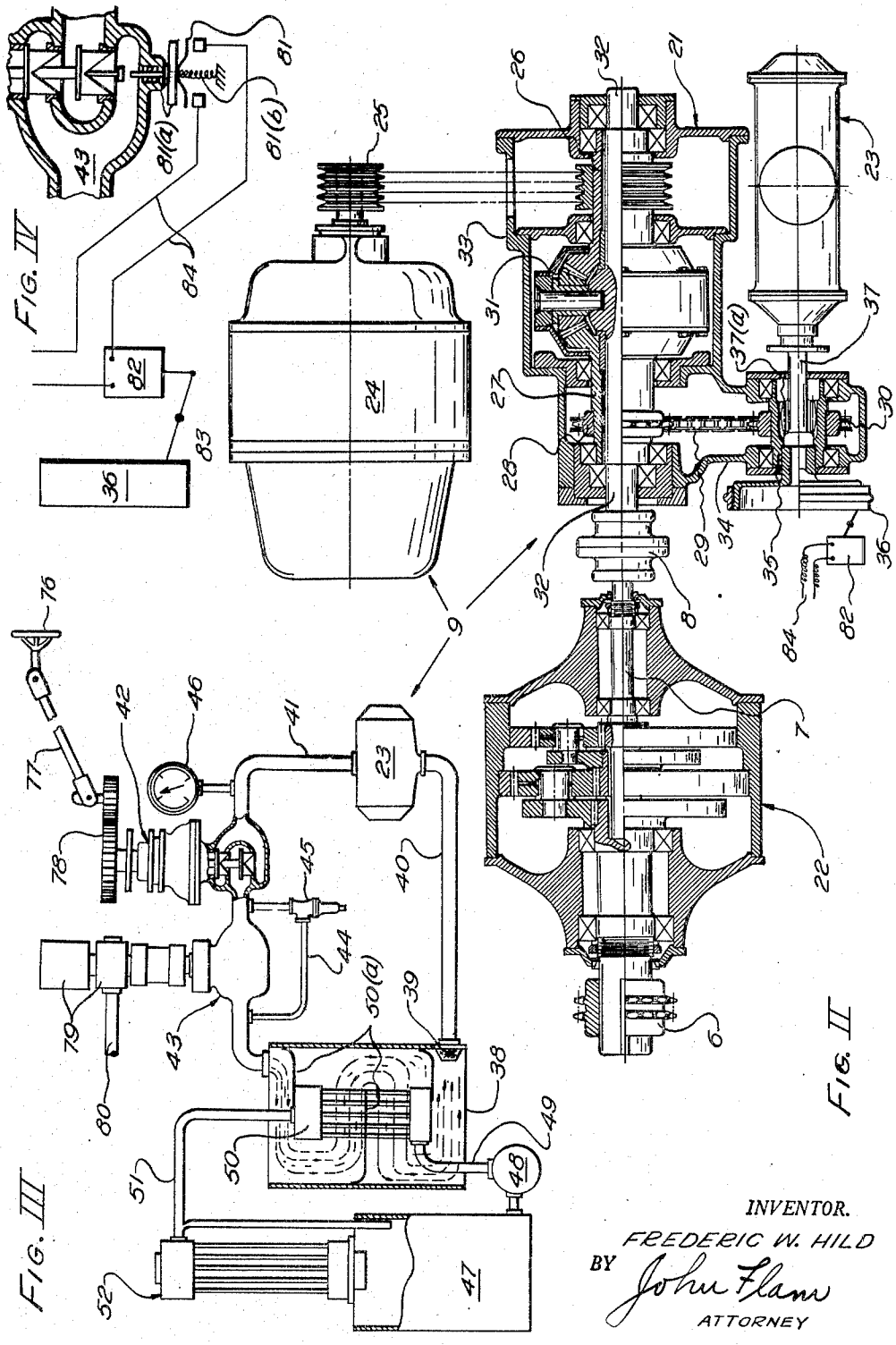
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HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

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HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

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FIG. V

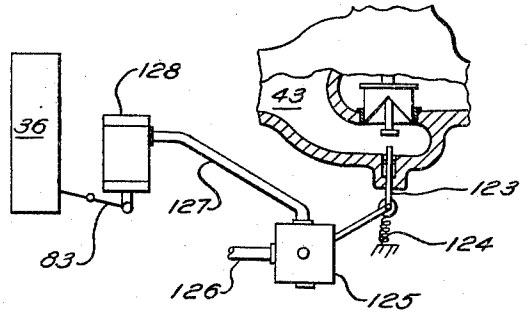


FIG. XII

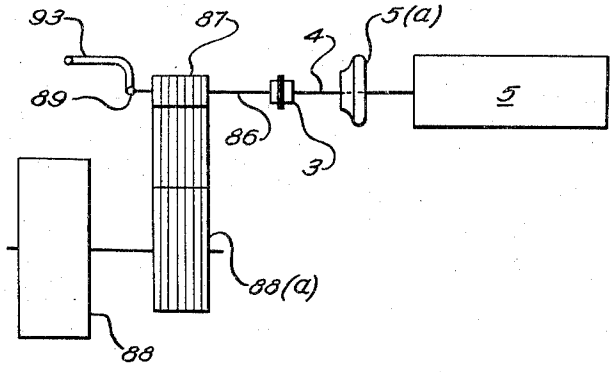
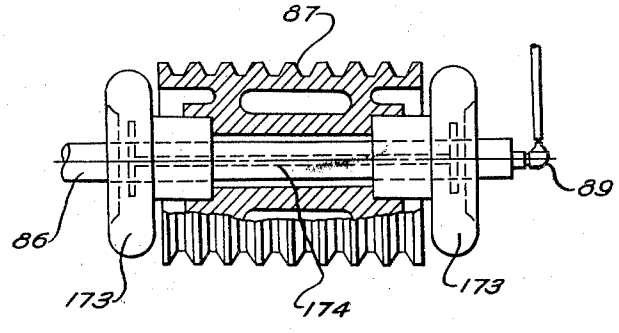


FIG. XI



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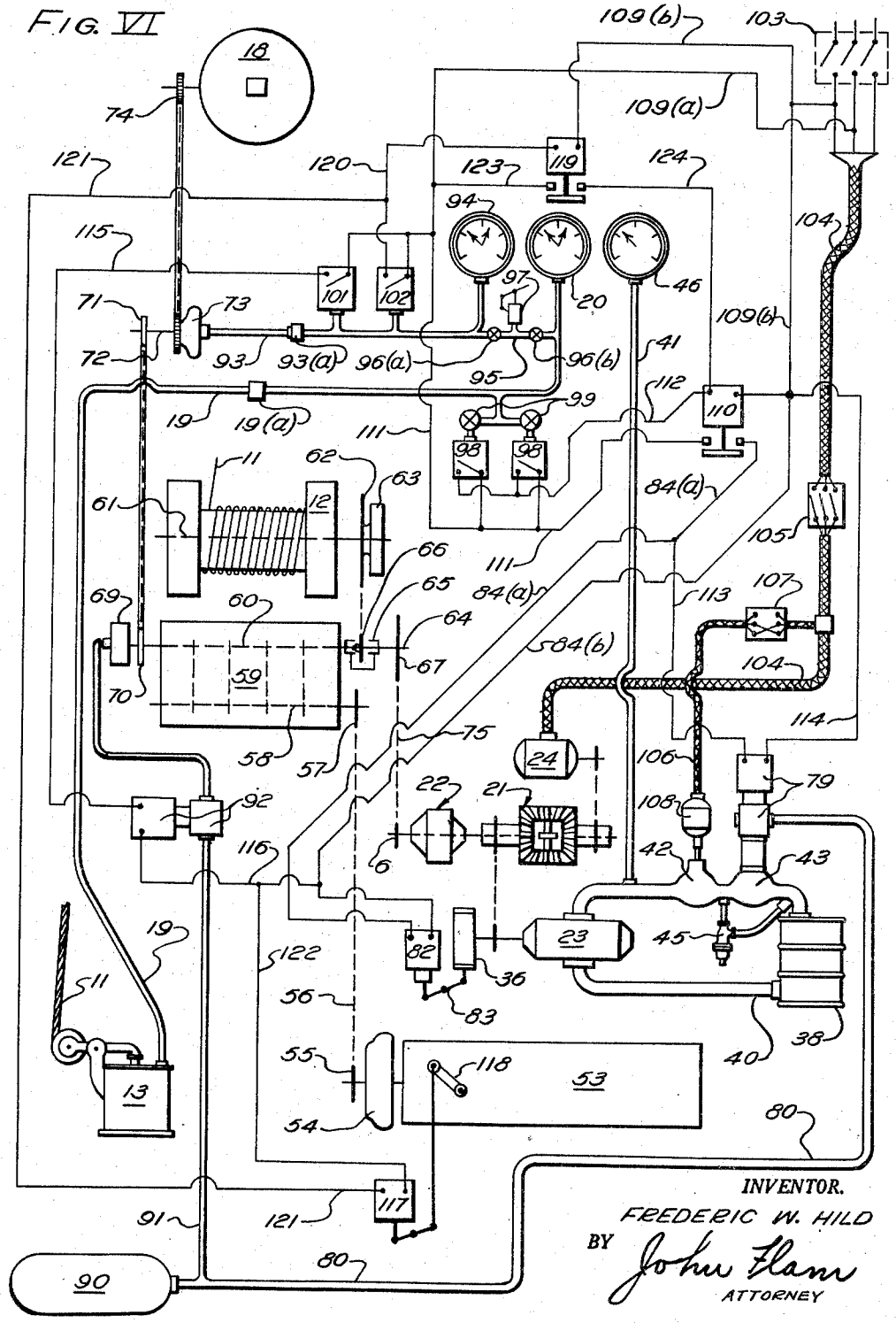
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FIG. VI



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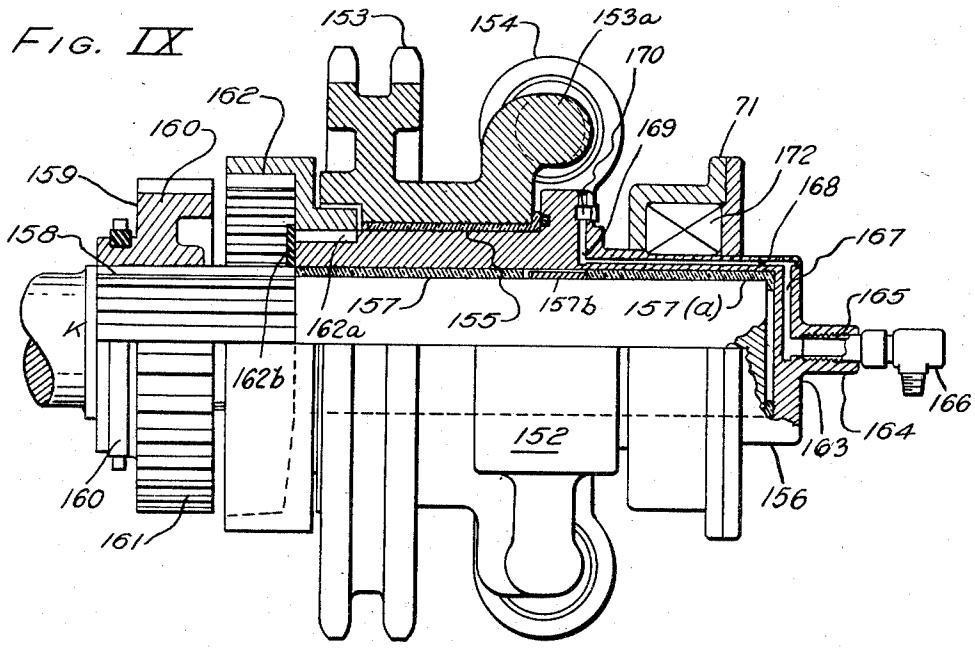
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HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

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FIG. IX



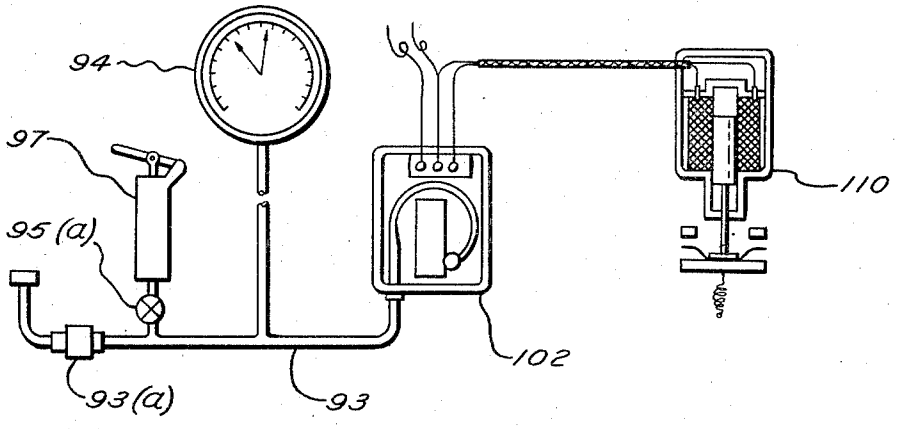


FIG. X

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HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

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FIG. XIII

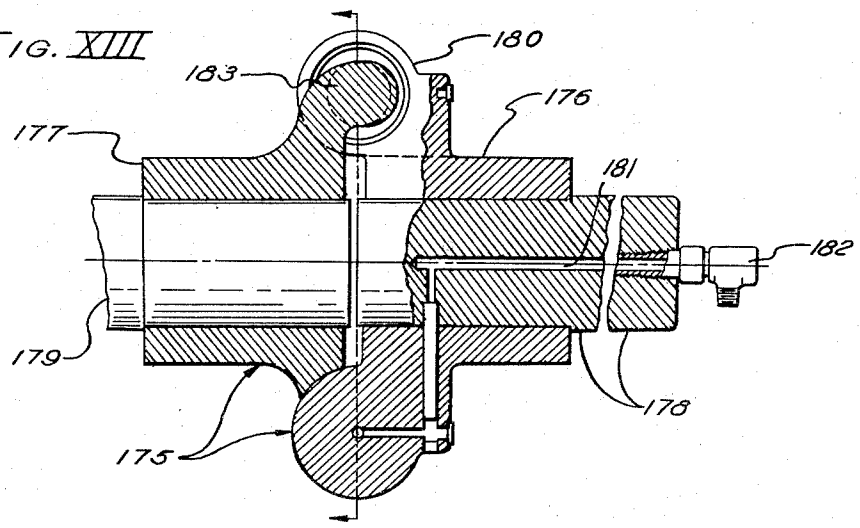
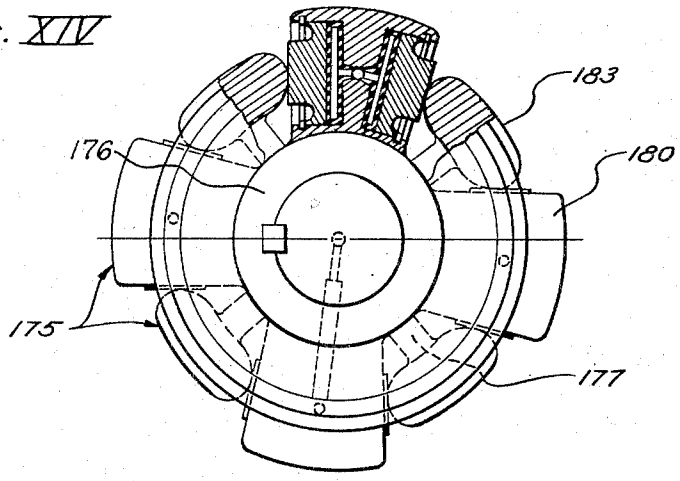


FIG. XIV



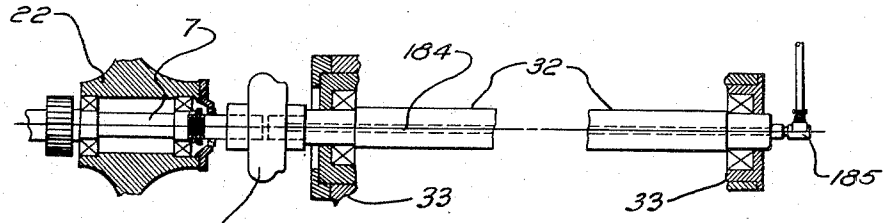


FIG. XV

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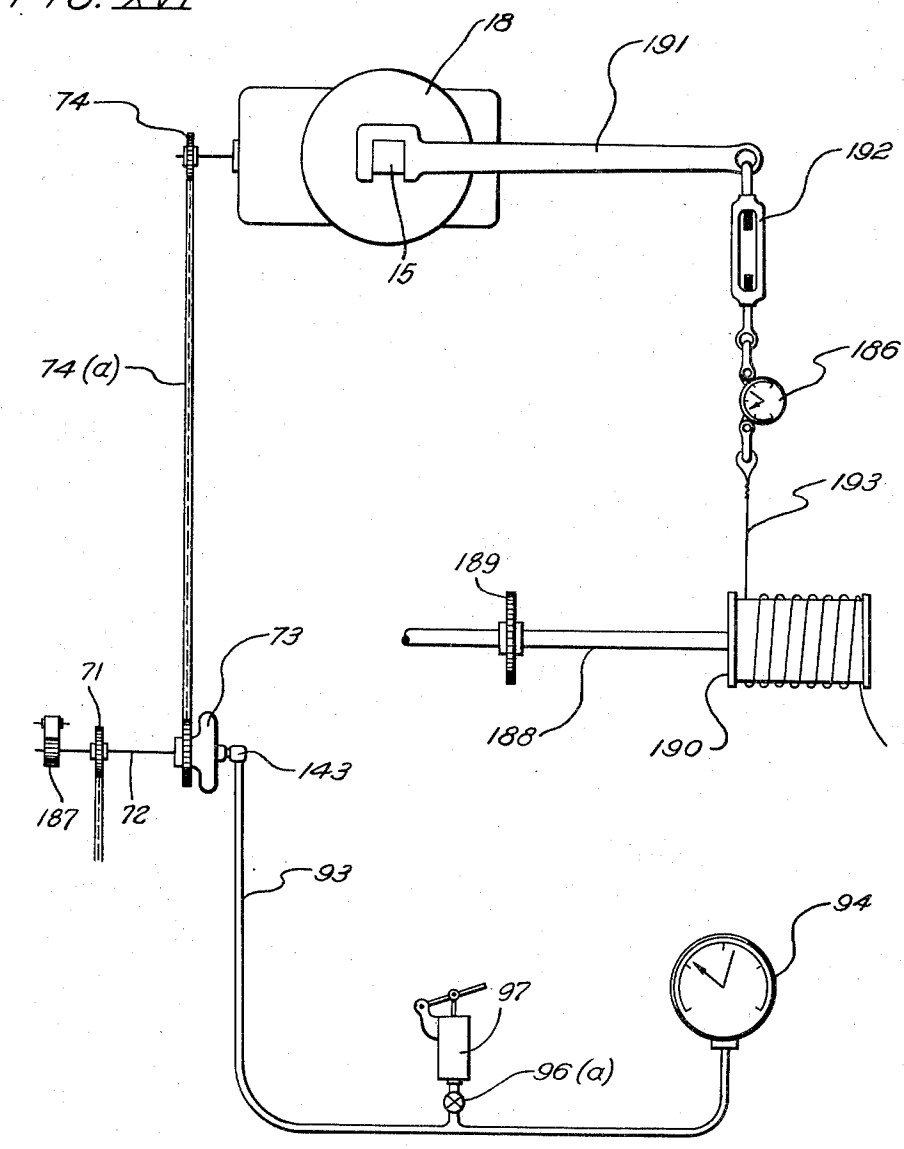
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FIG. XVI



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United States Patent Office 2,709,071 Patented May 24, 1955

2,709,071

HYDRO-GEAR RETRIEVING FEED APPARATUS FOR ROTARY DRILLING

Frederic W. Hild, Los Angeles, Calif.

Application December 3, 1949, Serial No. 130,997

9 Claims. (Cl. 255—19)

My invention relates to rotary well drilling apparatus and particularly to apparatus for controlling the feed of the drill. My present invention is an improvement of Drilling Control disclosed in U. S. Patent #2,136,356 issued to me on November 8, 1938.

This application is a continuation in part of my application Serial No. 107,674 for Automatic Drilling Control, filed July 30, 1949, now abandoned.

It is well understood that excessive torque or excessive weight on the drill when it occurs should be reduced or relieved as quickly as possible.

It is further understood that the conventional hand feed and each of nearly all the automatic feeds provides only one-way weight and feed control; that is, they can feed the drill downward only but cannot retrieve nor feed upwardly.

When the driller becomes aware of an overload condition on the drill, all that he can do with one-way feed is to apply the brakes on the hoist and stop its movement.

While this stops the feed at the surface, it does not stop the bit from continuing to feed downward into the formation because the lower portion of the drill string being in compression, the downward feed continues until the entire drill string is in tension, unless the driller sooner stops or declutches the engine so as to stop the rotary, and then reclutches the hoist and raises the drill off bottom. Then he must again declutch, stop the hoist and reclutch to start the rotary and lower the drill by means of the hoist brakes and resume drilling.

All these steps to rectify a single overload condition take appreciable time. As there are usually a number of such rectifications in the course of the driller's 8-hour tour, the aggregate of the time thus lost from actual drilling and the labor of the driller are both considerable; moreover such frequent rectification causes considerable wear and tear and maintenance expense on the equipment.

Excessive torque on the drill may occur from causes other than weight on the bit. It may be due to drill speed conditions combined with other causes and may not be reflected by the weight indicator.

It is an object of my present invention to provide a torque and weight control having a two-way retrieving feed, said control comprising a torque measuring rotative member and a differential gear and a pump with suitable valves.

This two-way retrieving feed is greatly superior, very much faster and far more economical than any form of one-way feed. This holds true whether the said two-way retrieving feed be used at a manually controlled feed or an automatic feed. In either case my invention, when feeding downward, automatically maintains the weight bit pressure within predetermined limit.

When used as an automatic two-way feed and upon occurrence of bit pressure in excess of such limit, the feed automatically reverses direction thus hoisting the drill to retrieve automatically and thereby reducing the excess pressure. Likewise, when excessive torque on the drill occurs due to other causes, the drill retrieves automatically and moves upward until the excess torque is reduced.

Upon such reduction of excess torque or bit pressure, the drill instantly moves downward again into cutting action against the formation and may again retrieve and return to feeding action repeatedly, until the formation is penetrated or until the driller readjusts the control setting. This he can do without stopping any of the apparatus or declutching.

This improved system of two-way feed and weight and torque control can be used with any type of motive power for drilling, such as the steam engine, internal combustion engine whether variable speed or governed speed or the constant speed electric motor A. C. or D. C.

Other objects, advantages and benefits of my invention will become apparent upon consideration of the following description and drawings herewith:

Figure I shows an oil derrick having apparatus of my invention.

Figures I, II, III, IV and V show apparatus comprising the two-way power feed.

Figure II shows in plan and part section a motor driven differential gearing which drives a pump and which is coupled to a reduction gear.

Figure III shows the valve control and circulatory system for the pump of Figure II.

Figure IV shows a fragmentary view in section of the shut-off valve of Figure III together with a schematic diagram of the solenoid operated brake controlled by the shut-off valve.

Figure V shows a modification of the arrangement of Figure IV.

Figure VI shows schematically and diagrammatically the drilling apparatus involved and the automatic control system for the torque and weight control and automatic two-way retrieving feed.

Figures VII to XV inclusive show various torque measuring devices embodying my invention.

Thus:

Figures VII and VIII show the torque sprocket keyed to the shaft.

Figure IX shows the torque sprocket rotatable on the shaft and adapted to engage a clutch.

Figure X shows an arrangement of devices adapted to connect with the torque sprocket or torque pulley or torque coupling for indicating and applying torque measurements for control purposes.

Figure XI shows the mud pump pulley embodying the torque measuring device of my invention.

Figure XII shows an engine driving a mud pump through the torque pulley of Figure XI.

Figures XIII, XIV and XV show the torque coupling adapted to connect two power transmitting shafts.

Figure XIV is a view in part section on the line AA of Figure XIII.

Figure XVI shows an arrangement including the replenisher pump of Figure VI and a conventional dynamometer for easy calibration of the pressure gauges.

In Figure I, the derrick with its crown block, travelling block and hook collectively are identified by the numeral **10**. The line **11** is reeved through the two blocks, the live end of the line is secured and wound on the hoist drum **12** and the dead end is secured to the anchor **13**. The drill string **14** which is suspended from the hook comprises the mud swivel, the kelly **15**, the drill pipe **16** and the bit **17**. The kelly, the drill pipe and the bit are rotated by the rotary machine **18**.

The anchor **13** embodies the hydraulic piston and cylinder principle for measuring the weight of the drill string disclosed in my Patent #2,003,078, issued May 28, 1935.

A tube 19 connects the anchor 13 to a weight indicator 20.

In Figure II the differential gear 21, the reduction gear 22 of conventional type, the screw pump 23 of well known type and the motive power member 24 form a group assembly which with the pump circulatory control members may be designated alternatively as "two-way power feed" or "retrieving two-way feed" and identified by the numeral 9.

The output shaft 32 of differential gearing 21 is connected by a coupling 8 to the input shaft 7 of reduction gear 22. A sprocket 6 is secured to the output shaft of reduction gear 22.

The motive power member 24 may be an internal combustion engine or it may be an electric motor either D. C. or A. C. and preferably constant speed. The capacity of engine or motor 24 is relatively quite small, being about 2½% to 3% of the usual total engine capacity for drilling 20,000 foot hole. Obviously the other members and parts of the two-way power feed 9 are in proportion to the small engine or motor 24. The same feed set 9 for maximum depth of hole can be used for any lesser depth.

The two-way power feed set 9 can lower, hoist or hold the rotating drill string stationary, free of the hoist drum brakes and separately from and independently of the main power plant engines. Thus the two-way power feed 9 may be incorporated into any rotary drilling rig.

The motor 24 has pulley 25 for belt driving the bevel sun gear 26 of the differential gearing 21. However, the engine or motor may be coupled to the sun gear 26 so as to form a straight line coupled assembly of the engine or motor 24, the differential gearing 21 with pump 23 and the reduction gear 22.

The bevel sun gear 27 has sprocket 28 which drives chain 29 to sprocket 30 for driving the pump 23.

The two sun gears engage the bevel planetary pinion gears 31 which are mounted on the output shaft 32 of the differential gearing 21. The sun gears and the shaft rotate separately of one another on suitable ball or roller bearings in the housing 33 of the gearing.

The housing 33 has an extension 34 which supports on suitable bearings the hollow coupling sleeve 35 on which is rigidly mounted the sprocket 30. The drum of solenoid operated friction brake 36 is firmly secured to the outer end of the coupling sleeve.

The shaft 37 of pump 23 projects axially into the hollow space of coupling sleeve 35. The end of the shaft and the sleeve have mating splines 37(*a*) in engagement and together they form a flexible coupling which compensates for misalignment.

In Figure III the oil circulatory system of pump 23 comprises oil tank 38 which supplies oil through an oil screen 39, suction pipe 40 into pump 23, the oil discharging therefrom through pipe 41 regulating valve 42, shutoff valve 43, and into tank 38. A pressure gauge 46 is connected to pipe 41.

The regulating valve 42 as its name implies, operates to restrict or increase the pump discharge very gradually and with fine sensitivity. It is usually hand operated but may also be power operated for remote control as shown in Figure VI.

The shutoff valve 43 has only two positions, full open and complete closure. The valve has a conventional compressed air cylinder containing a spring and a piston. The spring normally holds the valve in full open position. When compressed air is admitted into the cylinder the piston moves the valve to complete closure.

A small by-pass pipe 44 containing a small relief valve 45 by-passes the shutoff valve 43. The purpose of this by-pass is to prevent excessive hydraulic pressure in the pump 23 which might be caused by surging when the shut-off valve closes.

The cooling system for the circulating oil comprises water tank 47 which supplies cooled water to a small water pump 48, the water discharging through pipe 49 into oil cooler 50 which is immersed in the oil tank 38. The water flows from the cooler through pipe 51 into the upper tank of recirculating radiator 52, the water flowing downward through the cooling passages of the radiator directly into the water tank 47 which serves as the lower tank for the radiator. This recirculating radiator which needs no cooling fan is the same as disclosed in my co-pending application Serial #2,121, filed January 13, 1948.

Baffles 50–*a* in the oil tank 38 and associated with the oil cooler 50 cause the oil to pass twice through the spaces between the water tubes of the oil cooler as shown by the arrows which indicate the path of the circulating oil.

Referring to Figure VI engine 53 drives through air clutch 54, sprocket 55 and chain 56 to sprocket 57 which is on the end of input shaft 58 of the conventional speed change transmission 59 which has a plurality of sprockets and chains for speed-torque changes between its input shaft 58 and its output shaft 60.

The hoist drum 12 has shaft 61 on one end which is the usual low speed sprocket 62 with its airflex clutch 63 and on the other end is the usual high speed sprocket (not shown).

In axial alignment with the output shaft 60 at its right end is short shaft 64 which is adapted to be clutched to output shaft by a double clutch 65. Keyed to the short shaft is sprocket 66 which is chain connected to the low speed sprocket 62 on the drum shaft. Rotatably mounted on the other end of the short shaft 64 is sprocket 67 which may be clutched to the short shaft by the double clutch 65.

At the left end of the output shaft is the airflex clutch 69 which may engage sprocket 70 so as to chain drive sprocket 71 on rotary jack shaft 72. On this jack shaft is the torque sprocket 73 which chain drives sprocket 74 of the rotary machine 18.

It will be seen that engine 53 may drive the rotary machine 18 via the various gearing changes of transmission 59. Similarly when the double clutch 65 is moved to the left so that output shaft 60 and short shaft 64 are connected to each other, then the engines may drive the hoist 12 via transmission 59.

The sprocket 6 on the output shaft of the reducing gear 22 is connected by chain 75 to sprocket 67 on short shaft 64 of transmission 59.

When the double clutch 65 is shifted to the right, the short shaft 64 is disconnected from the output shaft 60 of transmission 59 and at the same time the sprocket 67 is clutched to the short shaft by the double clutch 65.

For manual control of the two-way power feed 9, the regulating valve 42 may be operated by a hand wheel 76 which is connected by a flexible shaft 77 through reduction gearing 78 to the valve stem. The flexible shaft may consist of universal joints and telescopic rods.

The gearing combined with the thread of the valve stem enables fine small valve movement and close regulation of the fluid flow through the valve 42.

The shut-off valve 43 as previously explained is operated to close by the piston of a conventional air cylinder containing a spring for return to open position. A solenoid air valve 79 which controls the operation of the cylinder and its piston is connected by pipe 80 to suitable compressed air supply 90.

Closure of the shut-off valve, will of itself cause the pump 23 to come almost to substantial stoppage and thereby similarly restrain the sungear 27 through the sprockets 28 and 30 and chain 29. During such time the torque on the pump may cause creeping and slow movement of the pump, the sungear and planetary output shaft 32.

In order to overcome and eliminate this pump slippage, the brake 36 is provided and utilized upon closure of the shut-off valve 43 to positively stop and hold sprocket 30, chain 29, sprocket 28 and sungear 27, so that no torque is transmitted to the pump 23 and both the pump and the valve 43 are freed of hydraulic pressure.

Figures IV, V and VI show three optional arrangements

for actuating the brake 36 upon closure of the shut-off valve 43.

As shown by Figure IV, the shut-off valve stem at its closure end may be extended to register with the push rod 81(*a*) of single pole electric switch 81 and to engage said push rod so as to push the switch to closure when the shut-off valve 43 is closed.

The two switch contacts are connected by wires 84 to the solenoid 82 which by means of linkage 83 applies the brake 36 when the shut-off valve 43 is closed. The push bar 81(*a*) of switch 81 is urged by spring 81(*b*) to open the switch as and when the shut-off valve 43 opens.

In Figure V which is a modification of Figure IV, the electric switch 81 and solenoid 82 of Figure IV are eliminated. Thus in Figure V, the shut-off valve 43 has push rod 123 which is linked to a spring 124 and to the operating handle of air valve 125. A pipe 126 connects the air valve to a source of compressed air such as tank 90 of Figure VI. A pipe 127 connects the air valve 125 to a conventional air cylinder 128 containing a spring for return action. The piston of the air cylinder is connected by linkage 83 to brake 36.

Thus when shut-off valve 43 closes, it pushes the push rod 123 and the handle of air valve 125 so as to admit compressed air into cylinder 128 and thereby apply the brake 36.

Referring to Figure VI consider the automatic weight and torque control system for the two-way retrieving feed 9.

The tank 90 supplies compressed air through pipe 80 to air valve 79 for the air cylinder of shut-off valve 43. Also pipe 91 leads from the tank 90 through air valve 92 to airflex clutch 69 for sprocket 70 of transmission 59.

The tube 19 which contains pulsation damper 19(*a*) conducts hydraulic oil from the anchor 13 to weight indicator 20. Likewise tube 93 which contains pulsation damper 93(*a*) connects the torque sprocket 73 to the torque gauge 94. The tubes 19 and 93 are connected by a tube 95 containing two small valves 96(*a*) and 96(*b*). A replenisher pump 97 is between the two small valves for supplying hydraulic oil to the fluid systems of anchor 13 and torque sprocket 73. The pump enables the driller to add hydraulic oil to the fluid system to overcome leakage therefrom. Moreover by means of a conventional traction dynamometer the driller can quickly test and calibrate the gauges.

A pair of pressure switches 98 of the Bourdon tube type are hydraulically connected to tube 19. The two pressure switches are hydraulically and electrically in parallel, but each may be cut out of the hydraulic circuit by a small valve 99. One of the two pressure switches is intended for moderate fluid pressures in tube 19 during drilling at moderate depths. The other pressure switch is intended for the higher pressures in tube 19 at greater depths.

Likewise the tube 93 is hydraulically connected to pressure switches 101 and 102.

The hydro-pneumatic system just described is interconnected by the electric control system which may be either A. C. or D. C.

For weight control and two-way automatic feed, main switch 103 admits three phase A. C. to wires 104 which lead as a cable through switch 105 to motor 24 of the two-way retrieving feed set 9. A cable 106 leads from cable 104 through reversing switch 107 to the small motor 108, which operates the regulating valve 42. A pair of bus wires 109(*a*) and 109(*b*) lead from the wires 104.

The single pole pressure switches 98 operate the solenoid switch 110 to actuate both the shut-off valve 43 and the brake 36. The electrical circuits for this are as follows:

The bus wire 109(*a*) is connected by wire 111 to one contact of each pressure switch 98 and to a switch contact of solenoid switch 110. The wire 112 connects the other contacts of the two pressure switches to one terminal of solenoid 110 the return wire of which connects to bus wire 109(*b*). The other switch contact of solenoid switch 110 is connected by wire 84(*a*) to a terminal of brake solenoid 82 the return wire 84(*b*) connecting to wire 109(*b*). A wire 113 connects 84(*a*) to a terminal of valve solenoid 79, the return wire 114 connecting to bus wire 109(*b*).

For torque control of the rotary drill, the pressure switch 101 is set to operate at higher fluid pressure than pressure switch 102.

The purpose and functioning of the high pressure switch 101 is to stop the rotary machine 18 quickly when the torque on the drill is at or near the maximum safe limit of torsional strength of the weakest member of the drill string. Therefore the pressure switch 101 operates only the solenoid valve 92, thereby opening airflex clutch 69 and cutting off power to the rotary machine 18.

Thus one contact of pressure switch 101 is connected to wire 111 and therewith to bus wire 109(*a*). The other switch contact is connected by wire 115 to a terminal of solenoid valve 92, the other terminal of which being connected by wire 116 to wire 84(*b*) and therewith to bus wire 109(*b*).

The purpose and function of the low pressure switch 102 is to reduce the speed of the rotary machine 18 when high speed of said machine is a factor of excessive torque. At the same time the pressure switch 102 operates to close the shut-off valve 43 thereby simultaneously causing retrieval of the drill.

The pressure switch 102 which is set at lower fluid pressure, operates solenoid 117 which is connected by suitable linkage to the throttle valve 118 of main engine 53, thereby to reduce the speed of the engine. Also the pressure switch 102 operates relay switch 119 and therewith the solenoid switch 110 which, as just described, operates the shut-off valve 43 and the friction brake 36 of the two-way retrieving set 9. The electrical circuits are as follows:

One contact of pressure switch 102 is connected to wire 111 and therewith to bus wire 109(*a*). The other contact is connected by wire 120 to a terminal of the solenoid of relay switch 119, the other terminal of which is connected to bus wire 109(*b*). The same wire 120 is connected by wire 121 to a terminal of solenoid 117, the other terminal of which is connected by wire 122 to wire 116 and therewith to 84(*b*) which connects to 109(*b*). The other switch contact of the relay is connected by wire 124 to wire 112 and a terminal of solenoid switch 110, the other terminal of which, as previously explained, connecting bus wire 109(*b*).

Figures VII and VIII show the torque sprocket 73. This comprises torque member 125 and load member 126. The load member contains a sleeve bearing 127 both being concentrically mounted on the torque member so as to permit slight initial rotative adjustment between the members 125 and 126. The torque member 125 is keyed to the shaft 72.

The torque member 125 has a plurality of projecting radial arms 128, each arm containing a pair of cylinders 129 and 130 respectively which are connected to each other by a hole 131. Seated in the cylinders are the hollow flexible diaphragms 132 and 133. Each diaphragm has a hollow stem fitting into the hole 131. Also in the cylinders and pushing against the diaphragms are the pistons 134 and 135 respectively, which are retained in the cylinders by the snap rings 136.

Another hole 137 in the arm 128 intercepts the hole 131 and is itself intercepted by the hole 138 which leads from a closed concentric channel 139, the closure of which is effected by welding the ring 140 to body of torque member 125. A hole 141 extends radially from channel 139 in the body of torque member 125, and into the shaft 72 into a hole 142 which is bored in the axis of the shaft from the outer end. The hole 142

is threaded to receive the rotor seal **143** which is of well known conventional type. A taper plug **144** closes the outer end of hole **141**.

Next adjacent the radial arm **128** just described is radial arm **128**(*a*) which contains diaphragms **145** and **146** and the pistons **147** and **148**. All the other arms are likewise provided and have similar holes for fluid flow so that all of the diaphragms are in free fluid communication with one another and with rotor seal **143**.

The load member **126** has at one end the teeth of sprocket **73** and at the other end the intercepting arms **149** which project into the spaces between the radial arms **128** of torque member **125**. Each intercepting arm has a head **150** having end faces **151** and **151**(*a*) in pressure contact respectively with the piston **135** of radial arm **128** and piston **147** of radial arm **128**(*a*). In like manner all the intercepting arms of sprocket load member **126** are in pressure contact with the pistons of the radial arms of torque member **125**.

It is manifest that upon filling the diaphragms and the fluid passages with an incompressible liquid such as water or oil, hydraulic pressure applied to the liquid will have uniformly the same pressure in all of the diaphragms and these will transmit equally the same force through the pistons to the intercepting arms of sprocket load member **126**.

Torque on the sprocket as by a chain pull in either direction will be transmitted to torque member **125** and create hydraulic pressure in the fluid system which will be a definite measure of said torque and can be indicated by a pressure gauge.

Likewise torque caused by the shaft rotating in either direction will be transmitted by torque member **125** to the sprocket member **126** and this torque will be shown by the pressure gauge.

With the fluid system under pressure there will be no lost motion between the members **125** and **126**. There may be a slight degree of resilience which would help to absorb shocks. Thus there will be no hammering by either member against the other. Referring to Figure IX the torque sprocket **152** is rotatable on shaft K and is arranged to engage a clutch. This torque sprocket has the sprocket load member **153** and the torque member **154**. Sprocket member **153** is integrally joined to torque member **153***a*. A sleeve bearing **155** between them permits slight rotative adjusting movement between the two members in the same manner and for the same purpose as described for torque sprocket **73**.

Torque member **154** has a tubular extension **156** with a closed end extending over the end of shaft K and enclosing it. Sleeve bearings **157** and **157**(*a*) inserted into the torque member **154** and its tubular extension **156** have bearing fit on the shaft so that the torque sprocket **152** may rotate on shaft K. Spacer sleeve **157***b* is placed intermediate the sleeves **157** and **157**(*a*).

At the other end of torque sprocket **152** the shaft K has splines **158** for engaging the mating inner splines of clutch **159** which is slidable axially along the shaft. The clutch has an external circular groove containing the shifting ring **160**. The clutch **159** has outer splines **161**.

Secured to torque member **154**, as by key **162***a*, concentrically around the splined portion of **158** shaft K is the cylindrical clutching member **162** which has inner splines adapted to receive in mating engagement the outer splines **161** of clutch **159**. The spacer ring **162***b* is joined to the inner face of member **162**.

Thus by shifting the clutch **159** into an engagement with the torque member **154**, the torque sprocket **152** will be locked into engagement with shaft K so that both will then rotate together.

Projecting axially from the closed end **163** of tubular extension **156** is the stem **164** which has a threaded hole **165** for receiving the rotor seal **166**. Several holes **167** are drilled radially in the end **163** to intercept an equal number of holes **168** drilled in the cylindrical wall of tubular extension **156**. The holes **168** intercept a like number of radial extending holes **169** in the torque member **154** communicating with circular channel **170** which is the equivalent of channel **139** of torque sprocket **73**.

A pedestal bearing **171** containing roller bearing **172** carries the torque sprocket **152** at the tubular extension **156** in which the shaft K is carried. The other end of the shaft is carried in a suitable bearing (not shown).

The members **154** and **153** of torque sprocket **152** have radial arms and intercepting arms and diaphragms, pistons and fluid channels which are substantially the same as the corresponding members of torque sprocket **73**.

Inasmuch as the lever arm factor of torque on the sprocket is a constant, the gauge pressure readings can be calibrated to read torque directly. Thus when torque sprocket **73** or **152** is subjected to chain pull while stationary or rotating, the torque on the sprocket may be read or recorded directly on the pressure gauge with reasonable, practical accuracy.

Referring to Figure X, this shows the external fluid system which cooperates with the internal fluid system of the various torque devices of Figures VII, IX, XI and XII for indicating their respective torque manifestations and for applying them for control purposes.

The external system includes the tube **93** or its equivalent which is adapted to be connected to any of the said torque devices. The tube has the pulsation damper **93**(*a*) and is connected to a replenisher pump **97**, the pump cutoff valve **95**(*a*), the torque indicator gauge **94** and the fluid pressure switch **102**. The fluid pressure switch may be electrically connected by wires to a source of electricity and to a control device such as the solenoid relay switch **110**. It is understood that every rotary drilling rig includes one or more mud pumps driven by suitable motive power for circulating mud fluid to carry out the drill cuttings and for other needful purposes.

Referring to Figure XII, the engine **5** drives through friction clutch **5**(*a*) to the power shaft **4** which is connected by the coupling **3** to the countershaft **86** on which is mounted the torque pulley **87**.

The pump **88** has pulley **88**(*a*) which is belt driven by torque pulley **87**.

Considering now Figure XI and VII: by eliminating the sprocket teeth from torque sprocket **73** of Figure VII, we have the torque hub **173** which is adapted to have mounted upon it a gear, a sprocket, a pulley or other rotating power transmitter.

Figure XI shows the torque pulley **87** rigidly mounted on a pair of torque hubs **173**, each of which is keyed onto counter-shaft **86**. A hole **174** in the axis of the counter-shaft provides a common fluid passage connecting the fluid systems of the two torque hubs with rotor seal **89** on the outer end of the counter-shaft **86**. This fluid passage equalizes the fluid pressure of the two torque hubs.

As described in Figure X, the rotor seal **89** may be connected by a tube equivalent to tube **93** to a torque indicator gauge and to a pressure switch and by the latter to other control devices.

In the mud pump operation during drilling, if the bit becomes plugged, then mud circulation ceases, building up high pressure (hydraulic) in the drill pipe, the swivel, the mud hose and the pump. The pump has a pressure gauge but generally the first indication to the driller and the crew is when the pump begins to labor.

This is an emergency job which calls for fast action by the crew, such as starting a second pump, adjusting the mud valves, and when other important operations including stopping the rotary to change clutches, etc., so as to hoist the drill above the cuttings which accumulate at the bottom of the hole, augmented by the added settlings from above when circulation is stopped.

In conjunction with the drilling control system herein

described, the torque pulley 87 for the mud pump together with pressure switch and torque gauge will be valuable and helpful in this emergency.

This pressure switch may be connected so as to operate relay switch 110. The fluid switch should be set to close at a torque limit fluid pressure corresponding to a predetermined mud pressure below the setting of the mud relief valve.

Then when the bit becomes plugged, the increasing torque on the pulley may reach the predetermined torque limits, whereupon the pressure switch closes and operates tandem switch and causes the rotating drill to be hoisted off bottom and above the denser mass of settled cuttings.

This action does not interrupt the rotation of the drill and is manifestly much faster and time saving than the methods currently used.

Figures XIII and XIV show the torque coupling 175, which comprises the torque hub 176 and the load hub 177. The torque hub 176 is securely keyed to shaft 178 and the load hub 177 is similarly secured to shaft 179.

The torque hub 176 has radial arms 180 containing pistons, diaphragms and fluid chambers which are substantially the same as the corresponding members in torque member 125 of the torque sprocket 73.

The fluid channels include the hole 181 which extends axially from the torque hub 176 through shaft 178 and into which the rotor seal 182 is secured.

The load hub 177 has intercepting arms 183 which mate and between the radial arms 180 of the torque hub 176 in similar manner as described for torque sprocket 73. The torque coupling 175 mechanically is a flexible coupling which automatically compensated for appreciable misalignment of the two shafts 178 and 179.

The rotor seal 182 may be connected by a tube such as 93 to a torque gauge and control devices as described for Figures X and XI. Thus the torque coupling 175 for either direction of load or rotation provides practical means for torque determination and torque control of apparatus driving or driven by either of the shafts 178 and 179.

Referring to Figures II and XV: the torque coupling 175(*a*) may be substituted for coupling 8 which connects the output shaft of the differential gear 21 to the input shaft 7 of the reduction gear 22.

This is shown in Fig. XV in which shaft 32 is supported in suitable bearings in the differential housing 33 and the shaft 7 is likewise supported in the frame of reduction gear 22. The two shafts are connected by the torque coupling 175(*a*). A hole 184 extends axially from the torque coupling 175(*a*) through shaft 32. A rotor seal 185 is secured into the hole 184 and may be connected by a tube such as 93 of Figure X to a gauge such as gauge 94. The fluid pressure indications on the gauge will be proportional to the suspended weight of the drill string.

Weight control—two-way retrieving feed

Referring to Figures I, II and VI, for the above service the diaphragm of anchor 13 is the pressure source of the fluid-electric control system of Figure X and Figure VI. The hydraulic pressure in the said diaphragms is proportional to the weight of that portion of the weight of the drill string that is in tension and this is shown by the weight indicator 20.

The operation of the weight indicator is generally well known, but it may be recalled that the gauge has two hands, one active hand which is moved by the Bourdon tube, and a second or maximum hand which is pushed or carried in the clockwise direction by the active hand, both hands coinciding when the entire drill string is suspended off bottom and in tension.

As the bit presses against bottom, the tension lessens and the fluid pressure in the gauge dimnishes correspondingly so that the active hand moves back (counterclockwise), the maximum hand remaining in the maximum position. The angular difference between the two hands indicates the weight on bottom.

For the drilling cycle beginning with all the apparatus at rest, the hoist drum 12 being held stationary by its brakes, the driller moves double clutch 65 to the right, thereby engaging sprockets 66 and disconnecting short shaft 64 from transmission 59. He may then close airflex clutch 63 thus locking drum sprocket 62 to the hoist drum 61 which by means of the intervening sprockets, chains and gearing holds the planetary shaft 32 of differential 21 stationary.

It is well understood that in the bevel differential such as 21, when the two sun gears rotate in opposite directions at equal speed, the planetary shaft is stationary, and when the sun gears rotate at different speeds, the planetary shaft rotates at one half the difference of the sun gear speeds and in the direction of the greater speed. Also that torqu transmitted to the planetary pinions divides equally to the two sun gears.

During operation, there is never any reversal or change of rotative direction by the sun gears 26 and 27 and the pump 23. Movement of the drill string upward or downward is controlled by the regulating valve 42 and the shut-off valve 43.

Upon starting motor 24 the sun gears 26 and 27 rotate in opposite directions at equal speeds determined by the speed of motor 24. This condition continues as long as shaft 32 is held stationary.

Assume the regulating valve 42 in full open position, then there is slight resistance to the pump discharge and therefore slight resistance by the pump 23 and slight torque to the hoist 12. This torque would be in the direction tending to rotate the hoist drum 12 to hoist the drill string.

Upon gradually restricting the pump discharge by gradually moving regulating valve 42 toward closure, the resistance of pump 23 increases, and the power torque to hoist 12 likewise increases until this power torque attains a value equal to the weight torque to the hoist in the opposite direction due to the suspended weight of the drill string; that is, until these opposing torques balance each other. At that time the regulating valve 42 will be partly open in an intermediate position.

The driller can determine the progress of increasing or diminishing torque when the shaft 32 is stationary by correlating the reading of weight indicator 20 which indicated the torque due to the suspended weight of the drill string, and the readings of the pump pressure gauge 46 which indicates a proportion of the power torque to the hoist 12.

Better and more comprehensive torque indications, than those of pump pressure gauge 46, would be obtained if sprocket 6 of Figure II were a torque sprocket 73(*a*) such as in Figures VII and VIII, or if the coupling 8 be replaced by a torque coupling 175(*a*) such as shown by Figures XIII, XIV and XV.

For either the torque sprocket 73(*a*) or torque coupling 175(*a*) the readings of their respective torque gauges by appropriate calibration, can be compared directly with the weight indicator readings at any time whether the planetary shaft 32 be stationary or rotating.

When the gauges show that the power torque to the hoist 12 about balances the weight torque, the driller then releases drum brakes whereupon the drill string will be held so that movement of it up or down if any will be extremely slow, because the R. P. M. of shaft 32 is one-half the difference of the respective R. P. M. of the two sun gears 26 and 27; and furthermore the R. P. M. of hoist shaft 61 will be further greatly reduced by the intervening gearing, chains and sprockets.

For feeding the drill downward, the rotary machine 18 being in operation, the driller moves the regulating valve 42 toward "open" until he decides that the de-

sired weight on bottom or the desired rate of downward feed is reached. The drilling then proceeds automatically.

Referring again to Figure VI, the pressure switches **98** having been set for their predetermined fluid pressures, the main switch **103** may now be closed.

When a drilling condition causes excessive bit weight on bottom, the pressure switch **98** immediately closes thereby closing shut-off valve **43**, and almost immediately the hoist drum **12** reverses and hoists the drill string so that the bit weight swiftly diminishes toward or to zero, whereupon the pressure switch opens and the hoist drum **12** at once feeds the drill downward again and drilling resumes. The total action just described is extremely fast and obviously the retrieval and resumption of feed being great, many times faster than is possible with hand feed or any automatic one-way feed.

Change from high bit pressure to lower pressure and back again to high may occur repeatedly and continue until the formation is drilled through, or until the driller decides the condition calls for change of bit, or a reduction of allowable bit weight or rate of downward feed. The driller can do this very easily and quickly by merely opening the regulating valve **42** slightly more.

It is possible that the changes from excess bit pressure to lower pressure and again to high pressure may occur without causing the bit to break contact against the formation; because the compression in the drill string which causes bit pressure, decreases at the instant that retrieval begins.

Nearly all instances of excessive pressure are accompanied by torque overload of the drill pipe. But such overloads are quickly caught in their beginning and quickly reduced or eliminated by the swift acting weight controlled two-way retrieving feed.

The driller can see the above described changes of bit pressure by the readings of the weight indicator **20** and also by the pump gauge **46**. Moreover the torque gauge **94** will show the changes of torque on the drill whether due to weight of the bit on bottom or to other causes herein described.

Rotary torque control

Excessive torque on the drill pipe may occur from causes other than excessive bit pressure against the formation being drilled.

It has been shown by tests that when rotating the drill with the bit off bottom at customary speeds, the torque on the drill varies approximately as the square of the speed. Thus when rotary table speed is increased, the torque on the drill builds up very rapidly without gauge indication of such torque increase.

Also when the axis of the rotating drill is not straight but is curved, then the torque on the drill for cutting the formation is further increased by the increased friction of the drill rubbing against the walls of the hole. Moreover, the repeated reversals of stress from tension to compression to tension continuously during each revolution of the drill pipe add to the torque on the drill. Such combinations of torque may become excessive and should be controlled and limited.

My invention provides means for co-ordinating and combining adequate torque control with the aforesaid two-way power feed, thereby providing correct comprehensive automatic control and regulation of the drill.

The pressure switches **98** being responsive to the reduction of weight of the suspended drill string, are set to close upon the attainment of predetermined limits of decrease of the fluid pressure in tube **19** of anchor **13**.

On the other hand, the pressure gauges **101** and **102** being responsive to increases of torque on the drill, they therefore are set to close upon attainment of predetermined limits of increase of fluid pressure in tube **93** of torque sprocket **73**.

Upon closing of only one of the pressure switches **98**, **101** or **102**, then immediately the two-way power retrieving set **9** operates to retrieve and hoist the drill.

Referring to Figure VI when pressure switch **102** closes, it energizes relay **110** thereby energizing solenoid **79** which closes shut-off valve **43** and applies brake **36**, whereupon the two-way power retrieving set **9** operates to retrieve the drill. At the same time relay switch **110** energizes solenoid **117** which thereupon moves the throttle **118** of engine **53** to reduce the engine speed and thereby reduce the speed of rotary machine **18**.

When pressure switch **101** closes it energizes the solenoid of air valve **92** to open airflex clutch **69** whereupon sprocket **70**, rotary machine **18** and the drill string **14** all cease rotating.

The operation of any of the several pressure switches in no way nor at any time interferes with or cancels the operation of the other pressure switches, but instead, they all co-operate to provide comprehensive control and correct automatic regulation of the drill.

Referring to Figure XVI, this shows an arrangement utilizing the replenisher pump **97** and a conventional tension dynamometer for occasionally testing and recalibrating the fluid system of torque sprocket **73** and torque gauge **94**, without disconnecting any part of the system or any of the apparatus. All that is required is to hold stationary the shaft **72** onto which the torque sprocket **73** is secured. There are various ways of doing this. A simple means would be a pawl and ratchet **187** on the shaft as shown.

The usual drilling rig has a cathead shaft such as **188** having a sprocket **189** and a cathead **190**. The sprocket is chain connected to a shaft of transmission **59** and driven thereby. A member of the drill string such as kelly **15**, is held in the rotary machine **18** so that they both would rotate together. The kelly **15** is gripped by a lever **191**.

A tension measuring line comprising turn buckle **192**, tension dynamometer **186** and line **193**, connect the lever **191** to cathead **190** in such manner that when the line **193** is snubbed around the slowly rotating cathead, a pull can be exerted on lever **191**.

Then with pawl and ratchet **187** set to hold shaft **72** stationary, the pull through the tension line and dynamometer **186** will be transmitted to the torque sprocket **73** which is held stationary. The lever **191** and the tension line should be substantially square (90°) with each other. The turnbuckle **192** will facilitate establishing the desired tension on dynamometer **186**.

By means of the replenisher pump **97** and valve **96**(*a*), hydraulic oil may be forced into the fluid system so that the torque gauge **94** will show torque readings caused by the torque sprocket **73** coresponding to the readings of dynamometer **186**.

Having described several specific embodiments of my invention, I claim:

1. In a feed control system for a rotary drill string having a hoisting and lowering mechanism: means for rotating said string; a source of rotary motion for operating the mechanism; differential gearing having a planetary gear element, and two sun gear elements; one of the elements being in driving relation to the hoisting mechanism; another element being in driving relation to the source of motion; a variable resistance load connected to the third of said elements; means responsive to a reduction in the load imposed by the drill string on the mechanism for increasing the resistance of said variable resistance load; and supplemental means responsive to an increase in the resistive torque of the drill string for restraining movement of that element which is connected to the variable resistance load.

2. In a rotary system for a drill string having a hoisting and lowering mechanism as well as means for rotating the string: a source of rotary motion for operating the mechanism; differential gearing having a planetary element and two sun gear elements; one of the elements

being in driving relation to the mechanism; another element being in driving relation to the source of motion; a variable resistance load connected to the third of said elements; means responsive to an increase in the resistive torque of the rotary motion of the string for increasing the resistance of said variable resistance load; and supplemental means responsive to an increase in the resistive torque of the drill string for restraining movement of that element which is connected to the variable resistance load.

3. In a rotary system for a drill string having a hoisting and lowering mechanism as well as means for rotating the string: a source of rotary motion for operating the mechanism; differential gearing having a planetary element and two sun gear elements; one of the elements being in driving relation to the mechanism; another element being in driving relation to the source of motion; a variable resistance load connected to the third of said elements; said means including a rotary drive for the string; a liquid pressure device interposed in the drive to transmit a torque to rotate the string in which liquid pressure device the pressure increases as the torque for rotating the string increases; and means responsive to an increase in said pressure for increasing the resistance of said variable resistance load.

4. In a rotary system for a drill string having a hoisting and lowering mechanism as well as means for rotating the string: a source of rotary motion for operating the mechanism; differential gearing having a planetary element and two sun gear elements; one of the elements being in driving relation to the mechanism; another element being in driving relation to the source of motion; a variable resistance load connected to the third of said elements; said means including a rotary drive for the string; a liquid pressure device interposed in the drive to transmit a torque to rotate the string in which liquid the pressure increases as the torque for rotating the string increases; means responsive to an increase in said pressure for increasing the resistance of said variable resistance load; and supplemental means responsive to an increase in the resistive torque of the drill string for restraining movement of that element which is connected to the variable resistance load.

5. In a rotary drilling system for a drill string: a source of rotary motion for rotating the string; means for adjusting the speed of said source; means transmitting torque between the source and the drill string; said transmitting means including a liquid pressure device subjected to the transmitted torque, the liquid pressure therein increasing with an increase in torque; and means responsive to an increase in pressure in the device for operating the adjusting means to reduce the speed of the source.

6. In a rotary drilling system for a drill string: a source of rotary motion for rotating the string; means for adjusting the speed of said source; means transmitting torque between the source and the drill string; said transmitting means including a liquid pressure device subjected to the transmitted torque, the liquid pressure therein increasing with an increase in torque; means responsive to a predetermined increase in pressure in the device for operating the adjusting means to reduce the speed of the source; and supplemental means, including a coupling member, responsive to a further increase in pressure in the device for disconnecting the source of motion from the drill string.

7. In a rotary drilling system for a drill string: a source of rotary motion for rotating the drill string; a transmission mechanism operated by the source; means connected to the transmission mechanism for rotating the drill string; said means including a hydraulic device for transmitting a torque to the drill string, and in which the pressure increases as the torque of the drive increases; a coupling for connecting and disconnecting the drive to the drill string; and means responsive to an increase in the hydraulic pressure for operating the coupling to disconnect the drive.

8. In a rotary drilling system for a drill string: a source of rotary motion for rotating the drill string; a transmission mechanism operated by the source; means connected to the transmission mechanism for rotating the drill string; said means including a hydraulic device for transmitting a torque to the drill string, and in which the pressure increases as the torque of the drive increases; means for adjusting the speed of the source; and means responsive to an increase in the hydraulic pressure for operating said adjusting means to reduce the speed of said source.

9. In a rotary drilling system for a drill string: a hoist mechanism for raising and lowering the string; a differential gearing having a planetary element and two sun gear elements, one of the elements being in driving relation to the hoist mechanism; a source of motion in driving relation to another element; a pump system having a circulatory path for the liquid and connected to the third element; a valve controlling the flow of liquid through the path; means for rotating the string; a brake for the third element; and means, responsive to an increase in the resistive torque of the rotating means, for operating the valve toward closed position and for applying said brake.

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