

[54] **LOGGING-WHILE-DRILLING TOOL**

[75] Inventors: **Bobbie Joe Patton; Maurice Jack Prior**, both of Dallas; **James Howard Sexton**, Duncanville; **Vasel Roy Slover, Jr.**, Irving, all of Tex.

[73] Assignee: **Mobil Oil Corporation**, New York, N.Y.

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[51] Int. Cl. **G01v 1/40**

[58] Field of Search **340/18 NC, 18 LD**

[56] **References Cited**

UNITED STATES PATENTS

3,309,656	3/1967	Godbey.....	340/18 R
2,700,131	1/1955	Otis et al.....	340/18 LD
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Primary Examiner—Maynard R. Wilbur

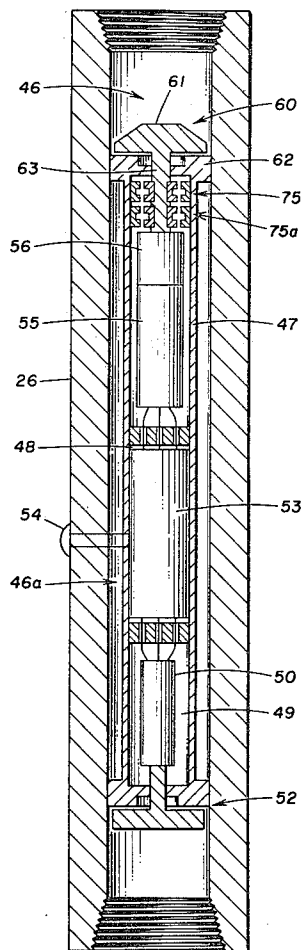
Assistant Examiner—N. Moskowitz

Attorney, Agent, or Firm—A. L. Gaboriault; Drude Falconer

[57] **ABSTRACT**

A logging-while-drilling tool which is adapted to be positioned within the drill string of a well drilling apparatus. The tool has a turbinelike, signal-generating valve which opens and closes at a rate to generate a pressure wave signal in the drilling fluid which is representative of a measured downhole condition. The tool includes a means for both biasing the valve toward an open position and holding it there when the tool is not operating and for canceling or substantially reducing the torque loads applied to the drive train of the tool when the tool is operating. This means comprises a magnetic unit which develops a magnetic torque characteristic which opposes the normal hydraulic torque characteristics of the valve.

8 Claims, 5 Drawing Figures



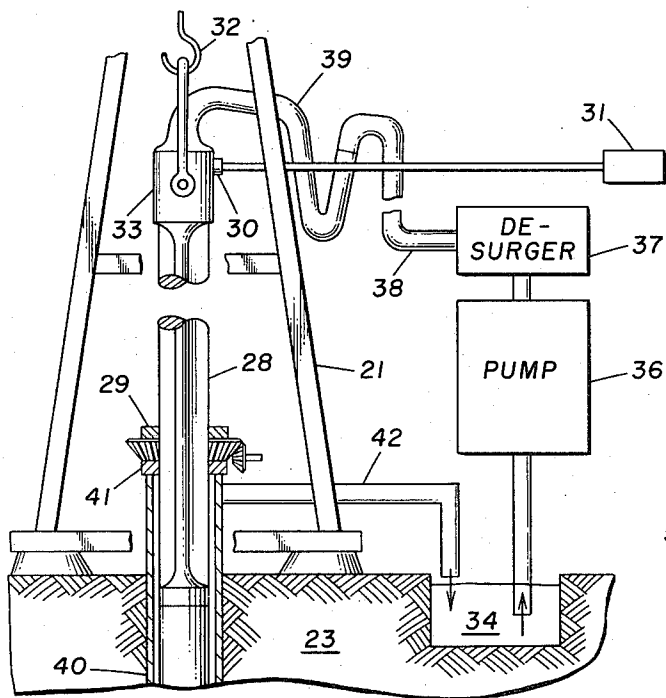


FIG. 1

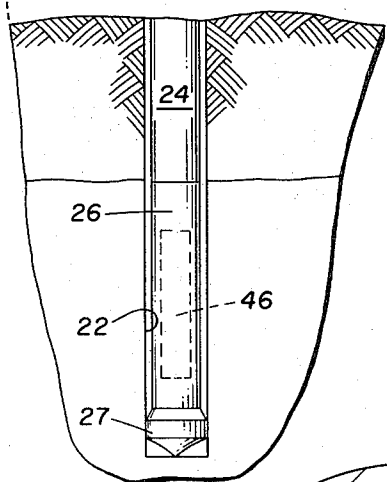


FIG. 4

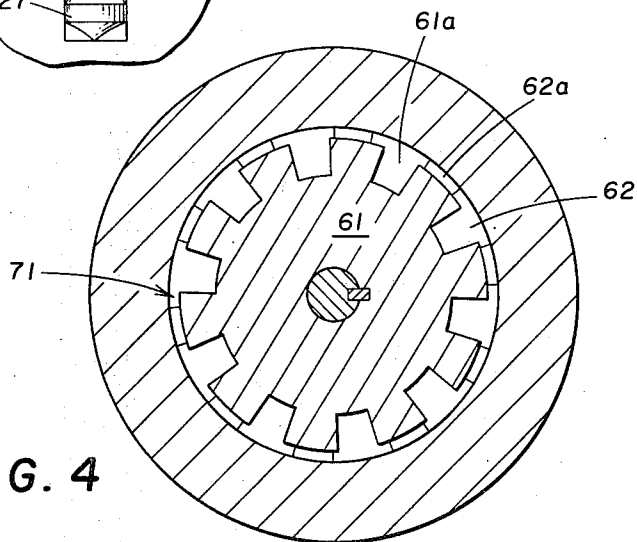
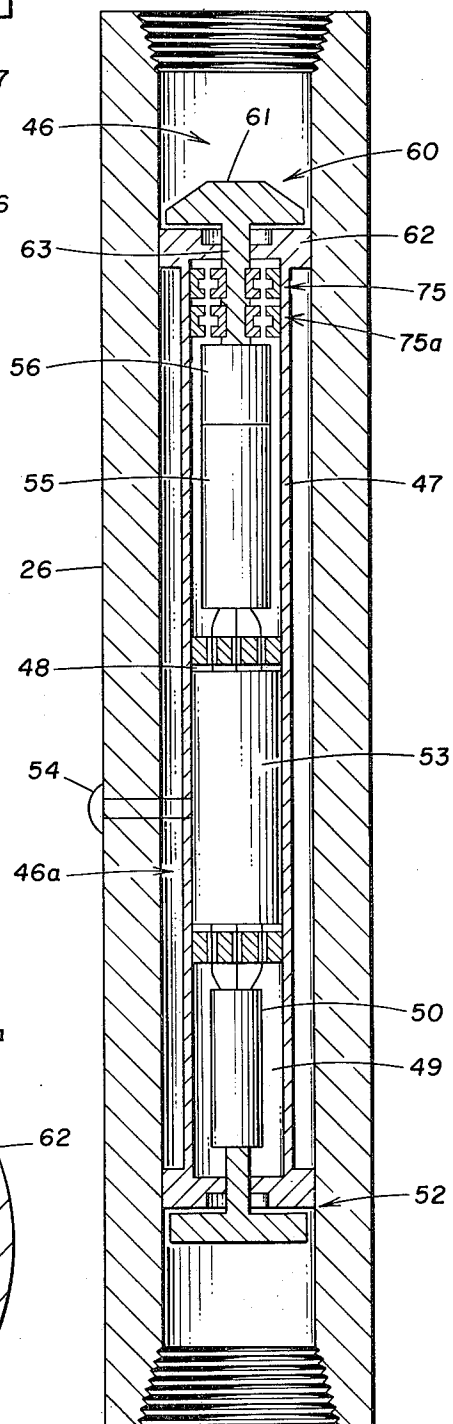


FIG. 2



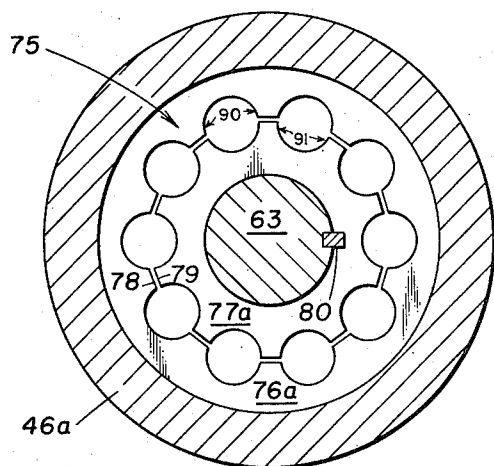
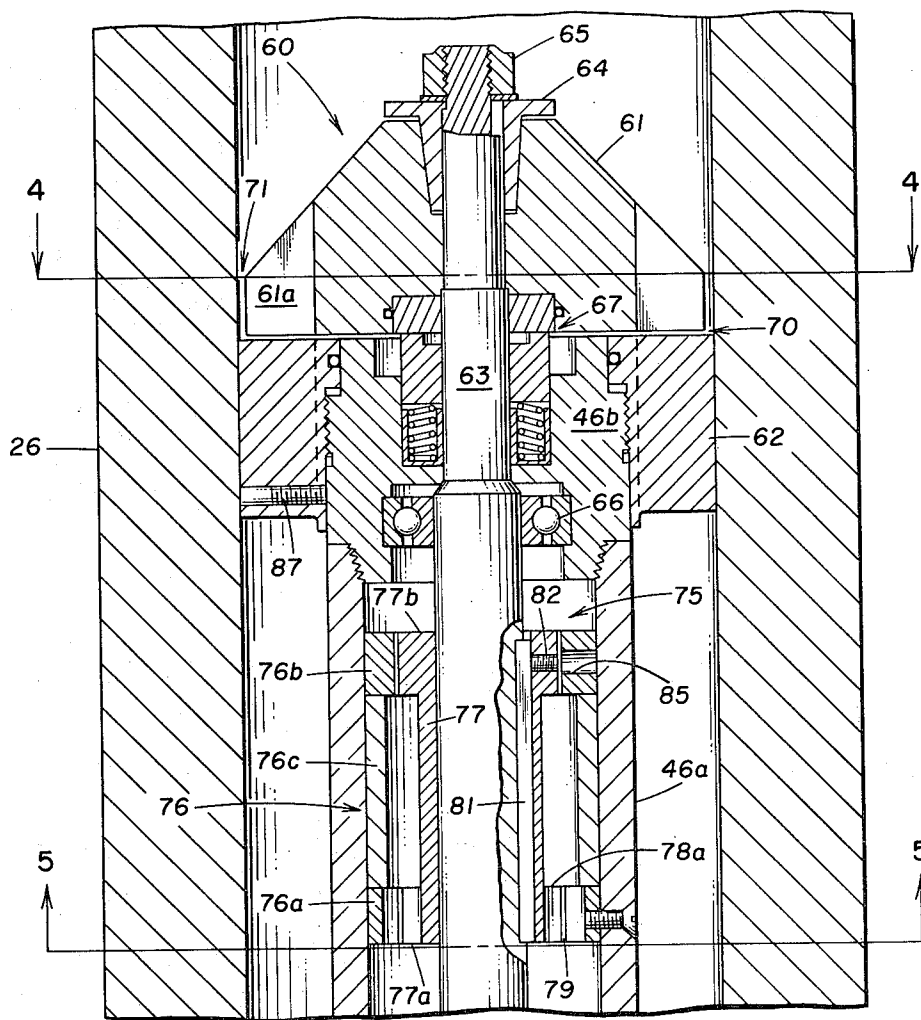


FIG. 5

FIG. 3



LOGGING-WHILE-DRILLING TOOL**BACKGROUND OF THE INVENTION**

The present invention relates to a logging-while-drilling tool and more particularly relates to a logging-while-drilling tool which has a means both to bias the signal-generating valve of said tool toward an open position when the tool is not operating and to reduce the torque loads which are applied to the drive train of said tool when the tool is operating.

The desirability of a system which is able to measure downhole drilling parameters and/or formation characteristics and transmit them to the surface while actual drilling of an earth well is being carried out has long been recognized. Several such systems have been proposed and are commonly referred to as "logging-while-drilling" systems. In logging-while-drilling systems, one of the major problems exists in finding a means for telemetering the information from a downhole location to the surface and having it arrive in a meaningful condition.

In this regard, it has been proposed to telemeter the desired information by means of a pressure wave signal generated in and transmitted through the circulating mud system normally associated with rotary drilling operations. The pressure wave signal which is representative of a particular piece of desired information is generated in the mud downhole near the bit by a single-generating valve and the wave travels up the hole through the mud to a signal processor at the surface. One logging-while-drilling system utilizing this technique of telemetry is disclosed and fully described in U.S. Pat. No. 3,309,656 to John K. Godbey, issued Mar. 14, 1967.

In a logging-while-drilling tool of the type disclosed in U.S. Pat. No. 3,309,656, a turbinelike, signal-generating valve is positioned in the circulating mud path near the drill bit. The valve is comprised of a stator and a rotor, each having openings therethrough which when aligned allow full flow of drilling mud through the valve. When the openings are misaligned, the flow therethrough is at least partially blocked. A motor in the tool is energized in response to a measured piece of information to open and close the valve at a rate producing a pressure wave in the mud which is representative of said measured information.

However, in logging-while-drilling tools of this type, the signal-generating valve normally develops certain hydraulic torque characteristics as a function of the flow rate through the valve which tend to force the valve to its closed position. This creates problems as drilling mud is pumped down the drill string and through the valve before the tool begins operation and the motor begins to power the valve. Due to the composition of standard drilling mud, solid material is normally present therein which tends to strain out of the mud as it is forced through restricted passages in the valve which are present when the valve is in its closed position. This solid material may continue to collect in the valve and does present a real problem in that it may plug the valve to such an extent that the valve cannot be opened by the motor when operation of the tool is commenced.

Also, due to the construction of this type of valve, the drive train of the tool which couples the motor to the valve experiences substantial torque loads while the

tool is operating. These loads can cause considerable wear on the drive train which may eventually lead to failure of the tool.

SUMMARY OF THE INVENTION

The present invention provides an improved logging-while-drilling tool of the type described above which includes a means for biasing and maintaining the signal-generating valve in an open position when the tool is not operating. The means of the present invention also cancels or substantially reduces torque loads normally applied to the drive train of the tool during operation.

Structurally, the tool of the present invention is comprised of a housing which is mounted within the central passage of a drill collar. This drill collar is adapted to be connected into and form a portion of a drill string of an earth drilling apparatus. The tool housing carries a rotary turbinelike, signal-generating valve which is positioned so that at least a portion of the drilling fluid flowing through the drill string will pass through the valve. The valve is comprised of a stator which is affixed to the housing and a rotor which is carried by a rotating drive train extending from a motor within the housing. Both the rotor and stator have openings therein which when aligned (i.e., open position) allow full flow through the valve and when misaligned (i.e., closed position) block at least a portion of the flow therethrough.

To insure that full flow through the valve will be permitted while the tool is in an inoperable or off condition, the present invention includes a means for biasing the valve toward an open position and for holding it there when the tool is not in operation. This means is comprised of a magnetic unit which has a magnet attached to the tool housing and a cooperating magnetic element attached to the drive train of the tool. The unit develops magnetic torque characteristics which are greater than the hydraulic torque characteristics of the valve when the tool is not operating so that the valve will be biased toward and held in its open position when the tool is not operating.

The hydraulic torque characteristic of the valve is an increasing function of the flow rate through the valve. Since the maximum flow rate will normally occur during operation of the tool, the torque characteristic of the unit is designed to be roughly equal to the hydraulic torque at this operating flow rate. By positioning the unit so that the magnetic torque is 180° out of phase with the hydraulic torque, the resulting torque applied to the drive train at any time during operation will be negligible.

BRIEF DESCRIPTION OF THE DRAWINGS

The actual construction, operation, and the apparent advantages of the invention will be better understood by referring to the drawings in which like numerals identify like parts and in which:

FIG. 1 is a schematic elevation of a rotary drilling apparatus including in vertical section a well containing a drill string in which the present invention is employed;

FIG. 2 is a schematic elevation, partly in section, of a portion of the drill string of FIG. 1, having a logging-while-drilling tool mounted therein in accordance with the present invention;

FIG. 3 is a detailed sectional view of one modification of the upper portion of FIG. 2 illustrating the present invention;

FIG. 4 is a sectional view taken along section line 4—4 of FIG. 3; and

FIG. 5 is a sectional view taken along section line 5—5 of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring more particularly to the drawings, FIG. 1 discloses the present invention as used in a logging-while-drilling system which is incorporated in a rotary drilling apparatus. A derrick 21 is disposed over a well 22 being formed in the earth 23 by rotary drilling. A drill string 24 is suspended within the well and has a drill bit 27 at its lower end and a kelly 28 at its upper end. A rotary table 29 cooperates with kelly 28 to rotate string 24 and bit 27. A swivel 33 is attached to the upper end of kelly 28 which in turn is supported by hook 32 from a traveling block (not shown). This arrangement not only supports the drill string 24 in an operable position within well 22 but also forms a rotary connection between the source of circulating drilling fluid, such as mud, and the drill string 24. It should be understood that "mud" as used throughout this disclosure is intended to cover those fluids normally used in rotary drilling operations.

The pump 36 transfers drilling mud from a source, such as pit 34, through desurger 37 into mudline 38. Desurger 37 is adapted to reduce the pulsating effect of pump 36 as is well known in the art. The mud flows through mudline 38, flexible hose 39, swivel 33, drill string 24, and exits through openings (not shown) in drill bit 27 to pass outwardly into well 22. The mud then circulates upward carrying drill cuttings with it through the annulus between the well and drill string 24 to the surface of the earth 23. At the surface, well head 41 is secured to casing 40 which is cemented in the well 22. Pipe 42 is connected to casing 40 for returning the mud to pit 34.

As schematically illustrated in FIGS. 1 and 2, a logging-while-drilling tool 46 is located in drill collar 26 which forms a part of the lower end of drill string 24 near bit 27. Tool 46 has a motor-actuated, signal-generating, rotary valve which periodically interrupts at least a portion of the drilling fluid flowing through the valve to thereby generate a pressure wave in the fluid which is representative of a measured downhole condition. This is the type of logging-while-drilling tool which is disclosed and described in U.S. Pat. No. 3,309,656 to John K. Godbey. The present invention is directed to a means for holding the valve in an open position when the tool is not operating and for reducing torque loads on the drive train of the tool when the tool is operating. However, in order to fully understand and appreciate the present invention, a brief description of the entire tool 46 will be helpful.

A transducer means which is capable of measuring a desired downhole condition and converting the measurement to an electrical signal is positioned downhole on or near tool 46. As illustrated, transducer means 54, e.g., a strain gauge, is positioned on drill collar 26 to measure the downhole weight on bit 27. The signal from transducer means 54 is applied to electronic package 53 which is sealed in compartment 48 of tool housing 46a. For an example of such an electronic

package, see U.S. Pat. No. 3,309,656. Circuitry in package 53, in response to the signal from means 54, allows a defined amount of power from electric power generator 50 in compartment 49 of housing 46a to flow to the variable speed, electric motor 55 in compartment 47 of housing 46a. A turbine 52 driven by the mud flow rotates generator 50 to produce electrical power. Motor 55, in response to the amount of electricity passing through package 53, will drive rotor 61 of signal-generating valve 60 through drive train 56 at the rotational speed necessary to generate a pressure wave signal in the mud which is representative of the measured condition.

Referring now to the more detailed representation in FIG. 3, signal-generating valve 60 is comprised of a rotor 61 and a stator 62. Rotor 61 is fixed on shaft 63 of drive train 56 by means of tapered bushing 64 and nut 65. Shaft 63 is journaled in housing 46a by means of bearings 66. Seal 67 around shaft 63 seals the interior of housing 46a against the influx of drill mud. Preferably, both rotor 61 and stator 62 contain the same number of identical spaced slots, 61a, 62a, respectively (FIG. 5), each of the slots being of equal area. Valve 60 is in an "open position" when the slots are aligned and is in a "closed position" when the slots are completely misaligned. When valve 60 is in a closed position, the only flow through the valve is that which passes through gap 70 and bypass 71. Gap 70, as can best be seen in FIG. 3, is that distance between the bottom surface of rotor 61 and the top surface of stator 62. Bypass 71 (FIGS. 3 and 5) is that distance between the outer periphery of rotor 61 and the wall of the conduit adjacent the rotor. The outer diameter of stator 62 is effectively the same as the interior diameter of the conduit.

When there is flow through valve 60 but before generator 50 develops sufficient power to operate tool 46, the torque characteristics of valve 60 tend to force it to its closed position. Therefore, when drill string 24 is lowered into the well and mud is flowed through tool 46 to rotate turbine 52 at a speed sufficient to generate the necessary power for the tool, the mud must flow through the restrictive passages in valve 60 formed by bypass 71 and gap 70. Since drilling mud normally contains solid materials which tend to strain out within the restricted passages of the closed valve, a serious problem of plugging exists. If valve 60 becomes plugged to the extent that it cannot be opened when motor 55 commences operation, the entire drill string 24 has to be removed to unplug valve 60 before tool 46 can operate.

Furthermore, due to the construction of valve 60, hydraulic torque loads are applied to drive train 56 as motor 55 rotates valve 60 between its open and closed positions during operation of tool 46. These constantly reversing torque loads can cause considerable wear on the drive train which may lead to any early failure of tool 46.

The present invention provides a means for tool 46 which both biases valve 60 toward its open position and holds it there when tool 46 is not operating and, at the same time, cancels or substantially reduces the torque loads normally applied to drive train 56 during operation of tool 46. The means of the present invention is preferably a magnetic unit 75 which is comprised of magnet 76 and magnetic element 77. Magnetic element 77, as illustrated, is of cylindrical shape having a re-

cessed midportion and raised ends 77a and 77b and is affixed to shaft 63 for rotation therewith by means of key 80 and set screw 81. Magnet 76 has a configuration which mirrors that of magnetic element 77. Magnet 76 may be constructed in one piece although it is illustrated as being comprised of three members, 76a, 76b, 76c. Member 76a and end 77a are "toothed" as shown in FIG. 5 to provide attracting poles 78, 79, respectively, between magnet 76 and magnetic element 77. As illustrated, both 76a and 77a have 10 poles which correspond to the number of slots in both rotor 61 and stator 62 (FIG. 4) thereby providing ten stable positions for valve 60 in which it will be in an open position. The magnetic unit 75 is comprised of material, e.g., Alnico, which will retain magnetism for long periods while housing 46a is comprised of a relatively nonmagnetic material, e.g., Monel.

To assemble the upper portion of tool 46, unit 75 preferably having a "keeper shaft" (not shown) through the central passage in magnetic element 77 is placed in an electrical coil and magnetized. Unit 75, now held together by magnetic force, is then slipped over shaft 63 which in turn displaces the keeper from element 77 as unit 75 is moved into place over key 80. Set screw 81 is tightened through hole 85 in member 76b to further affix magnetic element 77 to shaft 63. Next, shaft 63, unit 75, and upper housing element 46b are positioned within housing 46a, and 46b is secured thereto. Shaft 63, which carries entire unit 75, is rotated to align magnet 76 with openings in housing 46a so screws 86 (only one shown) can be inserted to secure magnet 76 to housing 46a. Stator 62 is rotated on threads on upper housing element 46b so that the slots in stator 62 are aligned with the slots in rotor 61, thereby positioning valve 60 in an open position. Set screw 87 is tightened to secure stator 62 against rotation during operation of tool 46. It can now be seen that when the poles of 76a and 77a are aligned in any of ten possible positions, valve 60 will be in an open position.

To insure that valve 60 will be held in its open position when tool 46 is not operating, it is only necessary to design unit 75 so the magnetic torque of same exceeds the hydraulic torque characteristics of valve 60 which exist when tool 46 is not operating. However, in addition to the above, the present invention is designed to cancel or substantially reduce the hydraulic torques normally applied to drive train 56 while tool 46 is operating.

The hydraulic torque characteristics of valve 60 increase as a function of the flow rate through the valve so that in tool 46, maximum flow rate through valve 60 will normally occur during actual drilling operations, at which time tool 46 will be operating. Therefore by designing unit 75 for this flow rate, there will always be sufficient magnetic torque to hold valve 60 open until tool 46 begins operation. The nominal flow rate of mud which will be used during a particular drilling operation is generally known and varies very little unless emergencies arise during drilling. The hydraulic torque characteristics of valve 60 which occur at this nominal flow rate can be determined by bench tests and the magnetic torque characteristic of unit 75 is designed to roughly equal those torques of valve 60 during these operating conditions. By positioning unit 75 as described above, the magnetic torque applied to drive train 56 will be 180° out of phase with the hydraulic torque applied to drive train 56 by the operation of

valve 60. If the two torques are substantially equal, the resulting torque applied to drive train 56 at any time during operation will be negligible. Also, by effectively canceling the torques on drive train 56, motor 55 will be operating under essentially no-load conditions, thereby allowing less powerful motors to be used in tool 46.

Since it is not critical that all torques on drive train 56 be exactly canceled, changes from the nominal flow rate can be tolerated. Motor 55 is designed to have sufficient power to overcome any positive hydraulic or magnetic torques which might normally occur during drilling due to changes in flow rate of the mud. However, even at varying flow rates, the reduction in applied torques on drive train 56 due to the counterbalancing effects of the hydraulic and magnetic torques is highly beneficial.

In unit 75, as illustrated, magnetic torque is a function of the opposed surface areas of poles 78 and 79. By varying the diameter of openings 90 and 91 in member 76a and end 77a, respectively, the surface area of said poles can be varied and the desired magnetic torque of unit 75 can be established. Further, more than one unit 75, 75a (FIG. 2) having the same or different magnetic torques, can be "stacked" on shaft 63 whereby the individual torque characteristics of each unit are combined to shape a torque curve having the specific characteristics desired for a specific tool 46.

Although one embodiment of the present invention has been shown, certain modifications might be made without departing from the spirit of the invention. For example, less than one magnetic pole for each slot in the valve could be used which would still hold the valve open but would reduce the number of stable open positions available. Likewise, the magnetic unit could be placed at other positions within drive train 56, e.g., before a reducing transmission, which would change the number of poles necessary for insuring a number of stable open positions for valve 60 when tool 46 is not operating.

What is claimed is:

1. A logging-while-drilling tool comprising:

a housing adapted to be positioned in a drill string of an earth drilling apparatus wherein drilling fluid which is circulated through the drill string will flow around said housing;

a rotary valve positioned on said housing so that at least a portion of the drilling fluid flowing through the drill string will flow through said valve whereby a pressure wave signal will be generated in the drilling fluid as said valve opens and closes in response to a downhole condition measured by said tool, said valve comprising:

a rotor having openings therethrough mounted on a drive train extending from said housing; and
a stator on said housing having openings therethrough which when aligned with said openings in said rotor will allow full flow through said valve and when misaligned will at least partially block flow through said valve; and

means for biasing said rotor and said stator when said tool is not operating toward a position relative to each other where said openings through said rotor and said stator will be aligned and said valve will be in an open position.

2. The logging-while-drilling tool of claim 1 wherein said means for biasing said valve toward an open position comprises:

a means for applying a torque to said valve in a direction necessary to move said valve toward an open position, said torque being greater than the hydraulic torque applied to said valve by flow there-through which tends to bias said valve to a relative closed position when said tool is not operating.

3. The logging-while-drilling tool of claim 2 wherein: said means for applying said torque to said valve is magnetic.

4. The logging-while-drilling tool of claim 3 wherein: said magnetic means comprises a magnetic unit having at least two elements which magnetically attract each other, one of said elements secured to said drive train for rotation therewith and another of said elements secured against rotation in said housing at a point adjacent said one element.

5. A logging-while-drilling tool comprising: a housing adapted to be positioned in a drill string of an earth drilling apparatus wherein drilling fluid which is circulated through the drill string will flow around said housing;

a rotary valve positioned on said housing so that at least a portion of the drilling fluid flowing through the drill string will flow through said valve whereby a pressure wave signal will be generated in the drilling fluid as said valve opens and closes in response to a downhole condition measured by said tool, said valve comprising:

a rotor having openings therethrough mounted on a drive train extending from said housing; and

a stator on said housing having openings there-through which when aligned with said openings in said rotor will allow full flow through said valve and when misaligned will at least partially block flow through said valve; and

magnetic means for biasing said rotor and said stator when said tool is not operating toward a position relative to each other where said openings through said rotor and said stator will be aligned and said valve will be in an open position;

said magnetic means comprises at least two magnetic units, each of said units having at least two elements which magnetically attract each other, one of said elements of each of said units secured to said drive train for rotation therewith and another of said elements of each of said units secured against rotation in said housing at a point adjacent their respective one elements, whereby the combined magnetic torque characteristic of said units

equals the magnetic torque characteristic desired for said tool.

6. A logging-while-drilling tool comprising:

a housing adapted to be positioned in a drill string of an earth drilling apparatus wherein drilling fluid which is circulated through the drill string will flow around said housing;

a rotary valve positioned on said housing so that at least a portion of the drilling fluid flowing through the drill string will flow through said valve whereby a pressure wave signal will be generated in the drilling fluid as said valve opens and closes in response to a downhole condition measured by said tool, said valve comprising:

a rotor having openings therethrough mounted on a drive train extending from said housing; and

a stator on said housing having openings there-through which when aligned with said openings in said rotor will allow full flow through said valve and when misaligned will at least partially block flow through said valve;

means for biasing said rotor and said stator when said tool is not operating toward a position relative to each other where said openings through said rotor and said stator will be aligned and said valve will be in an open position; and

means for applying torque to said drive train in a direction necessary to reduce hydraulic torque which is imposed on said drive train during operation of said tool.

7. The logging-while-drilling tool of claim 6 wherein said means for biasing said valve toward an open position and said means for reducing hydraulic torque on said drive train comprises:

magnetic means having at least two elements which magnetically attract each other, one of said elements secured to said drive train for rotation therewith and another of said elements secured against rotation in said housing at a point adjacent said one element, said magnetic means having torque characteristics essentially equal to but 180° out of phase to the hydraulic torque which is normally applied to said drive train during operation of said tool.

8. The logging-while-drilling tool of claim 7 wherein said magnetic means further comprises:

at least one magnetic pole on said one element and at least one magnetic pole on said another element, the number of poles on each of said elements corresponding to the number of desired stable open positions of said valve.

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