United States Patent [19]

Sexton et al.

[11] **3,770,006**

[45] **Nov. 6, 1973**

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

[75] Inventors: **James H. Sexton,** Duncanville; **Vasel R. Slover, Jr.,** Irving; **Bobbie J. Patton,** Dallas; **Wilton Gravley,** Carrollton, all of Tex.

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

[22] Filed: **Aug. 2, 1972**

[21] Appl. No.: **277,220**

[52] **U.S. Cl.** ..... **137/499,** 340/18 NC

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

[58] **Field of Search** ..... 137/499, 495; 340/18 NC; 73/152; 181/0.5; 324/1

[56] **References Cited**

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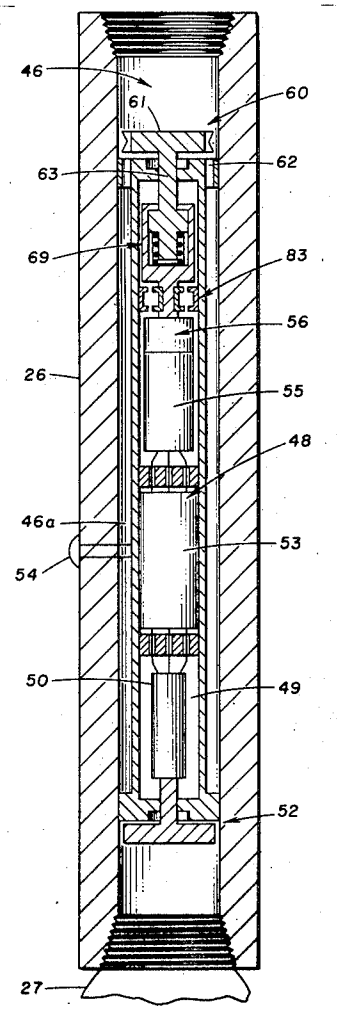
3,309,656 3/1967 Godbey ..... 340/18 NC

Primary Examiner—Henry T. Klinksiek
Assistant Examiner—Robert J. Miller
Attorney—Andrew L. Gaboriault et al.

[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 defined rate to generate a pressure wave signal in the drilling fluid which is representative of a measured downhole condition. The tool includes spring means to normally bias the rotor away from the stator of the valve. The force constant of the spring means is greater than the pressure drop across the rotor at low flow rates but is less than the pressure drop at the flow rate at which the tool begins operation. This allows the tool to maintain a large gap between the rotor and stator prior to operation of the tool or during periods of nonoperation thereby alleviating the problem of plugging and/or jamming of the valve. During normal operation the net force holding the rotor down, i.e., the force due to hydraulic pressure drop minus the spring force, is relatively small so that the rotor will ride up over and free itself from material which may become lodged in the gap, thus alleviating jamming of the valve. Also, structural features of the rotor aid in alleviating plugging of the valve.

16 Claims, 6 Drawing Figures



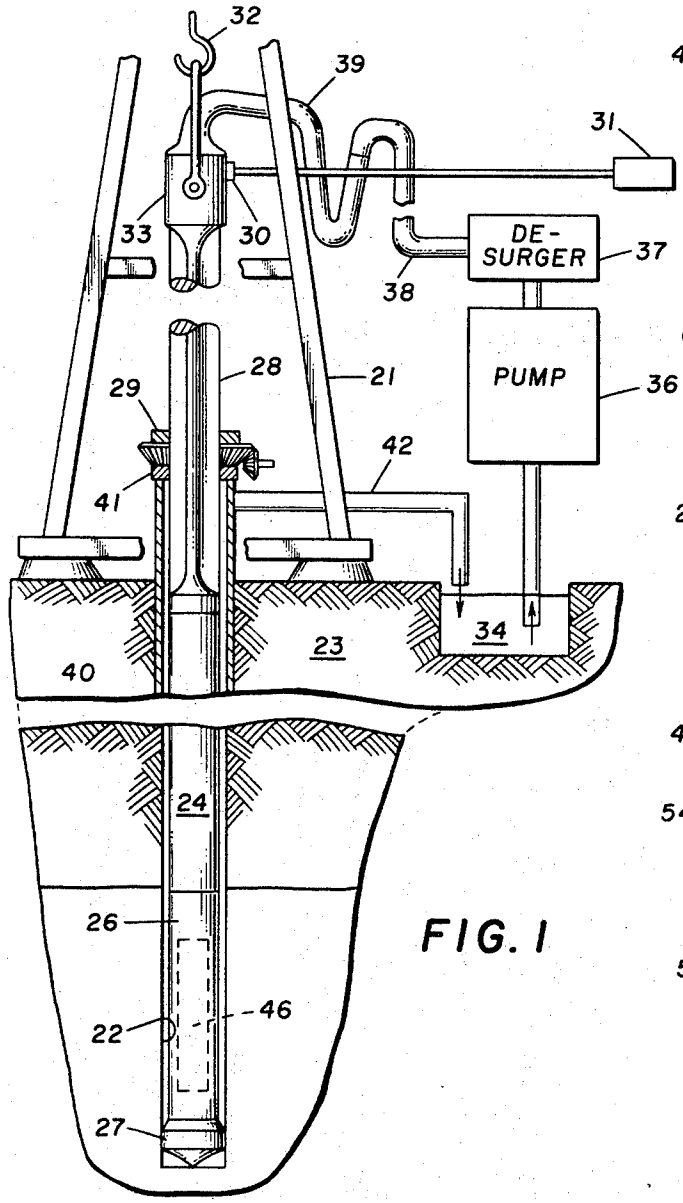

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FIG. 1

FIG. 2

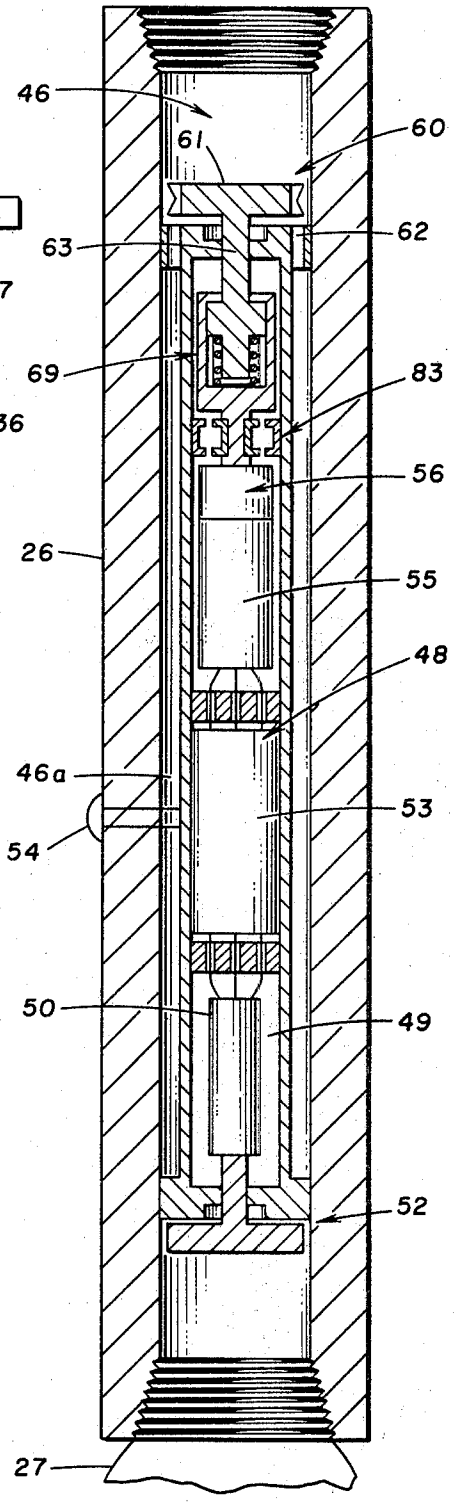

46
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FIG. 3

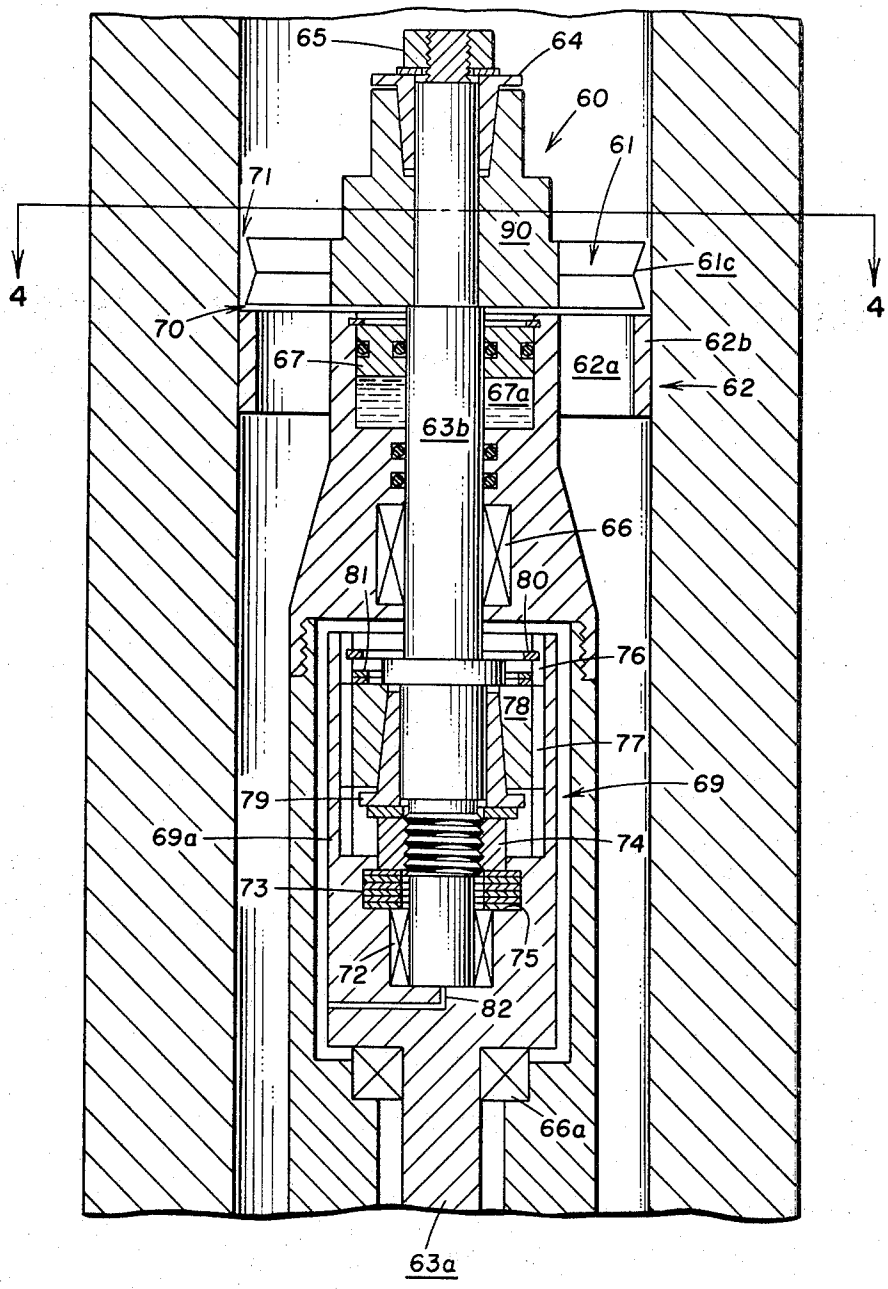
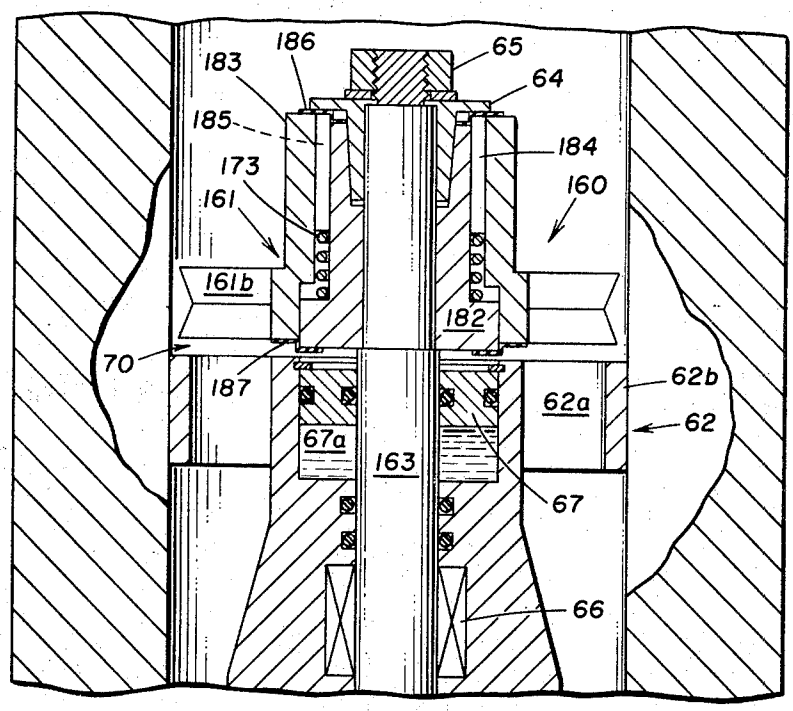

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FIG. 6



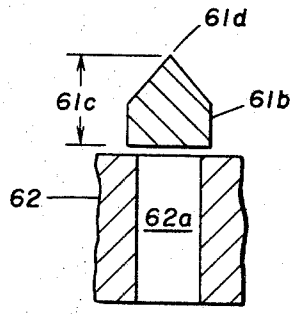
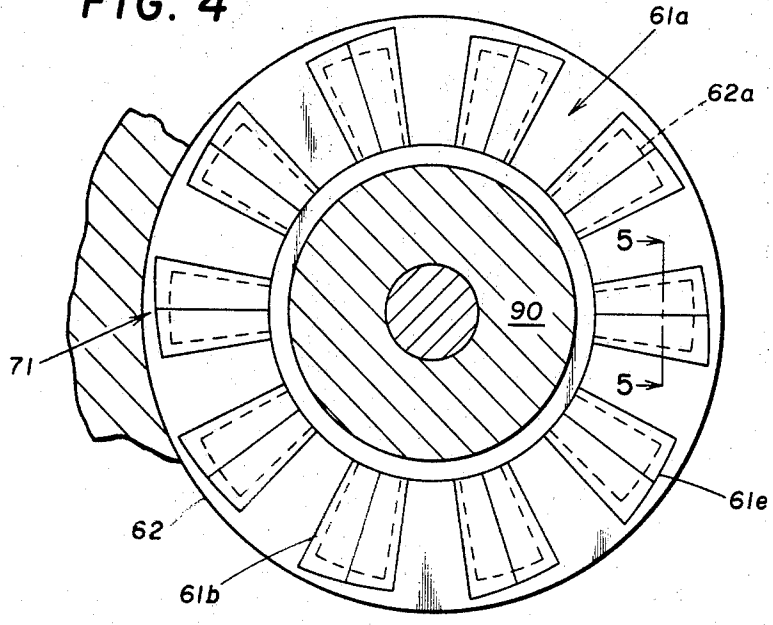


FIG. 5

FIG. 4



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 includes a means for alleviating plugging or jamming of the signal-generating valve of the tool while the tool is in an operable position within a well being drilled.

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 signal-generating valve and the wave travels up the hole through the mud to a signal processor at the surface. Logging-while-drilling systems utilizing this technique of telemetry are disclosed and fully described in U.S. Pat. No. 3,309,656 to John K. Godbey, issued Mar. 14, 1967 and in copending application Ser. No. 213,061, filed Dec. 28, 1971.

In logging-while-drilling systems of the types mentioned above, a tool having 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 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.

Furthermore, even when the tool is operating and the valve is being rotated by the motor, large debris, e.g., wood chips which may be present in the drilling mud may become wedged between the rotor and stator as

the mud flows through the valve thereby jamming the valve and making the tool inoperable. If the valve becomes plugged prior to startup of the tool or becomes jammed during operation of the tool, the entire drill string has to be removed to free the valve for rotation before the tool can carry out its function.

SUMMARY OF THE INVENTION

The present invention provides a logging-while-drilling tool of the type described above which includes means to alleviate plugging and/or jamming of the tool's signal-generating valve before and during the operation of the tool.

Structurally, the tool of the present invention is comprised of a housing which is adapted to be mounted within the central passage of a drill collar. This drill collar, in turn, 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. A turbine, powered by the mud flow, is located at the lower end of the tool which rotates a generator which, in turn, furnishes the electrical power for the tool.

When the valve is in a closed position prior to startup of the tool, mud must flow through restricted passages in the valve in order to reach the mud turbine to generate the power necessary to operate the tool. The restricted passages are formed by the bypass between the outer edges of the rotor lands and the wall of the drill collar and the gap between the lower surface of the rotor and the upper surface of the stator. The gap in the tool must be relatively small during operation of the tool in order for the signal generated by the valve to have sufficient strength to reach the surface.

In the present tool, means is provided to allow relative movement between the rotor and the stator so that a large gap will exist when the tool is not operating and a small gap will exist at operating conditions. Structurally, a spring means is included in the tool which has sufficient force to bias the rotor upwardly away from the stator when a low rate of flow is passing down the drill string. As the flow rate increases, the pressure drop across the rotor also increases. When the pressure drop exceeds the force of the spring means, the rotor moves downward toward the stator which establishes the gap necessary for satisfactory operation of the tool. By allowing the gap to be large during the time the tool is not operating, the passages available for flow through the valve during this time are increased and the problem of plugging the valve is substantially decreased. Further, since the spring means tends to force the rotor away from the stator when the flow rate is decreased, if the valve becomes jammed during operation of the tool by material in the mud, the flow rate can be reduced and the valve cleared by the relative movement between the rotor and stator. Even if the flow rate is not reduced during partial jamming, the rotor can ride up against the bias of the spring over the debris be-

tween the rotor and stator and continue to operate under most circumstances.

Additional structural features of the rotor of the present invention further aid in alleviating plugging and/or jamming of the valve and these will become evident from the following description.

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 the present logging-while-drilling tool mounted therein;

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;

FIG. 5 is a sectional view taken along section line 5—5 of FIG. 4; and

FIG. 6 is a detailed view of a second modification of the upper portion of FIG. 2 illustrating the present invention.

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 outward 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, rotary signal-generating 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. The present invention is directed to a means for alleviating plugging and/or jamming of the valve but, 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 examples of package 58, see U.S. Pat. No. 3,309,656 or U.S. application Ser. No. 213,061, filed Dec. 28, 1971. 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 driven shaft 63*b* of drive train 56 by means of tapered bushing 64 and nut 65. Shaft 63*b* is journaled in housing 46*a* by means of bearings 66. Seal 67 and grease-filled cavity 67*a* around shaft 63*b* seal the interior of housing 46*a* against the influx of drill mud. Preferably, both rotor 61 and stator 62 contain the same number of identical spaced slots, 61*a*, 62*a*, respectively, (FIG. 4). 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 4) 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.

The rate at which valve 60 opens and closes determines the frequency of the pressure wave signal thus generated in the drilling mud, but the amplitude or strength of the signal is directly related to the minimum area defined by gap 70 and bypass 71 which is available for flow when valve 60 is closed. As this area decreases, signal strength increases. Since a strong signal is desired, gap 70 should be as small as practical while tool 46 is operating.

However, 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, if gap 70 is too small during this time, 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.

The present invention provides a means for tool 46 which alleviates the problem of plugging valve 60 before tool 46 begins operation. This means is comprised of structure which permits rotor 61 and stator 62 to move relative to each other under certain operating conditions so that gap 70 is large while tool 46 is not operating but of a desired small value when tool 46 commences operation. Structurally, in a first modification (FIG. 3) the means comprises a "telescoping joint" 69 in output shaft 63 of drive train 56. Driving shaft 63a of output shaft 63 is journaled in housing 46*a* by means of bearings 66a and has a cuplike chamber 69*a* at its outer end. Driven shaft 63b telescopes into chamber 69*a* and is slidably positioned within centralizing bearing 72. Spring means 73, e.g., Belleville spring washers, is provided between nut 74 which is threaded on shaft 63*b* and shoulder 75 within chamber 69*a* to normally bias shaft 63*b* outward or upward from shaft 63*a*. Shafts 63*a* and 63*b* are coupled together for rotation by interlocking splines 76 and 77, respectively. Splines 76 are formed longitudinally on the inner periphery of chamber 69*a* while splines 77 are formed as part of ring 78 which, in turn, is frictionally affixed to shaft 63*b* by tapered bushing 79. Of course, splines 77 could be constructed as an integral part of shaft 63*b* if desired. Snap ring 80 is positioned in chamber 69*a* to limit upward movement of shaft 63*b* with respect to shaft 63*a*. Spacer washers 81 can be used to adjust the actual length of travel between the two shafts.

In the tool described, as mud flows through openings in rotor 61, there is a pressure drop across the rotor which increases with flow rate. This pressure drop causes a downward force on the rotor. The force constant of spring means 73 is selected so that the upward force of spring means 73 is greater at low flow rates than the downward force on rotor 61. Therefore, at the low flow rates such as those used prior to commencement of operation of tool 46, spring means 73 will maintain rotor 61 in an "up" position thereby providing the maximum gap 70 for tool 46. This increase in gap 70 provides larger passages for flow through valve 60 during nonoperation of tool 46 and substantially reduces the problem of plugging. When flow rates are increased to those necessary to drive turbine 52 at a speed required to generate sufficient power to operate tool 46, the pressure drop across rotor 61 increases to a value greater than the force constant of the spring means so that spring means 73 is overcome and rotor 61 moves downward to its "down" position. In this position, gap 70 will be a set value which is necessary for successful operation of tool 46.

To further alleviate plugging of valve 60, a magnetic valve positioner 83 (FIG. 2) can be included in tool 46 which holds valve 60 in an open position until tool 46 begins operation. The construction and operation of valve positioner 83 are fully described in assignee's copending U.S. application Ser. No. 267,851, filed June 30, 1972. Where valve positioner 83 is used in tool 46, the force constant of spring means 73 is selected such that rotor 61 will be held in its up position as long as valve 60 is held in its open position by valve positioner 83. When tool 46 begins operation and motor 55 powers valve 60 to its closed position, the resulting force from the higher pressure drop due to the valve's closed position will exceed the force constant of spring means 73 and rotor 61 will move to its down position to establish the desired gap 70 necessary for generating a satisfactory signal.

Since normally tool 46 is oil filled and pressure balanced, as clearly described in assignee's copending U.S. application Ser. No. 145,372, filed May 30, 1971, a bleed port 82 is provided so that any oil trapped under shaft 63b within bearing 72 can flow therefrom as rotor 61 moves downward.

When tool 46 is operating and rotor 61 is in a "down" position, large debris, e.g., wood chips, etc., in the drilling mud may become lodged between openings in rotor 61 and stator 62 or in gap 70, thereby jamming valve 60 against further rotation. If this should occur, in accordance with the present invention the flow rate of the drilling mud is decreased to a valve where the force of spring means 73 again becomes dominant. This force causes rotor 61 to move toward its "up" position which, in most cases, will clear whatever material is jamming the valve. After valve 60 has been cleared, the operating flow rate is resumed and operation of tool 46 is continued.

If the jamming due to a buildup of particles between stator and rotor is not too severe, tool 46 will continue to operate satisfactorily without reducing the flow rate. This is due to the compliance provided by spring means 73 which allows rotor 61 to ride up over the debris in gap 70 against the bias of the spring means and to continue to rotate. This continued rotation will, in many cases, eventually erode the accumulated debris to the point where the mud flow can carry it on through the valve.

Tool 46 of the present invention includes other structural features which also aid in alleviating plugging and/or jamming of valve 60. Lands 61*b* of rotor 61 extend outward from hub 90 to a point over openings 62*a* of stator 62 (FIGS. 4 and 5) so that they overlap opening 62*a* when valve 60 is in a closed position. This overlapping of the stator openings provides higher amplitude and quality of signal for a given gap 70 by minimizing leakage of valve 60 when rotor 61 is in a down position and valve 60 is in a closed position. Thus, a larger gap 70 can be used in generating a signal of a desired strength than otherwise could be used. Accordingly, there is less tendency for valve 60 to jam during operation of tool 46.

Jamming tendencies are further reduced and operating performance is improved by other structural characteristics of rotor 61. First the longitudinal length 61c (FIG. 5) of rotor lands 61*b* is reduced to a minimum value but not below that which is sufficient to maintain structural rigidity of the rotor lands during operation. The smaller lands 61*b* will reduce the turbulence in the area of valve 60 which, in turn, reduces the hydraulic torque loads which are applied to drive train 56 during operation of tool 46. The upper surfaces 61*d* (FIG. 5) are peaked to reduce erosion and to continuously di-

rect flow toward openings 61*a* in rotor 61 instead of toward radial edges 61*e* (FIG. 4) of lands 61*b* where plugging is more likely to occur. Further, radial edges 61*e* are constructed with the leading face of each land 61*b* extending further from the center of rotor 61 than the trailing edge of said land. This radial streamlining provides a bypass which is constantly varying between a small value to a larger value thereby preventing a gradual buildup of particles in the bypass. Also, radial edges 61*e* are relieved as shown in FIG. 3 to further avoid trapping of materials in bypass 71.

In FIG. 6, a second modification of tool 46 is disclosed which utilizes a different means for providing relative movement between rotor 161 and stator 62 of valve 160. The lower portion of tool 46 is the same as before except shaft 163 is continuous without a telescoping joint therein. Rotor 161 is comprised of mounting element 182 and land element 183. Mounting element 182 is secured to shaft 163 for rotation therewith by means of tapered bushing 64 and nut 65. Land element 183 which carries rotor lands 161*b* is slidably mounted on mounting element 182. Cooperating splines 184, 185 between elements 182 and 183, respectively, provide a driving connection between the two elements so that both will be rotated by shaft 163. Spring means 173 is positioned between a shoulder on mounting element 182 and splines 185 to normally bias land element 183 upward against a stop provided by tapered bushing 64. Diaphram seals 186 and 187 provide protection for the interior of rotor 161.

Operation of this modification is basically the same as that of FIG. 3. The force constant of spring means 173 is selected so that it will exceed the pressure drop across rotor 161 at flow rate lower than the operating flow rate. When the operating flow rate is achieved, land element 183 will move downward on mounting element 182 to establish the gap 70 necessary to generate the desired signal.

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 a 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, said valve comprising:
- a rotor having openings therethrough mounted on a drive train extending from said housing;
- a stator on said housing having openings therethrough which when aligned with said openings in said rotor allow flow through said valve and when misaligned at least partially block flow through openings in said rotor; and
- means for normally biasing said rotor and said stator relatively away from each other.

2. The logging-while-drilling tool of claim 1 wherein said biasing means comprises:
- spring means having a force constant which is greater than the pressure drop across said rotor at flow rates less than the flow rate at which said tool will operate but which is less than the pressure drop across said rotor at said operational flow rate whereby said rotor and said stator will be separated from each other at a maximum distance during said low flow rates but will move toward each other to establish a desired gap at said operational flow rate.

3. The logging-while-drilling tool of claim 1 including:
- means to hold said rotor and said stator in a relative position wherein their respective openings are aligned until said tool begins operation.

4. The logging-while-drilling tool of claim 1 wherein said drive train comprises:
- a driving shaft and a driven shaft, said rotor being mounted on said driven shaft; and
- said biasing means comprising:
  - means for coupling said driving shaft to said driven shaft for rotation therewith while allowing limited, longitudinal, relative movement therebetween; and
  - spring means for normally biasing said driven shaft away from said driving shaft.

5. The logging-while-drilling tool of claim 4 wherein:
- said spring means has a force constant which is greater than the pressure drop across said rotor at flow rates less than the flow rate at which said tool will operate but which is less than the pressure drop across said rotor at said operational flow rate whereby said rotor and said stator will be separated from each other at a maximum distance during said low flow rates but said rotor will move toward said stator to establish a desired gap at said operational flow rate.

6. The logging-while-drilling tool of claim 5 including:
- means to hold said rotor and said stator in a relative position wherein their respective openings are aligned until said tool begins operation.

7. The logging-while-drilling tool of claim 1 wherein said biasing means comprises:
- means for mounting said rotor on said drive train for rotation therewith while allowing limited, longitudinal movement of said rotor on said drive train; and
- spring means for normally biasing said rotor on said drive means in a direction away from said stator.

8. The logging-while-drilling tool of claim 7 wherein:
- said spring means has a force constant which is greater than the pressure drop across said rotor at flow rates less than the flow rate at which said tool will operate but which is less than the pressure drop across said rotor at said operational flow rate whereby said rotor and said stator will be separated from each other at a maximum distance during said low flow rates but said rotor will move toward said stator to establish a desired gap at said operational flow rate.

9. The logging-while-drilling tool of claim 1 wherein said rotor comprises:
- a hub; and
- a plurality of lands extending radially outward from said hub, the space between respective lands defining said openings through said rotor, said lands extending outward to a point whereby said lands completely overlap said openings in said stator when said valve is in a closed position.

10. The logging-while-drilling tool of claim 9 wherein:

the upper surface of each of said lands is peaked so flow will normally be directed to said openings between said lands.

11. The logging-while-drilling tool of claim **9** wherein:

the leading edge of each of said lands extends radially out from said hub for a distance greater than the trailing edge of each of said lands.

12. The logging-while-drilling tool of claim **9** wherein:

the radial surface of each of said lands is relieved inward from its upper and lower surfaces.

13. A logging-while-drilling tool comprising:

a housing adapted to be positioned in a drill string of an earth drilling apparatus wherein a 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 stator on said housing having openings therethrough; and

a rotor mounted on a drive train extending from said housing, said rotor comprising:

a hub and a plurality of lands extending radially outward from said hub, the spaces between respective lands defining openings through said rotor, said lands extending outward to a point whereby said lands completely overlap said openings through said stator when said valve is in a closed position.

14. The logging-while-drilling tool of claim **13** wherein:

the upper surface of each of said lands is peaked so flow will normally be directed to said openings between said lands.

15. The logging-while-drilling tool of claim **13** wherein:

the leading edge of said lands extends radially out from said hub for a distance greater than the trailing edge of each of said lands.

16. The logging-while-drilling tool of claim **13** wherein:

the radial surface of each of said lands is relieved inward from its upper and lower surfaces.

* * * * *