DIRECT DRIVE MWD TOOL

Inventors: Marvin GEARHART, Fort Worth, TX (US); Daniel E. MILLIGAN, Willow Park, TX (US); Howard SMITH, Granbury, TX (US); Dennis L. NAYLOR, Hasket, TX (US); Michael REDMOND, Arlington, TX (US)

Correspondence Address:
STORM LLP
BANK OF AMERICA PLAZA, 901 MAIN STREET, SUITE 7100
DALLAS, TX 75202 (US)

Appl. No.: 12/508,338
Filed: Jul. 23, 2009

Related U.S. Application Data

Provisional application No. 61/083,052, filed on Jul. 23, 2008.

Publication Classification

Int. Cl. E21B 21/08 (2006.01)
U.S. Cl. ......................................................... 175/48

ABSTRACT

The present invention relates to a measurement-while-drilling tool [2] with a mechanically driven poppet [216] which eliminates the flow of drilling fluid through the tool, and reliance on surface supplied hydraulic force to activate the poppet [216]. The present invention eliminates the pilot valve system, and generates a fluid pulse from a direct drive relationship between a reversible motor [414], actuator [300], and poppet valve [216]. A pulser [200] has a push rod [214] slidably located inside. Poppet [216] is located on the push rod [214]. Actuator [300] is connected to the pulser [200], and has a ball screw [334] mechanically connected [330] to the push rod [214]. An electric motor [414] and gear train is operatively connected [338] [340] [342] to the ball screw [334]. Motor [414] generates linear movement of the poppet [216] in relation to an orifice [112] to restrict flow and generate a pulse.
DIRECT DRIVE MWD TOOL

TECHNICAL FIELD OF THE INVENTION

[0001] The present invention relates to a measurement-while-drilling tool with a direct drive poppet. The tool eliminates the flow of drilling fluid through the tool, and eliminates reliance on surface supplied hydraulic force to activate the main poppet. The present invention eliminates the pilot valve system, and generates a fluid pulse from a direct drive relationship between a reversible motor, actuator, and poppet valve. The simplified and compartmentalized tool vastly increases reliability in formations where lost circulation material is required. The tool design facilitates rapid field servicing and component replacement without the need to remove the tool from the drilling site for specialized service. In particular, the pressure compensation system and reservoir are segregated from fluid integration with the actuator mechanism's lubricants. The present invention provides MWD stocking. The present invention also permits disconnection of tool sections adjacent the pressure compensating reservoir without drawing a vacuum for oil filling of those sections. The present design also provides for the manufacture of a much shorter and less expensive tool.

BACKGROUND OF THE INVENTION

[0002] In the exploration of oil, gas, and geothermal energy, drilling operations are used to create boreholes, or wells, in the earth. In many locations, it has been found to be advantageous to be able to track the position and direction of the subterranean drill bit during the drilling process. Measurement-while-drilling (MWD) tools have been developed for this purpose.

[0003] MWD tools typically have electromechanical accelerometers mounted with their sensitive axis aligned orthogonally to the spin axis and to each other. Micro-electrical-mechanical systems (MEMS) based accelerometers are also available. Tools may also include other sensors for determining properties such as wellbore temperature and azimuthal direction of inclination of the wellbore. For example, gyroscopes or magnetometers may also be included. The sensors are operated on power provided by a rechargeable battery pack located in the tool. Data recorded from the sensors is sent to onboard memory. The data is coded into pulses similar in theory to Morse code. Each MWD system has its own proprietary code.

[0004] A pulser located in the MWD tool is provided to generate hydraulic pulses at the MWD tool. The pulses create waves in the fluid mud column that reach the surface, where pressure sensors record them. The recorded pulses are filtered to remove normally occurring extraneous signal noise unrelated to the pulses sent by the MWD tool. The filtered pulses are then decoded to reveal the data recorded by the MWD sensors. The data is then displayed at the surface in a manner useful to the drilling personnel.

[0005] Pulses may be generated in a variety of manner, including positive pulse, negative pulse, and combinations thereof. Conventional MWD units have a pilot valve that actuates a primary pulser or poppet. In this manner, a stronger pulse can be sent into the mud column which permits detection and identification apart from system noise and decoding by the surface equipment.

[0006] MWD tools are available in retrievable or non-retrievable designs. Retrievable MWD tools can be removed from the drill string at any time. Non-retrievable MWD tools remain in the drill string until the drill string is removed from the wellbore. Upon retrieval, MWD tools frequently require mechanical and electrical service.

[0007] Conventional pulser units include solenoid and motor driven varieties. Conventional motor driven pulser utilize a magnetic coupling to transmit power between the motor and a ball screw assembly. The ball screw assembly actuates a pilot valve, which in turn operates the pulser. This system takes advantage of the hydraulic fluid power provided by the surface pumps, which pump fluid over and through the MWD tool. By redirecting the fluid with a low power pilot valve, a pressure differential is created within the tool that operates the pulser to create a pressure pulse within the mud column.

[0008] Conventional MWD designs have combined lubrication and pressure compensation system. The system is intended to equalize the internal pressure of the lubrication and compensating reservoir with the external wellbore pressure, while using the compensating fluid for lubrication of the actuator mechanism. A pressure balance rod on which the pilot valve is attached is exposed to both internal and external pressures, and operates better when the internal and external pressures are balanced. Without a balanced system, the motor and actuator must overcome the pressure differential, with energy supplied by the limited batteries source. The reservoir also serves as the lubrication system for the actuator, substantially enclosing the magnetic coupler and ball screw assemblies.

[0009] Due to the harsh environment in which survey tools operate, they are carefully sealed to protect the internal components. When motors are used, special seals are required to prevent the oil from leaking past the magnetic couplers into the motor. The lubrication and compensation reservoir is typically vacuum-filled and sealed on a shop bench.

[0010] A principal disadvantage of existing MWD tools is the susceptibility of pilot valves to clogging due to lost circulation material (LCM). The LCM becomes trapped between the pilot valve and the seat of the valve, causing the tool to fail. Even when complete failure is averted, the magnetic couplings may begin to slip in the high torque condition created by the interfering LCM, and thus rendering false pulse patterns.

[0011] When an MWD tool fails from pilot valve clogging with LCM, drilling fluid is unable to pass through the tool. This raises the fluid pressure of the system. The result is that even if the operator elected to forgo the measurements provided by the tool, he cannot drill ahead, as there is insufficient fluid flow rate passing through the tool to the drill bit. Pressure (or flow rate) to the drill bit is critical to the operation of the drill bit. The only available solution is to pull the tool from the drill string, and replace it with another tool.

[0012] Another disadvantage of the combined lubrication and pressure compensation system of known MWD tools is reliability and serviceability. When direct drive motors are used instead of magnetic couplings, the pressure compensating and lubrication oil must be sealed from the rotating shaft of the motor. The seal against the rotating shaft will have a limited life. The brushes and field coils of the motor will eventually pick-up the metal-iron lines and impurities in the oil, causing the motor to fail. When the motor fails, servicing the motor requires disassembly and drainage of the lubrication and compensation reservoir and, thus, return of the tool to the shop bench for sealing, reassembly and reservoir refilling.
under vacuum. Conventional MWD tools with lengthy components and integrated lubrication and compensation reservoirs are not, thus, serviceable in the field.

Another disadvantage of known MWD tools is the pressure loss associated with the location of the tool within the confines of the internal diameter of drill collars. Pressure is lost due to high flow rates between the exterior of the MWD tool and the drill collar I.D. This pressure is then unavailable to the drill bit. Pressure (or flow rate) to the drill bit is critical to the rate of penetration and life of the drill bit, and is a significant factor in the calculation of the cost per foot of the drilling operation. The larger the diameter of the MWD tool, the greater the system pressure loss will be. Similarly, the longer the MWD tool, the greater the system pressure loss will be.

Another disadvantage of known MWD tools is material cost. Due to the high velocity of the fluid between the exterior of the MWD tool and the inside diameter of the drill collars, expensive alloyed materials are required. Typically, the housing of conventional MWD tools is made from beryllium copper or a similarly wear resistant material. As a result, larger MWD tool diameters and longer length tools substantially increase the material cost of the tool.

Another disadvantage of known MWD tools utilizing motors is that commercially available motors have a significantly larger form factor (profile) than do solenoid systems, thus requiring larger diameter housings and increased material cost. Also, higher-powered commercially available motors capable of extended service are larger in diameter. Additionally, motors are provided with mounting brackets that are external to the circumference of the motor housing. Therefore, increasing the motor power requires increasing the diameter of the tool. Of similar disadvantage, magnetic couplings are relatively lengthy assemblies.

Therefore, there is a need to develop an MWD tool which can withstand the application of LCM in the drilling environment without clogging, failing, or communication false pulse signals. There is also a need for creating an MWD tool that upon failure, permits continued drilling. There is also a need for creating an MWD tool that can be serviced at the rig floor without draining the lubrication and compensation system, and without requiring shop delivery to be assembled and refilled. There is a further need to develop an improved MWD tool having a shorter length to save cost and drilling efficiency. There is also a need to develop an MWD tool having greater reliability obtained from a more powerful motor driven actuator, without the increasing manufacturing and drilling costs associated with increased tool diameter. Lastly, there is a further need to develop a more compact and effective pressure compensation system that allows optimization of motor lubricants and pressure compensating capabilities.

There is also a need to accomplish these goals at a reasonable cost. The harsh drilling environment has prevented efforts to accomplish these goals in the past.

SUMMARY OF THE INVENTION

As referenced herein throughout, the terms “downward,” “lower,” “bottom,” and “below” refer to the direction or portion of a part or assembly located or oriented towards the bottom of the wellbore when being used in a drilling assembly. The terms “upward,” “upper,” “top,” and “above” refer to the direction or portion of a part or assembly located or oriented towards the top of the wellbore when being used in a drilling assembly.

The present invention provides a substantially improved MWD tool. More specifically, the present invention is directed to a new and novel direct drive pulsing system. Secondly, the present invention is directed to the pressure balance and actuator assembly portion of the tool which includes a pressure compensation reservoir isolated from the actuator chassis, motor and ball screw mechanism.

The MWD tool of the present invention has a lower pulser housing having an orifice provided therein. A pulser is connectable inside the lower pulser housing, and has a hollow pulser chassis with a push rod slidably located inside the pulser chassis. A poppet is located on the lower end of the push rod. An actuator is connected above the pulser, and has a ball screw mechanism mechanically connected to the upper end of the push rod. A motor-electronics assembly is connected above the actuator, and has an electric motor and gear train. The gear train is operatively connected to the upper end of the ball screw mechanism. Rotation of the motor mechanically generates linear movement of the poppet in relation to the orifice.

In another preferred embodiment, the actuator has an actuator chassis having an internal central bore throughout. An enlarged chamber is formed on the central bore. A compression spring is located in the chamber between the actuator chassis and the ball screw mechanism. In this embodiment, movement of the poppet towards the orifice compresses the spring, and the spring urges the poppet to return to the retracted (non-actuated) position.

In another preferred embodiment, when compressed (actuated position), the spring applies sufficient force against the ball screw mechanism to retract the poppet away from the orifice when no power is supplied to the motor.

In another preferred embodiment, the spring has a spring rating between 100 and 300 pounds, and has a pre-load compression of between 10 and 80 pounds in the retracted (non-actuated) position.

In another preferred embodiment, a piston is formed on the push rod. The piston is axially slideable within a cylinder formed inside the pulser chassis. A fluid-filled pressure compensating reservoir is provided in axially sealed relationship on the pulser chassis. The fluid in the reservoir is in fluid communication with the piston in the cylinder. A pliable bladder circumferentially surrounds the pressure compensating reservoir. A plurality of vents is located through the lower housing in substantial alignment with the bladder such that the bladder is exposed to the drilling fluid flowing over the MWD tool. In this embodiment, the drilling fluid pressure on the bladder is transferred to the piston, and directly to the poppet itself.

Also, in this embodiment, upon disconnection of the motor-electronics chassis from the actuator for service of the tool, the fluid in the compensating reservoir remains axially sealed within the pulser.

In another preferred embodiment, the cross-sectional area of the cylinder bore minus the cross-sectional area of the push rod above the piston is substantially equal to the cross-sectional area of the push rod below the piston.

In another preferred embodiment, the motor-electronics chassis is connected to the upper end of the actuator chassis. A motor is located inside the motor-electronics chassis and has a gear train attached to the motor, extending into the actuator chassis. In this embodiment, the gear train and motor are not exposed to the pressure compensating fluid.
In another preferred embodiment, the actuator chassis has a pair of diametrically opposing longitudinal slits extending to the upper end of the actuator chassis. A pair of threaded fastener holes intersect each slit in a perpendicular relation. A threaded fastener is located in each fastener hole. A portal is located internally of the fastener holes. A cylindrical and preferably case-hardened gear train housing is attached to the motor. The gear train housing is locatable in the portal. Tightening the fasteners in the fastener holes compresses the portal interior onto the gear train housing to secure the gear train housing in position.

The principal advantage of the present invention is that it provides a much more compact, cost effective, and reliable MWD tool that is strongly resistant to clogging with LCM. Another advantage of the present invention is that it provides a tool that, if the electrical power supply, electronics, or motor fail, the tool will mechanically return to a retracted position, so as to prevent restriction of drilling fluid so that drilling operations can continue. Another advantage of the present invention is that it provides a tool that permits addition of a second MWD tool above it as a reserve tool. A principal advantage of the present invention is that it provides a compact and effective pressure compensation system. Another advantage of the present invention is that it provides segregation between actuator lubricants and pressure compensating fluids, permitting optimized selection of each.

Another advantage of the present invention is that it provides enhanced serviceability on the rig floor by permitting disassembly without draining the lubrication system or the pressure compensating system, and thus does not require return of the tool to the shop bench for reservoir refilling and sealing.

Another advantage of the present invention is that it provides an MWD tool with a lower material cost. As referred to heretofore and throughout, the “present invention” refers to one or more embodiments of the present invention, which may or may not be claimed, and such references are not intended to limit the language of the claims, or to be used to construe the claims in a limiting manner.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The objects and features of the invention will become more readily understood from the following detailed description and appended claims when read in conjunction with the accompanying drawings in which like numerals represent like elements.

The drawings constitute a part of this specification and include exemplary embodiments to the invention, which may be embodied in various forms. It is to be understood that in some instances various aspects of the invention may be shown exaggerated or enlarged to facilitate an understanding of the invention.

**FIG. 1** is a partially sectioned side view of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention, shown as fully assembled with centralizer and lifting sub in place.

**FIG. 2** is a side sectional view of a landing sub of the type that may be used in conjunction with the preferred embodiments of the present invention, illustrated with a lower housing positioned in the landing sub.

**FIG. 3** is an isometric view of the lower housing portion of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention, and showing an outer portion, an inner portion and lugs connecting the outer and inner portions.

**FIG. 4** is a side sectional view of the lower portion of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention, and showing the pulser in the lower housing, with the direct drive actuator attached above the pulser and the motor electronics assembly attached above the direct drive actuator.

**FIG. 5** is a side sectional view of the pulser and pressure balance assembly of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention.

**FIG. 6** is a partial cross-sectional view of the actuator chassis component of the actuator illustrated in accordance with a preferred embodiment of the present invention.

**FIG. 7** is a side sectional view of the actuator of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention, and shown connected to the direct drive pulser.

**FIG. 8** is a side sectional view of the motor and electronics assembly of the MWD tool, illustrated in accordance with a preferred embodiment of the present invention.

**DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS**

The following description is presented to enable any person skilled in the art to make and use the invention, and is provided in the context of a particular application and its requirements. Various modifications to the disclosed embodiments will be readily apparent to those skilled in the art, and the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention. Thus, the present invention is not intended to be limited to the embodiments shown, but is to be accorded the widest scope consistent with the principles and features disclosed herein.

**FIG. 1** is a partially sectioned side view of MWD tool 2, illustrating MWD tool 2 engaged in a landing sub 10. MWD tool 2 has an upper end and a lower end, the lower end being disposed closest to the drill bit. A lower housing 100 comprises the lower end. A pulser 200 is located in lower housing 100. Pulser 200 includes a pressure balance system. An actuator 300 is attached above pulser 200. A motor and electronics assembly 400 is attached above actuator 300. A centralizer 500 is typically attached above motor and electronics assembly 400. A battery barrel 600 is attached above centralizer 500. A lifting connection 700, such as a rope socket, is typically attached above battery barrel 600.

**FIG. 2** is a side sectional view of landing sub 10, illustrating a lower housing 100 of MWD tool 2 located in place inside landing sub 10. Landing sub 10 is provided or located in the collar section of a drill string. Landing sub 10 is positioned in the drill string above the drill bit and mud motor, if one is used. Lower housing 100 is secured in position within landing sub 10 by a plurality of positioning fasteners such as set screws. An orifice sleeve 110 is located at the bottom of lower housing 100. A carbide orifice 112 is located inside orifice sleeve 110. Orifice sleeve 110 is secured in lower housing 100 by set screws 114. Seals 116 prevent fluid passage between orifice sleeve 110 and lower housing 100. An orifice seal 118 prevents fluid passage between carbide orifice 112 and sleeve 110. A plurality of pulser housing seals 120...
prevent fluid passage between the exterior of lower housing 100 and landing sub 10. The upper end of lower housing 100 has a threaded coupling 140.

[0046] FIG. 3 is an isometric view of the lower housing 100, illustrated in accordance with a preferred embodiment of the present invention. Lower housing 100 has a hollow outer section 102 on its lower end. A plurality of fins 104 extend upwards from outer section 102. In the preferred embodiment, three fins 104 are located 120° apart. A fastener hole 130 is provided in one or more fins 104 for receiving a fastener 122 for attachment of pulser 200 inside housing 100 (see FIG. 4). A hollow inner section 106 is located between fins 104 at the upper end of lower housing 100. A plurality of vents 108 extend between the interior and exterior of inner section 106. A threaded connection 140 is located on the upper end of inner section 106. A plurality of slots 132 are provided for receiving positioning fasteners such as set screws which locate and position lower housing 100 inside landing sub 10.

[0047] FIG. 4 is a side sectional view of the lower portion of MWD tool 2, illustrated in accordance with a preferred embodiment of the present invention. As seen in this illustration, pulser 200 is located in lower housing 100. Unique to the present invention, actuator 300 is attached directly to pulser 200. Motor and electronics assembly 400 is attached directly above actuator 300. An upper housing 490 is located over actuator 300 and motor and electronics assembly 400, and attached at its lower end by threaded connection to threaded coupling 140 of lower housing 100. As seen in this view, pulser 200 is secured in lower housing 100 by one or more fasteners such as cap screw 122.

[0048] FIG. 5 is a side sectional view of pulser 200. Pulser 200 is comprised of a pulser chassis 210 having a profiled interior bore 212. A push rod 214 slides through interior bore 212 of pulser chassis 210 and beyond the top and bottom ends of pulser chassis 210. A poppet 216 is attached to the lower end of push rod 214. Poppet 216 is normally made of a hard, wear resistant material, such as carbide. At least one rod seal 218 is located at the lower end of pulser chassis 210 for sealing between push rod 214 and pulser chassis 210. In the preferred embodiment, a second rod seal 219 is located at the lower end of pulser chassis 210 for sealing between push rod 214 and pulser chassis 210. An enlarged cylinder portion 220 is formed in interior bore 212 of pulser chassis 210. A piston 222 is formed on push rod 214. Piston 222 is located inside cylinder 220.

[0049] Pulser chassis 210 has an external relief portion 230 having a reduced external diameter. Circumferential grooves 232 may be provided on pulser chassis 210 on the upper and lower sides of external relief portion 230. A pliable bladder 234 surrounds external relief 230, forming a reservoir 236 between relief portion 230 and bladder 234.

[0050] Bladder 234 is circumferentially secured and sealed to the external surface of pulser chassis 210 on both sides of external relief 230 in a fluid-tight manner, by clamps 238, which may be wrapped buss wire, or another clamping device. Clamps 238 are preferably located over grooves 232.

[0051] As disclosed, reservoir 236 is a compact and uniquely isolated pressure-compensating reservoir. Vents 108 through the inner section 106 of lower housing 100 are located above reservoir 236 to facilitate equalization of fluid pressure between the exterior of pulser 200 and pressure-compensating reservoir 236.

[0052] Reservoir fluid passages 240 provide fluid communication of compensating fluid between pressure compensating reservoir 236 and cylinder 220 above piston 222. One or more circumferential grooves 242 in piston 220 support a piston seal 226 located therein, forming a seal between piston 222 and cylinder 220. Piston seals 226 prevent passage of compensating fluid in cylinder 220 below piston 222. A pipe plug 248 in pulser chassis 210 provides access for fluid filling of pressure-compensating reservoir 236.

[0053] In the preferred embodiment, pulser chassis 210 has a receptacle 250 on its upper end for receiving an actuator chassis 310 of actuator 300. A first bushing 314 is formed on the lower end of actuator chassis 310 and received in cylinder portion 220, forming the upper end of cylinder 320. A plurality of holes 252 are drilled axially through receptacle 250 for receiving fasteners for secure attachment of actuator 300 to pulser 200. A plurality of exterior seals 254 form a fluid tight seal between pulser chassis 210 and lower housing 100.

[0054] FIG. 6 is a partial cross-sectional view of the actuator chassis component of the actuator illustrated in accordance with a preferred embodiment of the present invention.

[0055] A first bushing 314 is formed on the lower end of actuator chassis 310. A second bushing 320 is formed above first bushing 314. Referring to FIG. 4 and FIG. 5, when actuator chassis 310 is connected to pulser chassis 210, first bushing 314 is received inside cylinder 220, forming the upper end of cylinder 220. Second bushing 320 is received in complementary fit inside receptacle 250. A plurality of holes 326 are drilled axially through second bushing 320. Holes 326 align with holes 252 in receptacle 250 for receiving fasteners for secure attachment of actuator 300 to pulser 200.

[0056] Actuator chassis 310 has a central bore 312 for receiving push rod 214 in sliding relation. A seal groove 316 is formed in central bore 312 within bushing 314 for location of one or more rod seals 318. An external seal groove 322 is provided on the exterior of bushing 314 for location of one or more seal shells 324 for sealing between bushing 314 of actuator chassis 310 and internal bore 212 of pulser chassis 210. In this embodiment, rod seals 318 and chassis seals 324 provide the upper end seals of the pressure compensating system.

[0057] In the above described configuration, piston 222 operates to move push rod 214 in response to pressure changes at the surface of bladder 234 from within the bore. This configuration is unique in that the hydrostatic pressure within the well is fluid compensated directly to poppet 216. In the preferred embodiment, the cross-sectional area of cylinder 220 minus the cross-sectional area of the portion of push rod 214 above piston 222 is substantially equal to the cross-sectional area of push rod 214. The result is a force-balanced movement of poppet 216, in either direction, in response to pressure changes acting on substantially equal areas.

[0058] In this manner, an isolated and minimized volume pressure-compensating reservoir 236 can operate in direct mechanical connection to poppet 216 and still ensure downhole hydrostatic pressure does not impair or impede the ability of the actuator 300 to operate poppet 216 directly.

[0059] The configuration detailed above isolates the pressure compensation fluid from other moving parts within the actuator 300. Importantly, this permits utilization of lubricants that may be less suitable in performance as pressure compensating fluids, and vice-versa. In particular, grease has
been found to be a superior lubricant for the actuator ball screw, but inferior in performance as a compensating fluid.

[0060] The above-described design further permits service to most component portions of MWD tool 2 without the need to return the tool to the shop to replace the compensating fluid. Simple bench service of the tool can be performed without the loss of the critical compensating fluid. This is increasingly useful as newer tools are beginning to have reconfiguration options related to the well conditions and required information.

[0061] Referring again to FIG. 6, the upper end of actuator chassis 310 is configured for connection to a motor-electronics chassis 410. Tabs 354 extend axially upward from the upper end of actuator chassis 310 to engage with complementary slots on a motor-electronics chassis 410. A pair of diametrically opposed slits 356 extends longitudinally downward from the upper end of actuator chassis 310. A pair of threaded fastener holes 358 intersects each slit in perpendicular relation. A portal 362 is located internally of fastener holes 358.

[0062] FIG. 7 is a side sectional view of actuator chassis 300 of the MWD tool 2, illustrated in accordance with a preferred embodiment of the present invention, and shown with actuator chassis 310 rotated 90° relative to FIG. 6. As seen in FIG. 7, and unique to the present invention, actuator 300 is directly connected to pulser 200. Actuator chassis 310 is located centrally inside upper housing 490 between pulser chassis 210 and motor-electronics chassis 410 and secured to each. Actuator chassis 310 has a central bore 312 for receiving push rod 214 in sliding relation. At the upper end of actuator 300, a gear train 430 of a motor 414 extends into the interior of actuator chassis 310. Actuator 300 connects push rod 214 to an output shaft of gear train 430 through a ball screw mechanism, which translates rotation of motor 414 into linear movement of push rod 214.

[0063] An enlarged chamber 350 is formed on central bore 312. Inside chamber 350, a shoulder bolt 350 connects the upper end of push rod 214 to a ball screw nut connector 332 on actuator chassis 310. A compression spring 370 is partially compressed between actuator chassis 310 and nut connector 332. In the preferred embodiment, spring 370 is a helical coil spring having a compressive strength of between about 200 and 300 pounds/inch. In a more preferred embodiment, spring 370 is pre-compressed with a force of between 10 and 80 pounds with poppet 216 in the non-actuated position (retracted from orifice 112). In a still more preferred embodiment, spring 370 has sufficient strength, when compressed, to force nut connector 332 of the ball screw mechanism and push rod 214 to retract poppet 216 away from orifice 112 when no power is applied to the motor.


[0065] In the preferred embodiment, an Oldham connector 342 is connected to motor gear train 430. A thrust bearing assembly 340 is attached to Oldham connector 342 at one end. At its opposite lower end, thrust bearing assembly 340 is connected to screw shaft 334 by shaft connector 338. Shoulder bolt 330 limits the longitudinal travel of nut connector 332 within a longitudinal slot 352 in actuator chassis 310. Rotation of nut connector 332 is also thus prohibited.

[0066] Operation of motor 414 moves nut connector 332 and push rod 214 longitudinally to open poppet 216 in relation to orifice 112. In the normal, non-actuated position, poppet remains open. In the actuated position, poppet 216 is closed. Closing poppet 216 creates a marked restriction in the total flow area causing a pressure spike, or pulse, in the supply side of the fluid system, which is received by pressure monitoring equipment at the surface of the well. Closing poppet 216 compresses spring 370, which urges return of poppet 216 back to the non-actuated position.

[0067] FIG. 8 is a side sectional view of motor and electronics assembly 400 illustrated in accordance with a preferred embodiment of the present invention. Motor-electronics chassis 410 supports motor 414, gear train 430 (see FIGS. 4 and 7), and a motor electronics circuit board 420. A compressible rubber snubber 438 internally secures motor-electronics chassis 410. Removal of upper housing 490 provides access to actuator chassis 310 and motor-electronics chassis 410. Upper housing 490 can be removed without loss of oil from a pressure compensation reservoir 236.

[0068] Referring to FIGS. 6 and 7, tabs 354 extend axially upward from the upper end of actuator chassis 310. Tabs 412 extend downward from the lower end of motor-electronics chassis 410. Tabs 354 and 412 engage complementary slots for aligned engagement of actuator chassis 310 and motor-electronics chassis 410, and preventing relative rotation between actuator chassis 310 and motor-electronics chassis 410.

[0069] As seen in FIG. 6, a pair of diametrically opposed slits 356 extends longitudinally from the lower end of actuator chassis 310. Threaded fastener holes 358 intersect each slit 356 in perpendicular relation. Threaded fasteners 360 (FIG. 7) are located in holes 358. The upper end of actuator chassis 310 also has a portal 362 located internally of fastener holes 358. As seen in FIG. 7, when motor-electronics chassis 410 is attached to actuator chassis 310, portal 362 receives gear train 430 and motor 414 is received beneath tabs 354 and 512.


[0071] A centralizer 500 is typically attached above motor and electronics assembly 400 to centralize MWD tool 2 in the drill string. A battery barrel 600 is attached above motor and electronics assembly 400. Battery barrel 600 provides the power needed to operate MWD tool 2. A lifting connection with a centralizer 700 is typically attached above battery barrel 600 to centralize the upper portion of MWD tool 2 in the drill string.

Operation of the Invention

[0072] Conventional MWD tools provide the drilling fluid with two primary flow paths controlled by the presence and operation of the conventional MWD tool. A first flow path is through the interior of the tool, and the second flow path is over the exterior of the tool. All flow rate eventually passes between a poppet and an orifice.

[0073] Conventional MWD tools use a motor and actuator to activate a pilot valve. Operation of the pilot valve alters the internal and exterior flow paths, which changes the flow rates of each as the drilling fluid seeks the path of least resistance.
For example, opening the pilot valve causes the main poppet to close, sending a pulse. Closing the pilot valve causes the poppet to remain open, sending no pulse. Thus, in summary, conventional MWD systems use a motor and actuator to operate a pilot valve, which redirects flow through the tool. The redirected flow then utilizes a portion of the hydraulic power from the mud pumps to operate the poppet. Closing the poppet creates a marked restriction in the total flow area, which causes a pressure spike, or pulse, in the supply side of the fluid system. Pressure monitoring equipment at the surface of the well senses and records the pressure spikes. System software decodes the sequence of pressure spikes to obtain well direction data.

[0074] The present invention eliminates the conventional pilot valve system entirely, and eliminates the loss of system pressure associated with internal tool flow and operation of the poppet. As a result, more system pressure is available to the drill bit, and plugging of the pilot valve system with LCM has been eliminated. Additionally, because MWD tool 2 significantly reduces pressure loss associated with flow through the tool internally, it is possible to set a second MWD tool above MWD tool 2 in the event of any failure of MWD tool 2.

[0075] Referring to FIG. 3, lower housing 100 has a hollow outer section 102 on its lower end, a plurality of fins 104 extending upwards from outer section 102, and overlap onto inner section 106. Orifice 112 is located inside outer section 102. Drilling fluid flows over inner section 106 between fins 104. The drilling fluid then passes through orifice 112. Poppet 216 is moved axially towards and away from orifice 112, restricting the flow area at orifice 112, which causes a pressure spike, or pulse, in the supply side of the fluid system. Pressure monitoring equipment at the surface of the well senses and records the pressure spikes. System software decodes the sequence of pressure spikes to obtain well direction data. Thus, it is seen that unlike conventional MWD tools, drilling fluid does not otherwise enter any interior section of MWD tool 2 in any diverted flow pattern.

[0076] Referring to FIG. 7, a spring 370 is located in a chamber 350 in actuator chassis 310. In opposite configuration to conventional MWD tools, spring 370 is configured to urge poppet 216 into the retracted position. In the preferred embodiment, spring 370 has sufficient strength, when compressed, to force nut connector 332 of the ball screw mechanism and push rod 214 to retract poppet 216 away from orifice 112 when no power is applied to the motor. In this manner, de-energizing motor 414 due to failure of battery barrel 600 or motor-electronics assembly 400, results in retraction of poppet 216 from orifice 112. This designed response has the significant advantage of allowing drilling to continue when MWD tool 2 fails, as drilling fluid can pass through orifice 112 unobstructed by poppet 216. Spring 370 is also designed to assist motor 414 in retracting poppet 216 in the face of turbulent flow over poppet 216. This is in contrast to conventional tools which redirect the drilling fluid to the exterior of the tool to retract the main poppet.

[0077] Referring to FIG. 4, the direct drive operation of MWD tool 2 is disclosed. Motor-electronics assembly 400 receives power from battery barrel 600 (FIG. 1). In the preferred embodiment, the navigation electronics 440 are included on motor-electronics assembly 400. The electronics control the operation of motor 414. As motor 414 operates, the rotation of motor 414 is translated into linear motion by actuator 300, which is mechanically connected to poppet 216 through push rod 214.

[0078] Referring to FIG. 5, the configuration detailed above provides a pressure compensating system that places a balancing force directly on poppet 216, through piston 222 on push rod 214. The system isolates the pressure compensating fluid from other moving parts within actuator 300, including motor 414, and thus protecting motor 414 from premature failure. This permits utilization of lubricants that may be less suitable in performance as pressure compensating fluids, and vice-versa. In particular, grease has been shown to be a superior lubricant for the actuator ball screw, but is inferior in performance as a compensating fluid. Similarly, oils that maintain constant viscosity over the operating temperature range of MWD tool 2 are superior pressure compensating fluids, but may be inferior to certain greases, such as a ball screw or thrust bearing lubricant.

[0079] One result of the design described is that it is significantly shorter than prior art designs, and is smaller in diameter than conventional designs using a motor having the same performance characteristics. This reduces the material cost of the MWD tool. An additional benefit is that the shorter length and smaller diameter reduce the drilling fluid pressure loss through MWD tool 2, providing more hydraulic horsepower to the jet nozzles of the drill bit.

[0080] It will be readily apparent to those skilled in the art that the general principles defined herein may be applied to other embodiments and applications without departing from the spirit and scope of the present invention.

[0081] Having thus described the present invention by reference to certain of its preferred embodiments, it is noted that the embodiments disclosed are illustrative rather than limiting in nature and that a wide range of variations, modifications, changes, and substitutions are contemplated in the foregoing disclosure and, in some instances, some features of the present invention may be employed without a corresponding use of the other features. Many such variations and modifications may be considered desirable by those skilled in the art based upon a review of the foregoing description of preferred embodiments. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

1. Measurement-While-Drilling Tool, comprising:
   a. lower housing having an orifice;
   b. a pulser connectable inside the lower housing, and having a hollow pulser chassis, a push rod slidably located inside the pulser chassis, and a poppet located on a lower end of the push rod;
   c. an actuator connected to an upper end of the pulser, and having a ball-screw mechanism mechanically connected to an upper end of the push rod;
   d. a motor-electronics assembly connected to an upper end of the actuator, and having an electric motor and gear train, the gear train operatively connected to the ball screw mechanism; and,
   e. wherein rotation of the motor generates linear movement of the poppet in relation to the orifice.

2. The Measurement-While-Drilling Tool of claim 1, further comprising:
   a. the actuator having an internal central bore;
   b. an enlarged chamber formed on the central bore;
   c. a compression spring located in the chamber, between the actuator chassis and the ball screw mechanism; and,
   d. wherein movement of the poppet towards the orifice compresses the spring.
3. The Measurement-While-Drilling Tool of claim 1, further comprising:
wherein as compressed, the spring applies sufficient force against the ball screw mechanism to retract the poppet away from the orifice when no power is supplied to the motor.

4. The Measurement-While-Drilling Tool of claim 1, further comprising:
the spring having a spring rating between 100 and 300 pounds; and,
the spring having a pre-load of between 10 and 80 pounds in the uncompressed position.

5. The Measurement-While-Drilling Tool of claim 1, further comprising:
a piston formed on the push rod, the piston being axially slidable within a cylinder formed inside the pulser chassis;
a fluid-filled pressure compensating reservoir in axially sealed relationship on the pulser chassis;
the fluid in the reservoir being in fluid communication with the piston in the cylinder;
a pliable bladder circumferentially surrounding the pressure compensating reservoir;
a plurality of vents located through the lower housing in substantial alignment with the bladder such that the bladder is exposed to drilling fluid external to the MWD tool; and,
wherein drilling fluid pressure on the bladder is transferred to the piston.

6. The Measurement-While-Drilling Tool of claim 1, further comprising:
the cross-sectional area of the cylinder bore minus the cross-sectional area of the push rod above the piston being substantially equal to the cross-sectional area of the push rod below the piston.

7. The Measurement-While-Drilling Tool of claim 1, further comprising:
the motor-electronics chassis connected to the upper end of the actuator chassis;
a motor located inside the motor-electronics chassis;
a gear train attached to the motor and extending into the actuator chassis; and,
wherein the gear train and motor are not exposed to the pressure compensating fluid.

8. The Measurement-While-Drilling Tool of claim 1, further comprising:
the actuator chassis having a pair of diametrically opposing longitudinal slits, extending to the upper end of the actuator chassis;
a pair of threaded fastener holes intersecting each slit in perpendicular relation;
a threaded fastener located in each fastener hole;
a portal located internally of the fastener holes;
a cylindrical gear train housing for a motor;
the gear train housing being locatable in the portal; and,
wherein tightening the fasteners in the fastener holes compresses the portal interior onto the gear train housing to secure the gear train housing in position.

9. The Measurement-While-Drilling Tool of claim 8, further comprising:
the gear train housing being made of a case-hardened material.

10. A modular Measurement-While-Drilling Tool, comprising:
a lower housing receivable in a landing sub, the lower pulser having an orifice located at its upper end;
a pulser located inside the lower housing;
an actuator connected to an upper end of the pulser;
a motor-electronics assembly removably connected to an upper end of the actuator;
a hollow upper pulser housing connectable over the motor-electronics chassis and actuator, and removably connectable to the upper end of the lower housing;
a fluid-filled pressure compensating reservoir in axially sealed relationship within the pulser;
a pliable bladder circumferentially surrounding the pressure compensating reservoir;
a push rod extending through the pulser in slidable relation;
a piston formed on the push rod, the piston being axially slidable within a cylinder bore portion of the push rod;
the compensating reservoir being in fluid communication with the cylinder bore above the piston;
a poppet on a lower end of the push rod, positioned for flow restricting alignment with the orifice of the lower housing;
the lower housing having a plurality of venting perforations positioned in alignment with the bladder such that the bladder is exposed to drilling fluid external to the MWD tool;
wherein drilling fluid pressure acting on the poppet is substantially compensated by fluid pressure in the compensating reservoir acting on the piston; and,
wherein upon disconnection of the motor-electronics chassis from the actuator chassis, the fluid in the compensating reservoir remains sealed therein.

* * * * *