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(54) **DIRECT DRIVE MWD TOOL**

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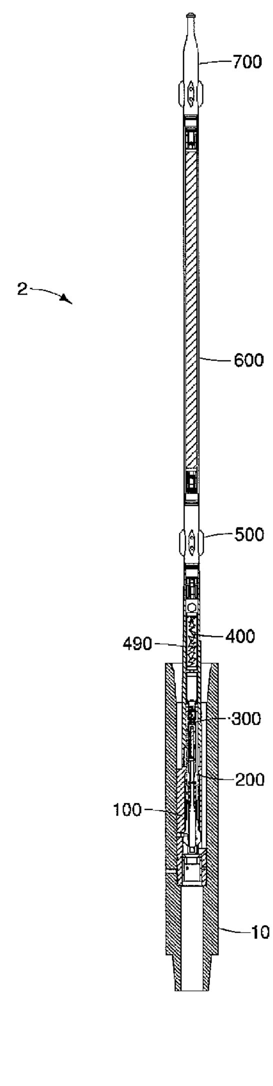
(52) **U.S. Cl.** **175/48**

(57) **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.



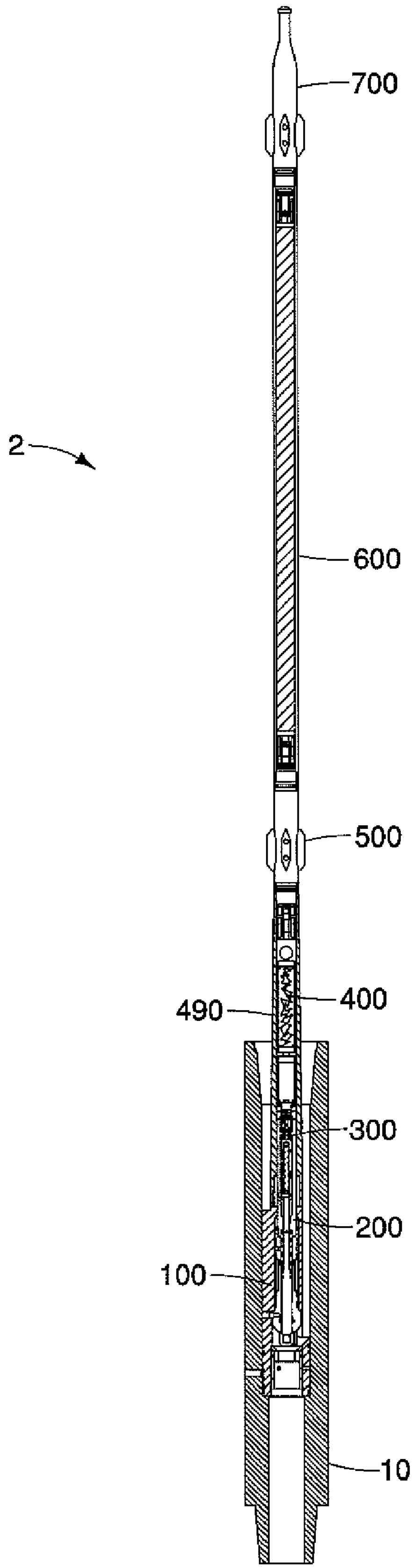


FIG. 1

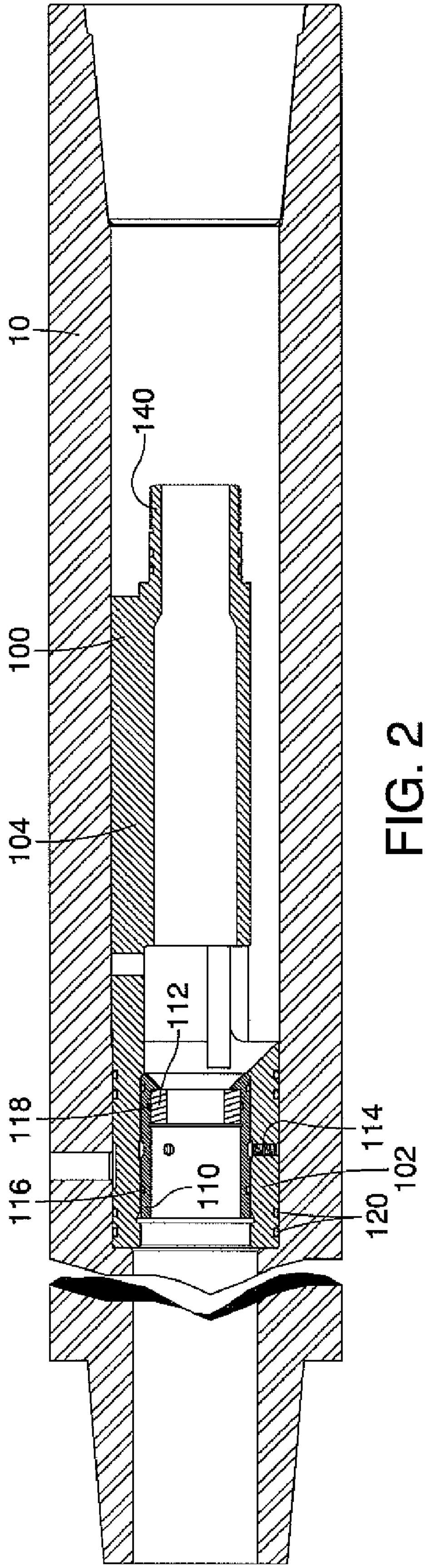


FIG. 2

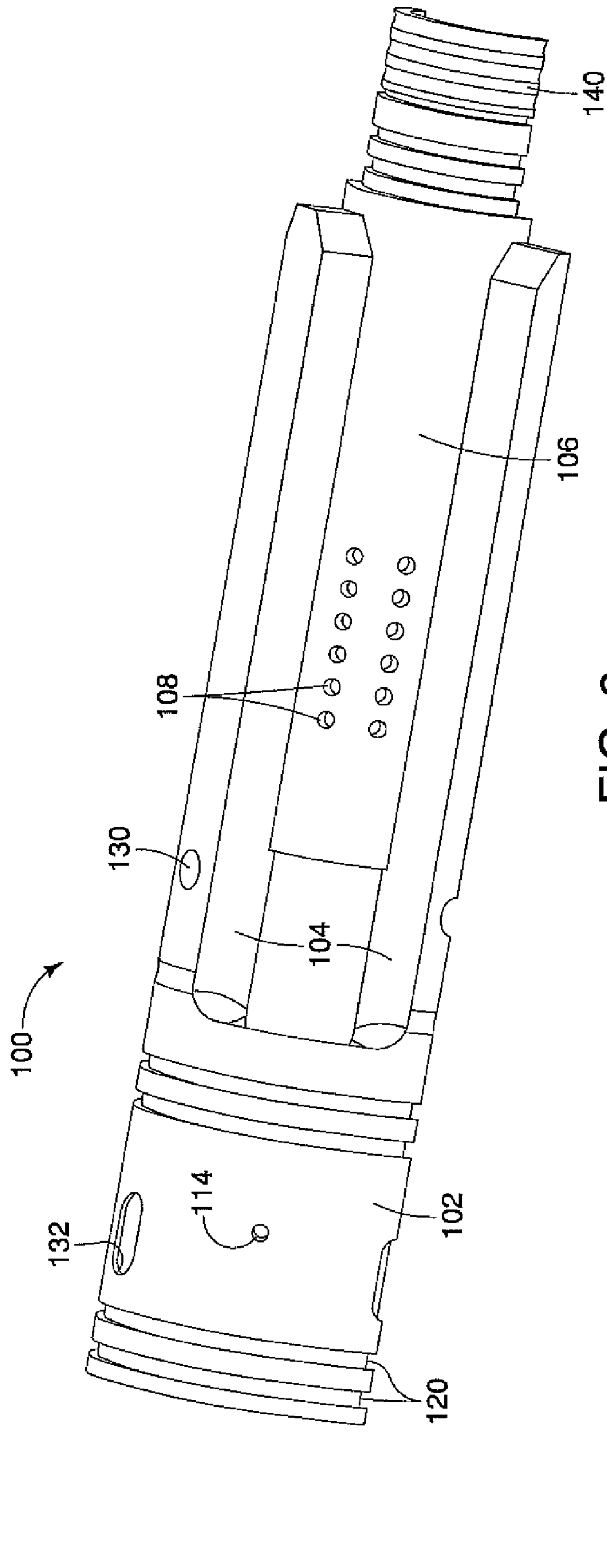


FIG. 3

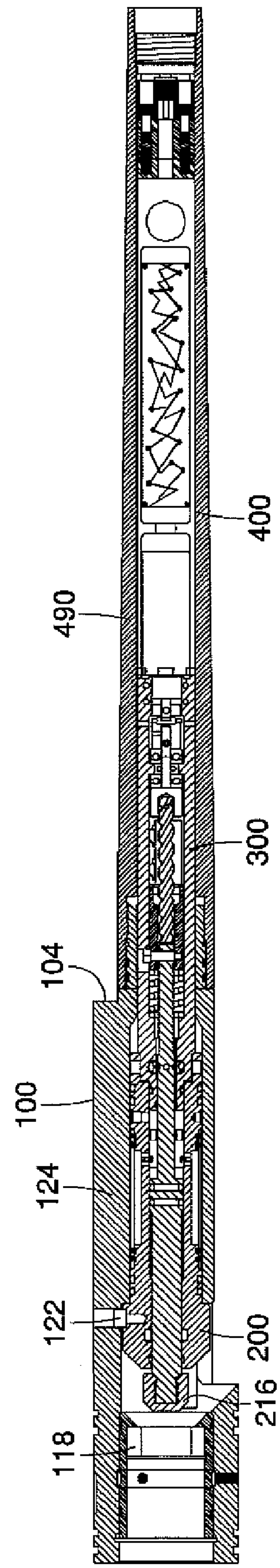


FIG. 4

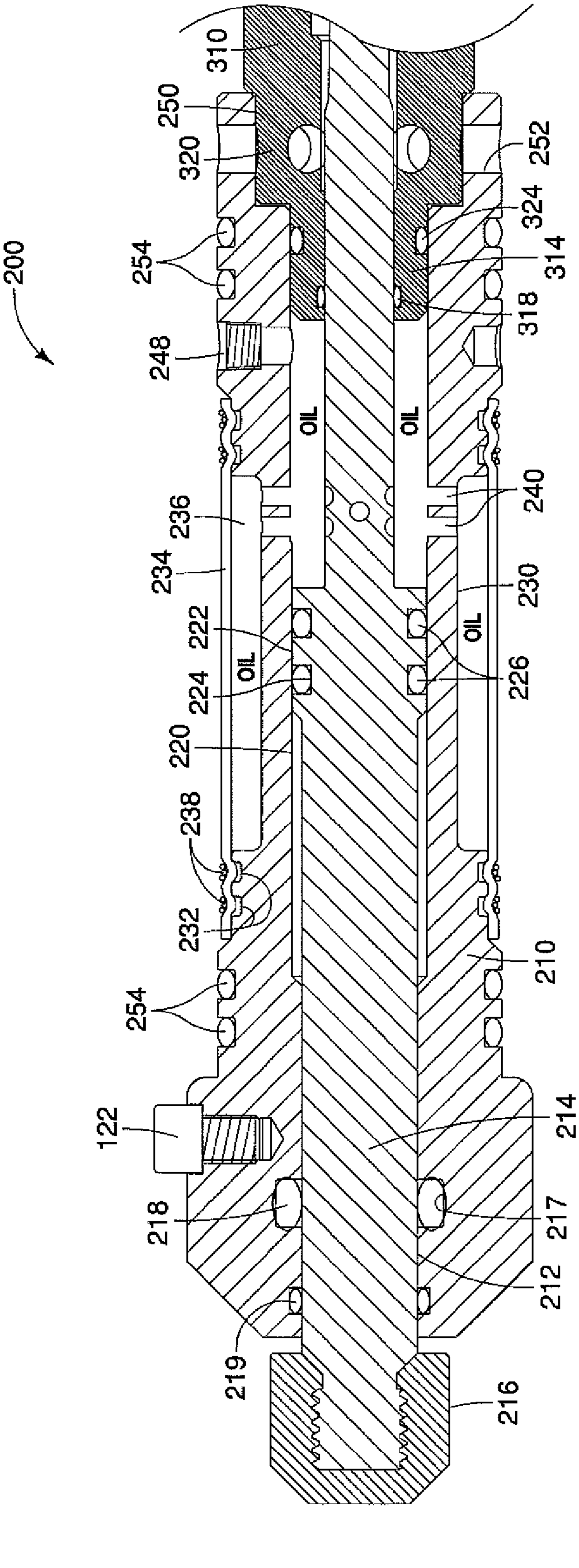

200
310
250
320
252
324
314
254
318
248
OIL
OIL
240
236
234
230
222
OIL
224
226
220
238
232
210
254
122
214
218
217
212
219
216

FIG. 5

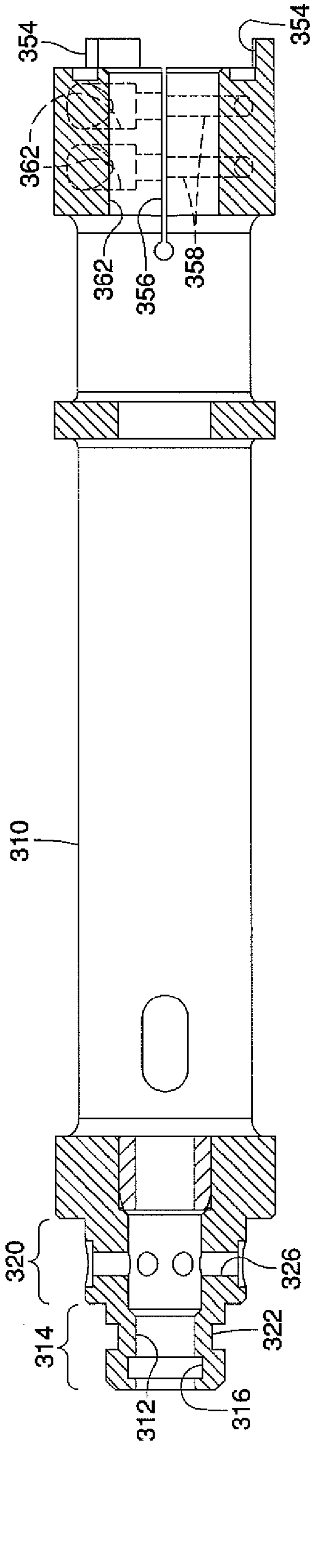


FIG. 6

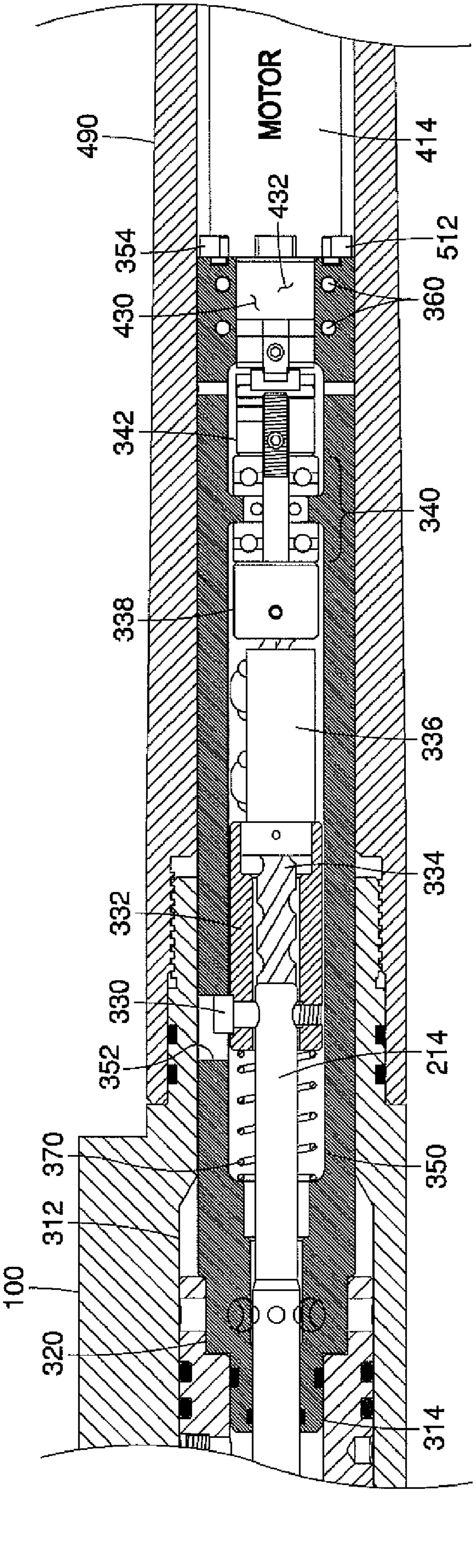

MOTOR
490
414
432
354
512
430
360
342
340
338
336
334
332
330
214
352
370
350
312
100
320
314

FIG. 7

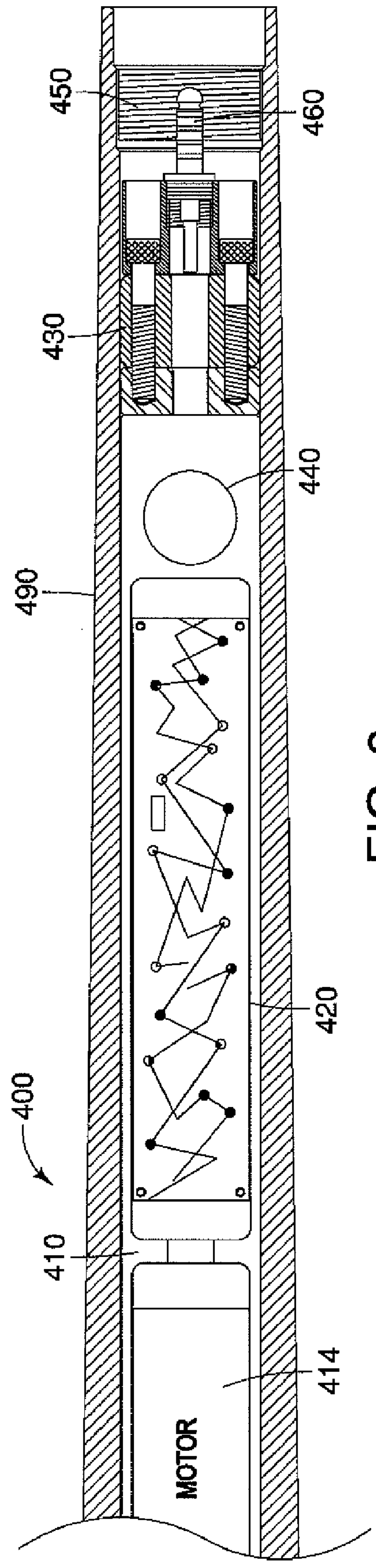


FIG. 8

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 stacking. 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 pulsers 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 a 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 though 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 fines 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.

[0013] 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 on 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.

[0014] 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.

[0015] 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.

[0016] 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 reassemble and refill. 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.

[0017] 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

[0018] 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.

[0019] 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.

[0020] 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.

[0021] 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.

[0022] 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.

[0023] 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.

[0024] In another preferred embodiment, a piston is formed on the push rod. The piston is axially slidable 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.

[0025] 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.

[0026] 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.

[0027] 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.

[0028] 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 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.

[0029] 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.

[0030] A principal advantage of the present invention is that it provides a more 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.

[0031] 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.

[0032] Another advantage of the present invention is that it provides an MWD tool with a lower material cost. As referred to hereinabove 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

[0033] 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.

[0034] 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.

[0035] 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.

[0036] 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.

[0037] 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.

[0038] 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.

[0039] 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.

[0040] 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.

[0041] 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.

[0042] 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

[0043] 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.

[0044] 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**.

[0045] 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** slidably extends 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 **224** in piston **222** 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** formed on the lower end of actuator chassis **310** is received in cylinder portion **220**, forming the upper end of cylinder **336**. 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 of more rod seals **318**. An external seal groove **322** is provided on the exterior of bushing **314** for location of one or more chassis seals **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 well 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 **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 **330** 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.

[0064] A screw shaft **334** extends upwards from nut connector **332** to a ball screw nut **336**. Axial movement of nut connector **332** results in movement of push rod **214** and opening and restricting flow in relation to orifice **112** of lower housing **100**.

[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**.

[0070] A housing **432** of gear train **430** is preferably case-hardened. Gear train housing **432** is compressively secured in portal **362** by tightening threaded fasteners **360** on actuator chassis **310**. Compression of longitudinal slits **356** by fasteners **360** secures gear train **430** in portal **362** of actuator chassis **310**.

[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;

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;

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;

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,

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:

the actuator having an internal central bore;

an enlarged chamber formed on the central bore;

a compression spring located in the chamber, between the actuator chassis and the ball screw mechanism; and,

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.

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