US009879529B2

(12) **United States Patent**
Scholz et al.

(10) **Patent No.: US 9,879,529 B2**
(45) **Date of Patent: Jan. 30, 2018**

(54) **APPARATUS FOR GENERATING PULSES IN FLUID DURING DRILLING OF WELLBORES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 252 days.

(21) Appl. No.: **14/714,442**

(22) Filed: **May 18, 2015**

(65) **Prior Publication Data**

US 2016/0341001 A1 Nov. 24, 2016

(51) **Int. Cl.**
E21B 34/06 (2006.01)
E21B 47/18 (2012.01)

(52) **U.S. Cl.**
CPC ***E21B 47/187*** (2013.01); ***E21B 47/185*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 47/18; E21B 47/12; E21B 47/187; E21B 47/185
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0145812 A1* 7/2005 Kumar F16K 31/10 251/129.15
2005/0260089 A1* 11/2005 Hahn E21B 47/182 417/505
2013/0342354 A1* 12/2013 Petrovic G01V 11/002 340/854.6
2015/0123808 A1* 5/2015 Vick, Jr. E21B 47/122 340/854.6

* cited by examiner

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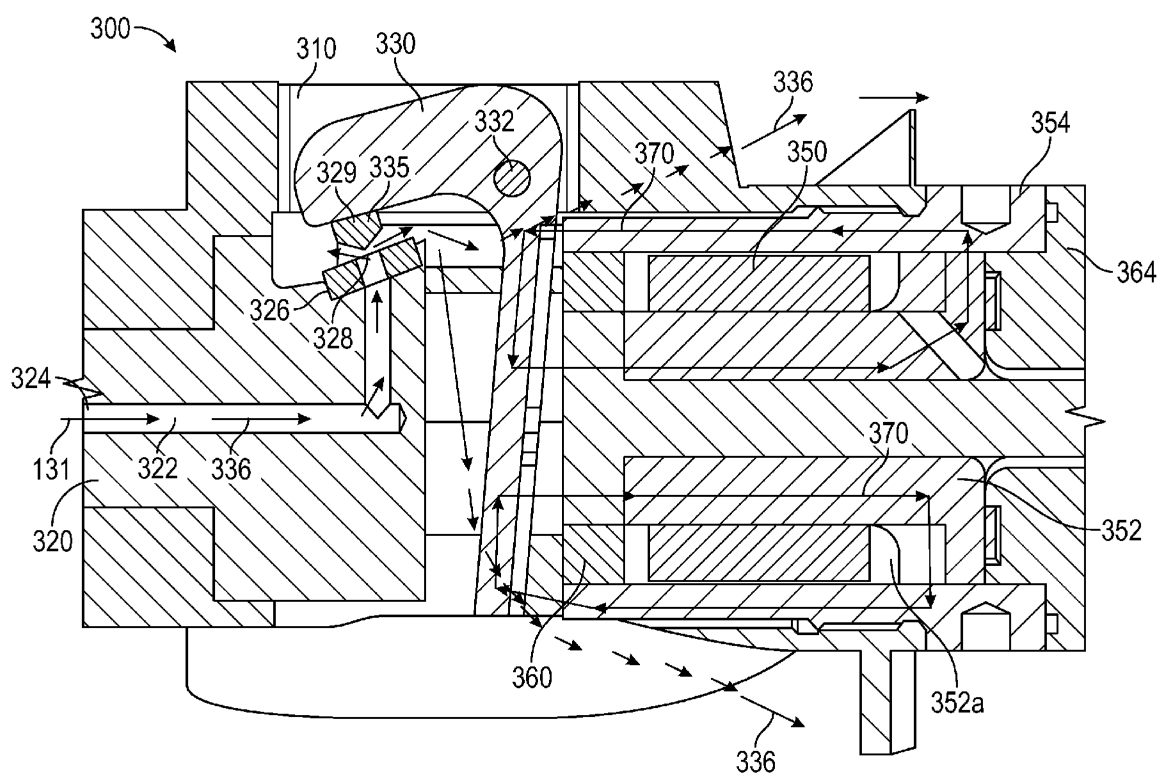
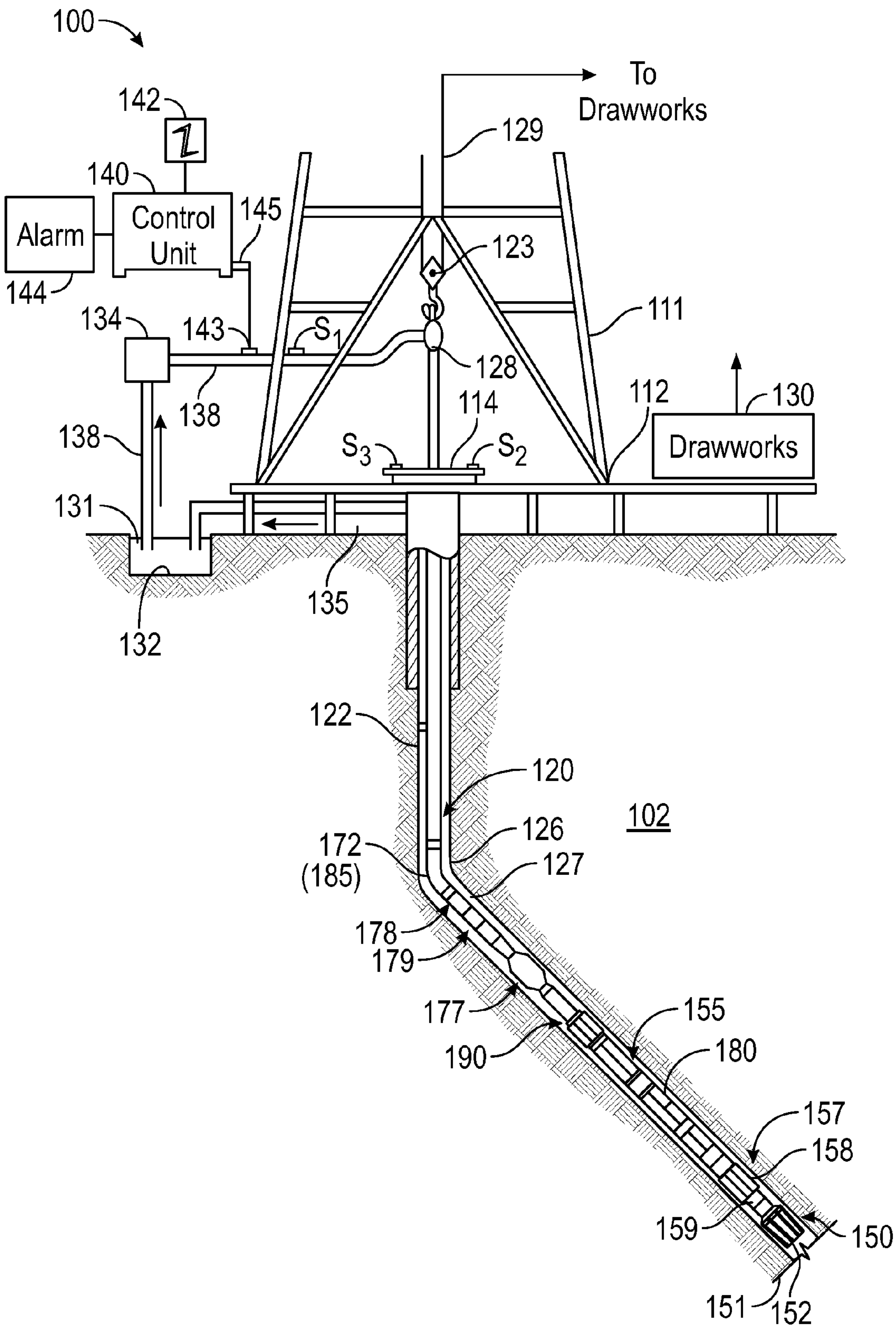
(57) **ABSTRACT**

In one aspect, an apparatus for use in a drilling assembly is disclosed that in one embodiment includes a flow control device that further includes: a fluid flow path having an inlet and an outlet; an electromagnetic circuit that includes a closing member made from a soft magnetic or magnetic material as a part of the electromagnetic circuit, wherein the closing member moves from a first open position to a second closed position to close the fluid flow path to produce a pressure pulse in a fluid flowing through the fluid flow path when the electromagnetic circuit is formed.

16 Claims, 4 Drawing Sheets

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Control Unit
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S_3
S_2
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Drawworks
131
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135
122
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172
(185)
127
178
179
177
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155
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157
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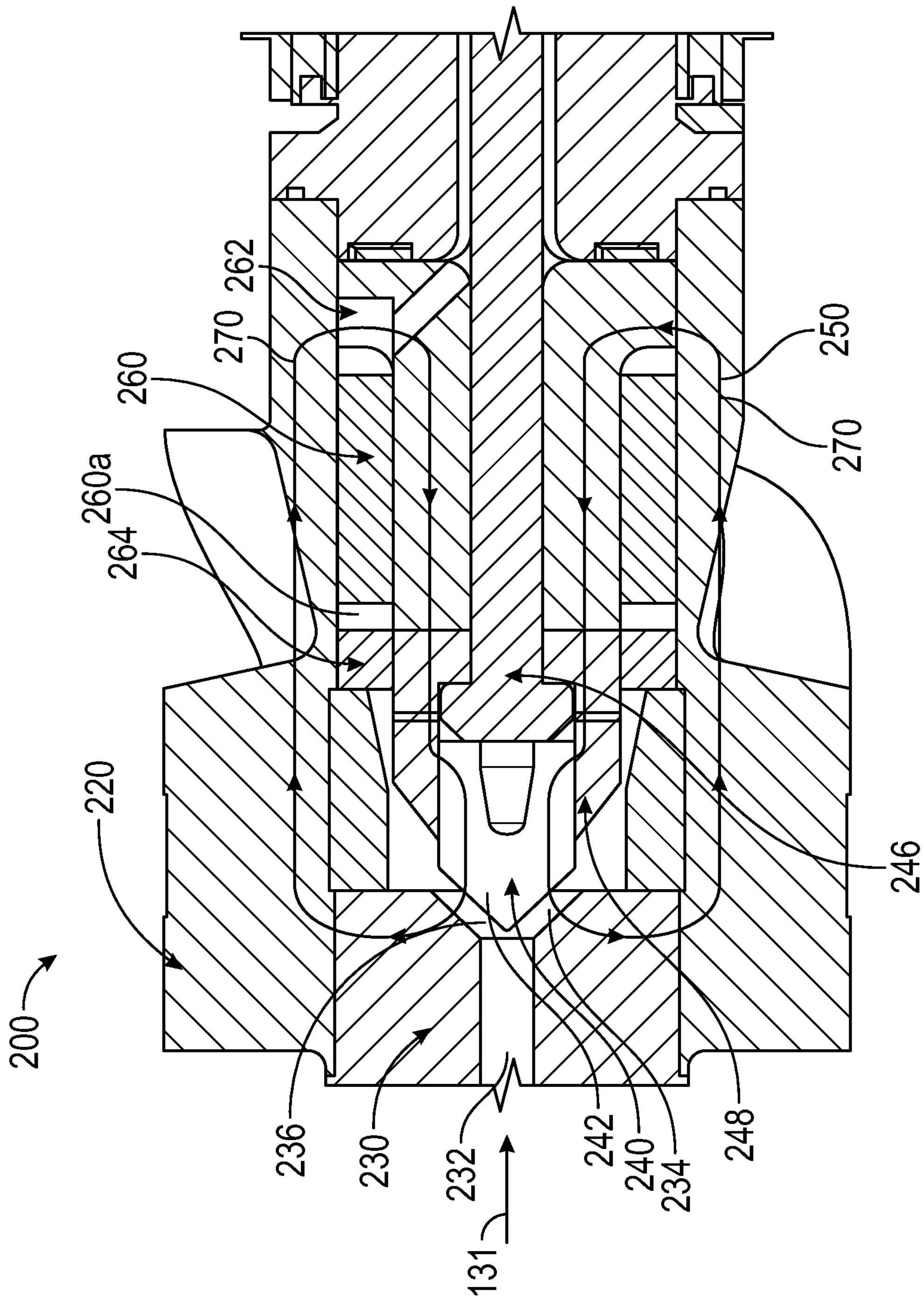
FIG. 1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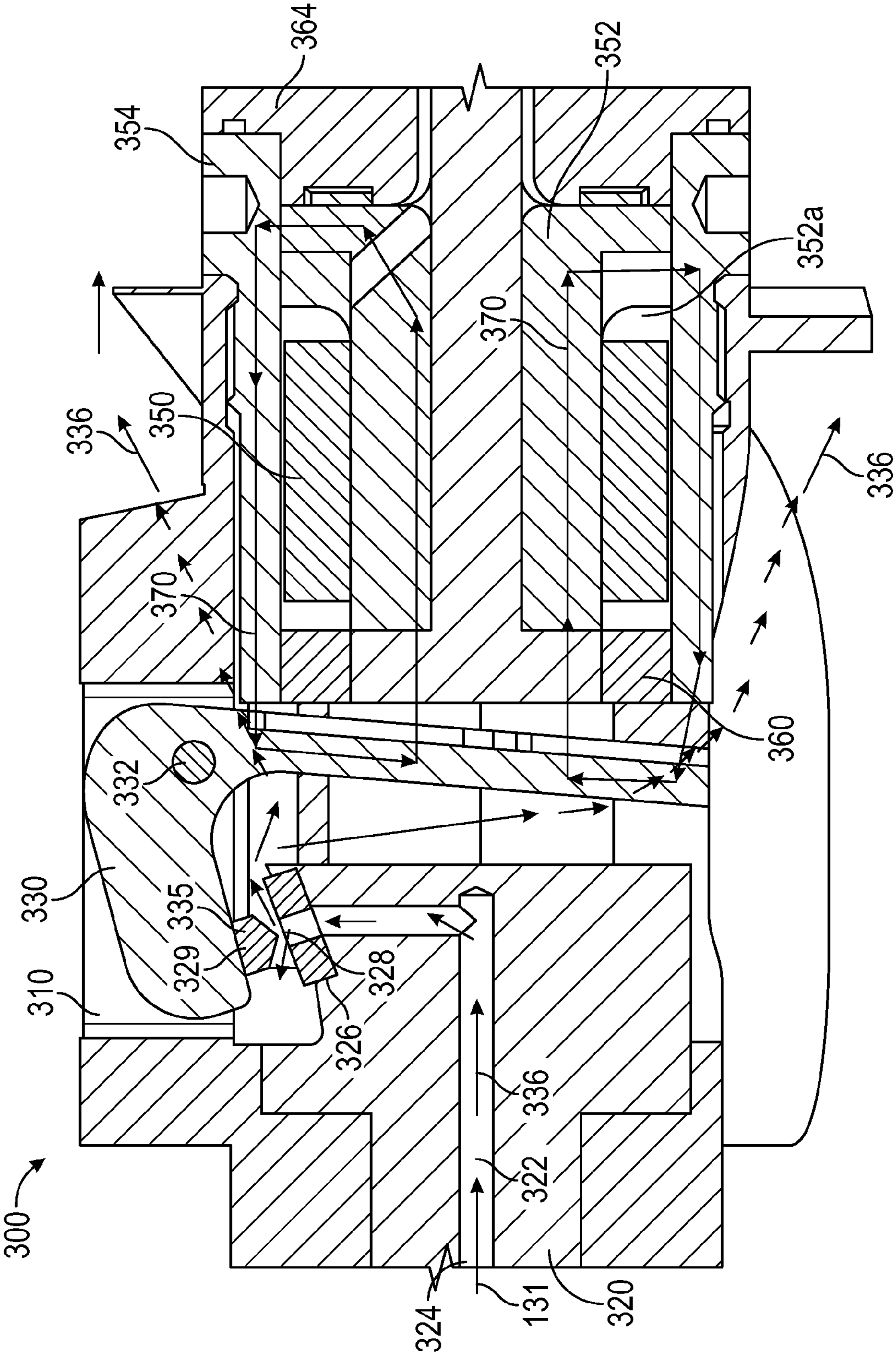
260a
264

FIG. 2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300
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131
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FIG. 3

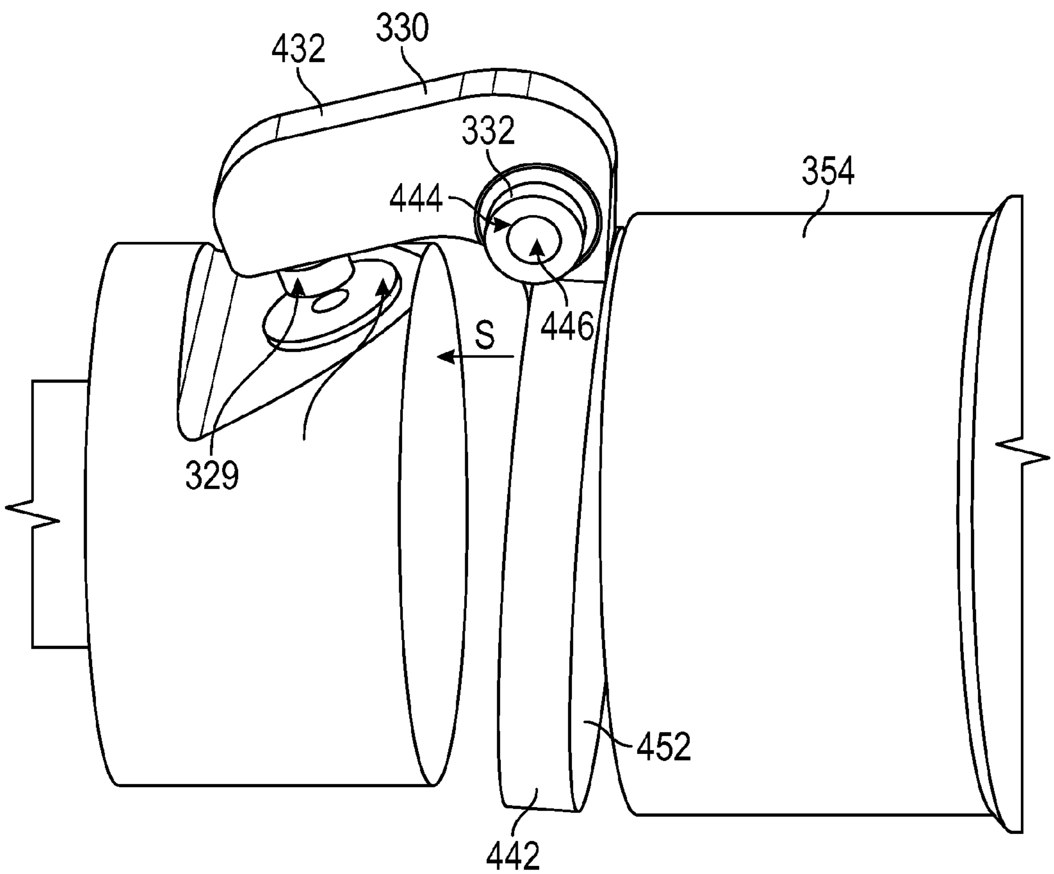

FIG. 4

APPARATUS FOR GENERATING PULSES IN FLUID DURING DRILLING OF WELLBORES

BACKGROUND

1. Field of the Disclosure

This disclosure relates generally to drilling system that include a drilling assembly that include a mud pulse telemetry system in a drilling assembly for transmitting signals between downhole locations and a surface location during drilling of wellbores.

2. Background of the Art

Wells (also referred to as wellbores or boreholes) are formed in earth formations for the production of hydrocarbons (oil and gas). A drill string including a drilling assembly (also referred to as a bottomhole assembly or "BHA") attached to a drill pipe is conveyed into the wellbore for drilling a wellbore. A drill bit connected to the end of the drilling assembly is rotated by rotating the drill pipe and/or by a motor in the drilling assembly to form the wellbore. A fluid (referred to as "mud") is supplied under pressure into the drill string, which fluid discharges at the bottom of the drill bit and returns to the surface along with rock cuttings cut by the drill bit. The drill string commonly includes a number of sensors, including a pressure sensor, vibration sensor, temperature sensor, accelerometers, gyroscopes, etc. and also tools referred to a logging-while-drilling tools that may include resistivity, acoustic and nuclear sensors for proving information or characteristics of the formations through which the wellbore is being drilled. The data obtained from such sensors and tools is processed in the drilling assembly to obtain certain parameters and some such information is transmitted during drilling to a surface computer system for further processing and to control the drilling operation. Mud pulse telemetry in which a pulsing device (also referred to as a "pulser") generates pressure pulses in the fluid passing through the drilling assembly is commonly used to transmit signals from the drilling assembly to the surface. The data or information is transmitted as coded pressure pulses, which are decoded by the surface computer. During drilling, a typical mud pulser substantially continuously generates pressure pulses over long time periods, often several days. In addition, a number of wellbores are currently drilled in formations having temperatures above 300 degrees Fahrenheit. A majority of currently utilized mud pulsers include oil fillings, elastomers and/or electrical high pressure connectors, which tend to deteriorate over time and are not suitable for use in high temperature wells.

The disclosure herein provides pulsers that are suitable for high temperature use and also may be made without the use of oil fillings, elastomers or electrical high pressure connectors.

SUMMARY

In one aspect, an apparatus for use in a drilling assembly is disclosed that in one embodiment includes a flow control device that further includes: a fluid flow path having an inlet and an outlet; an electromagnetic circuit that includes a closing member made from a soft magnetic or magnetic material as a part of the electromagnetic circuit, wherein the closing member moves from a first open position to a second closed position to close the fluid flow path to produce a pressure pulse in a fluid flowing through the fluid flow path when the electromagnetic circuit is formed.

In another aspect, a method of producing pressure pulses in a wellbore during drilling of the wellbore is disclosed, which method in one embodiment includes: conveying a drilling assembly in the wellbore, the drilling assembly including a flow control device that further includes a fluid flow path having an inlet and an outlet, a coil between a first soft magnetic or magnetic member and a second soft magnetic or magnetic member and a closing member made from a soft magnetic or magnetic material, wherein when the coil is energized, an electromagnetic circuit is formed that moves the closing member from a first open position to a second closed position to close the fluid path to produce a pressure pulse in a fluid flowing through the fluid flow path.

Examples of the more important features of a certain apparatus and methods have been summarized rather broadly in order that the detailed description thereof that follows may be better understood, and in order that the contributions to the art may be appreciated. There are additional features that will be described hereinafter, which will form the subject of the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed understanding of the apparatus and methods disclosed herein, reference should be made to the accompanying drawings and the detailed description thereof, wherein like elements are generally given same numerals and wherein:

FIG. **1** shows a drilling system in which a drilling assembly is conveyed in a wellbore that includes a flow control device made according to an embodiment of the disclosure for generating pressure pulses corresponding to information to be telemetered to the surface;

FIG. **2** shows a flow control device according an embodiment of the disclosure that may be utilized in a system, such as system shown in FIG. **1**;

FIG. **3** shows a flow control device according to another embodiment of the disclosure that may be utilized in a system, such as system shown in FIG. **1**; and

FIG. **4** shows a mechanism relating for operating a closing member for closing and opening the flow path of the flow control shown in FIG. **3**.

DETAILED DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a schematic diagram of a drilling system **100** with a drill string **120** that includes a drilling assembly **190** (also referred to as the bottomhole assembly, or BHA) attached to a bottom end of a conveying member, such as a drill pipe or coiled tubing **122**. The drill string **120** is shown conveyed into the wellbore **126** being formed in formation **102**. The drilling system **100** is further shown to include a conventional derrick **111** erected on a floor **112** that supports a rotary table **114** that is rotated by a prime mover such as an electric motor (not shown) at a desired rotational speed. A top drive (not shown) may be used instead of a motor to rotate the rotary table. The drill string **120** is pushed into the wellbore **126** when a drill pipe **122** is used as the tubing. For coiled-tubing applications, a tubing injector (not shown) is used to move the tubing from a reel (not shown), to the wellbore **126**. A drill bit **150** attached to the end of the drilling assembly **190** breaks up the geological formations when it is rotated to drill the borehole **126**. If a drill pipe **122** is used, the drill string **120** is coupled to a draw works **130** via a swivel **128** and line **129** through a pulley **123**. During drilling, the draw works **130** is operated to control the weight on bit to control the rate of penetration of the drill bit.

During drilling, a suitable drilling fluid **131** from a mud pit (source) **132** is pumped into the drill string **120** by a mud pump **134**. The drilling fluid **131** passes from the mud pump **134** into the drill string **120** and discharges at the bottom **151** of the borehole **126** through openings **152** in the drill bit **150**. The drilling fluid **131** circulates uphole through the annular space **127** (annulus) between the drill string **120** and the borehole **126** and returns to the mud pit **132** via a return line **135**. The drilling fluid **131** lubricates the drill bit **150**, carries the rock cutting made by drill bit **150** to the surface and maintains pressure in the wellbore **126** above the formation pressure along the wellbore **126** to prevent blow outs. A sensor S_1 placed in the line **138** provides information about the fluid flow rate. Surface sensors S_2 and S_3 associated with the drill string **120** respectively provide information about the torque and rotational speed of the drill string **120**. Additional sensor (not shown) may be utilized to provide the hook load and other desired parameters relating to the drilling operations.

In one embodiment of the disclosure, the drill bit **150** is rotated by only rotating the drill pipe **122**. In another embodiment of the disclosure, a downhole motor **155** (mud motor) disposed in the drilling assembly **190** rotates the drill bit **150**. The drill pipe **122** may be rotated to supplement the rotational power of the mud motor **155** and to effect changes in the drilling direction. In the embodiment of FIG. **1**, the mud motor **155** is coupled to the drill bit **150** via a shaft disposed in a bearing assembly **157**. The mud **155** motor rotates the drill bit **150** when the drilling fluid **131** passes through the mud motor **155** under pressure. The bearing assembly **157** supports the radial and axial forces of the drill bit. A stabilizer **158** coupled to the bearing assembly **157** acts as a centralizer for the lowermost portion of the drilling assembly **190**.

In one embodiment of the disclosure, a drilling sensor module **159** is placed near the drill bit **150**. The drilling sensor module **159** contains sensors, circuitry and processing software and algorithms relating to the dynamic drilling parameters. Such parameters include, but are not limited to bit bounce, stick-slip, backward rotation, torque, shocks, borehole and annulus pressure, acceleration and other parameters of the drill bit and drilling assembly condition. The drilling assembly **190** further includes a number of logging-while-drilling (LWD) tools or sensors (collectively designated by numeral **180**). The LWD tools may include a resistivity tool, an acoustic tool, an active source nuclear tool, a gamma ray tool, a formation testing tool to provide information about various parameters or characteristics of the formation **102**. The various tools include processors and electronic circuitry that process information from their respective tools and provides information about the various parameters of interest to be transmitted to the surface. The drilling assembly **190** also includes electronic circuitry and processors that process signals from the sensors **159** and provide information of parameters to be transmitted to the surface. The drilling assembly **190** further includes a power unit **179** that generates power for use by the various devices in the drilling assembly and a telemetry unit **172** that includes a fluid control device or pulser **185** made according to one embodiment of the disclosure that generated pressure pulses corresponding to information desired to be sent to the surface. The operation of the pulser **185** is controlled by a processor associated with the telemetry unit **172**.

The processor associated with the pulser **185** causes the pulser **185** to generate pressure pulses corresponding to the signals to be sent to the surface. Sensor **145** detects such pressure pulses and provides information relating thereto to a surface control unit **140**. The system **140** may be a computer-based system that processes the received pulses and provides information to an operator to takes action or takes action by itself in accordance with programs provided to the control unit **140**. The control unit **140** displays desired drilling parameters and other information on a display/monitor **142** utilized by an operator to control the drilling operations. The control unit **140** activates alarms **144** when certain unsafe or undesirable operating conditions occur. Certain embodiments of fluid control devices **185** for use in the system **100** are described below in reference to FIGS. **2-4**.

FIG. **2** shows a flow control device **200** in an open position made according to one embodiment of the disclosure that may be utilized in a drilling assembly, such as drilling assembly **190** of system **100** of FIG. **1** for performing a selected downhole function. The flow control device **200** may be incorporated into a hydraulically-controlled main valve and may act as a control valve. The flow control device **200** is also referred to herein as a valve or pulser. The device **200** includes an inlet guide **220** of a turbine (not shown) that houses a member **230** having a fluid flow through path or a passage **232** that terminates in an outlet **234**. Fluid **131** supplied to the drilling assembly (**190**, FIG. **1**) will flow through the flow through path **232** and discharge at an outlet **234**. The outlet **234** terminates at a valve seat **236**. The device **200** further includes a movable member, such as a plunger **240** having a face **242** that conforms to the shape of the seat **236** so that when the face **242** moves into or engages the seat **236**, it blocks or substantially blocks the flow of the fluid **131** through the passage **232** to generate a positive pressure pulse in the fluid **131** in the drill string **120** (FIG. **1**). The plunger **240** is linearly supported by a support member **246**, which in one embodiment may be the head of a screw. The plunger **240** is radially supported by and moves linearly or axially inside a cylindrical support member **248** within the inlet guide **220**. A member **250** made from a magnetic material surrounds the support member **246**. For the purpose of this disclosure, the term magnet includes any suitable magnet, including a soft magnet and the phrase magnetic member or magnetic material includes any suitable magnetic member or material, including soft magnetic member or soft magnetic material. A coil **260** placed in a coil carrier **262** may be placed around the magnetic member **250** and inside the inlet guide **220**. A non-magnetic cylindrical spacer or ring **264** around the support member **248** axially supports the coil carrier **262** at its front end **260***a*.

Referring to FIGS. **1** and **2**, the inlet guide **220**, member **250**, cylindrical support member **248**, plunger **240**, inlet guide **230** are made from a suitable magnetic material, while the support ring **264** and the linear support member **246** are made from a suitable non-magnetic material. In the particular configuration of the device **200**, when the coil **250** is excited (electrically powered), an electromagnetic circuit is formed from the magnetic material **250** to the inlet guide **220** via the support member **248**, the plunger **240** and the inlet guide **220**, as shown by arrows **270**. The magnetic flux created by the circuit **270** causes the plunger **240** to move axially toward the valve seat **236**, causing the face **242** to engage with the valve seat **236**, blocking or substantially blocking the flow of the fluid **131** through the passage **232**. Blocking the flow of the fluid **131** generates a pressure pulse in the fluid **131** flowing through the drill string **120**. Removing the power from or de-energizing the coil **260** interrupts the magnetic circuit **270** and the pressure of the fluid **131** applies a force on the plunger **240**, causing it to retract to the open position shown in FIG. **2**, which opens the fluid passage **232**, which in turn produces a negative pressure pulse in the fluid **131**. Thus, each energizing of the coil **260** produces a positive pressure pulse and each de-energizing causes a negative pressure pulse. Thus, a positive pressure generated by the device **200** will provide a leading edge of a pulse (when the coil is energized) and a negative pressure will provide a trailing edge of a pulse (when the coil is de-energized). Alternatively, the negative pressure may be designated as the leading edge and the positive pressure as the trailing edge of a pulse. In either case a pressure pulse will include a leading edge and a trailing edge. In either case, the flow rate through the passage **232** defines the amplitude of the pulse, the duration between energizing and de-energizing of the coil **260** or vice versa defines the pulse width and the number of pulses in a selected time period defines the frequency of the pulses generated. In aspects, the flow control device **200** can operate in the main flow of a fluid, that is the entire flow of the fluid passes through the device **200** or it can operate in a bypass mode such that only a certain portion of the fluid passes through the device **200** or alternatively it can operate as a control valve of a larger hydraulically-actuated main valve that acts on the entire flow of the fluid.

The magnetic flux path or circuit **270** is formed each time the coil **250** is energized. The magnetic flux path **270** is formed from the core **256** to the support member **248**, from the support member **248** to the plunger **240**, from the plunger **240** to the inlet member **230** and from the inlet member **230** to the inlet guide **220**. The non-magnetic spacer **264** prevents shorts in the circuit **270**. In the embodiment of the flow control device **200**, the coil **260** may be placed in a sealed and clean 1-bar environment. In the particular embodiment of the device **200** in FIG. **2**, the plunger **240** is the only part of the device **200** that moves when the coil **260** is powered. The magnetic flux generated in the circuit **270** moves the plunger **240** in the direction of the valve seat **236**. While pulsing, the plunger **240** slides in an environment that is flooded with fluid **131**, which enables the plunger **240** to slide back and forth with relatively low friction.

FIG. **3** shows a flow control device or pulser **300** in an open position made according to another embodiment of the disclosure that may be utilized as a pulser in the drilling system **100** of FIG. **1** for generating pressure pulses downhole or to perform another selected function. The device **300** includes a non-magnetic body **310** that houses a valve member **320** having a fluid flow path or passage **322** therein that includes an inlet **324** for receiving a fluid **308** and an outlet **326** for discharging the fluid **308** therethrough. The outlet **326** includes a valve seat **328** for accepting therein a plunger or poppet **329** for closing and opening of the fluid flow path **322**. In one embodiment, the plunger **329** may be attached to a movable member **330** for moving the plunger **329** in and out of the valve seat **328**, which movable member in one embodiment may be a lever **330** that rocks about a pivot **332**. The lever **330** includes the closing member **329** at an end thereof, wherein the face **335** of the closing member **329** is shaped to sit or engage with inside the valve seat **328** to block or substantially block the flow of the fluid **131** through the passage **322**. The flow of the fluid **131** through the device **300** when the flow passage **322** is open is shown by arrows **336**.

Still referring to FIG. **3**, the device **300** further includes a coil **350** disposed around a magnet **352**. The coil **350** is supported on one end by the soft magnet or magnet end **352***a* and on the other end by a non-magnetic spacer **360**. The magnet **352** may be placed around and supported on both sides by a magnetic member **364**. Another magnet member **354** may be placed around the coil **350**. Thus, in the particular embodiment of the device **300** of FIG. **3**, magnets **352**, and **354** and the lever **330** are made from suitable magnetic materials while the valve member **320**, valve seat **328**, plunger **329** and the spacer **360** are made from suitable non-magnetic materials. When the coil **350** is energized by the supply of a current therethrough, a magnetic circuit is formed from the magnet **354** to the lever **330** that returns to the magnet **354** via magnet **352** as shown by arrows **370**. When the coil **350** is energized, the lever **330** rocks about the pivot **332** toward the valve seat **328**, causing the plunger **329** to seat inside the valve seat **328** to block or substantially block the flow of the fluid **131** through the passage **322** and thus the device **300**. Blocking of the fluid **131** through passage **322** causes a positive pressure in the fluid **131** flowing through the drill string **120** (FIG. **1**). When the coil **350** is de-energized, the lever **330** moves away from the seat **328** due to the pressure applied by the fluid **131** on the plunger **329**, allowing the fluid **131** to flow through the passage **322** and thus the device **300**. Each de-energizing of the coil **350** opens the fluid passage **322**, generating a negative pressure in the fluid **131** flowing through the drill string **120** (FIG. **1**). As described in reference to FIG. **2**, the flow rate through the passage **322** defines the amplitude of a pulse, the time between successive energizing and de-energizing of the coil **350** defines the length or duration of the pulse, the time between the de-energizing and energizing defines the time or duration between the pulses and the number of pulses over a selected time period defines the frequency of the pulses. The flow of the fluid **131** through the device **300** is shown by arrows **336**.

FIG. **4** shows a valve mechanism relating to the operation of the lever **330** shown in FIG. **3**, according to one embodiment of the disclosure. In one embodiment, the lever **330** may include a head member **432** and cylindrical member or pole plate **442**, wherein the lever **330** rocks about a pivot **332**. The pole plate **442** may include perforations **452** to prevent clogging of the fluid **131** flowing through the device **300** by debris or other particles in the fluid **131**. In one embodiment, the pivot **332** may include a male bearing **444** and a female bearing **446**. In the configurations of the flow control devices shown in FIGS. **3** and **4**, the pole plate **442** moves in the space "S" between the valve member **320** and the shell **354**. The movement of the plunger **329** is not transitional. The plunger **329** is fixed to the lever **330** that rotates about a selected axis. In this embodiment, the lever **330** is part of the magnetic circuit and may be made of a material having good magnetic properties, such as 9 Cr. Also, the plunger **329** and the valve seat **328** may be made from any material that does not influence the magnetic circuit **370**. In the embodiments described hereinabove, the fluid in the gap of the magnet circuit is a drilling fluid when such devices are utilized in a drilling system.

Although the flow control device herein is described as a mud pulser for generating pressure pulses in a drilling assembly, the device may be utilized for any other suitable purpose or for performing any other function, including, but not limited to: control of mud hydraulic driven steering tools, expandable reamers and expandable stabilizers; setting of packers; operating sliding sleeves and production valves; control of additive dosing devices; and control and/or operation of devices at the surface.

The foregoing disclosure is directed to the certain exemplary embodiments and methods. Various modifications will be apparent to those skilled in the art. It is intended that all such modifications within the scope of the appended claims be embraced by the foregoing disclosure. The words "comprising" and "comprises" as used in the claims are to be interpreted to mean "including but not limited to".

The invention claimed is:

1. An apparatus for use in a drilling assembly during drilling of a wellbore, comprising:

a flow control device that includes:

a fluid flow path having an inlet and an outlet; and

an electromagnetic circuit that includes a closing member made from a magnetic material as a part of the electromagnetic circuit, wherein the closing member at least partially rotates about a selected axis to move from a first open position to a second closed position to close the fluid path to produce a pressure pulse in a fluid flowing through the fluid flow path when the electromagnetic circuit is formed, wherein the closing member includes a plunger at an end thereof and a pole plate at an opposite end thereof that is included in the electromagnetic circuit when the electromagnetic circuit is formed.

2. The apparatus of claim **1**, wherein the electromagnetic circuit closes via a gap filled with a drilling fluid.

3. The apparatus of claim **1**, wherein the closing member is immersed in a fluid.

4. The apparatus of claim **1** further comprising a coil between a first magnetic member and a second magnetic member and wherein when the coil is energized, the electromagnetic circuit is formed among the first magnetic member, the second magnetic member and the closing member to cause the closing member to move from the first open position to the second closed position.

5. The apparatus of claim **4**, wherein the pole plate moves to rotate a lever about the selected axis when the electromagnetic circuit is formed.

6. The apparatus of claim **4**, wherein the plunger is made from a hard material dimensioned to close the outlet of the fluid flow path when the electromagnetic circuit is formed.

7. The apparatus of claim **1**, wherein the closing member remains in the first open position when a fluid under pressure is supplied to the fluid flow path and the coil is not energized due to the pressure applied by the fluid on the plunger.

8. The apparatus of claim **4**, wherein the first magnetic member is enclosed by a non-magnetic body.

9. The apparatus of claim **5**, wherein the pole plate has flow through paths to allow passage of solid particles below a selected size therethrough.

10. A method of producing pressure pulses in a drilling assembly during drilling of a wellbore, the method comprising:

conveying a drilling assembly in the wellbore, the drilling assembly including a flow control device that further includes:

a fluid flow path having an inlet and an outlet;

a coil between a first magnetic member and a second magnetic member; and

a closing member made from a magnetic material, wherein the closing member includes a plunger at an end thereof and a pole plate at an opposite end thereof;

wherein when the coil is energized, an electromagnetic circuit is formed among the first magnetic member to rotate the closing member about a selected axis from a first open position to a second closed position to close the fluid path to produce a pressure pulse in a fluid flowing through the fluid flow path;

supplying the fluid to the flow control device; and

selectively energizing the coil to form the electromagnetic circuit to rotate the closing member about the selected axis to the second closed position to generate a pressure pulse in the fluid flowing through the flow control device.

11. The method of claim **10**, wherein the closing member is a lever that rotates about the selected axis when the electromagnetic circuit is formed.

12. The method of claim **10**, wherein the plunger is made from a hard material dimensioned to close the outlet of the fluid flow path when the electromagnetic circuit is formed.

13. The method of claim **10**, wherein the closing member remains in the first open position when the fluid under pressure is supplied to the fluid flow path and the coil is not energized due to the pressure applied by the fluid on the plunger.

14. The method of claim **10**, wherein the first magnetic member is enclosed by a non-magnetic body.

15. The method of claim **11**, wherein the pole plate has at least one flow through path to allow passage of solid particles below a selected size therethrough.

16. The method of claim **10**, wherein the drilling assembly further includes a sensor that provides signals relating to a parameter of interest and a circuit that processes the signals to generate the parameter of interest, the method further comprising transmitting the generated parameter of interest as pressure pulses generated by fluid flow control device during drilling of the wellbore.

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