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Seutter

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(54) **MULTI-ACTIVATION REAMER WITH ACTIVATION CONFIRMATION**

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E21B 10/32 (2006.01)

(52) **U.S. Cl.**
CPC ***E21B 7/28*** (2013.01); ***E21B 10/32*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 7/28; E21B 10/32; E21B 10/26
See application file for complete search history.

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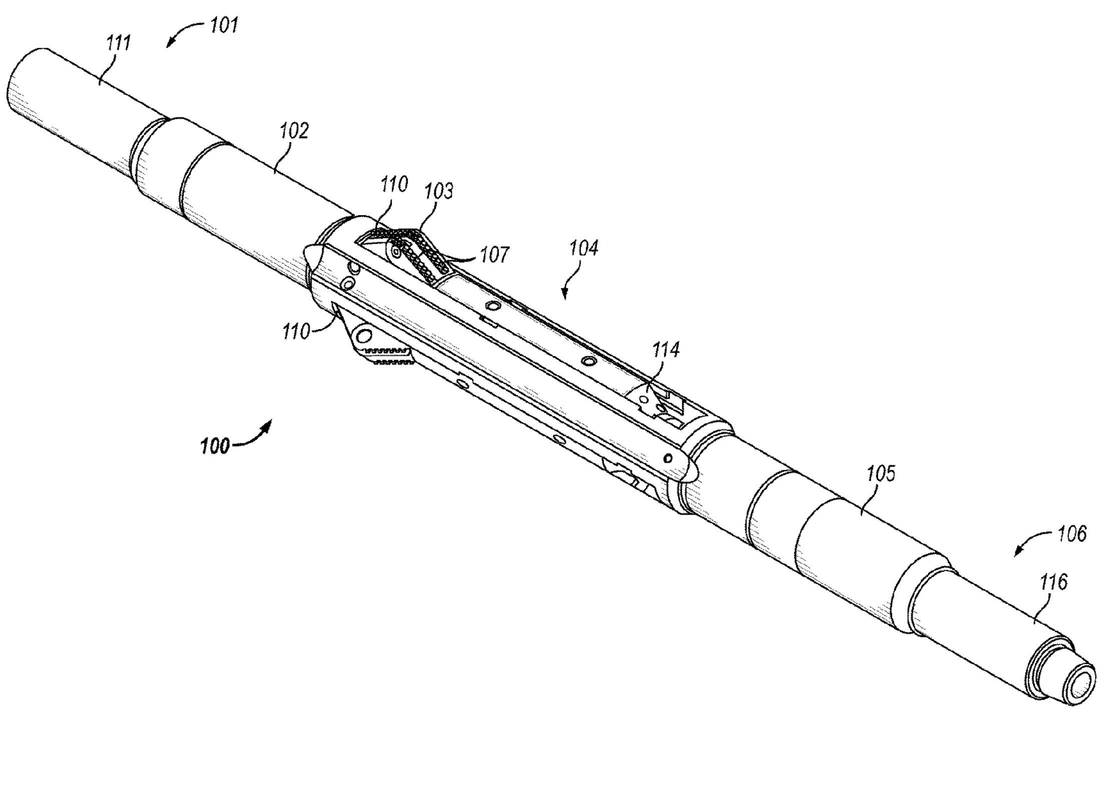
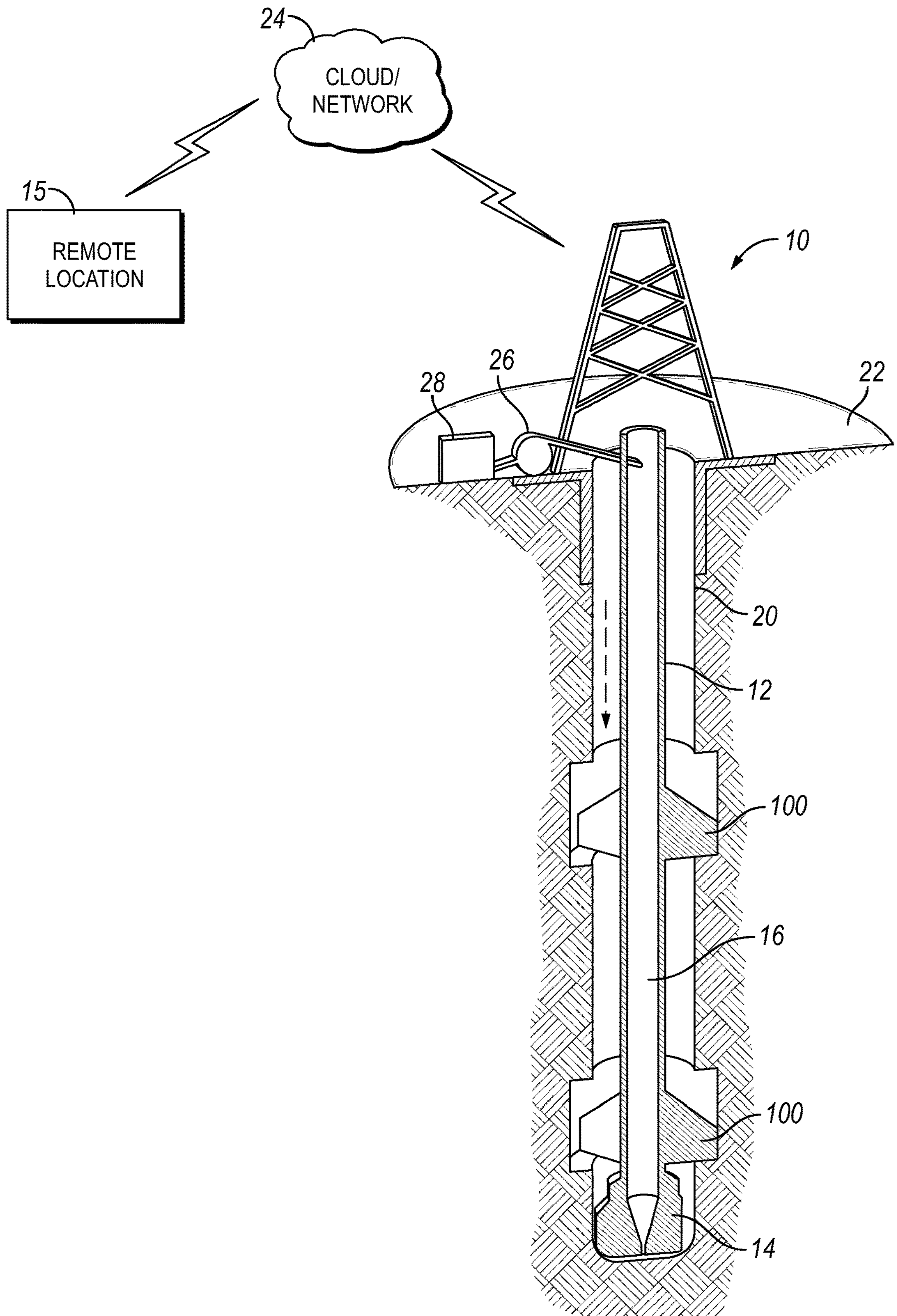
(57) **ABSTRACT**

A multi-activation reamer optionally includes modular activation and pulse confirmation blocks for activating the reamer and confirming activation. A reamer activation signal may be communicated downhole, optionally using an activation sequence of drill string flow and rotation detectable by downhole sensors. An on-board controller receives the activation signal and opens an activation flow path in the activation block to hydraulically actuate the reamer arms. A pulse flow path is also opened in the pulse confirmation block, optionally using pressure from the activation flow path. Flow along the pulse flow path is modulated to generate a flow pattern detectable uphole of the reamer to confirm activation of the reamer.

19 Claims, 11 Drawing Sheets

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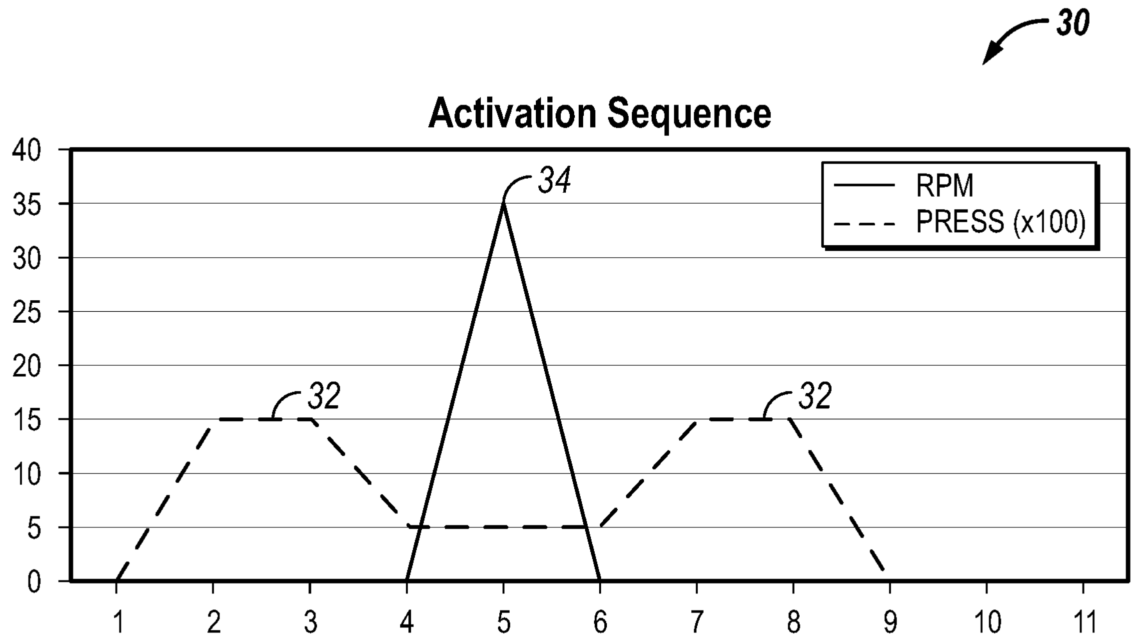
NETWORK
15
REMOTE
LOCATION
10
26
28
22
20
12
100
16
100
14

FIG. 1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Activation Sequence
RPM
PRESS (x100)
34
32
32
40
35
30
25
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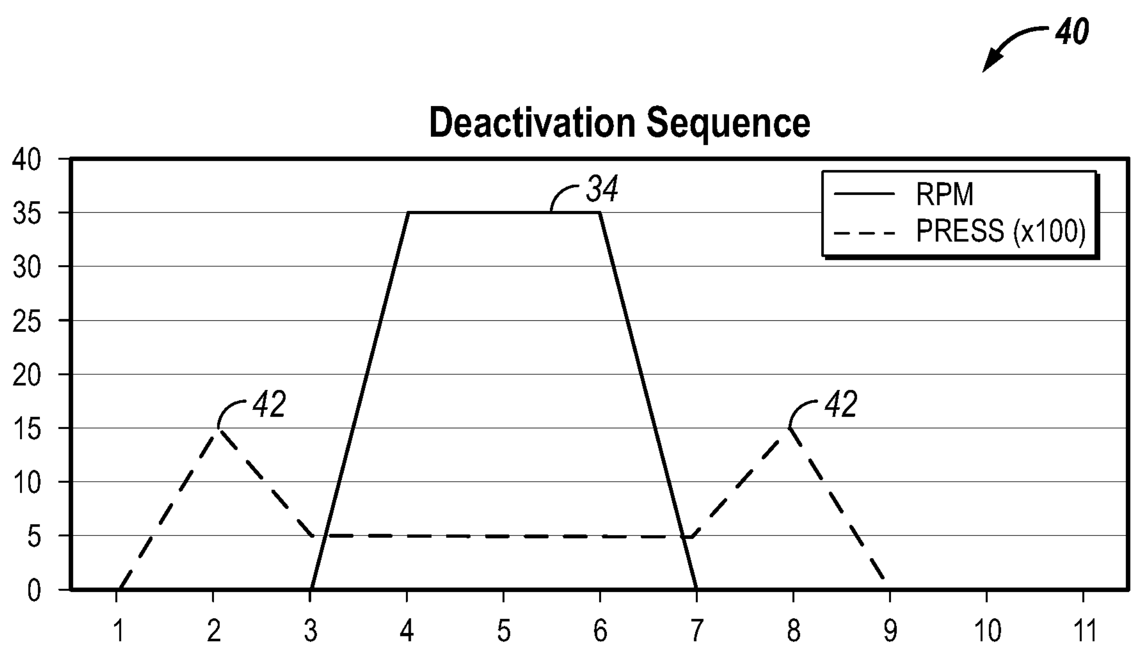
10
5
0
1
2
3
4
5
6
7
8
9
10
11

FIG. 2


40
Deactivation Sequence
RPM
PRESS (x100)
34
42
42
40
35
30
25
20
15
10
5
0
1
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3
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5
6
7
8
9
10
11

FIG. 3

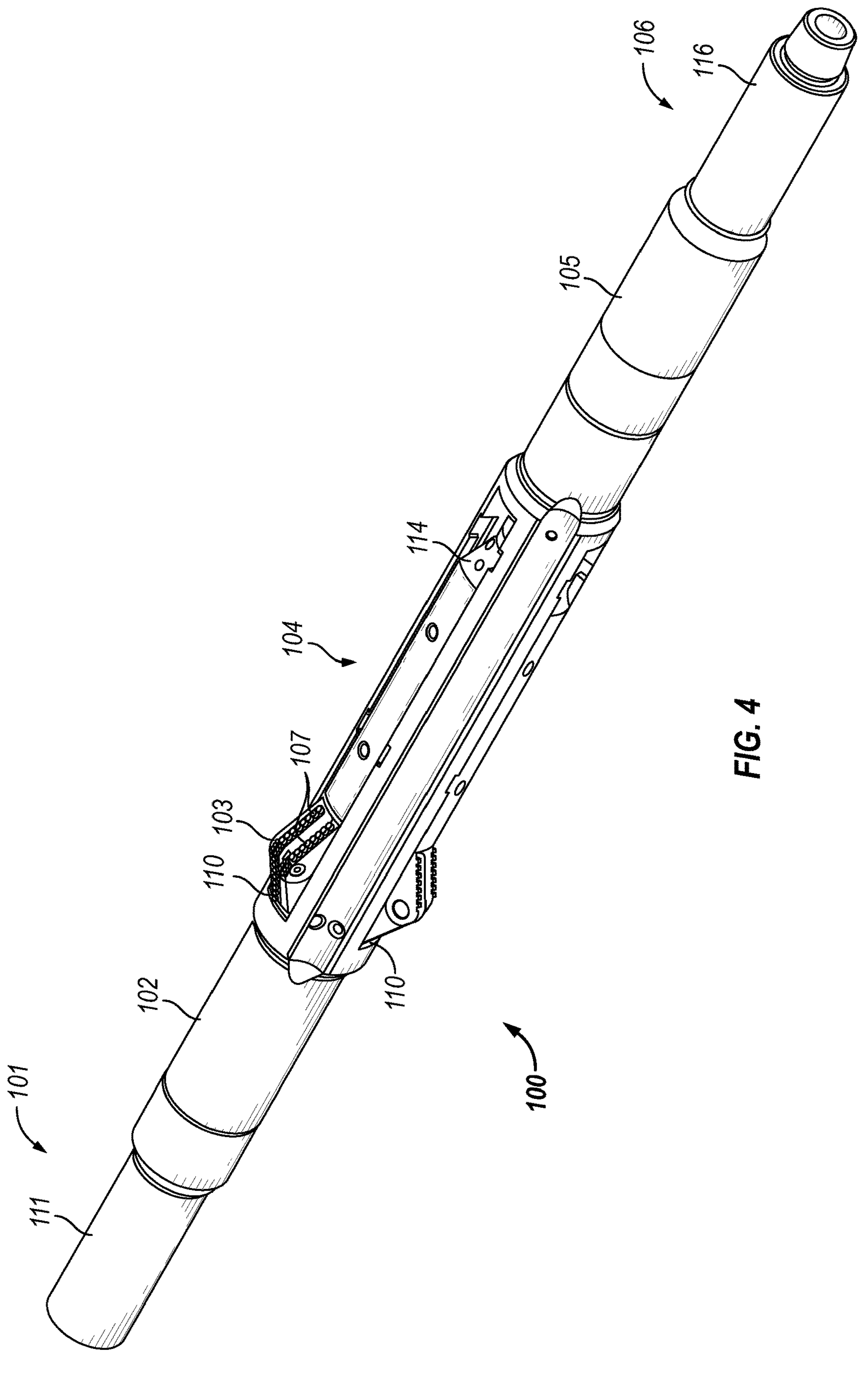

FIG. 4

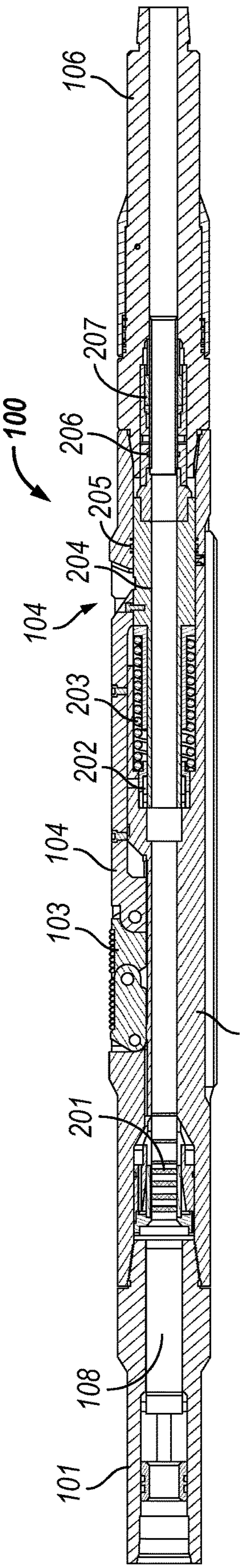

FIG. 5

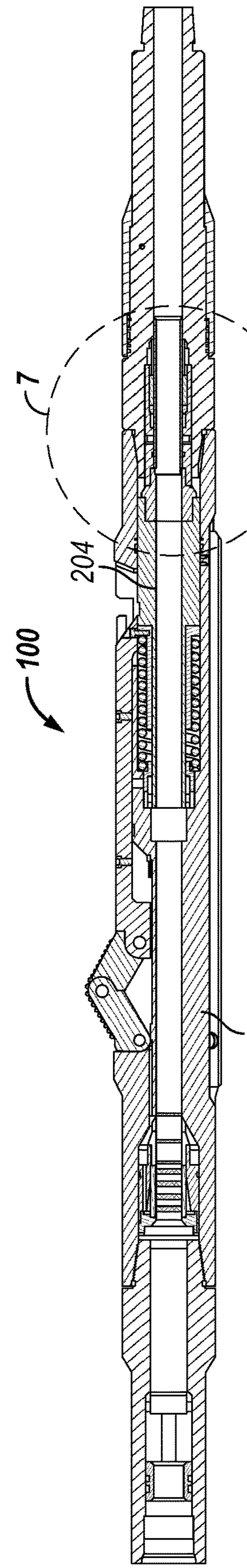

FIG. 6

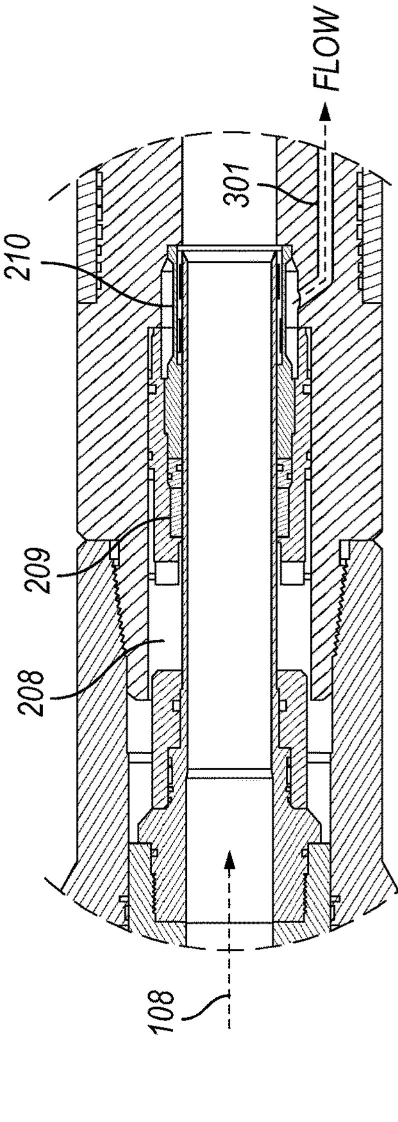

FIG. 7

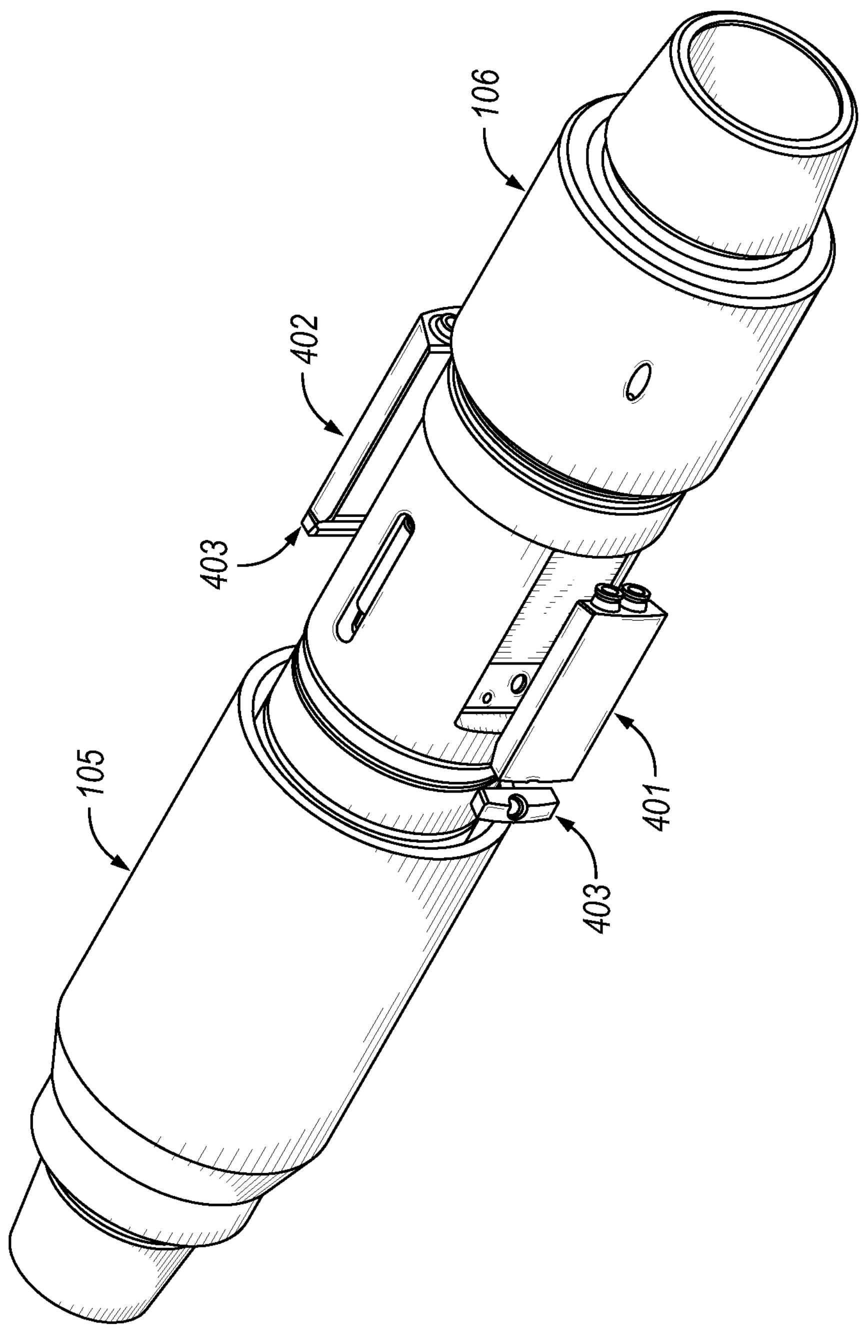

FIG. 8

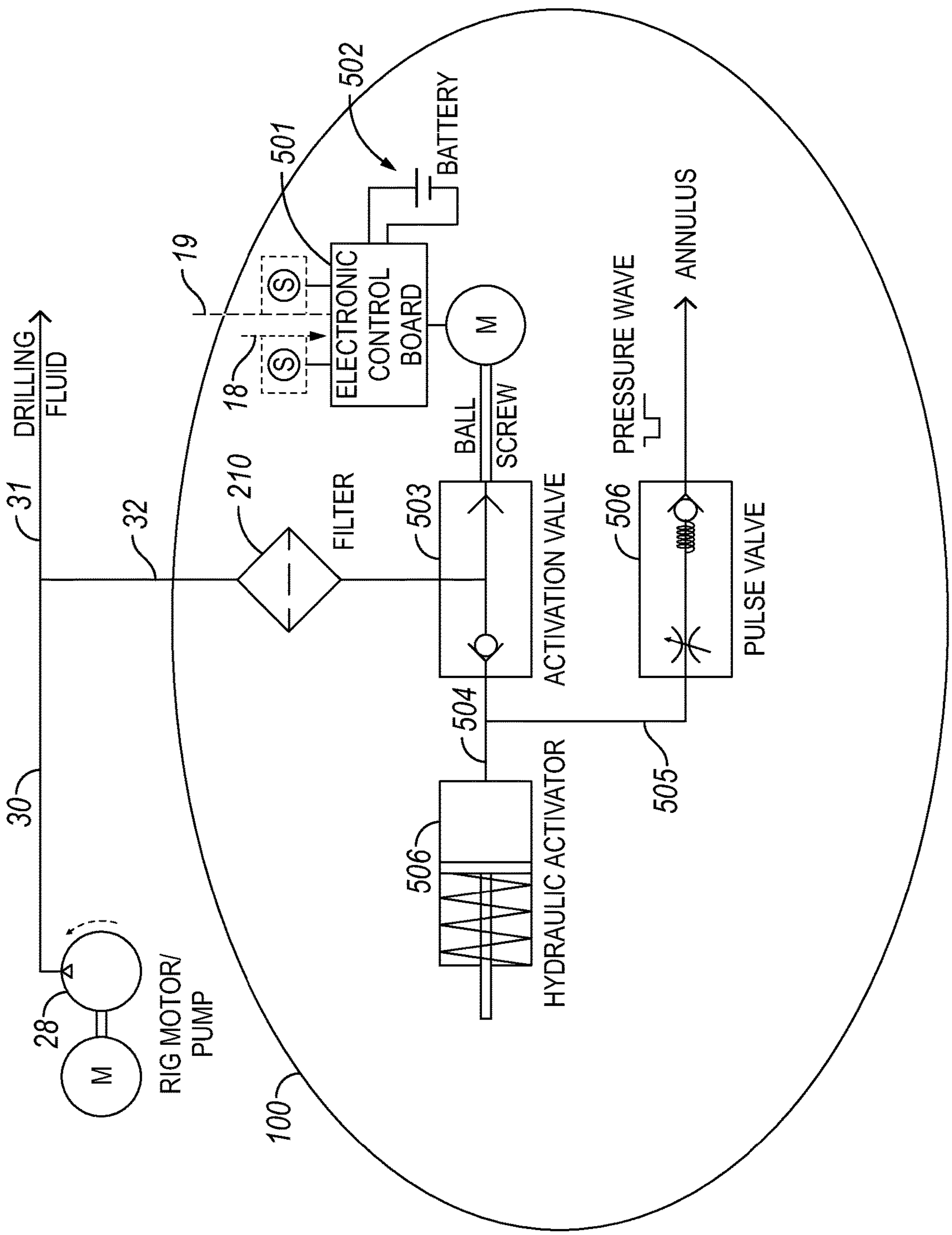
DRILLING FLUID
31
30
32
210
FILTER
503
ACTIVATION VALVE
504
HYDRAULIC ACTIVATOR
506
505
PULSE VALVE
506
PRESSURE WAVE
ANNULUS
BALL SCREW
M
ELECTRONIC CONTROL BOARD
S
S
18
19
501
502
BATTERY
RIG MOTOR/ PUMP
M
28
100

FIG. 9

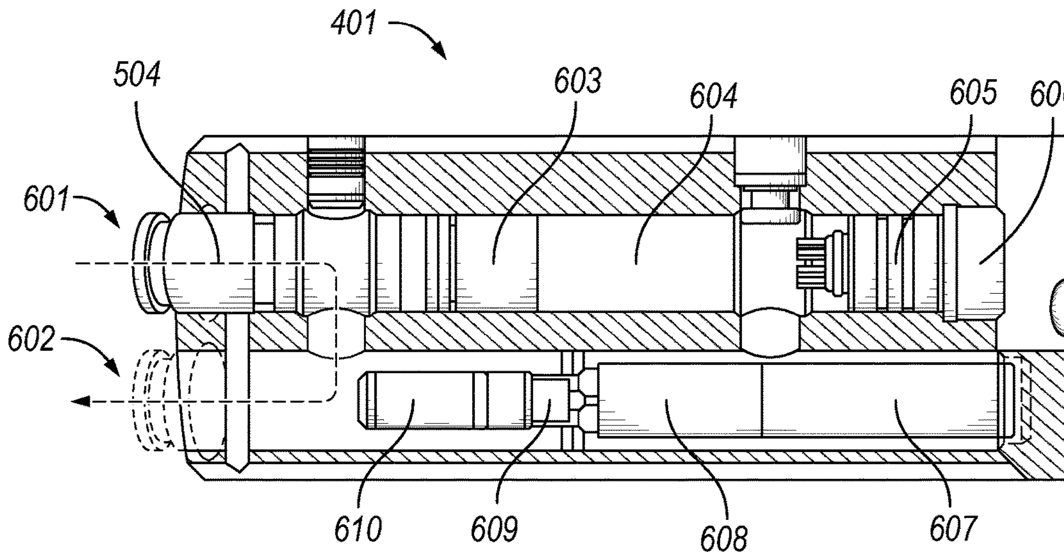
401
504
603
604
605
606
601
602
610
609
608
607

FIG. 10

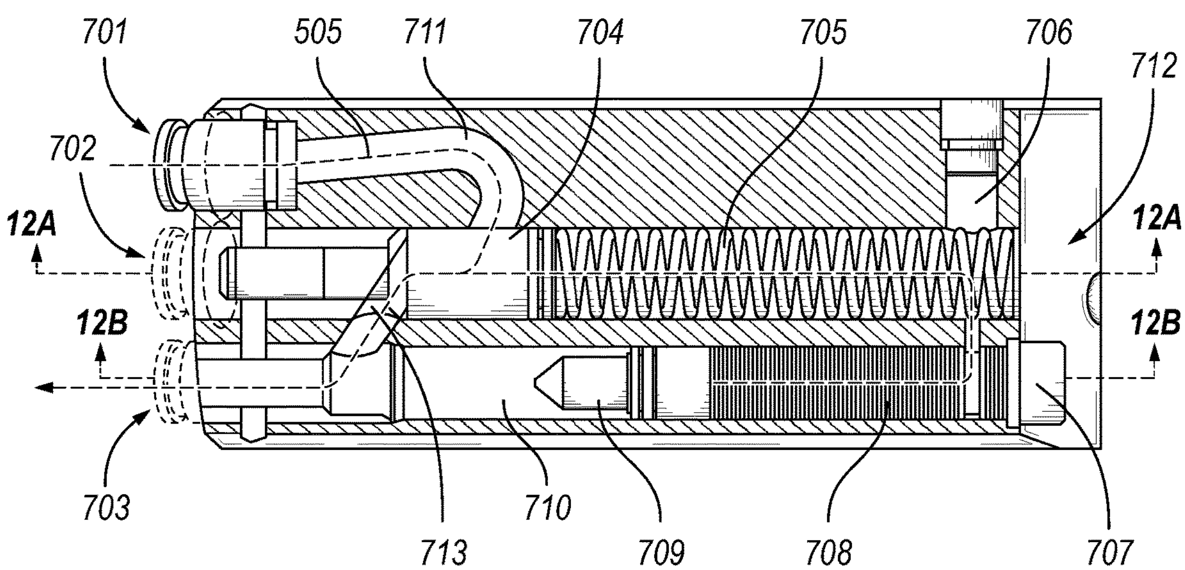
701
505
711
704
705
706
712
702
12A
12A
12B
12B
703
713
710
709
708
707

FIG. 11

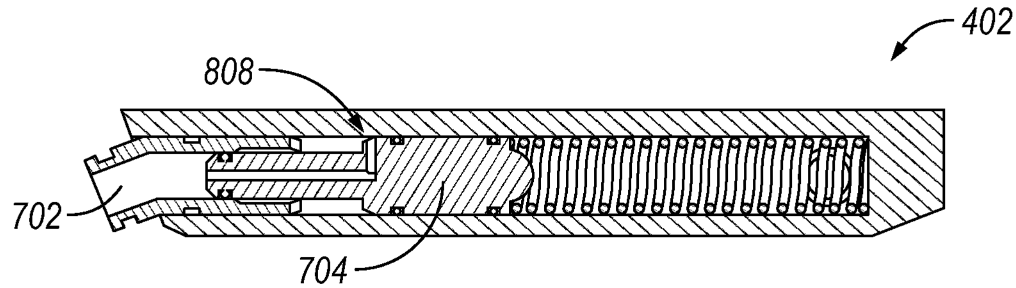

FIG. 12A

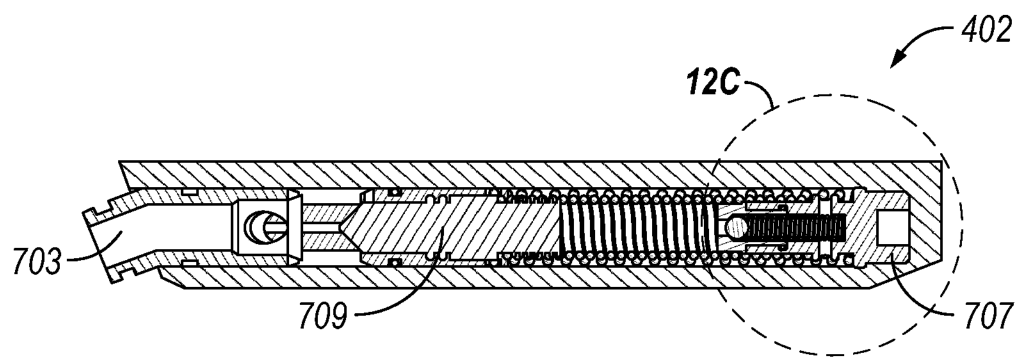

FIG. 12B

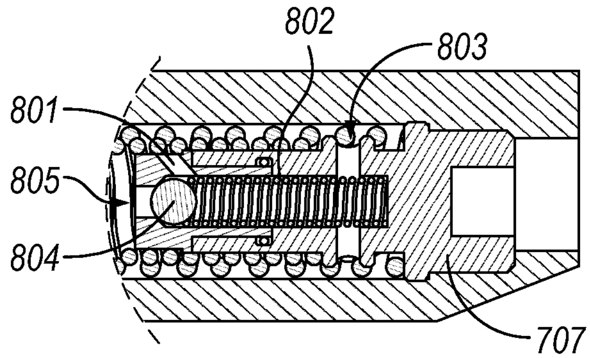

FIG. 12C

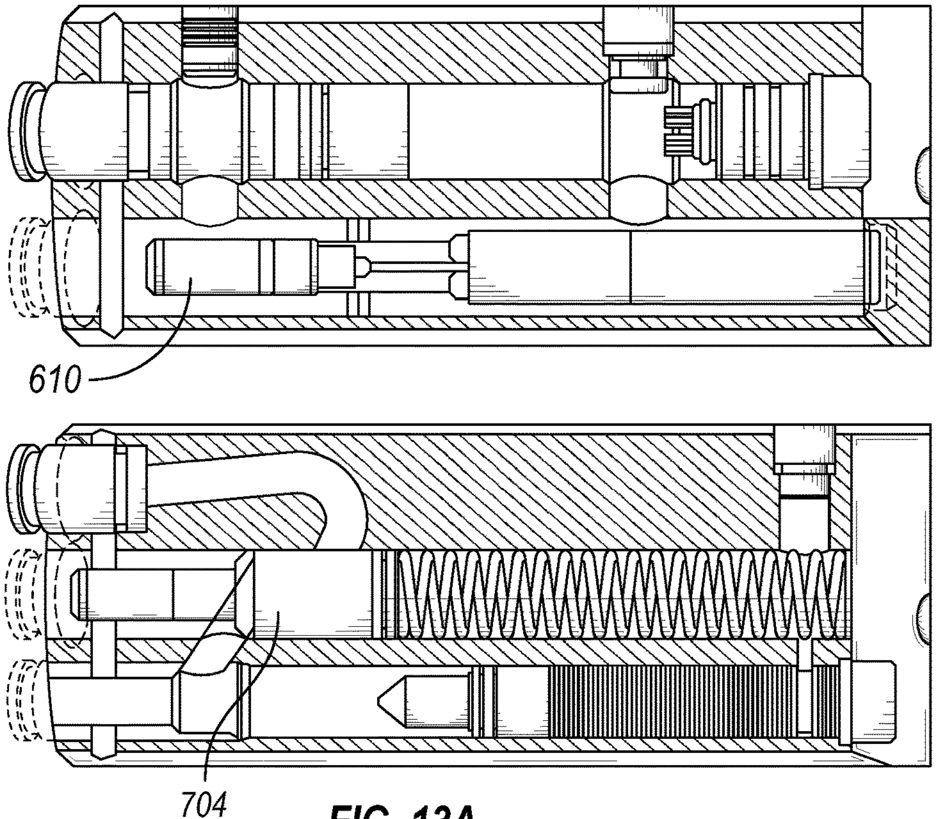

FIG. 13A

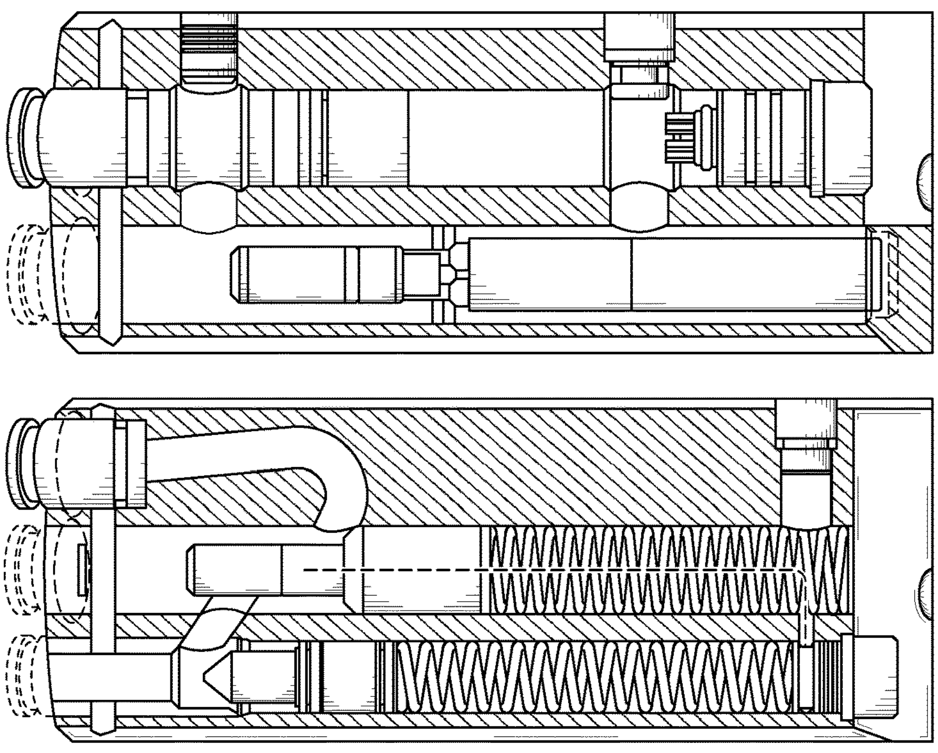

FIG. 13B

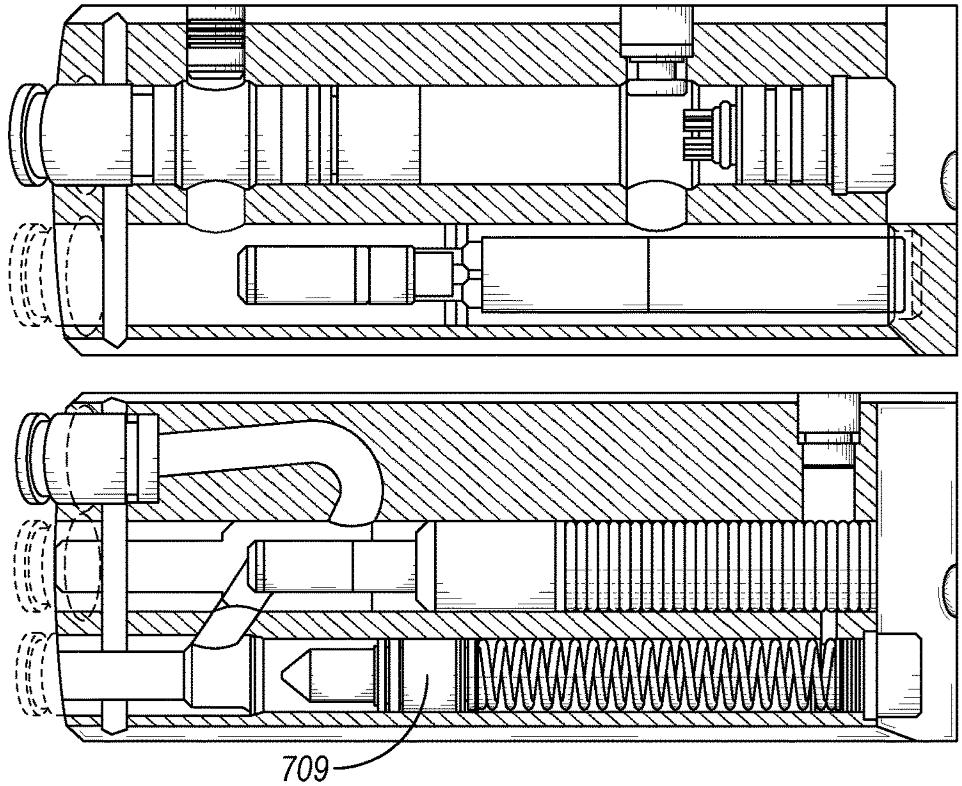

FIG. 13C

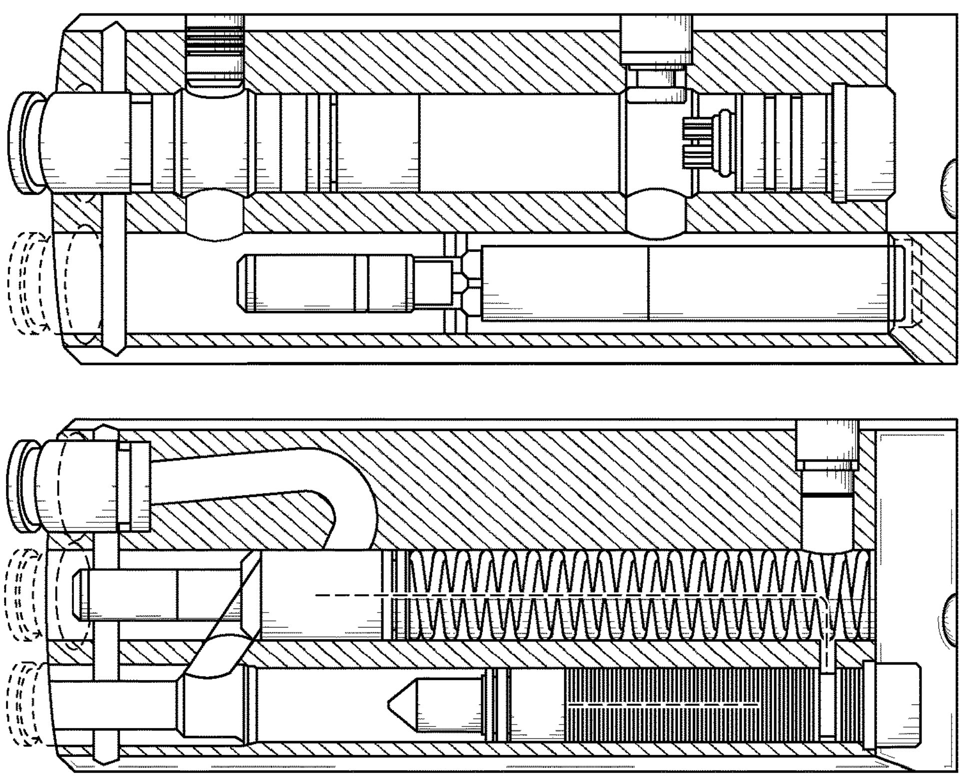

FIG. 13D

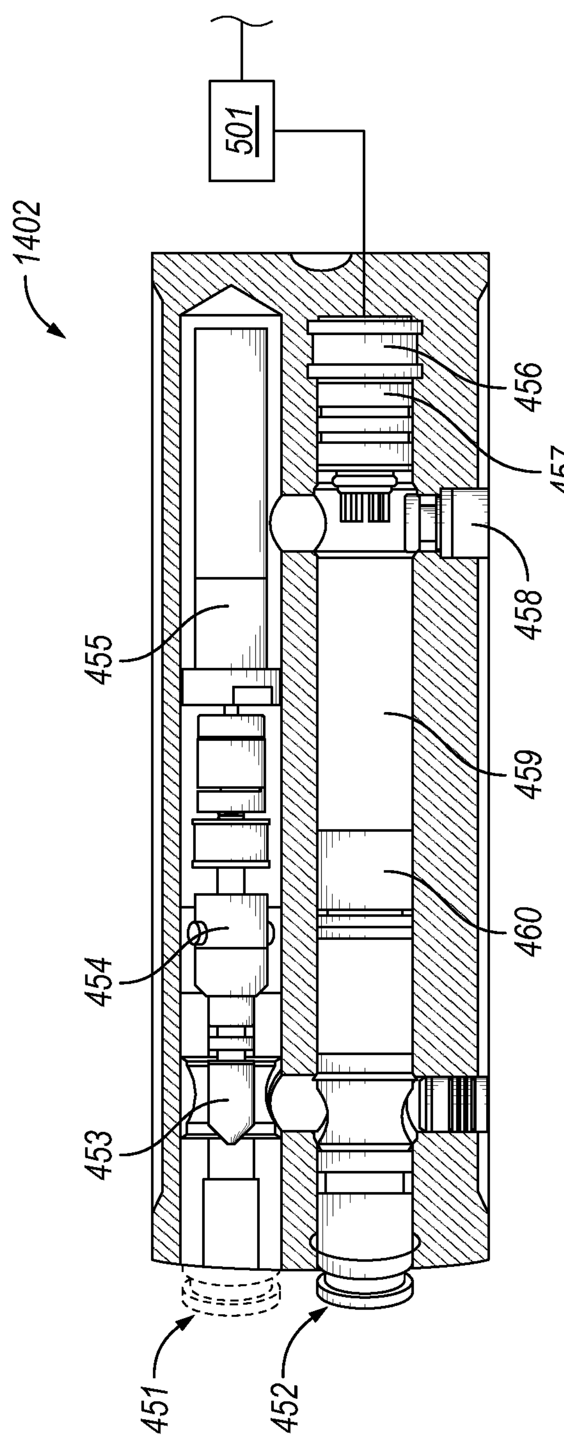

FIG. 14

MULTI-ACTIVATION REAMER WITH ACTIVATION CONFIRMATION

BACKGROUND

Wells are commonly drilled to recover hydrocarbons such as oil and gas from subterranean formations. Reamers are used to increase the wellbore size at various depth intervals in a wellbore. This increased wellbore size has various benefits such as enabling the installation of larger casing diameters or to increase the borehole surface area to enhance production of hydrocarbons. Various reamer activation methods have been utilized, such as ball drop, flow darts, differential pressure and flow rate changes. Some approaches limit the number of activations to a single event. Many of these activation designs restrict the through-bore size of the tool or even block the bore. Reamers that are capable of more than one activation (i.e., multiple activation) generally increase the length of the tool due to the mechanism utilized for the multiple activation.

BRIEF DESCRIPTION OF THE DRAWINGS

These drawings illustrate certain aspects of some of the embodiments of the present disclosure and should not be used to limit or define the method.

FIG. **1** is a schematic, elevation view of a well site **10** at which a well may be constructed.

FIG. **2** is a graphical representation of an activation sequence **30** according to an example that combines an activation sequence of rotation and flow.

FIG. **3** is a graphical representation of a deactivation sequence **40** according to an example that also combines another activation sequence of rotation and flow.

FIG. **4** is a perspective view of the reamer **100** with modular activation and pulse confirmation blocks according to an example configuration.

FIG. **5** is a cross-sectional side view of the reamer **100** of FIG. **4** in a deactivated state.

FIG. **6** is a cross-sectional side view of the reamer **100** of FIG. **5** in an activated state.

FIG. **7** is an enlarged detail view of the portion encircled at "7" in FIG. **6**.

FIG. **8** is a perspective view of the Bottom Sub **116** according to an example configuration having modular activation and pulse confirmation block assemblies.

FIG. **9** is a fluid circuit diagram schematically describing the hydraulic operation of the reamer **100** according to one or more embodiments and modes of operation.

FIG. **10** is a sectional side view of the modular activation block **401** of FIG. **8**.

FIG. **11** is a sectional side view of the modular pulse confirmation block **402**.

FIG. **12**A is a sectional view taken along **12**A in FIG. **11**, showing an equalization port **808** in the delay piston **704**.

FIG. **12**B is a sectional view taken along section line **12**B in FIG. **11**.

FIG. **12**C is an enlarged detail view of the portion encircled in FIG. **12**B.

FIG. **13**A shows the block assemblies in an initial state, wherein the reamer is inactive and conventional drilling can be carried out.

FIG. **13**B shows the block assemblies in a second state, with the delay piston in a mid-stroke position.

FIG. **13**C shows a third state at the instant when the indicator pulse is terminated.

FIG. **13**D shows a fourth state in which the delay piston in the reset condition after the rig pumps are stopped and the reverse oil flow has occurred.

FIG. **14** illustrates a different embodiment for the pulse confirmation block.

DETAILED DESCRIPTION

A multi-activation reamer and method are disclosed that allow for reamer activation from the surface of a wellsite or even from a remote location. The reamer may be activated and re-activated any number of times, without having to drop a ball or other flow restrictor to induce a pressure increase, without increasing the length of the reamer tool, and without having to trip out of the wellbore to reset the reamer. A reamer activation signal can be communicated downhole without the need for a dedicated electrical, electromagnetic, or optical signal transmission pathway along the drill pipe. Instead, the reamer activation signal may be communicated downhole in the form of an activation sequence of flow through the drill string and/or rotation of the drill string that is detectable downhole, such as a combination of drill string pressure and rotation, that are sensed downhole and interpreted by an electronic controller on the reamer body.

In response to the reamer activation signal, flow of pressurized drilling fluid is opened along an activation flow path through the reamer to actuate the reamer arms. Flow is also opened along a pulse flow path, which flow may be modulated using a metering system to generate a flow pattern detectable uphole as confirmation of reamer activation. The confirmation of the reamer activation (or deactivation) may trigger one or more steps, such as to commence (or cease) reaming, or any other step related to reaming, drilling, or other wellbore activities that may or may not involve the use of the drill string. The activation flow path, pulse flow path, controller, metering system, and other reamer components may be embodied on modular block assemblies, such as an activation block and a pulse confirmation block.

In examples discussed below, a multi-activation mechanism may be integrated into a lower tubular section of the reamer. The multi-activation mechanism may be controlled with a low voltage electronic system that can initiate valve transitions during a "pumps off" condition activating the reamer. As flow is re-established, the adjusted porting activates the reamer cutting components with filtered drilling mud based on differential pressure. As the reamer is rotated through the desired depth interval, a larger bore hole diameter is achieved. The reamer is then deactivated and the arms are retracted. Two modular block assemblies that are mounted radially on the outer surface of the tubular control the routing of the filtered drilling fluid and subsequently control the deployment of the cutting arms. One block, which may be referred to as the activation block, provides an activation flow path for activating the reamer cutting components. The second block, which may be referred to as the pulse confirmation block, provides a damping flow path to create a time-controlled pressure transition indicating reamer activation. This pressure transition is large enough to be recognized on surface.

The block assemblies used in the reamer may both be oil-filled and pressure compensated for ensuring the longevity of the internal components such as seals. An additional benefit of the external block design is that the sub-assemblies can be assembled and oil filled in a clean environment. This modular design will also help to reduce the servicing time required for maintenance or turn-around procedures. These and other features and technical advantages are described below in association with example embodiments in the figures.

FIG. **1** is a schematic, elevation view of a well site **10** at which a well may be constructed. Aspects of constructing the well include drilling a wellbore **20** and selectively widening one or more portions of the wellbore **20** by reaming. The wellbore **20** may be drilled using a drill string **12** having a drill bit **14** at the lower end and one or more reamers **100** supported anywhere along the drill string **12** above the drill bit **14**. This particular example shows two reamers **100** supported at different axial locations on the drill string **12** above the drill bit **14**. The wellbore **20** may be drilled by rotating the entire drill string **12** from surface **22** and/or by rotating the drill bit **14** relative to the drill string **12**, such as using a mud motor. The reamers **100** are typically deactivated during drilling and would rotate along with the drill string **12** without appreciably engaging the wellbore **20**. A portion of the wellbore **20** may then be subsequently reamed by activating the reamers **100** and rotating the drill string **12** with reamer arms engaging a selected portion of the wellbore **20**, as further discussed below. However, if desired, drilling and reaming could be performed simultaneously, such as by rotating the drill string with the reamers activated to extend the wellbore and simultaneously ream an existing portion of the wellbore uphole of the drill bit. A variety of drill string configurations and drill string modes of operation are known in the art including various uses of drill string rotation, mud motor rotation, and combinations thereof for achieving any of a variety of wellbore forming steps and features, any of which may incorporate aspects of this disclosure.

The drill string **12** may be progressively assembled over the course of drilling by adding any number of drill pipe segments or stands **16**, the reamers **100**, and other drill string components until the desired wellbore depth is reached. Because the reamers **100** in this example are included on the same drill string **12** used to drill the wellbore **20**, the wellbore **20** may be drilled and reamed in a single trip. However, a reamer and method according to the disclosure may be used to ream an existing wellbore if desired.

While drilling or reaming, fluid may be circulated downhole to help lubricate the bit or reamer cutting structures and circulate the cuttings back to surface. Typically, the overall drilling fluid path would be down through the drill string **12** and up through an annulus **21** between the drill string **12** and the wellbore **20**, as diagrammed. One or more surface pump **26** may be provided at the surface **22** to generate the pressurized flow. A filtration system **28** may be provided at surface to remove the bulk of cuttings and other contaminants from the fluid as it is circulated. As this fluid circulation equipment is generally available for drilling purposes, the fluid circulated downhole may be referred to herein as drilling fluid, even when not actively drilling or reaming. This pressurized drilling fluid may additionally be used as described below to activate the reamer(s) **100**.

The reamers **100** are generally tripped into the wellbore **20** in a deactivated stated, e.g., with reamer arms retracted, as further discussed in relation to subsequent figures. The reamers **100** may be selectively activated (or alternately, deactivated) by generating a reamer activation (or deactivation) signal **18**, which can be received and detected downhole at the reamers **100**. The reamer activation signal **18** may be generated at a surface **22** of the wellsite **10**, such as at an above-ground location where a human operator and/or control equipment may be located. The activation signal **18** according to this disclosure may comprise any form of a signal that may be communicated and detectable downhole for activating the reamer(s) **100** and distinguishable from other phenomena that are not intended as the activation signal.

The activation signal in at least some examples may comprise an electrical, electromagnetic, or optical signal. The electrical, electromagnetic, or optical signal may be used to at least initiate activation of the reamer(s) **100**. In some cases the reamer activation signal could even be initiated at a remote location **15** and communicated to the wellsite **10** over any suitable communication network **24**, e.g., a cloud, Internet, cellular, satellite network, etc., over any suitable transmission medium such as wireless, electromagnetic, fiber optic, and/or electrical transmission medium of any suitable type.

In certain well installations, electrical, electromagnetic, or optical signal pathways can sometimes be provided along the drill string **12**, and may be used to communicate the activation signal **18** downhole to the reamer(s) **100** from the surface **22** of the well site. More commonly, however, such electrical, electromagnetic, or optical signal pathways are not available in a drill string. In those cases, the activation signal **18** may still comprise an electrical, electromagnetic, or optical signal to initiate the reamer activation, e.g., at surface **22** or the remote location **15**, and the activation signal **18** may further comprise an activation sequence of physically measurable drill string parameters such as flow through and/or rotation of the drill string **12** that is detectable downhole, and unlikely to occur by accident or otherwise which does not indistinguishably resemble some other flow and/or rotational sequence that might occur during routine drill string operation when activation of the reamer is not intended. The activation sequence of flow and/or rotation may include absolute values and/or changes in the flow and/or changes in the rotation. Rotation may include, for example, rotation count, revolutions per minute (RPMs), stop/go patterns, or other detectable parameter related to rotation of the drill string **12**. Flow may include, for example, volumetric rate of flow, pressure, or other flow parameter, either absolute values or changes in value. Such an activation sequence may be used to communicate from the surface **22** downhole to the reamer(s) **100** without the need for electrical, electromagnetic, or optical pathways running down the entire drill string **12**. The activation sequence may be detected downhole, such as using flow, pressure, and RPM sensors and converted back to an electronic signal. The signal can be analyzed for detecting the predefined activation sequence.

FIG. **2** is a graphical representation of an activation sequence **30** according to an example that combines an activation sequence of rotation and flow. The rotation may be expressed in terms of revolutions per minute (RPMs) of the drill string. The flow may be expressed in terms of a flow pressure of a drilling fluid through the drill string or along an annulus between the drill string and the wellbore. In this case, the activation signal is embodied as an activation sequence comprising two pressure rises **32** interspersed with an RPM spike **34**. Sensors may be located downhole in a well, specifically in a reamer or a controller in communication with a reamer, for sensing the activation sequence **30**. For example, a pressure sensor may be used to sense the pressure rises **32** and a velocity sensor may be used to sense the RPM spike **34**.

FIG. **3** is a graphical representation of a deactivation sequence **40** according to an example that also combines another activation sequence of rotation and flow. Generally, a deactivation signal could be substantially the same as the activation signal, such as for use in a toggle on/off (open/closed) control logic for a reamer. In this case, however, the deactivation signal is embodied as a deactivation sequence comprising two pressure rises **42** interspersed with an RPM spike **44** that are distinguishable from the activation sequence of FIG. **2**.

FIG. **4** is a perspective view of the reamer **100** according to an example configuration having modular activation and pulse confirmation blocks. It is understood that other reamers may be constructed within the scope of this disclosure having any suitable combination of the various features disclosed or ascertainable in view of this disclosure whether or not such features or combinations of features are explicitly disclosed herein. The reamer **100** includes a reamer body **102** that may support various reamer components. Some reamer components (discussed further below) may be housed within a compartment in the reamer body **102** or the bottom sub **116** under a sleeve **105**. This sleeve **105** ensures pressure integrity of the components contained inside the blocks, which may include valve members, pistons, batteries, and electronic circuitry.

A top sub **111** and a bottom sub **116** on opposing inlet and outlet ends **101**, **106** of the reamer body **102** provide connections (e.g., threaded connections) to couple the reamer **100** within a drill string. An internal through bore (not explicitly shown) passes from the inlet end **101** to the outlet end **106** to allow flow of drilling fluid and other components or materials along the drill string through the reamer **100**. Thus, one or more instances of the reamer **100** may be assembled within a drill string along with other drill string components.

The reamer body **102** optionally includes any number of exterior axial pockets for receiving certain reamer components (e.g., reamer arms, electronic control modules, etc.). FIG. **4** specifically shows, for example, reamer arm pockets **110** on the reamer body **102** that contain expandable reamer arms **103**. The reamer arms **103** are pivotably secured to the reamer body **102** and may be moved between a retracted position and an extended position in response to activation and deactivation signals. In the retracted position, the reamer arms **103** may be receded at least partially into the reamer arm pockets **110** on the reamer body **102** to help protect the reamer arms **103** as the reamer is tripped in or out of the wellbore prior to or subsequent to a reaming operation. The reamer arms **103** including cutting structures **107** that, when engaged with the wellbore, enlarge the wellbore as the assembly is subsequently rotated through the formation. The reamer arms **103** can be fashioned after a pivoting pin set or a wedge style that rides outward on a track arrangement. A hydraulic reamer arm actuator **104** includes a travel block **114** that transfers axial force to the reamer arms **103** to expand the reamer arms **103** outwardly to engage the surrounding formation.

FIG. **5** is a cross-sectional side view of the reamer **100** of FIG. **4** in a deactivated state, with the reamer arm(s) **103** in a retracted position, such as for tripping in or out of a wellbore or otherwise when not reaming. The reamer arm actuator **104** further includes a piston assembly **204** inside the reamer body **102** loosely coupled to the travel blocks **104**. At least some of the pressurized drilling fluid flowing through the through bore **108** of the reamer body **102** may be diverted from the reamer body **108** and filtered for use as the working fluid for various reamer components such as the reamer arm actuator **104**. The reamer arm actuator **104** further includes seals **205** and **207** that allow the piston assembly **204** to travel axially inside the reamer body **102** as fluid pressure to the piston assembly **204** increases. As the piston assembly **204** responds to the pressure increase in FIG. **5**, filtered drilling fluid will fill an activation chamber **208** (FIG. **7**) of the hydraulic reamer arm actuator. This, in turn, will compress a biasing member (e.g., spring) **203** of the hydraulic reamer arm actuator **104** to expand the reamer arms **103** toward the extended position. A seal packing **202** provides a stationary seal that maintains seal integrity of the piston assembly **204** inside of the reamer body **102**.

FIG. **6** is a cross-sectional side view of the reamer **100** of FIG. **5** in an activated state. The reamer arms **103** have been actuated to an extended position, after the piston assembly **204** has responded to the pressure increase as discussed in FIG. **5**.

FIG. **7** is an enlarged detail view of the portion encircled at "7" in FIG. **6**, showing an activation chamber **208**, a filter screen **210**, a seal retainer **209**, and an inlet port **301** not visible in FIG. **6**. The bulk of drilling fluid flowing through a drill string may flow through a through bore **108** from the uphole end **101** to the downhole end **106** of the reamer **100**. Some of the drilling fluid may be diverted for use as a working fluid to components of the reamer **100**. The bulk drilling fluid may include particulates such as drilling fluid additives, formation cuttings, or other impurities that can migrate into the drilling fluid despite filtering by surface equipment. The filter screen **210** is therefore provided to filter the drilling fluid before it enters one or more inlet port **301** for use as the working fluid to operate the reamer. The filtered drilling fluid may then pass through reamer flow paths in the reamer, such as an activation flow path for activating the reamer arms and a pulse flow path used to generate a confirmation of the activated reamer arms, as will be further discussed below. After actuating the reamer arms or performing another reamer function the diverted drilling fluid ultimately may be exhausted back to the bulk flow of drilling fluid, such as to the annulus about the drill string. Although not explicitly shown, a system could be constructed within the scope of this disclosure to alternatively route flow back into the through bore or drill string downstream.

FIG. **8** is a perspective view of the bottom sub **116** according to an example configuration having modular activation and pulse confirmation block assemblies **401**, **402** that define working fluid paths through the reamer body **102**. The block assemblies, which may be referred to generally as "blocks," include an activation block **401** used for activating reamer arms and a pulse confirmation block **402** used for confirming the activation of the reamer arms. The activation block **401** and pulse confirmation block **402** are mounted to respective pockets in the outer surface of the bottom sub **106**. These blocks **401**, **402** may also be secured in position by retaining wedges **403**, to ensure a tight, secure fit to the reamer body and minimize shaking or rattling. The sleeve **105** may slide over the blocks **401**, **402** to cover and constrain the blocks **401**, **402** inside of the reamer body.

Pressurized drilling fluid is used as the working fluid for the activation block **401** and the pulse confirmation block **402**. The filtered drilling fluid feeds into the working fluid paths defined by the activation block **401** and pulse confirmation block **402** to perform the various functions. The use of modular block assemblies facilitate manufacturing, including forming the working fluid paths, as well as installing, repairing, and/or replacing the block assemblies. For example, the main structure for the blocks and the flow paths defined therein may be manufactured by additive manufacturing (aka 3D printing) that might be hard to form by other manufacturing methods such as subtractive machining.

Other embodiments may be constructed wherein the working fluid paths are defined by the reamer body or other reamer components without the use of modular block assemblies.

FIG. **9** is a fluid circuit diagram schematically describing the hydraulic operation of the reamer **100** according to one or more embodiments and modes of operation. The pump **28** may comprise a rig pump that provides the pressurized flow of drilling fluid **30** for downhole use such as for drilling and reamer operation. The bulk of the drilling fluid may be circulated along a primary flow path **31** through the drill string. The pressurized drilling fluid is therefore available all along the drill string, and may be used as a working fluid within the hydraulic circuit within the reamer **100**. Thus, a portion of the drilling fluid is diverted to a secondary flow path **32** for use as the working fluid for the reamer. The drilling fluid along the secondary flow path **32** is filtered by the filter screen **210** as it enters the reamer **100**.

A controller **501** is located downhole, which may be inside the reamer **100** or a sub connected thereto. The electronic controller **501** may be powered by a downhole electrical power source, such as an on-board battery **502**. The controller **501** may monitor a signal input **19** for the activation signal **18**. In some cases, the activation signal **18** may be communicated downhole along a transmission path comprising electrical, electromagnetic, optical, and/or optical pathways. In cases where the activation signal **18** is embodied by an activation sequence, various sensors "S" in communication with the controller **501** may detect components of the activation sequence (e.g., flow and RPM) and the controller **501** may detect the activation sequence by matching the activation sequence with a representation of this activation sequence in memory.

In response to receiving the activation signal **18**, the controller **501** initiates activation of the reamer and the generation of a flow pattern detectable uphole to confirm the activation of the reamer. In this example, the controller **501** is coupled to a first valve, referred to as the activation valve **503**. The activation valve **503** can be any of a variety of valve types, such as a shuttle valve that the controller **501** may open in response to the activation signal. Opening the activation valve **503** supplies pressure from the drilling fluid along a first reamer fluid path referred to as the activation fluid path **504** to a hydraulic reamer arm actuator to actuate the reamer arms.

The pressurized fluid is supplied in parallel along a second reamer flow path referred to as the pulse flow path **505**. Flow along the pulse flow path **505** is used to operate a second valve referred to as the pulse valve **506** and to supply flow through the pulse valve **506** to generate a flow pattern in the well (e.g., in the annulus) to confirm the actuation of the reamer arms. The flow pattern may comprise a pulse, such as a negative fluid pulse, that propagates uphole of the reamer and may be detectable uphole of the reamer, such as at the surface of the wellsite. The features of the fluid circuit in FIG. **9** may be achieved using any of a variety of reamer configurations within the scope of this disclosure, examples of which provided below include use of an activation block and pulse confirmation block.

Confirmation of the reamer activation (or reamer deactivation) may trigger one or more steps, such as to commence (or cease) reaming, or any other step related to reaming, drilling, or other wellbore activities that may or may not involve the use of the drill string. For example, it may be desirable to confirm that the reamer arms are activated before performing a reamer operation, which may involve resuming rotation of the drill string. As another example, it may be desirable to confirm that the reamer arms are deactivated before tripping out of the wellbore.

FIG. **10** is a sectional side view of the modular activation block **401** of FIG. **8**. The activation block **401** may be in communication with the controller, which is not carried on the activation block **401** in this example. Various components carried on the activation block **401** may include an activation valve comprising a shuttle valve **610** are carried on the activation block **401**. The activation block **401** also defines the activation flow path **504** that is fluidically coupled as part of a fluid circuit through the reamer from the through bore of the reamer body to the activation chamber **208** (see, e.g., FIG. **7**) and ultimately exhausted to the annulus. The shuttle valve **610** is provided along the activation flow path **504** to open or close flow through the activation flow path **504**. Initially, the shuttle valve **610** is in the closed position. The controller **501** includes an electronic control board connected to a motor **607** via a bulkhead connector **605**. The motor **607** is coupled to the shuttle valve **610** via a gearbox **608** and ball screw **609** assembly. In response to the activation signal, the controller **501** powers the motor **607** to move the shuttle valve **610** from a closed position to an open position. Opening the activation flow path **504** allows filtered drilling fluid to flow through the activation flow path from an inlet port **601** to an outlet port **602** to drive expansion of the reamer arms. A compensation piston **603** is included as one way to provide pressure equalization to an oil volume **604** to minimize seal wear and friction levels during the shuttle valve transition. The outlet port **602** is fluidically coupled to the hydraulic reamer arm actuator (e.g., to the fill volume **208** of FIG. **7**), whereby the pressurized drilling fluid is used to drive reamer arm actuation. The outlet port **602** of the activation flow path **504** is also fluidically coupled to ports on a pulse confirmation block **402** of FIG. **11**, both to provide pressure for opening a pulse flow path and for flowing the pressurized fluid along the open pulse flow path.

FIG. **11** is a sectional side view of the modular pulse confirmation block **402**. The pulse confirmation block **402** defines the pulse flow path **505**, which extends at least from an inlet port **701** to an outlet port **703**. The outlet port **602** of the activation block (FIG. **10**) is fluidically coupled to the inlet port **701** and also to a valve control port **702** in FIG. **11**. A second valve comprising a delay piston **704** in this example is operable in response to pressure at the valve control port **702**. Thus, pressurized fluid may be used to open flow along the pulse flow path **505** and to supply pressurized fluid to the pulse flow path **505**. The delay piston **704** may be biased to a closed position with a biasing member, such as a spring **705**, preventing filtered drilling fluid from flowing through a bore **711** and venting to outlet port **703**.

A metering assembly, contained in component **707** (e.g., a retainer plug), is used to influence a duration of the flow along the pulse flow path **505**. A first piston (the delay piston **704**) and a second piston (referred to as the pulse piston **709**) are separated by a damping fluid (e.g., oil or other incompressible fluid) in a volume **706** defined along a damping flow path **712**. Movement of the delay piston **704** initially opens flow along the pulse flow path **505** and movement of the pulse piston **709** subsequently re-closes the flow along the pulse flow path **505**. This movement is damped by the damping fluid to modulate flow along the pulse flow path **505** such as to control how long the pulse flow path **505** is open. The flow of damping fluid along the damping flow path **505** continues until enough oil has transferred to the point when the pulse piston **709** closes off port **703**. At this point the internal bore pressure will increase to the previous level completing the negative pulse profile detected on surface.

In operation of the reamer, when the activation block **401** of FIG. **10** is closed, no pressure is supplied to the valve control port **701** and so the pulse flow path **505** remains closed. When the activation block **401** of FIG. **10** is in an open state to actuate the reamer arms, drilling fluid pressure from outlet port **602** acts on the end of the delay piston **704** in FIG. **11**. At some threshold, the pressure acting on the delay piston **704** overcomes the pressure at the outlet port **703**, the bias of the spring **705**, etc., thus urging the delay piston **704** to the right. As the delay piston **704** moves, it acts on the damping fluid in volume **706**, which is metered through a bore of a retainer plug **707**. The delay piston **704** begins to compress the spring **705** and extend a lower spring **708**. During this transition, a bore **711** along the pulse flow path **505** is opened, allowing fluid to flow across the delay piston **704** and out through the outlet port **703**. A resulting pressure drop of the internal bore pressure can result in a flow pattern having, such as a fluid pulse having certain expected characteristics so that the flow pattern can be detected uphole of the reamer, such as at the surface of the well site.

FIGS. **12**A-**12**C are sectional views illustrating further features of the pulse confirmation block assembly **402**. FIG. **12**A is a sectional view taken along **12**A in FIG. **11**, showing an equalization port **808** in the delay piston **704**. The purpose for this small port is to equalize pressure within the activation chamber **208** (see FIG. **7**) while tripping the reamer assembly into the hole. FIG. **12**B is a sectional view taken along section line **12**B in FIG. **11**. FIG. **12**C is an enlarged detail view of the portion encircled in FIG. **12**B. A retainer plug **707** controls the flow rate of oil from behind the delay piston **704** over to volume acting on pulse piston **709**. The retainer plug **707** is sealed to ensure the flow of damping fluid (e.g., oil) is throttled through a restrictor hole **801** when the shuttle valve **610** is open and a pressure differential is present between ports **702** and **703**. The direction of the oil flow continues until the pulse piston **709** contacts the inner upset of the port **703**. This is when the indicator pulse is terminated. Drilling may continue with the reamer arms in their expanded state until the rig pumps are shut down. When that event occurs, the dual spring bias will reverse the oil flow back to the center bore of block **806**. A spring-loaded ball **804** will also be forced off its seat to increase the flow area through bore **805**. This will decrease the time required for the delay piston to reset. Once the delay piston is reset, the reverse oil flow stops and the spring-loaded ball is forced back on its seat.

One benefit of this oil return feature is that the pulse confirmation block is reset and a pulse profile will be generated after a pump cycle occurs. This will be a confirmation to the rig personnel that the reamer is active and no deactivation sequence has been recognized.

The timing of and the duration of the negative pulse is determined by various parameters. First the oil viscosity contained in the block influences the delay piston movement. The size of the restrictor hole **803** and the combined spring stiffness also contribute to the timing of the pulse and duration. The axial distance between ports **711** and **713** (FIG. **11**) also determines the duration of the pulse. The diameter of the bores in which the pistons travel is also selected to optimize the pulse timing.

The manufacturing of the activation block and the pulse confirmation block raises certain considerations. For example, the block material selected should have the strength to handle internal pressures of up to 20 kpsi and atmospheric pressure between surfaces. The placement of the internal bores **711** and **713** are influential on the desired timing of the indicator pulse. Material erosion is also a consideration for the profile of these internal bores. It is for these reasons that a three-dimensional metallic printing of the block can be desirable to minimize the leak paths and erosion rates while ensuring adequate strength for this application.

FIGS. **13**A-**13**D illustrate the coordinated operation of the activation block and the pulse confirmation block at different states, States **1** to **4**, respectively. FIG. **13**A (State **1**) shows the block assemblies in an initial state. The shuttle valve **610** and the delay piston **704** are in the closed positions. In this state, the reamer is inactive and conventional drilling can be carried out. This state continues until the controller recognizes the activation profile. Once that profile is recognized the shuttle valve is opened as shown in FIG. **13**B (State **2**). This state is shown with the delay piston in a mid-stroke position. The indicator pulse is occurring in this state. FIG. **13**C (State **3**) shows the instant that the indicator pulse is terminated. The pulse piston **709** has closed the port **703**. The reamer has the arms extended and drilling continues. FIG. **13**D (State **4**) shows the delay piston in the reset condition after the rig pumps are stopped and the reverse oil flow has occurred.

FIG. **14** is a sectional side view of a different embodiment for the pulse confirmation block **1402**. When this embodiment is utilized, the controller **501** is connected to both the activation block (e.g., as shown in FIG. **9**) and to this alternative embodiment of the pulse confirmation block **1402**. The controller **501** may include a control board wired to the motor/gearbox **455** via a bulkhead connector **457**. The programming of the controller determines when the reamer is active. At preprogrammed events a pulse sequence is generated to provide an indication on surface that the reamer is active. Initially the shuttle valve **453**, is in the closed position. When the motor that is coupled to a gearbox and ball screw **454** assembly is activated, the shuttle valve is moved from a closed position to an open position. This allows the filtered drilling fluid to enter port **452** and exit port **451** to create a momentary pressure decrease. After a short period of time, the motor is repowered to close the shuttle valve. The internal pipe pressure from the drill string then rises back to the initial level. This pulse signature can be a single pulse or a series of pulses. The timing and duration of these negative pulses is controlled by the controller. The compensation piston **460** provides a method of pressure equalization to the oil volume **459** to minimize seal wear and friction levels during the shuttle valve transition. In this scenario, the ports between the activation and pulse confirmation blocks do not have to be connected.

Accordingly, the present disclosure includes a multi-activation reamer and method that allow for reamer activation from the surface of a wellsite or even from a remote location, using a reamer activation signal communicated downhole in the form of an activation sequence of flow through the drill string and/or rotation of the drill string that is detectable downhole, such as a combination of drill string pressure and rotation, that are sensed downhole and interpreted by an electronic controller on the reamer body. Aspects of this disclosure may be embodied in a method, apparatus (e.g., a remotely-actuatable reamer), drilling system, and so forth, and may include any of the various features disclosed herein, including one or more of the following statements.

Statement 1. A method, comprising: generating a reamer activation signal at a well site having a reamer in a drill string in a well; receiving the reamer activation signal downhole; initiating a flow of a drilling fluid along an activation flow path in the reamer in response to the reamer activation signal to hydraulically actuate one or more reamer arms of the reamer; initiating a flow of the drilling fluid along a pulse flow path in the reamer and using the flow along the pulse flow path to generate a flow pattern in the well; and detecting the flow pattern uphole of the reamer to confirm the actuation of the reamer arms.

Statement 2. The method of statement 1, wherein generating the reamer activation signal comprises performing a predetermined sequence of one or both of flow through the drill string and rotation of the drill string, and wherein receiving the reamer activation signal downhole comprises electronically detecting the predetermined sequence.

Statement 3. The method of statement 2, wherein initiating the flow of the drilling fluid along the activation flow path comprises electronically opening a first valve along the activation flow path in response to electronically detecting the predetermined sequence.

Statement 4. The method of statement 1, wherein actuating the one or more reamer arms comprises using a pressure along the activation flow path to drive a hydraulic reamer arm actuator coupled to the reamer arms.

Statement 5. The method of statement 4, wherein initiating the flow of the drilling fluid along the pulse flow path comprises using the pressure along the activation flow path to also open a second valve along the pulse flow path.

Statement 6. The method of statement 1, wherein generating the flow pattern comprises generating a pressure pulse by controlling the flow along the pulse flow path between the drill string and an annulus about the drill string, the pressure pulse propagating up the well from the reamer.

Statement 7. The method of statement 6, wherein generating the pressure pulse by controlling the flow along the pulse flow path further comprises using a pressure along the first flow path to drive a metering assembly to temporarily open and then close the flow along the pulse flow path.

Statement 8. The method of statement 7, wherein driving the metering assembly to open and then close the flow along the pulse flow path comprises moving a first piston and a second piston separated by a damping fluid along a damping flow path, wherein movement of the first piston initially opens the flow along the second flow path and movement of the second piston subsequently closes the flow along the second flow path.

Statement 9. The method of statement 8, further comprising: subsequently reducing the pressure along the first flow path; and biasing the first and second pistons back toward their previous positions along the damping flow path.

Statement 10. A method of reaming a wellbore, comprising: lowering a reamer into the wellbore to a selected reaming location; generating a reamer activation signal to open an activation flow path; flowing pressurized drilling fluid along the activation flow path, when open, and using a pressure along the activation flow path to hydraulically extend one or more reamer arms of the reamer; opening flow of the pressurized drilling fluid along a pulse flow path to generate a flow pattern in the well; detecting the flow pattern in the well uphole of the reamer to confirm the extension of the reamer arms; and rotating the reamer with the reamer arms extended against the wellbore while advancing the reamer axially in the wellbore.

Statement 11. The method of statement 10, wherein opening flow of the pressurized drilling fluid along a pulse flow path comprises using the pressure along the activation flow path to open the flow of the pressurized drilling fluid along the pulse flow path.

Statement 12. The method of statement 10, wherein generating the flow pattern in the well comprises moving a first piston and a second piston separated by a damping fluid along a damping flow path, wherein movement of the first piston initially opens the flow along the second flow path and movement of the second piston subsequently closes the flow along the second flow path.

Statement 13. The method of statement 10, further comprising: at least reducing the flow of drilling fluid from a drilling fluid pump to reduce the flow of pressurized drilling fluid along the activation flow path; closing the activation and pulse flow paths; and retracting the one or more reamer arms in response to closing the activation flow path.

Statement 14. A remotely-actuatable reamer, comprising: a reamer body positionable in a well including opposing inlet and outlet ends for connection within a drill string and a through bore extending from the inlet end to the outlet end; one or more reamer arms pivotably secured to the reamer body; a hydraulic reamer arm actuator coupled to the one or more reamer arms; an activation block within the reamer body defining an activation flow path fluidically coupling the through bore of the reamer body with the hydraulic reamer arm actuator, the activation block including a first valve along the activation flow path operable in response to a reamer activation signal; and a pulse confirmation block within the reamer body defining a pulse flow path fluidically coupling the through bore of the reamer body with an annulus exhaust port, the pulse confirmation block including a second valve along the pulse flow path operable in response to the reamer activation signal to generate a flow pattern comprising a detectable fluid pulse.

Statement 15. The reamer of statement 14, further comprising: an electronic controller in the reamer body coupled to the first valve in the activation block, the electronic control module comprising one or more electronic sensors and control logic responsive to the activation signal to open the first valve in response to the activation signal.

Statement 16. The reamer of statement 15, wherein the electronic controller is modular and is removably secured within the reamer body.

Statement 17. The reamer of statement 15, wherein the reamer activation signal comprises a predetermined sequence of flow through the reamer and/or rotation detectable at the reamer.

Statement 18. The reamer of statement 14, wherein the pulse confirmation block further comprises: a first piston moveable within the activation block to alternately open and close the pulse flow path; a second piston moveable within the pulse confirmation block to alternately open and close the pulse flow path; a damping fluid along a damping flow path between the first piston and the second piston, whereby pressurized drilling fluid in the activation flow path moves the first piston, second piston, and damping fluid to open the pulse flow path with the first piston and to subsequently close the pulse flow path with the second piston.

Statement 19. The reamer of statement 18, wherein the first and second pistons are biased to close the pulse flow path at the first piston and open the pulse flow path at the second piston when pressure in the activation flow path is reduced.

Statement 20. The reamer of statement 14, wherein one or more of the activation block and pulse confirmation block are modular and are removably secured within the reamer body.

Therefore, the present embodiments are well adapted to attain the ends and advantages mentioned as well as those that are inherent therein. The particular embodiments disclosed above are illustrative only, as the present embodiments may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Although individual embodiments are discussed, all combinations of each embodiment are contemplated and covered by the disclosure. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. Also, the terms in the claims have their plain, ordinary meaning unless otherwise explicitly and clearly defined by the patentee. It is therefore evident that the particular illustrative embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the present disclosure.

What is claimed is:

1. A method, comprising:
generating a reamer activation signal at a well site having a reamer in a drill string in a well;
receiving the reamer activation signal downhole;
opening an activation valve in response to the reamer activation signal, wherein the activation valve is disposed along a secondary flow path between a pulse valve and a primary flow path of drilling fluid;
initiating a flow of a drilling fluid along an activation flow path in the reamer in response to the activation valve opening, wherein the activation flow path is fluidly connected to the activation valve, and wherein the flow of drilling fluid along the activation flow path is configured to hydraulically actuate one or more reamer arms of the reamer;
initiating a flow of the drilling fluid along a pulse flow path in the reamer in response to the activation valve opening, wherein the pulse flow path fluidly connects to the activation valve to the pulse valve, and wherein the pulse valve uses the flow along the pulse flow path to generate a flow pattern in the well; and
detecting the flow pattern uphole of the reamer to confirm the actuation of the reamer arms.

2. The method of claim **1**, wherein generating the reamer activation signal comprises performing a predetermined sequence of one or both of flow through the drill string and rotation of the drill string, and wherein receiving the reamer activation signal downhole comprises electronically detecting the predetermined sequence.

3. The method of claim **2**, wherein the activation valve is electronically opened in response to electronically detecting the predetermined sequence.

4. The method of claim **1**, wherein actuating the one or more reamer arms comprises using a pressure along the activation flow path to drive a hydraulic reamer arm actuator coupled to the reamer arms.

5. The method of claim **1**, wherein the pulse valve is configured to open in response to pressure from the flow of the drilling fluid along the pulse flow path.

6. The method of claim **1**, wherein generating the flow pattern comprises generating a pressure pulse by controlling the flow along the pulse flow path between the drill string and an annulus about the drill string, the pressure pulse propagating up the well from the reamer.

7. The method of claim **6**, wherein generating the pressure pulse by controlling the flow along the pulse flow path further comprises using a pressure along the activation flow path to drive a metering assembly to temporarily open and then close the flow along the pulse flow path.

8. The method of claim **7**, wherein driving the metering assembly to open and then close the flow along the pulse flow path comprises moving a first piston and a second piston separated by a damping fluid along a damping flow path, wherein movement of the first piston initially opens the flow along the pulse flow path and movement of the second piston subsequently closes the flow along the pulse flow path.

9. The method of claim **8**, further comprising:
subsequently reducing the pressure along the activation flow path; and
biasing the first and second pistons back toward their previous positions along the damping flow path.

10. A method of reaming a wellbore, comprising:
lowering a reamer into the wellbore to a selected reaming location;
generating a reamer activation signal to open an activation flow path;
opening an activation valve in response to the reamer activation signal, wherein the activation valve is disposed along a secondary flow path between a pulse valve and a primary flow path of drilling fluid;
flowing pressurized drilling fluid along the activation flow path in response to the activation valve opening, wherein the activation flow path is fluidly connected to the activation valve, and using a pressure along the activation flow path to hydraulically extend one or more reamer arms of the reamer;
flowing the pressurized drilling fluid along a pulse flow path in response to the activation valve opening, wherein the pulse flow path fluidly connects to the activation valve to the pulse valve, and wherein the pulse valve uses the flow of the pressurized drilling fluid along a pulse flow path to generate a flow pattern in the well;
detecting the flow pattern in the well uphole of the reamer to confirm the extension of the reamer arms; and
rotating the reamer with the reamer arms extended against the wellbore while advancing the reamer axially in the wellbore.

11. The method of claim **10**, wherein generating the flow pattern in the well comprises moving a first piston and a second piston separated by a damping fluid along a damping flow path, wherein movement of the first piston initially opens the flow along the pulse flow path and movement of the second piston subsequently closes the flow along the pulse flow path.

12. The method of claim **10**, further comprising:
at least reducing the flow of drilling fluid from a drilling fluid pump to reduce the flow of pressurized drilling fluid along the activation flow path;
closing the activation flow path and the pulse flow paths via closing the activation valve; and
retracting the one or more reamer arms in response to closing the activation flow path.

13. A remotely-actuatable reamer, comprising:
a reamer body including opposing inlet and outlet ends for connection within a drill string and a through bore extending from the inlet end to the outlet end, wherein the through bore forms a primary flow path for drilling fluid passing through the reamer body;
one or more reamer arms pivotably secured to the reamer body;
a hydraulic reamer arm actuator coupled to the one or more reamer arms;
an activation block within the reamer body defining an activation flow path that fluidically couples the primary

flow path with the hydraulic reamer arm actuator, the activation block including an activation valve disposed along the activation flow path between the primary flow path and the hydraulic reamer arm actuator, and wherein the activation valve is operable in response to a reamer activation signal; and

a pulse confirmation block within the reamer body defining a pulse flow path that fluidically couples the primary flow path with an annulus exhaust port, wherein the pulse confirmation block includes a pulse valve disposed along the pulse flow path, wherein the activation valve is disposed between the pulse valve and the primary flow path, and wherein the pulse valve is operable in response to the reamer activation signal to generate a flow pattern comprising a detectable fluid pulse.

14. The reamer of claim **13**, further comprising:

an electronic controller in the reamer body coupled to the activation valve in the activation block, the electronic control module comprising one or more electronic sensors and control logic responsive to the activation signal to open the activation valve in response to the activation signal.

15. The reamer of claim **14**, wherein the electronic controller is modular and is removably secured within the reamer body.

16. The reamer of claim **14**, wherein the reamer activation signal comprises a predetermined sequence of flow through the reamer and/or rotation detectable at the reamer.

17. The reamer of claim **13**, wherein the pulse confirmation block further comprises:

a first piston moveable within the activation block to alternately open and close the pulse flow path;

a second piston moveable within the pulse confirmation block to alternately open and close the pulse flow path;

a damping fluid along a damping flow path between the first piston and the second piston, whereby pressurized drilling fluid in the activation flow path moves the first piston, second piston, and damping fluid to open the pulse flow path with the first piston and to subsequently close the pulse flow path with the second piston.

18. The reamer of claim **17**, wherein the first and second pistons are biased to close the pulse flow path at the first piston and open the pulse flow path at the second piston when pressure in the activation flow path is reduced.

19. The reamer of claim **13**, wherein one or more of the activation block and pulse confirmation block are modular and are removably secured within the reamer body.

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