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(71) Applicant: **COMPLETIONS RESEARCH AG**
[CH/CH]; Zentralstrasse 44, CH-6003 Luzern (CH).(72) Inventors: **GRAF, Robert James**; 61 River Rock Court SE, Calgary, Alberta T2C 4P3 (CA). **SMOLKA, Robert Steve**; 74 Marbrooke Circle NE, Calgary, Alberta T2A 2W6 (CA).(74) Agents: **SCHULTZ, Melanie** et al.; 709 Main Street, Suite 300, Canmore, Alberta T1W 2B2 (CA).

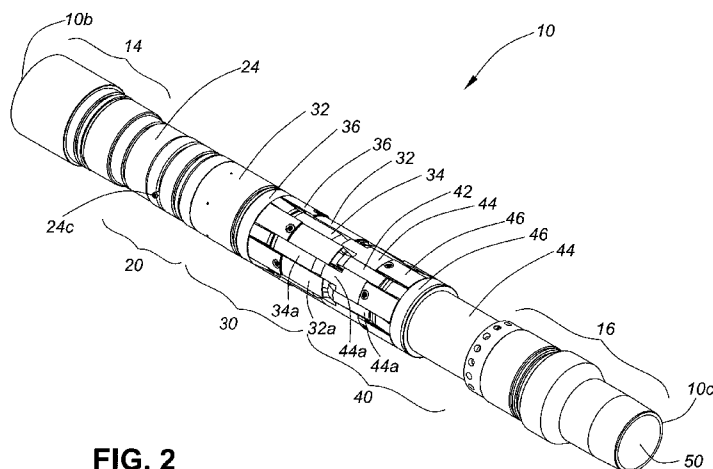
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(54) Title: DART-INITIATED MULTISTAGE HIGH PRESSURE FRACTURING SYSTEM

**FIG. 2**

(57) Abstract: A system and method for fracturing multiple zones in a hydrocarbon well is provided. The system comprises a series of multistage fracturing devices (MFD's) that are connected along a casing or completion tubing string and have ports that can be opened to allow fracturing of the formation adjacent the MFD. The ports in each MFD are triggered to open by a dart having a specific geometry that is pumped downhole and caught by a catching mechanism that comprises levers or "fingers" in the MFD. Upon catching of the dart, the section downhole of the dart can be sealed off and the ports located uphole of the dart can be opened to allow fracturing operations to occur.

DART-INITIATED MULTISTAGE HIGH PRESSURE FRACTURING SYSTEM

FIELD OF THE INVENTION

[0001] The invention generally relates to a system and method for fracturing multiple zones in an oil and gas well. The invention specifically relates to a system and method comprising a series of multistage fracturing devices operatively connected along a tubing string, wherein the sealing of the tubing string where a multistage fracturing device is located is triggered by a dart of specific dimensions that is pumped down the tubing string and captured by the multistage fracturing device.

BACKGROUND OF THE INVENTION

[0002] In the oil and gas industry, during well completion operations, there is often a need to conduct different operations at various zones within the well in order to enhance production from the well. That is, within a particular well, there may be several zones of economic interest that after drilling and/or casing, the operator may wish to access the well directly and/or open the casing in order to conduct fracturing operations to promote the migration of hydrocarbons from the formation to the well for production.

[0003] In the past, there have been a number of techniques that operators have utilized in cased wells to isolate one or more zones of interest to enable access to the formation as well as to conduct fracturing operations. In the simplest situation, a cased well may simply need to be opened at an appropriate location to enable hydrocarbons to flow into the well. In this case, the casing of the well (and any associated cement) may be penetrated at the desired location such that interior of the well casing is exposed to the formation and hydrocarbons can migrate from the formation to the interior of the well.

[0004] While this basic technique has been utilized in the past, it has been generally recognized that the complexity of penetrating steel casing/cement at a desired zone is more complicated and more likely to be subject to complications than positioning specialized sections of casing adjacent a zone of interest and then opening that section after the well has been cased. Generally, if a specialized section of casing is positioned adjacent a zone of interest, various techniques can be utilized to effectively open one or

more ports in a section of casing without the need to physically cut through the steel casing.

[0005] In other situations, particularly if there is a need to fracture one or more zones of the formation, systems and techniques have been developed to isolate particular sections of the well in order to both enable selective opening of specialized ports in the casing and conduct fracturing operations within a single zone.

[0006] One such technique is to incorporate packer elements and various specialized pieces of equipment into one or more tubing strings, run the tubing string(s) into the well and conduct various hydraulic operations to effect opening of ports within the tubing strings.

[0007] Importantly, while these techniques have been effective, there has been a need for systems and methods that minimize the complexity of such systems. That is, any operation involving downhole equipment is expensive in terms of capital/rental cost and time required to complete such operations. Thus, to the extent that the complexity of the equipment can be reduced and/or the time/personnel required to conduct such operations, such systems can provide significant economic advantages to the operator.

[0008] In the past, such techniques of isolating sections of a well have included systems that utilize balls within a tubing string to enable successive areas of a tubing string to be isolated. In these systems, a ball is dropped/pumped down the tubing string where it may engage with specialized seats within the string and thereby seal off a lower section of the well from an upper section of the well. In the past, in order to ensure that a lower section is sealed before an upper section, a series of balls having different diameters are dropped down the tubing starting with a smallest diameter ball and progressing uphole with progressively larger balls. Typically, each ball may vary in diameter by 1/8th of an inch and will engage with a downhole seat sized to engage with a specific diameter ball only. While effective, this system is practically limited by the range in diameters in balls. That is, to enable 16 zones of interest to be isolated, the smallest ball would be 2 inches smaller in diameter compared to the largest ball. As a result, there are practical limitations in the number of zones that can be incorporated into a tubing string which thus limits the number of zones that can be fracturing. As a modern well may wish to

initiate up to approximately 40 or more fracturing operations, typical ball drop and capture systems cannot be incorporated into such wells.

[0009] Thus, there has been a need for a system that is not limited by the size of the balls being dropped and that can enable a significantly larger number of fracturing windows to be incorporated within a tubing string.

SUMMARY OF THE INVENTION

[0010] In accordance with the invention, there is provided a device for connection to a casing or completion tubing in a wellbore to enable fluid access between an inner cavity of the device and a zone of interest in a hydrocarbon formation adjacent the device, the inner cavity being continuous with an internal bore in the casing or completion tubing, the device comprising an outer sleeve for operative connection to the casing or completion tubing, the outer sleeve having at least one port to enable fluid access between the inner cavity and the zone of interest; a catchment system operatively retained within the outer sleeve for catching a projectile moving through the inner cavity; a sealing system operatively retained within the outer sleeve for sealing a downhole section of the device from an uphole section of the device when the projectile is caught; wherein the at least one port can be opened through hydraulic activation when the sealing system is sealed; and wherein an outer profile of the projectile determines whether the projectile will be caught.

[0011] In one embodiment of the invention, the projectile includes at least one shoulder on the outer profile, and the location and dimensions of the at least one shoulder determines whether the projectile will be caught by the catchment system. Furthermore, a first projectile having an outer diameter and an outer profile will be caught, while a second projectile having the same outer diameter as the first projectile and a different outer profile will pass through the catchment system.

[0012] In another embodiment, the catchment system comprises a plurality of levers pivotably connected around the circumference of the inner cavity, wherein the levers operatively engage with a projectile having a certain outer profile. The catchment system may further comprise a biasing means in operative connection with the levers for biasing the levers in a first position.

[0013] In yet another embodiment, the sealing system comprises a piston and a sealing member positioned uphole and adjacent to a caught projectile, the sealing member deformable against the caught projectile by hydraulic actuation of the piston to seal the downhole section from the uphole section of the device.

[0014] In a further embodiment, the catchment system is in a first shearing engagement with the outer housing, and wherein catchment of a projectile enables the first shearing engagement to disengage and the catchment system to move downhole with respect to the outer housing to enable the sealing system to seal. Further, the catchment system may be in a second shearing engagement with the outer housing, and wherein sealing of the sealing system enables the second shearing engagement to disengage and the catchment system to move further downhole with respect to the outer housing to open the at least one port.

[0015] In one embodiment, the caught projectile can be released from the catchment system to re-open the inner cavity. The caught projectile may be dissolvable.

[0016] In another aspect of the invention, there is provided a system for use in a wellbore comprising a plurality of the above-described devices, each device connected to the casing or completion tubing at a different location to selectively enable access to a zone of interest at each location by sending a projectile downhole from a well surface, the projectile having an outer profile configured to be caught by the catchment system at the desired location.

[0017] In a further aspect of the invention, there is provided a method for selectively enabling fluid access to a plurality of zones in a wellbore comprising the steps of: (a) running an assembly having a plurality of actuatable devices into a wellbore having a plurality of zones, each device actuatable between a closed state and an open state, wherein in the open state fluid access between an internal bore of the assembly and a zone adjacent each device is enabled; (b) selectively actuating a device at the desired zone by dropping a projectile having an outer profile with dimensions to be caught by the device at the desired zone; catching the projectile in the device at the desired zone; applying hydraulic pressure in the internal bore from a well surface to seal a section downhole of the caught projectile from a section uphole of the caught projectile; and

applying hydraulic pressure to move a member in the device downhole with respect to the assembly to open at least one port to provide fluid access between the internal bore and the adjacent zone; (c) performing well operations that require access to the desired zone; and (d) repeating steps b) and c) to successively actuate other devices in the assembly.

[0018] In a further embodiment, the outer profile of the projectile includes at least one shoulder, and the position and dimensions of the shoulder determine whether the projectile is caught by a device.

[0019] In one embodiment, the projectile is caught by pivotable levers in the device.

[0020] In another embodiment, the plurality of devices are successively actuated in a downhole to uphole direction.

[0021] In a further embodiment, the well operations include fracturing operations.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] The invention is described with reference to the accompanying figures in which:

FIG. 1 is a schematic diagram of a deployed casing or completion tubing string incorporating several multi-stage fracturing devices in accordance with the invention together with corresponding packer elements.

FIG. 2 is a perspective view of a multi-stage fracturing device (MFD) in accordance with the invention. The outer housing is removed for purposes of illustration.

FIGS. 3A, 3B and 3C are perspective views of a catcher mechanism of the MFD sequentially illustrating a dart being captured in accordance with the invention.

FIG. 4 is a partial perspective view of the MFD illustrating an outer housing having a plurality of ports in a closed position, wherein the ports can be opened to allow for fracturing operations to occur.

FIG. 5 is a perspective view of a support mechanism of the MFD.

FIGS. 6A, 6B and 6C are a series of a cross-sectional side view of the MFD illustrating the normal position of the MFD wherein a dart is entering the uphole end of the MFD but has not yet been captured.

FIGS. 7A to 7F are a sequence of partial cross-sectional side views of the MFD illustrating a dart being captured by the catcher mechanism.

FIGS. 8A to 8F are a sequence of partial cross-sectional side views of the MFD illustrating a dart passing through the catcher mechanism without being captured due to the geometry of the dart.

FIGS. 9A, 9B and 9C are a series of a cross-sectional side view of the MFD illustrating the first stage of operation wherein a dart is captured by the catcher mechanism.

FIGS. 10A, 10B and 10C are a series of a cross-sectional side view of the MFD illustrating the second stage of operation wherein the support mechanism has been set to brace the captured dart.

FIGS. 11A, 11B and 11C are a series of a cross-sectional side view of the MFD illustrating the third stage of operation wherein the sealing mechanism has been set to seal off a downhole section from an uphole section of the tubing string.

FIGS. 12A, 12B and 12C are a series of a cross-sectional side view of the MFD illustrating the fourth stage of operation wherein the ports have been opened to ready the MFD for the commencement of fracturing operations.

FIG. 13 is a side view of a dart in accordance with one embodiment of the invention.

FIG. 14A is a partial cross-sectional side view of the MFD illustrating the sealing mechanism in the first (unsealed) stage of operation as in FIGS. 9A-9C.

FIG. 14B is a partial cross-sectional side view of the MFD illustrating the sealing mechanism in the second stage of operation as in FIGS. 10A-10C, wherein there is a pressure differential to allow the piston to set the sealing mechanism.

FIG. 14C is a partial cross-sectional side view of the MFD illustrating the sealing mechanism in the third (sealed) stage of operation as in FIGS. 11A-11C.

DETAILED DESCRIPTION OF THE INVENTION

[0023] With reference to the figures, a multistage fracturing device (MFD) 10 and methods of operating the MFD are described.

[0024] For the purposes of description herein, the MFD 10 may be configured to a casing or completion tubing string 4 together with appropriate packer elements 10a to enable the isolation of particular zones 8a within a formation as shown in Figure 1. The combination of MFDs 10 and packer elements 10a on a casing or completion tubing 4 enable fracturing operations to be conducted within a formation zone 8a within a well 8. Alternatively, the system may be utilized without packer elements in situations for example where the completion tubing is cemented in place. While the following description assumes the use of packer elements 10a, this is not intended to be limiting.

[0025] Operational Overview

[0026] With reference to FIG. 1, a number of MFDs 10 are connected to a casing or completion tubing 4 between packer elements 10a at positions that correspond to zones of interest (formations) 8a within the well. Generally, after placement of the casing or completion tubing 4 within the well 8, the assembled system can be pressurized at the surface 6 through wellhead equipment 6a to cause the packer elements 10a to seal against the well 8. Thereafter, a dart 18 is released at the surface 6 within the casing or completion tubing and falls and/or is pumped through the casing or completion tubing to engage with a specific MFD, preferably the MFD located nearest the downhole end 4a of the tubing. The dart has a specific external geometry and diameter that enables the dart to be captured by a specific MFD 10 and to pass through other MFD's without being caught.

[0027] When the dart 18 is captured, shown in zone 8a of FIG. 1, the dart causes the interior of the casing or completion tubing to be sealed from the lower regions of the casing or completion tubing such that additional hydraulic events can be initiated to open a plurality of ports within the MFD that the dart is captured in. That is, when the dart has

been captured and a port in the MFD 10 is opened, a fracturing operation can be completed within a zone of interest 8a adjacent that MFD.

[0028] After a zone 8a has been fractured, further darts are successively introduced into the casing or completion tubing to enable successive MFDs to be opened and fracturing operations to be completed within other zones. As a result, each of the zones of interest within the well 8 can be sequentially fractured moving from the downhole end of the tubing upwards.

[0029] Importantly, the darts are designed such that over a period of time, typically a few days, the darts will at least partially dissolve such that their diameter is eroded and they will fall to the bottom of the well. Thus, after all fracturing operations have been completed, all the zones of the well are then opened to the interior of the casing or completion tubing to enable production of the well through the casing or completion tubing.

[0030] It should be noted that the lowermost zone of the completion string does not require an MFD 10 and that a simple hydraulic valve that opens on pressure would normally be utilized at the lowermost zone (not shown) to initially establish circulation and to enable fracturing of the lowermost zone.

[0031] Structural Overview

[0032] Referring to FIG. 2, the MFD 10 generally comprises an upper housing 14, a sealing mechanism 20, a catcher mechanism 30, a support mechanism 40, a lower housing 16, and a continuous inner cavity 50 extending from an uphole end 10b to a downhole end 10c of the MFD that is in fluid communication with the completion tubing and through which a dart 18 (not shown in FIG. 2) moves to trigger the setting and sealing mechanics of the MFD. The components of the MFD illustrated in FIG. 2 are all contained within an outer housing, which has been removed for illustrative purposes. The operation and components of the system are described in greater detail below.

[0033] Dart 18

[0034] The dart 18 is shown entering the uphole end 10b of the MFD inner cavity 50 in FIG. 6A. In one embodiment, shown in FIG. 13, the dart is cylindrical-shaped and has a leading end 18a with a beveled edge 18f and a circumferential leading shoulder 18b; a trailing end 18c with a circumferential trailing shoulder 18d; and an outer surface 18e. The widest part of the dart's diameter is located between the leading shoulder 18b and the leading end 18a. The geometrical configuration and diameter of the dart determines whether the catcher mechanism catches the dart or allows the dart to pass through and continue downhole to subsequent MFD's, one of which may have a catcher mechanism sized to catch the dart. Other geometrical configurations of the dart than that which is illustrated could also be used as will be explained below.

[0035] Preferably, the dart has an approximate diameter in the range of 3.25 to 3.75 inches and an approximate length of 4 to 6 inches.

[0036] After completion of the fracturing operations, the darts are released from the catcher mechanism and flowed back to the surface to re-open the inner cavity 50. Preferably, the dart is made of dissolvable, or degradable composite material, such that after a period of time, typically a few days, the dart will at least partially dissolve such that its diameter is reduced and it will fall to the bottom of the well, thereby re-opening the inner cavity. Alternative means for releasing the dart could also be used including systems having dissolvable components within the catcher mechanism or electronic release systems.

[0037] Housing 12, 14, 16

[0038] The cross-sectional view of the MFD 10 in FIGS. 6A to 6C illustrates the housing elements which comprise the outer housing 12, the upper housing 14 and the lower housing 16.

[0039] The outer housing 12 contains the components of the MFD and generally comprises an uphole end 12a, a downhole end 12b and a plurality of ports 12d, shown in FIG. 4, that when open, allow fluid access from the inner cavity 40 to the formation for completing fracturing operations, and when closed, seal the inner cavity from the

formation. The at least one piston shear pin 24c (FIGS. 2 and 4) removably connects the outer housing 12 to a piston sleeve of the sealing mechanism 20.

[0040] The upper housing 14 is partially retained within and in sealing connection with the outer housing uphole end 12a. An uphole end of the upper housing is in sealing connection with the casing or completion tubing 4.

[0041] The lower housing 16 is partially retained within and in sealing connection with the outer housing downhole end 12b, and comprises an outer shoulder 16c for abutment with the outer housing downhole end, and an inner shoulder 16b for abutment with a support sleeve 44 of the support mechanism 40 when the system is in the final downhole position (FIGS. 12 to 12C). The lower housing 16 includes a plurality of shear pin holes 16a through which the downhole shear pins 52 are inserted to connect the lower housing to the support sleeve 44. A downhole end of the lower housing is in sealing connection with the casing or completion tubing 4.

[0042] Various sealing elements, such as o-rings, are employed between the housing elements in circumferential grooves for sealing purposes.

[0043] Catcher Mechanism 30

[0044] The catcher mechanism 30 functions to “catch” or trap the dart 18 as it moves downhole through the MFD inner cavity 50 if the dart is dimensioned to be caught. Referring to FIG. 2, the catcher mechanism 30 generally comprises a catcher sleeve 32, a catcher member 34 and a catcher spring 36.

[0045] *Catcher Member 34*

[0046] Referring to FIGS. 3A and 7A, the catcher member 34 comprises a plurality of pivotable catcher fingers 34a spaced apart around the circumference of the catcher member, each pivotable catcher finger 34a having an uphole end 34b, a downhole end 34d and an inner surface 34g, and being pivotable about a dowel pin 34h that is connected to the catcher sleeve 32. The inner surface 34g has an upper shoulder 34c and a lower shoulder 34e which are used to catch the dart 18. The catcher fingers 34a are radially pivotable about a tangential axis of the catcher member, as shown in FIG.

3B, which allows the catcher member to either catch a dart 18 or allow the dart to pass through the catcher member. The catcher fingers 34a also each have an outer tapered surface 34f at the downhole end 34d that engages the support mechanism 40, as explained in greater detail below.

[0047] *Catcher Sleeve 32*

[0048] Referring to FIG. 3A, the catcher sleeve 32 is connected to the catcher member 34 and generally comprises an uphole end 32c and a downhole end 32b, the downhole end having a plurality of rigid catcher sleeve fingers 32a spaced apart around the circumference of the catcher sleeve 32, interspersed between the pivotable catcher fingers 34a. At the downhole end 32b of each catcher sleeve finger 32a there is an inner tapered surface 32d for engagement with the support mechanism 40. The catcher sleeve uphole end 32c is attached, preferably by a threaded connection, to the piston sleeve 24 that forms part of the seal setting mechanism.

[0049] *Catcher Spring 36*

[0050] The catcher spring 36 encircles a section of the catcher member 34 and the catcher sleeve 32 for biasing the pivotable catcher fingers 34a in a neutral position, wherein the catcher fingers are generally parallel with the axis of the inner cavity 50 (shown in FIG. 3A and 6B). Preferably, the catcher spring 36 is a collet spring that forms a collar around the catcher member 34 and catcher sleeve 32. In one embodiment, the catcher spring 36 has a plurality of fixed arms 36a interspersed with a plurality of biasing arms 36b. The fixed arms are attached to the rigid catcher sleeve finger 32a by fastening means, such as screws or pins 36c operatively retained within apertures 32e in the catcher sleeve. The biasing arms 36b are biased against the pivotable catcher fingers 34a.

[0051] *Support Mechanism 40*

[0052] The support mechanism 40, shown in FIG. 5, comprises a support member 42, a support sleeve 44, and a support spring 46. The support member and the support sleeve work in conjunction with the catching mechanism 30 to support the dart 18 after it has caught.

[0053] *Support Member 42*

[0054] Referring to FIGS. 5 and 10B, the support member 42 is similar to the catcher member 34 in that it comprises a plurality of radially pivotable support fingers 42a spaced apart around the circumference of the support member 42 that pivot about a tangential axis of the support member. Each pivotable support finger 42a has an uphole end 42b with an upper shoulder 42c on the inner surface, and an outer tapered surface 42d. Each pivotable support finger 42a is lined up end to end with a corresponding rigid catcher sleeve finger 32a along the longitudinal axis of the MFD, as shown in FIG. 2. The pivoting of the support fingers 42a allows a dart 18 to pass through the support member 42 if it was not caught by the catcher mechanism 30.

[0055] *Support Sleeve 44*

[0056] Referring to FIG. 5, the support sleeve 44 is in operative connection with the support member 42, and has a similar structure to the catcher member 34. The support sleeve 44 generally comprises an uphole end 44f and a downhole end 44b, the uphole end 44f having a plurality of rigid support sleeve fingers 44a spaced apart around the circumference of the support sleeve 44 each having an inner tapered surface 44e and interspersed between the pivotable support fingers 42a. Each rigid support sleeve finger 44a is lined up end to end along the longitudinal axis of the MFD 10 with a corresponding pivotable catcher finger 34a, as shown in FIG. 2.

[0057] The support sleeve downhole end 44b is shearingly engaged with the lower housing 16 via at least one shear pin 52. Preferably, the support sleeve downhole end 44a has a circumferential groove 44c that receives the at least one shear pin 52. Upon breaking of the at least one shear pin 52 via fluid pressure, the support sleeve 44, along with the entire support mechanism 40, catcher mechanism 30 and sealing mechanism 20, moves downhole with respect to the lower housing 16, outer housing 12 and upper housing 14 into a final downhole position, shown in FIGS. 12A to 12C.

[0058] *Support Spring 46*

[0059] The support spring 46 is similar in structure and function to the catcher spring 36. The support spring 46 encircles a section of the support member 42 and the support

sleeve 44, as shown in FIG. 5, for biasing the pivotable support sleeve fingers 44a in a neutral position, wherein the pivotable support sleeve fingers are generally parallel with the axis of the inner cavity 50 (shown in FIG. 5 and 6B). Preferably, the support spring 46 is a collet spring that forms a collar around the support member 42 and support sleeve 44 and has a plurality of fixed arms 46a interspersed circumferentially with a plurality of biasing arms 46b. The fixed arms 46a are attached to the rigid support sleeve fingers 44a by fastening means, such as screws or pins 46c operatively retained within apertures 44d (shown in FIG. 6B) in the support sleeve 44. The biasing arms 46b are biased against the pivotable support fingers 42a.

[0060] Sealing Mechanism 20

[0061] Referring to FIGS. 6A and 6B, the sealing mechanism 20 generally comprises a piston 22, a piston sleeve 24 and a compressible seal 26. The sealing mechanism 20 enables the sealing of a downhole section 54 of the MFD and casing or completion tubing located downhole from the seal 26, from an uphole section 56 located uphole of the seal when a dart 18 is captured to enable fracturing operations to occur. FIGS. 14A, 14B and 14C are close up views of most of the sealing mechanism 20 (they do not show the entire piston sleeve 24) from FIGS. 9A-9C, 10A-10C, and 11A-11C, respectively, illustrating the sequence of setting the sealing mechanism.

[0062] *Piston Sleeve 24*

[0063] The piston sleeve 24 is operatively retained within and connected to the outer housing by the at least one piston shear pin 24c (FIGS. 2 and 4) located in at least one shear pin groove 24f (FIG. 14A). The piston sleeve generally comprises an uphole end 24a and a downhole end 24b, the downhole end connected to the catcher sleeve 32 of the catcher mechanism 30, and the uphole end 24a adjacent but not connected to the upper housing 14. At least one vent hole 24d (FIG. 14A) exists between the piston sleeve and the catcher sleeve 32 for providing pressure to the piston 22, as discussed in more detail below.

[0064] Within the outer housing 12, the piston sleeve 24 is movable from a first uphole position, shown in FIGS. 9A-9C and FIG. 14A, to a second intermediate position, shown

in FIGS. 10A-10C and FIG. 14B, to the final downhole position, shown in FIGS. 11A-11C and FIG. 14C. In the first uphole position and the second intermediate position, the outer housing main ports 12 are covered by the piston sleeve 24 and therefore closed. In the final downhole position, the piston sleeve 24 has moved downhole past the outer housing main ports 12, opening the ports 12 such that they are in fluid engagement with the inner cavity 50 in order for fracturing operations to occur.

[0065] Shearing of the piston shear pin 24c due to an increase in fluid pressure in the completion tubing causes the movement of the piston sleeve 24, along with the rest of the sealing mechanism 20 and the catcher mechanism 30, from the first uphole position to the second intermediate position. Shearing of a second downhole shear pin 52, as discussed in further detail below, due to a further increase in fluid pressure, causes the movement from the second intermediate position to the final downhole position.

[0066] *Piston 22 and Compressible Seal 26*

[0067] Referring to FIG. 14A, the piston 22 comprises an uphole end 22a and a downhole end 22b and is operatively retained and moveable within a section of the piston sleeve 24 and the catcher sleeve 32. At least one chamber 72 at atmospheric pressure or a pressure lower than the annulus pressure is provided between the piston 22 and catcher sleeve 32.

[0068] The compressible seal 26 is preferably a ring-shaped seal, having an uphole end 26a bordering the piston downhole end 22b, and a downhole end 26b bordering the catcher fingers uphole end 34b.

[0069] When the piston 22 moves downhole, it causes the compressible seal 26 to deform and compress against the catcher fingers 34 and a captured dart 18, as shown in FIGS. 11B and 14C, thereby providing a high pressure seal between the downhole section 54 of the MFD downhole of the seal and the uphole section 56 uphole of the seal.

[0070] To stroke the piston 22 and move it downhole to compress the seal, a pressure differential is developed as shown in FIGS. 14A to 14C. Prior to the at least one shear pin 24c (contained within shear pin groove 24f) shearing (FIGS. 14A and 9A-9C), the

piston is pressure balanced because the vent hole 24d, which provides pressure to the piston, is sealed from the annulus pressure by a seal in a seal groove 24e located between the piston sleeve 24 and the outer housing 12. When the at least one shear pin shears and the sealing mechanism 20 and catcher mechanism 30 move from the first uphole position to the second intermediate position, described above, and shown in FIGS. 14B and 10A-10C, the seal and seal groove 24e no longer seal, exposing the vent hole 24d to the downhole annulus pressure. The chamber 72, which is at atmospheric pressure or a lower pressure than the downhole annulus pressure, remains sealed, which provides the pressure differential needed to stroke the piston 22 and cause the piston to move downhole and compress the seal, as shown in FIGS. 14C and 11A-11C.

[0071] In one embodiment, the seal is made of rubber, such as hydrogenated nitrile butadiene rubber (HNBR), fluoroelastomer rubber (FKM) (e.g. VitonTM), or a combination of synthetic rubbers and composite material.

[0072] The compressible seal 26 is one example of a compressible element that can be compressed by the piston 22. Other types of compressible elements could be used.

[0073] Inner Cavity 50

[0074] The inner cavity 50 is continuous through the MFD from the uphole end 10b to the downhole end 10c when no dart 18 is caught by the catcher mechanism. When no dart has been caught, the inner cavity is comprised of the inner surfaces of the upper housing 14, piston sleeve 24, piston 22, seal 26, catcher sleeve 32, catcher member 34, support sleeve 44, support member 42 and lower housing 16. Various sealing elements, such as o-rings, are located between the components of the MFD to ensure the inner cavity is tightly sealed.

[0075] When a dart 18 has been caught by the catcher mechanism 30, the dart creates a blockage in the inner cavity 50 that enables the ports 12d of the MFD to open using fluid pressure within the tubing string. Importantly, if a dart has not been captured within the catcher mechanism 30, maintaining or increasing the pressure within the tubing string and the inner cavity 50 does not enable the opening of the ports 12d.

[0076] Sequence of Operation

[0077] In operation, after one or more MFD's are situated within a casing or completion tubing in a well, the following general steps are taken to prepare for fracturing operations in a zone of interest 8a adjacent an MFD: 1) catchment of the dart; 2) setting of the dart support mechanism; 3) setting of the sealing mechanism; and 4) opening of the ports.

[0078] Stage 1: Catchment of the Dart

[0079] A dart 18 is inserted into the well casing or completion tubing at the surface 6 and free falls or is pumped downhole into the inner cavity 50 of the MFD 10. FIGS. 6A to 6C illustrate the dart 18 entering the inner cavity 50. The sequential process of the catcher mechanism 30 catching the dart is illustrated in a perspective view in FIGS. 3A to 3C and in a cross-sectional view in FIGS. 7A to 7F.

[0080] In the first step (FIGS. 3A and 7A), no dart is present in the catcher mechanism 30 and the pivotable catcher fingers 34a are biased to the neutral position by the catcher spring 36. Next, referring to FIG. 7B, the dart 18 moves downhole such that the dart leading end 18a contacts the pivotable catcher finger uphole ends 34b, causing the spring loaded catcher fingers to pivot and allow the dart to continue moving downhole (FIGS. 7C to 7E). That is, as the dart leading end 18a moves past the catcher member upper shoulders 34c (FIGS. 3B and 7C), the uphole end 34b of each pivotable catcher finger 34a is pivoted radially outwards against the catcher spring 36, causing each catcher finger downhole end 34d to pivot radially inwards. The dart continues to move downhole, with the dart outer surface 18e maintaining contact with the catcher finger inner surfaces 34g (FIG. 7D). During this movement, the biasing force from the catcher spring 36 causes the pivotable catcher fingers 34a to gradually pivot back towards the neutral position (i.e. the catcher finger downhole ends 34d pivots outward and the uphole ends 34b pivots inward) as the dart 18 progresses downhole (FIG. 7E).

[0081] In the final catchment step (FIGS. 3C and 7F), the dart leading end 18a contacts the catcher finger lower shoulders 34e and attempts to push the fingers outwards and upwards so the dart can pass through. However the design of the system does not allow the catcher fingers to pivot out of the way, since the catcher finger uphole ends 34b are in contact with the dart lower shoulders 34e, thereby preventing the catcher fingers from pivoting out of the way and effectively trapping the dart. That is, the dart leading end 18a

and trailing end 18c are trapped, respectively, by the catcher finger lower shoulders 34e and upper shoulders 34c. In this position, the dart has been “caught” by the catcher member 34 and provides a significant restriction in the cavity 50 of the MFD.

[0082] The outer geometry of the dart, for example the position of the dart trailing shoulder 18d, the length of the dart and/or the diameter of the dart, determine whether the dart is caught by the catcher mechanism 30. FIGS. 8A through 8F illustrate a sequence wherein the dart 18 is not caught by the catcher member 34 but instead passes through the catcher member. In the illustrated example, the dart trailing shoulder 18d is positioned further towards the dart leading end 18a than in the previously referred to sequence illustrated in FIGS. 7A through 7F. In this case, when the dart leading shoulder 18b contacts the catcher finger lower shoulders 34e and forces them outwards (FIGS. 8A and 8B), the catcher finger upper shoulders 34c contact the dart trailing end 18c at a location *downhole* from the dart trailing shoulder 18d (FIG. 8D), instead of *uphole* of the dart trailing shoulder as is the case when the dart is caught by the catcher fingers in the previous example (FIG. 7F). This allows the catcher finger downhole ends 34d to be pivoted further outwards (FIG. 8E), allowing the dart leading shoulder 18b to pass by the catcher finger lower shoulders 34e (FIG. 8F), thus allowing the dart to pass completely through the catcher member 34.

[0083] After the dart has passed through the catcher fingers 34a, the dart passes through the support mechanism 40 and continues downhole. Similarly, if a dart 18 has a smaller diameter than a dart that is sized to be caught by the catcher member 34, the dart would pass through the catcher fingers without being caught. Alternatively, all or some of the darts may have the same geometry and diameter, however the length, diameter, and/or inner surface profile of some or all of the catcher fingers is varied in subsequent catcher MFD's.

[0084] In the preferred embodiment, approximately 10 stages can be fractured using the same diameter of dart but by varying the profile of the dart. For example, if the largest diameter of dart used is 3.75”, and the diameter drops by 1/8” every 10 stages, then 40 stages could be fractured before the dart size drops below 3.375”. I.e. Stages 1 to 10 use a 3.75” diameter dart; stages 11 to 20 use a 3.625” diameter dart; stages 21 to 30 use a 3.5” diameter dart; and stages 31 to 40 use a 3.375” diameter dart.

[0085] Stage 2) Setting of the Dart Support Mechanism

[0086] After a dart 18 has been caught by the catcher mechanism 30, there is a significant restriction within the cavity 50 which creates enough pressure build-up to cause the piston shear pin(s) 24c to break. This causes the sealing mechanism 20 (i.e. the piston 22, piston sleeve 24 and seal 26) and the catcher mechanism 30 (i.e. catcher sleeve 32, catcher member 34, and catcher spring 36) move downhole as one unit within the outer housing 12 to contact the support mechanism 40. i.e. The sealing mechanism 20 and catcher mechanism 30 move from the first uphole position (FIGS. 9A to 9C) to the second intermediate position (FIGS. 10A to 10C). The catcher mechanism 30 and sealing mechanism 20 are prevented from moving beyond the second intermediate position by the abutment of the downhole end of the catcher mechanism (i.e. the catcher finger donwhole ends 34d and catcher sleeve fingers downhole ends 32b) with the uphole end of the support mechanism 40 (i.e. the support finger uphole ends 42b and support sleeve fingers uphole ends 44f).

[0087] In the second intermediate position, there is an interlacing of alternating fingers such that the pivotable fingers are supported by the rigid fingers, thereby setting the dart support system. That is, the outer tapered surface 34f of each pivotable catcher finger 34a abuts the inner tapered surface 44e of the corresponding rigid support sleeve finger 44a, thereby causing the rigid support sleeve finger to bear down on the pivotable catcher finger, supporting the pivotable catcher finger and locking it in place. Similarly, the outer tapered surface 42d of each pivotable support finger 42a abuts the inner tapered surface 32d of the corresponding catcher sleeve finger, thereby causing the rigid catcher sleeve finger 32a to bear down on the pivotable support finger 42a, supporting the pivotable support finger and locking it in place.

[0088] Setting the dart support system has two purposes: to provide increased reinforcement to the dart 18 to prevent the dart from pushing through the catcher fingers when increased fluid pressures are applied to the system in further stages of operation, and to open a path for pressure to create a pressure differential between the uphole end of the piston 22 and the atmospheric chamber 70 in the piston, thereby allowing for setting of the sealing mechanism. The creation of the pressure differential was described in more detail above with respect to FIGS. 14A-14C

[0089] Stage 3) Setting of the Sealing Mechanism

[0090] When the dart support system has been set and a pressure differential created, the piston 22 is stroked, moving downhole with respect to the other components of the system, compressing the seal 26 against the uphole end of the pivotable catcher fingers 34a, catcher sleeve fingers 32a and dart 18 (FIGS. 11A to 11C), thereby sealing the downhole section 54 of the seal from the uphole section 56 of the seal.

[0091] Stage 4) Opening of the Ports

[0092] In the fourth stage of operation, the fluid pressure is further increased to open the ports 12d in the outer housing. In this stage, an increase in fluid pressure in the system causes the shear pins 52 connecting the support sleeve 44 to the lower housing 16 to break, thus releasing the sealing mechanism 20, catcher mechanism 30 and support mechanism 40 from the housing which then moves downhole as one unit from the second intermediate position to the final downhole position shown in FIGS. 12A to 12C. The abutment of the downhole end 44b of the support sleeve with the lower housing inner shoulder 16b acts as a stop to prevent the sealing mechanism, catcher mechanism and support mechanism from moving beyond the final downhole position. In this position, the piston sleeve uphole end 24a has moved downhole past the ports 12d, thereby opening the ports and allowing fluid and pressure communication between the inner cavity 50 and the adjacent formation 8a through the ports.

[0093] Fracturing Operations

[0094] After the fourth stage of operation wherein the ports have been opened, fracturing operations can commence in the zone of interest in the formation 8a adjacent the ports 12a. Upon completion of the fracturing operations in a particular zone, further darts can be successively introduced into the completion tubing to enable successive MFDs to be opened and fracturing operations to be completed within other zones.

[0095] Pressurization

[0096] The pressure in the completion string will be varied throughout the operation of the system to trigger the stages to occur. That is, various stages of the operation may

have a threshold pressure that will enable each stage to be sequentially completed. For example, the pressure initially starts at typical fracturing circulation pressures for the type of formation being fractured, which is generally in the range of 2000 and 8000 psi. Once a dart has been caught by the catcher mechanism 30, the pressure may increase another 500 to 1500 psi over the circulation pressure to shear the piston shear pin 24c and move the sealing mechanism 20 and catcher mechanism 30 downhole to set the dart support mechanism., The pressure may then increase another 500 to 1500 psi to stroke the piston 22 and set the seal 26, after which the second downhole shear pin 52 shears in order to open the ports 12d to allow fracturing operations to occur.

[0097] Although the present invention has been described and illustrated with respect to preferred embodiments and preferred uses thereof, it is not to be so limited since modifications and changes can be made therein which are within the full, intended scope of the invention as understood by those skilled in the art.

CLAIMS

1. A device for connection to a casing or completion tubing in a wellbore to enable fluid access between an inner cavity of the device and a zone of interest in a hydrocarbon formation adjacent the device, the inner cavity being continuous with an internal bore in the casing or completion tubing, the device comprising:

an outer sleeve for operative connection to the casing or completion tubing, the outer sleeve having at least one port to enable fluid access between the inner cavity and the zone of interest;

a catchment system operatively retained within the outer sleeve for catching a projectile moving through the inner cavity;

a sealing system operatively retained within the outer sleeve for sealing a downhole section of the device from an uphole section of the device when the projectile is caught;

wherein the at least one port can be opened through hydraulic activation when the sealing system is sealed; and

wherein an outer profile of the projectile determines whether the projectile will be caught.

2. The device of claim 1 wherein the projectile includes at least one shoulder on the outer profile, and the location and dimensions of the at least one shoulder determines whether the projectile will be caught by the catchment system.

3. The device of claim 1 or 2 wherein a first projectile having an outer diameter and an outer profile will be caught, while a second projectile having the same outer diameter as the first projectile and a different outer profile will pass through the catchment system.

4. The device of any one of claims 1-3 wherein the catchment system comprises a plurality of levers pivotably connected around the circumference of the inner cavity, wherein the levers operatively engage with a projectile having a certain outer profile.

5. The device of claim 4 wherein the catchment system further comprises a biasing means in operative connection with the levers for biasing the levers in a first position.
6. The device of any one of claims 1-4 wherein the sealing system comprises a piston and a sealing member positioned uphole and adjacent to a caught projectile, the sealing member deformable against the caught projectile by hydraulic actuation of the piston to seal the downhole section from the uphole section of the device.
7. The device of any one of claims 1-6 wherein the catchment system is in a first shearing engagement with the outer housing, and wherein catchment of a projectile enables the first shearing engagement to disengage and the catchment system to move downhole with respect to the outer housing to enable the sealing system to seal.
8. The device of claim 8 wherein the catchment system is in a second shearing engagement with the outer housing, and wherein sealing of the sealing system enables the second shearing engagement to disengage and the catchment system to move further downhole with respect to the outer housing to open the at least one port.
9. The device of any one of claims 1-8 wherein a caught projectile can be released from the catchment system to re-open the inner cavity.
10. The device of claim 9 wherein the caught projectile is dissolvable for releasing the caught projectile from the catchment system.
11. A system for use in a wellbore comprising a plurality of devices as in any one of claims 1-10, each device connected to the casing or completion tubing at a different location to selectively enable access to a zone of interest at each location by sending a projectile downhole from a well surface, the projectile having an outer profile configured to be caught by the catchment system at the desired location.
12. A method for selectively enabling fluid access to a plurality of zones in a wellbore comprising the steps of:
 - a) running an assembly having a plurality of actuatable devices into a wellbore having a plurality of zones, each device actuatable between a closed state and

an open state, wherein in the open state fluid access between an internal bore of the assembly and a zone adjacent each device is enabled;

b) selectively actuating a device at the desired zone by:

dropping a projectile having an outer profile with dimensions to be caught by the device at the desired zone;

catching the projectile in the device at the desired zone;

applying hydraulic pressure in the internal bore from a well surface to seal a section downhole of the caught projectile from a section uphole of the caught projectile; and

applying hydraulic pressure to move a member in the device downhole with respect to the assembly to open at least one port to provide fluid access between the internal bore and the adjacent zone;

c) performing well operations that require access to the desired zone; and

d) repeating steps b) and c) to successively actuate other devices in the assembly.

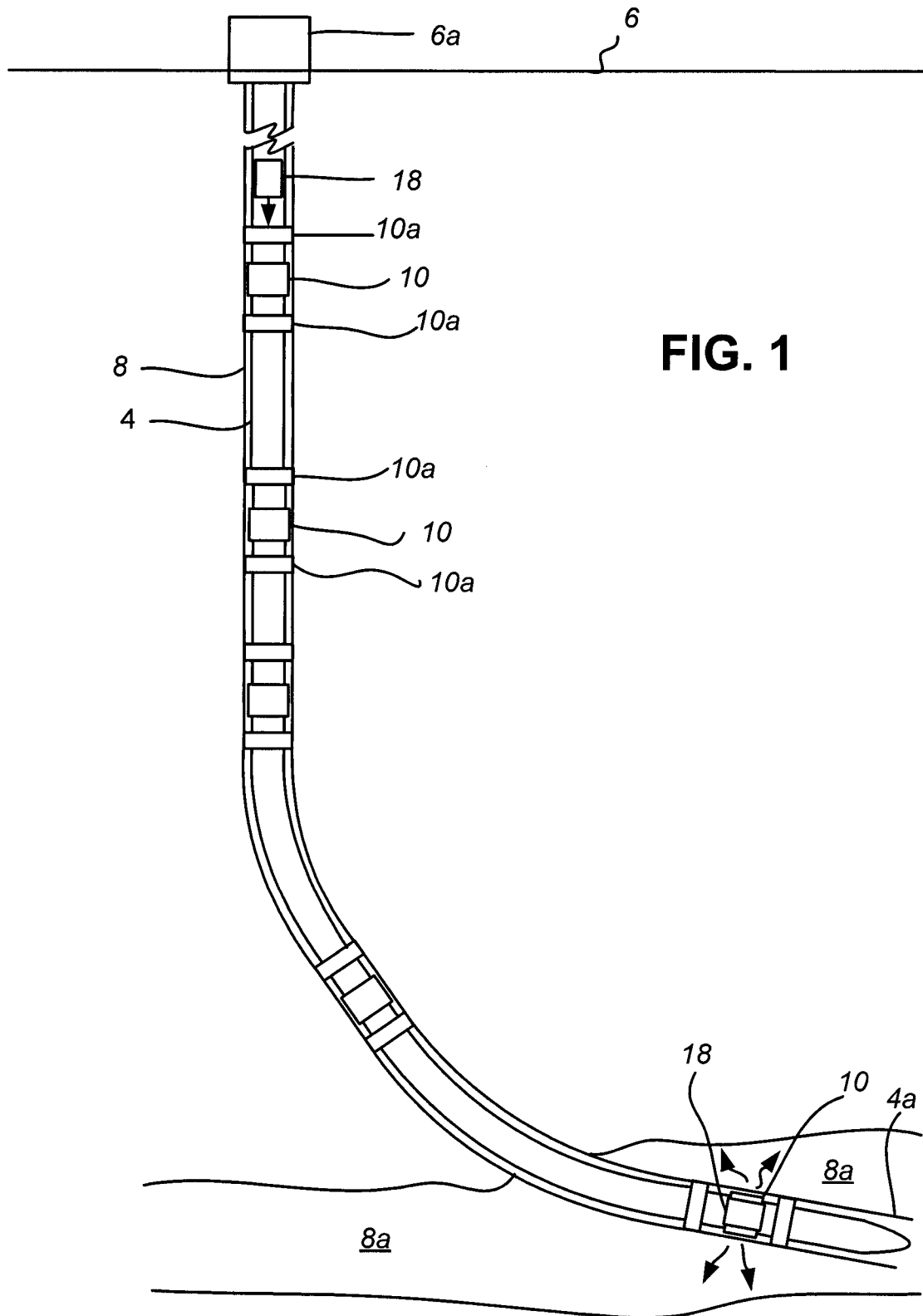
13. The method of claim 12 wherein the outer profile of the projectile includes at least one shoulder, and the position and dimensions of the shoulder determine whether the projectile is caught by a device.

14. The method of claim 12 or 13 wherein the projectile is caught by pivotable levers in the device.

15. The method of any one of claims 12 to 14 wherein the plurality of devices are successively actuated in a downhole to uphole direction.

16. The method of any one of claims 12 to 15 wherein the well operations include fracturing operations.

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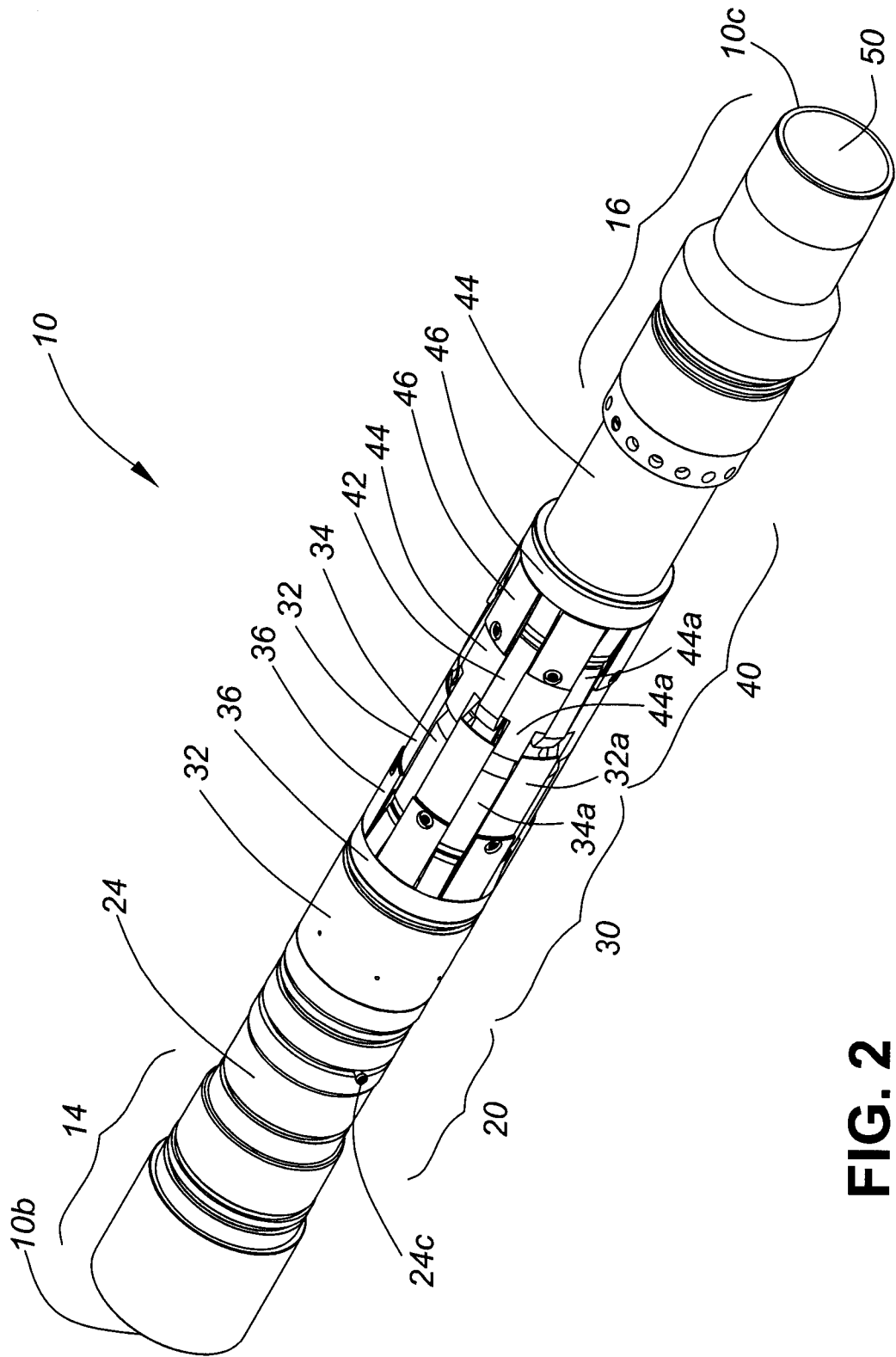


FIG. 2

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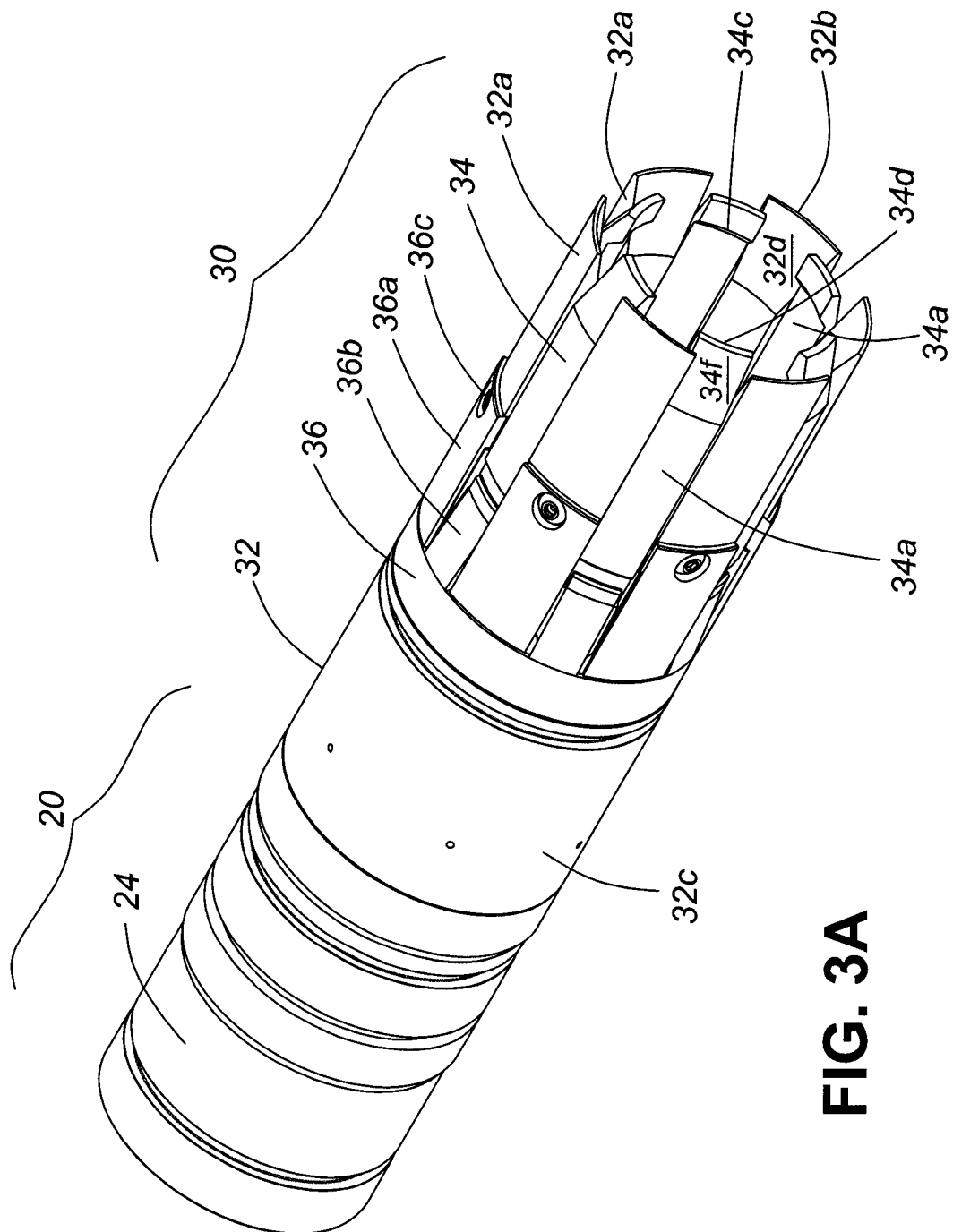


FIG. 3A

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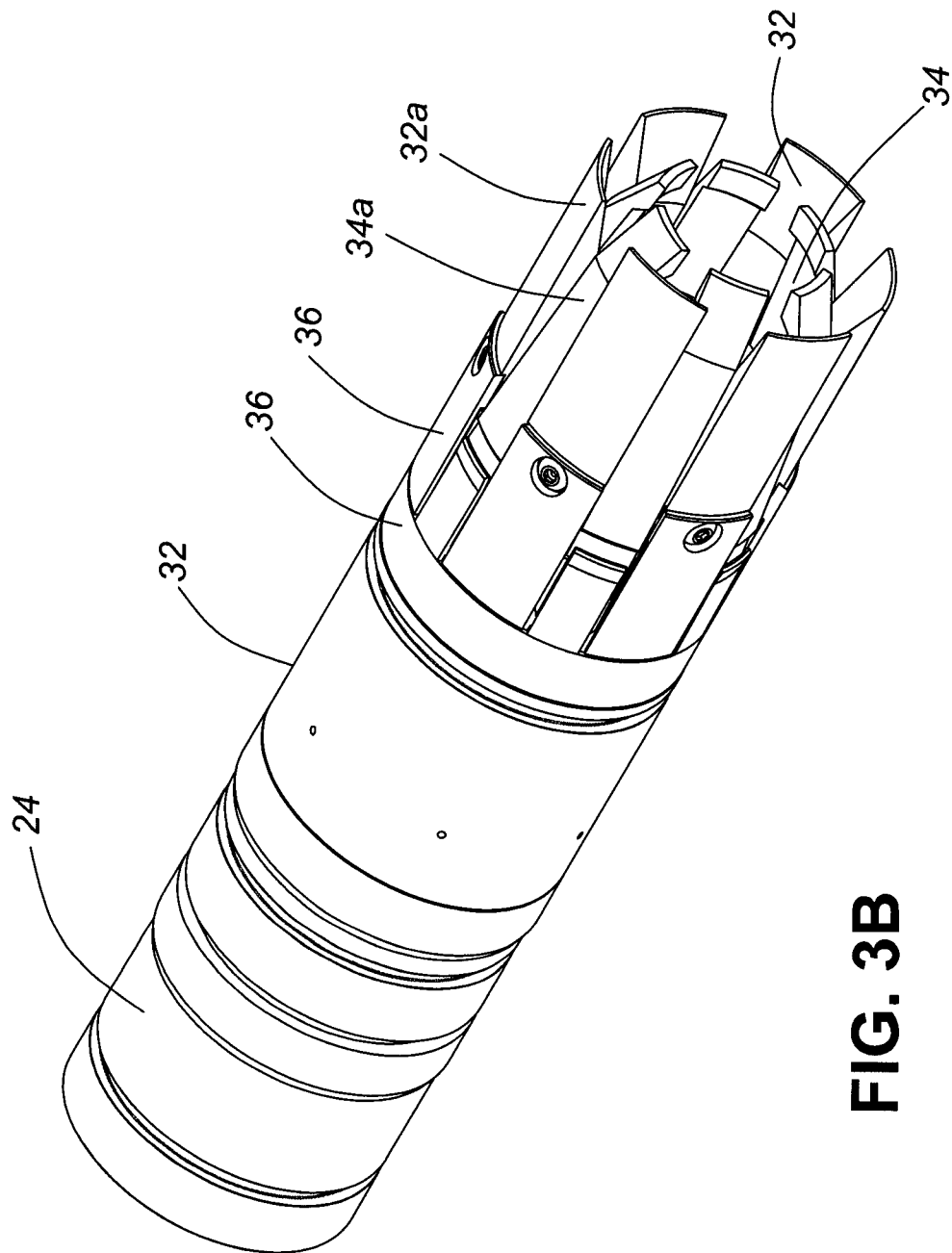


FIG. 3B

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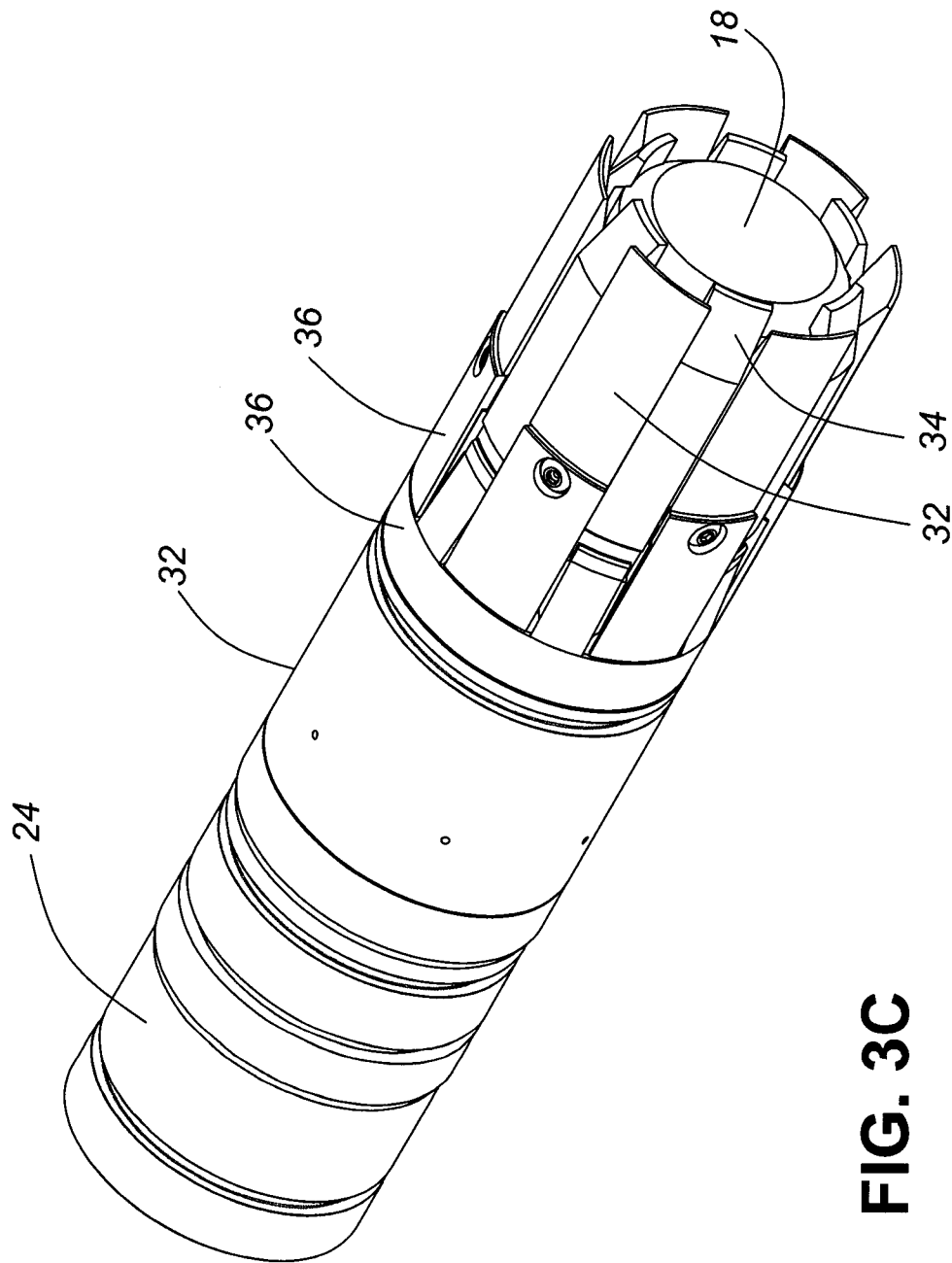


FIG. 3C

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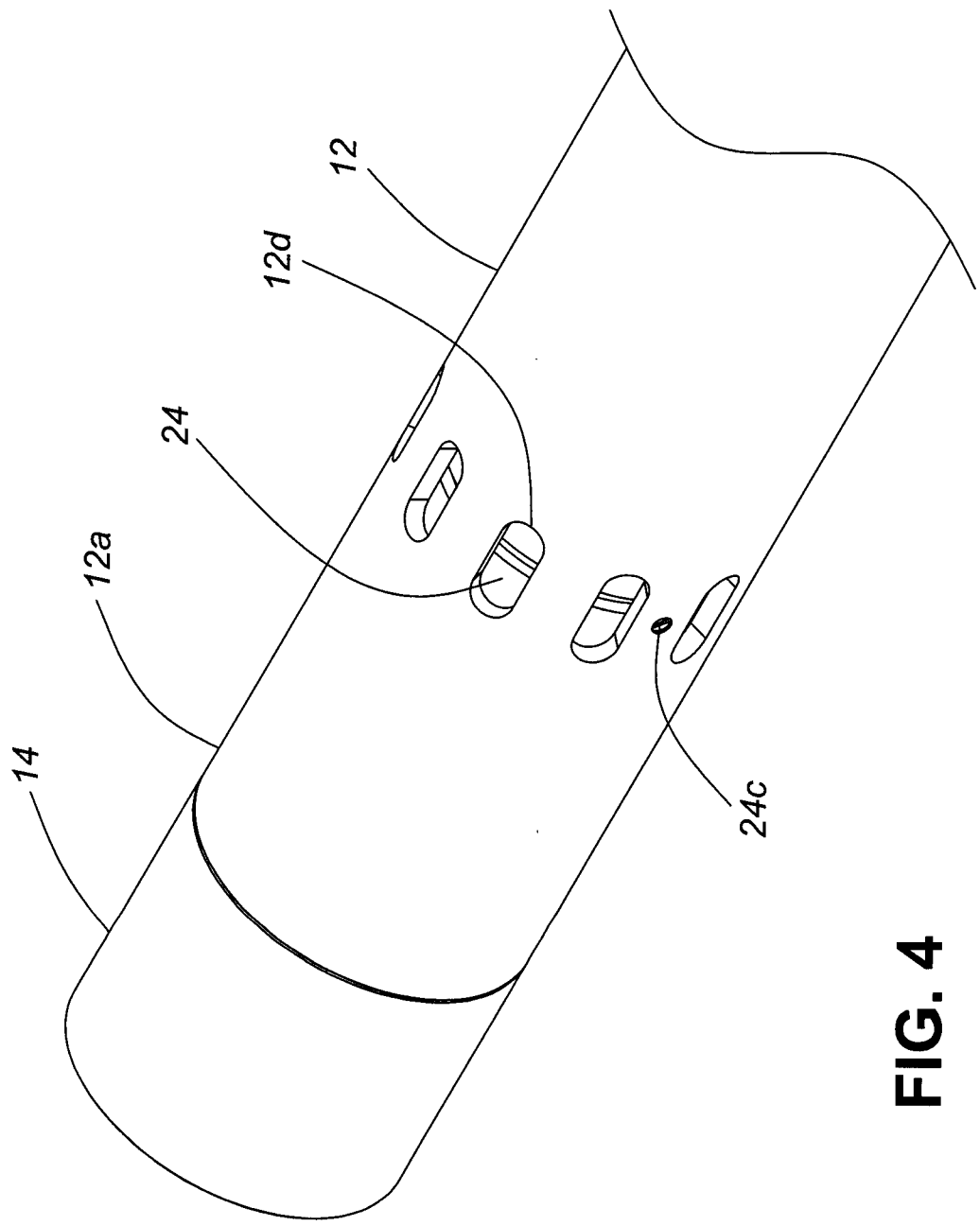


FIG. 4

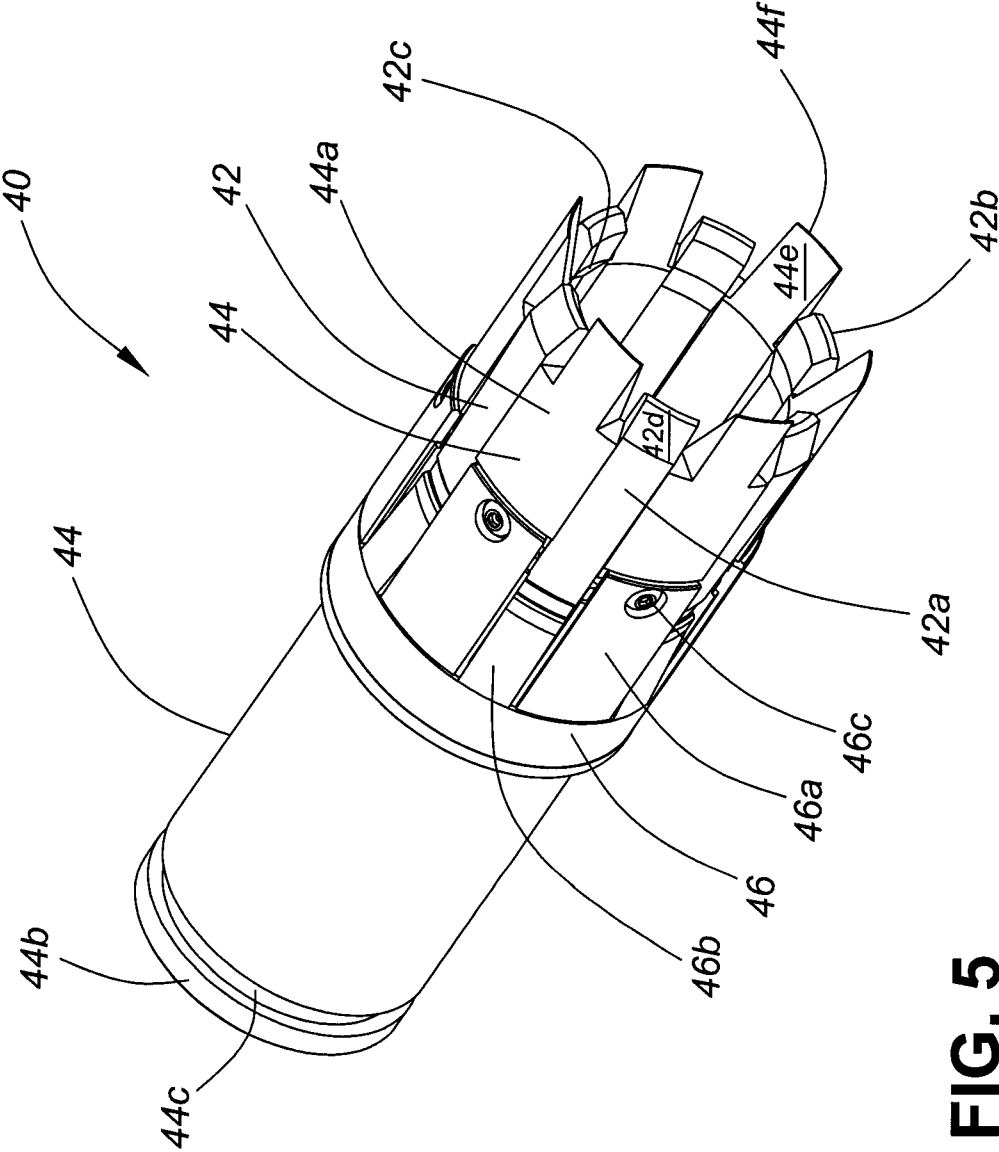


FIG. 5

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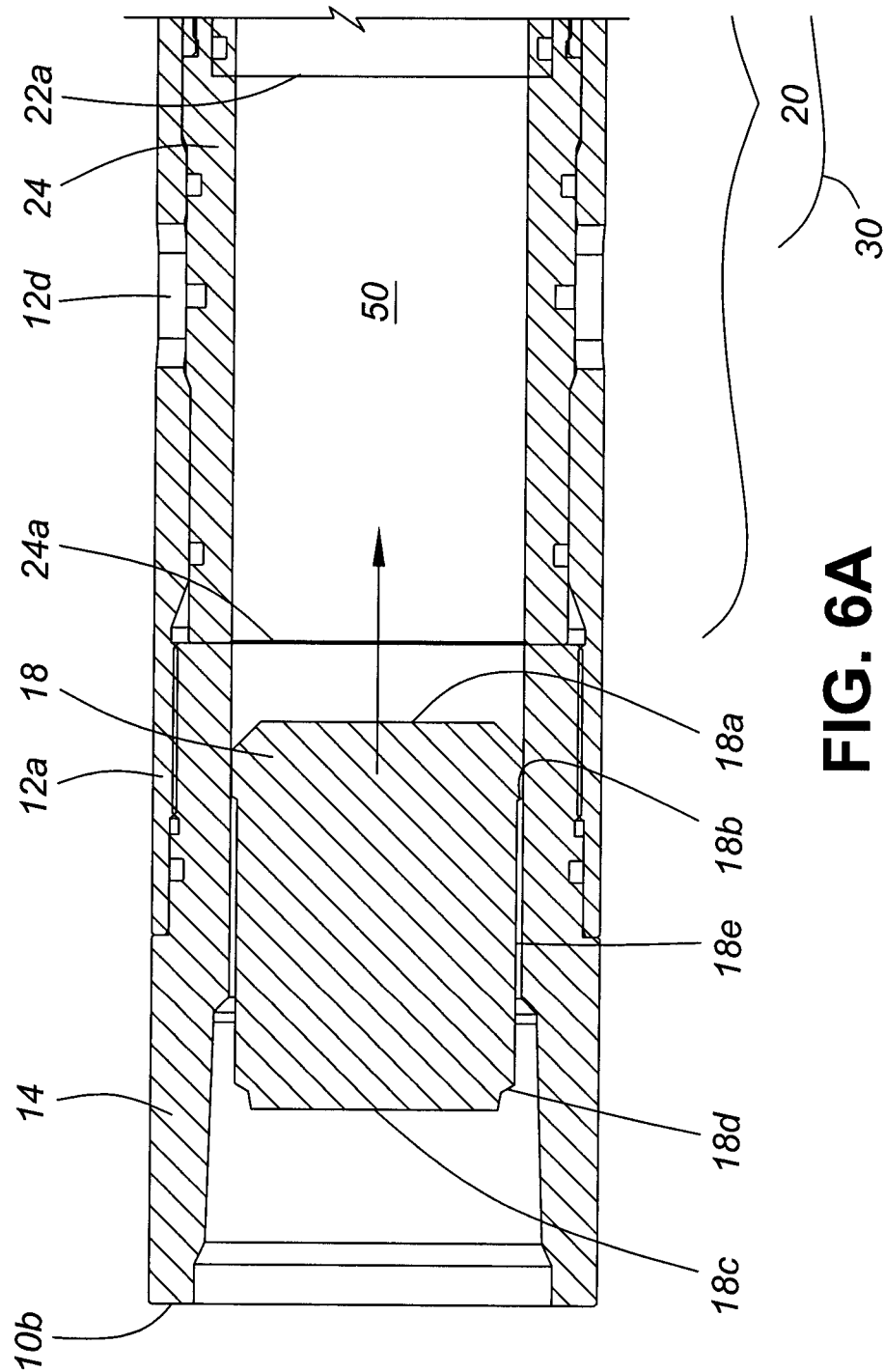


FIG. 6A

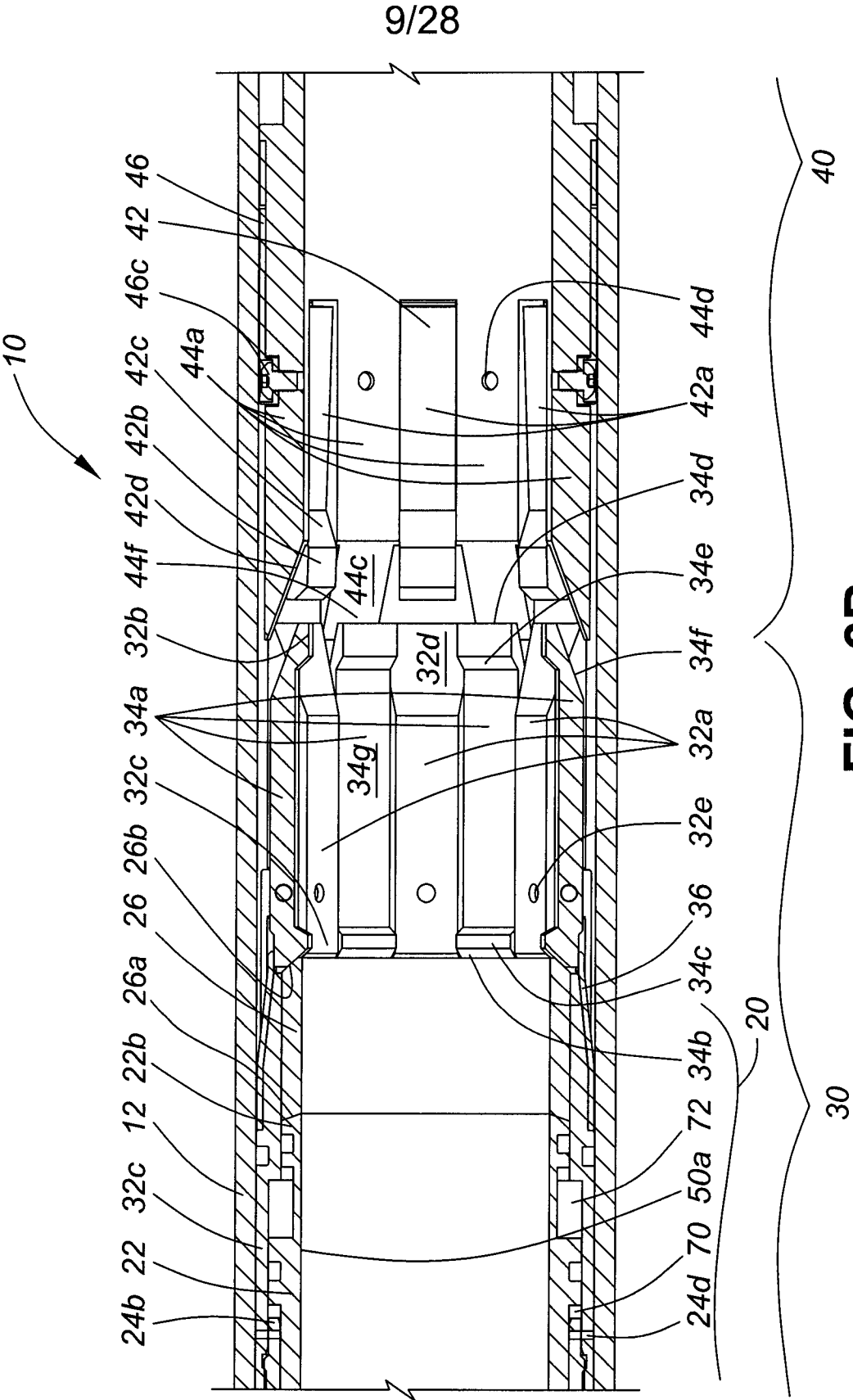


FIG. 6B

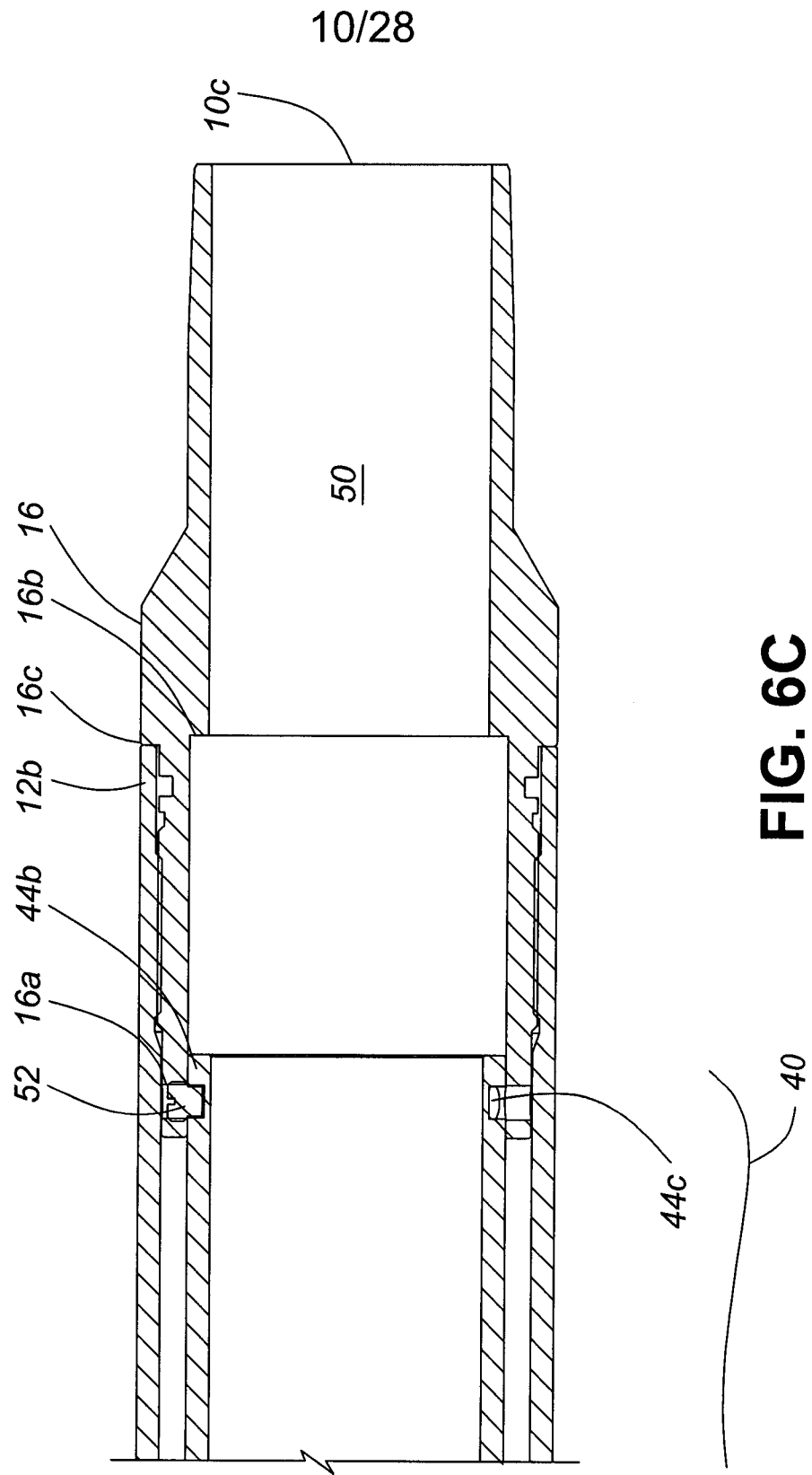


FIG. 6C

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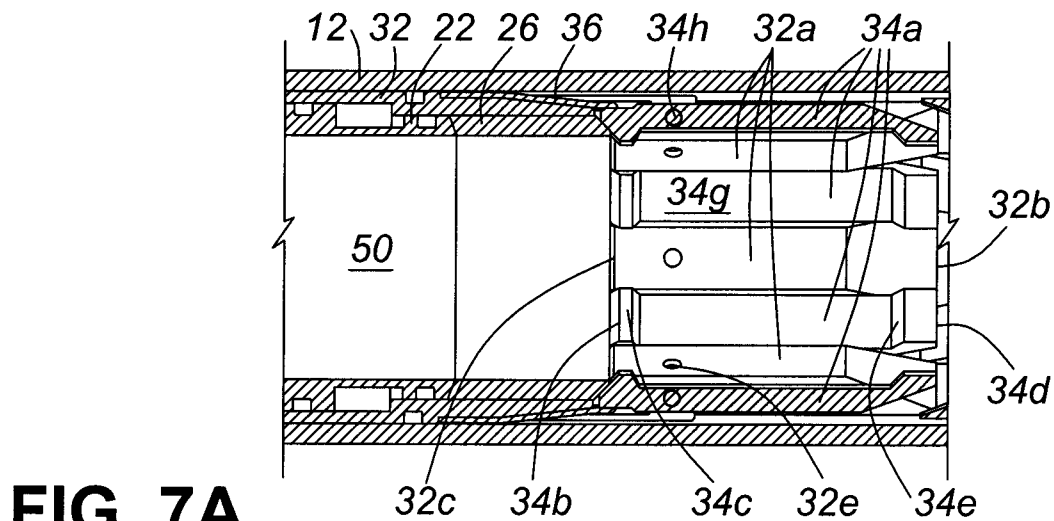


FIG. 7A

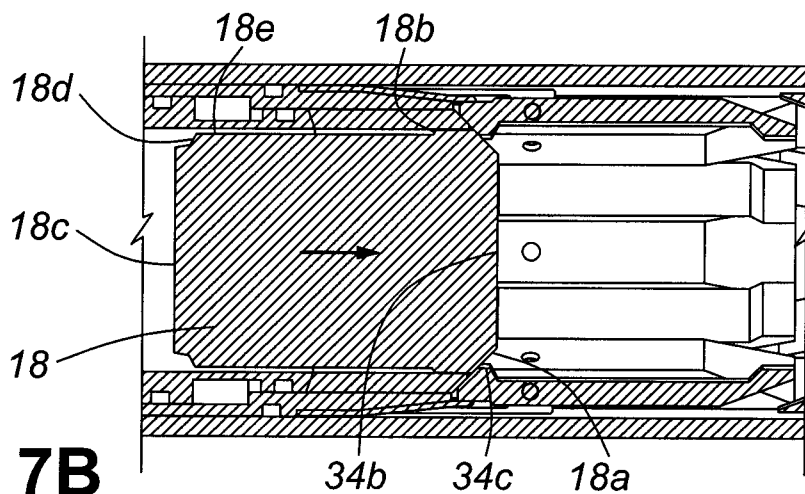


FIG. 7B

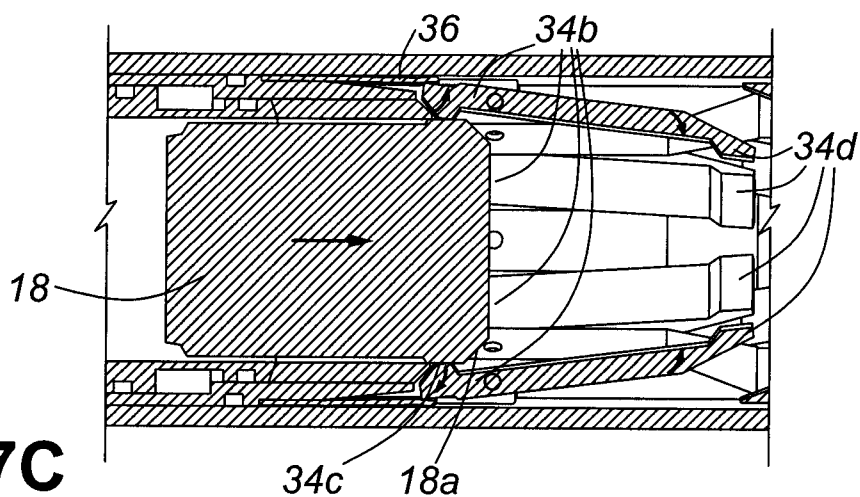


FIG. 7C

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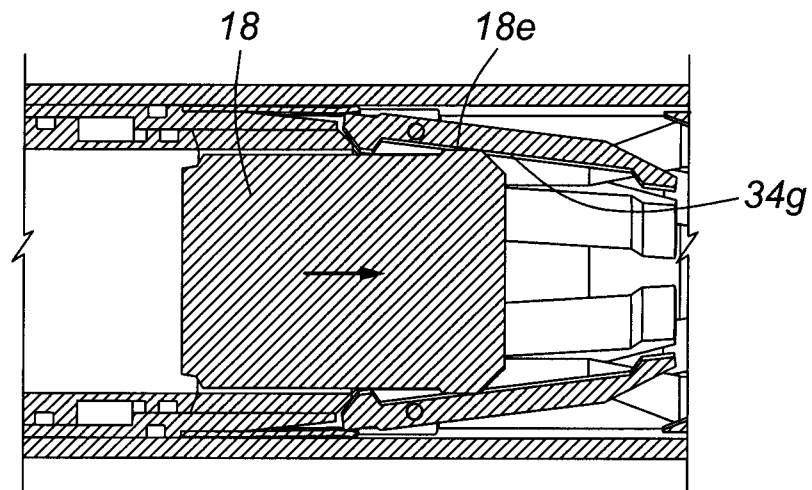


FIG. 7D

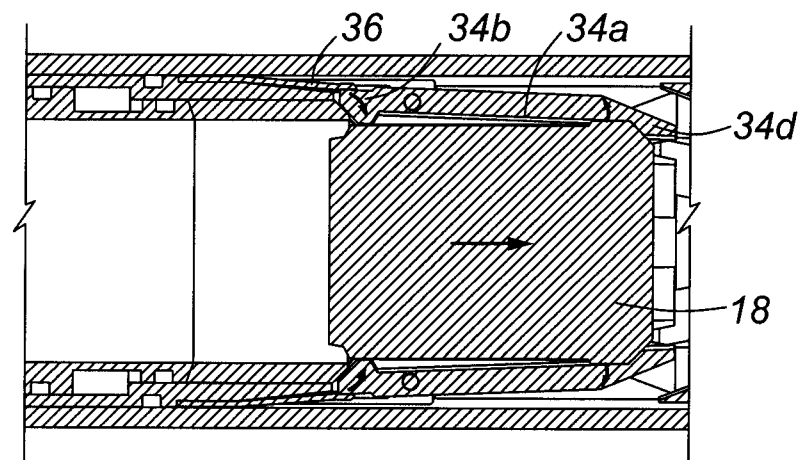


FIG. 7E

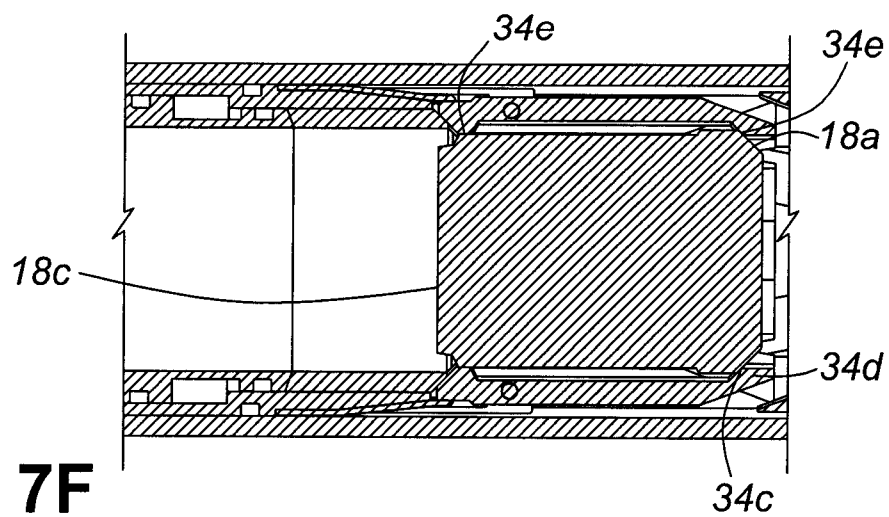
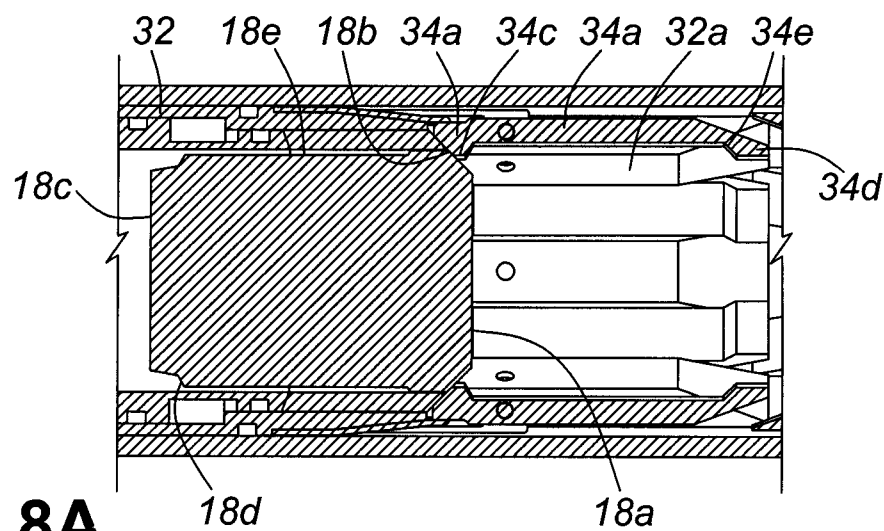
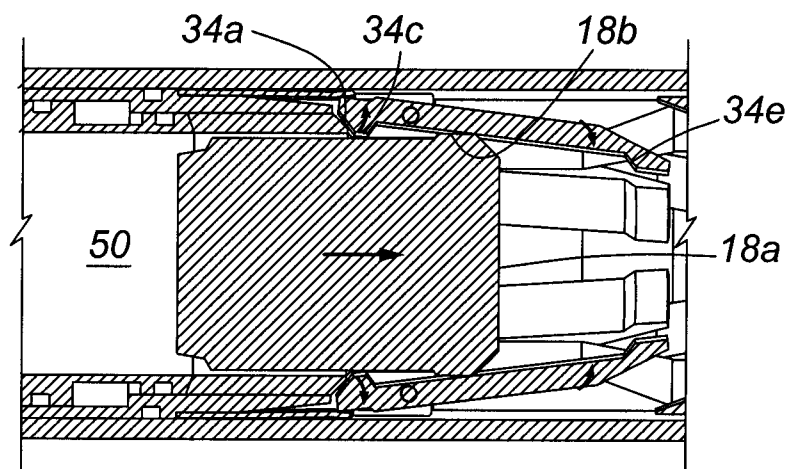
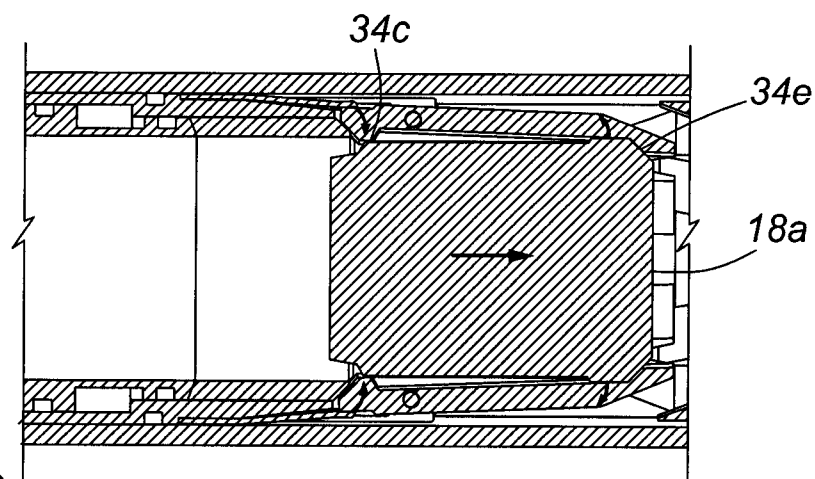


FIG. 7F

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**FIG. 8A****FIG. 8B****FIG. 8C**

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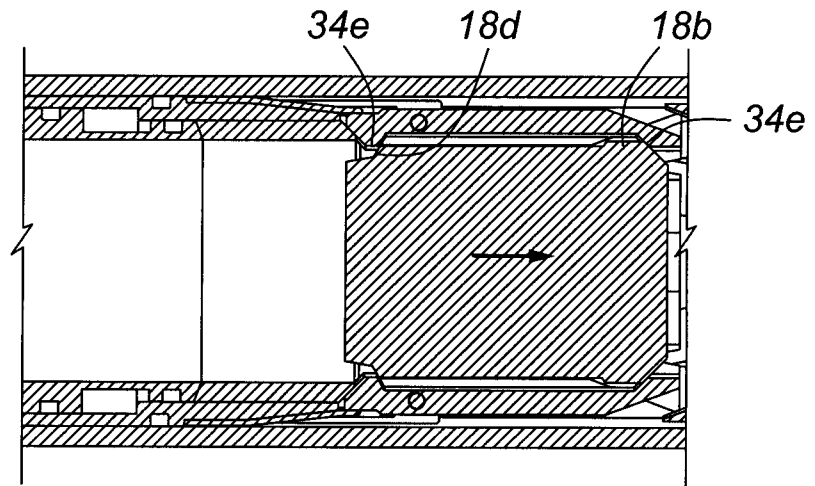


FIG. 8D

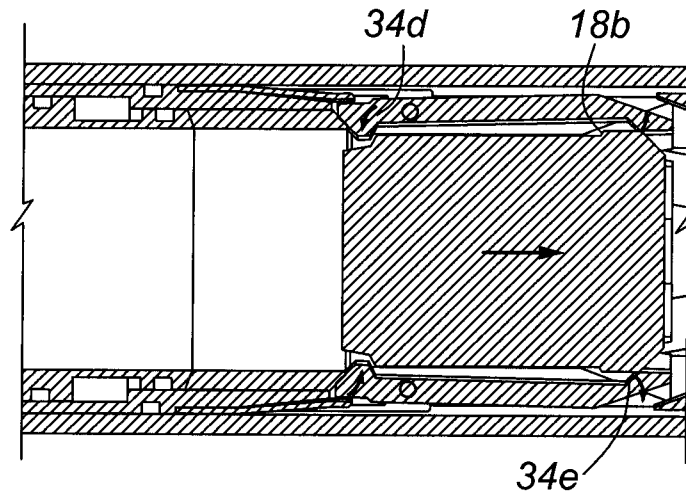


FIG. 8E

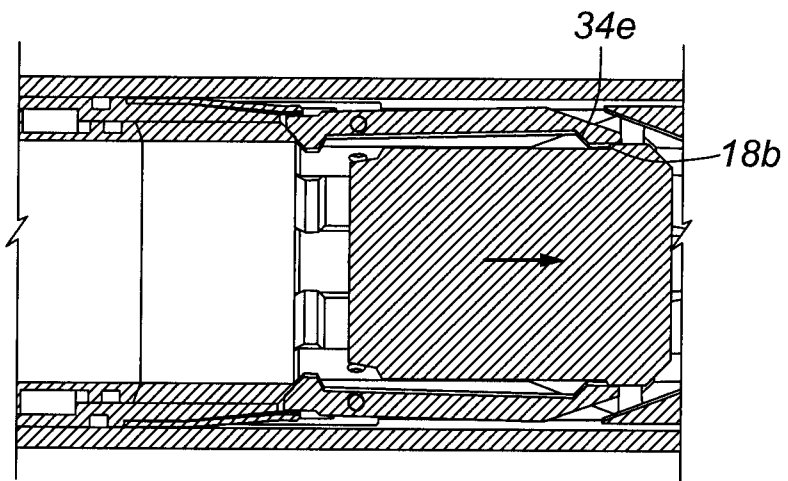


FIG. 8F

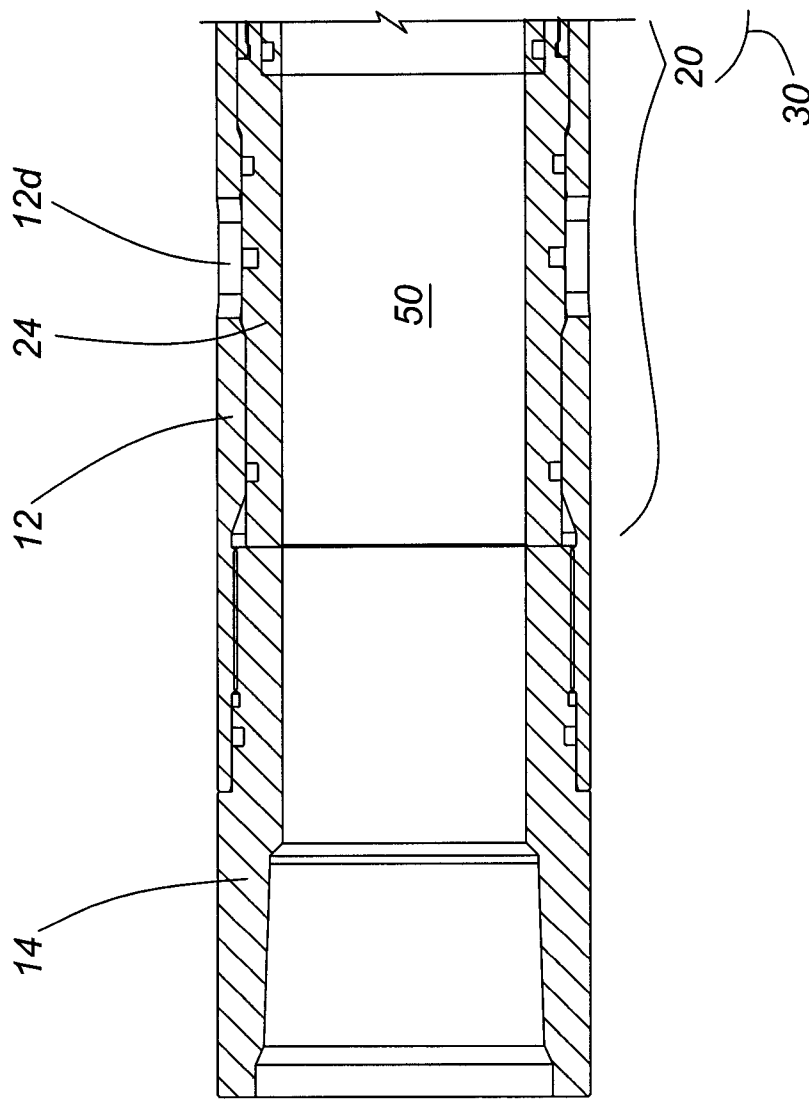


FIG. 9A

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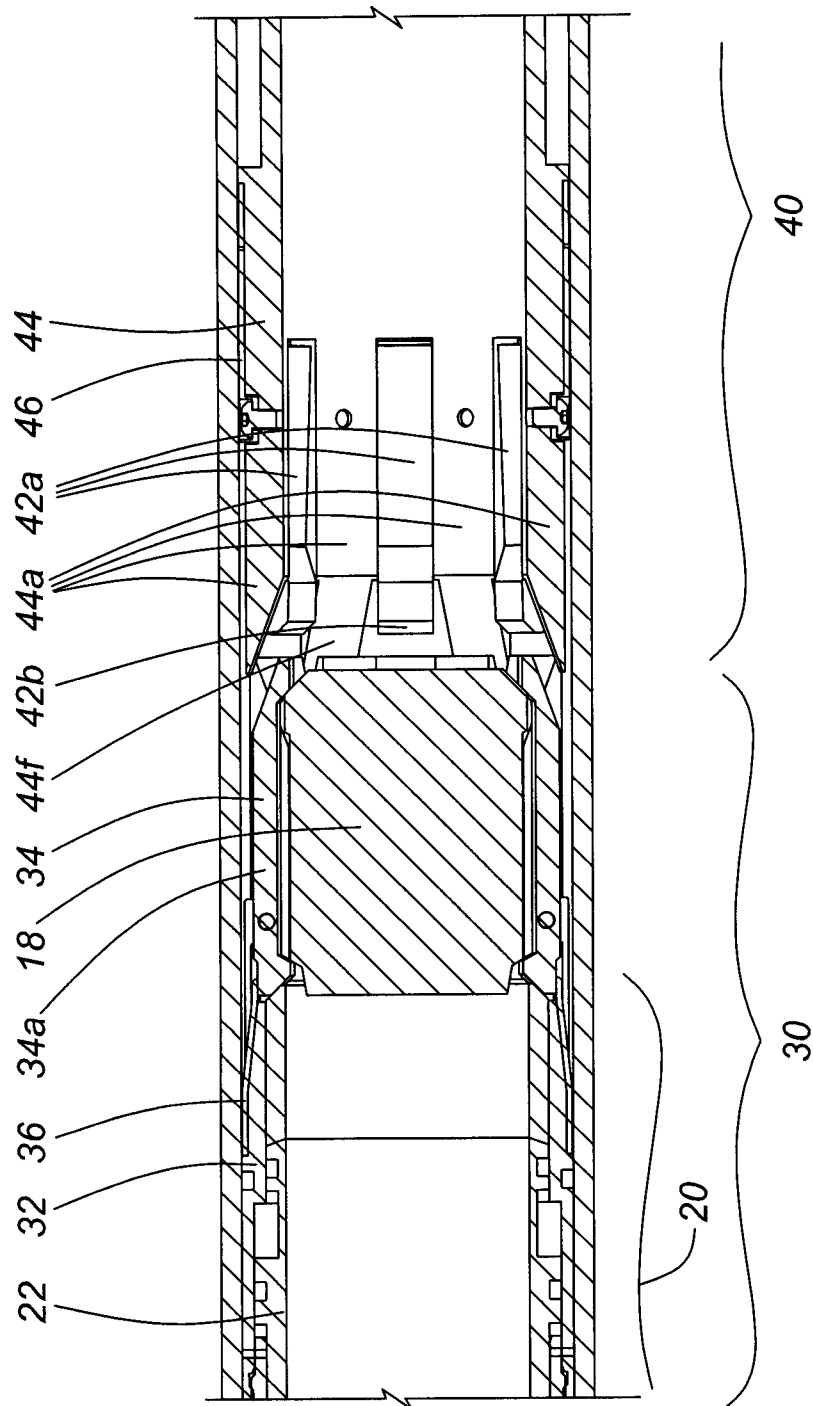


FIG. 9B

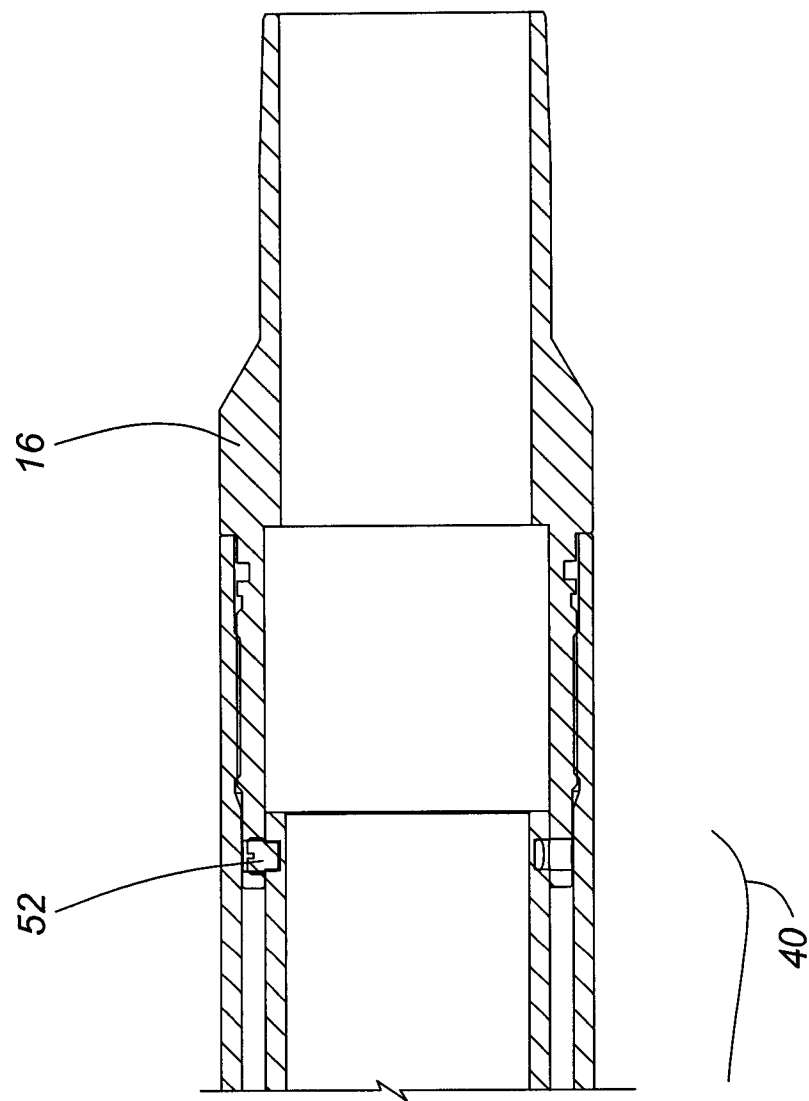


FIG. 9C

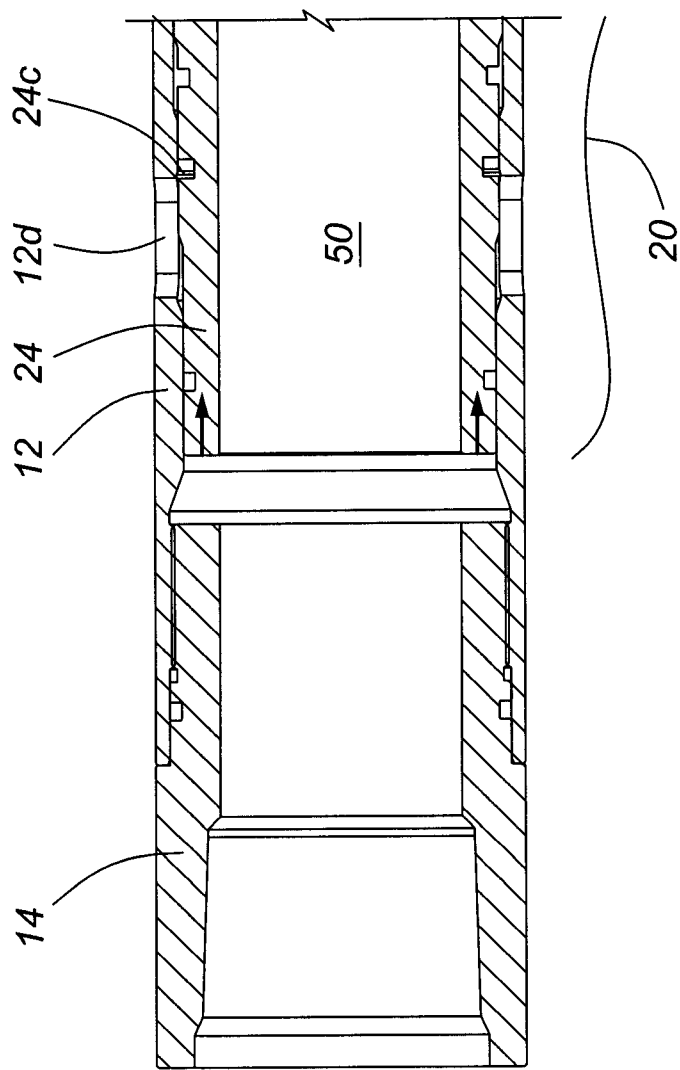


FIG. 10A

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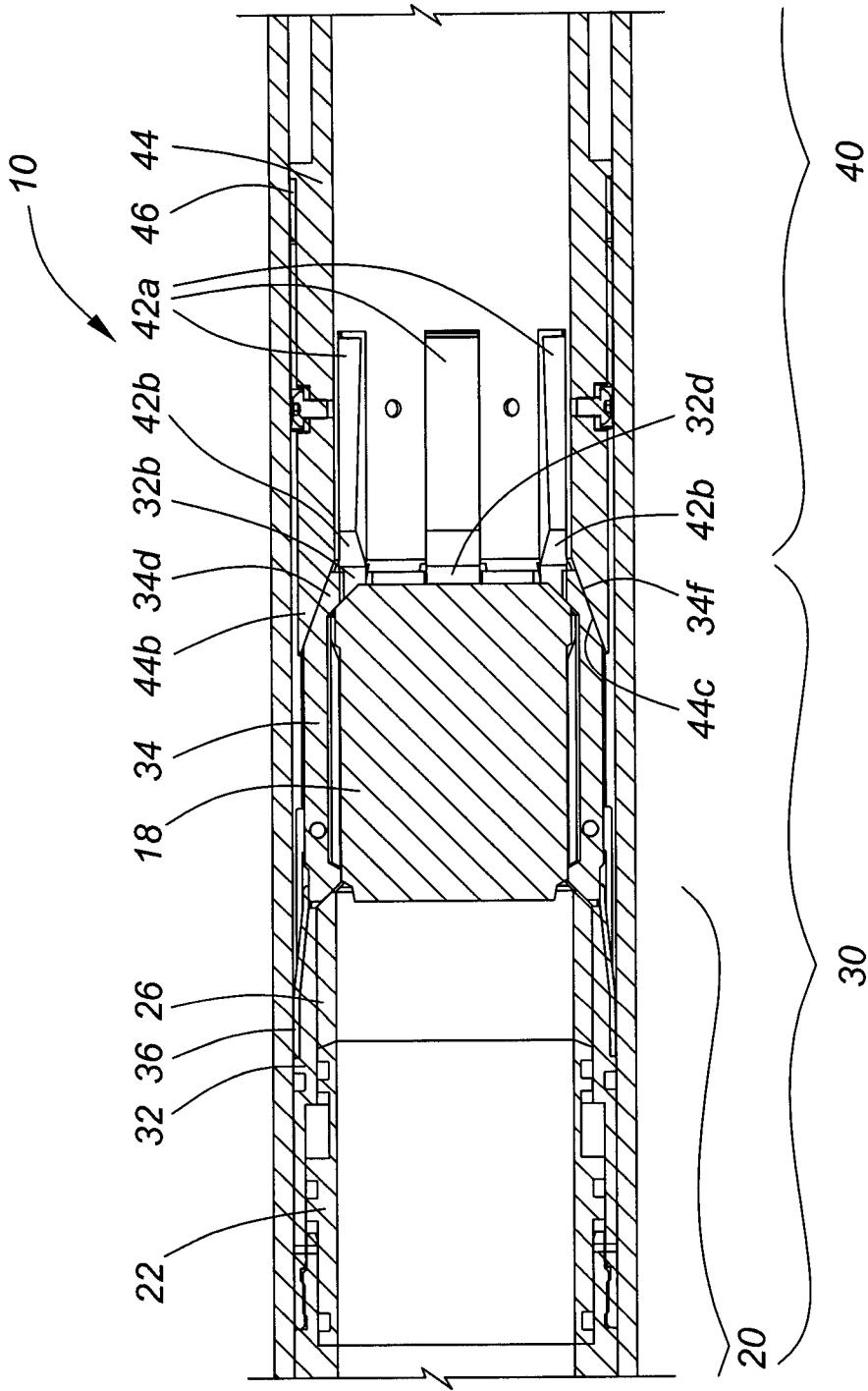


FIG. 10B

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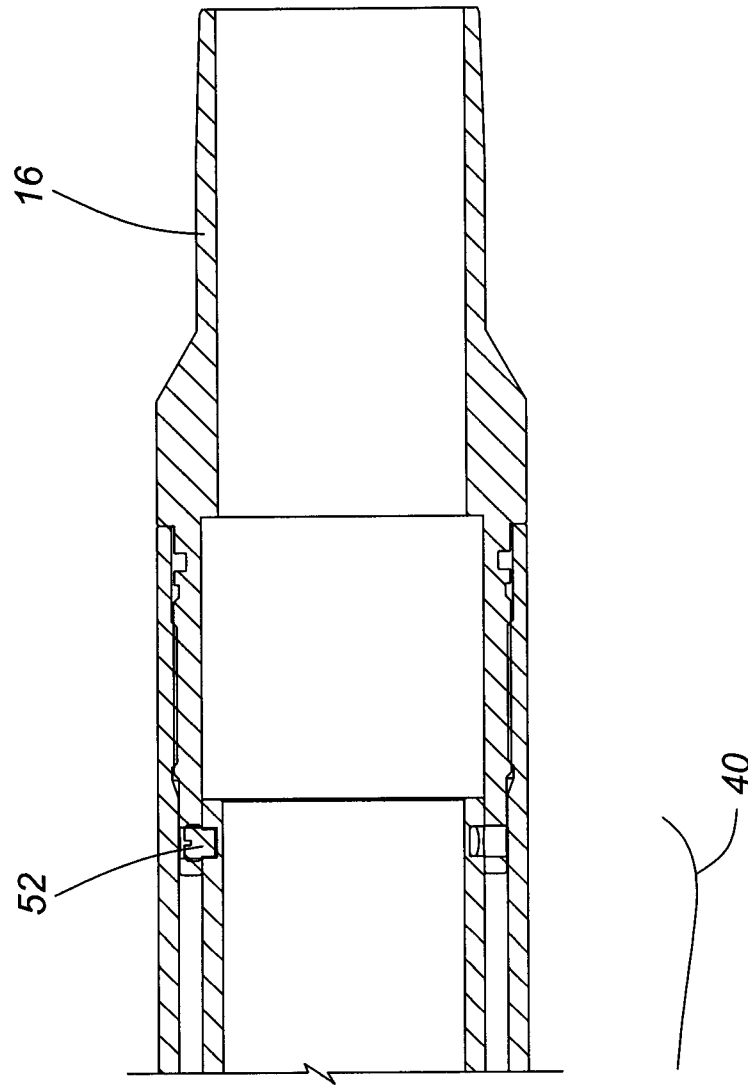


FIG. 10C

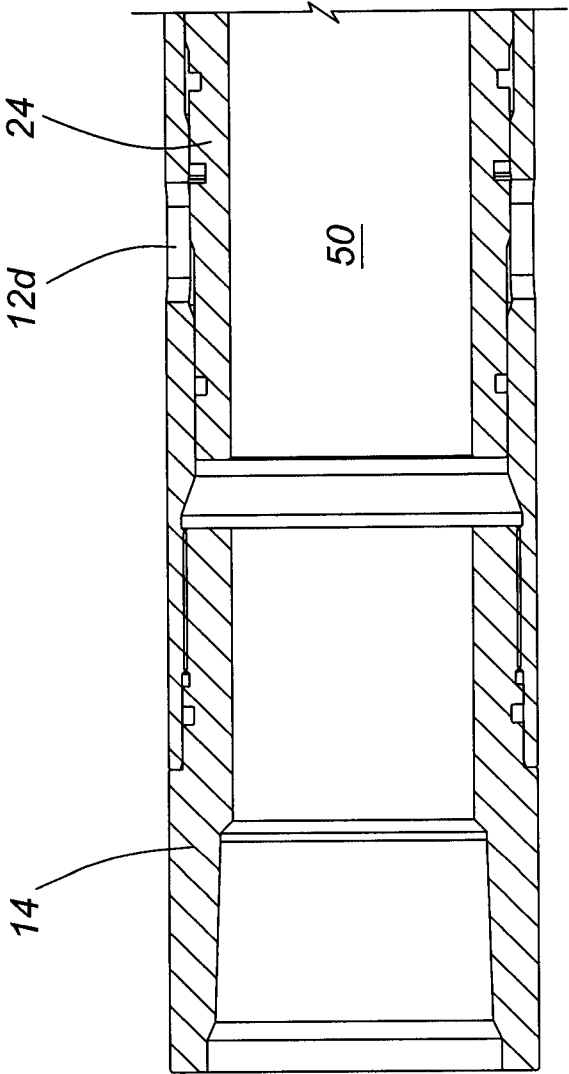


FIG. 11A

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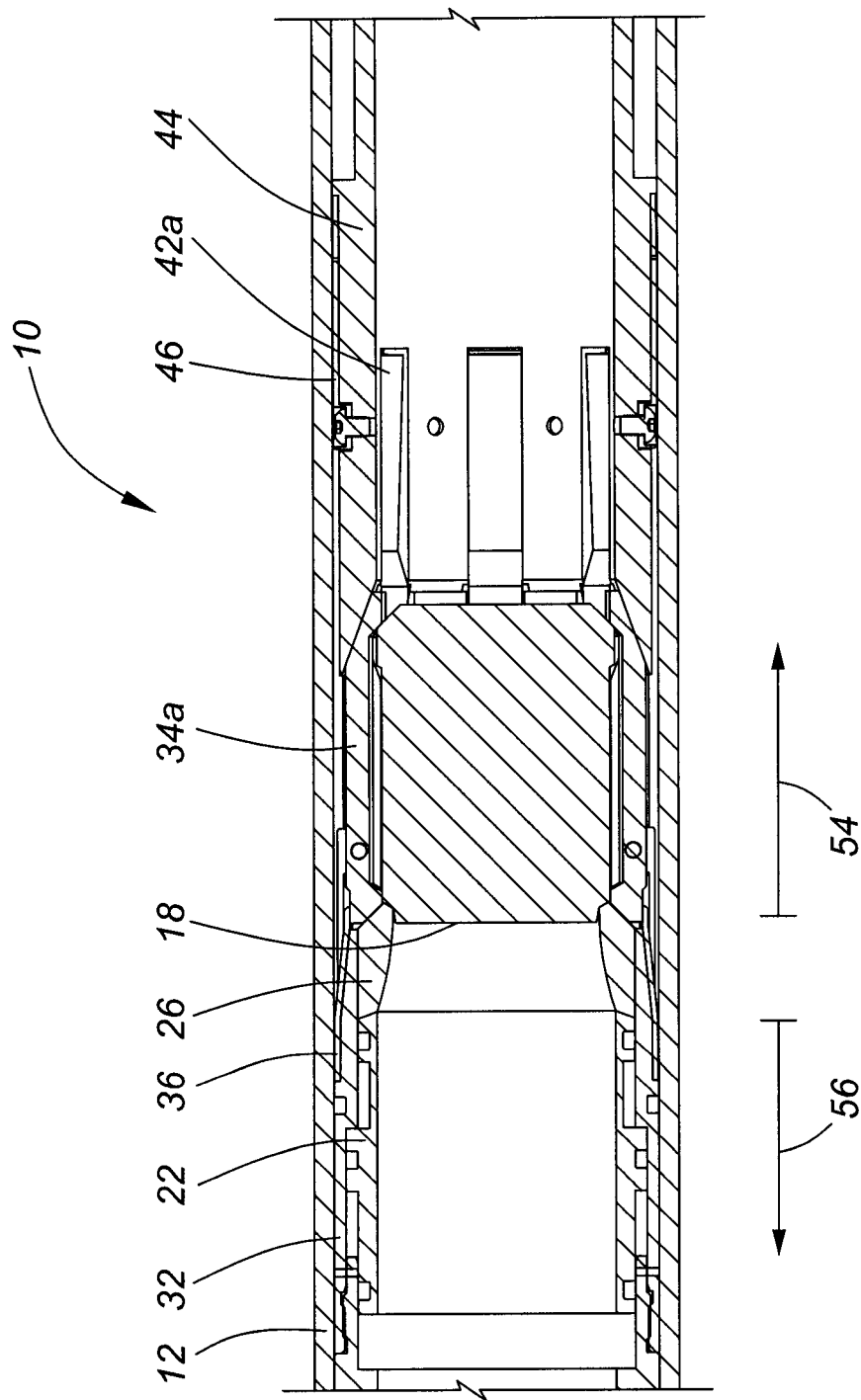


FIG. 11B

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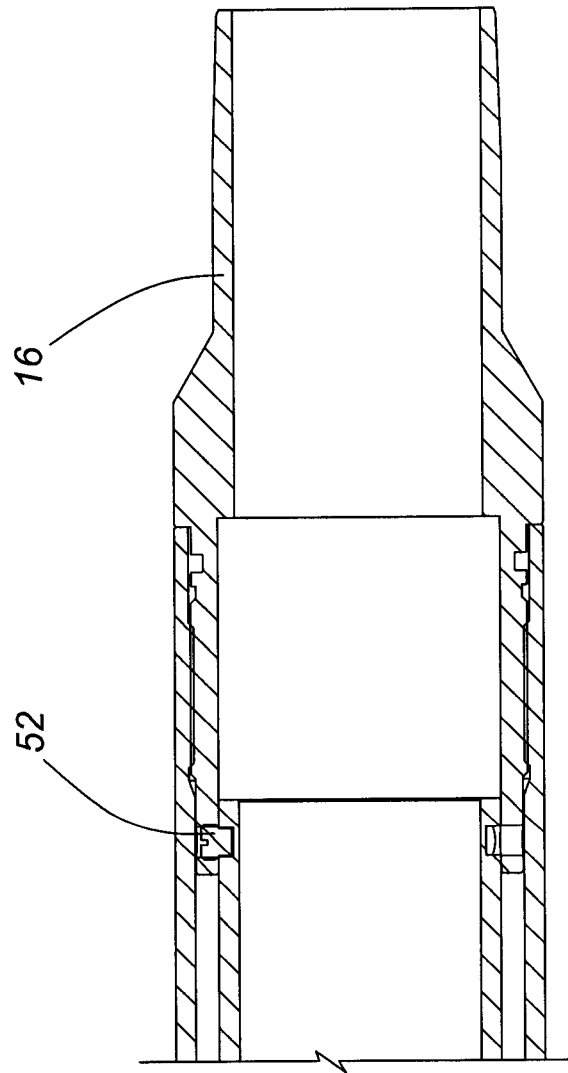


FIG. 11C

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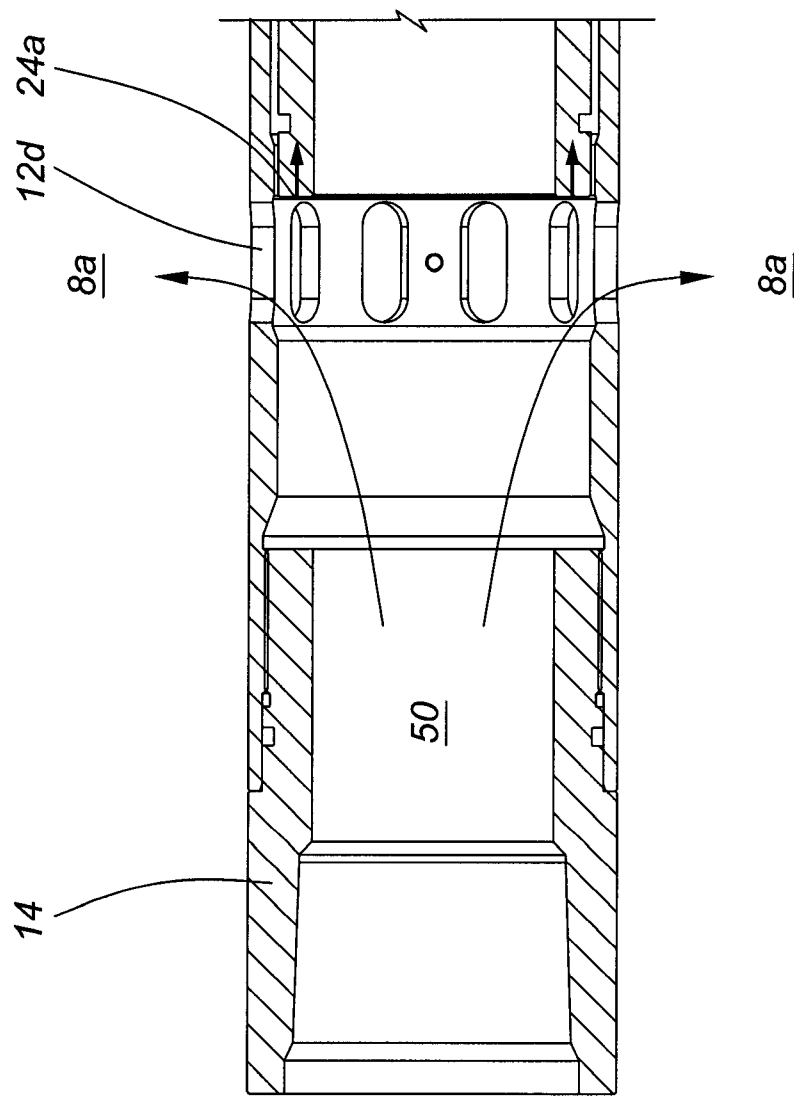


FIG. 12A

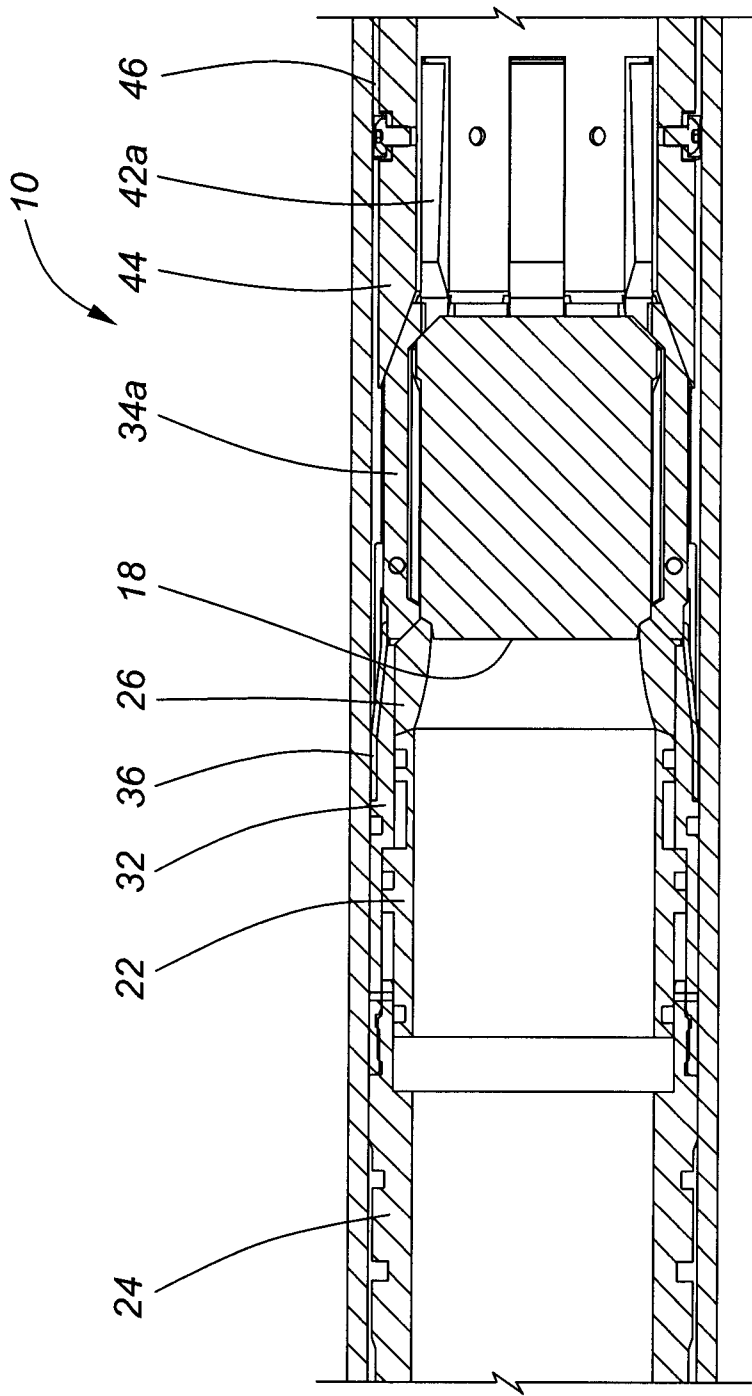


FIG. 12B

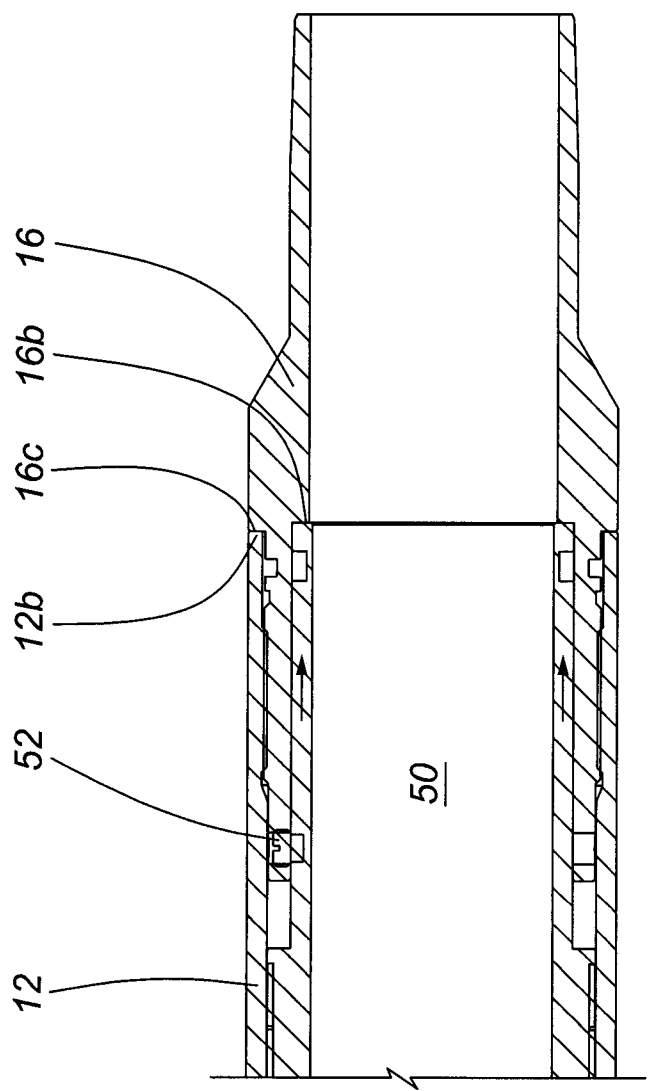
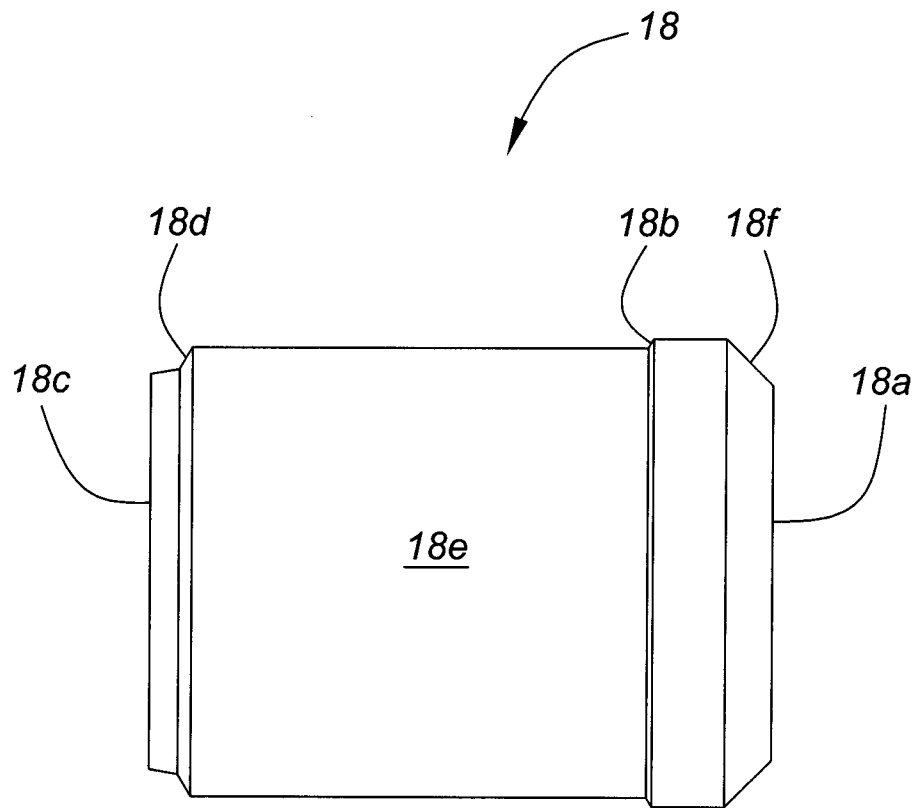


FIG. 12C

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**FIG. 13**

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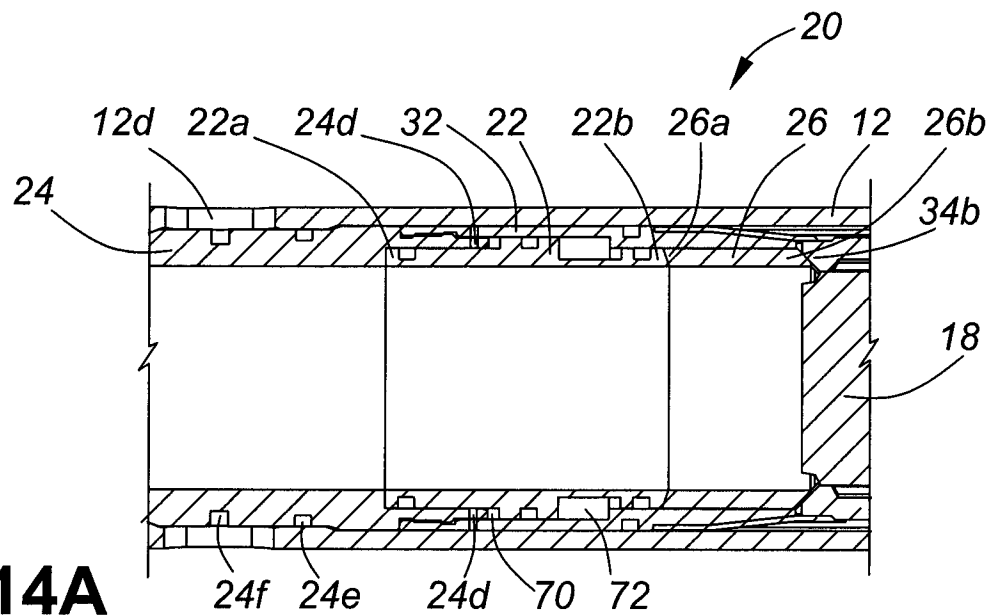


FIG. 14A

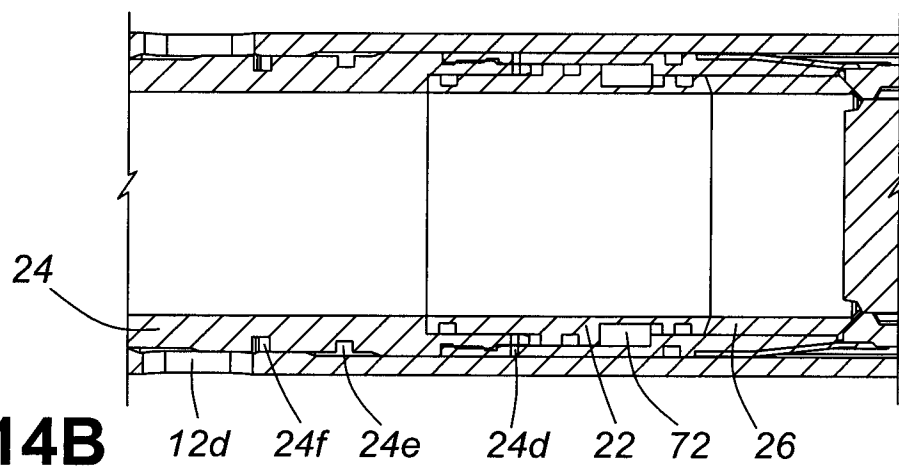


FIG. 14B

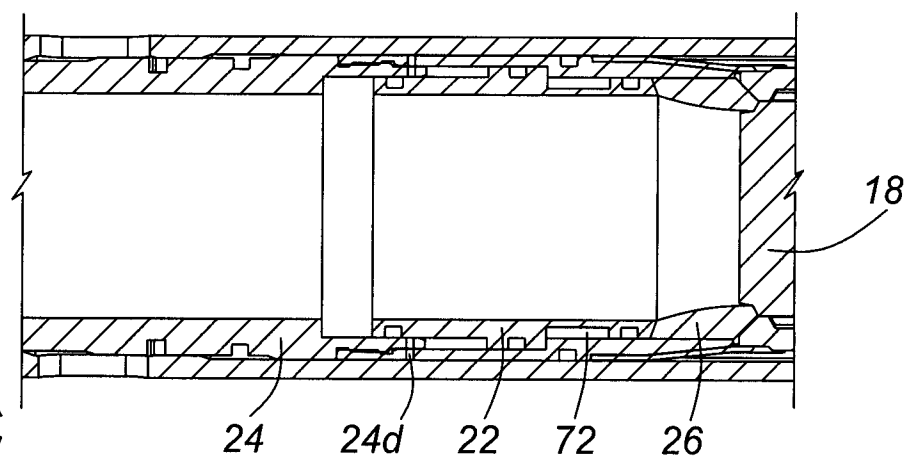


FIG. 14C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CA2015/050246

A. CLASSIFICATION OF SUBJECT MATTER

IPC: **E21B 23/08** (2006.01), **E21B 23/10** (2006.01), **E21B 34/14** (2006.01), **E21B 43/12** (2006.01),
E21B 43/26 (2006.01)

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: **E21B 23/08** (2006.01), **E21B 23/10** (2006.01), **E21B 34/14** (2006.01), **E21B 43/12** (2006.01), **E21B 43/26** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
 NONE

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)

Questel (Orbit), keywords: wellbore, fluid, cavity, inner bore, sleeve, port, projectile, dart, drop ball, seal, case, tubing, lever, spring, bias, shoulder *and like terms*.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	WO 2014041123 A1 (HALLUNDBAEK, J et al.), 20 March 2014 (20-03-2014) *Entire Document*	1, 6, 9, 11, 12, 15, 16 4, 5, 10, 14
X Y	WO 2013053057 A1 (THEMIG, D et al.), 18 April 2013 (18-04-2013) *Entire Document*	1, 6, 7-9, 11, 12, 15, 16 4, 5, 10, 14
Y	US 2014027127 A1 (FRAZIER, W et al.), 30 January 2014 (30-01-2014) *Entire Document*	10
Y	WO 2010129678 A2 (GERRARD, D et al.), 11 November 2010 (11-11-2010) *Entire Document*	4, 5, 14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* "A" "E" "L" "O" "P"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance earlier application or patent but published on or after the international filing date document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) document referring to an oral disclosure, use, exhibition or other means document published prior to the international filing date but later than the priority date claimed	"T" "X" "Y" "&"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art document member of the same patent family
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Date of the actual completion of the international search
 18 June 2015 (18-06-2015)

Date of mailing of the international search report
 02 July 2015 (02-07-2015)

Name and mailing address of the ISA/CA
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Authorized officer

 Daniel Burwell (819) 953-0965

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Information on patent family members

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