

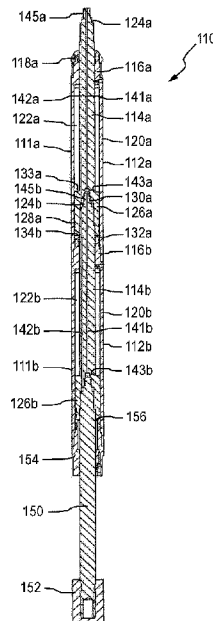


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(54) Titre : DISPOSITIF ACTIONNEUR DE FOND DE TROU, APPAREIL, OUTIL DE REGLAGE ET PROCEDES D'UTILISATION

(54) Title: DOWNHOLE ACTUATOR DEVICE, APPARATUS, SETTING TOOL AND METHODS OF USE



(57) **Abrégé/Abstract:**

The invention provides an actuator assembly for a downhole tool and a method of use. The actuator assembly comprises an actuator device, which includes a housing and a piston element movable with respect to the housing. First and second fluid paths are configured to couple first and second sides of the piston element to at least one source of fluid pressure in a drive module, and an actuator member is configured to be coupled to a downhole device. The actuator member is movable between a first position and a second position to operate the downhole device in response to a force acting on the piston element. The actuator assembly comprises a pressure release mechanism which is operable to equalise pressure between the first and second fluid paths of the actuator device. The invention may be used in conjunction with a valve module which includes the pressure release mechanism, and the valve member preferably comprises a forward flow position, in which a first side of the piston element is pressurised to urge the piston element in a first direction, and a reverse flow position in which a second side of the piston element is pressurised to urge the piston element in a second direction, opposite the first direction. A preferred embodiment of the invention is setting tool incorporating the actuator assembly.

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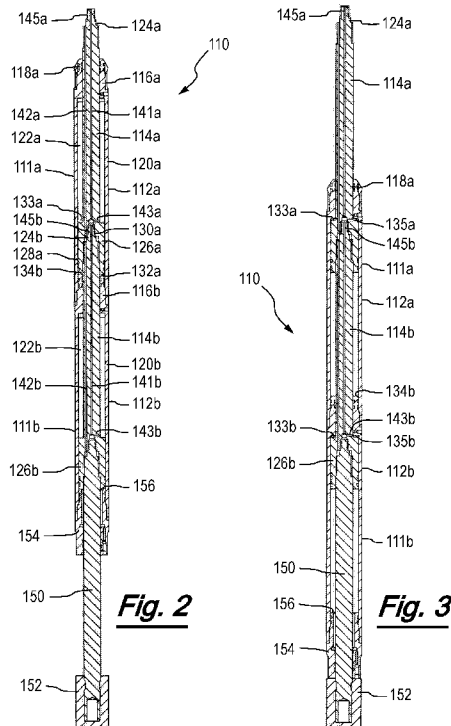
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1 Downhole actuator device, apparatus, setting tool and methods of use

2

3 The present invention relates to a downhole actuator device, a downhole tool, and
4 methods of use in hydrocarbon wellbore applications, and in particular to a setting tool for
5 setting and/or releasing a downhole plug or packer and a method of use. Aspects of the
6 invention relate to downhole apparatus including valve modules for setting tool and
7 downhole actuator applications, and downhole assemblies which incorporate a setting tool
8 and/or a valve module.

9

10 Background to the invention

11

12 In the field of hydrocarbon exploration and production, it is common to use actuator
13 devices and tools to controllably actuate or operate from surface downhole components
14 and tools between first and second operational conditions. A typical application is the
15 setting and/or releasing of a downhole plug or packer during a wellbore operation. Other

1 applications include but are not limited to setting straddles, whipstocks, and/or cement
2 retainers. A wide range of setting tools have been developed or proposed for use with
3 different drive systems, and many have been used in the field with successful results. The
4 majority of setting tools are hydraulically operated, and use hydraulically actuated pistons
5 to drive a setting mechanism, which is often (but not always) configured to force an outer
6 sleeve downwards with respect to an inner rod or mandrel.

7

8 Drive systems used to operate setting tools include gas drive systems, pump drive
9 systems, and hydrostatic pressure drive systems. In a gas drive system, a downhole
10 module is used to generate high pressure gas from a pyrotechnic device, a chemical
11 reaction, or a thermal reaction. The high pressure gas drives the actuator pistons of the
12 setting tool, either by directly acting on the actuator pistons, or by driving a piston down to
13 generate a flow of hydraulic fluid to the actuator pistons. Typical pressures generated from
14 pyrotechnic systems of this type are around 62,000 kPa to 90,000 kPa (around 9,000 psi
15 to 13,000 psi), which is sufficient for many downhole setting applications.

16

17 An example of a gas drive setting tool is disclosed in US 5,396,951. A preferred
18 embodiment uses a resistance heater to initiate a pyrotechnic chemical reaction and
19 generate a gas pressure which acts on a primary floating piston. The floating piston acts
20 on hydraulic fluid to pressurise a secondary piston, which in turn transfers a force to a
21 setting sleeve. The described setting tool is said to avoid the requirement for primary and
22 secondary igniters, and is said to enable a single drive module to be assembled, sold and
23 shipped.

24

25 Pump drive systems use a combination of a motor and a pumps, which may be located
26 downhole or at surface. Downhole pump drive systems have been developed as an
27 alternative to pyrotechnic drive mechanisms such as that disclosed in US 5,396,951. A
28 downhole pump drive system uses electric current from surface or downhole batteries to
29 drive a motor, which in turn drives a high pressure pump. The pump causes hydraulic fluid
30 to flow to the actuator pistons of the setting tool. A surface pump drive system uses a
31 surface motor and pump to cause fluid to be pumped from surface down drill pipe or coiled
32 tubing to the setting tool system where it acts on the actuator pistons.

33

34 Limitations to the pressure capabilities of downhole pumps has led to the use of
35 multistage, stacked piston arrangement with downhole pump drive systems in order to

1 increase the available setting force. More recently, WO2014/170640 describes a non-
2 explosive setting tool which uses high pressure downhole pumps to generate a system
3 pressure of up to around 96,500 kPa (about 14,000 psi) in a single-stage actuation
4 system. The setting tool comprises a downhole motor and pump assembly which is used
5 to pump hydraulic fluid from a first chamber to drive a piston arrangement between an
6 unset and a set position. After use, a plug is opened to enable return of hydraulic fluid
7 from the piston chamber back to the first fluid chamber, ready for reuse.

8

9 Hydrostatic drive systems comprise a mechanism configured to open a valve and expose
10 a flow system in the setting tool to hydrostatic pressure. The hydrostatic pressure causes
11 wellbore fluids to enter the flow system and actuate the pistons to operate the tool.

12 Depending on the available hydrostatic pressure, hydrostatic drive systems may use
13 stacked piston arrangements to provide the desired setting force.

14

15 An alternative mechanism is disclosed in WO 2012/150189, which describes a setting tool
16 with first and second fluid chambers fluidly connected via first and second channels. Fluid
17 is pumped from the first chamber to the second chamber via the flow channels. The
18 volume of the first chamber is adjusted to maintain an ambient pressure condition in the
19 first chamber while a fixed volume of the second chamber becomes pressurised and
20 charges a spring-loaded piston. A trigger releases a sleeve from an inner mandrel and
21 causes relative movement of the sleeve and the mandrel to a setting position. After use,
22 the pressure in the first and second chamber can be equalised by reversing the pumping
23 direction or through an optional additional flow channel which is open in the fully set
24 position of the tool.

25

26 US 7,913,770 describes a setting tool with a porous plug that enables an atmospheric
27 chamber to be equalised to wellbore pressure after actuation of the tool.

28

29 While the above-described setting tools may be useful in certain applications, many of
30 these systems have significant drawbacks. Firstly, the use of pyrotechnics in gas drive
31 modules and systems requires special permits and particular safety considerations which
32 complicate operation and logistics.

33

34 The use of downhole motors and pump modules addresses these safety issues, but the
35 motors and pumps themselves are often relatively expensive and complex, presenting

1 commercial and technical barriers to their widespread use. Surface pumps and
2 hydrostatic systems may be limited in the available input pressure, and may therefore
3 provide insufficient actuation force for some applications (particular those which require
4 higher setting or release forces). In addition, in hydrostatic applications, fluid levels may
5 be uncertain and therefore the available hydrostatic pressure and actuation force may not
6 be reliably known.

7

8 Other drawbacks include the specificity of setting tools to a particular category of drive
9 module (or proprietary drive module), and a fixed force output from the actuator device.
10 Furthermore, typically actuator devices are unidirectional; they can only provide a force
11 one direction. These drawbacks limit the operational efficiency of the tools and increase
12 operational inventory.

13

14 In addition, many downhole plug systems rely on the shearing of a solid shear stud or
15 shear ring attached to the plug in order to release the setting tool from the plug at the end
16 of the setting sequence. A consequence of these configurations is that in the event of a
17 failure in the setting tool system, which may result from motor burn out, a damaged piston
18 seal or a gas leak, the setting tool can remain permanently attached to the plug which is
19 partially set in the wellbore. This represents a significant operational problem and in some
20 extreme cases may result in the loss of the well. Furthermore, in some cases, such as a
21 burnt out motor-pump drive system, or an insufficient fluid column when relying on
22 hydrostatic pressure, the partial setting force remains 'trapped' in the tool. This prevents
23 various contingencies that might otherwise be employed (for example, a mechanical
24 release system) from releasing the setting tool from the plug.

25

26

27

1 Summary of the invention

2

3 There is generally a need for apparatus and method of use which addresses one or more
4 of the problems identified above. It is amongst the aims and objects of the invention to
5 provide an apparatus and method of use which obviates or mitigates one or more
6 drawbacks or disadvantages of the prior art.

7

8 In particular, one aim of an aspect of the invention is to provide an actuator device or
9 actuator assembly which is capable of releasing a setting force or setting pressure, and
10 which may therefore facilitate the removal of a setting tool from a partially set plug or
11 packer.

12

13 Another aim of an aspect of an aspect of the invention is to provide an actuator device or
14 actuator assembly which is bidirectional or reversible.

15

16 A further aim of an aspect of the invention is to provide an actuator device or actuator
17 assembly suitable for use with a wide range of drive modules.

18

19 A further aim of an aspect of the invention is to provide an actuator device or actuator
20 assembly which is modular or stackable, and which therefore enables force output and/or
21 operating pressure to be modified according to application and/or the drive module or
22 methodology employed.

23

24 Additional aims of the invention include provide downhole tools incorporating the actuator
25 devices described above, and/or valve modules for use in such downhole tools.

26

27 Further aims and objects of the invention will become apparent from the following
28 description.

29

1 According to a first aspect of the invention, there is provided an actuator assembly for a
2 downhole tool, the actuator assembly comprising:
3 an actuator device comprising:
4 a housing;
5 a piston element movable with respect to the housing;
6 first and second fluid paths configured to couple first and second sides of the piston
7 element to at least one source of fluid pressure;
8 an actuator member configured to be coupled to a downhole device, the actuator
9 member movable between a first position and a second position to operate the downhole
10 device in response to a force acting on the piston element;
11 and a pressure release mechanism, wherein the pressure release mechanism is operable
12 to equalise pressure between the first and second fluid paths of the actuator device.

13

14 The pressure release mechanism enables pressure on opposing sides of the piston
15 element to be equalised, and renders the piston element free to move under an external
16 force (i.e. it is unimpeded by a pressure differential across the piston element). This may
17 facilitate decoupling or disconnection of the actuator device from the downhole device.
18 Applications include releasing of the actuation device from a partially set downhole plug or
19 packer.

20

21 The piston element may be actuatable to move with respect to the housing by a pressure
22 acting on the piston element. The piston element may be a hydraulic piston element, or
23 may be a gas (or pneumatic) piston element.

24

25 The terms "upper", "lower", "above", "below", "up" and "down" are used herein to indicate
26 relative positions in the wellbore. The invention also has applications in wells that are
27 deviated or horizontal, and when these terms are applied to such wells they may indicate
28 "left", "right" or other relative positions in the context of the orientation of the well.

29

30 Preferably, the pressure release mechanism is operable to vent internal pressure in the
31 actuator device. Thus an excess of pressurised fluid may be discharged from the actuator
32 device, which may be an advantage when decoupling or disconnecting the actuator device
33 from a downhole device, and/or if recovering the actuator device to surface.

34

1 The pressure release mechanism may be implemented in a valve module, which may be
2 operable to move between a first position in which the first and second fluid paths are
3 isolated from one another and in communication with first and second sides of the piston
4 element, and a second position in which the first and second fluid paths are in fluid
5 communication with one another.

6

7 The pressure release mechanism may be actuatable from surface, and may be actuatable by
8 imparting a mechanical force, such as a pulling force or downweight force on the pressure
9 release mechanism.

10

11 The pressure release mechanism may be operable at a point in the movement range of
12 the piston element and/or actuator member between the first position and the second
13 position. Thus the pressure release mechanism may be operable at a point in the
14 movement range of the piston element other than a fully unset or a fully set position, and
15 may be operable throughout the movement range of the piston element and/or actuator
16 member.

17

18 The valve module preferably comprises a first sub assembly and a second sub assembly.
19 Preferably, the first sub assembly and second sub assembly are movable between a first
20 position in which the first and second fluid paths are isolated from one another and in
21 communication with first and second sides of the piston element, and a second position in
22 which the first and second fluid paths are in fluid communication with one another.

23

24 Preferably, prior to actuation, the first and second sub assemblies are retained in the first
25 position by a releasable connection, which may comprise one or more shearable or
26 frangible components. The one or more shearable or frangible components may comprise
27 one or more shear pins or shear sleeves.

28

29 Preferably, the pressure release mechanism comprises a locking mechanism which
30 functions to retain the pressure release mechanism in its second position subsequent to
31 actuation. The locking mechanism may comprise a ratchet. The locking mechanism may
32 be releasable.

33

34 Preferably, the actuator assembly comprises a first mode of operation in which a first side
35 of the piston element is pressurised to urge the piston element in a first direction. The

1 actuator assembly may comprise a second mode of operation in which a second side of
2 the piston element is pressurised to urge piston element in a second direction, opposite
3 the first direction.

4

5 Preferably, the first and/or second fluid paths may be provided within a rod of a piston
6 element, and may comprise fluid bores formed in a rod of a piston element. The fluid
7 bores may be axially oriented in a rod of the piston element. The fluid bores may comprise
8 at least one fluid bore which is radially offset from a central axis of a rod of the piston
9 element, and/or may comprise at least one fluid bore which is aligned with a central axis of
10 a rod of the piston element.

11

12 The fluid paths may comprise an annular flow channel, which may be formed around a
13 central axis of a rod of the piston element. Alternatively, the fluid paths may comprise first
14 and second axially oriented bores which are substantially parallel to one another, and
15 displaced from one another in a radial direction.

16

17 Preferably, the actuator device comprises a substantially tubular outer housing comprising
18 an internal volume defining at least one hydraulic fluid chamber, and an inner rod
19 extending through the outer housing and sealed with the outer housing at first and second
20 ends of the outer housing. The piston element may form a part of the inner rod, and may
21 disposed in the internal volume and sealed with an inner surface of the outer housing.

22

23 In a preferred embodiment, the inner rod comprises a first fluid path in communication with
24 the internal volume on a first side of the piston element, and a second fluid path in
25 communication with the internal volume on a second opposing side of the piston element.

26

27 The first and/or second fluid paths may extend through an inner rod of a piston element,
28 and may comprise first and second openings, the first opening disposed at one end of the
29 inner rod, and the second opening disposed at the second (opposing) end of the inner rod.

30

31 The first and/or second openings may be oriented longitudinally with respect to the inner
32 rod. The first and/or second openings may be positioned on longitudinal axes which are
33 within the boundary defined by an outer diameter of the inner rod. The first and/or second
34 openings may therefore be positioned in first and/or second end faces of the inner rod.

34

1 The first fluid path may be configured to be coupled to a source of fluid pressure in a first
2 mode of operation to pressurise a first side of the piston element and urge the inner rod in
3 a first direction with respect to the outer housing. The second fluid path may be configured
4 to be coupled to a source of fluid pressure in a second mode of operation, to pressurise
5 the second side of the piston element and urge the inner rod in a second direction with
6 respect to the outer housing, opposite the first direction.

7

8 Providing fluid paths within the interior of an inner rod of a piston element in the manner of
9 some embodiments of the invention provides certain operational advantages. For
10 example, such a configuration enables exit points for the hydraulic actuation circuit to be
11 formed within the inner rod, rather than in one or more separate fluid paths that are
12 external to the inner rod. This arrangement facilitates provision of an outer housing which
13 is pressure-balanced in use. The outer housing may have first and second ends that have
14 surface areas which are substantially equal (and preferably identical within manufacturing
15 tolerances). Such a configuration may be difficult or impossible to achieve if one or more
16 fluid paths were arranged outside of the inner rod, as in such circumstances it may be
17 necessary to design the outer housing to account for or accommodate the position of one
18 or more of the fluid paths.

19

20 Preferably, the actuator assembly comprises a flow direction means, which is operable to
21 configure the actuator assembly in the first mode of operation or the second mode of
22 operation.

23

24 Preferably, the flow direction means is implemented in a flow direction valve. The flow
25 direction valve may have a forward flow position, in which a first side of the piston element
26 is pressurised to urge the piston element in a first direction, and a reverse flow position in
27 which a second side of the piston element is pressurised to urge the piston element in a
28 second direction, opposite the first direction.

29

30 Preferably the flow direction means is implemented in a valve module, and more
31 preferably the valve module comprises the flow direction means and the pressure release
32 mechanism.

33

34 Preferably, the flow direction means defines a flow path between the at least one source of
35 fluid pressure and the first and/or second flow paths. The flow direction means may be

1 configured to be coupled to a drive module, and may define an interface between the drive
2 module and the actuator device. Preferably the flow direction means comprises an inlet
3 for receiving pressurised fluid from a drive module, and a return line for receiving fluid
4 returned from the actuator device. The return line may comprise an outlet, which may be
5 connected to the drive module, or may discharge to an exterior of the flow direction
6 means.

7

8 Preferably, the valve module or a component thereof is operable to be moved between its
9 forward flow and reverse flow positions. In one embodiment, the valve module or a
10 component thereof is operable to be rotated with respect to the actuator device to move
11 between its forward flow and reverse flow positions. In another embodiment, the valve
12 module or a component thereof is operable to slide with respect to the actuator device to
13 move between its forward flow and reverse flow positions.

14

15 The valve module may be operable to be moved between its forward flow and reverse flow
16 positions when in a downhole location. The valve module may therefore be reconfigured
17 between its forward flow and reverse flow positions without necessarily recovering the
18 device to surface. Alternatively, or in addition, the valve module may be reconfigured
19 between its forward flow and reverse flow positions when at surface, for example prior to
20 or between downhole operations.

21

22 The valve module preferably comprises a first sub assembly and a second sub assembly.
23 In one embodiment, the first sub assembly is operable to be rotated with respect to the
24 second sub assembly to move between its forward flow and reverse flow positions. In
25 another embodiment, the first sub assembly is operable to slide with respect to the second
26 sub assembly to move between its forward flow and reverse flow positions.

27

28 In some embodiments, the valve module is provided with an alignment mechanism which
29 engages the first and/or second sub assemblies when in a desired relative alignment.
30 Preferably the alignment mechanism is configured to engage the first and/or second sub
31 assemblies when in a first desired relative alignment, which may be the forward flow
32 position, and is configured to engage the first and/or second sub assemblies when in a
33 second desired relative alignment, which may be the reverse flow position. The alignment
34 mechanism may comprise at least one recess and at least one pin. The at least one pin

1 may be configured to engage the recess when in a desired relative alignment. The valve
2 module may comprise one or more visual alignment indicators.

3

4 In a preferred embodiment, the valve module comprises a housing sub assembly and a
5 body sub assembly at least partially disposed within the housing. Preferably, the housing
6 sub assembly is configured to be rotated with respect to the body sub assembly between
7 the forward flow position in which the source of fluid pressure is connected to the first fluid
8 path, and a reverse flow position in which the source of fluid pressure is connected to the
9 second fluid path. Preferably, in the first position the second fluid path is connected to the
10 return line. More preferably, in the second position the first fluid path is connected to the
11 return line.

12

13 The housing sub assembly may be configured to be rotated 180 degrees with respect to
14 the body sub assembly between the forward flow and reverse flow positions.

15

16 In one embodiment, the housing sub assembly comprises a sleeve. The body sub
17 assembly may comprise a plurality of radial ports. The sleeve may comprise one or more
18 annular recesses, and the annular recesses may be configured to fluidly connect radial
19 ports of housing sub assembly.

20

21 The actuator device may comprise at least one actuator module. The actuator device may
22 comprise at least two actuator modules. Preferably an actuator module is configured to be
23 connectable to another actuator module to assemble the actuator device. An actuator
24 module may therefore be stackable with at least one other actuator module to form an
25 actuator device.

26

27 Preferably each actuator module comprises a piston element and a housing.

28

29 More preferably, each actuator module comprises a substantially tubular outer housing
30 section comprising an internal volume defining at least one hydraulic fluid chamber, and an
31 inner rod section extending through the outer housing and sealed with the outer housing
32 section at first and second ends of the outer housing section. The piston element may
33 form a part of the inner rod section, and may be disposed in the internal volume and sealed
34 with an inner surface of the outer housing section.

35

1 As noted above, the first and/or second fluid paths may extend through an inner rod of a
2 piston element, and may comprise first and second openings, the first opening disposed at
3 one end of the inner rod, and the second opening disposed at the second (opposing) end
4 of the inner rod. Such a configuration facilitates stacking and/or connecting multiple
5 actuator modules, as their respective inner rods may be connected to one another in a
6 simple manner, while providing fluid communication between the respective first and
7 second fluid path sections defined by each inner rod section.

8

9 Each module may be capable of providing an output force within a particular range,
10 depending on the design and particular size of the module. In some embodiments, it may
11 be desirable for an actuator module to have an operating pressure that is within below a
12 particular operating pressure threshold. This threshold may be determined by the
13 available pressure from a preferred drive module, a desired operating pressure due to
14 design, equipment, or material constraints, and/or the pressure range in which readily
15 available pressure test equipment operates. In some embodiments, the maximum
16 operating pressure is selected to be less than around 18,000 psi (about 124,000 kPa), and
17 may be in the region of 15,000 psi (about 103,000 kPa).

18

19 The actuator device may comprise a pair of actuator modules. Therefore the actuator
20 device may be capable of delivering an output force of up to twice that of the output force
21 of a single module for the same operating pressure.

22

23 Although the invention has general application to the setting and releasing of plugs and
24 packers, the modularity of the invention renders it particularly suitable for applications
25 which require relatively high setting or releasing forces, and/or for tool configurations using
26 a range of different drive modules and methodologies. For example, an embodiment with
27 two modules may have particular application to the setting and/or releasing of radially
28 extendable plugs, anchors and seal arrangements comprising one or more metal
29 extendable segments, of the type described in the applicant's WO2013/0779965. The
30 relatively low operating pressure facilitates use with pyrotechnic gas drive modules and/or
31 downhole pump and motor drive modules, and is still capable of generating the relatively
32 high setting forces required in these applications.

33

34 The actuator device may comprise four or more actuator modules. Therefore the actuator
35 device may be capable of delivering an output force of up to four times that of the output

1 force of a single module for the same operating pressure. Such an embodiment may have
2 particular utility with hydrostatic drive modules, which may have lower available input
3 pressure.

4

5 Alternative embodiments of the invention may comprise unequal numbers of inner rod
6 sections and outer housing sections. For example, the actuator device may comprise a
7 single inner rod and a plurality of outer housing sections mounted on the inner rod.

8 Alternatively, the device may comprise multiple inner rod sections and an unequal number
9 of outer housing sections (for example two inner rod sections and three outer housing
10 sections of appropriate length and appropriately positioned piston heads).

11

12 The actuator assembly may be configured for use with at least one drive module selected
13 from the group consisting of: a downhole motor-pump drive module; a downhole gas drive
14 module; a surface driven pump drive module; a hydrostatic pressure drive module.

15

16 According to a second aspect of the invention, there is provided an actuator device for a
17 downhole tool, the actuator device comprising:

18 a substantially tubular outer housing comprising an internal volume defining at least one
19 hydraulic fluid chamber;

20 an inner rod extending through the outer housing and sealed with the outer housing at first
21 and second ends of the outer housing;

22 wherein the inner rod comprises a piston element disposed in the internal volume and
23 sealed with an inner surface of the outer housing;

24 wherein the inner rod comprises a first fluid line in communication with the internal volume
25 on a first side of the piston element, and a second fluid line in communication with the
26 internal volume on a second opposing side of the piston element;

27 wherein the first and second fluid lines each comprise a first opening in a first end face of
28 the inner rod and a second opening in a second end face of the inner rod.

29

30 Embodiments of the second aspect of the invention may include one or more features of
31 the first aspect of the invention or its embodiments, or vice versa.

32

33 According to a third aspect of the invention, there is provided an actuator device for a
34 downhole tool, the actuator device comprising:

1 a substantially tubular outer housing comprising an internal volume defining at least one
2 hydraulic fluid chamber;
3 an inner rod extending through the outer housing and sealed with the outer housing at first
4 and second ends of the outer housing;
5 wherein the inner rod comprises a piston element disposed in the internal volume and
6 sealed with an inner surface of the outer housing;
7 wherein the inner rod comprises a first fluid line in communication with the internal volume
8 on a first side of the piston element, and a second fluid line in communication with the
9 internal volume on a second opposing side of the piston element;
10 wherein the first and second fluid lines each comprise a first opening and a second
11 opening, wherein the first and second openings are oriented longitudinally with respect to
12 the inner rod, and are positioned on longitudinal axes which are within a boundary defined
13 by an outer diameter of the inner rod.

14

15 Embodiments of the third aspect of the invention may include one or more features of the
16 first or second aspects of the invention or their embodiments, or vice versa.

17

18 According to a fourth aspect of the invention, there is provided an actuator device for a
19 downhole tool, the actuator device comprising:
20 a substantially tubular outer housing comprising an internal volume defining at least one
21 hydraulic fluid chamber;
22 an inner rod extending through the outer housing and sealed with the outer housing at first
23 and second ends of the outer housing;
24 wherein the inner rod comprises a piston element disposed in the internal volume and
25 sealed with an inner surface of the outer housing;
26 wherein the inner rod comprises a first fluid line in communication with the internal volume
27 on a first side of the piston element, and a second fluid line in communication with the
28 internal volume on a second opposing side of the piston element;
29 wherein the first fluid line is configured to be coupled to a source of fluid pressure in a first
30 mode of operation to pressurise the first side of the piston element and urge the inner rod
31 in a first direction with respect to the outer housing;
32 and wherein the second fluid line is configured to be coupled to a source of fluid pressure
33 in a second mode of operation, to pressurise the second side of the piston element and
34 urge the inner rod in a second direction with respect to the outer housing, opposite the first
35 direction.

1

2 By providing first and second fluid lines in the inner rod, connected respectively to first and
3 second sides of the piston element, the actuation device can be operated in either
4 direction, depending on the relative movement required between the inner rod and the
5 outer sleeve, by reversing a pressure differential between the first and second fluid lines.

6

7 Preferably, the first and second fluid lines comprise bores extending longitudinally in the
8 inner rod.

9

10 The first and/or second fluid lines may comprise first and second openings, the first
11 opening disposed at one end of the inner rod, and the second opening disposed at the
12 second (opposing) end of the inner rod. The first and/or second openings may be oriented
13 longitudinally with respect to the inner rod. The first and/or second openings may be
14 positioned on longitudinal axes which are within the boundary defined by an outer
15 diameter of the inner rod. The first and/or second openings may therefore be positioned in
16 first and/or second end faces of the inner rod.

17

18 Providing fluid paths within the interior of an inner rod of a piston element in the manner of
19 some embodiments enables exit points for the hydraulic actuation circuit to be formed
20 within the inner rod, rather than in one or more separate fluid paths that are external to the
21 inner rod. This arrangement facilitates provision of an outer housing which is pressure-
22 balanced in use, as the outer housing may have first and second ends that have surface
23 areas which are substantially equal (and preferably identical within manufacturing
24 tolerances).

25

26 The actuator device may comprise at least one actuator module. The actuator device may
27 comprise at least two actuator modules. Preferably an actuator module is configured to be
28 connectable to another actuator module to assemble the actuator device. An actuator
29 module may therefore be stackable with at least one other actuator module to form an
30 actuator device.

31

32 As noted above, the first and/or second fluid lines may extend through an inner rod of a
33 piston element, and may comprise first and second openings, the first opening disposed at
34 one end of the inner rod, and the second opening disposed at the second (opposing) end
35 of the inner rod. Such a configuration facilitates stacking and/or connecting multiple

1 actuator modules, as their respective inner rods may be connected to one another in a
2 simple manner, while providing fluid communication between the respective first and
3 second fluid line sections defined by each inner rod section.

4

5 Embodiments of the fourth aspect of the invention may include one or more features of the
6 first to third aspects of the invention or their embodiments, or vice versa.

7

8 According to a fifth aspect of the invention, there is provided an actuator device for a
9 downhole tool, the actuator device comprising:

10 a housing;

11 a piston element movable with respect to the housing;

12 first and second fluid paths configured to couple first and second sides of the piston
13 element to at least one source of fluid pressure via a drive module;

14 an actuator member configured to be coupled to a downhole device, the actuator member
15 movable between a first position and a second position to operate the downhole device in
16 response to a force acting on the piston element;

17 wherein the actuator device is compatible with at least two drive modules selected from
18 the group consisting of: a downhole motor-pump drive module; a downhole gas drive
19 module; a surface driven pump drive module; a hydrostatic pressure drive module.

20

21 The actuator device may comprise at least one actuator module, and preferably comprises
22 at least two actuator modules. Preferably an actuator module is configured to be
23 connectable to another actuator module to assemble the actuator device.

24

25 Preferably each actuator module comprises a piston element and a housing.

26

27 Embodiments of the fifth aspect of the invention may include one or more features of the
28 first to fourth aspects of the invention or their embodiments, or vice versa.

29

1 According to a sixth aspect of the invention, there is provided a downhole tool comprising:
2 a drive module; and
3 an actuator assembly according to the first aspect of the invention.

4

5 Preferably the downhole tool is a setting tool. Alternatively, or in addition, the downhole
6 tool may be releasing or retrieval tool.

7

8 Alternatively, the downhole tool is a punch communication tool.

9

10 Embodiments of the sixth aspect of the invention may include one or more features of the
11 first to fifth aspects of the invention or their embodiments, or vice versa.

12

13 According to a seventh aspect of the invention, there is provided a downhole tool
14 comprising:

15 a drive module; and

16 an actuator device according to the second, third, fourth or fifth aspects of the invention.

17

18 Preferably the downhole tool is a setting tool. Alternatively, or in addition, the downhole
19 tool may be releasing or retrieval tool.

20

21 Alternatively, the downhole tool is a punch communication tool.

22

23 Embodiments of the seventh aspect of the invention may include one or more features of
24 the first to sixth aspects of the invention or their embodiments, or vice versa.

25

26 According to an eighth aspect of the invention, there is provided a downhole assembly
27 comprising a setting tool according to the fourth or fifth aspects of the invention, and a
28 downhole apparatus connected to the downhole tool.

29

30 Preferably the downhole apparatus functions to form a plug, a seal, a flow restriction, a
31 support structure, or an anchor in a wellbore. The downhole apparatus may be selected
32 from the group comprising a bridge plug, a straddle, an anchor, or a wellbore packer.

33

1 Preferably, the downhole apparatus comprises one or more segments defining an
2 extendable structure, which may be at least partially formed from a metal tubular, and may
3 comprise a metal tubular and an elastomeric material.

4

5 Embodiments of the eighth aspect of the invention may include one or more features of the
6 first to seventh aspects of the invention or their embodiments, or vice versa.

7

8 According to a ninth aspect of the invention, there is provided a valve module for a
9 downhole tool, the valve module comprising:

10 a first housing sub assembly and a second body sub assembly;

11 wherein the valve module is configured to be connected between a downhole actuator
12 device comprising a piston element, and a drive module for the downhole actuator device;
13 and wherein the valve module is configured to be connected to first and second fluid bores
14 of the downhole actuator device;

15 wherein the first housing sub assembly and a second body sub assembly are operable to
16 be moved between a first condition in which the first and second fluid bores of the actuator
17 device are isolated from one another, and a second condition in which the first and second
18 fluid bores are in fluid communication with one another to equalise pressure between the
19 first and second fluid bores.

20

21 The valve module may comprise an inlet for receiving pressurised fluid from a drive
22 module, and a return line for receiving fluid returned from the actuator device.

23

24 Preferably, the valve module comprises:

25 a forward flow position, which defines a first flow path between a source of fluid pressure
26 in the drive module and a first bore of actuator device, and a return flow path between a
27 second bore of the actuator device and the return line; and

28 a reverse flow position which defines a second flow path between the source of fluid
29 pressure in the drive module and the second bore of actuator device, and a return flow
30 path between the first bore of the actuator device and the return line.

31

32 Embodiments of the ninth aspect of the invention may include one or more features of the
33 first to eighth aspects of the invention or their embodiments, or vice versa.

34

1 According to a tenth aspect of the invention, there is provided a method of operating an
2 actuator device of a downhole tool, the method comprising:

3 providing an actuator device comprising:

4 a housing; a piston element, and first and second fluid paths coupled to first and
5 second sides of the piston element to at least one source of fluid pressure; and an actuator
6 member coupled to a downhole device;

7 the method comprising:

8 moving the actuator member between a first position and a second position in response to
9 a force acting on the piston element to actuate the downhole device; and

10 operating a pressure release mechanism to equalise pressure between the first and
11 second fluid paths of the actuator device.

12

13 The method may comprise pressurising a first side of the piston element via the first fluid
14 line, and directing return fluid from the second side of the piston element via the second
15 fluid line.

16

17 The method may comprise coupling the first fluid line to a source of fluid pressure in a first
18 mode of operation to pressurise the first side of the piston element and urge the inner rod
19 in a first direction with respect to the outer housing.

20

21 The method may comprise coupling the second fluid line to a source of fluid pressure in a
22 second mode of operation, to pressurise the second side of the piston element and urge
23 the inner rod in a second direction with respect to the outer housing, opposite the first
24 direction.

25

26 Embodiments of the tenth aspect of the invention may include one or more features of the
27 first to ninth aspects of the invention or their embodiments, or vice versa.

28

29 According to an eleventh aspect of the invention, there is provided a method of operating
30 an actuator device of a downhole tool, the method comprising:

31 providing an actuator device comprising:

32 a housing; a substantially tubular outer housing comprising an internal volume
33 defining at least one hydraulic fluid chamber;

34 an inner rod extending through the outer housing and sealed with the outer housing
35 at first and second ends of the outer housing;

1 wherein the inner rod comprises a piston element disposed in the internal volume
2 and sealed with an inner surface of the outer housing; a first fluid line in communication
3 with the internal volume on a first side of the piston element; and a second fluid line in
4 communication with the internal volume on a second opposing side of the piston element;
5 wherein the method comprises:

6 pressurising a first side of the piston element via the first fluid line, and directing
7 return fluid from the second side of the piston element via the second fluid line.

8

9 The method may comprise coupling the first fluid line to a source of fluid pressure in a first
10 mode of operation to pressurise the first side of the piston element and urge the inner rod
11 in a first direction with respect to the outer housing.

12

13 The method may comprise coupling the second fluid line to a source of fluid pressure in a
14 second mode of operation, to pressurise the second side of the piston element and urge
15 the inner rod in a second direction with respect to the outer housing, opposite the first
16 direction.

17

18 The method may comprise operating a pressure release mechanism to equalise pressure
19 between the first and second fluid paths of the actuator device.

20

21 The first and second fluid lines may each comprise a first opening and a second opening.
22 The first opening may be in a first end face of the inner rod and the second opening may
23 be in a second end face of the inner rod.

24

25 The first and second openings may be oriented longitudinally with respect to the inner rod,
26 and may be positioned on longitudinal axes which are within a boundary defined by an
27 outer diameter of the inner rod.

28

29 Embodiments of the eleventh aspect of the invention may include one or more features of
30 the first to tenth aspects of the invention or their embodiments, or vice versa.

31

32 According to a twelfth aspect of the invention, there is provided a method of operating a
33 downhole actuator device, the method comprising:

1 providing a valve module comprising a first housing sub assembly and a second body sub
2 assembly, the valve module connected between a downhole actuator device comprising a
3 piston element, and a drive module for the downhole actuator device;
4 wherein the valve module is connected to first and second fluid bores of the downhole
5 actuator device;
6 wherein the method comprises:
7 moving the first housing sub assembly and the second body sub assembly between a first
8 condition in which the first and second fluid bores of the actuator device are isolated from
9 one another, and a second condition in which the first and second fluid bores are in fluid
10 communication with one another; and
11 equalising pressure between the first and second fluid bores.

12

13 Embodiments of the twelfth aspect of the invention may include one or more features of
14 the first to tenth aspects of the invention or their embodiments, or vice versa.

15

16 According to a further aspect of the invention, there is provided an actuator device
17 substantially as described herein with reference to Figures 1 to 4.

18

19 According to a further aspect of the invention, there is provided a downhole tool
20 substantially as described herein with reference to Figures 5 and 6; 7 and 8; 9 and 10; or
21 11 and 12.

22

23 According to a further aspect of the invention, there is provided a valve module
24 substantially as described herein with reference to Figures 13 to 15; 16; or 17.

21a

In some embodiments disclosed herein, there is provided an actuator assembly for a downhole tool, the actuator assembly comprising: an actuator device comprising: a housing; a piston element movable with respect to the housing; first and second fluid paths configured to couple first and second sides of the piston element to at least one source of fluid pressure; an actuator member configured to be coupled to a downhole device, the actuator member movable between a first position and a second position to operate the downhole device in response to a force acting on the piston element; and a pressure release mechanism, wherein the pressure release mechanism is operable to equalize pressure between the first and second fluid paths of the actuator device;

5

10 wherein the actuator device comprises a tubular outer housing comprising an internal volume defining at least one hydraulic fluid chamber, and an inner rod extending through the outer housing and sealed with the outer housing at first and second ends of the outer housing.

15 In some embodiments disclosed herein, there is provided a method of operating an actuator device of a downhole tool, the method comprising: providing the actuator device comprising a tubular outer housing comprising an internal volume defining at least one hydraulic fluid chamber; an inner rod extending through the outer housing and sealed with the outer housing at first and second ends of the outer housing; a piston

20 element, and first and second fluid paths coupled to first and second sides of the piston element to at least one source of fluid pressure; and an actuator member coupled to a downhole device; the method comprising: moving the actuator member between a first position and a second position in response to a force acting on the piston element to actuate the downhole device; and operating a pressure release mechanism to equalize

25 pressure between the first and second fluid paths of the actuator device.

1 Brief description of the drawings

2

3 There will now be described, by way of example only, various embodiments of the
4 invention with reference to the drawings, of which:

5

6 Figure 1A is an elevation of a downhole tool according to the first embodiment of the
7 invention;

8

9 Figure 1B is a part-sectional view of the downhole tool in Figure 1A;

10

11 Figures 2 and 3 are sectional views of an actuator device of the downhole tool of Figures
12 1A and 1B, shown respectively in first and second conditions;

13

14 Figure 4 is an enlarged sectional view of internal features of the apparatus of Figures 1A
15 and 1B;

16

17 Figure 5A is a longitudinal sectional view of a downhole tool according to an embodiment
18 of the invention, configured for use with a motor pump drive module;

19

20 Figure 5B is an elevation of the downhole tool of Figure 5A;

21

22 Figures 6A to 6C are schematic representations of the downhole tool of Figures 5A and 5B
23 in various operating conditions;

24

25 Figure 7A is a longitudinal sectional view of a downhole tool according to an alternative
26 embodiment of the invention, configured for use with a gas drive module;

27

28 Figure 7B is an elevation of the apparatus of Figure 7A;

29

30 Figures 8A to 8C are schematic representations of the downhole tool of Figures 7A and 7B
31 in various operating conditions;

32

33 Figure 9A is a longitudinal sectional view of a downhole tool according to an alternative
34 embodiment of the invention, configured for use with a surface pump drive system;

35

1 Figure 9B is an elevation of the apparatus of Figure 9A;

2

3 Figures 10A to 10C are schematic representations of the downhole tool of Figures 9A and
4 9B in various operating conditions;

5

6 Figure 11A is a longitudinal sectional view of a downhole tool according to an alternative
7 embodiment of the invention, configured for use with a hydrostatic pressure drive system;

8

9 Figure 11B is an elevation of the apparatus of Figure 11A;

10

11 Figures 12A to 12C are schematic representations of the downhole tool of Figures 11A
12 and 11B in various operating conditions;

13

14 Figure 13 is a sectional view of a valve module of a preferred embodiment of the invention;

15

16 Figure 14 is an isometric view of a body sub assembly of the valve module of Figure 13;

17

18 Figures 15A to 15C are sectional views through the valve module of Figure 14, shown in
19 various operating positions;

20

21 Figures 16A and 16B are sectional views through a valve module according to an
22 alternative embodiment of the invention, shown respectively in first and second operating
23 positions; and

24

25 Figures 17A and 17B are sectional views through a valve module according to a further
26 alternative embodiment of the invention, shown respectively in first and second operating
27 positions.

28

1 Detailed description of preferred embodiments

2

3 Referring firstly to Figures 1A, 1B, 2 and 3, there is shown a downhole tool in accordance
4 with a first embodiment of the invention. The downhole tool, generally depicted at 100, is
5 a setting tool configured for the setting and/or releasing of a downhole plug or packer
6 during a wellbore operation. It will be understood that this implementation of the principles
7 of the invention in a setting tool is merely an example, and other applications of the
8 invention are also envisaged as will be described below.

9

10 Figure 1A is an elevation of the downhole tool, which consists of drive module 102 and
11 actuator device 110, and an interface 104 between the drive module 102 and the actuator
12 device 110. It is a feature of the invention that a variety of techniques and equipment can
13 be used to drive the actuator device 110 to operate the downhole tool, and therefore the
14 drive module 102 may comprise internal downhole drive components (not shown), or may
15 be functionally connected to drive components (not shown) located remotely from the tool,
16 for example at surface.

17

18 Figure 1B is a part-sectional view of the downhole tool 100. The actuator device 110 and
19 its interface 104 to the drive module 102 are shown in section, with the drive module 102
20 shown in external elevation.

21

22 The downhole tool 100 is substantially cylindrical in form. The downhole tool may be
23 conveyed by a flexible conveyance such as electric line or slick line, or may be conveyed
24 on coiled tubing or drill pipe, depending on the application and the configuration of the
25 drive module 102. An upper end 103 of the drive module 102 has a connector for
26 connecting the tool into its wellbore conveyance.

27

28 The actuator device 110 comprises a substantially cylindrical outer housing 112 disposed
29 around an inner rod 114. A lower end 115 of the inner rod 114 extends beyond the axial
30 length of the outer housing 112, and is configured to be coupled to a downhole plug or
31 packer which is to be set (not shown). The outer housing 112 is configured to be
32 moveable with respect to the inner rod 114 between a first (unset or run-in) position is
33 shown in Figures 1 and 2, and a second (set or pulling) position shown in Figure 3.

34 Relative displacement of the housing 112 with respect to the rod 114 mechanically sets
35 and/or releases the downhole packer or plug in use.

1

2 The operation of setting and/or releasing a plug or packer by relative movement of a
3 housing and inner rod is known will be familiar to one skilled in the art. However, the
4 principles and details of the actuator device 110 and its interface with the drive module 102
5 are novel and inventive over the prior art, as will be described in detail below.

6

7 The actuator device 110 is shown most clearly in Figures 2, 3 and 4. The actuator device
8 110 of this embodiment is configured as a dual-stage device, comprising two actuation
9 modules 111a and 111b, axially stacked to operate together during use. Each actuation
10 module 111a, 111b comprises a respective inner rod section 114a, 114b and a respective
11 outer housing section 112a, 112b.

12

13 The uppermost outer housing 112a is substantially cylindrical and defines a throughbore
14 sized and shaped to receive inner rod section 114a. An upper end of the outer housing
15 section 112a comprises an upper bore portion 116a, with which the inner rod section 112a
16 is sealed by elastomeric o-rings 118a. The majority of the length of the outer housing
17 section 112a defines an enlarged bore portion 120a which, when assembled with the inner
18 rod section 114a, defines an annular chamber 122a between the inner surface of the
19 housing section and the outer surface of the inner rod. The annular chamber 122a
20 functions as a hydraulic chamber in use as will be described below. A lower end of the
21 outer housing section 112a has a profiled inner surface which is arranged to correspond
22 with and couple to an upper end of an adjacent outer housing section 112b, enabling
23 multiple outer housing sections to be stacked together in a modular fashion.

24

25 The inner rod section 114a is substantially cylindrical and extends from an upper end to a
26 lower end. The majority of the length of the inner rod section 114a is formed to an outer
27 diameter which corresponds to the inner diameter of the upper bore portion 116a, so that
28 the rod is spaced from the inner diameter of the housing to define the chamber 122a. An
29 upper end of the inner rod section 114a comprises a male connector 124a which is
30 received in a corresponding recess of the drive module interface 104. A lower end of the
31 inner rod section 114a comprises an enlarged mandrel portion 126a, which has an outer
32 diameter corresponding to the inner diameter of the enlarged bore portion 120a.

33 Elastomeric o-rings 128a create a seal between the mandrel portion 126a and the outer
34 housing 114a. A lower surface of the mandrel portion 126a defines a shoulder 132a which
35 abuts an upper shoulder 134b of the adjacent outer housing section 112b. The mandrel

1 portion 126a also defines a recess 130a for receiving the upper end of an adjacent inner
2 rod section 114b, enabling multiple inner rod sections to be stacked together in a modular
3 fashion.

4

5 The inner rod section 114a comprises a pair of bores 141a, 142a extending axially through
6 the inner rod section from its first end to its second end.

7

8 The first bore 142a in this embodiment is offset gun-drilled bore extending from an upper
9 end of the inner rod section to its lower end at a position radially offset from the second
10 bore 141a. The first bore extends directly through the inner rod section, and has no
11 communication with the annular chamber 122a. The first bore 142a is in fluid
12 communication with the first bore 142b of the adjacent inner rod section.

13

14 In this embodiment, the second bore 141a is concentric with the inner rod section and
15 extends from its upper end to its lower end. A radial bore 143a links the second bore 141a
16 with the annular chamber 122a disposed between the inner rod section and the outer
17 housing section. The second bore 141a is in fluid communication with the second bore
18 141b of the adjacent inner rod section 114b.

19

20 The provision of the first and/or second bores extending through the inner rod sections
21 facilitates stacking and/or connecting multiple actuator modules, as their respective inner
22 rods may be connected to one another in a simple manner, while providing fluid
23 communication between the respective first and second fluid bore portions defined by
24 each inner rod section.

25

26 Elastomeric o-rings 145a are disposed between the openings of the first and second
27 bores, so that when the inner rod section is received in the drive module interface 104, the
28 openings of the bores 141a, 141b are isolated from one another. When the inner rod
29 section 114a is connected with a male connector of an adjacent rod section, the lower
30 openings of the first and second bores are isolated from one another by elastomeric o-ring
31 seals (145b on rod section 114b).

32

33 The second bore 141b is isolated from the first bore but is in fluid communication with the
34 lower end of the inner rod section via the annulus (or micro-annulus) 144 between the
35 inner surface of the recess 130a and the male connector portion 124b of the adjacent

1 inner rod 114b). The first bore 142a is therefore in fluid communication with the shoulder
2 134b of the adjacent outer housing section 112b, and the shoulder 132a of the inner rod
3 section.

4

5 The second module 111b is similar to first module 111a, with like parts identified with like
6 reference numerals. The outer housing section 112b and the inner rod section 114b
7 together define a second annular chamber 122b in communication with the second bore
8 141b. The lower end of the inner rod section 114b is connected to a lower rod extension
9 member 150, which in turn is connected to a rod termination sub 152. The lower rod
10 extension member 150 extends through and is sealed with a housing termination sub 154.
11 The housing termination sub 154 is joined to and sealed against the lower end of the outer
12 housing section 114b, and defines a shoulder 156 which abuts the lower end of the lower
13 rod section 114b in the position shown in Figure 2. Apertures are provided in the outer
14 housing, and extend through the outer housing to the inner rod to accommodate shear
15 pins (not shown).

16

17 The basic principles of operation will now be described with reference to Figure 4. The
18 drive module 102 may be of a range of different drive modules as noted above, and is
19 coupled to the actuator device 110 to selectively provide pressurised fluid to the first and
20 second interface bores 105, 106. In the first operative condition, shown in Figure 2, fluid is
21 pressurised in the second bore 106, and is a relatively low pressure in the first interface
22 bore 105. High pressure hydraulic fluid is present in the second bore 142 throughout the
23 first and second inner rod sections 114a and 114b. Relatively low pressure fluid is present
24 in the second bore 141 and annular chambers 122a, 122b.

25

26 The fluid pressure in the first bore acts on the shoulders 134b and 156 defined by the
27 upper end of the lower outer housing section 112b and the housing termination sub 154.
28 The shoulders define a piston face which generates a net force on the outer housing 112
29 relative to the inner rod 114. When the force on the outer housing is sufficient to shear the
30 pins in the apertures, the outer housing 112 slides along the inner rod assembly towards a
31 lower setting position, shown in Figure 3. During movement of the outer housing 112, the
32 volume of the annular chambers 122a, 122b is contracted and the hydraulic fluid is
33 returned to the drive module 102 via the second bore 141. When the housing termination
34 sub 154 abuts the rod termination sub 152, the device is in the required position to
35 complete the setting of the plug or packer, as shown in Figure 3.

1
2 The downhole tool 110 can also be operated in a reverse mode as follows. With the
3 pressure application from the drive module 102 inverted, the first interface bore 105 is
4 pressurised relative to the second interface bore 106. High pressure fluid is therefore
5 provided to the contracted annular chambers 122a, 122b, and acts between the piston
6 faces defined by the upper shoulders 133a, 133b of the inner rod sections and the lower
7 shoulders 135a, 135b of the outer housing sections 112a. The pressure differential
8 causes a net force on the housing assembly 112, and as a consequence, the outer
9 housing 112 moves upwards relative to the inner rod to the position shown in Figures 1
10 and 2. The downhole tool may therefore be used to release or unset a plug or packer, by
11 upward movement of a setting mechanism (not shown) coupled to the outer housing 112.
12 This is a significant benefit over those prior art setting tools which are only capable of
13 operating in one direction to set a downhole packer or plug.

14

15 During operation of the downhole tool 100 in a wellbore environment, both the upper and
16 lower end faces of the outer housing 112 are exposed to wellbore pressure. The outer
17 housing has first and second ends with surface areas that are identical within
18 manufacturing tolerances. The outer housing 112 is therefore pressure balanced, and
19 movement of the outer housing 112 on the inner rod does not need to act against
20 hydrostatic pressure in the wellbore. All of the hydraulic energy input to the system is
21 therefore available to drive the actuator device 110 and the setting/releasing mechanism.
22 This is an advantage over those prior art setting tools which must act against hydrostatic
23 pressure and apply sufficient force to actuate the setting mechanism. The pressure-
24 balanced condition of the outer housing is facilitated by the provision of fluid paths and
25 their exit points within the interior of the inner rods. Such a configuration may be difficult or
26 impossible to achieve if one or more fluid paths were arranged outside of the inner rod, as
27 in such circumstances it may be necessary to design the outer housing to account for or
28 accommodate the position of one or more of the fluid paths.

29

30 It will be appreciate that during the above-described operation of the tool 100, hydraulic
31 fluid is recirculated in the tool: forward operation of the pistons moves hydraulic fluid from
32 a first volume (or volumes) on a first side of a piston element to a volume on a second side
33 of the piston elements, and reverse operation moves the hydraulic fluid back to the first
34 volume. Therefore the majority of the hydraulic fluid is contained within the actuator
35 device itself, and circulated between opposing sides of the piston. This mitigates the

1 requirement for additional, separate, hydraulic fluid reservoirs, which may otherwise by
2 required at axially separated positions on the tool. (In this regard it should be noted that
3 the reservoir 167 functions to provide capacity for thermal expansion, not to provide the
4 hydraulic fluid as such). Reducing or eliminating the requirement for additional reservoirs
5 has the benefits of reducing required tool length and reducing fluid path lengths.

6

7 The dual stage configuration of the actuation mechanism 110 enables the force applied to
8 each piston module to be utilised in the setting or releasing operations without increasing
9 the operating pressure of the hydraulic system. In this example, each actuator module is
10 capable of generating a force of the order of 52,000 lbf (about 231,000 Newtons) for an
11 operating pressure of the order of 15,000 psi (about 103,000 kPa). Therefore, the dual
12 stage actuator device of Figures 1 to 4 is capable of delivering a setting or releasing force
13 of the order of 104,000 lbf (about 463,000 Newtons) at the same operating pressure of
14 15,000 psi (about 103,000 kPa). This configuration enables very high forces to be
15 generated without increasing operating pressures to levels which would significantly
16 increase the pressure rating of equipment used. Increasing the operating pressure of the
17 equipment beyond around 15,000 psi may be undesirable in many applications. The high
18 operating pressures increase technical and operational risk, and high pressure rated
19 equipment generally requires upgrading of material selection and/or design parameters
20 and may therefore be undesirable.

21

22 The increase in available setting and releasing force facilitates the application of the
23 actuator device to the setting and releasing of metal-to-metal plugs and seals and hybrid
24 metal-elastomer seals which use an actuation force to deform or otherwise reshape
25 bellows or tubular components for radial displacement. Examples of such applications are
26 described in WO 2013/079965. It is common for plugs of these types to require setting
27 forces up to and around 150,000 lbf (about 670,000 Newtons), and therefore the required
28 force can be generated using two actuator modules in a dual stage set up, as shown in
29 Figures 1 to 3.

30

31 The principles of the invention do of course apply to other configurations of the actuator
32 device. For example, where lower setting forces are required, or where higher input
33 pressure is available (and is technically and operationally acceptable), a single stage
34 actuator device comprising a single outer housing section and a single inner rod section
35 may be used. In such a configuration, the inner rod section would be connected directly to

1 a rod extension member. The outer housing section would be terminated by a housing
2 termination sub, through which the rod extension member would extend. The operating
3 principles described in relation to the dual stage actuator device of Figures 1 to 4 would
4 apply in the same way to provide a single stage reversible setting and releasing actuator
5 device.

6

7 Alternatively, the actuator device may comprise two or more outer housing sections on a
8 single inner rod. Such a configuration made up with two outer housing sections would
9 resemble the tool 100, and its form and function will be understood from the foregoing
10 description. However, the device would comprise a single inner rod with first and second
11 piston heads in place of the assembled first and second rod sections. Each outer housing
12 section would extend over a part of the length of the inner rod, and provide multiple piston
13 faces for the relative movement of the outer housing under hydraulic pressure. More than
14 two outer housing sections may be used on a single inner rod, and it will be appreciated
15 that multiple inner rod sections may also be used with an unequal number of outer housing
16 sections (for example two inner rod sections and three outer housing sections of
17 appropriate length and appropriately positioned piston heads).

18

19 Similarly, device configurations may be used with additional actuator modules, and the
20 modular nature of the outer housing and inner rod sections facilitate stacking of multiple
21 stages using multiple housing sections and inner rods which are identical in form.
22 Additional modules may be desirable where a higher setting or releasing force is required,
23 or conversely, where a lower system pressure is available. An increased number of
24 modules may also be used as a design choice, where it is desirable to reduce the
25 operating pressure for a given output force for technical or commercial reasons.

26

27 As noted above, the actuator device of the present invention is suitable for use with a
28 range of different drive modules and methodologies, and the embodiments described with
29 reference to Figures 1 to 4 are not specific to a particular type of drive module. There will
30 now be described various embodiments of the invention in context of specific drive
31 modules.

32

33 Referring to Figures 5A and 5B, there is shown a downhole tool according to an alternative
34 embodiment of the invention. The downhole tool, generally depicted at 160, is shown in
35 Figure 5A in longitudinal section view and in Figure 5B from a side view. The tool 160 is

1 similar to the tool 100, and its features and operation will be understood from Figures 1 to
2 4 and their accompanying description. The tool comprises a drive module 161, an
3 actuator device 110, and an interface assembly 162. In this embodiment, the apparatus is
4 deployed on electric wireline. It will be appreciated that conveyance on slick line is
5 possible in alternative embodiments of the invention (where downhole power is available),
6 and the same tool could be deployed on drill pipe or coiled tubing if desirable.

7

8 The actuator device 110 is the same as the device shown in Figures 2 and 3. In this
9 embodiment, the drive module is a downhole motor and pump drive module, and
10 comprises a housing assembly 163 for a pump and motor (not shown). The housing
11 assembly 163 is substantially cylindrical and is centrally disposed within the module. An
12 annular chamber 164 is defined between the outer surface of the housing assembly and
13 the inner surface of a drive module housing. A floating piston 165 is provided in the
14 annular chamber and separates an upper sub chamber 166 from a lower sub chamber
15 167. The lower sub chamber 167 defines a hydraulic reservoir which is in fluid
16 communication with the interface assembly via the pump, and the upper sub chamber 166
17 is initially filled with air at atmospheric pressure. In use, the floating piston 165 is movable
18 to accommodate thermal expansion of the hydraulic fluid in the reservoir 167 and the
19 hydraulic circuit.

20

21 Figures 6A to 6C show schematically the operation of the downhole tool of Figure 5A and
22 5B. Each drawing shows schematically the drive module 161, the interface module 162,
23 and the actuator device 110. The drive module 161 comprises a motor 170, a pump 171
24 and a reservoir of hydraulic fluid 173. A hydraulic circuit provides first and second fluid
25 connectors to the first and second interface bores.

26

27 The dual bore configuration of the actuator device enables bidirectional operation, by
28 inverting the application of pressure through the hydraulic system, and driving movement
29 of the pistons in a reverse direction. The interface module therefore comprises a flow
30 direction valve 174 which is configurable in first and second conditions to selectively
31 determine the direction of pressure application in the device.

32

33 As noted above, a typical application of the invention is the setting and/or releasing of
34 downhole plugs or packers. Most downhole plug systems rely on the shearing of a solid
35 shear stud or shear ring attached to the plug in order to release the setting tool from the

1 plug at the end of the setting sequence. A consequence of these configurations is that in
2 the event of a failure in the setting tool system, which may result from motor burn out, a
3 damaged piston seal or a gas leak, the setting tool can remain permanently attached to
4 the plug which is partially set in the wellbore. This represents a significant operational
5 problem and in some extreme cases may result in the loss of the well. Furthermore, in
6 some cases, such as a burnt out motor-pump drive system, or an insufficient fluid column
7 when relying on hydrostatic pressure, the partial setting force remains 'trapped' in the tool.
8 This prevents various contingencies that might otherwise be employed (for example, a
9 mechanical release system) from releasing the setting tool from the plug. To address this
10 issue, the interface module 162 comprises a pressure dump valve 175 which is operable
11 to equalise and/or vent hydraulic pressure retained in the tool as will be described below.
12

13 In the configuration shown in Figure 6A, the apparatus is in an unset condition, with the
14 outer housing 112 in its uppermost position on the inner rod 114. The flow direction valve
15 174 is in its setting position, with the pressurised outlet of the pump in fluid communication
16 with the second bore 142 of the actuator device to act between the piston faces 132, 134.
17 In use, the motor 170 is operated to pump high pressure hydraulic fluid along the first bore
18 142 to act on the outer housing, and low pressure hydraulic fluid is discharged from the
19 chambers 122 to the fluid reservoir 173 via bore 141.
20

21 Figure 6B schematically shows the same apparatus 160 in a pressure dump mode. This
22 mode may be required when it is required to release the setting tool from a partially set
23 plug as described above. In this condition, the pressure dump valve 175 is actuated to a
24 pressure dump condition, which short circuits the first and second bores 142, 141 and
25 vents internal pressure to the wellbore. Unpressurised hydraulic fluid flows on both sides
26 of the pistons defined by the inner rod and is vented to the wellbore. The outer housing
27 112 is rendered free to move on the inner rod 114, and a mechanical release mechanism
28 or other contingency can be operated to release the apparatus 160 from the partially set
29 plug.
30

31 Figure 6C shows the apparatus 160 in a pulling or releasing mode. In this condition, the
32 flow direction valve 174 has been actuated to reverse the direction of the hydraulic circuit
33 through the actuator device 110. High pressure fluid from the pump 171 is therefore
34 provided to act on the piston faces 133, 135, and low pressure hydraulic fluid is returned to

1 the reservoir via the first bore 142. The net force on the outer housing 112 causes it to
2 move upwards on the inner rod.

3

4 Referring to Figures 7A and 7B, there is shown a downhole tool according to an alternative
5 embodiment of the invention. The downhole tool, generally depicted at 180, is shown in
6 Figure 7A in longitudinal section view and in Figure 7B from a side view. The tool 180 is
7 similar to the tools 100 and 160, and its features and operation will be understood from the
8 foregoing description. The tool comprises a drive module 181, an actuator device 110,
9 and an interface assembly 182. In this embodiment, the apparatus is deployed on
10 slickline. It will be appreciated that conveyance on electric wireline drill pipe or coiled
11 tubing is possible in alternative embodiments of the invention.

12

13 The actuator device 110 is the same as the device shown in Figures 2 and 3. In this
14 embodiment, the apparatus 180 comprises a gas drive module 181. The gas drive module
15 181 may be any one of a number of gas drive modules known in the art, including but not
16 limited to pyrotechnic, chemically and thermally reactive modules. In this embodiment, a
17 chemical reaction is triggered within chamber 187, to generate a high pressure gas which
18 drives the floating piston 183 to generate a flow of hydraulic fluid to the hydraulic circuit of
19 the interface module 182.

20

21 Figures 8A to 8C show schematically the operation of the downhole tool of Figure 6A and
22 6B. Each drawing shows schematically the drive module 181, the interface module 182,
23 and the actuator device 110. The actuator device 110 is the same as the device shown in
24 Figures 2 and 3, and is initially filled with unpressurised gas (at atmospheric pressure). The
25 interface module 182 comprises a flow direction valve 184 and a pressure dump valve
26 185, and in the configuration shown in Figure 8A, the apparatus is in an unset condition,
27 with the outer housing 112 in its uppermost position on the inner rod 114. The flow
28 direction valve 184 is in its setting position, with the pressurised outlet from the gas drive
29 module in fluid communication with the first bore 142 of the actuator device to act on the
30 piston faces 132, 134 and move the outer housing downwards on the inner rod.

31

32 Figure 8B schematically shows the same apparatus 180 in a pressure dump mode. In this
33 condition, the pressure dump valve 185 is actuated to a pressure dump condition, which
34 short circuits the first and second bores 142, 141. Unpressurised hydraulic fluid flows on
35 both sides of the pistons defined by the inner rod and is vented to the wellbore. The outer

1 housing 112 is rendered free to move on the inner rod 114, and a mechanical release
2 mechanism or other contingency can be operated to release the apparatus 180 from the
3 partially set plug.

4

5 Figure 8C shows the apparatus 180 in a pulling or releasing condition. In this condition,
6 the flow direction valve 184 has been actuated to reverse the direction of the hydraulic
7 circuit through the actuator device 110. High pressure fluid from the drive module is
8 therefore provided to act on the piston faces 133, 135, the net force on the outer housing
9 112 causes it to be pulled upwards on the inner rod.

10

11 Referring now to Figures 9A and 9B, there is shown a downhole tool according to an
12 alternative embodiment of the invention. The downhole tool, generally depicted at 260, is
13 shown in Figure 9A in a longitudinal section view and in Figures 9B from a side view. The
14 downhole tool 260 is similar to the tools 100, 160 and 180, and its features and operation
15 will be understood from the foregoing description. The tool comprises a drive module 261,
16 an actuator device 110, and an interface assembly 262. The actuator device 110 is the
17 same as the device shown in Figures 2 and 3. In this embodiment, the downhole tool
18 comprises a hydraulic drive module which is configured to be driven by surface pump
19 pressure, and the downhole tool is deployed on drill pipe. It will be appreciated that
20 deployment on coiled tubing is possible in an alternative embodiment of the invention.

21

22 Figures 10A to 10C show schematically the operation of the downhole tool 260 of Figures
23 9A and 9B. Each drawing shows schematically the drive module 261, the interface
24 module 262, and the actuator device 110. Figure 10A shows schematically the downhole
25 tool in a run-in condition. The hydraulic system and annular chambers of the actuator
26 device 110 are initially filled with unpressurised oil. The hydraulic drive module
27 incorporates a fluid cavity 263 which is in fluid communication with a bore of the drill pipe
28 on which the downhole tool is conveyed. The cavity 263 comprises a sliding sleeve which
29 carries a valve seat 264. A biasing spring 266 urges the sleeve 264 towards an upper
30 position, in which the fluid cavity is sealed from a hydraulic line that is in communication
31 with the interface module 262. A lower part of the fluid cavity comprises an outlet 265,
32 enabling flow of fluid through the cavity when the sleeve is in its upper position as shown
33 in Figure 10A.

34

1 Figure 10B shows the same apparatus 260 in a setting position. A ball 269 is dropped
2 from surface through the drill pipe and is pumped (or falls by gravity) to rest on the valve
3 seat 264. Fluid is pumped from surface, using surface pumps, through the drill pipe and to
4 the hydraulic drive module 261. Pressure builds on the upper side of the ball and sleeve
5 until it is sufficient to overcome the force of the biasing spring and move the sleeve
6 downwards to expose the hydraulic line to the interface module 262. High pressure fluid
7 may therefore be pumped through the interface module 262 and into the first bore of the
8 actuator device to act on the actuator pistons and move the outer housing to its lower, set
9 position. Hydraulic fluid on the opposing side of the actuator pistons is returned to the
10 drive module and vented to the wellbore.

11

12 The apparatus 260 may also be used in a reverse mode, and Figure 10C schematically
13 shows the downhole tool in this condition. The flow direction valve 267 has been actuated
14 to reverse the direction of the hydraulic circuit through the actuator device. High pressure
15 fluid from the drive module is therefore provided to act on piston faces 133, 135, and
16 unpressurised hydraulic fluid is returned to the drive module 261 to discharge to the
17 wellbore. The net force on the outer housing causes it to be pulled upwards on the inner
18 rod to a release position. Optionally, the tool 260 also provides a fluid drain path, so that
19 when fluid pumped from surface is depressurised and the downhole tool is recovered to
20 surface, fluid which is present above the ball and valve seat is allowed to drain into the
21 wellbore.

22

23 The downhole tool 260 may also be configured in a pressure dump mode, which may be
24 required when it is required to release the setting tool from a partially set plug as described
25 above. In this condition, the pressure dump valve 268 is actuated to a pressure dump
26 condition, which short circuits the first and second bores and vents internal pressure to the
27 wellbore. Unpressurised hydraulic fluid flows on both sides of the pistons defined by the
28 inner rod and is vented to the wellbore. The outer housing 112 is rendered free to move
29 on the inner rod 114, and a mechanical release mechanism or other contingency can be
30 operated to release the apparatus from the partially set plug.

31

32 Referring now to Figures 11A and 11B, there is shown a downhole tool according to a
33 further alternative embodiment of the invention. The downhole tool, generally depicted at
34 280, is shown in Figure 11A in a longitudinal sectional view, and in Figure 11B from a side
35 view. The tool 280 is similar to the tool 100, 160, 180 and 260, and its features and

1 operation will be understood from the foregoing description. The tool comprises a drive
2 module 281, an actuator device 110', and an interface assembly 282. In this embodiment,
3 the downhole tool 280 comprises a hydrostatic drive module operable to be driven by
4 wellbore pressure, and is deployed on drill pipe. It will be appreciated that the downhole
5 tool may be deployed on coiled tubing in alternative embodiments of the invention.
6

7 The actuator device 110' is similar to the device shown in Figures 2 and 3, although the
8 actuator device comprises four stacked piston modules. The use of four piston modules
9 enables a suitable output force to be generated from a lower system pressure. Figures
10 12A to 12C show schematically the operation of the downhole tool 280 of Figures 11A and
11 11B. Each drawing shows schematically the drive module 281, the interface module 282,
12 and the actuator device 110'. Figure 12A shows schematically the downhole tool in a run-
13 in condition. The hydraulic system and annular chambers of the actuator device 110' are
14 initially filled with unpressurised gas (at atmospheric pressure). The hydraulic drive
15 module incorporates a fluid cavity 283 which is in fluid communication with a bore of the
16 drill pipe on which the downhole tool is conveyed. The cavity 283 comprises a sliding
17 sleeve 284 which carries a valve seat 285. The sleeve 284 comprises flow apertures
18 291a, 291b which connect the outside of the sleeve with the cavity 283. A port 290 in the
19 drive module is in communication with hydrostatic fluid in the wellbore. A flow line 292 is
20 in fluid communication with the bore 142 of the actuator device. A biasing spring 286
21 urges the sleeve 284 towards an upper position, in which the fluid cavity 283 is isolated
22 from the port 290 and the flow line 292.
23

24 Figure 12B shows the same apparatus 280 in a setting position. A ball 289 is dropped
25 from surface through the drill pipe and is pumped (or falls by gravity) to rest on the valve
26 seat 284. Fluid is pumped from surface, using surface pumps, through the drill pipe and to
27 the hydraulic drive module 281. Pressure builds on the upper side of the ball and sleeve
28 until it is sufficient to overcome the force of the biasing spring 286 and move the sleeve
29 downwards to align the aperture 291a with the port 290 to expose the cavity 283 to
30 hydrostatic fluid. At the same time, aperture 291b is aligned with the flow line 292.
31 hydrostatic pressure is therefore communicated to the interface module 282 and into the
32 first bore of the actuator device to act on the actuator pistons to compress the gas on the
33 opposing side of the pistons and move the outer housing to its lower, set position.
34

1 The tool 280 may also be used in a reverse mode as shown in Figure 12C. The flow
2 direction valve 287 has been actuated to reverse the direction of the hydraulic circuit
3 through the actuator device. Hydrostatic pressure from the drive module is therefore
4 provided to act on piston faces 133, 135, and move the outer housing to a release
5 position. Optionally, the tool 280 also provides a fluid drain path, so that when fluid
6 pumped from surface is depressurised and the downhole tool is recovered to surface, fluid
7 which is present above the ball and valve seat is allowed to drain into the wellbore.

8

9 The downhole tool 280 may also be configured in a pressure dump mode. In this condition
10 (not shown), the pressure dump valve 268 is actuated to a pressure dump condition, which
11 short circuits the first and second bores and vents internal pressure to the wellbore. A
12 mechanical release mechanism or other contingency can be operated to release the
13 apparatus from the partially set plug.

14

15 As noted above, a typical application of the invention is the setting and/or releasing of
16 downhole plugs or packers, and it is desirable to incorporate a mechanism for releasing a
17 setting force or pressure which has built up in the event of a drive failure (or other system
18 failure); and to provide a reversible, directional tool to enable release of the plug or packer
19 to be set.

20

21 Although these valve functions may be implemented in a number of different ways within
22 the scope of the invention, including using conventional valve modules as schematically
23 shown in Figures 6, 8, 10 and 12, in a preferred embodiment of the invention, the valve
24 functions are implemented in a single compact module that enables both functions. An
25 example embodiment is described with reference to Figures 13, 14 and 15, which show a
26 valve module 300 incorporating flow reversing and pressure dump capabilities.

27

28 Figure 13 is a longitudinal sectional view of the valve module 300 in an assembled, setting
29 position. The valve module 300 comprises a housing sub assembly 302 and a body sub
30 assembly 304. Figure 14 is an isometric view of the body sub assembly 304.

31

32 The housing sub-assembly 302 is substantially cylindrical and comprises an upper end
33 301 which interfaces with the drive module (not shown). The upper end comprises
34 mechanical and fluid connectors for the drive module, including first and second interface
35 bores 305, 306. A relief bore 311a, 311b provides a fluid path from the bore 306 (on the

1 side of the pressure source) to the bore 305 (on the hydraulic fluid return side). An
2 enlarged portion 311b optionally accommodates a relief valve 313. Extending from a
3 lower end 303 of the housing 302 is a blind bore 307, which is sized and shaped to
4 accommodate the body 304. The blind bore 307 comprises a stepped profile, with a
5 reduced diameter portion of the blind bore sized to receive and seal with a neck portion
6 308 of the body. The main mandrel 310 of the body 304 is sized to fit within an enlarged
7 bore portion of the bore 307. A retaining ring 312 is disposed between the housing 302
8 and the body 304.

9

10 The body 304 comprises a recess at its lower end, which is shaped and sized to receive a
11 male connector of the inner rod section 314. First and second bores 142, 141 are in fluid
12 communication with bores 342, 341 in the body sub-assembly. The bores 341, 342 exit
13 the body sub-assembly in a radial direction, to exit point 314, 316 located in the neck
14 portion 308. The exit points 314, 316 are diametrically opposed at 180 degrees from one
15 another.

16

17 Surrounding the exit point 314 on the cylindrical surface of the neck portion 308 are
18 circular recesses 318, 320 which accommodate elastomeric seals. The seals form a
19 double elastomeric fluid seal between the body sub-assembly 304 and the housing sub-
20 assembly 302 around the exit point. An identical arrangement of recesses and seals is
21 provided around exit point 316. The interface bores 305, 306 are in fluid communication
22 with the exit points.

23

24 Provided in the housing sub-assembly are radial apertures 322, aligned with recesses 324
25 in the body sub-assembly. Shear pins (not shown) extend through the apertures 322 and
26 into the holes 324 to retain the housing sub-assembly 302 and the body sub-assembly 304
27 together. Apertures 336 in the housing sub-assembly correspond to the position of part-
28 circular recesses 337 in the edge of the body 304. The apertures 336 and recesses 337
29 together accommodate locating pins (not shown) when the assembly is in the position
30 shown in Figure 13, or when the respective sub-assemblies are rotated with respect to one
31 another by 180 degrees. In this embodiment, the pins are spring-loaded pins which are
32 removably mounted in the apertures 336. When the housing sub-assembly is not in the
33 correct rotational position with respect to the body sub-assembly, the pins are supported
34 by the edge of the body 304. The apertures 336 are also provided with side bores 338
35 which enable the pins to be supported in an outer position during assembly.

1

2 When the housing sub-assembly is not in the correct rotational position with respect to the
3 body sub-assembly, the pins align with the recesses and the action of the springs forces
4 them inwards to rotationally key the sub-assemblies with respect to one another in the
5 desired alignment. The housing sub assembly and body sub assembly are also provided
6 with visual alignment indicators to facilitate correct alignment.

7

8 The body 304 is provided with a profiled outer surface providing an axially separated pair
9 of annular recesses 326a, 326b, and a downward facing shoulder 328. The recesses and
10 the shoulder are designed to engage with a mechanism on the locking ring 312, as will be
11 described below. Axial groove 330 on the neck portion, along with an optional
12 corresponding axial groove on a diametrically opposed surface, functions to reduce or
13 minimise hydraulic lock between the two sub-assemblies.

14

15 Figures 15A to 15C are longitudinal sectional views of the interface module 300
16 respectively in forward flow, reverse flow and pressure dump conditions. The interface
17 module 300 is shown assembled with an inner rod section 314.

18

19 In the first condition, shown in Figure 15A, the valve module functions to provide a fluid
20 communication path between the drive module and the first and second bores of the inner
21 rod 114. Figure 15A shows the apparatus in a setting mode, in which high pressure
22 hydraulic fluid is provided by the drive module in the interface bore 306, the bore 342, and
23 into the first bore 142 of the inner rod 114. On the opposing side of the piston faces
24 defined by the inner rod, low pressure hydraulic fluid is present in the second bore 141, the
25 bore 341 and the interface bore 305. This forward flow configuration effects downward
26 movement of the outer housing on the inner rod.

27

28 The optional relief valve 313 functions to relieve pressure from the bore 306 (downstream
29 of the hydraulic pressure source) to bypass the actuator device when the actuator device
30 reaches its full stroke, or in the event of tool failure, for example if the tool becomes stuck
31 mid-stroke. The inclusion of a pressure relief valve is preferred in embodiments which
32 include a motor-pump drive module. When the actuator gets to the end of its stroke, the
33 pressure applied from the drive module would rise to the maximum rated output of the
34 pump/motor combination and put undue stress onto that system and the related power supply
35 until the motor is shut down. When the pressure threshold of the valve 313 is exceeded,
36 the valve opens to shunt this pressure to the return reservoir, to prevent the pump from

1 “dead-heading”. The motor and pump combination are therefore only required to operate
2 to the pressure determined by the threshold of the pressure relief valve.

3

4 The configuration of the valve module 300 enables the downhole tool to be operated in a
5 reverse direction. Such a configuration is shown in Figure 15B. In this mode, the housing
6 sub-assembly has been inverted by rotating it 180 degrees with respect to the housing
7 sub-assembly prior to re-assembling the valve module. In this embodiment, the
8 configuration of the valve module is performed at surface, prior to running the downhole
9 tool. The housing and body are separated, rotated relative to one another by 180 degrees,
10 and re-assembled to the configuration shown in Figure 15B. In this mode, high pressure
11 hydraulic fluid is delivered from the drive module through bore 306 and into bore 341. Low
12 pressure hydraulic fluid is returned from bore 342 via 342 and into interface bore 306. In
13 the configuration of Figure 15B, the tool is actuated to pull or release the downhole tool.

14

15 As noted above, in the event of a setting sequence failure, in which a partial setting force
16 has been applied such that the plug is partially set and the chambers and the fluid lines of
17 the actuator device are at elevated pressure, it is desirable to release the pressure in the
18 hydraulic system. With the valve module 300, this mode of operation is shown in Figure
19 15C. An upward force or overpull is applied to the housing sub-assembly via the wellbore
20 conveyance. When this overpull is sufficient to shear the shear pins (not shown) located in
21 the apertures 322 and annular groove 324, the housing sub-assembly 302 moves upwards
22 with respect to the body sub-assembly 304, until the shoulder 328 abuts an upper shoulder
23 332 of the locking ring 312. A ratchet mechanism provided on the locking ring engages
24 the grooves 326a, 326b to prevent relative movement of the housing sub-assembly and
25 the body sub-assembly until the module is reset at surface.

26

27 In this position, the radial exit point 314, 316 of the bores 341 and 342 are exposed to
28 annular chamber 334. Any pressure differential between the first and second bores 142,
29 141 of the inner rod 114 is equalised; i.e. the hydraulic circuit between the bores 141, 142
30 is ‘shorted’ through the annular chamber 334. In addition, shearing of the pins opens vent
31 holes 336, which open a fluid path from the annular chamber 334 and the exterior of the
32 tool. The pressure in the annular chamber 334 is therefore equalised with wellbore
33 pressure, and any excess pressure in the tool is vented to the wellbore annulus. With the
34 pressure equalised in the device, and equalised with wellbore pressure, a contingency
35 such a mechanical release system to release the setting tool for the partially set plug,

1 enabling the setting tool to surface. The vent holes 336 are circumferentially offset from
2 the apertures 322, to prevent parts of the shear pins being dropped into the annular space
3 322 in use.

4

5 Figures 16A and 16B are longitudinal sections through a valve module according to an
6 alternative embodiment of the invention. Figure 16A shows the valve module in a first,
7 forward flow condition, and Figure 16B shows the valve module in a second, reverse flow
8 condition.

9

10 The valve module 400 comprises a body sub-assembly 404 and a sliding sleeve 402
11 disposed on the body, and is configured as a shuttle valve. The body sub-assembly
12 comprises a first upper end 401 configured for attachment to a drive module, and a
13 second, lower end 402 is configured for attachment to an inner rod of an actuator device.
14 In this embodiment, the inner rod is configured for threaded mating with a recess 407 of
15 the body.

16

17 The body comprises a first bore 410 orientated along a longitudinal axis of the body, and a
18 pair of radially offset upper bores 411, 412. The bores 410, 411, 412 are fluidly connected
19 to a hydraulic drive module (not shown). The body also comprises lower bore 441, which
20 is fluidly connected with a second bore of the inner rod in use, and lower bore 442 is fluidly
21 connected with a first bore of the inner rod. Each of the bores in the body is provided with
22 a radial port, with the radial ports being axially spaced along the body.

23

24 The sleeve 402 comprises a pair of annular recesses 420, 422 which may be selectively
25 aligned with pairs of radial ports to connect the bores. Grub screws 424 secure the sleeve
26 with respect of the body in the required axial position, and annular seals 426 are provided
27 between the sleeve and the body between the locations of the radial ports.

28

29 In a first, forward flow position, shown in Figure 16A, annular recess 420 fluidly connects
30 the radial ports of the bore 412 and the bore 442, and annular recess 422 fluidly connects
31 the radial exit points of the bore 410 and the bore 441. Pressurised hydraulic fluid
32 delivered by the drive module to bores 412 and 411 delivered to the bore 442 via the
33 annular recess 420, and is delivered to the first bore of the inner rod to act on the piston
34 faces and push the outer housing of the actuator device to a downward, set position. High
35 pressure fluid in the bore 411 is blanked due to location of its radial port between a pair of

1 annular seals. Low pressure fluid on the reverse side of the piston faces is returned to the
2 drive module via the bore 441, the annular recess 422 and the bore 410.

3

4 In the configuration shown in Figure 16B, the sleeve has been moved on the body to a
5 lower position at which it has been secured using grub screws 424. In this configuration,
6 the annular recess 422 connects the bore 411 with the bore 441 and the annular recess
7 420 connects the bore 442 with the bore 410. Pressurised hydraulic fluid in the bore 411
8 is therefore able to pressurise hydraulic fluid in the second bore of the inner rod via the
9 annular recess 422. This pressure acts on the piston faces in a reverse direction to pull
10 the outer housing upwards on the inner rod.

11

12 In practice, the valve module 400 is configured in its first and second position at surface by
13 undoing grub screws 424, sliding the sleeve on the body and re-attaching the grub screws.
14 However, it will be appreciated that in alternative embodiments of the invention, the sleeve
15 may be configured to be actuated from a remote location, to move between first and
16 second positions, such that the flow direction can be reversed while the valve module is in
17 position downhole.

18

19 Referring now to Figures 17A and 17B, there is shown a valve module according to a
20 further embodiment of the invention. The valve module 500 is similar to the valve module
21 400, and its features and operation will be understood from Figures 16A, 16B and the
22 accompanying description. The valve module 500 comprises a sleeve 502 disposed on a
23 body 504. The valve module 500 is similar to the body 400, with like components
24 indicated by like reference numerals incremented by 100. However, the valve module 500
25 differs from the valve module 400 in the configuration of the body and the sleeve. The
26 sleeve 502 is asymmetric about a central plane perpendicular to its axis, with the annular
27 recesses 520 and 520 disposed towards a first end 521 of the sleeve. When assembled in
28 the configuration shown in Figure 17A, the annular recesses are disposed towards an
29 upper end 501 of the body, and are aligned to connect radial ports of the bores 512 and
30 542 through recess 520, and bores 510 and 541 through recess 522. In this configuration,
31 the flow direction is forwards, with pressurised hydraulic fluid in bore 512 being delivered
32 to the first bore of the inner rod, and lower pressure fluid being returned from the second
33 bore of the inner rod through bore 541, annular recess 522 and bore 510.

34

1 In the configuration shown in Figure 17B, the sleeve has been flipped, with its first end
2 towards a lower end of the sleeve. In this position, the annular recesses are disposed
3 towards a lower end 503 of the body, and are aligned to connect bores 511 and 541
4 through annular recess 522, and bores 510 and 542 through annular recess 520. In this
5 mode of operation, the flow direction of the hydraulic circuit is reversed, high pressure fluid
6 in bores 511 and 541 is delivered to the second bore of the inner section, with low
7 pressure fluid returned through bores 542 and 510.

8

9 It will be appreciated by one skilled in the art that shuttle valve embodiments described
10 with respect of Figures 16 and 17 may be modified to incorporate the pressure dump
11 functionality of valve module 300 (i.e. means for short-circuiting the dual bores and/or
12 venting pressure to the wellbore annulus). In one implementation, this can be achieved by
13 providing a sleeve with an additional annular recess and a third axial position which
14 provides connection of radial ports fluidly connected to the first and second bores of the
15 inner rod. Alternatively, a secondary shear out sleeve may be incorporated in the valve
16 module sleeve, such that an overpull on the valve module opens communicating radial
17 ports and vents to the exterior of the module.

18

19 Variations and modifications to the above-described embodiments are within the scope of
20 the invention. For example, although the described embodiments have first and second
21 axially oriented bores in the rod sections which are substantially parallel to one another,
22 and displaced from one another in a radial direction, other bore arrangements are within
23 the scope of the invention. For example, the both bores may be offset from the central
24 axis of the rod sections. Alternatively, one or both of the bores may define an annular flow
25 channel, which may be formed around a central axis of a rod of the piston element.

26

27 In the foregoing embodiments of the invention, the actuator devices are operable in
28 forward and reverse modes, and are reconfigured between the two modes at surface,
29 between downhole operations. Alternative embodiments of the invention are operable to
30 reconfigured when in a downhole location. For example, a mechanism may be provided in
31 the tool to reorient a flow-direction valve such as the valve assemblies 300, 400, or 500
32 when in situ in the wellbore. Such a mechanism may be actuated electrically, and may for
33 example include a downhole electric motor which effects a relative movement of two sub-
34 assemblies by rotation or axial shifting. Alternatively, the mechanism may be actuated by
35 a mechanical force such as a two (or multi)-stage overpull, one stage of which reorients a

1 flow direction valve (subsequent overpull stages may effect movement of a component of
2 the device to a pressure release condition). Alternatively, or in addition, the mechanism
3 may comprise one or more electronically actuated components such as solenoids which
4 are operable to release one two components of the device and enable reorienting of the
5 flow direction valve by a mechanically and/or electrically applied force. In any case, the
6 reconfiguration of the device may be enacted remotely, from surface, without a
7 requirement to pull the tool from hole for reconfiguration at surface.

8

9 The foregoing description relates predominantly to applications to setting and releasing of
10 a downhole plug or packer. However, other applications are within the scope of the
11 invention and include the setting of straddles, whipstocks, and/or cement retainers. The
12 invention facilitates application to advanced sealing technologies such as those which
13 deform or expand tubular components to form metal-to-metal or hybrid metal-elastomer
14 plugs or seals (and which may require relatively large setting and releasing forces).

15

16 Other downhole actuation applications are also within the scope of the invention. For
17 example, tubing punch and/or tubing cut tools are facilitated by the bidirectional nature of
18 the actuator device and its flexible output force.

19

20 The invention provides an actuator assembly for a downhole tool and a method of use.
21 The actuator assembly comprises an actuator device, which includes a housing and a
22 piston element movable with respect to the housing. First and second fluid paths are
23 configured to couple first and second sides of the piston element to at least one source of
24 fluid pressure in a drive module, and an actuator member is configured to be coupled to a
25 downhole device. The actuator member is movable between a first position and a second
26 position to operate the downhole device in response to a force acting on the piston
27 element. The actuator assembly comprises a pressure release mechanism which is
28 operable to equalise pressure between the first and second fluid paths of the actuator
29 device. The invention may be used in conjunction with a valve module which includes the
30 pressure release mechanism, and the valve member preferably comprises a forward flow
31 position, in which a first side of the piston element is pressurised to urge the piston
32 element in a first direction, and a reverse flow position in which a second side of the piston
33 element is pressurised to urge the piston element in a second direction, opposite the first
34 direction. A preferred embodiment of the invention is setting tool incorporating the
35 actuator assembly.

1

2 Embodiments of the invention comprise a modular system of actuator devices, and
3 embodiments are capable of utilisation with a wide range of drive modules, including gas
4 drive modules, downhole pump-motor drive modules, surface pump modules, and
5 hydrostatic drive modules.

6

7 The invention obviates or mitigates one or more drawbacks or disadvantages of prior art
8 actuator devices and setting tools. The actuator device or actuator assembly which is
9 capable of releasing a setting force or setting pressure, and which may facilitate the
10 removal of a setting tool from a partially set plug or packer. The actuator systems of the
11 invention are bidirectional or reversible, increasing flexibility of operation, reducing
12 required tool inventory, and avoiding the requirement for a hydraulic reservoir which may
13 increase the required tool length. Actuators of the present invention are modular or
14 stackable, and which enables force output and/or operating pressure to be modified
15 according to application and/or the drive module or methodology employed. Actuators are
16 also suitable for use with a wide range of drive modules.

17

18 Various modifications to the above-described embodiments may be made within the scope
19 of the invention, and the invention extends to combinations of features other than those
20 expressly claimed herein.

21

CLAIMS:

1. An actuator assembly for a downhole tool, the actuator assembly comprising:
 - 5 an actuator device comprising:
 - a housing;
 - a piston element movable with respect to the housing;
 - first and second fluid paths configured to couple first and second sides of the piston element to at least one source of fluid pressure;
 - an actuator member configured to be coupled to a downhole device, the
10 actuator member movable between a first position and a second position to operate the downhole device in response to a force acting on the piston element;
 - and a pressure release mechanism, wherein the pressure release mechanism is operable to equalize pressure between the first and second fluid paths of the actuator device;
 - 15 wherein the actuator device comprises a tubular outer housing comprising an internal volume defining at least one hydraulic fluid chamber, and an inner rod extending through the outer housing and sealed with the outer housing at first and second ends of the outer housing.
- 20 2. The actuator assembly according to claim 1, wherein the pressure release mechanism is operable to vent internal pressure in the actuator device.
3. The actuator assembly according to claim 1, wherein the pressure release
25 mechanism is operable to move between a first position in which the first and second fluid paths are isolated from one another and in communication with first and second sides of the piston element, and a second position in which the first and second fluid paths are in fluid communication with one another.
4. The actuator assembly according to claim 1, wherein the pressure release
30 mechanism is actuatable from surface by imparting a mechanical force on the pressure release mechanism.

5. The actuator assembly according to claim 1, wherein the pressure release mechanism is operable at one or more positions in the movement range of the actuator member between its first position and its second position.
- 5 6. The actuator assembly according to claim 1, wherein the pressure release mechanism is implemented in a valve module.
7. The actuator assembly according to claim 6, wherein the valve module comprises a first sub assembly and a second sub assembly, and wherein the first sub
10 assembly and second sub assembly are moveable between a first position in which the first and second fluid paths are isolated from one another and in communication with first and second sides of the piston element, and a second position in which the first and second fluid paths are in fluid communication with one another.
- 15 8. The actuator assembly according to claim 7, wherein prior to actuation, the first and second sub assemblies are retained in the first position by a releasable connection.
9. The actuator assembly according to claim 1, comprising a first mode of
20 operation in which a first side of the piston element is pressurized to urge the piston element in a first direction, and a second mode of operation in which a second side of the piston element is pressurized to urge piston element in a second direction, opposite the first direction.
- 25 10. The actuator assembly according to claim 1, wherein the inner rod comprises a first bore in communication with the internal volume on a first side of the piston element, and a second bore in communication with the internal volume on a second opposing side of the piston element.
- 30 11. The actuator assembly according to claim 10, wherein each of the first and second fluid bores extend through an inner rod of a piston element, and each comprises

first and second openings positioned respectively in first and/or second end faces of the inner rod.

12. The actuator assembly according to claim 1, wherein the outer housing is
5 pressure-balanced in use.

13. The actuator assembly according to claim 1, comprising a flow direction
means having a forward flow position in which a first side of the piston element is
pressurized to urge the piston element in a first direction, and a reverse flow position in
10 which a second side of the piston element is pressurized to urge the piston element in a
second direction, opposite the first direction.

14. The actuator assembly according to claim 13, wherein the flow direction
means comprises an inlet for receiving pressurized fluid from a drive module, and a
15 return line for receiving fluid returned from the actuator device.

15. The actuator assembly according to claim 13, wherein the flow direction
means is operable to be moved between its forward flow and reverse flow positions.

20 16. The actuator assembly according to claim 15, wherein the flow direction
means is operable to be rotated with respect to the actuator device to move between its
forward flow and reverse flow positions.

25 17. The actuator assembly according to claim 15, wherein the flow direction
means is operable to slide with respect to the actuator device to move between its
forward flow and reverse flow positions.

18. The actuator assembly according to claim 15, wherein the flow direction
means operable to be moved between its forward flow and reverse flow positions when
30 in a downhole location.

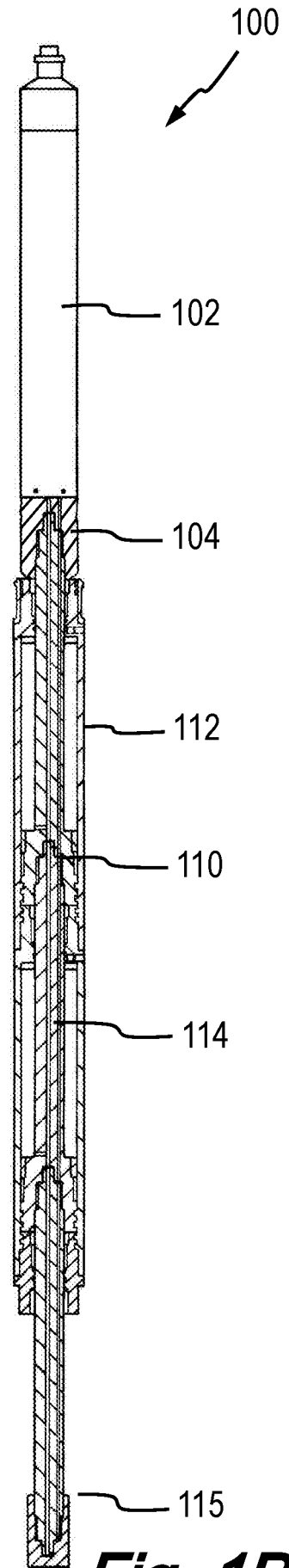
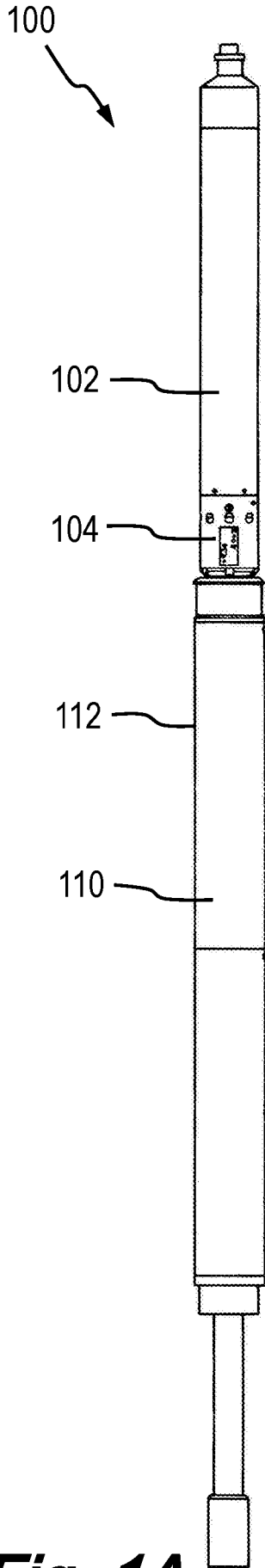
19. The actuator assembly according to claim 13, wherein the flow direction means is operable to be reconfigured between its forward flow and reverse flow positions when at surface.
- 5 20. The actuator assembly according to claim 13, wherein the flow direction means is implemented in a valve module, wherein the valve module comprises a first sub assembly and a second sub assembly, and wherein the valve module is provided with an alignment mechanism which engages the first and/or second sub assemblies when in a desired relative alignment.
- 10 21. The actuator assembly according to claim 1, wherein the actuator device comprises at least two actuator modules connected together to assemble the actuator device, wherein each actuator module comprises a piston element and a housing.
- 15 22. The actuator assembly according to claim 1, configured to actuate the setting and/or releasing of a plug, a seal, a flow restriction, a support structure, or an anchor in a wellbore.
23. The actuator assembly according to claim 1, configured for use with at
20 least one drive module selected from the group consisting of: a downhole motor-pump drive module; a downhole gas drive module; a surface driven pump drive module; a hydrostatic pressure drive module.
24. A downhole tool comprising:
25 a drive module; and
an actuator assembly according to claim 1.
25. The downhole tool according to claim 24, wherein the downhole tool is a setting tool.
- 30 26. A downhole assembly comprising a setting tool according to claim 25, and a downhole apparatus connected to the setting tool, wherein the downhole apparatus

functions to form a plug, a seal, a flow restriction, a support structure, or an anchor in a wellbore.

27. The downhole assembly according to claim 26, wherein the downhole
5 apparatus comprises one or more segments defining an extendable structure at least partially formed from a metal tubular.
28. The actuator assembly according to claim 1, wherein the actuator device
is operable to pressurize the first side of the piston element via the first fluid path to urge
10 the piston element in a first direction and thereby move the actuator member between the first position and the second position.
29. The actuator assembly according to claim 1, further comprising a second
mode of operation in which the second side of the piston element is pressurized to urge
15 the piston element in a second direction, opposite the first direction.
30. A method of operating an actuator device of a downhole tool, the method comprising:
providing the actuator device comprising a tubular outer housing
20 comprising an internal volume defining at least one hydraulic fluid chamber; an inner rod extending through the outer housing and sealed with the outer housing at first and second ends of the outer housing; a piston element, and first and second fluid paths coupled to first and second sides of the piston element to at least one source of fluid pressure; and an actuator member coupled to a downhole device; the method
25 comprising:
moving the actuator member between a first position and a second position in response to a force acting on the piston element to actuate the downhole device; and
operating a pressure release mechanism to equalize pressure between
30 the first and second fluid paths of the actuator device.

31. The method according to claim 30, further comprising venting internal pressure in the actuator device.
32. The method according to claim 30, further comprising moving the pressure release mechanism between a first position in which the first and second fluid paths are isolated from one another and in communication with first and second sides of the piston element, and a second position in which the first and second fluid lines are in fluid communication with one another.
- 10 33. The method according to claim 30, further comprising actuating the pressure release mechanism from surface by imparting a mechanical force on the pressure release mechanism.
- 15 34. The method according to claim 30, further comprising actuating the pressure release mechanism at a position in the movement range of the actuator member between its first position and its second position.
- 20 35. The method according to claim 30, further comprising moving the actuator member by pressurizing a first side of the piston element via the first fluid path, and directing return fluid from the second side of the piston element via the second fluid path.
- 25 36. The method according to claim 30, further comprising disconnecting the actuator device from a downhole apparatus.
37. The method according to claim 30, further comprising pressurizing the first side of the piston element via the first fluid path to cause a force to act on the piston element and urge the piston element in a first direction.

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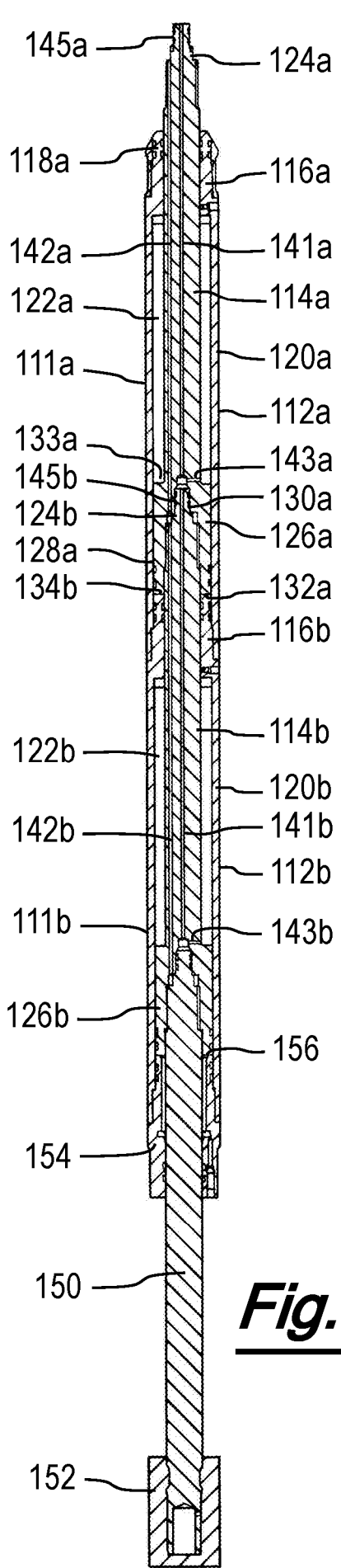


Fig. 2

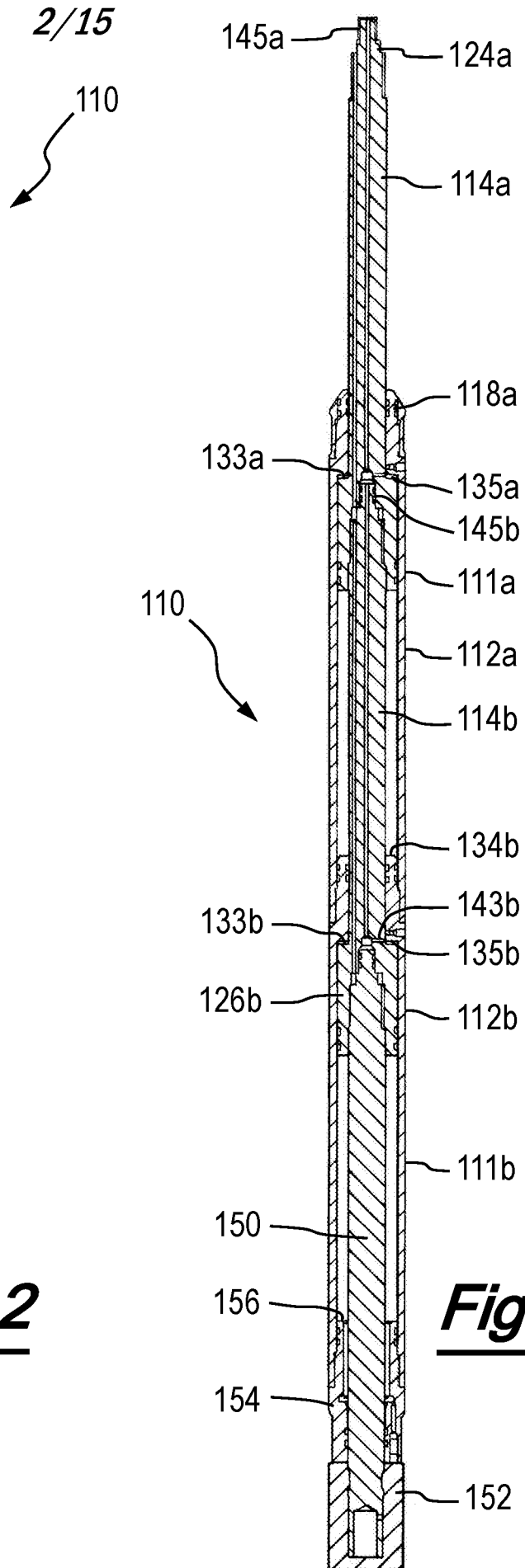


Fig. 3

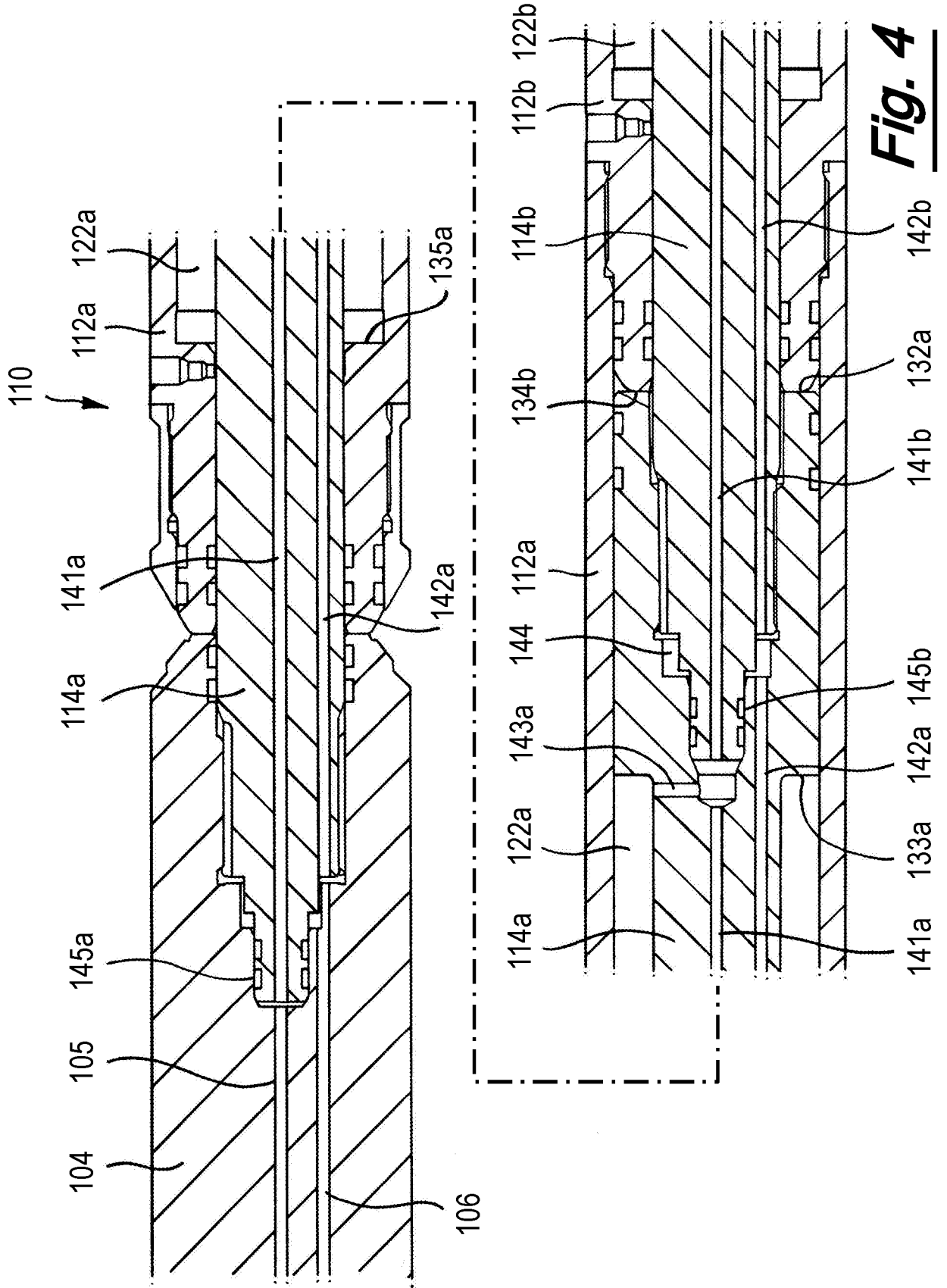


Fig. 4

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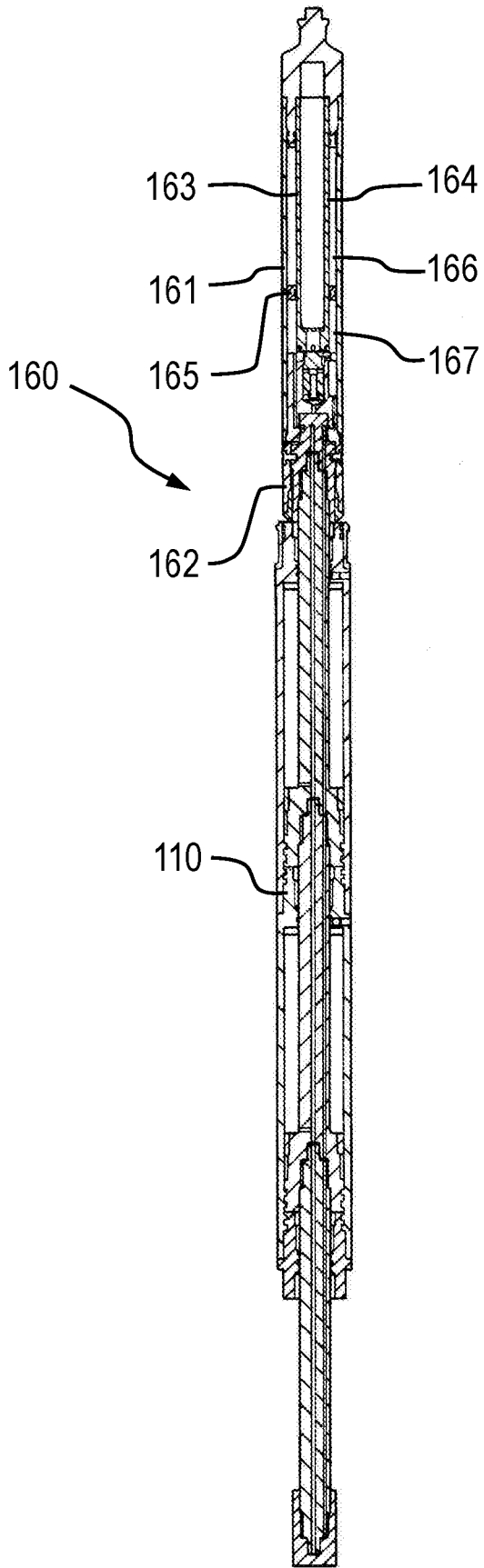


Fig. 5A

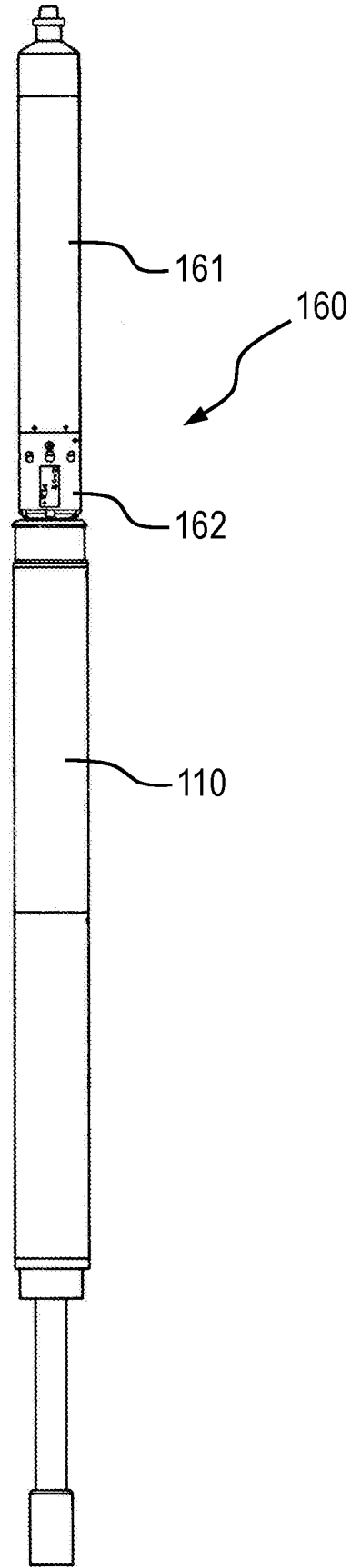
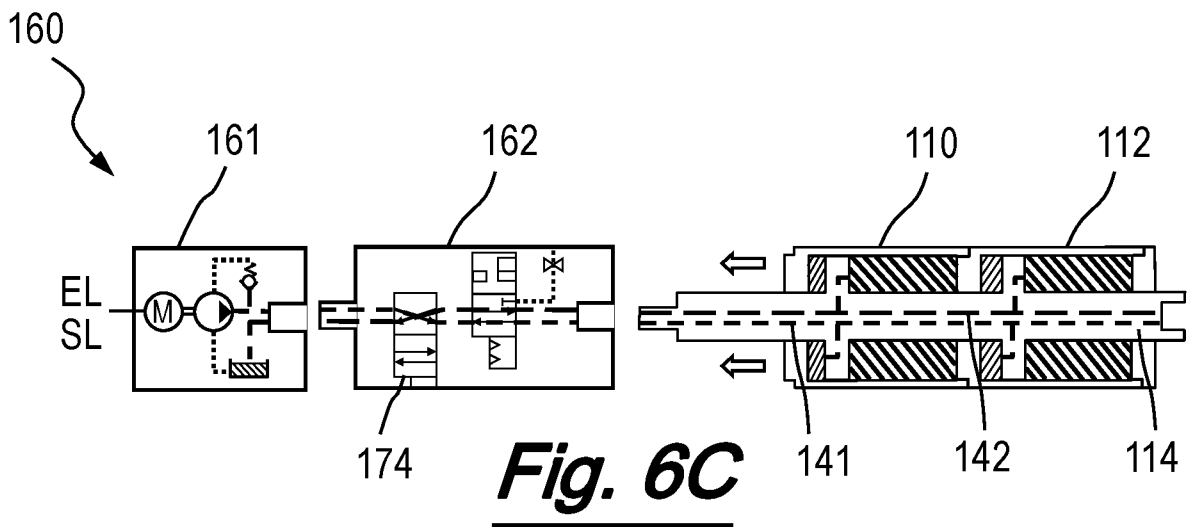
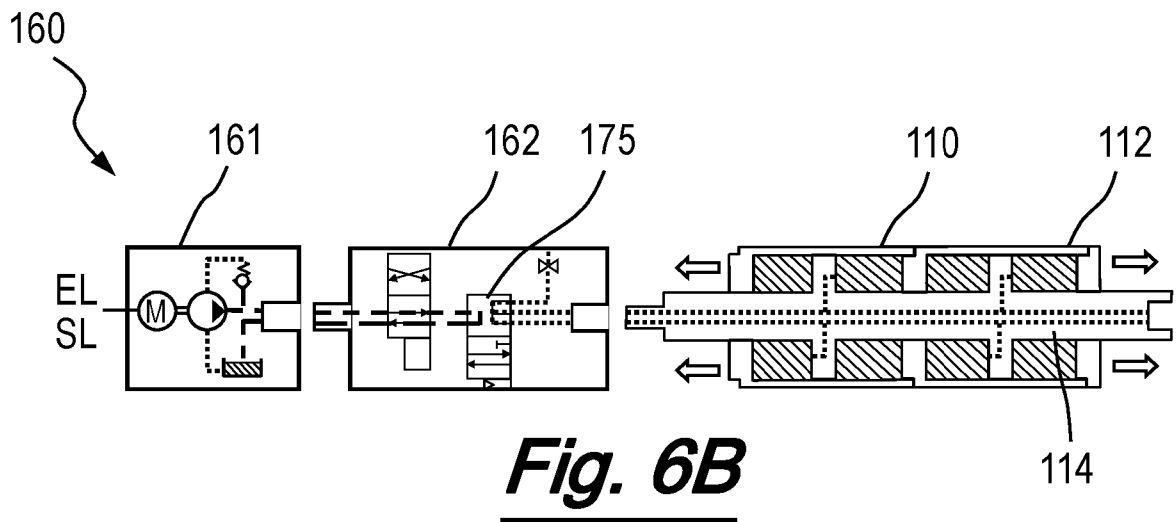
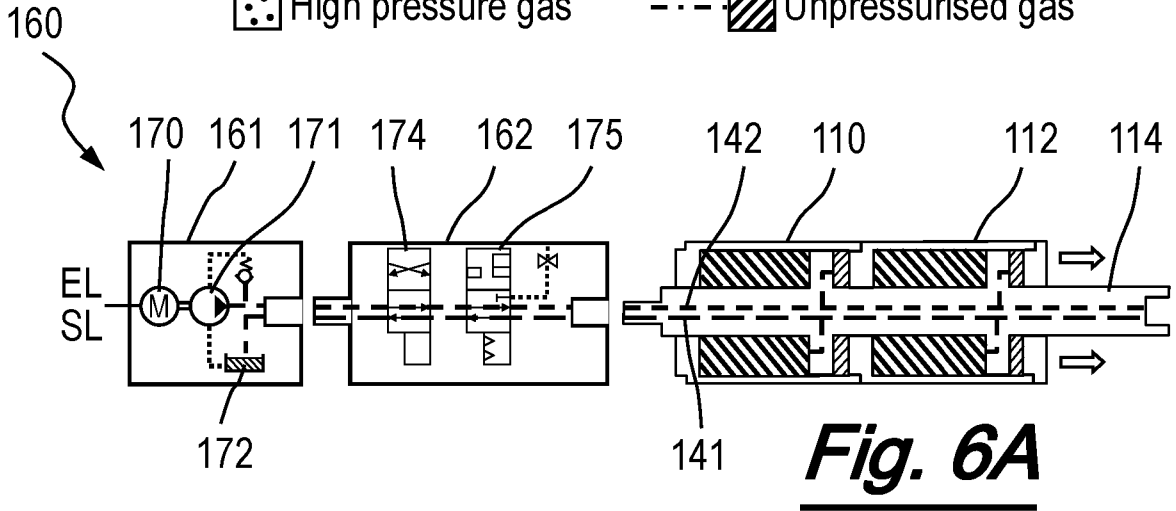
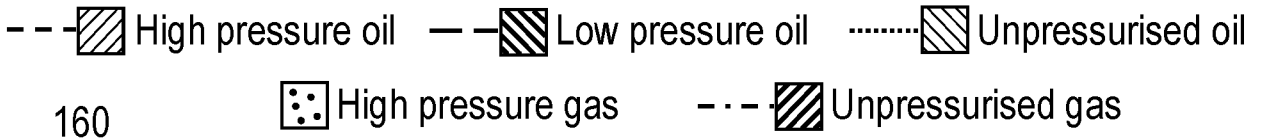


Fig. 5B

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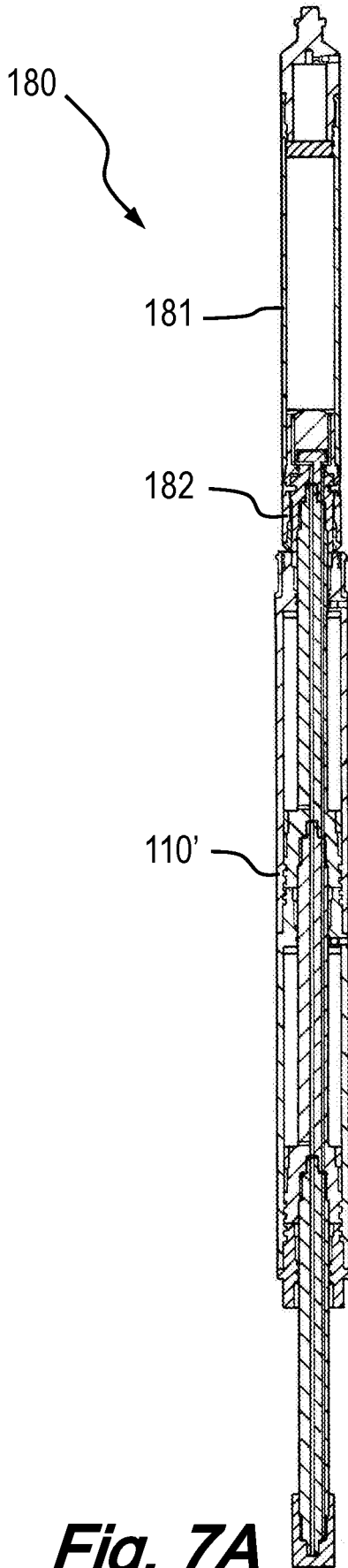


Fig. 7A

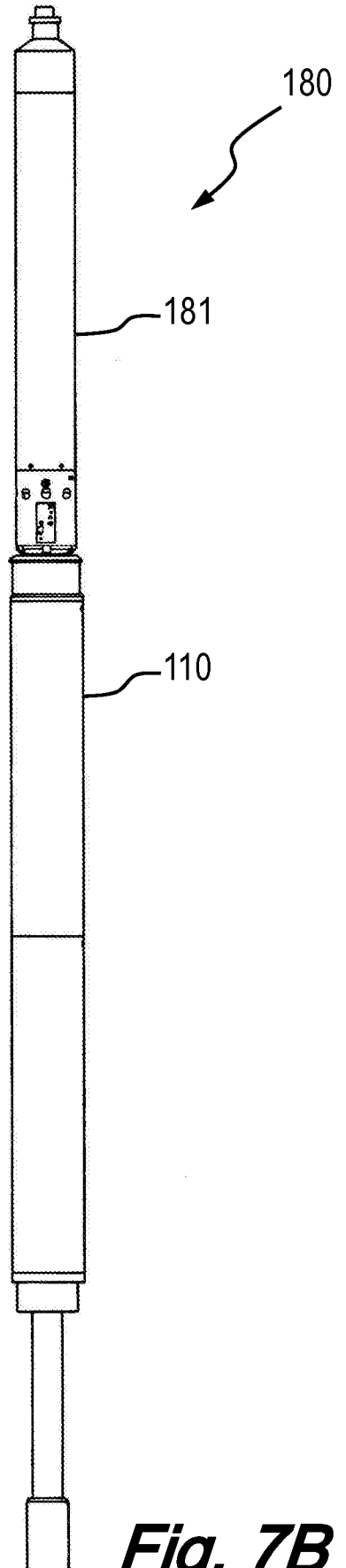
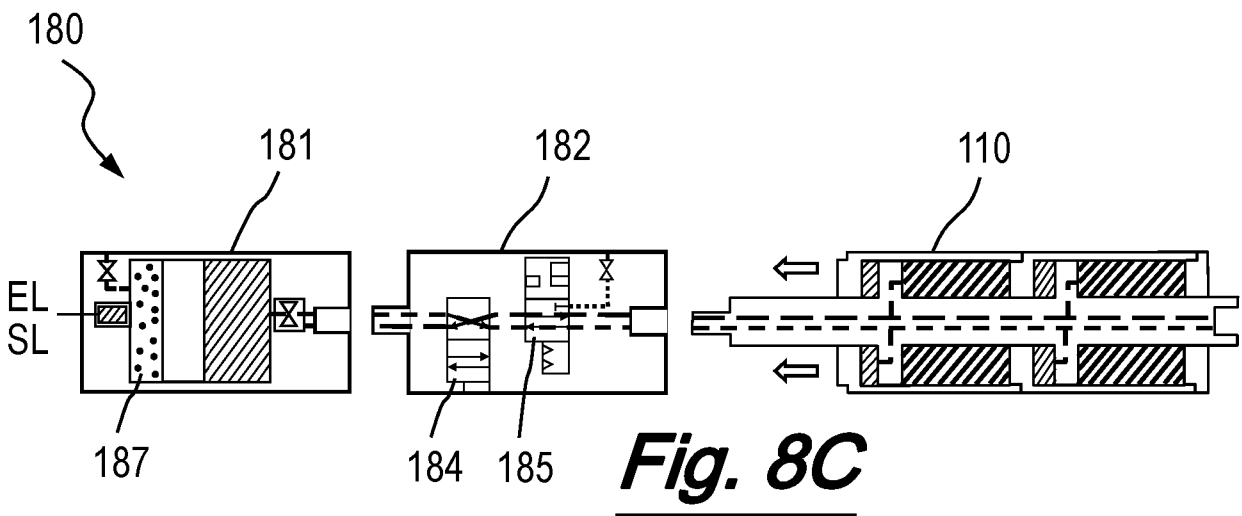
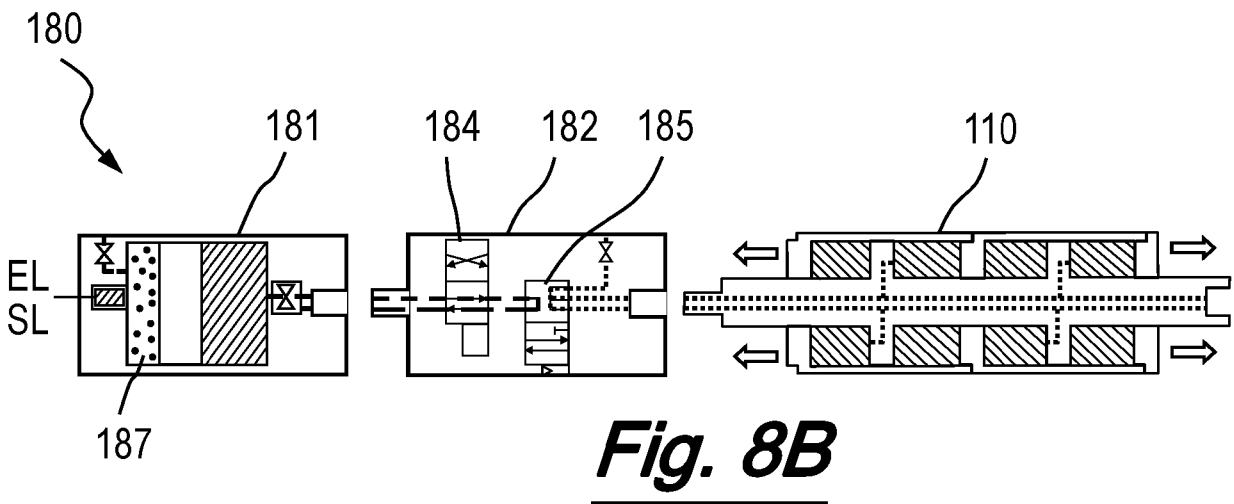
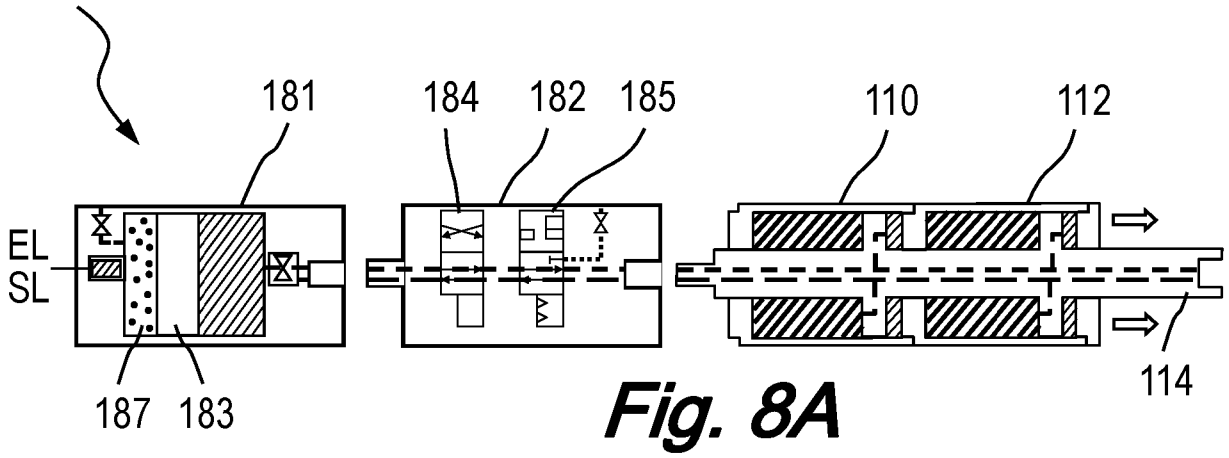
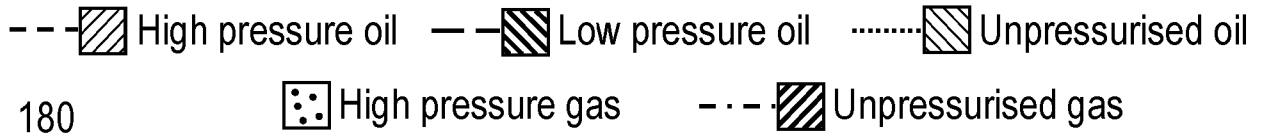


Fig. 7B



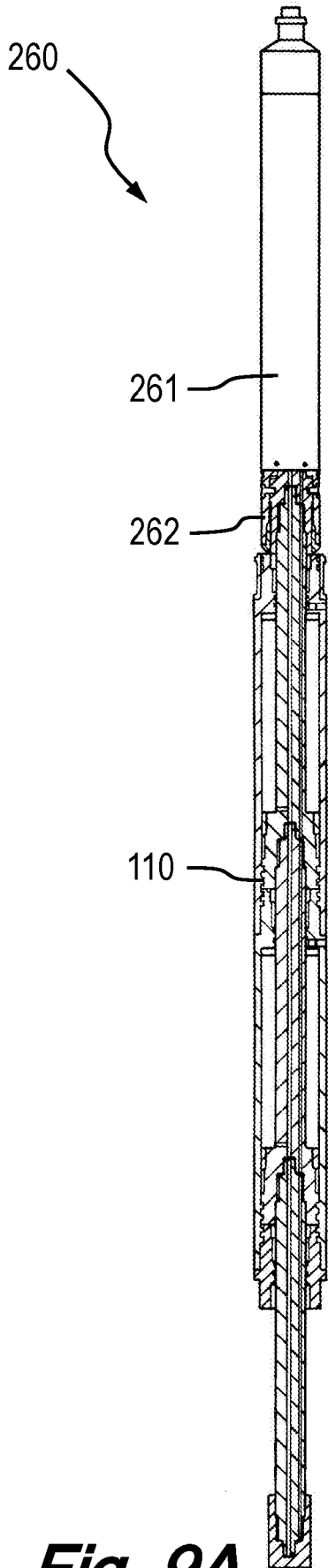


Fig. 9A

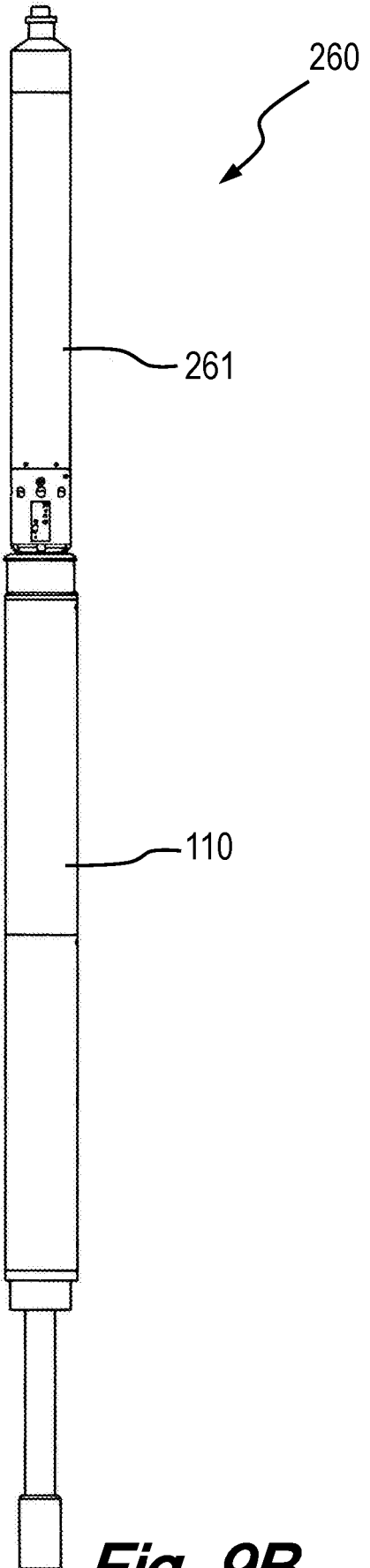


Fig. 9B

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-- ▨ High pressure oil - ▩ Low pressure oil ▨ Unpressurised oil

▣ High pressure gas - - - ▩ Unpressurised gas

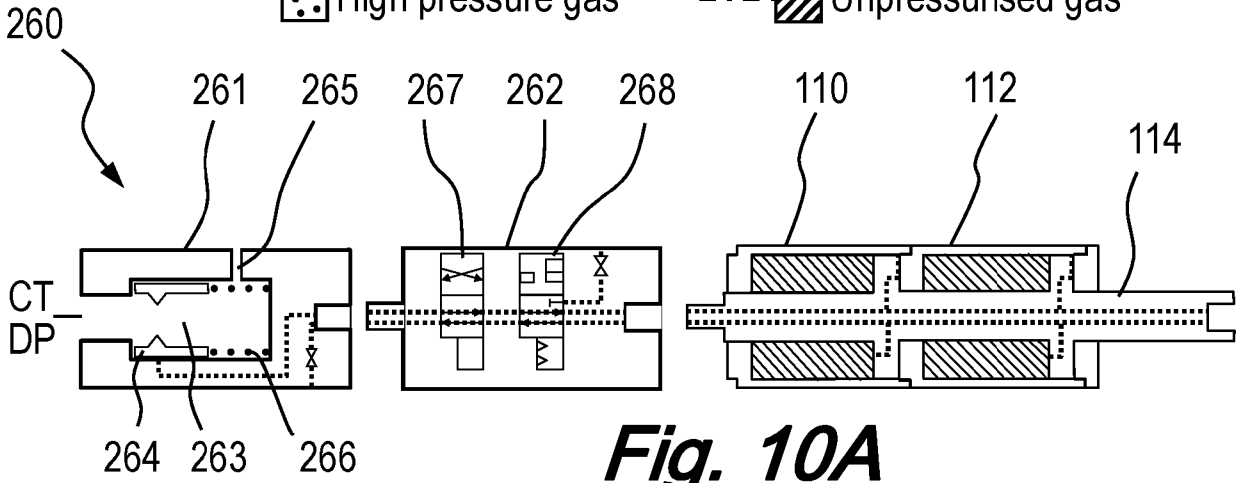


Fig. 10A

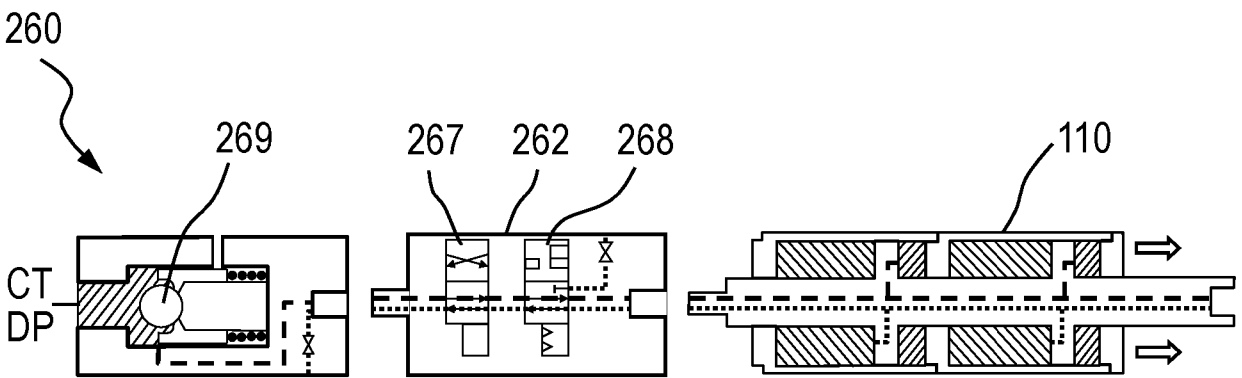


Fig. 10B

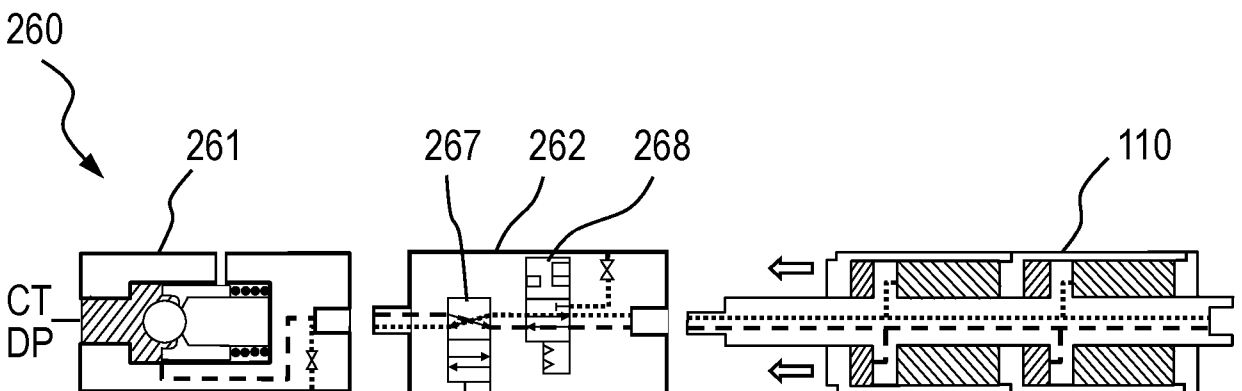


Fig. 10C

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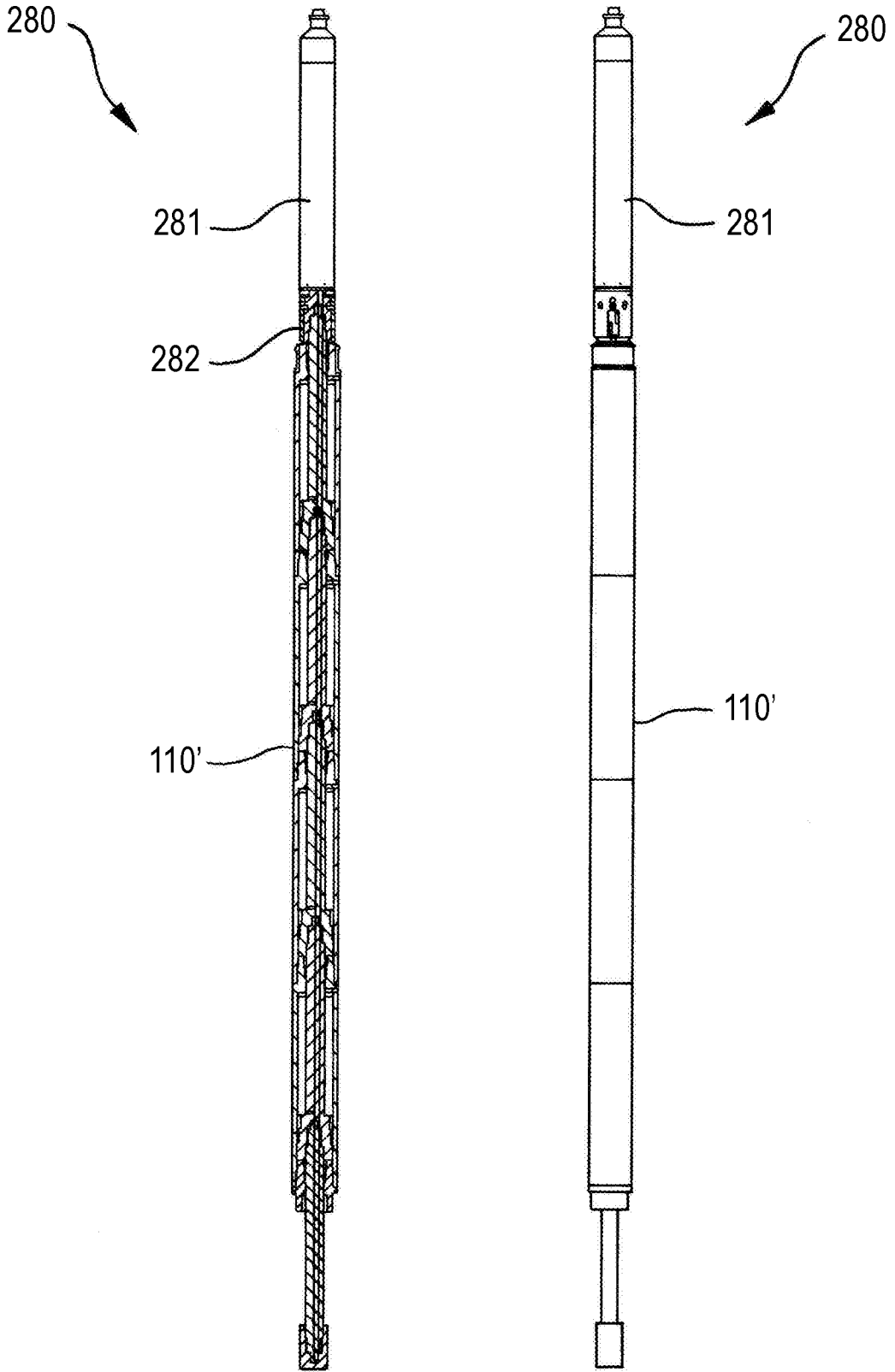


Fig. 11A

Fig. 11B

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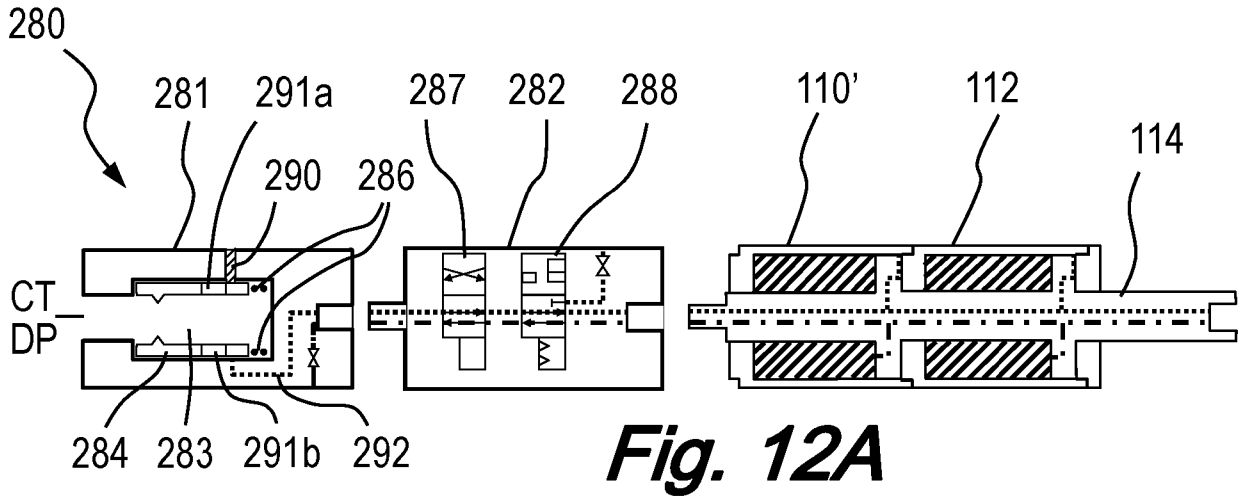


Fig. 12A

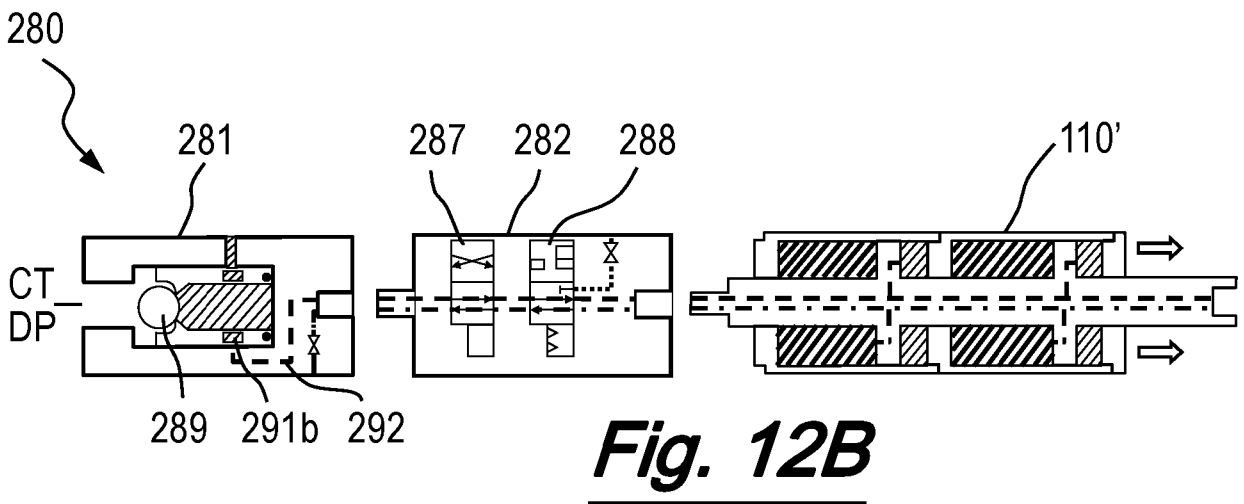


Fig. 12B

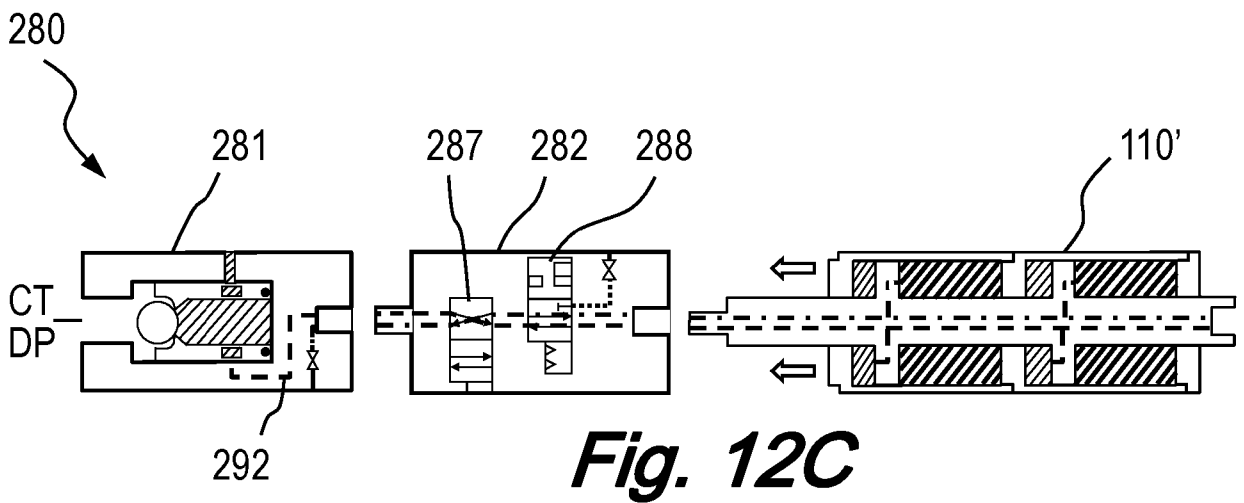
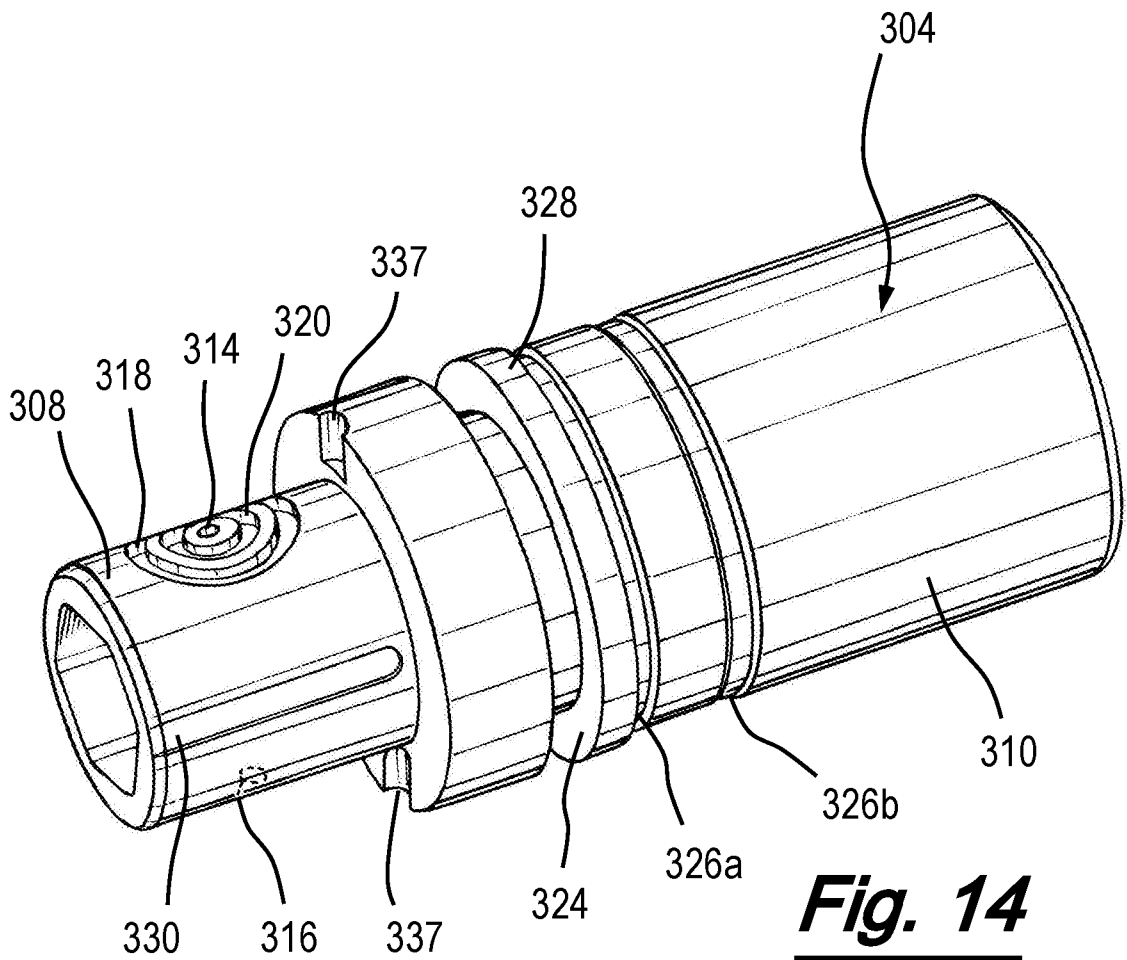
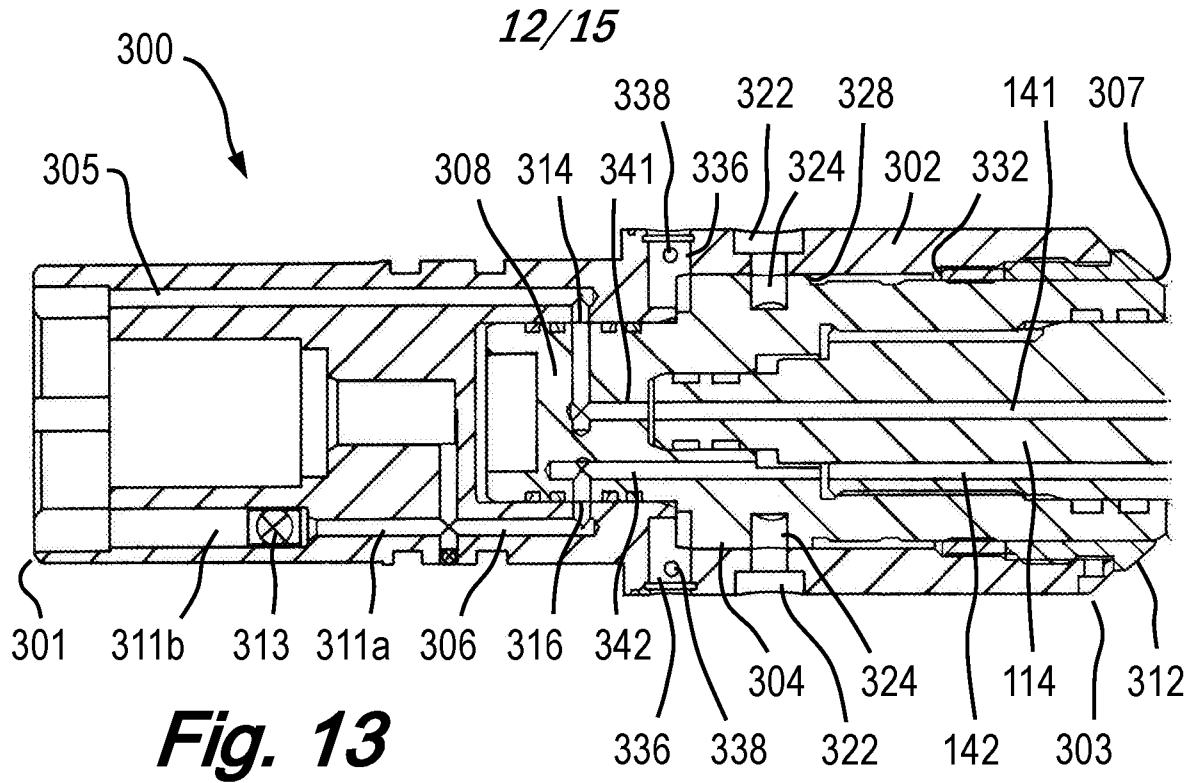
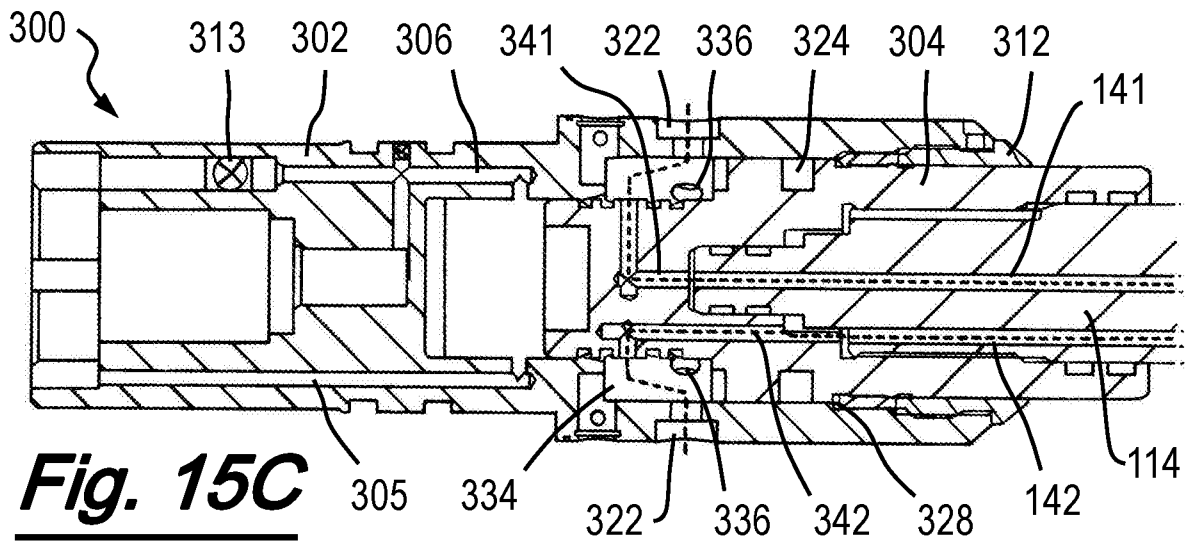
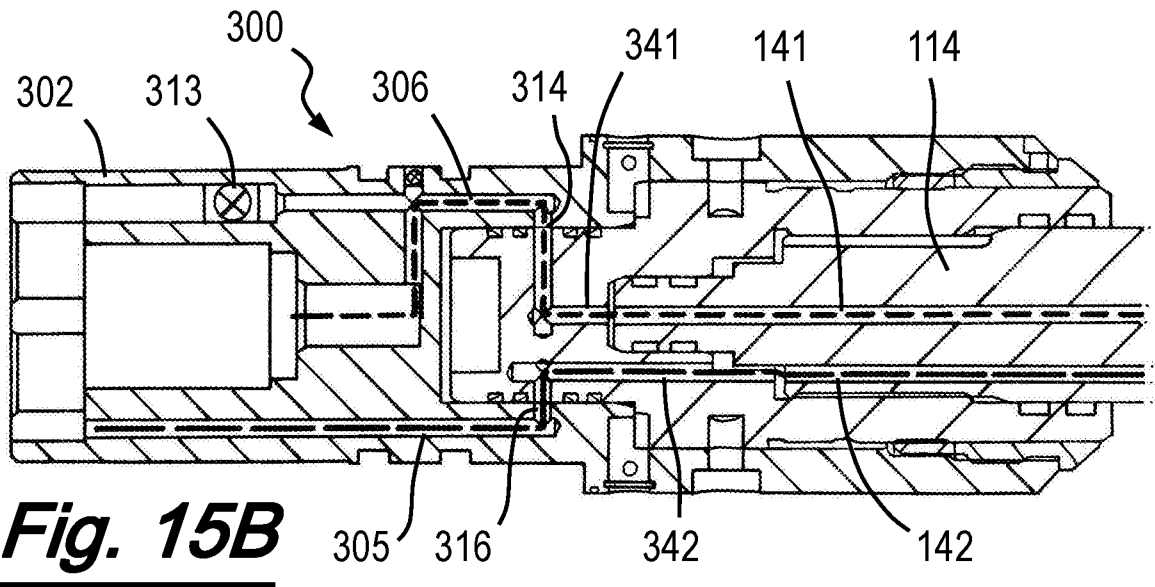
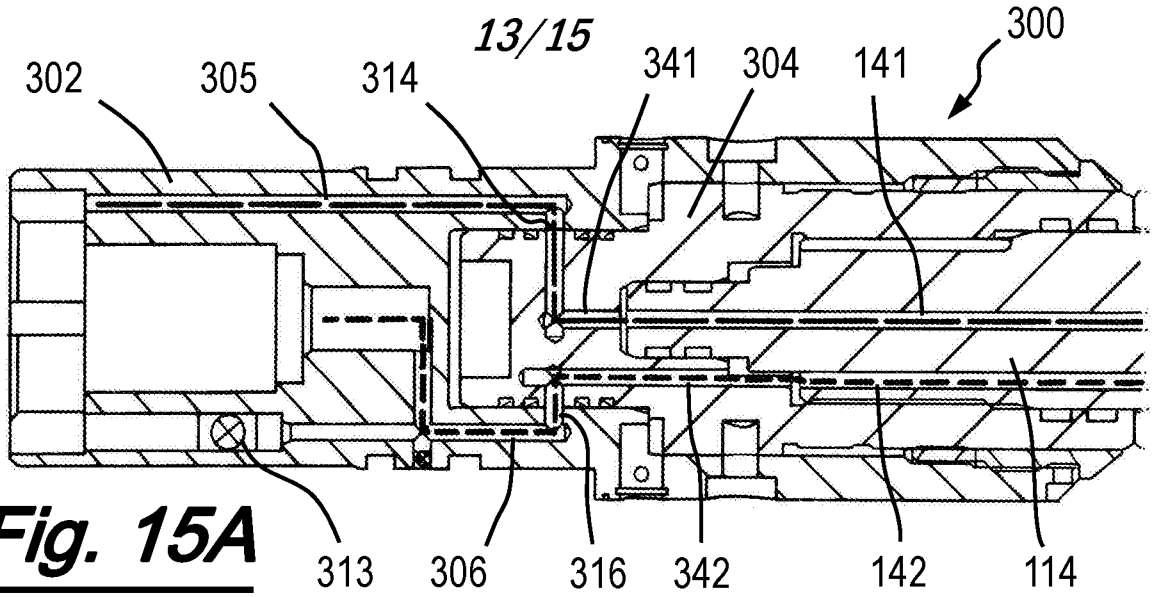


Fig. 12C





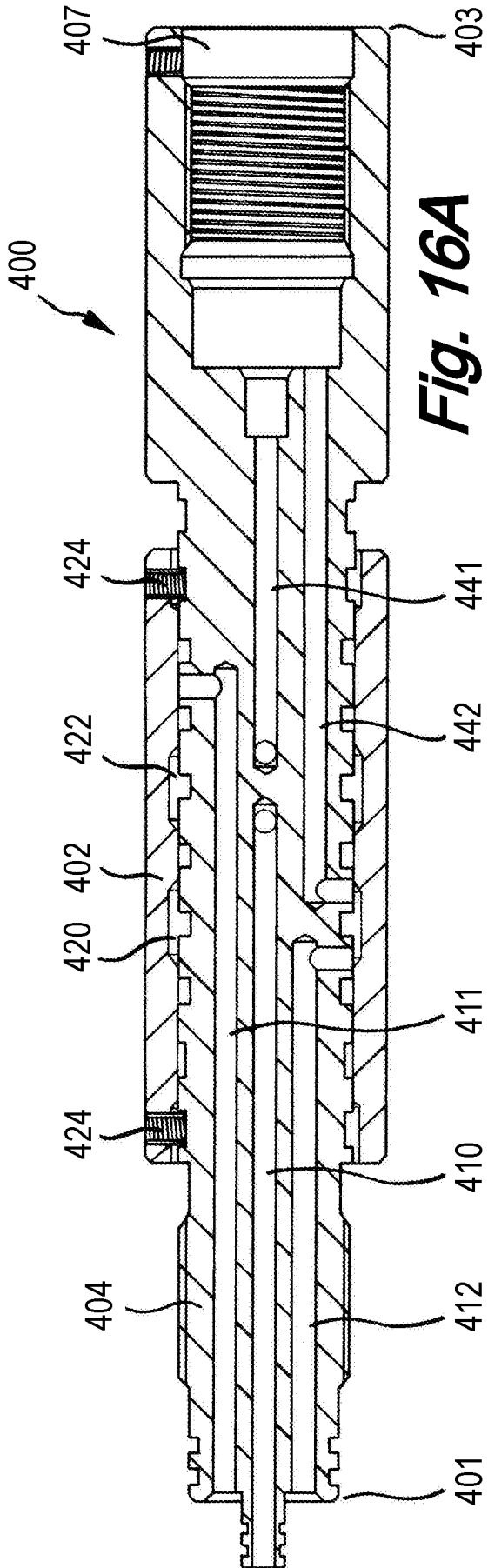


Fig. 16A

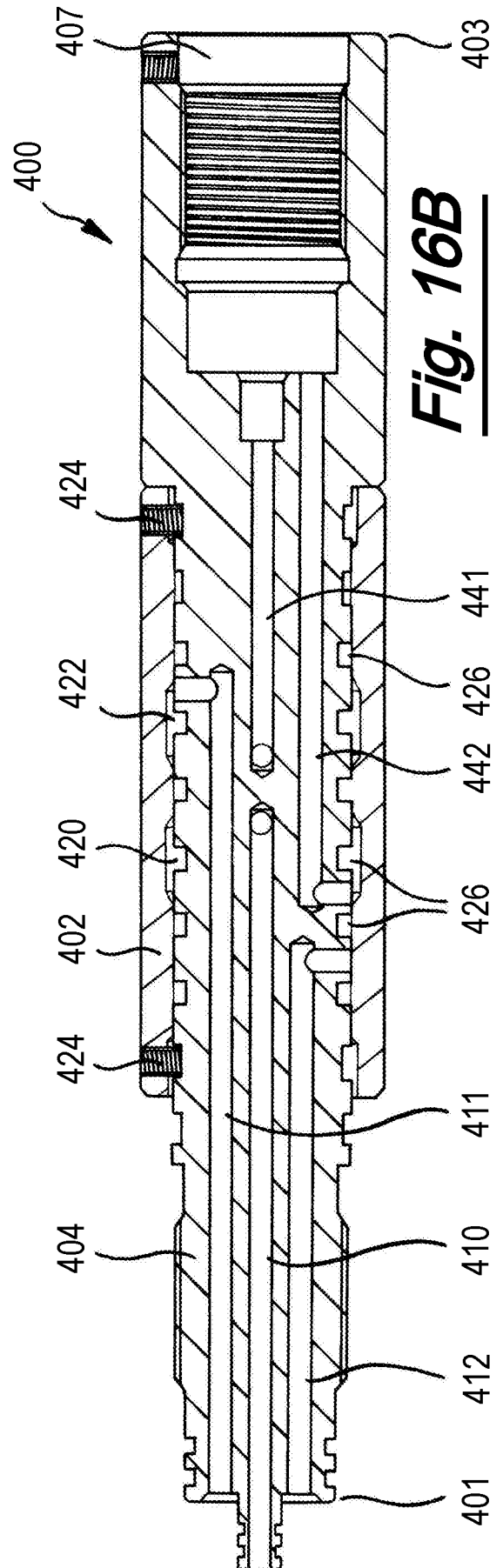


Fig. 16B

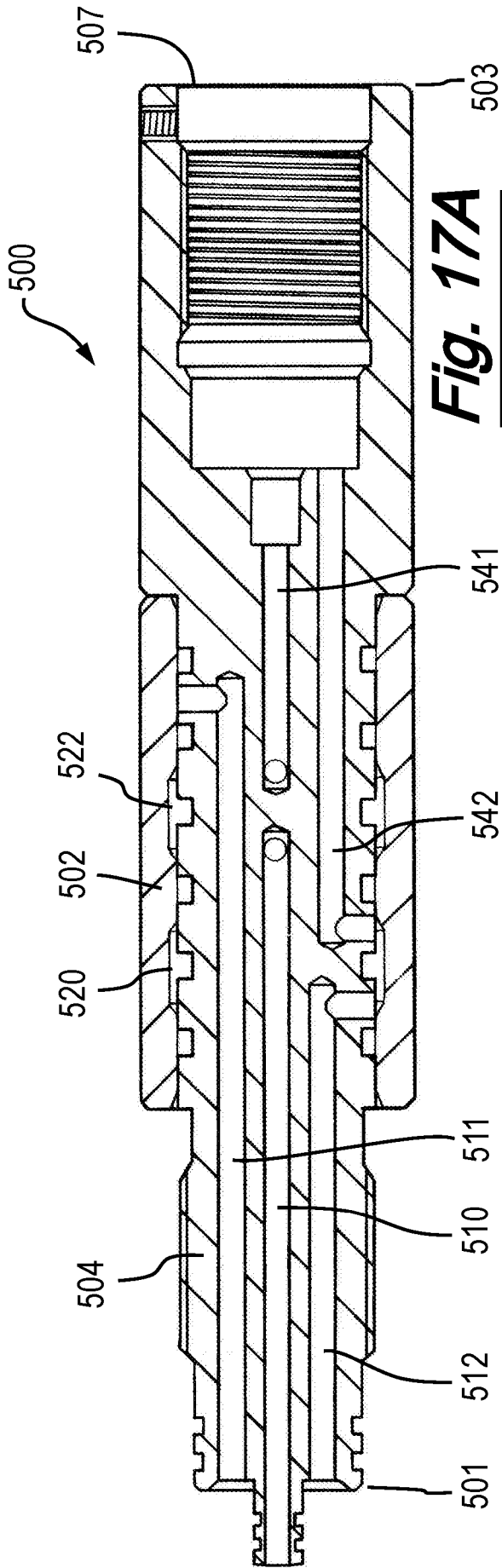


Fig. 17A

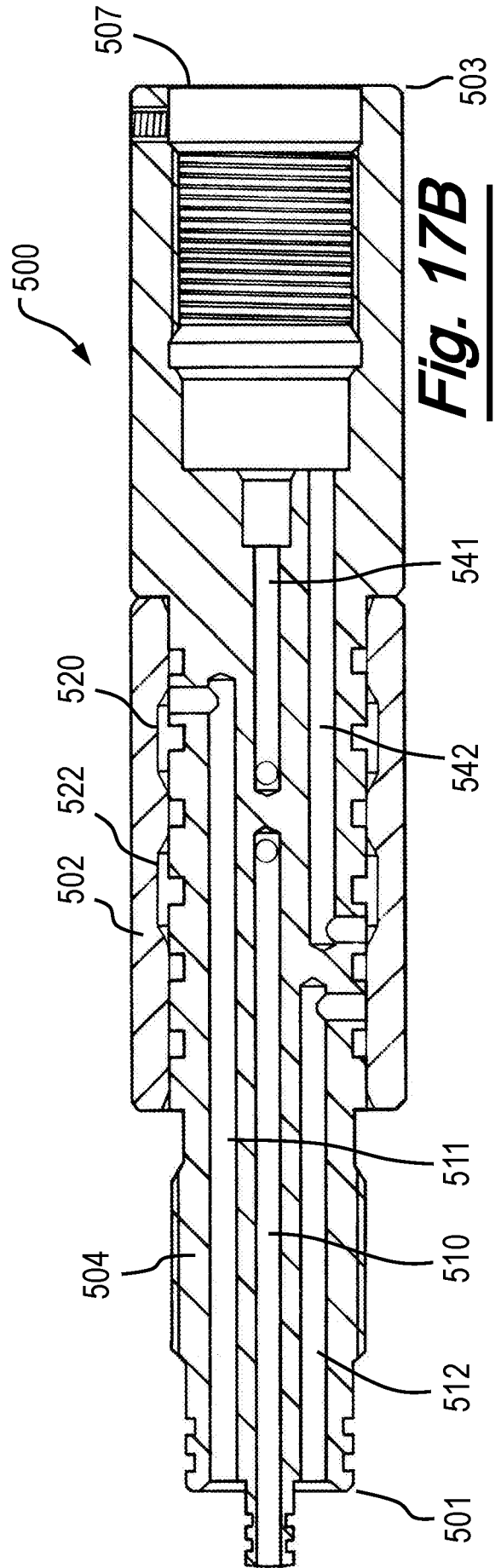


Fig. 17B

