

Ref: H13350WO

Title: Valve Actuator

Description of Invention

5 The present invention relates to a valve actuator, particularly, but not exclusively, for use in actuating a rotatable valve member mounted in a tubular used in oil or gas drilling and / or production.

The drilling of a borehole or well is typically carried out using a steel pipe known as a drill pipe or drill string with a drill bit on the lowermost end. The drill string comprises a series of tubular sections, which are connected end to end.

10 The entire drill string may be rotated using a rotary table, or using an over-ground drilling motor mounted on top of the drill pipe, typically known as a 'top-drive', or the drill bit may be rotated independently of the drill string using a fluid powered motor or motors mounted in the drill string just above the drill bit. As drilling progresses, a flow of mud is used to carry the debris created by the
15 drilling process out of the borehole. Mud is pumped down the drill string to pass through the drill bit, and returns to the surface via the annular space between the outer diameter of the drill string and the borehole (generally referred to as the annulus). The mud flow also serves to cool the drill bit, and to pressurise the borehole, thus substantially preventing inflow of fluids from
20 formations penetrated by the drill string from entering into the borehole. Mud is a very broad drilling term and in this context it is used to describe any fluid or fluid mixture used during drilling and covers a broad spectrum from air, nitrogen, misted fluids in air or nitrogen, foamed fluids with air or nitrogen, aerated or nitrified fluids to heavily weighted mixtures of oil and or water with
25 solid particles.

Significant pressure is required to drive the mud along this flow path, and to achieve this, the mud is typically pumped into the drill string using one or more

positive displacement pumps which are connected to the top of the drill string via a pipe and manifold.

Whilst the main mud flow into the well bore is achieved by pumping mud into a main, axial, passage at the very top end of the drill string, it is also known to
5 provide the drill string with a side passage which extends into the main passage from a port provided in the side of the drill string, so that mud can be pumped into the main passage at an alternative location to the top of the drill string.

For example, as drilling progresses, and the bore hole becomes deeper and
10 deeper, it is necessary to increase the length of the drill string, and this is typically achieved by disengaging the top drive from the top of the drill string, adding a new section of tubing to the drill string, engaging the top drive with the free end of the new tubing section, and then recommencing drilling. It will, therefore, be appreciated that pumping of mud down the drill string ceases
15 during this process.

Stopping mud flow in the middle of the drilling process is problematic for a number of reasons, and it has been proposed to facilitate continuous pumping of mud through the drill string by the provision of a side passage, typically in each section of drill string. This means that mud can be pumped into the drill
20 string via the side passage whilst the top of the drill string is closed, the top drive disconnected and the new section of drill string being connected.

In one such system, disclosed in US2158356, at the top of each section of drill string, there is provided a side passage which is closed using a plug, and a valve member which is pivotable between a first position in which the side
25 passage is closed whilst the main passage of the drill string is open, and a second position in which the side passage is open whilst the main passage is closed. During drilling, the valve is retained in the first position, but when it is time to increase the length of the drill string, the plug is removed from the side

passage, and a hose, which extends from the pump, connected to the side passage, and a valve in the hose opened so that pumping of mud into the drill string via the side passage commences. A valve in the main hose from the pump to the top of the drill string is then closed, and the pressure of the mud at
5 the side passage causes the valve member to move from the first position to the second position, and hence to close the main passage of the drill string.

The main hose is then disconnected, the new section of tubing mounted on the drill string, and the main hose connected to the top of the new section. The valve in the main hose is opened so that pumping of mud into the top of the
10 drill string is recommenced, and the valve in the hose to the side passage closed. The resulting pressure of mud entering the top of the drill string causes the valve member to return to its first position, which allows the hose to be removed from the side passage, without substantial leakage of mud from the drill string.

15 The side passage may then be sealed permanently, for example by welding or screwing a plug into the side passage, before this section of drill string is lowered into the well.

This process is commonly referred to as continuous circulation drilling.

In other similar systems, instead of providing a single valve member which is
20 operable to close either the side passage or the main passage of the drill string, it is known to provide two separate valve members – a main valve member which is operable to close the main passage, and an auxiliary valve member which is operable to close the side passage. In this case, the separate valve members may each have its own actuation mechanism, for
25 example as disclosed in WO2010/046653.

A further alternative arrangement in which the actuator for the main valve member is combined with the auxiliary valve member is disclosed in WO2012/085597. This arrangement is illustrated in Figures 1a and 1b.

In this arrangement, the main valve member 16 comprises a ball which is mounted in the main passage 12 of the drill string 10, and which is rotatable about an axis generally perpendicular to the longitudinal axis of the drill string, between an open position in which flow of fluid along the main passage 12 is permitted, and a closed position in which it prevents flow of fluid along the main passage 12. Rotation of the ball 16 between the open position and the closed position is achieved using a tubular actuator 18, which is also mounted within the main passage 12 of the drill string 10, coaxially with the drill string 10. The actuator 18 is connected to the ball 16 such that sliding movement of the 18 in the drill string 10 causes the ball 16 to move between the closed position and the open position. The actuator 18 also acts to block or unblock the side passage 14 as it slides along the drill string, and is configured to open the side passage 14 when the main valve 16 is in the closed position, and to close the side passage 14 when the main valve 16 is in the open position.

The actuator 18 is hydraulically actuated by means of an actuation chamber 38 which is provided between the actuator 18 and a lining 10a provided in the wall of the drill string 10. This is best illustrated in Figure 1c, and simply comprises an annular space between the two parts 18, 10a. Two ports 40a, 40b are provided through the drill string 10 into this chamber 38, one at each end of the chamber 38. The first port 40a is closest to a second end 18b of the actuator 18 (nearest the main valve member 16).

The chamber 38 is divided into two by a seal 41 which is mounted on the exterior surface of the actuator 18. In one embodiment, the seal 41 comprises 2 O-rings. The seal 41 substantially prevents flow of fluid between the two parts of the chamber 38 whilst permitting the actuator 18 to slide inside the drill string 10. The seal 41 ensures that flow of pressurised fluid into this chamber 38 via the first port 40a causes the actuator 18 to move towards the main valve member 16, whilst flow of pressurised fluid into the actuation chamber 38 via the second port 40b acts in the opposite direction to counterbalance the effect of pressurised fluid at the first port 40a. The actuator 18 therefore acts

as a double acting piston with one pressure port 40a to move the actuator 18 towards the main valve member 16 and one pressure port to move the actuator 18 away from the main valve member 16. In other words the actuator 18 is operated by means of a pressure differential across the first and second
5 ports 40a, 40b.

Figure 1a illustrates the actuator 18 when supply of pressurised fluid to the port 40b has pushed it away from the main valve member 16, so that the actuator 18 closes the side port 14, whilst Figure 1b illustrates the sleeve 18 when supply of pressurised fluid to the port 40a has pushed it towards the
10 main valve member 16, thus opening the side port 14.

The mechanism whereby the actuator sleeve 18 is connected to the ball 16 so that sliding movement of the actuator sleeve 18 causes the ball 16 to rotate is described fully in WO2012/085597. Various similar arrangements are also known from GB 2 413 373, US 3,236,255, GB 1 416 085, US 3,703,193 and
15 US 3,871,447.

These arrangements may also be used to control flow of fluid through a side passage in what is known as a “pump in sub”, which is used in the event of an emergency, for example to facilitate the provision of additional mud pressure required to control a sudden surge in well-bore pressure due to fluid inflow
20 from a formation penetrated by the well entering the well in what is known as a “kick”.

This invention relates to an alternative configuration of actuator assembly suitable for use in such a valve arrangement, where operation of the valve is achieved by the sliding of an actuator sleeve relative to the drill string.

25 According to a first aspect of the invention we provide a fluid pressure operated actuator assembly comprising a tubular body having a wall, with an interior surface and an exterior surface and enclosing a main passage which extends generally parallel to a longitudinal axis of the tubular body, an actuator

located in and movable along the main passage, a first direction chamber formed between the wall of the tubular body and the actuator, and at least one second direction chamber formed between the tubular body and the actuator, wherein the assembly is configured such that when a first pressure of fluid in
5 one of the first direction chamber and the at least one second direction chamber exceeds a second pressure of fluid in the other of the first direction chamber and the at least one second direction chamber by a predetermined amount, the first pressure of fluid exerts a force on the actuator which acts to push the actuator in a first direction relative to the tubular body, when the first
10 pressure is a pressure of fluid in the first direction chamber, and in a second direction relative to the tubular body, when the first pressure is a pressure of fluid in the at least one second direction chamber, and when the first pressure of fluid falls below the predetermined amount in excess of the second pressure of fluid, the second pressure of fluid exerts a force on the actuator which acts
15 to push the actuator in the second direction relative to the tubular body, when the first pressure is the pressure of fluid in the first direction chamber, and in the first direction relative to the tubular body, when the first pressure is the pressure of fluid in the at least one second direction chamber, characterised in that the exterior surface of the tubular body is provided with a first port which
20 communicates with a passage extending through the wall of the tubular body from the first port to the first direction chamber, a second port which communicates with a passage extending through the wall of the tubular body from the second port to

- the or one of the second direction chamber(s), and a third port which communicates with a passage extending through the wall of the tubular body from the third port to the or another one of the second direction chamber(s), the first port lying on a first plane, the second port lying on a second plane and
- 5 the third port lying on a third plane, the first plane, second plane and third plane being generally parallel to one another and the first plane lying between the second plane and the third plane.

In one embodiment, the longitudinal axis of the tubular body extends generally normal to the first plane, second plane and third plane.

- 10 In one embodiment, one or both of the first and second directions is/are generally parallel to the longitudinal axis of the tubular body.

In one embodiment, the first direction is generally opposite to the second direction.

In one embodiment, the actuator is connected to a main valve member in such a way that movement of the actuator in the first direction and second direction causes the valve member to move. In this embodiment, the main valve member may be movable between a closed position in which the main valve member closes the main passage of the tubular body and an open position in which the main passage of the tubular body is open. The movement of the main valve member caused by the movement of the actuator in the first direction and second direction may comprise rotation.

In one embodiment, the main valve member moves to the closed position when the actuator moves in the first direction and to the open position when the actuator moves in the second direction.

The main valve member may comprise a ball valve member.

The actuator may be connected to valve member by means of a track and pin arrangement whereby a pin extends from one of the valve member or actuator into a slot or groove provided in the other of the valve member or actuator, the pin moving along the slot or groove as the actuator slides in the tubular body and the valve member rotates.

In one embodiment, the tubular body is provided with a side passage which extends through the wall of the tubular body from the exterior of the tubular body into the main passage, and the actuator is movable between a closed position in which the actuator substantially prevents flow of fluid along the side passage, and an open position in which flow of fluid along the side passage is permitted. In this case, movement of the actuator in the first direction may bring the actuator into the open position, and movement of the actuator in the second direction may bring the actuator into the closed position. Where a main valve member is also provided as described above, movement of the

actuator in the first direction may bring the actuator into the open position and the main valve member into the closed position, whilst movement of the actuator in the second direction brings the actuator into the closed position, and the main valve member into the open position.

- 5 The passage from the third port may connect to the passage from the second port into the or one of the second direction chamber(s).

The first direction chamber and the or each second direction chamber may be formed in a space between an exterior surface of the actuator and an interior surface of the wall of the tubular body. This space may extend around the
 10 entire perimeter of the actuator. This space may be divided into the first direction chamber and second direction chamber by means of a seal which substantially prevents flow of fluid between the chambers whilst allowing the actuator to move along the main passage of the tubular body. This space may be divided into the first direction chamber and two second direction chambers
 15 by means of a seal arrangement which substantially prevents flow of fluid between the chambers whilst allowing the actuator to move along the main passage of the tubular body. The first direction chamber may be located between the two second direction chambers. In this case, the passages from the first port, second port and third port into their respective chambers may
 20 extend through the tubular body generally perpendicular to its longitudinal axis. Alternatively, at least one of the passages from the first port, second port and third port into their respective chambers may extend through the tubular body generally at an angle of less than 90° to its longitudinal axis.

In one embodiment, the actuator assembly is configured such that if the
 25 pressure in the first direction chamber equals the pressure in the or both second direction chamber(s), there is no net force acting on the actuator, if the pressure in the first direction exceeds the pressure in the or both the second direction chamber(s), there is a net force acting on the actuator pushing the actuator in the first direction, and if the pressure in the first direction chamber

is less than the pressure in the or either one of the second direction chamber(s), there is a net force acting on the actuator pushing the actuator the second direction.

5 In one embodiment, the actuator assembly is configured such that when the pressure in the first direction chamber equals the pressure in the or both second direction chamber(s), there is a net force acting on the actuator.

In this case, the actuator assembly may be configured such that this net force tends to push the actuator in the second direction.

10 Embodiments of the invention will now be described, by way of example only, with reference to the following figures of which;

FIGURES 2a and 2b show a longitudinal cross-section through a portion of one embodiment of actuator assembly according to the invention, the actuator having been moved in the second direction in Figure 2a and in the first direction in Figure 2b,

15 FIGURES 3a and 3b show a longitudinal cross-section through a portion of an alternative embodiment of actuator assembly according to the invention, the actuator having been moved in the second direction in Figure 3a and in the first direction in Figure 3b, AND

20 FIGURES 4a and 4b show a longitudinal cross-section through a portion of an alternative embodiment of actuator assembly according to the invention, the actuator having been moved in the second direction in Figure 4a and in the first direction in Figure 4b.

Referring now to Figures 2a and 2b, there is shown a fluid pressure operated actuator assembly comprising a tubular body 110 having a wall enclosing a
25 main passage 112 which extends generally parallel to a longitudinal axis of the tubular body 110, an actuator 118 located in and movable along the main passage 112, a first direction chamber 138a and a second direction chamber

138b formed between the wall of the tubular body 110 and the actuator 118. The tubular body 110 may be part of a drill string or may comprise a sub for mounting in a drill string.

5 In this embodiment, both the tubular body 110 and actuator 118 are tubular with a generally circular cross-section. The first direction chamber 138a and the second direction chamber 138b are formed in an annular space around the actuator 118 between an exterior surface of the actuator 118 and an interior surface of the tubular body 110. This space is divided into the first direction chamber 138a and second direction chamber 138b by means of a seal 141
10 which substantially prevents flow of fluid between the chambers 138a 138b. Two further seals 118a, 130a are provided between the exterior surface of the actuator 118 and the interior surface of the tubular body 110, one at each end of the annular space.

15 In this embodiment, the seals 118a, 130a, and 141 each comprise a pair of generally circular O-rings which are located in circumferential grooves around the exterior surface of the actuator 118. It should be appreciated, however, that the invention is not restricted to the use of this particular type of seal, and any other type of seal which substantially prevents flow of fluid between the actuator 118 and the tubular body 110 whilst allowing the actuator 118 to slide
20 in the tubular body 110, could be used instead. The seals could equally be mounted on the tubular body 110 rather than on the actuator 118.

The tubular body 110 is provided with a first port 140a which communicates with a first control passage 139a extending through the wall of the tubular body 110 from the first port 140a to the first direction chamber 138a, a second port
25 140b which communicates with a second control passage 139b extending through the wall of the tubular body 110 from the second port 140b to the second direction chamber 138b and a third port 140c which communicates with a third control passage 139c extending through the wall of the tubular body 110 from the third port 140c to the second control passage 139b. In this

example, the first and second control passages 139a, 139b extend through the wall of the tubular body generally perpendicular to its longitudinal axis. The third passage 139c is inclined at angle of less than 45° to the longitudinal axis of the tubular body. In this example, the first and second control passages 139a, 139b are co-planar and so both can be seen in the cross-sections illustrated in Figures 2a and 2b. The third control passage 139c necessarily extends along a different plane and so is shown in dashed lines in these Figures.

The first, second and third ports 140a, 140b, 140c are spaced along the longitudinal axis of the tubular body 110 so that if the first port 140a is considered to lie on a first imaginary plane, the second port 140b on a second imaginary plane and the third port 140c on a third imaginary plane, the first plane, second plane and third plane being generally parallel to one another and generally normal to the longitudinal axis of the tubular body 110, the first plane lies between the second plane and the third plane.

The actuator assembly is configured such that when the pressure of fluid in the first direction chamber 138a exceeds the pressure of fluid in the second direction chamber 138b, the pressure of fluid in the first direction chamber 138a exerts a force on the actuator 118 which acts to push the actuator 118 in a first direction along the main passage 112 in the tubular body 110, and when the pressure of fluid in the second direction chamber 138b exceeds the pressure of fluid in the first direction chamber 138a, the pressure of fluid in the second direction chamber 138b exerts a force on the actuator 118 which acts to push the actuator 118 in a second, opposite, direction along the main passage 112 in the tubular body 110.

In this example, this is achieved by providing the interior of the tubular body 110 with a portion of increased internal diameter 110a. At either end of this portion 110a, the interior surface of the tubular body 110 forms a shoulder 110b, 110c where the internal diameter of the tubular body 110 decreases

slightly. The actuator 118 is substantially longer than the portion of increased internal diameter 110a and the outer diameter of the actuator 118 is less than the internal diameter of the tubular body 110 either side of the portion of increased internal diameter 110a. The first direction and second direction chambers 138a, 138b are formed between the actuator 118 and the portion of increased internal diameter 110a, and the seal 141 extends outwardly of the exterior surface of the actuator 118 to engage with the interior surface of increased internal diameter portion 110a of the tubular body 110. The first direction chamber 138a is thus formed between the exterior surface of the actuator 118, the first shoulder 110b, part of the increased internal diameter portion of the tubular body 110, and the seal 141. Similarly, the second direction chamber 138b is formed between the exterior surface of the actuator 118, the second shoulder 110c, part of the increased internal diameter portion of the tubular body 110, and the seal 141.

When pressurised fluid is supplied to the first port 140a, the fluid pressure pushes the seal 141 away from the first shoulder 110b to increase the volume of the first direction chamber 138a. The actuator 118 is therefore pushed in the first direction. Similarly, when pressurised fluid is supplied to the second or third ports 140b, 140c, the fluid pressure in the second direction chamber 138b pushes the seal 141 away from the second shoulder 110c to increase the volume of the second direction chamber 138b. The actuator 118 is thus pushed in the second direction. The actuator 118 therefore acts as a double acting piston with a first port 140a to move the actuator 118 in a first direction along the main passage 112 in the tubular body 110 (in this example to the left in Figures 2a and 2b) and a second port 140b or a third port 140c to move the sleeve 18 in a second direction along the main passage 112 in the tubular body 110 (in this example to the right in Figures 2a and 2b).

It should be appreciated that this embodiment differs from the prior art actuator described in WO2012/085597, and GB 2 413 373, for examples, by virtue of the provision of the third port 140c. The third port 140c may be advantageous

as it may assist in preventing unwanted movement of the actuator 118 when the exterior of the tubular body 110 is exposed to a pressure differential. This is particularly important where the tubular body is portion of a drill string, or a sub mounted in a drill string, and the drill string is used in managed pressure drilling (MPD).

In a conventional drilling fluid system, only one drilling fluid gradient exists, and differential pressure between two points in the drill string can be described by the hydrostatic head and any frictional forces associated with a dynamic system. Managed pressure drilling (MPD) is a style of drilling in which the bottom hole pressure (BHP) is maintained through various methods including fluid level maintenance, effective fluid density manipulation, applied back pressure, and potentially combinations of these and other practices. The use of a rotating control device (RCD) is becoming increasingly common in offshore applications to meet the demands of MPD wells in deep water environments.

An RCD clamps around the drill string to main fluid pressure differential in the annulus around the drill string (typically there is higher pressure below the RCD), whilst allowing the drill string to rotate as required for drilling. The RCD is intended as a means of isolating one part of the wellbore from another during drilling operations, and can be inserted at any point in a riser string, depending on the application, for the purpose of dual gradient drilling (DGD) or applying back pressure to the riser annulus, or other purposes.

The RCD therefore creates an irregularity or discontinuity in the overall pressure profile of the well, which, in practical terms, may mean that as the drill string is inserted into the well, a point on the drill string may experience a sudden increase in pressure by 500 psi or more having travelled only 6 inches or less. This differential pressure may act from below a drill string element, i.e. the area of high pressure being lower than the area of low pressure.

Differential pressure may also act from above, however, for example if the riser and RCD is configured more toward well control.

The valve assembly described in WO2012/085597 is reliable in conventional single fluid gradient environments, as the distance between the first and second ports 40a, 40b is relatively short. This means that as the portion of the drill string containing these ports 40a, 40b is advanced into the well, any pressure differential across the ports as a result of the pressure gradient in the annulus is negligible, and is not sufficient to move the actuator 18. This may not be the case, however, if the drill string were to pass through a discontinuity in the pressure gradient such as one introduced by an RCD. Where an RCD is used, there may exist a point in the riser where, when the portion of the drill string including the ports 40a, 40b passes through, differential pressure may be seen from above or below, which exceeds the actuating pressure of the actuator 18. This may, therefore, result in unintended movement of the actuating sleeve 18. The provision of the third port 140c may prevent this as will be described below.

To achieve this, in use, the actuator 118 should be arranged such that its default or rest position is as illustrated in Figure 2b, and is adopted by virtue of the supply of pressurised fluid to the second and/or third ports 140b, 140c. As the tubular body 110 passes through a pressure discontinuity such as one introduced by an RCD, if the portion of the tubular body 110 shown on the left hand side of Figures 2a and 2b encounters the high pressure first, the second port 140b is exposed to high pressure (the high pressure also being communicated to the third port 140c), whilst the first port 140a is at low pressure. The high pressure at the second and third ports 140b, 140c will act to maintain the actuator 118 in its rest / default position. As the passage of the tubular body 110 through the pressure discontinuity continues, the first port 140a will then also be exposed to the high pressure, but as this is balanced by the same high pressure at the second and third ports 140b, 140c the actuator

118 will not move. As the pressure discontinuity passes, the pressure at all three ports 140a, 140b, 140c is substantially equal.

Similarly, if the portion of the tubular body 110 shown on the right hand side of Figures 2a and 2b encounters the high pressure first, the third port 140c is
5 exposed to high pressure (which is also communicated to the second port 140b), whilst the first port 140a is at low pressure. The high pressure at the second and third ports 140b, 140c will act to maintain the actuator 118 in its rest / default position. As the passage of the tubular body 110 through the pressure discontinuity continues, the first port 140a will then also be exposed
10 to the high pressure, but as this is balanced by the same high pressure at the second and third port 140c, the actuator 118 will still not move.

Thus, the actuator 118 will not be moved from its default or rest position by the pressure discontinuity, whichever end of the tubular body 110 is exposed to the high pressure first, and the actuator assembly can therefore cope with
15 pressure differential from above and below without unintended actuation.

Although not essential to the invention, in this embodiment, the tubular body 110 is provided with a side passage 114 which extends from the exterior of the body 110 into the main passage 112. The actuator 118 is provided with a
20 further seal 130b which provide a substantially fluid tight seal between the actuator 118 and the tubular body 110 to ensure that, when the actuator is in a closed position (illustrated in Figure 2b), the actuator substantially prevents flow of fluid along the side passage 114.

In this example, this further seal 130b comprises two seals each of which is a generally circular O-ring which are located in circumferential grooves around
25 the exterior surface of the actuator 118. The further seal 130b and the seal 130a provided to contain fluid pressure in the first direction chamber 138a are spaced such that when the actuator 118 is in the closed position, the side port 114 lies between the two seals 130a, 130b. Again, it should be appreciated

that the invention is not restricted to the use of this particular type of seal, and any other type of seal which substantially prevents flow of fluid between the actuator 118 and the tubular body 110 whilst allowing the actuator 118 to slide in the tubular body 110, could be used instead.

5 In this embodiment, movement of the actuator 118 from the closed position to the open position comprises movement in the first direction, which movement is, as described above, achieved by supply of pressurised fluid to the first port 140a. Correspondingly, movement of the actuator 118 from the open position to the closed position comprises movement in the second direction, which
10 movement is, as described above, achieved by supply of pressurised fluid to the second or third port 140b, 140c. This means that, when the actuator 118 is in the closed position, it is maintained in that position even when the tubular body 110 passes through a pressure discontinuity such as created by an RCD in a managed pressure drilling situation. Thus, leakage of fluid out of the main
15 passage 112 of the tubular body 110 via the side port 114 when the tubular body passes through a pressure discontinuity should be avoided.

Figure 2a illustrates the actuator 118 when supply of pressurised fluid to the first port 140a has pushed it in the first direction, thus opening the side port 114, whilst Figure 2b illustrates the actuator 118 when supply of pressurised
20 fluid to the second or third port 140b, 140c has pushed it in the second direction, so that the actuator 118 closes the side port 114.

It will be appreciated, however, that the actuator assembly could equally be configured such that the opposite is true – i.e. movement of the actuator 118 from the closed position to the open position comprises movement in the
25 second direction etc, so that the actuator 118 is brought to or maintained in the open position when it passes through a pressure discontinuity.

In one embodiment the actuator 118 is connected to a main valve member (not shown) in such a way that movement of the actuator 118 in the first

direction and second direction causes the main valve member to move. The main valve member may be movable between a closed position in which the main valve member closes the main passage 112 of the tubular body 110 and an open position in which the main passage 112 of the tubular body 110 is open. The movement of the main valve member caused by the movement of the actuator 118 in the first direction and second direction may comprise rotation, and the main valve member may be a ball valve.

In one embodiment, the actuator 118 is connected to valve member by means of a track and pin arrangement whereby a pin extends from one of the valve member or actuator into a slot or groove provided in the other of the valve member or actuator, the pin moving along the slot or groove as the actuator 118 slides in the tubular body 110 and the valve member rotates. Various possible mechanisms whereby the actuator 118 could be connected to the main valve member so that sliding movement of the actuator 118 causes the main valve member to rotate are described in WO 2012/085597, GB 2 413 373, US 3,236,255, GB 1 416 085, US 3,703,193 and US 3,871,447.

In a preferred embodiment, the main valve member moves to its closed position when the actuator 118 moves in the first direction, which movement is, as described above, achieved by supply of pressurised fluid to the first port 140a. Correspondingly, the main valve moves to its open position when the actuator 118 moves in the second direction, which movement is, as described above, achieved by supply of pressurised fluid to the second or third port 140b, 140c. This means that, the main valve member is brought to or maintained in its open position when the tubular body 110 passes through a pressure discontinuity such as created by an RCD in a managed pressure drilling situation. Thus, unintentional blocking of the main passage 112 of the tubular body 110 by the main valve member when the tubular body 110 passes through a pressure discontinuity should be avoided. This is particularly advantageous when the assembly is used in a drill string in managed pressure drilling, as closing of the main valve stops the flow of drilling fluid down the drill

string, and this could lead to potential sticking and well control issues, and is likely to force a trip out of the well at significant cost.

Not only is it possible for the actuator 118 to either facilitate the opening or closing of a side port 114 through the tubular body 110 or control the opening
5 or closing of a main valve member, it is possible for the actuator 118 to do both. In other words, both a side port 114 and main valve member as described above, may be provided. In this case, the assembly is advantageously configured such that movement of the actuator 118 in the first direction brings the actuator 118 into the open position and the main valve
10 member into the closed position, whilst movement of the actuator 118 in the second direction brings the actuator 118 into the closed position, and the main valve member into the open position.

An alternative embodiment of actuator assembly is illustrated in Figures 3a and 3b. In this embodiment, two second direction chambers 138b, 138c are
15 provided, the second port 138b connecting the exterior of the tubular body 110 with the first second direction chamber 138b and the third port 138c connecting the exterior of the tubular body 110 with the second second direction chamber 138c. The first direction chamber 138a is located between the two second direction chambers 138b, 138c. In this embodiment, the
20 passages from the first port 140a, second port 140b, and third port 140c into their respective chambers 138a, 138b, 138c extend through the tubular body 110 generally perpendicular to its longitudinal axis.

Again, in this embodiment, both the tubular body 110 and actuator 118 are tubular with a generally circular cross-section. The first direction chamber
25 138a and the second direction chambers 138b, 138c are formed in an annular space around the actuator 118 between an exterior surface of the actuator 118 and an interior surface of the tubular body 110. This space is divided into the first direction chamber 138a and two second direction chambers 138b, 138d by means of three seals 141, 143, 145 which substantially prevent flow of fluid

between the chambers 138a 138b, 138c. Again, two further seals 118a, 130a are provided between the exterior surface of the actuator 118 and the interior surface of the tubular body 110, one at each end of the annular space.

As before, in this embodiment, the seals 118a, 130a, 141, 143, 145 each
5 comprise a pair of generally circular O-rings which are located in two circumferential grooves around the exterior surface of the actuator 118. It should be appreciated, however, that this invention is not restricted to the use of this particular type of seal, and any other type of seal which substantially prevents flow of fluid from the chambers 138a, 138b, 138c whilst allowing the
10 actuator 118 to slide in the tubular body 110, could be used instead. The seals could equally be mounted on the tubular body 110 rather than on the actuator 118.

Again, the actuator assembly is configured such that when the pressure of fluid in the first direction chamber 138a exceeds the pressure of fluid both of
15 the second direction chambers 138b, 138c, the pressure of fluid in the first direction chamber 138a exerts a force on the actuator 118 which acts to push the actuator 118 in a first direction along the main passage 112 in the tubular body 110, and when the pressure of fluid in either of the second direction chambers 138b, 138c exceeds the pressure of fluid in the first direction
20 chamber 138a, the pressure of fluid in the second direction chamber in question 138b, 138c exerts a force on the actuator 118 which acts to push the actuator 118 in a second, opposite, direction along the main passage 112 in the tubular body 110.

In this example, this is achieved by providing the interior of the tubular body
25 110 with two portions of increased internal diameter 110a, 110a'. At either end of these portions 110a, 110a', the interior surface of the tubular body 110 forms a shoulder 110b, 110c, 110d, 110e where the internal diameter of the tubular body 110 decreases slightly. The actuator 118 is substantially longer than both the portions of increased internal diameter 110a, 110a' together, and

the outer diameter of the actuator 118 is less than the internal diameter of the tubular body 110 either side of the portions of increased internal diameter 110a, 110a'. The first direction and second direction chambers 138a, 138b, 138c are formed between the actuator 118 and the portions of increased internal diameter 110a, 110a', and two of the seals 141, 145 extend outwardly of the exterior surface of the actuator 118 to engage with the interior surface of increased internal diameter portions 110a, 110a' of the tubular body 110, one being located in each portion of increased internal diameter 110a, 110a'. The middle seal 143 engages with a portion of the internal surface of the tubular wall 110 between the two portions of increased internal diameter 110a, 110a'.

As in the embodiment illustrated in Figures 2a and 2b, the first direction chamber 138a is formed between the exterior surface of the actuator 118, the first shoulder 110b, the middle seal 143, part of the first increased internal diameter portion 110a of the tubular body 110, and the seal 141. Similarly, the first second direction chamber 138b is formed between the exterior surface of the actuator 118, the end seal 118a, the second shoulder 110c, part of the first increased internal diameter portion 110a of the tubular body 110, and the seal 141. The second direction chamber 138c is formed between the exterior surface of the actuator 118, the middle seal 143, the third shoulder 110d, part of the second increased internal diameter portion 110a' of the tubular body 110, and the seal 145.

When pressurised fluid is supplied to the first port 140a, the fluid pressure pushes the seal 141 away from the first shoulder 110b to increase the volume of the first direction chamber 138a. The actuator 118 is therefore pushed in the first direction. Similarly, when pressurised fluid is supplied to the second port 140b, the fluid pressure in the first second direction chamber 138b pushes the seal 141 away from the second shoulder 110c to increase the volume of the second direction chamber 138b. The actuator 118 is thus pushed in the second direction. Also, when pressurised fluid is supplied to the third port 140a, the fluid pressure in the second second direction chamber 138c pushes

the seal 145 away from the third shoulder 110d to increase the volume of the second second direction chamber 138c. The actuator 118 therefore acts as a double acting piston with a first port 140a to move the actuator 118 in a first direction along the main passage 112 in the tubular body 110 (in this example to the left in Figures 3a and 3b) and a second port 140b or a third port 140c to move the sleeve 18 in a second direction along the main passage 112 in the tubular body 110 (in this example to the right in Figures 3a and 3b). In other words, the effect of fluid pressure at the first, second and third ports 140a, 140b, 140c is exactly the same as in the embodiment described in relation to Figures 2a and 2b, and any or all of the additional features of the earlier embodiment can also be applied to this embodiment.

A further alternative embodiment of the invention is illustrated in Figures 4a and 4b. This embodiment is very similar to the embodiment described with reference to Figures 3a and 3b, in that it too has a second second direction chamber 138c - the difference lies in relation to the order of the chambers 138a, 138b, 138c. Whilst in the Figure 3a/3b embodiment, the first direction chamber 138a is located between the two second direction chambers 138b, 138c, in this alternative embodiment, the two second direction chambers 138b, 138c are next to one another. So that the first port 140a can lie on an imaginary plane which is between the imaginary plane on which the second port 140b and the third port 140c lie, the control passage 139a to the first direction chamber 138a and the control passage 139c to the second second direction chamber 138c extend diagonally through the wall of the tubular body 110. In this example, the control passage 139b to the first second direction chamber 138b extends through the tubular body 110 generally perpendicular to its longitudinal axis.

In this example, this arrangement of the chambers is achieved by providing the interior of the tubular body 110 with three portions of increased internal diameter 110a, 110a', 110a''. At either end of each of these portions 110a, 110a', 110a'', the interior surface of the tubular body 110 forms a shoulder

110b, 110c, 110d, 110e where the internal diameter of the tubular body 110 changes slightly. The internal diameter of the tubular body 110 in the first and third increased diameter portions 110a, 110a'', is less than the internal diameter of the tubular body 110 in the second increased diameter portion 110a'. The second increased diameter portion 110a' lies directly between the first and third increased internal diameter portions 110a, 110a''.

The actuator 118 is substantially longer than all the portions of increased internal diameter 110a, 110a', 110a'' together, and the outer diameter of the actuator 118 is less than the internal diameter of the tubular body 110 either side of the portions of increased internal diameter 110a, 110a', 110a''. The first direction and second direction chambers 138a, 138b, 138c are formed between the actuator 118 and the portions of increased internal diameter 110a, 110a', and the three seals 141, 143, 145 extend outwardly of the exterior surface of the actuator 118 to engage with the interior surface of increased internal diameter portions 110a, 110a', 110a'' of the tubular body 110, one being located in each portion of increased internal diameter 110a, 110a', 110a''. The seal 141 engages with the first increased diameter portion 110a, the middle seal 143 engages with the second increased internal diameter 110a', and the final seal 145 engages with the third increased diameter portion 110a''.

In contrast to the arrangement shown in Figures 3a and 3b, the first direction chamber 138a is formed between the exterior surface of the actuator 118, the middle seal 143, part of the third increased internal diameter portion 110a'' of the tubular body 110, the end shoulder 110e and the seal 145. Similarly, the first second direction chamber 138b is formed between the exterior surface of the actuator 118, the shoulder 110c, the end seal 118a, part of the first increased internal diameter portion 110a of the tubular body 110, and the first seal 141. The second second direction chamber 138c is formed between the exterior surface of the actuator 118, the shoulder 110b, the first seal 141, part

of the second increased internal diameter portion 110a' of the tubular body 110, and the middle seal 143.

When pressurised fluid is supplied to the first port 140a, the fluid pressure pushes the seal 143 away from the first shoulder 110d to increase the volume of the first direction chamber 138a. The actuator 118 is therefore pushed in
5 of the first direction. Similarly, when pressurised fluid is supplied to the second port 140b, the fluid pressure in the first second direction chamber 138b pushes the seal 141 away from the shoulder 110c to increase the volume of the second direction chamber 138b. The actuator 118 is thus pushed in the
10 second direction. Also, when pressurised fluid is supplied to the third port 140a, the fluid pressure in the second second direction chamber 138c pushes the seal 143 away from the shoulder 110b to increase the volume of the second second direction chamber 138c. The actuator 118 therefore acts as a double acting piston with a first port 140a to move the actuator 118 in a first
15 direction along the main passage 112 in the tubular body 110 (in this example to the left in Figures 4a and 4b) and a second port 140b or a third port 140c to move the sleeve 18 in a second direction along the main passage 112 in the tubular body 110 (in this example to the right in Figures 4a and 4b). In other words, the effect of fluid pressure at the first, second and third ports 140a,
20 140b, 140c is exactly the same as in the embodiment described in relation to Figures 2a and 2b, and any or all of the additional features of the earlier embodiment can also be applied to this embodiment.

As the tubular body 110 passes through a pressure discontinuity such as one introduced by an RCD, if the portion of the tubular body 110 shown on the left
25 hand side of Figures 3a, 3b, 4a or 4b encounters the high pressure first, the second port 140b is exposed to high pressure whilst the first and third ports 140a, 140c are at low pressure. The high pressure at the second port 140b will only act to maintain the actuator 118 in its rest / default position. As the passage of the tubular body 110 through the pressure discontinuity continues,
30 the first port 140a will then also be exposed to the high pressure, but as this is

balanced by the same high pressure at the second port 140b, the actuator 118 will not move. Finally, the third port 140c will also be exposed to the high pressure, so the pressure at all three ports 140a, 140b, 140c is substantially equal.

- 5 Similarly, if the portion of the tubular body 110 shown on the right hand side of Figures 3a, 3b, 4a and 4b encounters the high pressure first, the third port 140c is exposed to high pressure whilst the first and second ports 140a, 140b are at low pressure. The high pressure at the third port 140c will only act to maintain the actuator 118 in its rest / default position. As the passage of the
10 tubular body 110 through the pressure discontinuity continues, the first port 140a will then also be exposed to the high pressure, but as this is balanced by the same high pressure at the third port 140c, the actuator 118 will still not move. Finally, the second port 140b will also be exposed to the high pressure, so the pressure at all three ports 140a, 140b, 140c is substantially equal.
- 15 The embodiments described in relation to Figures 3a, 3b, 4a and 4b has an advantage over the embodiments described in relation to Figures 2a and 2b when passed through a device such as an RCD which seals around the tubular body 110 to maintain a pressure discontinuity either side of the RCD. Where the embodiment illustrated in Figures 2a and 2b is used, when one of
20 the second port 140b or third port 140c is exposed to the high pressure at one side of the RCD, if the RCD seals do not close the other of the second port 140b or third port 140c, these ports provide a flow path for flow of fluid across the RCD. This cannot occur when the third port 140c connects to a second second direction chamber 138c.
- 25 In the embodiments of the invention described above, the actuator assembly is configured such that the first direction and second direction chamber(s) 138a, 138b, 138c are pressure balanced. This means that if the pressure in the first direction chamber 138a equals the pressure in the or both second direction chamber(s) 138b, 138c, there is no net force acting on the actuator 118, if the

pressure in the first direction exceeds the pressure in the or both the second direction chamber(s), there is a net force acting on the actuator 118 pushing the actuator 118 in the first direction, and if the pressure in the first direction chamber 138a is less than the pressure in the or either one of the second direction chamber(s) 138b, 138c, there is a net force acting on the actuator 118 pushing the actuator 118 in the second direction. This is achieved by configuring the first direction and second direction chamber(s) 138a, 138b, 138c in such a way that the cross-sectional area of the first direction chamber 138a perpendicular to the first direction is equal to the cross-sectional area of the or each second direction chamber 138b, 138c perpendicular to the second direction.

This is realised in the embodiment illustrated in Figures 2a and 2b by ensuring that the shoulder 110c which partly encloses the second direction chamber 138b has substantially the same depth as the shoulder 110b which partly encloses the first direction chamber 138a. This is realised in the embodiment illustrated in Figures 2a, and 2b by ensuring that the shoulder 110c which partly encloses the first second direction chamber 138b, the shoulder 110b which partly encloses the first direction chamber 138a, and the shoulder 110d which partly encloses the second second direction chamber 138c are substantially equal in depth.

This need not be the case, however, and the actuator assembly may be configured in a non-pressure balanced fashion so that when the pressure in the first direction chamber 138a equals the pressure in the or both second direction chamber(s), there is a net force acting on the actuator 118.

In this case, it is preferable for this net force to push the actuator 118 in the second direction. If this is the case, it will be appreciated that to move the actuator 118 in the first direction, it will be necessary to increase the fluid pressure in the first direction chamber 138a relative to the fluid pressure in the or both of the second direction chamber(s) 138b, 138c so that the fluid

pressure in the first direction chamber 138a exceeds the pressure in the or both of the second direction chamber(s) 138b, 138c by a predetermined margin. Moreover, once the actuator 118 has been moved in the first direction, it will be pushed back in the second direction once the fluid pressure
5 in the first direction chamber 138a falls below the level set by that predetermined margin, even if it still exceeds the pressure in the or both of the second direction chamber(s) 138b, 138c.

This can be achieved by configuring the first direction and second direction chamber(s) 138a, 138b, 138c in such a way that the cross-sectional area of
10 the first direction chamber 138a perpendicular to the first direction is less than the cross-sectional area of the or each second direction chamber 138b, 138c perpendicular to the second direction.

In the embodiment shown in Figures 2a and 2b one way this relative decrease of the cross-sectional area of the first direction chamber 138a with respect to
15 the cross-sectional area of the second direction chamber 138b could be realised is by increasing the depth of the shoulder 110c which partly encloses the second direction chamber 138b (by decreasing the internal diameter of the tubular body 110 on the side of the shoulder 110c outside the increased internal diameter portion 110a and decreasing the outer diameter of the
20 actuator 118 on the second direction chamber 138b side of the seal 141 between the two chambers 138a, 138b). In the embodiment illustrated Figures 3a and 3b, one way this relative decrease of the cross-sectional area of the first direction chamber 138a with respect to the cross-sectional area of the second direction chambers 138b, 138c could be realised is by increasing the
25 depth of the shoulder 110c which partly encloses the first second direction chamber 138b (by decreasing the internal diameter of the tubular body 110 on the side of the shoulder 110c outside the increased internal diameter portion 110a and decreasing the outer diameter of the actuator 118 on the second direction chamber 138b side of the seal 141 between the two chambers 138a,
30 138b) and increasing the depth of shoulder 110d which partly encloses the

second second direction chamber 138c (by increasing the internal diameter of the second increased internal diameter portion 110a' of tubular body).

When used in this specification and claims, the terms "comprises" and "comprising" and variations thereof mean that the specified features, steps or
5 integers are included. The terms are not to be interpreted to exclude the presence of other features, steps or components.

The features disclosed in the foregoing description, or the following claims, or the accompanying drawings, expressed in their specific forms or in terms of a means for performing the disclosed function, or a method or process for
10 attaining the disclosed result, as appropriate, may, separately, or in any combination of such features, be utilised for realising the invention in diverse forms thereof.

CLAIMS

1. A fluid pressure operated actuator assembly comprising a tubular body having a wall, with an interior surface and an exterior surface and enclosing a main passage which extends generally parallel to a longitudinal axis of the tubular body, an actuator located in and movable along the main passage, a first direction chamber formed between the wall of the tubular body and the actuator, and at least one second direction chamber formed between the tubular body and the actuator, wherein the assembly is configured such that when a first pressure of fluid in one of the first direction chamber and the at least one second direction chamber exceeds a second pressure of fluid in the other of the first direction chamber and the at least one second direction chamber by a predetermined amount, the first pressure of fluid exerts a force on the actuator which acts to push the actuator in a first direction relative to the tubular body, when the first pressure is a pressure of fluid in the first direction chamber, and in a second direction relative to the tubular body, when the first pressure is a pressure of fluid in the at least one second direction chamber, and when the first pressure of fluid falls below the predetermined amount in excess of the second pressure of fluid, the second pressure of fluid exerts a force on the actuator which acts to push the actuator in the second direction relative to the tubular body, when the first pressure is the pressure of fluid in the first direction chamber, and in the first direction relative to the tubular body, when the first pressure is the pressure of fluid in the at least one second direction chamber, characterised in that the exterior surface of the tubular body is provided with a first port which communicates with a passage extending through the wall of the tubular body from the first port to the first direction chamber, a second port which

- communicates with a passage extending through the wall of the tubular body from the second port to the or one of the second direction chamber(s), and a third port which communicates with a passage extending through the wall of the tubular body from the third port to the or another one of the second
- 5 direction chamber(s), the first port lying on a first plane, the second port lying on a second plane and the third port lying on a third plane, the first plane, second plane and third plane being generally parallel to one another and the first plane lying between the second plane and the third plane.

2. A fluid pressure operated actuator assembly according to claim 1 wherein the longitudinal axis of the tubular body extends generally normal to the first plane, second plane and third plane.
3. A fluid pressure operated actuator assembly according to any preceding
5 claim wherein one or both of the first and second directions is/are generally parallel to the longitudinal axis of the tubular body.
4. A fluid pressure operated actuator assembly according to any preceding claim wherein the first direction is generally opposite to the second direction.
5. A fluid pressure operated actuator assembly according to any preceding
10 claim wherein the actuator is connected to a main valve member in such a way that movement of the actuator in the first direction and second direction causes the valve member to move.
6. A fluid pressure operated actuator assembly according to claim 5 wherein the main valve member is movable between a closed position in
15 which the main valve member closes the main passage of the tubular body and an open position in which the main passage of the tubular body is open.
7. A fluid pressure operated actuator assembly according to claim 5 or 6 wherein the movement of the main valve member caused by the movement of the actuator in the first direction and second direction comprises rotation.
- 20 8. A fluid pressure operated actuator assembly according to claim 5, 6 or 7 wherein the main valve member moves to the closed position when the actuator moves in the first direction and to the open position when the actuator moves in the second direction.
9. A fluid pressure operated actuator assembly according to claim 5, 6 or 7
25 wherein the main valve member comprises a ball valve member.

10. A fluid pressure operated actuator assembly according to any one of claims 5 to 9 wherein the actuator is connected to a main valve member by means of a track and pin arrangement whereby a pin extends from one of the valve member or actuator into a slot or groove provided in the other of the valve member or actuator, the pin moving along the slot or groove as the actuator slides in the tubular body and the valve member rotates.

11. A fluid pressure operated actuator assembly according to any preceding claim wherein the tubular body is provided with a side passage which extends through the wall of the tubular body from the exterior of the tubular body into the main passage, and the actuator is movable between a closed position in which the actuator substantially prevents flow of fluid along the side passage, and an open position in which flow of fluid along the side passage is permitted.

12. A fluid pressure operated actuator assembly according to claim 11 wherein movement of the actuator in the first direction brings the actuator into the open position, and movement of the actuator in the second direction may bring the actuator into the closed position.

13. A fluid pressure operated actuator assembly according to claims 11 or 12 where dependant on any one of claims 5 to 10 wherein movement of the actuator in the first direction may bring the actuator into the open position and the main valve member into the closed position, whilst movement of the actuator in the second direction brings the actuator into the closed position, and the main valve member into the open position.

14. A fluid pressure operated actuator assembly according to any preceding claim wherein the passage from the third port connects to the passage from the second port into the at least one second direction chamber.

15. A fluid pressure operated actuator assembly according to any preceding claim wherein the first direction chamber and the at least one second direction

chamber are formed in a space between an exterior surface of the actuator and an interior surface of the wall of the tubular body.

16. A fluid pressure operated actuator assembly according to claim 15 wherein this space extends around the entire perimeter of the actuator.

5 17. A fluid pressure operated actuator assembly according to claim 15 or 16 wherein this space is divided into the first direction chamber and the at least one second direction chamber by means of a seal which substantially prevents flow of fluid between the chambers whilst allowing the actuator to move along the main passage of the tubular body.

10 18. A fluid pressure operated actuator assembly according to claim 15 or 16 comprising two second direction chambers, wherein this space is divided into the first direction chamber and the two second direction chambers by means of a seal arrangement which substantially prevents flow of fluid between the chambers whilst allowing the actuator to move along the main passage of the
15 tubular body,

19. A fluid pressure operated actuator assembly according to claim 18 wherein the first direction chamber located between the two second direction chambers.

20 20. A fluid pressure operated actuator assembly according to claim 18 wherein the passages from the first port, second port and third port into their respective chamber extend through the tubular body generally perpendicular to its longitudinal axis.

25 21. A fluid pressure operated actuator assembly according to claim 18 wherein at least one of the passages from the first port, second port and third port into their respective chamber extends through the tubular body generally at an angle of less than 90° to its longitudinal axis

22. A fluid pressure operated actuator assembly according to any preceding claim wherein the actuator assembly is configured such that if the pressure of fluid in

the first direction chamber equals the pressure of fluid in the at least one second direction chamber, there is no net force acting on the actuator, if the pressure of fluid in the first direction exceeds the pressure in the at least one second direction chamber, there is a net force acting on the actuator pushing the actuator in the first direction, and if the pressure of fluid in the first direction chamber is less than the pressure of fluid in the at least one the second direction chamber, there is a net force acting on the actuator pushing the actuator the second direction.

23. A fluid pressure operated actuator assembly according to any one of claims 1 to 19 wherein the actuator assembly is configured such that when the pressure of fluid in the first direction chamber equals the pressure of fluid in the at least one second direction chamber, there is a net force acting on the actuator.

24. A fluid pressure operated actuator assembly according to claim 23 wherein the actuator assembly is configured such that this net force tends to push the actuator in the second direction.

25. A fluid pressure operated actuator assembly according to claim 23 wherein the actuator assembly is configured such that this net force tends to push the actuator in the first direction.