(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 781 685 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
24.09.2014 Bulletin 2014/39

(51) Int Cl.:
E21B 34/08 *(2006.01)*

(21) Application number: **14165023.4**

(22) Date of filing: **16.04.2014**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

(30) Priority: **20.03.2013 GB 201305085**

(71) Applicant: **Multilift Wellbore Technology Limited
Aberdeen AB10 1WF (GB)**

(72) Inventor: **Leitch, Andrew
Aberdeen, AB15 9AS (GB)**

(74) Representative: **Walker, Stephen
Lincoln IP
9 Victoria Street
Aberdeen
Aberdeenshire AB10 1XB (GB)**

(54) **Free flow valve**

(57) A valve for use with a downhole pump, wherein the valve comprises a single moving part that in a first position forms only a first interface and in a second position forms only a second interface, each interface presenting a barrier that cannot be breached by fluid, whereby the first interface directs fluid to the production tubing only from the annulus and the second interface directs fluid to the production tubing only from the pump, the pump and annulus and production tubing are simultaneously interconnected by a chamber of the valve when the single moving part is between the first and second positions, each interface is maintained or broken depending on the fluid pressure differential across the associated interface, the single moving part moves between the first position and second position according to the fluid direction through the valve, characterised by each of the two interfaces being formed between a convex surface of the single moving part and a concave surface of a non moving part of the valve, whereby the single moving part self aligns with each interface and only via the interface, and where the single moving part does not house or incorporate one or more rotational or/and linear axes.

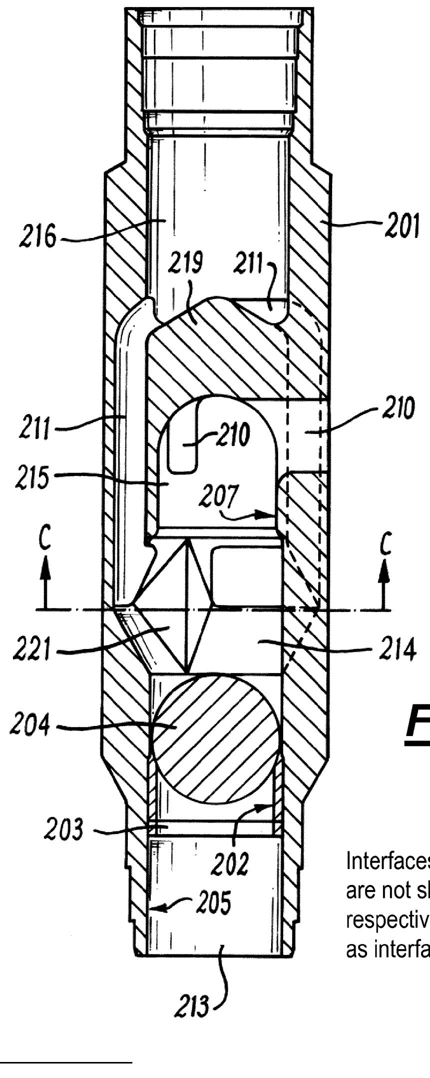


Fig. 10

Interfaces 217, 218 are not shown but are respectively the same as interfaces 17, 18

EP 2 781 685 A2

Description

[0001] Within this entire document each of the following terms has their associated meaning or/and definition irrespective of any alternative meanings or/and definitions that may exist outside of this document.

[0002] FFV - meaning an abbreviation for Free Flow Valve, the FFV is the invention herein described.

[0003] Well - meaning water well or hydrocarbon well.

[0004] Fluid - meaning hydrocarbon or water.

[0005] Distance - meaning a distance between fifty feet and twenty thousand feet or between fifteen metres and six thousand metres.

[0006] Lift - meaning moving fluid a distance from below ground level or from below sea bed level or from beneath the bed level of another body of water to a location.

[0007] Location - meaning a location determined by the purpose of the associated lift operation where the location can be a land based or sea based rig such as an oil rig, or ship, or water treatment plant such as filtration or/and desalination, or reservoir, or sub-terrain or subsea installation such as a valve, or instrumentation, or a further pumping means, and the like as known by those skilled in the art.

[0008] Natural lift - meaning a well's ability to lift by natural well pressure alone unassisted by artificial lift.

[0009] Artificial lift or enhanced recovery - meaning to artificially lift or artificially assist lifting.

[0010] Downhole pump - meaning a fluid pumping device installed in a well to provide artificial lift.

[0011] ESP- meaning an abbreviation for Electrical Submersible Pump which is one of several types of downhole pump.

[0012] Production - meaning an acceptable quantity of fluid from a well to a location in an acceptable time.

[0013] ESP problems - meaning (a) (b1) (b2) (b3) (c1) (c2) (c3) (c4) (c5) (d) (e1) (e2) as described herein.

[0014] Most common ESP problems - meaning (a) (b1) (b2) (b3).

[0015] Prior art problems - meaning any of the problems associated with the prior art.

[0016] First interface - meaning a first seal face that defines a fluid path through the FFV between the annulus with the associated production tubing.

[0017] Second interface - meaning a second seal face that defines a fluid path through the FFV between the ESP with the associated production tubing.

[0018] String or production tubing - means the production carrying tubing to which the ESP and valve are connected.

[0019] FFV first goal - meaning to overcome the most common ESP problems.

[0020] FFV second goal - meaning improved reliability over the prior art.

[0021] FFV third goal - meaning a design that minimises production costs.

[0022] Casing - meaning the inner diameter of the well bore often defined by the inner diameter of a series of tubular components inserted into the well.

[0023] Annulus - defines the space between the casing and the outside diameter of the FFV or/and ESP.

[0024] Formation -The rock that holds the fluid before the fluid enters the well.

[0025] Single moving part or single sealing member-meaning the FFV's only moving part and whose function it is to form a seal with two seal faces but not simultaneously. Wherein each said seal is achieved only by the single moving part self aligning with the associated seal face. The single sealing member/moving part does not house or incorporate a rotational or linear axis and does not move between the two seal faces via an articulation.

[0026] Natural lift production is usually at its greatest when the well is new. Thereafter, natural lift production usually dissipates with the passage of time. Eventually the well loses its ability to produce by natural lift. Thereafter, artificial lift is the only way to satisfy production. Since production is increasingly dependent on ageing wells the need for artificial lift is consequently increasing.

[0027] ESPs are a very common means of artificial lift and are particularly relevant to the FFV. The FFV is the invention herein described.

[0028] ESPs are considered to be a highly efficient means of artificial lift and are capable of high production rates with lighter hydrocarbons with a low sand and/or low solid content. It is generally accepted that ESP production can exceed other means of artificial lift within the fluid viscosity range that ESPs operate.

[0029] ESPs attach to the string and are independently powered from, typically, the surface by a power cable which extends along the string to the motor part of the ESP. ESPs lift fluid from the annulus and in the process cause a continuous pressure differential between the annulus and formation. The pressure differential allows more fluid to re-charge the annulus from the formation due to the formation pressure overcoming the reduced annulus pressure.

[0030] To reduce installation costs and to maximise production duration, ESPs are often installed but not used before the associated well stops producing by natural lift. Thereafter the ESP can be turned on without requiring a second installation. The alternative would require a first installation without an ESP until the associated well stopped producing by natural lift, then the removal of the first installation, then a second installation that included an ESP. Whilst a well is producing by natural lift the associated installed ESP is not used. This saves the ESP from needless wear and prolongs the ESP's life which reduces installation costs and maximises the ESP's future production duration.

[0031] However, when the installed but unused ESP is in a well that is producing by natural lift the fluid passes through the unused ESP and causes the following problems:

(a) The fluid path through the ESP is restricted by the multitude of impellers and diffusers that together make-up the ESP's pump. The restriction saps some of the natural lift which necessitates the earlier use of the ESP than otherwise would be the case had the restriction not existed.

(b) The fluid path through the ESP can rotate the combined mass of the ESP's, pump shaft, impellers, and motor, in the normal operational direction prior to start up which causes the following problems:

(b1) General ESP wear.

(b2) Particularly high wear to the ESP's thrust bearings. The ESP's thrust bearings are force lubricated when the ESP's pump and motor shaft rotate within their designed rpm range, usually when the ESP is powered. However, when the rpm is below the designed rpm range, which frequently occurs in the (b) and (c) type scenarios, the ESP's thrust bearings are insufficiently lubricated which causes them to wear excessively which shortens the ESP's operation life.

(b3) The ESP's motor becomes a generator that generates a current along the ESP's power cable. This current can detrimentally effect electronic and/or electrical apparatus positioned along or at the other end of the power cable.

[0032] Furthermore, when the installed and operational ESP is turned off in a well that has no natural lift, the fluid direction in the string will reverse back towards the ESP which can cause the following problems:

(c) Can rotate the combined mass of the ESP's, pump shaft, impellers, and motor, in the opposite direction to the ESP's normal operational rotational direction which can cause the following problems:

(c1) General ESP wear.

(c2) Particularly high wear to the ESP's thrust bearings as per (b2) above.

(c3) The ESP's motor becomes a generator with the associated problem as per (b3) above.

(c4) Increase start-up torque which can twist or shear the shaft of the ESP's pump.

(c5) Increase start-up torque which increases start-up current which can detrimentally effect the ESP's power cable and electronic or/and electrical equipment connected to the ESP's power cable.

(d) To avoid (c4) and (c5) time is often lost waiting for the pump to stop turning.

(e) ESP production can be insufficient to carry solids such as sand out of the string and instead the solids remain supported in the string by the passing fluid. When the ESP is turned off the previously supported solids are no longer supported by the passing fluid and fall down on top of the ESP and clog the ESP's pump which causes the following problems:

(e1) Increase start-up torque which can twist or shear the shaft of the ESP's pump as per (c4).

(e2) Increase start-up torque which increases start-up current which can be detrimental to the ESP's power cable and to electronic and/or electrical equipment connected to the ESP's power cable as per (c5).

[0033] In reference to (c4) (e1) and (c5) (e2), ESP operators are supposed to check to see if the ESP pump is rotating before start-up by checking to see if an electrical current is being produced by the similarly rotating ESP motor. However, in practice this check is often overlooked or is not possible. In any case, production duration is lost waiting for the ESP motor to stop registering a current to indicate that the ESP pump is not turning before start up, as per (d). In reference to (b3) (c3) and (c5) (e2), there are safety devices to stop these problems but they are not always installed and if they are installed they do not always work when required.

[0034] Therefore (a) (b1) (b2) (c1) (c2) (c4) and (e1) can all reduce the ESP's life, (b3) (c3) (c5) and (e2) can all damage supporting equipment, (d) can lose production duration. All of which is very costly in terms of lost production duration and/or repair or replacement of damaged equipment.

[0035] Because the ESP problems are synonymous with ESP use the discovery of the ESP problems must have shortly followed the invention of the ESP, a period now approaching one hundred years. During that period there have been several prior art inventions aimed at overcoming the ESP problems with varying degrees of success.

[0036] The prior art can be categorised by the following two design philosophies both of which have their associated problems.

[0037] Firstly, the prior art that fully closes the fluid path between the annulus and string before opening the fluid path between the ESP and string and vice versa. Such designs are hampered by either, the complexity of their close moving parts which can become jammed by trapped silt, the requirement for close machining tolerances which has a high manufacturing cost implication, pulsing of moving components which adversely effects production, or combinations thereof.

[0038] Secondly, the prior art that opens the fluid path between the ESP and string before closing the fluid path between the annulus and string and vice versa. Such designs are hampered by either, unfavourable porting positions which can adversely effects production, close machining tolerances which has a high manufacturing cost implication, pulsing of moving components which adversely effects production, only able to work in a limited flow rate range which adversely effects production, or combinations thereof.

[0039] Perishable seals are another problem in some instances of prior art.

[0040] Therefore, in the process of resolving or trying to resolve all of the ESP problems the prior art has created its own prior art problems in terms of reliability and cost which are both associated with complexity.

[0041] However the ESP problems (c1) (c2) (c3) (c4) (c5) (d) (e1) (e2) and their causes (c) (e) only occur when the ESP is turned off in a well that has no natural lift. ESP operators try to minimise turning the ESP off and aim for the ideal of never turning off the ESP because any lack of production is undesirable. On the few occasions when an ESP is turned off, the well may still be capable of natural lift which avoids encountering ESP problems (c1) (c2) (c3) (c4) (c5) (d) (e1) (e2) and their causes (c) (e). Consequently, ESP problems (c1) (c2) (c3) (c4) (c5) (d) (e1) (e2) and their causes (c) (e) are quite rare.

[0042] In the interest of reliability the FFV is not designed to overcome all of the ESP problems. Instead the FFV's scope is limited to only overcoming the most common ESP problems (a) (b) (b1) (b2) (b3), the FFV's first goal. The FFV's limited scope allows for a much simpler and thereby inherently more reliable design by comparison to the prior art, the FFV's second goal. Whereby, the FFV's simplicity minimises production costs, the FFV's third goal. In essence the FFV exchanges scope for reliability and cost efficiency by comparison to the prior art. The FFV employs a single sealing member that performs its sealing function by the sole parameter of self alignment with either of the two sealing faces. Thereby negating the need for the sealing member to house or incorporate additional parameters, such as one or more rotational or/and linear axes, for sealing function purposes. The sealing member also does not need said additional parameters to move from one seal face to the other seal face. The absence of said additional parameters reduces the opportunity for silt to impair the sealing function by getting trapped between the static and moving parts of the said additional parameters, thus promoting the FFV's second goal. Furthermore, the fewer moving parts the fewer the associated precision tolerances which reduces manufacturing costs which promotes the FFV's third goal. The FFV's design philosophy is based on opening the fluid path between the ESP and string before fully closing the fluid path between the annulus and string and vice versa.

[0043] The FFV has one moving part that moves between a first position and a second position. The first position is synonymous with the ESP not being operated and the well having natural lift.

[0044] The second position is synonymous with the ESP being operated. However, the second position is also synonymous with the ESP being turned off to leave a column of fluid above the FFV in the string generating greater pressure in the FFV than from the natural well pressure through the FFV to keep the moving part in the second position. In the first position the moving part forms a first interface. In the second position the moving part forms a second interface. The moving part cannot simultaneously form both the first and second interfaces.

[0045] The first interface discommunicates the ESP outlet from the string and simultaneously communicates only the annulus to the string. The moving part is held in the first position by the natural lift pressure via the annulus being greater than the natural lift pressure via the ESP. The multitude of impellers and diffusers in the ESP pump restricts natural lift through the ESP pump and thereby reduces the natural lift pressure through the ESP pump by comparison to the unrestricted natural lift pressure via the annulus. This pressure differential keeps the moving part in the first position when the ESP is turned off, i.e. not being operated in a well having natural lift.

[0046] The second interface only communicates the ESP outlet with the string and simultaneously discommunicates the annulus from the string when the ESP is being used. The moving part is held in the second position by the artificial lift pressure overcoming the annulus pressure. This pressure differential keeps the moving part in the second position when the ESP is turned on, i.e. being operated.

[0047] After turning off the ESP the moving part remains in the second position whilst the pressure in the FFV generated by the fluid held in the string above the FFV exceeds the pressure in the FFV from natural lift. Wherein, the fluid held in the string flows back into the annulus through the ESP pump which reduces the pressure in the FFV from the fluid column whilst the annulus pressure increases to match the formation pressure. Should the natural lift pressure in the FFV exceed the pressure in the FFV from the fluid column the moving part will move from the second position to the first position.

[0048] During the moving part's transition between the first and the second positions the, ESP outlet, string and annulus, are all interconnected via the FFV.

[0049] When the ESP in turned on the moving part is moved from the first position to the second position in three stages. Firstly by breaking the first interface when the artificial lift pressure overcomes the natural lift pressure. Secondly by the artificial lift's fluid flow carrying the moving part to the second position from the first position. Thirdly by the moving part forming the second interface by the artificial lift pressure overcoming the natural lift pressure.

[0050] After the ESP has been turned off the moving part is moved from the second position to the first position in three stages. Firstly by breaking the second interface when the natural lift pressure via the annulus overcomes both the natural lift pressure via the ESP and the string fluid column pressure. Secondly by gravity, unless the FFV is horizontal or to any degree inverted, and by the natural lift fluid flow via the annulus carrying the moving part to the first position from the second position. Thirdly by the moving part forming the first interface by the natural lift pressure via the annulus overcoming the natural lift pressure via the ESP.

[0051] The FFV is positioned either between the ESP outlet and string or along the string from the ESP. The FFV is a Free Flow Valve in that the moving part can move between the first position and the second position and vice versa by the direction of fluid passing through the FFV either via natural lift or via artificial lift.

[0052] The FFV will now be further described with reference to the not to scale and non limiting examples of Figures 1, 1a, 2, 3, 3a, 4, 5, 6, 6a, 7, 7a, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, where

Figure 1 shows a cross hatched section of the FFV along the longitudinal centre line of the FFV with single moving part (4) in the first position forming the first interface and where housing (1) is a machined casting.

Figure 1a of Figure 1 shows a detailed view of first interface (17).

Figure 2 shows cross section AA of Figure 1.

Figure 3 shows Figure 1 but where single moving part (4) is in the second position forming the second interface.

Figure 3a of Figure 3 shows a detailed view of second interface (18).

Figure 4 shows a simplified view of Figure 1 installed in the string where the ESP is turned off and the well is producing by natural lift which forces moving part (4) into the first position forming the first interface (17) as indicated by the fluid flow arrows.

Figure 5 shows a simplified view of Figure 3 installed in the string where the ESP in turned on and the well is producing by artificial lift which forces moving part (4) into the second position forming the second interface (18) as indicated by the fluid flow arrows.

Figure 6 shows a variant of Figure 1 that permits housing (101) to be either machined from billet or from tubing or a machined casting and assembled using a press fit. Figure 6 shows moving part (104) in the first position forming the first interface as per moving part (4) in Figure 1. The natural lift fluid flow arrows of Figure 4 equally apply to Figure 6.

Figure 6a of Figure 6 shows a detailed view of first interface (117).

Figure 7 shows Figure 6 but with moving part (104) in the second position forming the second interface as per moving part (4) in Figure 3. The artificial lift fluid flow arrows of Figure 5 equally apply to Figure 7.

Figure 7a of Figure 7 shows a detailed view of the second interface (118).

Figure 8 shows cross section BB of Figure 6.

Figure 9 shows an exploded view of Figure 6 and of Figure 7 but without inner housing (108) or moving part (104) being cross sectioned.

Figure 10 shows Figure 1 but with the addition of guides (221) whose only function is to help guide moving part (204) between the first and second positions.

Figure 11 shows cross section CC of Figure 10.

Figure 12 shows moving part (304) as an elongated variant of moving part (4)/(104)/(204).

Figure 13 shows a variation of Figure 12 with reduced diameter sides to reduce the surface contact area of moving part (404) with guides (221) or inner housing (108).

Figure 14 shows a reduced mass variation of Figure 13 in cross section to reveal the bore that reduces mass.

Figure 15 shows another means of reducing the mass of Figure 13 that also helps the movement of moving part (604) between the first position and the second position.

Figure 16 shows a variation of Figure 15 that helps moving part (704) into either the first position or into the second position and where moving part (704) has a truncated sphere to reduce mass.

Figure 17 shows a variation of Figure 15 where moving part (804) has the addition of faces (822) to further help moving part (804) be carried by the fluid flow between the first position and the second position.

Figure 18 shows a variation of Figure 16 in cross section to reveal two mass reducing bores akin to Figure 14.

Figure 19 shows Figure 15 but with moving part (1004) having two half spheres of different diameters combined with a face (1022) akin to faces (822) in Figure 17.

Figure 20 shows a variation of Figure 15 with the addition of longitudinal sections (1124) to promote a rotational torque to moving part (1104).

Figure 21 shows cross section DD of Figure 20.

Figure 22 shows a convex variation for the concave surface that forms the first and second interfaces.

Figure 23 shows a concave variation for the concave surface that forms the first and second interfaces.

Figure 24 shows Figure 1 but using an alternative thread arrangement for assembly.

[0053] In Figures 1, 2, 3, the FFV comprises four separate components which are housing (1) shoulder (2) locking ring (3) moving part (4). Housing (1) is a machined casting. By comparison, shoulder (2), locking ring (3), moving part (4), can each be either machined from billet or a machined casting. Moving part (4) is spherical and of solid construction. Shoulder (2) and locking ring (3) are both positioned via a thread to internal diameter (5) of housing (1). Shoulder (2) butts-up against step (6) as shown by detailed view Figure 1a of Figure 1. Locking ring (3) butts-up against shoulder (2) to prevent shoulder (2) from disuniting from step (6). The purpose of shoulder (2) being a removable component is to allow moving part (4) to be assembled. By contrast shoulder (7) in the detailed view Figure 3a of Figure 3 is an integral part of housing (1). Casting can be a cost effective manufacturing process when unit numbers are sufficient to justify the making of a casting mould.

[0054] Access for assembling moving part (4)-(1104) can be provided in a number of ways. For instance and by way of two non limiting examples, Figures 6,7,8,9, show a press fit or interference fit assembly method and Figure 24 shows an assembly method employing a threaded housing (1201).

[0055] In Figures 6, 7, 8, 9, the FFV comprises three separate components which are, outer housing (101), moving part (104), inner housing (108). Figure 9 shows the three components disassembled with only outer housing (101) in cross section. Each of these three components can be either machined from billet or a machined casting. Moving part (104) is spherical and of solid construction. Shoulder (102) is an integral part of outer housing (101) as shown by detailed view Figure 6a of Figure 6. Inner housing (108) is positioned via an interference fit to inner diameter (109) of outer housing (101) where the interference fit can be between tapered or parallel sides. Inner housing (108) also butts-up against shoulder (102) as shown by detailed view Figure 6a of Figure 6. Figure 8 shows section BB of Figure 6. With reference to Figure 8, to align ports (110) of inner housing (108) with ports (110) of outer housing (101) inner housing (108) can be rotated using a torque applying tool fashioned to fit into ports (111). Inner housing (108) is a separate component to allow outer housing (101) to be either a machined casting or machined from billet or from tubing. Whereby, moving part (104) can be assembled in the process of assembling inner housing (108) which negates the need for shoulder (102) to be a removable component. Machining from billet or from tubing is more cost effective than casting when the unit numbers are not sufficient to justify the cost of making a casting mould. Furthermore, component alterations can be made quicker and cheaper when machining from billet or from tubing than can be made via a casting manufacturing process.

[0056] With reference to Figures 6 and 7, outer housing (101) can be further fixed to inner housing (108) by one or more removable dowels (112). Whereby removable dowels (112) traverse the interference fit between outer housing (101) and inner housing (108) without breaking into any of the ports (110), (111), or into any of the chambers (113), (114), (115), (116). Preferably removable dowels (112) each have one through hole which is threaded. The through hole prevents air getting trapped in the dowels blind location hole. Otherwise trapped air will expand with the downhole heat which might push the dowel out. The edge of the dowel's blind hole can be swaged to retain the dowel. The through thread of dowel (112) provides a means by which the dowel can be removed to dissemble the FFV.

[0057] In Figure 1 moving part (4) is shown in the first position. In the first position moving part (4) forms a first interface (17) with shoulder (2) as shown in Figure 1a. In Figure 1a interface (17) is shown with a small gap between moving part (4) and shoulder (2). This gap is only present in Figure 1a to distinguish moving part (4) from shoulder (2) but in practice no such gap would exist when interface (17) is formed. Interface (17) forms a seal that for all practicable purposes prevents fluid from crossing from chamber (13) to chamber (14). In Figure 6 moving part (104) is shown in the first position. In the first position moving part (104) forms a first interface (117) with shoulder (102) as shown in Figure 6a. In Figure 6a interface (117) is shown with a small gap between moving part (104) and shoulder (102). This gap is only present in Figure 6a to clearly show moving part (104) from shoulder (102) but in practice no such gap would exist when interface (117) is formed. First interface (117) forms a seal that for all practicable purposes prevents fluid from crossing from chamber (113) to chamber (114).

[0058] In Figure 3 moving part (4) is shown in the second position. In the second position moving part (4) forms a second interface (18) with shoulder (7) as shown in Figure 3a. In Figure 3a interface (18) is shown with a small gap between moving part (4) and shoulder (7). This gap is only present in Figure 3a to clearly identify moving part (4) and shoulder (7) from each other but in practice no such gap would exist when interface (18) is formed. Second interface (18) forms a seal that for all practicable purposes prevents fluid from crossing from chamber (15) to chamber (14). In Figure 7 moving part (104) is shown in the second position. In the second position moving part (104) forms a second interface (118) with shoulder (107) as shown in Figure 7a. In Figure 7a interface (118) is shown with a small gap between moving part (104) and shoulder (107). This gap is only present in Figure 7a to clearly comprehend moving part (104) and shoulder (107) from each other but in practice no such gap would exist when interface (118) is formed. Second interface (118) forms a seal that for all practicable purposes prevents fluid from crossing chamber (115) to chamber (114).

[0059] Housing (1)/(101) respectively contains, pump discharge chamber (13)/(113) transfer chamber (14)/(114) annulus chamber (15)/(115) and valve discharge chamber (16)/(116). Pump discharge chamber (13)/(113) are respectively defined by the space between the ESP outlet and first interface (17)/(117). Transfer chambers (14)/(114) are respectively defined by the space between first interface (17)/(117) and second interface (18)/(118) excluding valve discharge ports (11)/(111). Annulus chambers (15)/(115) are respectively defined by the space between second interface (18)/(118) and cap (19)/(119) excluding annulus ports (10)/(110). Caps (19)/(119) dictate that the fluid path exiting the FFV from annulus chambers (15)/(115) is respectively limited to annulus ports (10)/(110). Valve discharge chambers (16)/(116) are respectively defined by the space between caps (19)/(119) and the string excluding valve discharge ports (11)/(111).

[0060] In the first position, entry to and exit from pump discharge chamber (13)/(113) is only via the ESP outlet, entry to and exit from transfer chamber (14)/(114) is only via valve discharge ports (11)/(111) and annulus chamber (15)/(115), entry to and exit from annulus chamber (15)/(115) is only via annulus ports (10)/(110) and transfer chamber (14)/(114), entry to and exit from valve discharge chamber (16)/(116) is only from valve discharge ports (11)/(111) and the string. Communication between annulus chamber (15)/(115) and the annulus is only via annulus ports (10)/(110). Communication between valve discharge chamber (16)/(116) and transfer chamber (14)/(114) is only via valve discharge ports (11)/(111). Communication between transfer chamber (14)/(114) and annulus chamber (15)/(115) is only across second interface (18)/(118).

[0061] In the second position, entry to and exit from pump discharge chamber (13)/(113) is only via the ESP outlet and transfer chamber (14)/(114), entry to and exit from transfer chamber (14)/(114) is only via valve discharge ports (11)/(111) and pump discharge chamber (13)/(113), entry to and exit from annulus chamber (15)/(115) is only via annulus ports (10)/(110, entry to and exit from valve discharge chamber (16)/(116) is only via valve discharge ports (11)/(111) and the string. Communication between annulus chamber (15)/(115) and the annulus is only via annulus ports (10)/(110). Communication between valve discharge chamber (16)/(116) and transfer chamber (14)/(114) is only via valve discharge ports (11)/(111). Communication between transfer chamber (14)/(114) and pump discharge chamber (13)/(113) is only across first interface (17)/(117).

[0062] Thereby, in the first position communication to and from valve discharge chamber (16)/(116) via transfer chamber (14)/(114) is limited to annulus chamber (15)/(115), and in the second position communication to and from valve discharge chamber (16)/(116) via chamber transfer (14)/(114) is limited to pump discharge chamber (13)/(113).

[0063] In Figure 2 the cross section AA of Figure 1 is shown to further reveal annulus ports (10) and valve discharge ports (11). In Figure 8 the cross section BB of Figure 6 is shown to further reveal annulus ports (110) and valve discharge ports (111).

[0064] Figure 4 shows a simplified version of Figure 1 installed between the string and the ESP outlet whereby, the string each side of the FFV is shown in a non hatched cross section along its longitudinal centre line. The arrows in Figure 4 show the fluid path when the FFV is installed in a naturally producing well but when the ESP is not operating. Whereby, the fluid from the annulus enters transfer chamber (14) through the aperture of shoulder (7) from annulus chamber (15) via annulus ports (10) forcing moving part (4) to form first interface (17) with shoulder (2), i.e. first position, which diverts the fluid from transfer chamber (14) into valve discharge ports (11) and then into valve discharge chamber (16) and then into the string. The flow path shown in Figure 4 equally applies to Figure 6. Thereby, the most common ESP problems are overcome by moving part (4)/(104) disconnecting pump discharge chamber (13)/(113) from transfer chamber (14)/(114) by forming first interface (17)/(117).

[0065] Figure 5 shows Figure 4 but where the arrows show the fluid path when the ESP is turned on and generating artificial lift. Whereby, the fluid from the ESP outlet enters transfer chamber (14) through shoulder (2) from pump discharge chamber (13) and forces moving part (4) to form second interface (18) with shoulder (7), i.e. second position, which diverts the fluid from transfer chamber (14) to the string via valve discharge ports (11) and valve discharge chamber (16). The flow path shown in Figure 5 equally applies to Figure 7.

[0066] Moving part (4)/(104) is held in the first position by the pressure in transfer chamber (14)/(114) being greater than the pressure in pump discharge chamber (13/(113). Moving part (4)/(104) is disunited from the first position by the pressure in pump discharge chamber (13)/(113) being greater than the pressure in transfer chamber (14/(114). Moving part (4)/(104) is held in the second position by the pressure in transfer chamber (14)/(114) being greater than the pressure in annulus chamber (15)/(115). Moving part (4)/(104) is disunited from the second position by the pressure in annulus chamber (15)/(115) being greater than the pressure in transfer chamber (14)/(114). After moving part (4)/(104)

has been disunited from the first position the movement of moving part (4)/(104) to the second position is dictated by the artificial lift fluid flow. After moving part (4)/(104) has been disunited from the second position the movement of moving part (4)/(104) to the first position is dictated by the artificial lift fluid flow.

[0067] Preferably, pump discharge chamber (13)/(113) transfer chamber(14)/(114) annulus chamber (15)/(115) valve discharge chamber (16)/(116) annulus ports (10)/(110) valve discharge ports(11)/(111) shoulders (2)/(102) (7)/(107) all have the largest possible through cross sectional area to maximise fluid flow through the FFV. However the FFV's construction material, relating to the various cross sections of housing (1) outer housing (101) inner housing (108), cannot be so thin that the structural integrity of any of the said cross sections is jeopardised. Therefore to maximise fluid flow whilst maintaining structural integrity, pump discharge chamber (13)/(113) transfer chamber(14)/(114) annulus chamber (15)/(115) valve discharge chamber (16)/(160) annulus ports (10)/(110) valve discharge ports (11)/(111) shoulders (2)/(102) (7)/(107) first interface (17)/(117) second interface (18)/(118), are preferably all concentrically aligned with their associated housing (1) outer housing (101) inner housing (108). To maintain the same fluid flow with the alternative of an eccentric alignment would require the FFV's constructional material to be too thin to maintain structural integrity. To maintain said structural integrity with the alternative of an eccentric alignment would require a smaller cross sectional area through the FFV which restricts fluid flow.

[0068] However, the cross sectional area of the artificial lift fluid path through the FFV can differ from the cross sectional area of the natural lift fluid path through the FFV. For instance where artificial lift exceeds natural lift the cross sectional area of the fluid path through the FFV for artificial lift can be larger than the cross sectional area of the fluid path through the FFV specific to natural lift. Wherein the artificial lift fluid path comprises, pump discharge chamber (13)/(113) shoulder (2)/(102) transfer chamber (14)/(114) valve discharge ports (11)/(111) valve discharge chamber (16)/(116), and the associated fluid path specific to natural lift comprises, annulus port (10)/(110) annulus chamber (15)/(115) shoulder (7)/(107). And where natural lift exceeds artificial lift the cross sectional area of the fluid path through the FFV for natural lift can be larger than the cross sectional area of the fluid path through the FFV specific to artificial lift. Wherein the natural lift fluid path comprises, annulus ports (10)/(110) annulus chamber (15)/(115) shoulder (7)/(107) transfer chamber (14)/(114) valve discharge ports (11)/(111) valve discharge chamber (16)/(116), and the associated fluid path specific to artificial lift comprises, pump discharge chamber (13)/(113) shoulder (2)/(102).

[0069] The wider the cross section of first interface (17)/(117) and of second interface (18)/(118) the greater the chance of first interface (17)/(117) and second interface (18)/(118) being hindered from sealing properly by solids carried by the fluid flow. To overcome this problem the FFV employs the smallest practicable cross section to form first interface (17/(117) and to form second interface (18)/(118). Whereby, first interface (17)/(117) and second interface (18)/(118) are each formed between the convex surface of a sphere segment and the concave surface of a cone segment as shown in Figure 1a (17) Figure 3a (18) Figure 6a (117) Figure 7a (118). In Figures 1, 3, 4, 5, 6, 7, 10, the convex surface is carried by the entire surface of moving part (4)/(104)/(204) which is a sphere. In Figures 12-21 inclusive the convex surface is respectively carried at each end of moving part (304), (404), (504), (604), (704), (804), (904), (1004), (1104), in the form of a sphere segment. In Figure 1a, Figure 3a, Figure 6a, Figure 7a the shown perpendicular cross section to the convex surface is straight. However, the said cross section could be convex as shown in Figure 22 or concave as shown in Figure23. Whereby the concave cross section in Figure 23 can have the same radius as the associated moving part's spherical section that forms the interface as per Figure 23, or where the concave cross section in Figure 23 has either a larger or smaller radius than the associated moving part's spherical section that forms the interface. Although the interfaces in Figure 22 and in Figure 23 show the first interface as per Figure 1 the interfaces in Figure 22 and in Figure 23 equally apply to the second interface and to Figures 1a, 3a, 6a, 7a, 4, 5, 9, 10, and with any of the moving part variations (4)-(1104) Although the preferred method of forming first interface (17)/(117) and second interface (18)/(118) is between a spherical segment and a cone segment, the said interfaces can each be formed between the convex surface of a cone carried by the single moving part and the concave surface of another cone fixed to a non moving part of the valve.

[0070] A component that moves requires a gap between itself and adjacent components in order to move. Without said gap moving components cannot move freely. The smaller the gap the greater is the risk of seizure due to solids becoming trapped in the gap or/and by heat or/and damage distorting components between which the gap is formed. The smaller the gap the smaller the associated manufacturing tolerances and greater need for manufacturing precision which proportionally increases manufacturing cost. Whereby, manufacturing cost and the risk of seizure both increase as the surface area of the gap increases. Also, the more moving components and/or more precision gaps the more risk of seizure. Furthermore, the greater the distance a moving component's movement is guided by a precision gap the greater is the need for the precision gap's axial accuracy over the moving component's movement in addition to the dimensional accuracy of the gap. Whereby, the gap's axial accuracy further increases manufacturing costs. The axial accuracy can be between two different diameters as with, for example, the exhaust and inlet poppet valves of an internal combustion engine or between more than two different diameters. In the poppet valve example precision machining is required between the, valve stem and valve guide, valve face and valve seat, and also require precision alignment between the, valve guide and valve seat, valve stem and valve face.

[0071] Therefore a design aimed at minimising the risk of seizure and minimising manufacturing costs would benefit from, the smallest number of moving components, the smallest number of gaps, gaps with the smallest surface area, the largest possible gap dimension, the least axial accuracy along the gap's length, the least dimensional accuracy of the moving component. In accord with this philosophy the FFV employs one moving component whose movement does not require a precision gap which negates issues about gap surface area, gap numbers, and gap axial alignment. Thereby, limiting the need for precision manufacturing associated with moving part (4)-(1104) to, a consistent radius of the one or each convex surface segment of moving part (4)-(1104) that forms first interface (17)/(117) and forms second interface (18)/(118), and to a consistent diameter of the concave portion of shoulder (2)/(102) and of shoulder (7)/(107) where first interface (17)/(117) and second interface (18)/(118) are respectively formed. The use of a spherical segment or segments for moving part (4)-(1104) permits first interface (17)/(117) and permits second interface (18)/(118) without the need for precision axial accuracy between first interface (17)/(117) and second interface (18)/(118). Furthermore, the use of a spherical segment or segments for moving part (4)-(1104) permits the entire movement of moving part (4)-(1104) between first interface (17)/(117) and second interface (18)/(118) without the need for precision axial accuracy because the spherical segments allow moving part (4)-(1104) to be misaligned longitudinally between first interface (17)/(117) and second interface (18)/(118) without jamming in the associated clearance gap unlike a moving part that has a surface parallel to the direction of travel. Consequently, the moving part as represented by the non limiting examples (4)-(1104) does not house or incorporate one or more rotational or linear axes for interface purposes or for moving between the two interfaces. In all instances the moving part as represented by the non limiting examples (4)-(1104) self aligns with each interface.

[0072] An interface formed by a spherical convex segment of the moving part provides the moving part with more than one interface line and thus distributes interface wear around the moving part's spherical segment which is especially relevant when the moving part is made from a softer material than the counterpart interface components.

[0073] Preferably, the diameter of the spherical segment of moving part (4)-(1104) that forms first interface (17)/(117) should be larger than but as close to the diameter of first interface (17)/(117) without moving part (4)-(1104) jamming in first interface (17)/(117). The spherical segment of moving part (4)-(1104) that forms second interface (18)/(118) should be larger than but as close to the diameter of second interface (18)/(118) without moving part (4)-(1104) jamming in second interface (18)/(118). In this way moving part (4)-(1104) is as small as possible which, provides more room for the fluid flow through transfer chamber (14)/(114), minimises the mass of moving part (4)-(1104) which permits moving part (4)-(1104) to be moved with smaller flow rates than otherwise would be the case, ensures first interface (17)/(117) and second interface (18)/(118) are formed with the smallest cone angle from the longitudinal direction which helps, first interface (17)/(117) and second interface (18)/(118) seal, moving part (4)-(1104) to be held in first interface (17)/(117) and in second interface (18)/(118), to minimise the profile of moving part (4)-(1104) exposed to the fluid flow in transfer chamber (14) which helps to prevent moving part (4)-(1104) from any undesirable breaking of first interface (17)/(117) and second interface (18)/(118).

[0074] Preferably second interface (18)/(118) should be as close as is practicable possible to annulus ports (10)/(110) and valve discharge ports (11)/(111) to limit the distance that natural lift is reversed during its transition from annulus chamber (15)/(115) to valve discharge chamber (16)/(116) to limit restriction to the natural lift fluid flow. Preferably valve discharge ports (11)/(111) should also be as close as is practicably possibly to second interface (18)/(118) to help ensure moving part (4)/(1104) is moved to the second interface (18)/(118) by the passing fluid exiting transfer chamber (14)/(114) into valve discharge ports (11)/(111) during artificial lift. Preferably all, or as many as is practicably possible, corners of the artificial lift and natural lift flow paths are rounded to assist fluid flow.

[0075] To further help first interface (17)/(117) and second interface (18)/(118) seal, the interfaces or/and moving part (4)/(1104) can be made from a material, dissimilar to shoulders (2)/(102), (7)/(107) that better helps to seal the interfaces. Wherein said dissimilar materiel can be but not necessarily, housed in a groove concentric to one or both interfaces. The said dissimilar material includes lignum vitae or other ironwood.

[0076] Figure 10 shows Figure 1 with the addition of guide rails (221) for moving part (204) to help ensure moving part (204) only moves between the first position and the second position. In relation to each other, guide rails (221) can be, the same, parallel, not parallel, of different cross sectional shapes symmetrical and non symmetrical, of different cross sectional areas, from each other or combinations thereof. Each guide rail (221) can vary in its cross sectional area and shape along its own length. Each guide rail (221) can be either, straight, or kinked or curved or combinations thereof in one or more locations along its length. The FFV can have one or more guide rails (221). Where more than one guide rail (221) exits each can be a separate component made from either the same or different material or formed from the same billet of material or combinations thereof. The guide rails (221) can be of different overall lengths from each other. The guide rails (221) should be positioned to ensure moving part (4)/(1104) reciprocates only between the first position and the second position in accord with the direction of the fluid flow. Guide rails (221) can also help moving part (4)/(1104) to initially rest concentrically to first interface (17) and second interface (18) towards the end of moving part's (4)/(1104) movement towards each interface. In Figures 6 and 7 moving part (104) is guided by inner housing (108). All of the previously discussed equally applies to Figure 10.

[0077] Figures 1, 3, 4, 5, 6, 7, 10 show moving part (4)/(104)/(204) as a solid sphere. Alternatively moving part (4)/(104)/(204) can be hollow to reduce mass and thereby better help moving part (4)/(104)/(204) move between the first position and the second position especially with small flow rates.

[0078] Guide rails (221) and inner housing (108) both allow an elongated alternative to a sphere for the single moving part. Figures 12 - 21 inclusive show a non limiting selection of alternatives to a sphere for the single moving part. Figure 12 shows two half spheres interconnected by a cylinder of the same diameter as the two half spheres. Figure 12 provides a greater scope for the positioning of valve discharge ports (11)/(111) in relation to the two interfaces without effecting the diameter of the two interfaces. Figure 13 shows Figure 12 but where the cylinder has a smaller diameter than the two half spheres. Figure 13 minimises the surface area of the close gap between moving part (404) and associated guide rails (221) or inner housing (108) to minimise the risk of jamming. Figure 14 shows Figure 13 but with a blind hole. Figure 14 reduces the mass of moving part (504) to help moving part (504) respond to smaller flow rates than otherwise would be the case. Figure 15 shows Figure 13 but with an alternative method of reducing mass to Figure 14 which has the benefit of providing additional faces (622) to help moving part (604) be carried by the fluid flow between the two interfaces. Figure 16 shows a variation of Figure 15 where Figure 16 has just one additional face (722) to better help moving part (704) be carried by the fluid flow in one direction and a tapered section (723) to better guide the fluid flow to additional face (722). Figure 16 is also truncated at one end to help reduce mass with the previously described advantages of reducing mass. Figure 17 expands the theme of Figure 15 by providing several more additional faces (822) to help moving part (804) be carried by the fluid flow. Figure 18 shows a cross section of Figure 16 to reveal a bored centre as a further way of reducing mass. Figure 19 shows Figure 15 but with one of the spherical halves having a smaller diameter than the other. Figure 19 would suit an FFV whose two interfaces have different diameters from each other to, for instance, facilitate different fluid flow rates between natural lift production and artificial lift production. Figure 19 also incorporates a Figure 17 type additional face (1022) which also serves to guide moving pat (1004) via guide rails (221) or inner housing (108) between the two interfaces. Figure 20 shows Figure 15 with the addition of longitudinal sections (1124). The fluid flow exiting the ESP twists according to the rotational direction of the ESP pump's impellers. Depending on how close the FFV is positioned to the ESP the fluid flow entering the FFV can also be twisting. This twist could be harnessed by longitudinal sections (1124) to cause moving part (1104) to similarly twist. The twisting motion can help moving part (1104) to remove solids from second interface (18)/(118) when second interface (18)/(118) is first formed to help second interface (18)/(118) seal. Figure 21 shows cross section CC of Figure 20.

[0079] So far annulus ports (10)/(110)/(210) and valve discharge ports (11)/(111)/(211) have been shown parallel to the longitudinal axis of the FFV. Alternatively annulus ports (10)/(110)/(210) and valve discharge ports (11)/(111)/(211) can be fashioned into a helix in a direction to match the twist direction of the fluid exiting the ESP to further reduce restrictions to the fluid flow through the FFV. The closer the FFV is to the ESP the more relevant said helix arrangement would be.

[0080] To assist moving parts (4)-(1104) move from the second position to the first position the moving part (4)-(1104) can spring assisted with one end of the spring in contact with moving part (4)-(1104) and with the spring's other end in contact with the internal wall of annulus chamber (15)/(115)/(215).

[0081] In Figure 1, for example, housing (1) is shown with a female thread (25) and with a male thread (26) for joining the FFV to the string or to the ESP and string. Alternatively, female thread (25) can be where male thread (26) is shown in Figure 1 with male thread (26) where female thread (25) is shown in Figure 1. Alternatively housing (1) can have a female thread (25) at both ends or a male thread (26) at both ends. Whereby one or both threads can be left hand or right hand or/and be single or multi start. The same equally applies to outer housing (101)/(201).

[0082] So far discussed shoulder (2) is retained by a thread. Alternatively shoulder (2) can be retained by an interference fit or/and by a circlip in a groove, or by any other commonly known fastening means. The FFV can be made from any suitable material that is also suitable for downhole operations.

[0083] In Figure 6 and Figure 7 cap (119) includes an internal thread (127) to which a draw bar can be fitted to help extract inner housing (108) from outer housing (101) should the FFV need to be disassembled.

[0084] The outer surface of housing (1)/(101)/(201) can be recessed to hold one or more power cable/s to ensure the or each power cable does not slip and cover any of the annulus ports (10)/(110)/(210). Alternatively the outer surface of housing (1)/(101)/(210) can be fashioned to fit a bracket/s or/and clip/s whereby the bracket/s or/and clip/s hold the power cable/s to ensure the or each power cable does to cover any of the annulus ports (10)/(110)/(210).

[0085] Figure 24 shows a variation of Figure 1 where housing (1201) is a two part component joined by thread (1225) as a means of assembling moving part (1204). Each component in Figure 24 can be a machined casting or machined from billet. All of the herein previously described variations equally apply to Figure 24. A guide for moving part (1204) can be provided by either the addition of guides (221) from Figure 10. Alternatively, a guide for moving part (1204) can be provided by extending the wall of chamber (1215) into chamber (1214) in the manner of inner housing (108) in Figures 6 and 7, or/and by extending the wall of chamber (1213) into chamber (1214), whereby said extended wall/s would include ports to provide communication between chambers (1214) and chambers (1213) and (1215).

Claims

1. A valve for use with a downhole pump, wherein the valve comprises a single moving part that in a first position forms only a first interface and in a second position forms only a second interface, each interface presenting a barrier that cannot be breached by fluid, whereby the first interface directs fluid to the production tubing only from the annulus and the second interface directs fluid to the production tubing only from the pump, the pump and annulus and production tubing are simultaneously interconnected by a chamber of the valve when the single moving part is between the first and second positions, each interface is maintained or broken depending on the fluid pressure differential across the associated interface, the single moving part moves between the first position and second position according to the fluid direction through the valve, **characterised by** each of the two interfaces being formed between a convex surface of the single moving part and a concave surface of a non moving part of the valve, whereby the single moving part self aligns with each interface and only via the interface, and where the single moving part does not house or incorporate one or more rotational or/and linear axes.

2. A valve according to claim 1 where the smallest cross sectional area of the fluid path defined by the first interface has a different cross sectional area to the smallest cross sectional area of the fluid path defined by the second interface.

3. A valve according to any of the preceding claims comprising four chambers and associated ports wherein the fluid directed by the first interface enters the production tubing from the valve via a discharge chamber via discharge port/s via a transfer chamber via an annulus chamber via annulus port/s and the fluid directed by the second interface enters the production tubing from the valve via a discharge chamber via discharge port/s via a transfer chamber, via a pump discharge chamber.

4. A valve according to claim 3 where the chambers and ports are concentric to the valve's longitudinal centre line.

5. A valve according to any of the previous claims where one or both of claim 1's concave surfaces are formed by a cone.

6. A valve according to any of the claims 1, 2, 3, 4, where one or both of claim 1's concave surfaces have a convex cross section.

7. A valve according to any of the claims 1, 2, 3, 4, where one or both of claim 1's concave surfaces have a concave cross section.

8. A valve according to any of the previous claims where the convex surface of claim 1 is formed by a single sphere.

9. A valve according to any of the claims 1-7 where the convex surface of claim 1 is formed by two cone segments positioned from each other by an interconnecting section.

10. A valve according to any of the claims 1-7 where the convex surface of claim 1 is formed by two spherical segments positioned from each other by an interconnecting section.

11. A valve according to any of the claims 1-7 where the convex surface of claim 1 is formed by one spherical segment and one cone segment positioned from each other by an interconnecting section.

12. A valve according to any of the claims 9, 10, 11, where at least one of the segments is truncated.

13. A valve according to any of the claims 9, 10, 11, 12, where the largest diameter of each segment is a different dimension from the other.

14. A valve according to any of the claims 9, 10, 11, 12, 13, where the interconnecting section is cylindrical.

15. A valve according to claim 14 where the interconnecting cylindrical section has a smaller diameter than the largest diameter of at least one of the two segments.

16. A valve according to claims 14 and 15 where the interconnecting cylindrical section is a cone.

17. A valve according to any of the claims 9 - 16 where the interconnecting section includes additional faces.

18. A valve according to any of the claims 9 - 17 where the interconnecting section includes one or more longitudinal sections.

19. A valve according to any of the preceding claims where the single moving part is hollowed.

20. A valve according to any of the previous claims where the single moving part is guided between the first and second positions by guide sections integral with the valve's housing.

21. A valve according to any of the claims 1-19 where the single moving part is guided between the first and second positions by a inner housing.

22. A valve according to any of the preceding claims where at least one of the concave surfaces of Figure 1 is carried by a separate component from the housing or from the outer housing.

23. A valve according to any of the claims 3 - 22 where the ports and/or guides are formed into a helix.

24. A valve according to any of the preceding claims where at least one of the interfaces is formed by a material dissimilar to the housing.

25. A valve according to any of the preceding claims where at least some of the internal corners intersecting fluid course changes are rounded.

26. A valve according to any of the preceding claims where the single moving part's movement is spring assisted.

27. A valve according to any of the preceding claims where the housing or outer housing is fashioned to directly or indirectly secure one or more power cables.

28. A valve according to any of the preceding claims carrying either a male or female thread at one or at both ends to secure the valve to the production tubing or to the production tubing and pump.

29. A valve according to any of the preceding claims where the pump is an ESP.

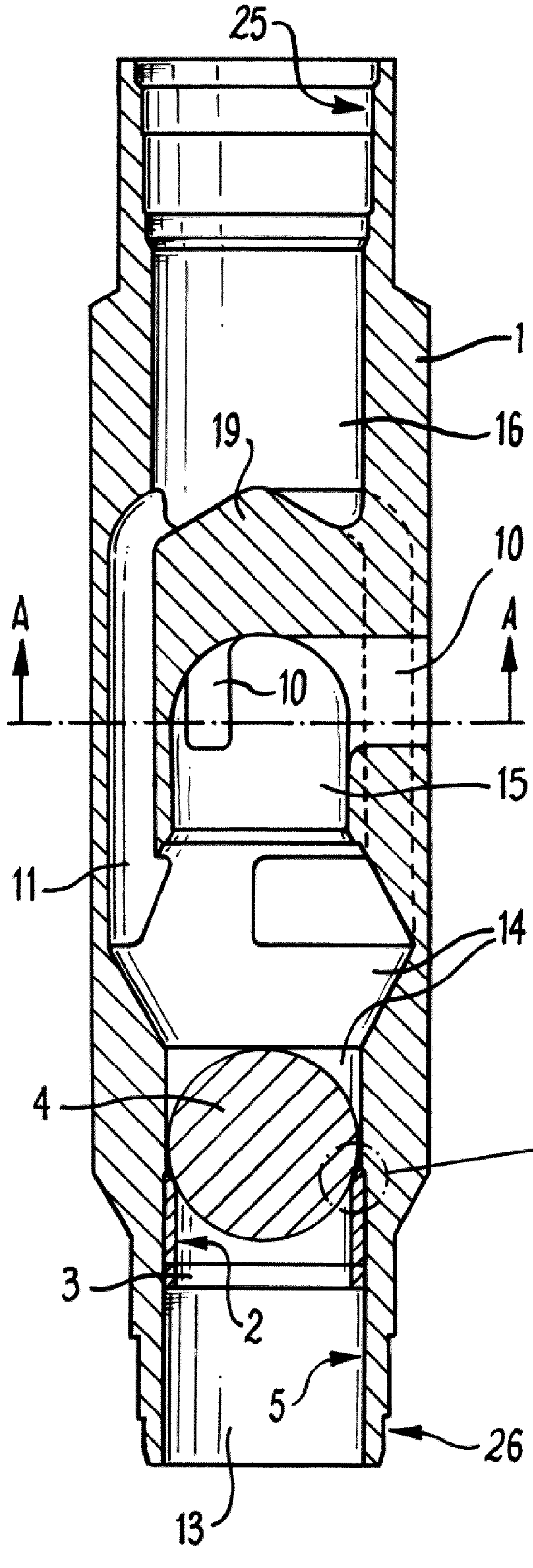


Fig. 1

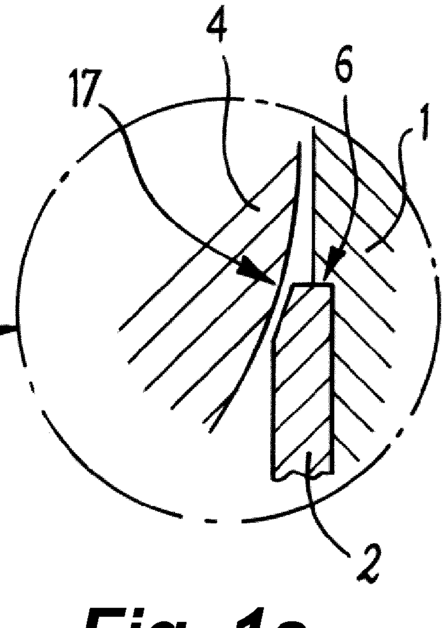
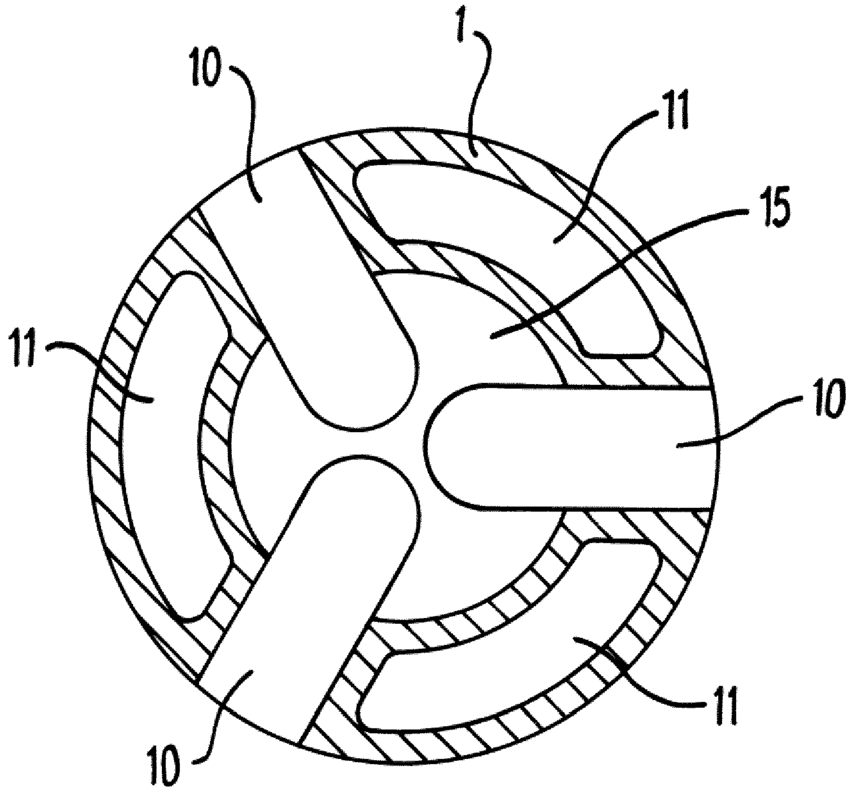


Fig. 1a



Section AA

Fig. 2

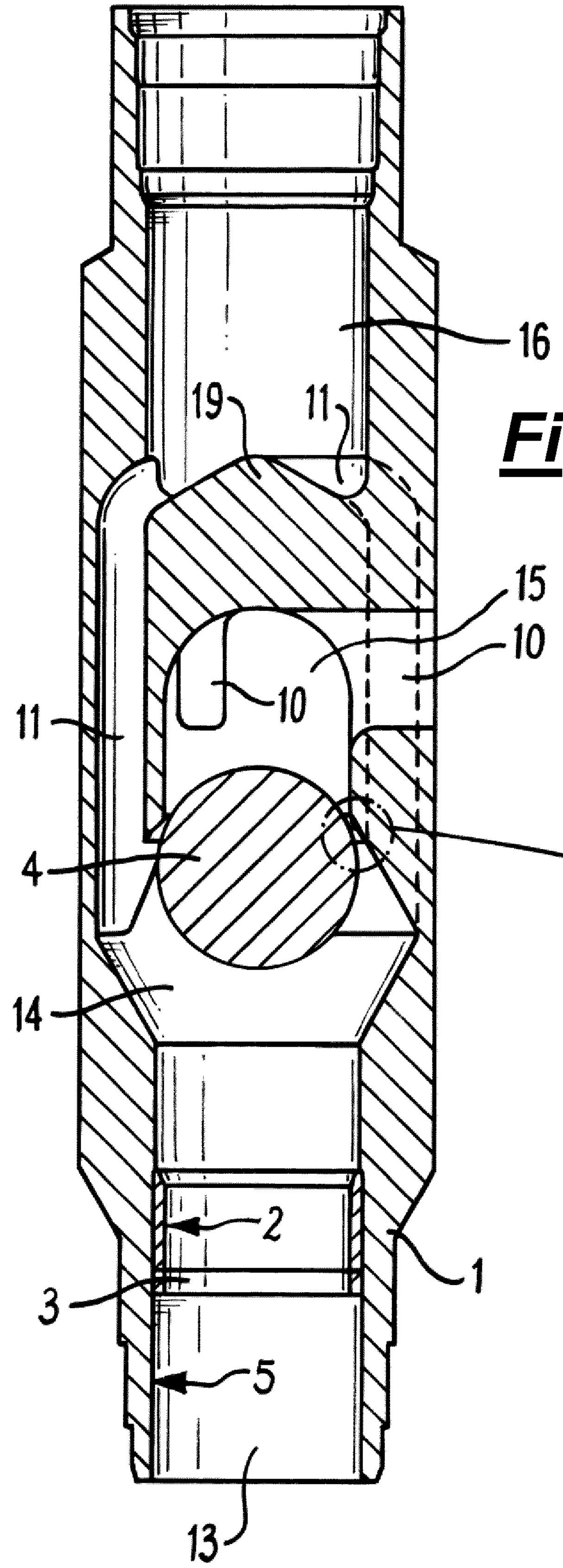


Fig. 3

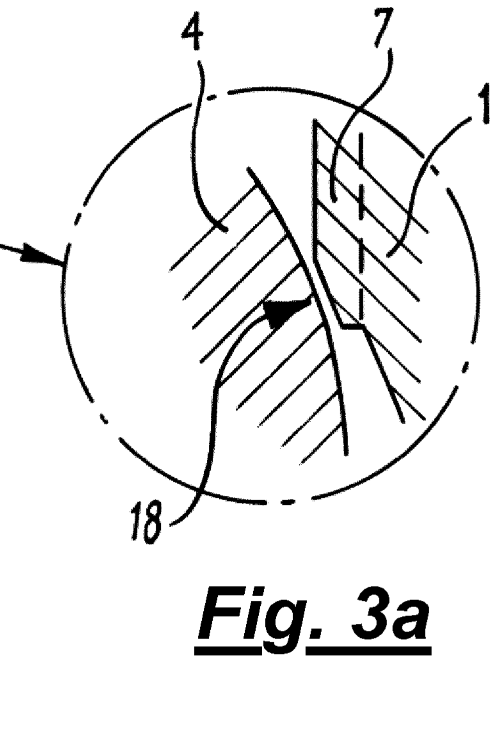


Fig. 3a

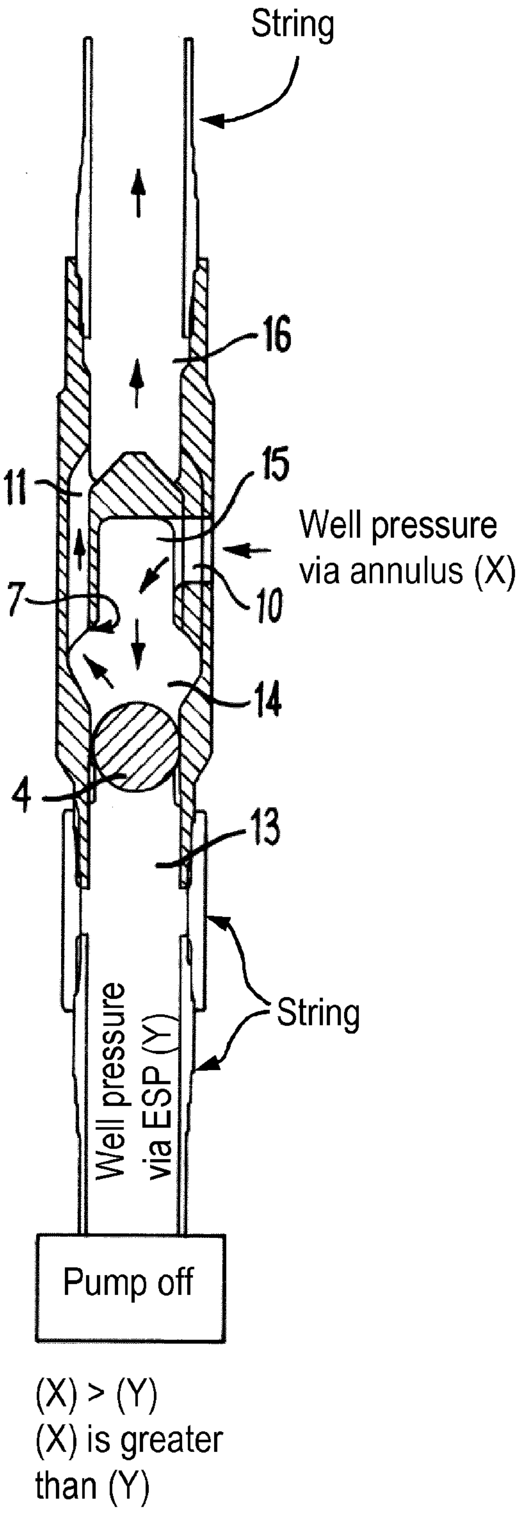

String
16
15
11
Well pressure
via annulus (X)
7
10
14
4
13
String
Well pressure
via ESP (Y)
Pump off
(X) > (Y)
(X) is greater
than (Y)

Fig. 4

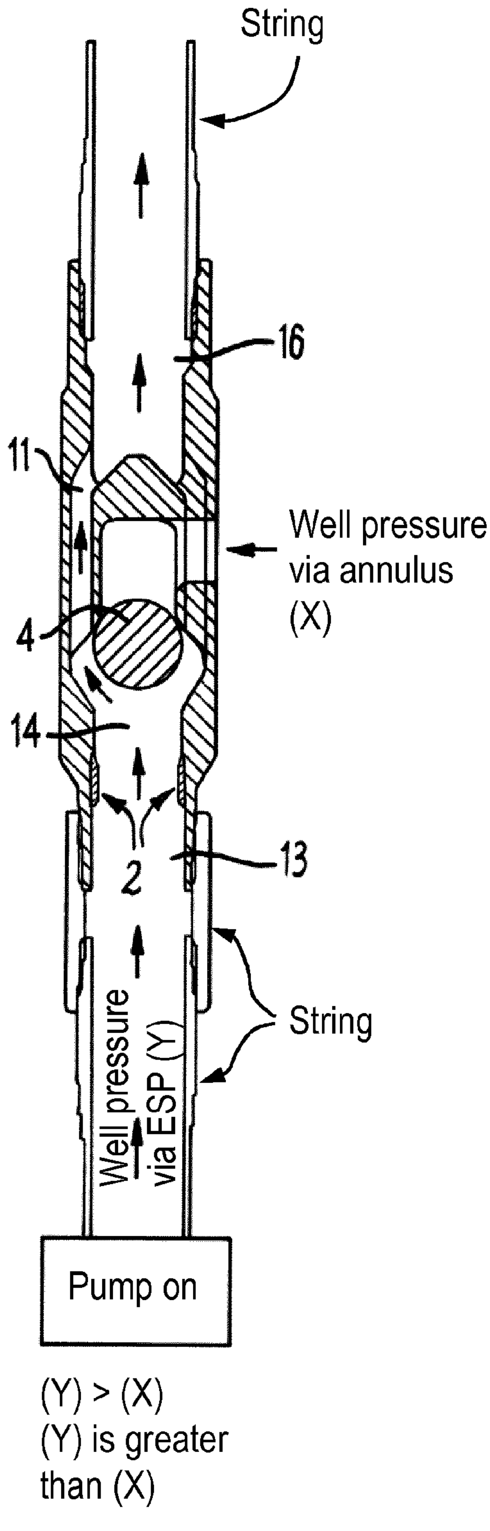

String
16
11
Well pressure
via annulus
(X)
4
14
13
2
String
Well pressure
via ESP (Y)
Pump on
(Y) > (X)
(Y) is greater
than (X)

Fig. 5

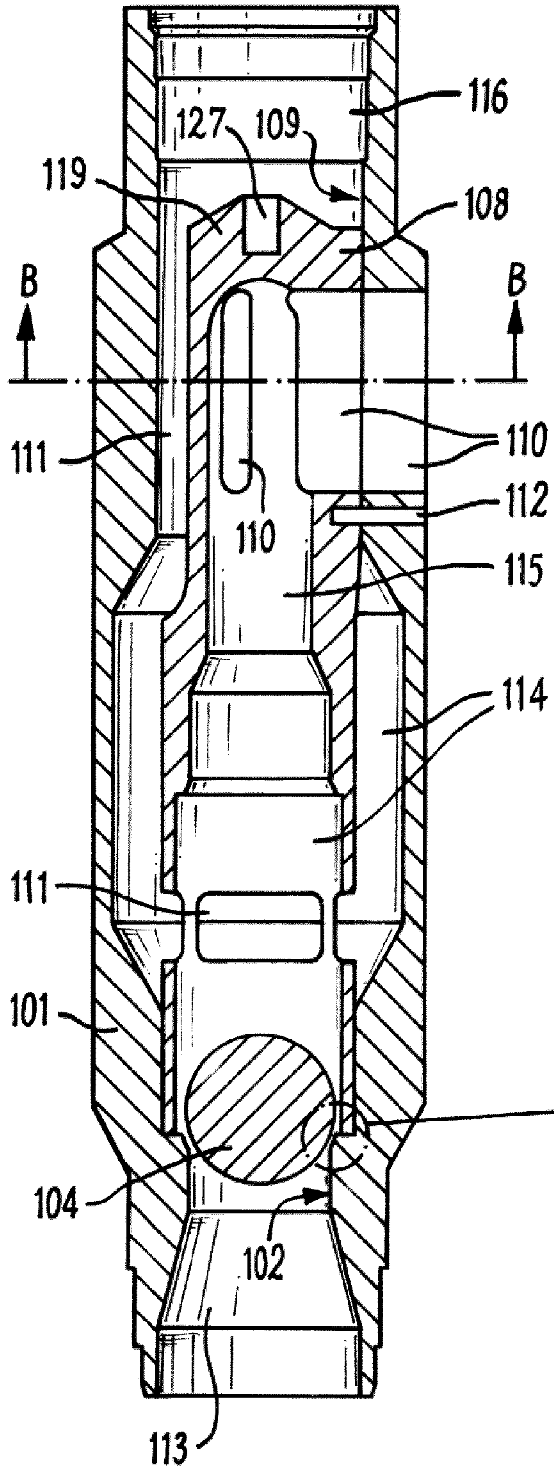

116
127
109
119
108
B
B
110
111
110
112
115
114
111
101
104
102
113

Fig. 6

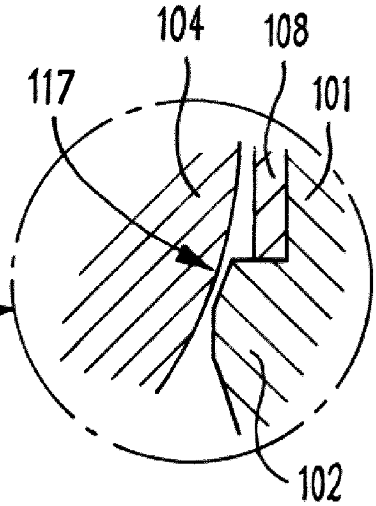

104
108
117
101
102

Fig. 6a

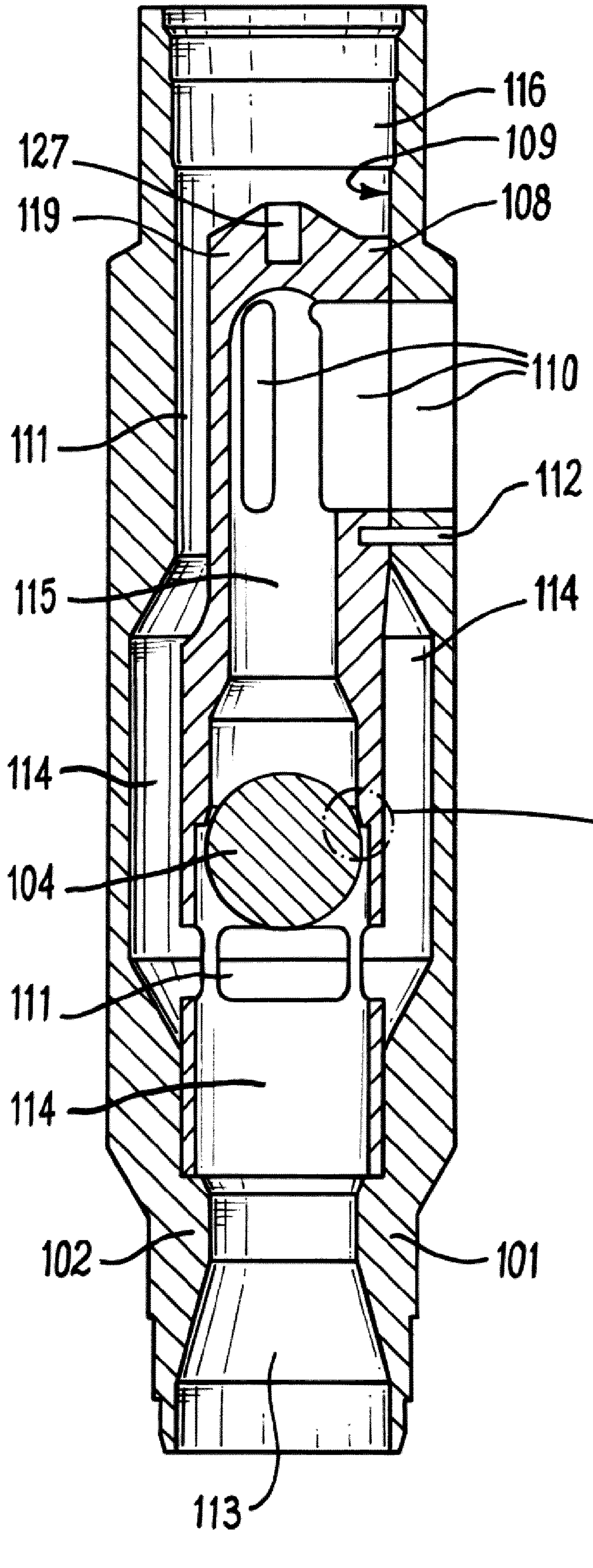

116
109
127
108
119
110
111
112
115
114
114
104
111
114
102
101
113

Fig. 7

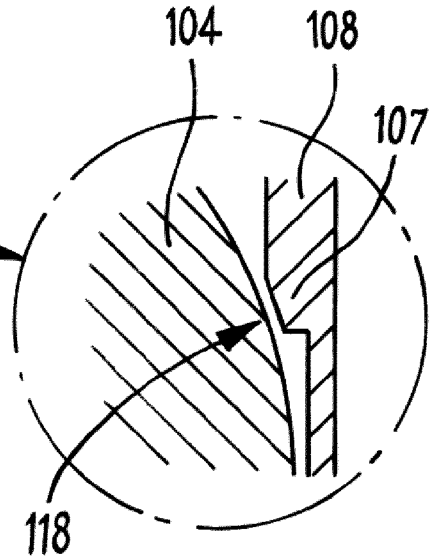
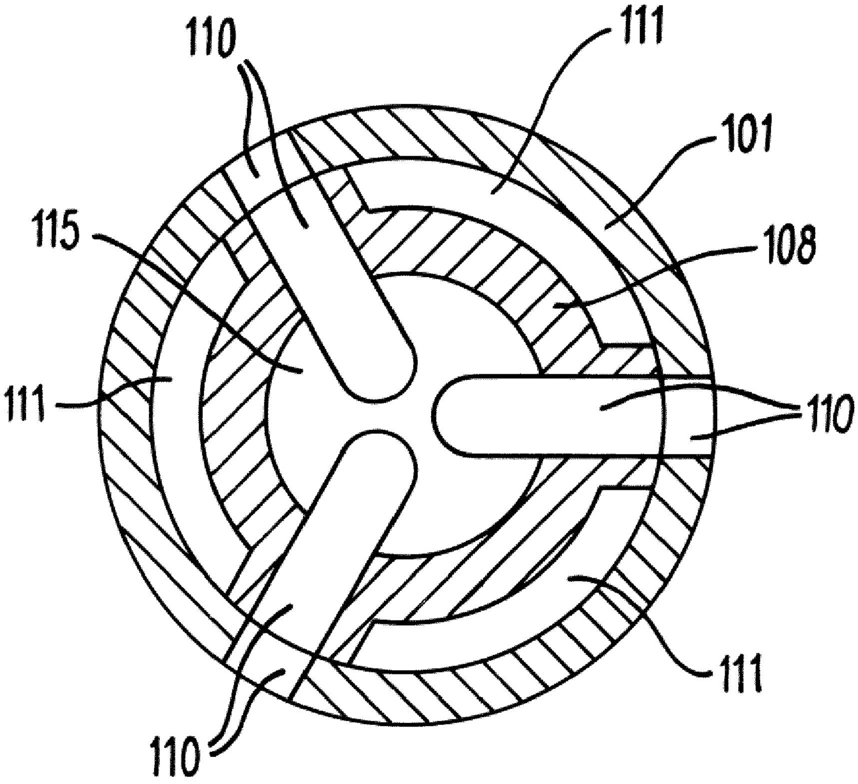

104
108
107
118

Fig. 7a



Section BB

Fig. 8

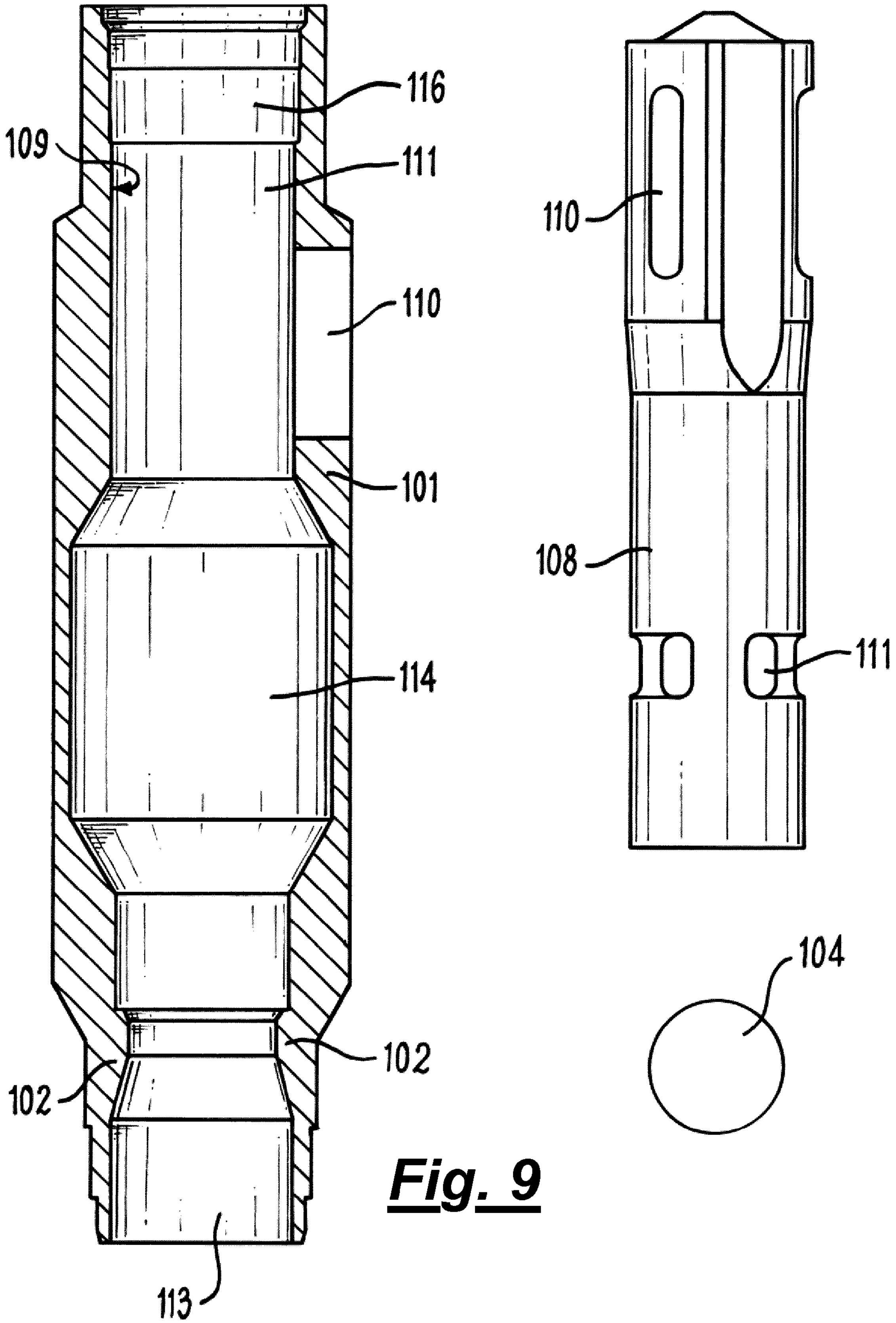


Fig. 9

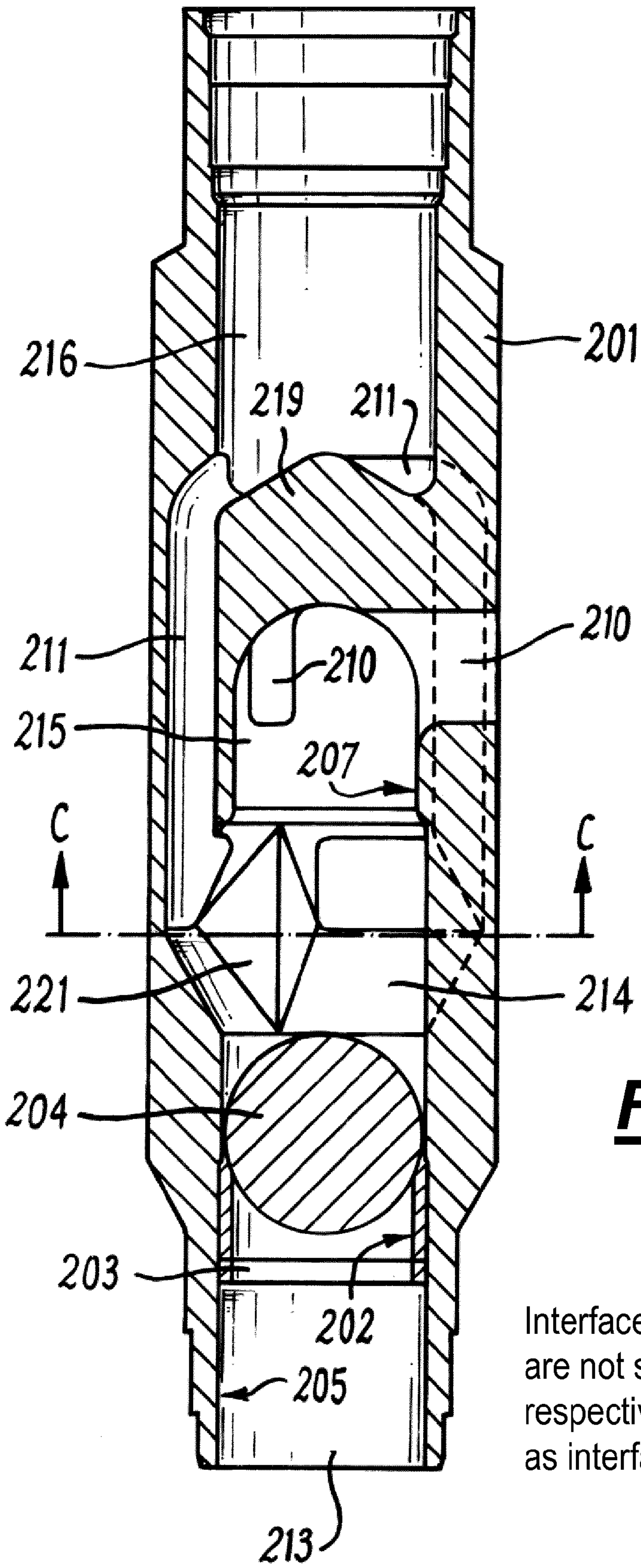
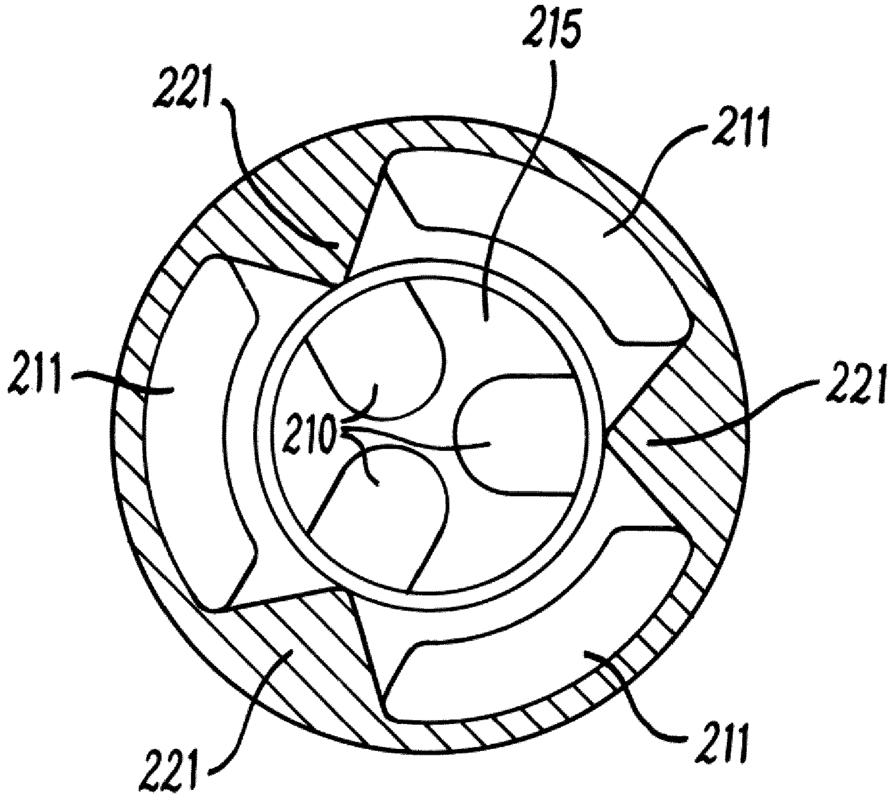


Fig. 10

Interfaces 217, 218 are not shown but are respectively the same as interfaces 17, 18



Section CC

Fig. 11

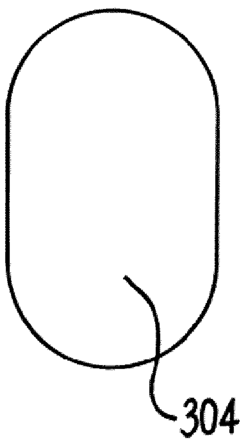


Fig. 12

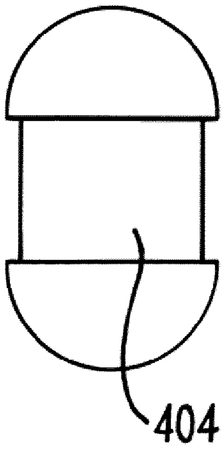


Fig. 13

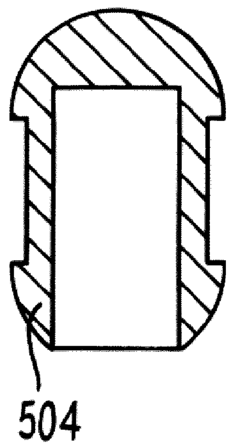


Fig. 14

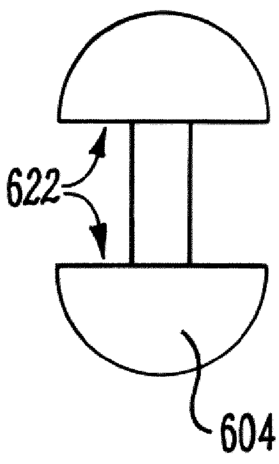


Fig. 15

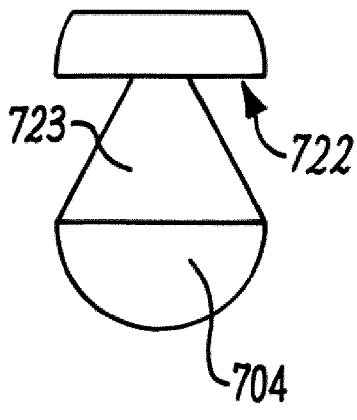


Fig. 16

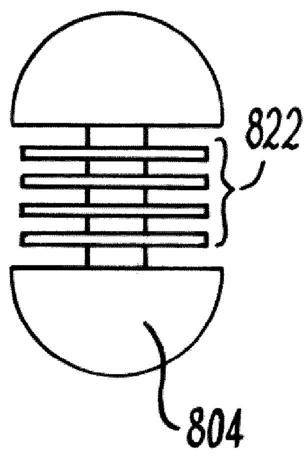


Fig. 17

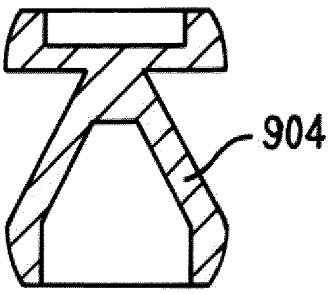


Fig. 18

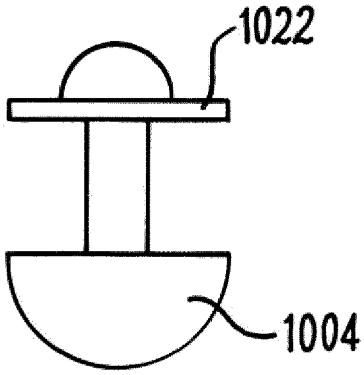


Fig. 19

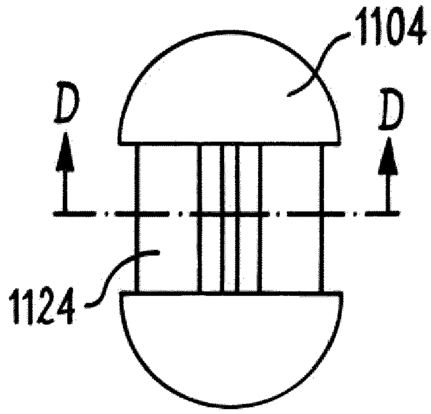


Fig. 20

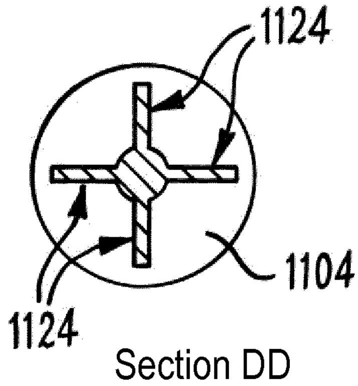


Fig. 21

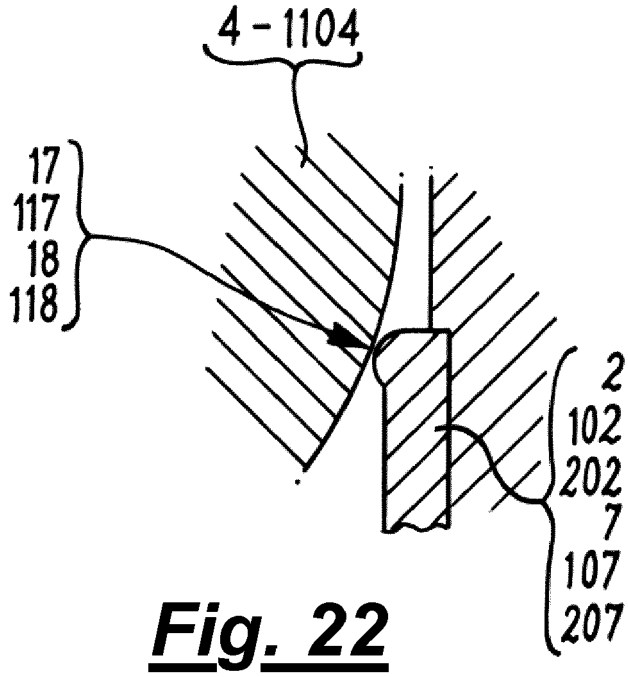

4 - 1104
17
117
18
118
2
102
202
7
107
207

Fig. 22

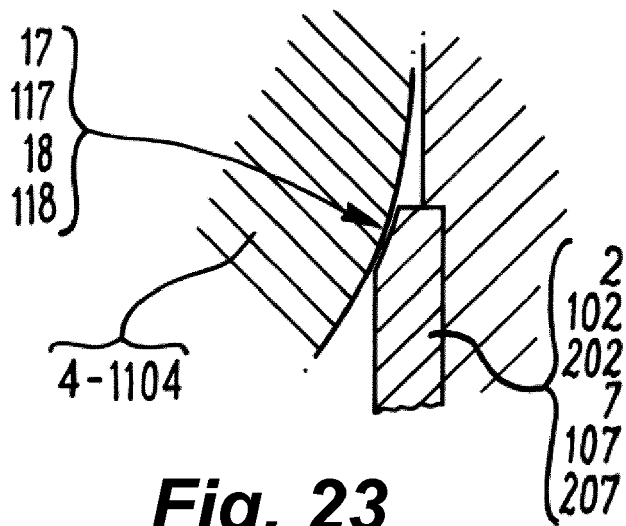

17
117
18
118
4-1104
2
102
202
7
107
207

Fig. 23

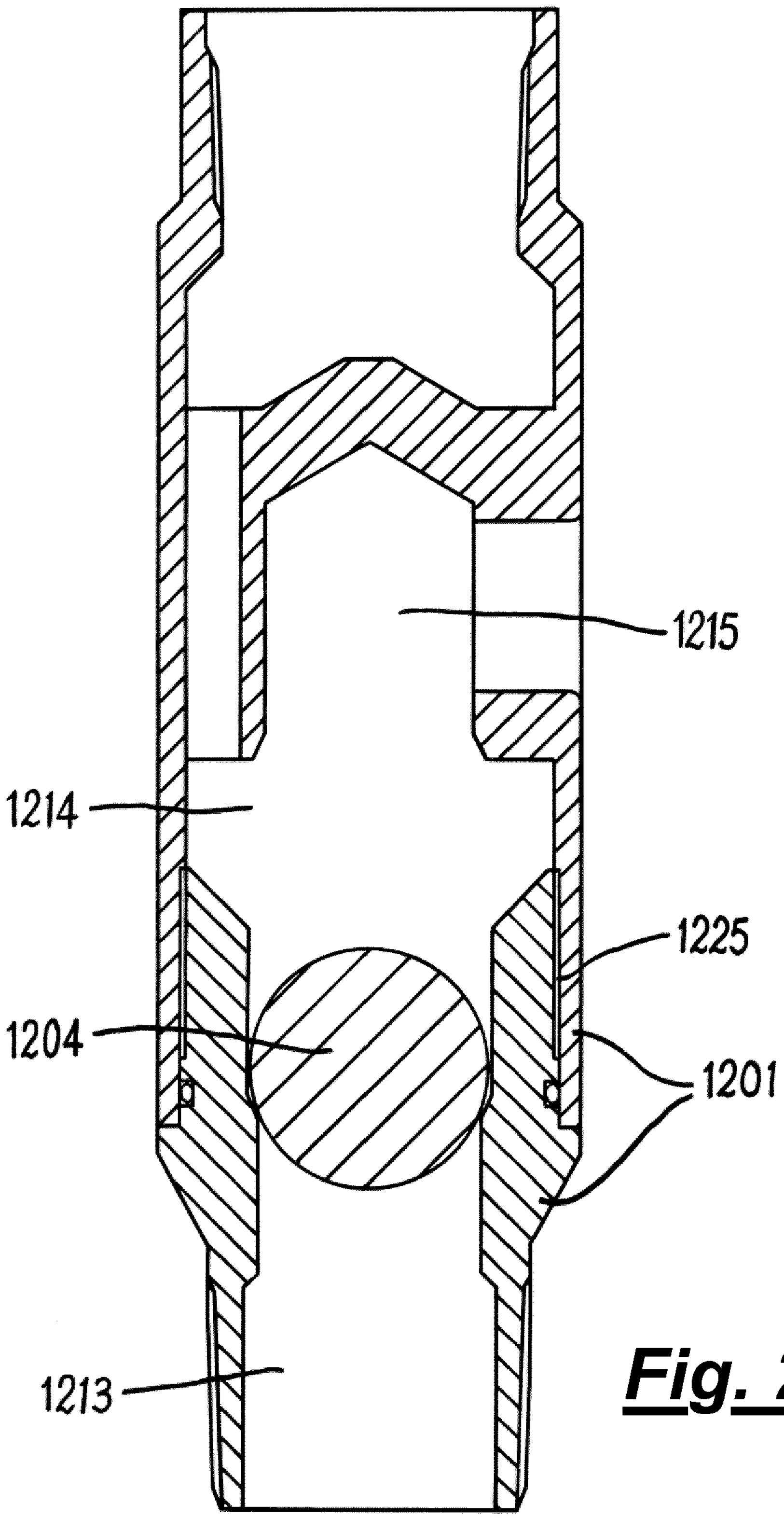


Fig. 24