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(54) HIGH PRESSURE GAS LIFT VALVE WITH DUAL EDGE WELDED BELLOWS

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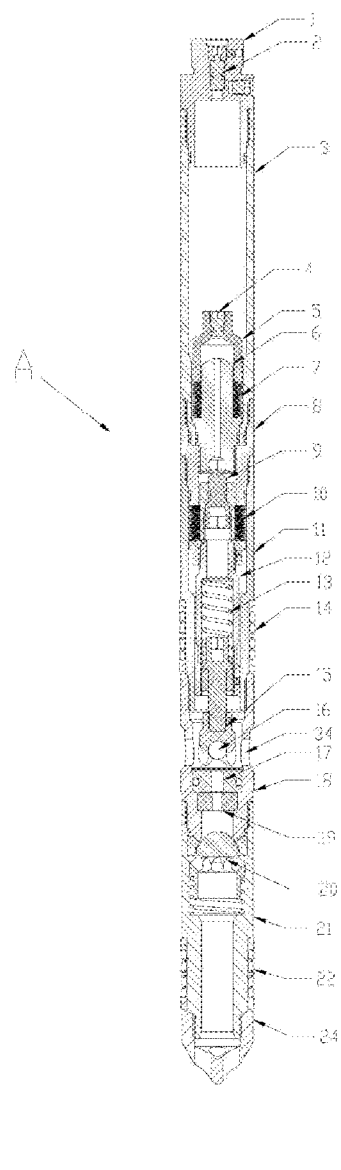
(57) **ABSTRACT**

High pressure gas lift valve with dual edge welded bellow subassembly where two bellows are incorporated in sealed configuration filled with silicone oil. Bellows are of different sizes featuring equal volumetric oil displacement for the pre-set total compression/expansion which corresponds to equal stem travel. By design both bellows can be fully compressed solid preventing bellows overstressing allowing extremely high pressure to be applied to both bellows. Lower bellow effective area is larger for orifice area than upper bellow area. This eliminates differential pressure across the bellows during valve opening resulting in equalized internal/external bellow stresses. Both bellows work only in compression from free length to full compression.

This results in bellow internal/external pressure and stress level equalization and long cycle life. Valve withstands high injection pressure for well integrity testing. Once lower bellow is fully compressed solid high pressure would not be transmitted to upper bellow and vice versa.



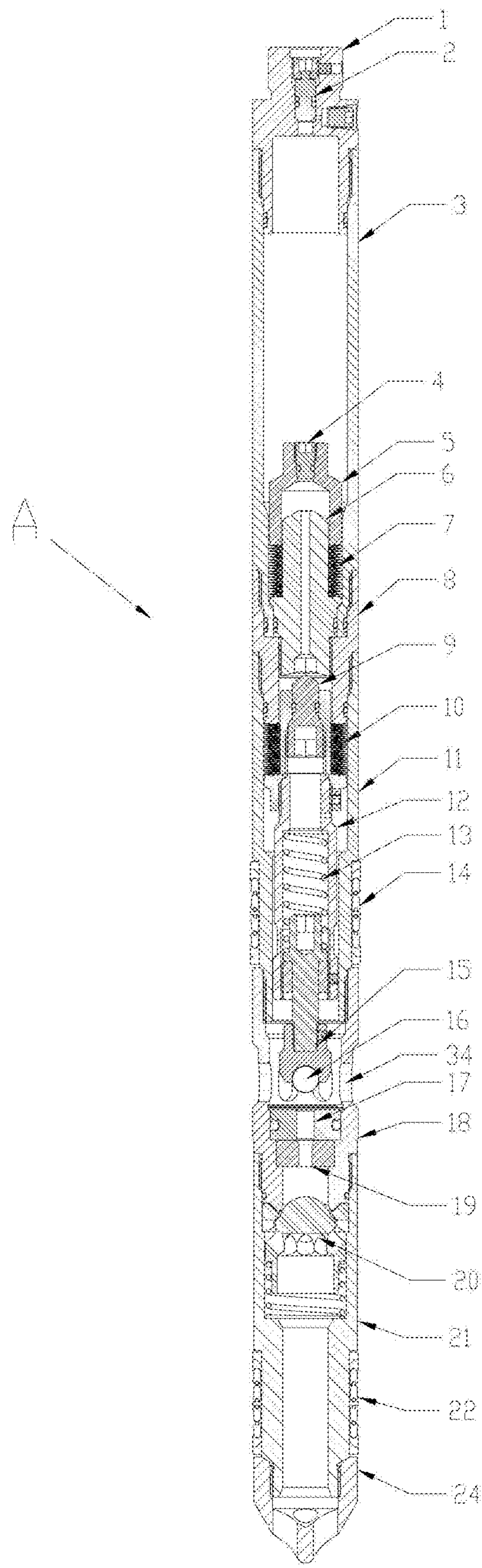


FIG. 1

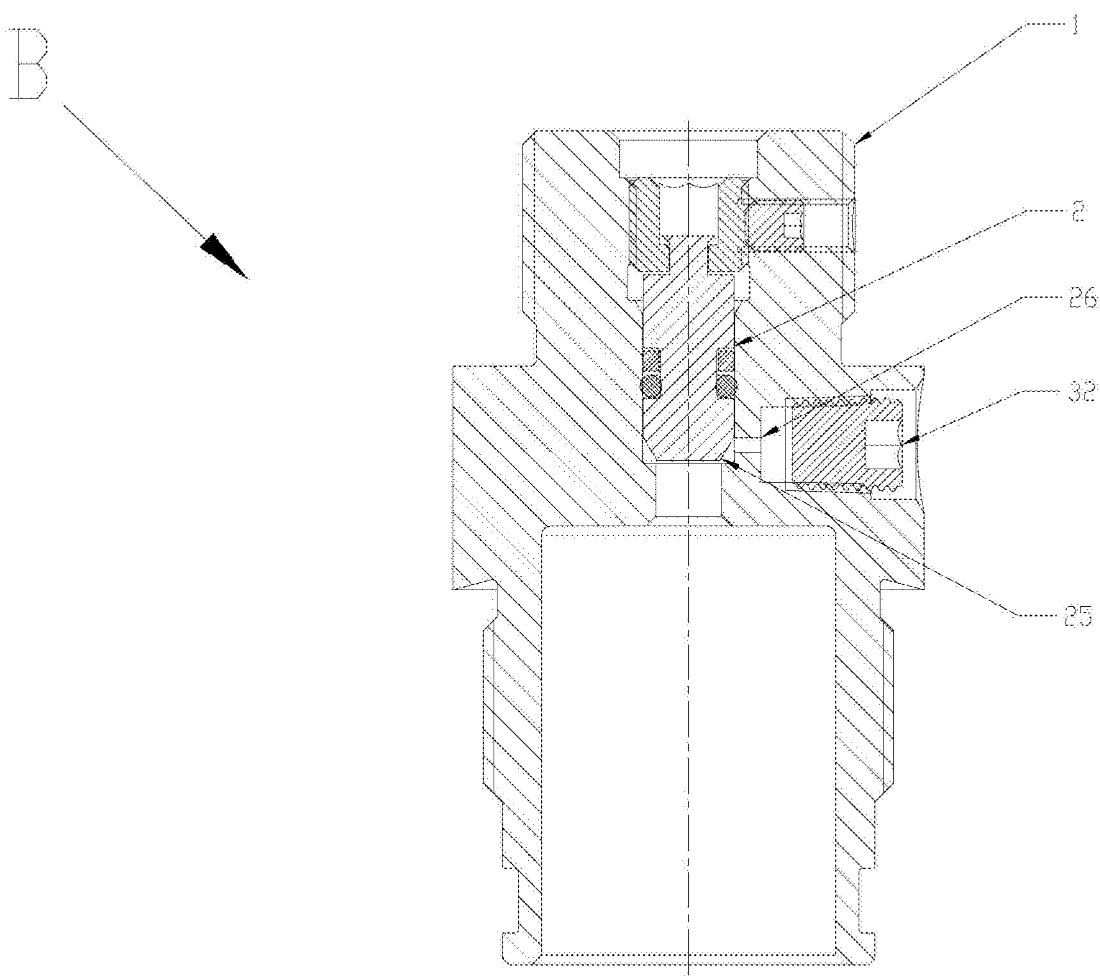


FIG. 2

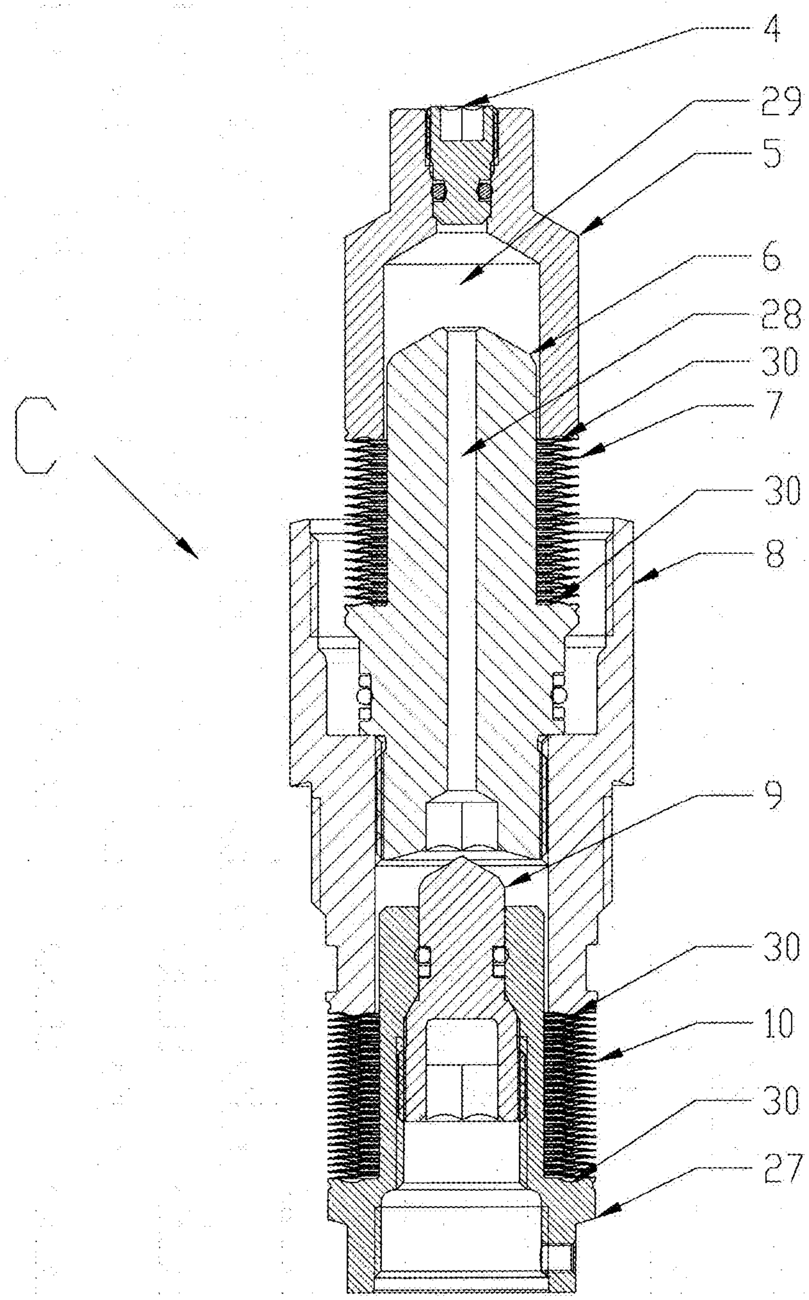


FIG. 3

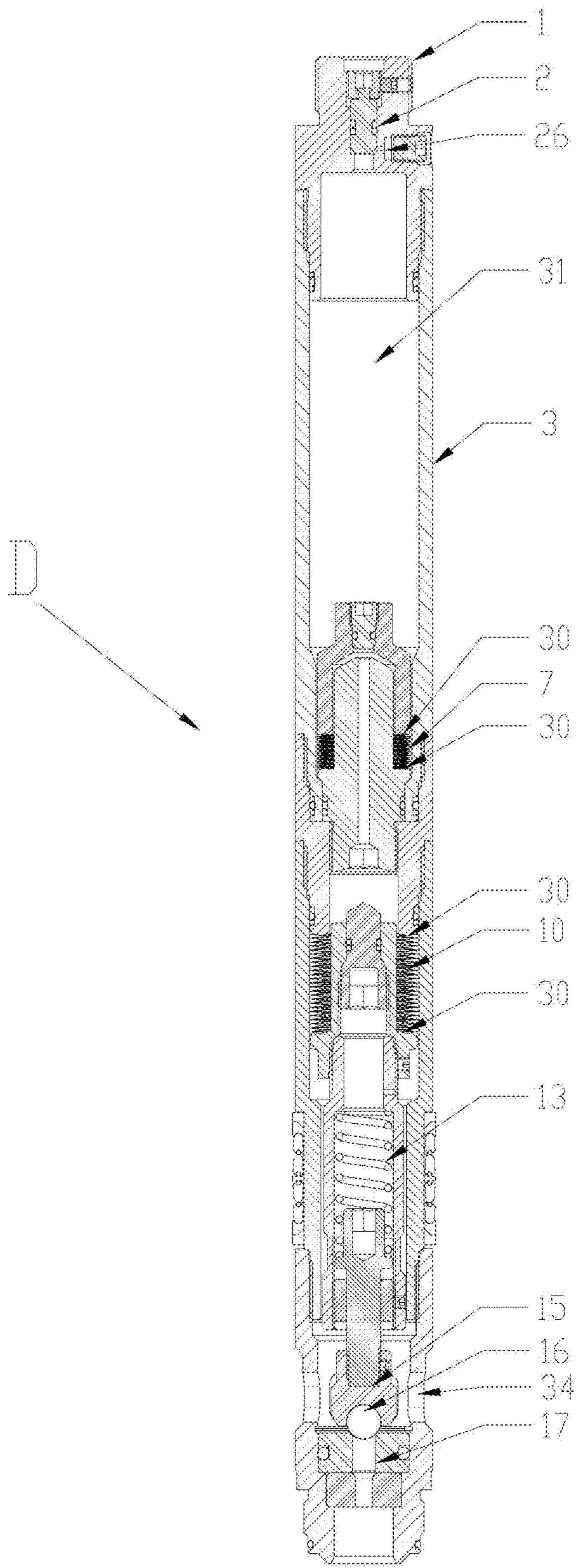


FIG. 4

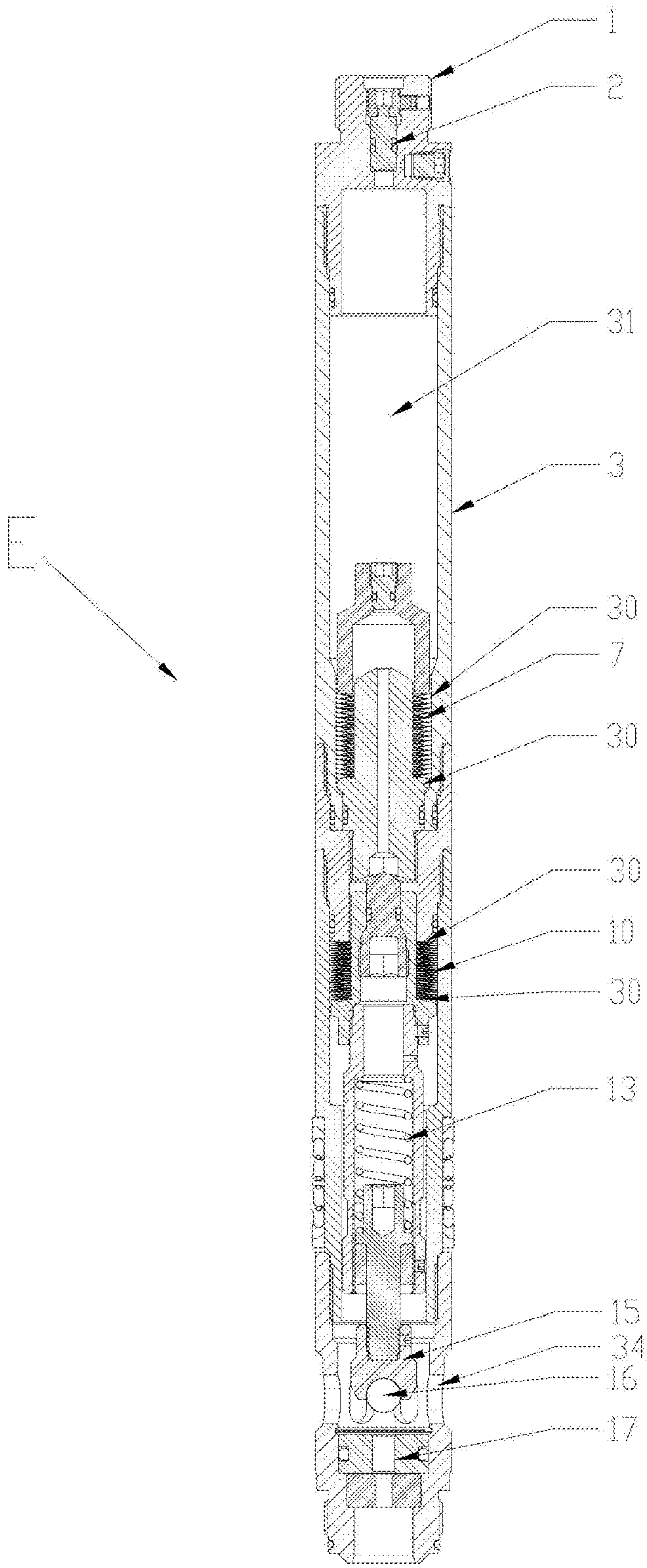


FIG. 5

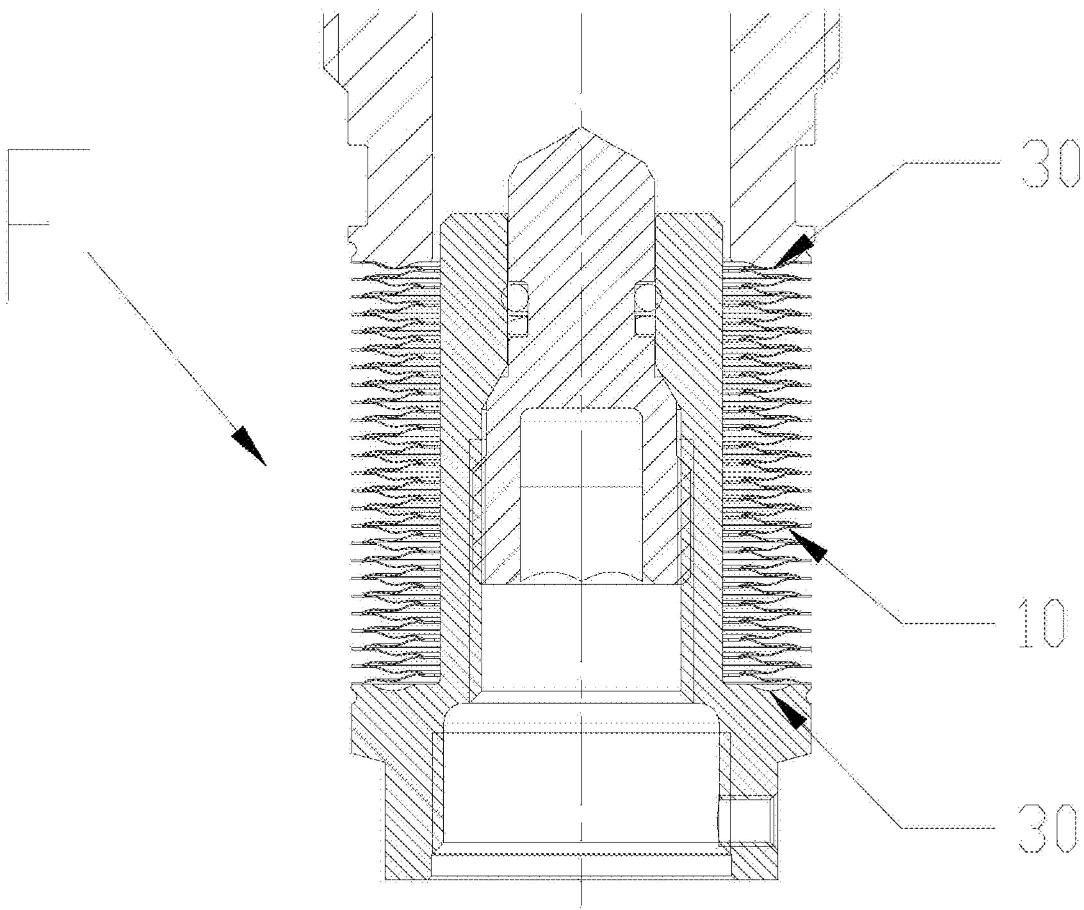


Fig. 6

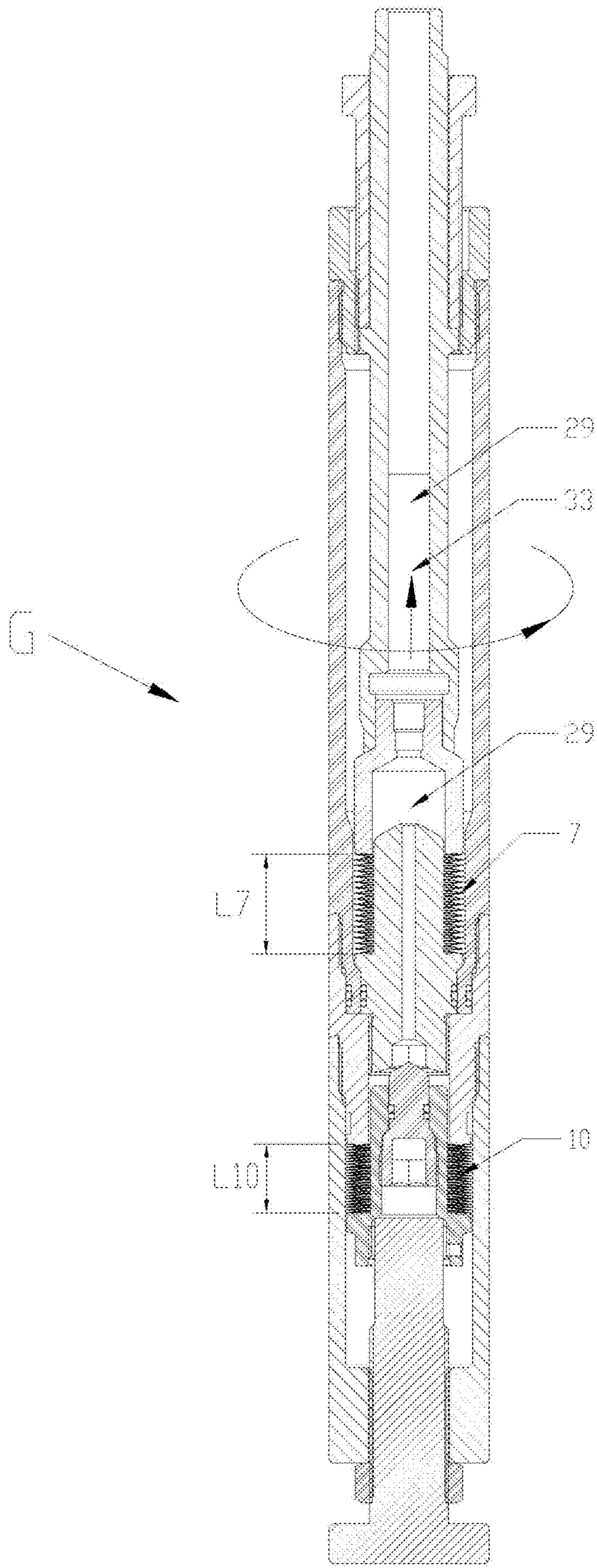


FIG. 7

HIGH PRESSURE GAS LIFT VALVE WITH DUAL EDGE WELDED BELLOWS

BACKGROUND OF THE INVENTION

1. Field of the Invention: Oil and Gas Industry

[0001] This invention generally relates to GLV-gas lift valve for artificial lift-production of oil from oil wells, and more particularly, to gas lift valves capable of operating at very high differential pressures.

2. Description of Related Art

[0002] Gas lift valves have been used for many years to inject compressed gas into oil and gas wells to assist in the lifting-production of well fluids to the surface. The valves have evolved into devices in which metal bellows, of variety of sizes, convert pressure into movement. This allows the injected compressed gas to act upon the bellows to open the valve and pass through a control mechanism into the fluid fed in from the well's producing zone into the well bore. As differential pressure is reduced on the bellows, the valve can close. Two types of GLV-gas lift valves use bellows. The first uses a non-gas charged, atmospheric bellows and requires spring to close the valve mechanism. The other mechanism uses an internal gas charge, usually Nitrogen, in the bellows and volume dome sub to provide the closing force for the valve. In both configurations, pressure differential on the bellows from the injected high-pressure gas opens the valve mechanism. Bellows are generally a seals that separate dome pressure from injection pressure.

[0003] In the case of the non-gas charged bellows, the atmospheric pressurized bellows are subjected to high differential pressure when the valve is installed in a well and exposed to high operating gas injection pressure. The Nitrogen charged bellows are subjected to high internal bellows pressure after dome charging and prior to installation. Once installed, the differential pressure across the bellows is lower than in non-gas charged bellows during operation of the GLV. High differential pressure across a bellows during operation reduces the bellow cycle life. The existing GLV and bellows are not designed to operate with set pressures or in operating pressures in excess of 2000 PSI without severe failure risks. Some existing valve bellows do have some form of fluid/and or mechanical protection from overpressure due to operating pressures in the fully open position. However, none provides protection from differential overpressure from set pressure in the bellows-dome sub when Nitrogen is pressurized and prior to installation into GLM-gas lift mandrel and well. In addition, Nitrogen is permanent gas which means it will not get to liquid state no matter how high the pressure is unless it is cooled which is not happening in GLV. When silicone oil is in direct contact with pressurized Nitrogen, bubbles of Nitrogen would be absorbed into silicone oil rendering it not non-compressible fluid, it is a mixture of fluid and gas bubbles. This means that all these theories for bellow hydraulic protection by non-compressible fluid are simply not accurate. Even if silicone oil is somehow de-gassed there must be separation of oil from pressurized Nitrogen but again, when bellow is exposed to higher pressures than designed for, convolution deformation occur, non-compressible fluid simply does not help: If high differential pressure is applied from outside bellow it would compress/deform outside OD convolutions against inner ID convolutions that will be exposed to expansion and would deform in expansion. These deformations would significantly reduce bellow cycle life. Wide accepted practice in gas lift industry bellow crimping and ageing process where bellows are compressed-shortened in controlled manner by exposing it to approximately 4000 PSI differential pressure to "stabilize" the shape of convolutions are flat out wrong. Bellows are deformed beyond repair by this practice and they work as long until they fail, and industry experience showed that failures occur randomly at various number of cycles.

SUMMARY OF THE INVENTION

[0004] The present invention comprises a gas-charged GLV A shown on FIG. **1** wherein the DEWB-dual edge welded bellows **7** and **10** of the said GLV are protected from both dome and injection high differential pressure. GLV features self-contained DEWB subassembly C shown on FIG. **3** filled with de-gassed and hence non-compressible silicone oil. GLV is normally in vertical orientation in well and upper **7** and lower bellow **10** naming is based on vertical orientation see FIG. **1**.

When dome sub **3** is charged with Nitrogen upper bellow **7** is compressed to solid representing mechanical stop, lower bellow **10** is extended for the appropriate distance and telescoping stem **12** which can't be mechanical stop is in closed position against TC orifice **17**. Oil contained inside bellow assembly is used as actuator and is pumped from upper bellow **7** to lower bellow **10** making it to expand. Nitrogen **31** is not in direct contact with silicone oil.

[0005] When injection pressure **34** is applied it acts against larger area of lower bellow **10** lifting valve closing mechanism-TC ball **16** of the seat **17**. Lower bellow **10** effective area is larger than upper bellow **7** effective area for the area of orifice **17** thus compensating for area of the orifice **17** which means that injection pressure **34** equals dome pressure **31** to open the valve. This eliminates differential pressure across the bellows in assembly. This can be optimized for desired port size in this case it is optimized for 0.375" port size. For smaller port sizes valve will open at injection pressure appropriately lower than dome pressure and both bellows **7** and **10** will be exposed to lower differential pressure comparing to system with upper and lower bellows of the same size. For larger port sizes valve will open at injection pressure **34** slightly higher than dome Nitrogen pressure **31** and differential pressure across both bellows **7** and **10** will be minimized. It is possible to equalize bellow sizes for each port size, but it is not necessary because EWB can withstand differential pressure that occurs.

[0006] Lower bellow **10** effective area is larger than upper bellow **7** effective area for the area of orifice **17**. Force balance equation is as follows:

$$Pb \times Aub - Bsru \times \Delta Lu - Ffu == Pi \times A1b - Bsr1 \times \Delta L1 - Ff1 + Ao \times Pt$$

When injection pressure **34** is applied and reaches value of dome Nitrogen pressure **31** valve starts to open and injection pressure **34** will act against full larger lower bellow **7** effective area (at this point TC ball **16** contact area is not subtracted from lower bellow area in force balance equation). Once TC ball **16** is slightly lifted of the orifice **17** injection pressure created force will be larger than dome pressure created force because of larger lower bellow **10** area and valve will slowly snap to fully open position. Force balance equation is as flows:

$$Pb\times Aub - Bsru\times\Delta Lu - Ffu == Pi\times A1b - Bsr1\times\Delta L1 - Ff1$$

Where:

[0007] Pb=bellow pressure
Aub=upper bellow effective area
Bsru=upper bellow spring rate
ΔLu=upper bellow compression length
Pi=injection pressure
Alb=lower bellow effective area
ΔL**1**=lower bellow compression length
Ffu=upper bellow friction, can be neglected
Ffl=lower bellow friction, can be neglected
Pt=tubing pressure
Ao=Orifice area

These equations can be solved per desired dome pressure or TROP-injection pressure since other values are design constants.

For particular bellows used for 1.5" nominal size gas lift valve bellow spring force when bellow is completely compressed from free to solid length is approximately 4.5% of pressure exerted force against bellows. Bellow effective area is defined as:

$$Ab=0.5\times(OD+ID)^2\times(\pi/4)==0.5\times(1.022+0.683)=0.668$$ sqin for upper bellow.

Dome force would be: Pd×Ab
For Pd=5000 PSI and Ab=0.668 sqin

Fd=3340 Lb

[0008] Injection force is: Fi=Alb×Pi
Upper bellow spring rate is 270 Lb/inch and for ΔLu=0.563 inch this force is 152 Lb to fully compress the bellow to solid. This corresponds to 227 PSI of dome pressure. This is only 4.5% of dome force created by dome pressure and can be neglected in force balance equation for quick calculations of desired parameters. The similar pertains to lower bellow. Silicone oil being transferred from lower **10** to upper bellow **7** will act as a dampener slowing down transition. When valve fully opens lower bellow **10** will be fully compressed to solid. At this point further increase of injection pressure **34** will not be transmitted through silicone oil and pressure transmission to upper bellow **7** stops. Injection pressure **34** at this point can be as high as possible and limited by valve components strength not bellows strength. The same process pertains to upper bellow **7** when dome is charged and injection pressure **34** is absent. This is very usable for well completion integrity testing thus avoiding need for dummy valve application saving one wireline job.

[0009] Bellows assembly C shown on FIG. **3** is assembled in fixture G shown on FIG. **7**. Silicone oil **29** is filled in excess and both bellows are in relaxed position. Complete fixture G is then rotated in appropriate apparatus and centrifugal force will cause lighter air bubbles contained in silicone oil to move toward to assembly centerline and evacuate upwards due to gravity as shown with arrow **33**. Process should last long enough to de-gas oil completely. After oil is de-gassed lower bellow **10** should be compressed to solid height L**10**, upper bellow **7** would be at free length L**7** and upper plug **4** should be installed in place using appropriate tools. This process would provide bellow assembly C proper adjustments. Bellow assembly C shown on FIG. **3** is now ready to be assembled to GLV.
GLV is using high pressure Lee AFO plug **2** shown on FIG. **2** instead of standard tire air valve.

BRIEF DESCRIPTION OF DRAWINGS

[0010] The apparatus of the invention is further described and explained in relation to the following figures wherein:

[0011] FIG. **1** is showing cross sectional view of a typical HP-high pressure wireline retrievable gas lift valve A of the preferred embodiment.

[0012] FIG. **2** shows cross sectional view of the high-pressure Lee AFO plug subassembly that is used instead of typical automotive low-quality valve to charge Nitrogen into dome volume with redundant NPT plug.

[0013] FIG. **3** shows cross section view of the bellow subassembly C of the preferred embodiment illustrated with both bellows in neutral position.

[0014] FIG. **4** shows GLV cross section D without lower portion of the valve removed for clarity with upper bellow in fully compressed position to solid with dome Nitrogen pressure applied, lower bellow in fully expanded position, telescoping stem in closed position and silicone oil transferred from upper to lower bellow.

[0015] FIG. **5** shows GLV cross section E without lower portion of the valve removed for clarity with upper bellow in fully expanded position with dome Nitrogen pressure applied, lower bellow in fully compressed position by applied injection pressure, telescoping stem in fully open position and silicone oil transferred from lower to upper bellow.

[0016] FIG. **6** shows lower bellow partial cross section F showing bellow concave and convex curvatures and mating surface curvatures that are both of equal geometry which provides perfect bellow alignment against mating surface to which bellow is welded once bellow is fully compressed to solid.

[0017] FIG. **7** shows GLV assembling fixture G that is used to constrain bellows to desired position for assembling and to de-gas silicone oil by rotating complete fixture.

DETAILED DESCRIPTION OF THE DRAWINGS AND OF THE EMBODIMENT OF THE INVENTION

[0018] Various aspects and relationships of a preferred embodiment of the current invention will be described in the context of what is commonly known to the gas lift industry as a casing operated 1.5" nominal size wireline retrievable HP GLV. It is within the scope of this patent to apply the present invention to other sizes and configurations of GLV, chemical injection valves both as wireline retrievable and tubing retrievable GLV and both IPO-injection pressure operated or PPO-production pressure operated GLV.

[0019] FIG. **1** illustrates valve A into which the present invention has been adapted. The valve A in FIG. **1** consist of Nitrogen charging assembly shown on FIG. **2** which includes Lee HP AFO plug **2** with sealing O-ring, redundant NPT plug **3** threaded into housing **1**. Dome chamber **3** is assembled against housing **1**. Bellow subassembly shown on

FIG. **3** is assembled against dome chamber **3**, telescoping stem **12** assembled into telescoping stem housing **11** and assembled against bellow subassembly shown on FIG. **3**. Valve lower portion containing inlet sub **18**, orifice **17**, check dart **20**, check dart housing **21** and nose **24** is assembled against telescoping stem housing **11**.

[0020] Valve features set of external upper seals **14** and lower seals **22** employed to pack off the valve into upper and lower seal bore of an appropriate GLM common to the industry and not illustrated herein. The appropriate latch mechanism not shown for clarity is assembled against upper housing **1** to lock valve in gas lift mandrel.

[0021] The HP EWB subassembly shown on FIG. **3** consists of upper bellow **7** that is welded against upper body **6** and upper sliding sub **5**, lower bellow **10** that is welded against mid sub **8** and lower sub **27**. Cavity of bellow subassembly is filled with silicone oil **29** and sealed by upper plug **4** and lower plug **9** which both feature O-rings for sealing the silicone oil. Upper sliding sub **5**, upper body **6**, mid sub **8** and lower sub **27** have geometry of bellow mating surfaces **30** of the same shape as bellows convex and concave surfaces.

[0022] FIG. **4** shows GLV A of present invention in closed position. Lower portion of the valve with check dart **20** is not shown for clarity. When Nitrogen **31** pressure is applied through port **26** to dome sub **3** upper bellow **7** will be fully compressed to solid and bellow elements will be touching each other and boot against mating surfaces **30**. Silicone oil **29** will be transferred from upper bellow **7** to lower bellow **10** that will expand, pushing telescoping stem **12** to closed position. TC ball **16** will close against orifice **17** while spring **13** would compensate movement of the telescoping stem **12** since solid upper bellow **7** will be mechanical stop because two mechanical stops at the same time are not possible. At this point injection pressure **32** is not present because valve is not installed to well and this pressure is atmospheric.

[0023] FIG. **5** shows valve A of present embodiment in fully open position with injection pressure **32** applied, lower bellow **10** fully compressed to solid, upper bellow **7** fully expanded by silicone oil **29** transferred from lower bellow **10** to upper bellow **7**. It should be noted that velocity of silicone oil **29** transfer between bellows is smooth and controlled by hole **28** size. Injection pressure **32** at this point is high enough to overcome Nitrogen dome pressure **31** and valve load rate. TC ball **15** is lifted of the orifice **17**, spring **13** is fully expanded and telescoping stem **12** is retracted following lower bellow **10** movement. GLV starts injecting gas into formation as soon as TC ball **16** is lifted of the orifice **17**. As injection pressure is decreasing GLV will start closing process in sequences opposite to valve opening.

[0024] FIG. **6** shows enlarged bellow **10** cross sectional detail where it is obvious that geometry **30** against which bellow is welded is of the exact same geometry as bellow elements. This would provide perfect contact between bellow element and mating part once bellow is fully compressed. The same pertains to both bellows **7**, **10** and mating parts **5**, **6**, **8**, and **27** to which bellows are welded. This feature reduces the stress of the bellows that will be exposed only to compression stress once in full compression to solid.

[0025] The above description of certain embodiment is made for the purposes of illustration only and are not intended to be limiting in any manner. Other alterations and modification of the preferred embodiment will become apparent to those of ordinary skill in the art upon reading this disclosure, and it is intended that the scope of the invention disclosed herein be limited only by the broadest interpretation of the appendix claims to which the invention is legally entitled.

What is claimed is:

1. A GLV capable of withstanding high differential pressure comprising of:

EWB containing a plurality of convolutions, wherein the bellows can contract and expand.

Dome sub connected to bellows subassembly containing pressurized gas-Nitrogen charge. Telescoping stem housing connected to lower bellow containing telescoping spring-loaded stem and TC ball closing mechanism.

EWB subassembly consisting of upper and lower bellows welded to mating parts containing sealed degassed silicone oil volume that can transfer between upper and lower bellow depending on dome and injection pressure.

Telescoping stem mechanism that is spring loaded with TC ball subassembly that opens and closes the injection gas passage through valve.

One-way check valve located at GLV lower end that prevent flow in direction opposite to normal flow.

Fluid selected from the group consisting of an injection gas and a well fluid wherein the injection fluid is located in exterior of the lower bellow and provides an external pressure to lower bellow.

2. GLV of claims **1** and **2** wherein the valve starts to open when injection pressure reaches proximity of Nitrogen dome pressure and closes as injection pressure decrease below dome Nitrogen pressure.

3. GLV of claims **1** and **2** wherein valve is tubing retrievable type.

4. GLV of claims **1** and **2** further comprising of upper and lower EWB where lower bellow features larger OD and larger EBA-effective bellow area than upper bellow OD and EBA. Difference in lower versus upper EBA is equal to orifice area which means that valve TROP-test rack opening pressure is very close to Nitrogen dome pressure resulting in near zero differential pressure across both bellows equalizing stress of the bellows. This pertains only for one selected-optimized orifice size. For smaller orifice size TROP will be lower than dome pressure. For orifice sizes larger than optimized orifice size TROP will be slightly higher than dome pressure. This can be optimized for every port size, but it will be not very practical. Orifice-bellow areas are optimized for median port size in this case 0.375". This TROP difference versus dome Nitrogen charge will be multiple times lower comparing to GLV where upper and lower bellows are of the same size which is the case with all existing dual bellow valves on the market today. End result is extreme bellow differential pressure reduction and hence stress level reduction.

5. GLV bellow assembly of claims **1** and **2** is filled with silicone oil degassed by proprietary centrifugal process where assembling fixture with said bellow assembly is rotated-centrifuged until gas is removed from oil making it fully non-compressible fluid.

6. GLV valve of claims **1** and **2** where Nitrogen dome pressure can be adjusted during valve TROP setting process by using unique AFO plug configuration with redundant NPT plug without removing valve from test donut. Normal GLV using Dill core valves for Nitrogen charging must be removed from test donuts to recharge Nitrogen when needed. AFO plug is capable of extremely high pressures in excess of 30 KSI.

7. GLV of claims **1** and **2** feature bellows selected to have the same volumetric oil displacement for selected bellow travel, compression/expansion. This means that oil transferred from upper to lower bellow has the equal volume.

8. GLV of claims **1** and **2** features upper and lower bellow that can be fully compressed to solid by design. Mating parts to which bellows are welded have the same convex and concave geometry as bellow element providing perfect fit and can withstand extremely high compression pressures higher than 30 KSI.

9. When EWB of GLV of claims **1** and **2** is fully compressed to solid at certain pressure, silicone oil is transferred to opposite bellow. Any further pressure increase against compressed bellow will not be transmitted to expanded bellow and expanded bellow will be fully pressure balanced and therefore protected from over-pressurizing. This feature is very useful for well integrity (pressure) testing and eliminates need for using dummy valve and saves at least one wireline job.

10. Silicone oil used to fill bellow subassembly is de-gassed using centrifugal force in custom designed fixture. Being heavier than air silicone oil would be pushed by centrifugal force against ID of the containing parts while lighter air bubbles would flow toward the centerline and upwards exiting the oil. Process can be improved by heating complete fixture. This method was never used in gas lift valve manufacturing. Once oil is sufficiently de-gassed bellow assembly is closed using plug with metal to metal seal and redundant O-ring seal. This process would create non-compressible oil.

11. During last step of assembling lower bellow is completely compressed to solid to length L**10** while upper bellow is expanded to free length L**7** and excess oil is pushed out of bellow assembly into cavity of the assembling fixture. Then upper plug is now secured sealing the oil chamber. When bellow assembly is removed from assembling fixture bellows will relax and set into neutral position. Due to different spring rates of upper and lower bellow neutral position will be somewhere off the middle. When installed to valve both bellows will work only in compression from free length to solid state. This is very beneficial for extended bellow life and lower overall stress level.

12. GLV is designed to snap to fully open position as soon as TC ball is lifted of the seat-orifice and injection pressure is held constant or slightly higher than dome pressure. This is provided by larger lower bellow resulting in larger effective bellow area comparing to upper bellow area. Area difference corresponds to orifice surface area. Once valve opens force exerted by injection pressure against lower bellow is larger than upper bellow force exerted by Nitrogen and this force differential would result in snap opening of the valve. Velocity of valve opening and closing can be further controlled by the size of connecting hole between two bellows.

13. GLV of claims **1** and **2** requires lower differential pressure between dome Nitrogen and injection pressure to fully opens. When injection pressure is introduced and reaches proximity of dome pressure valve starts to open. When valve slightly opens injection force Fi exerted on lower larger bellow is larger than dome force Fd created by Nitrogen pressure acting upon smaller upper bellow because at this point orifice area is not a factor in force balance equation and valve would snap to open position. Injection pressure required to keep valve in fully open position is much lower comparing to valves with same size of upper and lower bellow.

14. GLV of claims **1** and **2** significantly reduces possibility of chatter because valve snaps to fully open position much easier comparing to valves which have lower and upper bellow of the same sizes. In addition, chatter can be further decreased by optimizing diameter of connecting hole between two bellows. Valve chatter is a main reason for bellow failures.

15. GLS of claims **1** and **2** dome Nitrogen pressure is not limited by bellow strength but GLV component strength since bellow fully compressed to solid can withstand high pressure that is higher than components pressure. The same logic pertains to injection pressure and lower bellow.

* * * * *