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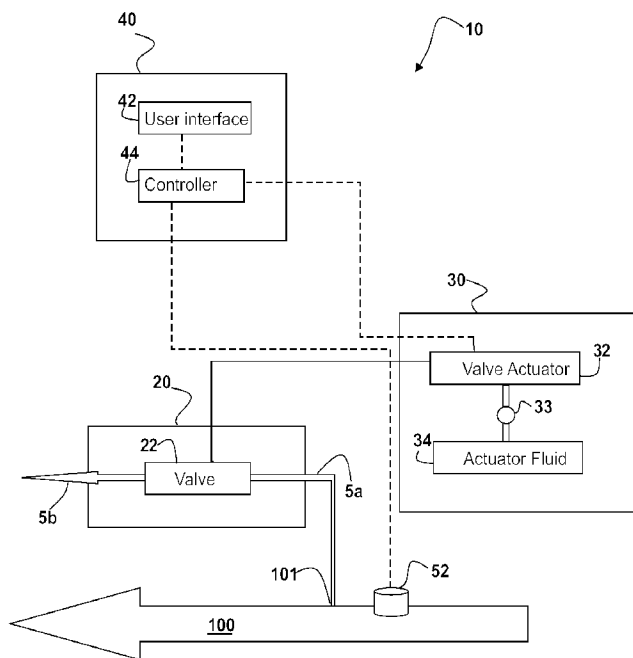


FIG. 1

(57) **Abrégé/Abstract:**

A pressure control system configured to automatically monitor and control pressure in fluid lines used in hydraulic fracturing or well stimulation activities is disclosed. The system generally includes at least two valve assemblies each having a valve and a valve actuation system, at least one pressure sensor, and an electro-mechanical control package. These components are configured such that the electro-mechanical controls automate the open and closed positions of the valve(s) via operation of the actuator(s) based on user inputs and information from the pressure sensor. This architecture allows the system to monitor and interpret pressures within the conduit and operate the valve position based on user defined signals and set-points. The valves may be positioned to redundantly monitor the same fluid conduit, or separate fluid conduits, and the system may be configured to enable independent valve positions based on independent user defined set-points or user inputted control signals.

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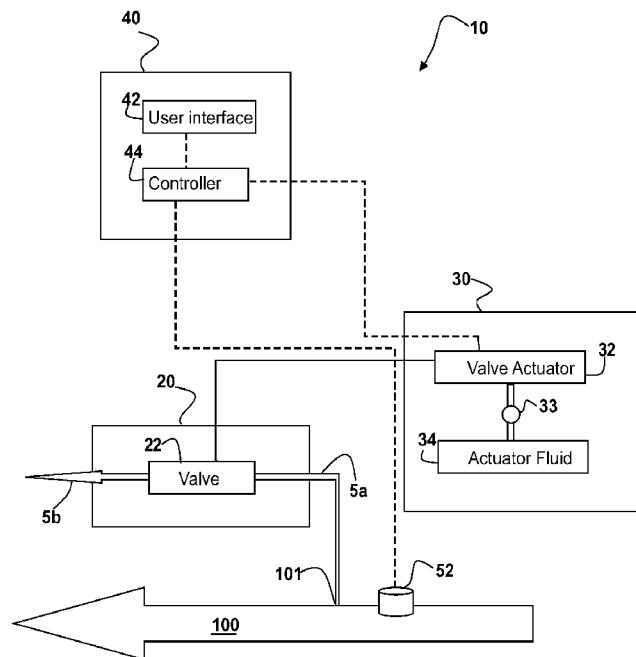


FIG. 1

(57) Abstract: A pressure control system configured to automatically monitor and control pressure in fluid lines used in hydraulic fracturing or well stimulation activities is disclosed. The system generally includes at least two valve assemblies each having a valve and a valve actuation system, at least one pressure sensor, and an electro-mechanical control package. These components are configured such that the electro-mechanical controls automate the open and closed positions of the valve(s) via operation of the actuator(s) based on user inputs and information from the pressure sensor. This architecture allows the system to monitor and interpret pressures within the conduit and operate the valve position based on user defined signals and set-points. The valves may be positioned to redundantly monitor the same fluid conduit, or separate fluid conduits, and the system may be configured to enable independent valve positions based on independent user defined set-points or user inputted control signals.



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## VALVES AND CONTROL SYSTEMS FOR PRESSURE EQUALIZATION AND DE-ENERGIZATION

### RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. § 119(e) of prior U.S. Provisional Application Serial Nos. 62/861,647, filed June 14, 2019, the entire content of which is incorporated herein.

### TECHNICAL FIELD

[0002] The present invention relates generally to systems and methods for pressure adjustment or control in fluid pipelines, and more specifically to valves and control systems for automatic monitoring and capturing of specific pressure conditions in high pressure conduits likely containing abrasive particles.

### BACKGROUND

[0003] Fluid lines under high pressure (e.g., pressure vessels and piping systems) are often designed with control valves to block or meter fluid flow from certain areas in an open or closed loop system. These pressure logic valves are generally manually operated or actuated devices set to adjust to a specified pressure level (set-point), allowing fluid to move in the system from an area of higher pressure to an area of lower pressure, e.g., direct acting check valves, ball trim valves, and plug-type trim valves. These control valves incorporate a specific geometry of the sealing mechanism that provides direct restriction of fluid movement, i.e., they place the sealing face of the mechanism in the direct path of the fluid flow. As a result of the abrasive action of the fluid flow on the sealing face, especially with fluids that may contain abrasive agents such as sand, replacement of parts before returning to leakage free service is generally needed after only minimal use. Moreover, arrangement of the sealing mechanisms in such valves does not provide a means to quickly replace the restrictive member of the valve when the component becomes worn.

[0004] Certain other examples, such as the labyrinth trim control valve, provide a means of downstream fluid flow restriction. However, the torturous path provided by such valves makes them unsuitable for passage of fluids containing particulates, e.g., slurries, due to likely clogging of the components. Other similar needle type assemblies allow direct impingement of the fluid

to the sealing surface of the needle, which, as discussed above, is detrimental to the sealing capability after only minimal exposure to an abrasive fluid.

**[0005]** Other solutions for pressure control attempt to electronically control the physical position of a rather standard valve, thus creating a calculated orifice size based on a partial open or closed status of the sealing components. However, while they improve upon the ease of user pressure adjustments and set-points, they fail to address the very elementary problem of abrasive slurry erosion on the sealing mechanisms mentioned above.

**[0006]** Still other solutions seek to utilize industry recognized rotary actuated valves that provide seals on the downstream sides of the valves, coupled to electro-mechanical control or manual operation. These solutions still fail to remove the upstream sealing face from abrasive fluid flow and quite substantially may expose human life to the consequences of catastrophic failure of the valve operator or actuation method. Moreover, in industries where the pressure in the conduits is extremely high and known to possess appreciable abrasive particles, such as in the hydraulic fracturing industry, these solutions to the problem of pressure control may fail to meet industry needs. That is, the valve and actuation means were never intended to be applied to slurry fluid metering valve service causing these valving attempts to result in a clogged inlet pipe due to particulate piling.

**[0007]** It should also be noted that the aforementioned electronic control mechanisms have consistently failed to meet the demands of the dynamic nature of the pressurized fluid systems used in the hydraulic fracturing industry, and generally cannot operate the valve in a consistent manner that allows a specific pressure to be “caught” and stabilized upon. Moreover, these electronic controls do not allow the user to fully integrate the valve controls into their previously established data interpretation methods.

**[0008]** Thus, it would be desirable to have a system that can adjust the pressure in one or multiple pressurized fluid conduit(s), wherein the conduit(s) can be monitored and relieved of fluid pressure in an independent manner. It would also be desirable to have a system that utilizes valves which provide a linear flow path, and which do not expose sealing surfaces to abrasive fluid flow. Moreover, it would be desirable to have a system that can control the flow rate through the valve, such as at preset flow rates or in a manner capable of preventing particulate clogging. Additionally, it would be desirable for the system valves to have flow restrictive elements that can be easily accessed for efficient maintenance.

[0009] Furthermore, it would be desirable to have a system that, by virtue of having two valves applied, may act in an independent manner of redundancy when connected to a single fluid conduit. Still further, it would be desirable to have a system that may be coupled to a single conduit such that a first valve is primarily controlled, and a second valve may act as a spare “in the wait” to allow efficient operational use. Still further yet, it would be desirable to have a control system configured to allow a user to define both valve settings independently and integrate valve control into their in-use data management systems. Moreover, it would be desirable for the system control to calculate pressure trends and, with anticipatory function, capture a predetermined pressure level for user safety and operational effectiveness.

[0010] Therefore, there currently exists a need in the industry for a system that provides effective pressure and flow control in a pressurized slurry laden conduit in a manner that incorporates two or more independently controlled valves, and which uses components, e.g., valves, sensors, etc., that are isolated or protected from the abrasive fluid flow in the pressurized conduit(s).

#### SUMMARY

[0011] The presently disclosed invention provides the aforementioned benefits by providing systems, devices, and methods for pressure control in fluid conduits, such as the fluid lines used in the hydraulic fracturing industry or in wellbore completion activities.

[0012] The present invention is related to a system for pressure control, wherein the system generally comprises at least two valve assemblies, and a controller configured to receive signals related to fluid pressure in a fluid conduit and communicate with the valve assembly to change a position of a valve housed therein, such that when the fluid pressure in the fluid conduit is remedied to the user-defined lesser pressure limit, the fluid movement is stopped, or when the fluid pressure in the fluid conduit is greater than the user desired pressure limit, a fluid path is allowed to open thereby decreasing the fluid pressure to the desired limit or held open for complete system de-energization.

[0013] According to certain aspects of the present invention, each valve assembly may include a valve actuation system having a source of actuation fluid and optionally a pump, and a valve housing having a longitudinal bore therethrough, the valve housing comprising an upstream connection, a downstream connection, and a valve positioned therebetween.

**[0014]** According to certain aspects of the present invention, the valve actuation system may comprise a biasing member in a valve actuation chamber that biases the valve to an open or closed position. Supply of the valve actuation fluid into the valve actuation chamber may then provide counterforce on the biasing member to move the valve to an open or closed position. The biasing member may be a spring, and the valve actuation fluid may be a gas or a hydraulic fluid. Moreover, the valve actuation system may comprise a combined rotary and linear movement, e.g., scotch yoke, crank/slider, rack and pinion.

**[0015]** According to certain aspects of the present invention, the valve actuation system may provide rapid actuation of the valve, i.e., opening or closing of the valve. For example, the valve actuation system may provide full actuation of the valve, i.e., fully open or close the valve, in less than 2 seconds, such as less than 1 second, or less than 0.5 seconds.

**[0016]** According to certain aspects of the present invention, the valve may comprise a ball valve having a ball with a throughbore, wherein an open position of the ball provides flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing, and a closed position of the ball provides an out of flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing. The valve may include an upstream seat and a downstream seat. The upstream seat may comprise an outward facing surface positioned perpendicular to the longitudinal bore of the valve housing, wherein a pressure on the outward facing surface forces the upstream seat against a sealing face of the ball. The sealing face may be a polished metal. The pressure on the outward facing surface of the upstream seat may include fluid pressure and/or pressure imposed by other upstream components (e.g., upstream connection).

**[0017]** According to certain aspects of the present invention, the upstream and downstream connections of the valve housing may have substantially the same diameter or a larger diameter than a diameter of the throughbore of the ball, and thus do not restrict the outflow of fluids. Thus, opening of the valve by the valve actuation system without restrictive components inserted may provide for rapid decline of pressure in a piping system, i.e., rapid pressure loss. For example, the valve assembly may reduce the fluid pressure in a fluid line or conduit by at least 10% within 1 second, or at least 20%, or at least 30%, or at least 50%, or at least 75% within 1 second.

**[0018]** According to certain aspects of the present invention, either the upstream or downstream connections of the valve housing may restrict the outflow of fluids such as by including a reduced diameter when compared to the diameter of the throughbore of the ball. Thus, opening of the valve by the valve actuation system may provide for controlled reduction of pressure in a conduit. The restricted outflow of fluids may alternatively, or additionally, be caused by one or more flow restrictors placed in-line in either the upstream or downstream connections of the valve housing. Alternatively, or additionally, the restricted outflow of fluids may be caused by inclusion of flow restrictors and/or reduced diameter portions of the conduit downstream from the valve and downstream valve connection (i.e., in a portion of the conduit that is distal from the valve and valve connections). Thus, opening such a valve assembly comprising restrictive regions or components may reduce the fluid pressure in the fluid line by at least 1% within 1 second, or 3% within 1 second, or even 5% within 1 second. Moreover, the controller may be configured to hold the valve open for a period when the user requires complete fluid pressure de-energization in the fluid line and, if/when the user desires, the controller may be configured to close the valve.

**[0019]** According to certain aspects of the present invention, the at least two valve assemblies may be the same or may be different. That is, one of the at least two valve assemblies may provide controlled pressure reduction within the fluid line, and the other of the at least two valve assemblies may provide rapid pressure decline in the same or a different fluid line. Moreover, when the system includes two controlled pressure reduction valve assemblies, the reduction in pressure may be the same or may be different.

**[0020]** According to certain aspects of the present invention, the system may utilize signals related to pressure in the fluid line to control the valve actuation system. For example, the controller may be configured to receive signals related to the fluid pressure via user input or from a pressure sensor. The pressure sensor may be part of the system, or independent from the system. Thus, according to certain aspects of the present invention, the system may further include at least one pressure sensor, wherein the at least one pressure sensor may include at least one pressure transducer and a pressure chamber having a diaphragm surrounding a pressure fluid within the pressure chamber. The pressure fluid may be fluidly connected to the at least one pressure transducer to transfer an external fluid pressure on the diaphragm to the pressure transducer(s), wherein the diaphragm comprises a flexible and deformable structure. The

pressure chamber may be attachable on the fluid line such that the fluid pressure in the conduit comprises the external fluid pressure on the diaphragm.

**[0021]** According to certain aspects of the present invention, at least two pressure transducers are included in the pressure sensor, and the signal from the pressure sensor received by the controller may comprise individual signals from the at least two pressure transducers. The individual signals may be received at a rate of at least 50 signals/second, such as 75 signals/second, or even 100 signals/second.

**[0022]** According to certain aspects of the present invention, various components of the system may be contained in a housing or frame, such as the valve assemblies, pressure transducer, and controller. The housing or frame may further comprise one or more batteries configured to provide power to at least one valve actuator, at least one pressure transducer, and a controller. The housing or frame may be a standalone component, or may be included as part of a tank which may collect fluids released from the fluid conduit when the valve is opened. Moreover, the tank may be a standalone component, such as a tank that may be dropped at a location (e.g., frac tank), or one that is included as part of a vehicle (e.g., tractor trailer).

**[0023]** According to certain aspects of the present invention, the system may comprise more than one housing or frame, wherein each housing comprises one, two, or more valve assemblies. Each housing may additionally comprise one or more batteries configured to provide power to the various components included therein, such as the valve actuator(s), pressure transducer(s), and the controller.

**[0024]** The present invention is also directed to methods for pressure control in a fluid line, wherein the method generally comprises providing a system according to any of the aspects described above; attaching a first end of a first bypass conduit to the upstream connection of the valve housing of a first valve assembly; attaching a first end of a second bypass conduit to the downstream connection of the valve housing of the first valve assembly; and setting a desired pressure limit for the first valve assembly using a user interface on the control system. The control system is configured to receive a signal related to a pressure in the fluid line, and communicate with the valve actuation system of the first valve assembly to change a position of the valve, such that when the fluid pressure in the fluid line reaches the desired pressure limit the valve is opened or closed, and if the fluid pressure is desired to be zero, the valve is maintained in the open position.

**[0025]** According to certain aspects of the present invention, the method may further comprise attaching a pressure chamber of a first pressure sensor on the fluid line such that an outward facing side of the diaphragm is in contact with a fluid in the fluid line. The controller may use a signal from the first pressure sensor indicating a fluid pressure in the fluid line to control the valve actuator. Alternatively, or additionally, the controller may use signals provided by user input, or communicated by a pressure sensor of another system position on the fluid line to control the valve actuator.

**[0026]** According to certain aspects of the present invention, the method may further comprise attaching a second end of the first bypass conduit to the fluid line; and directing a second end of the second bypass conduit to a fluid containment area. The fluid containment area may be a reservoir, earthen pit, or a tank such as a frac tank.

**[0027]** According to certain aspects of the present invention, the methods may further comprise attaching a first end of a third bypass conduit to the upstream connection of the valve housing of a second valve assembly; attaching a first end of a fourth bypass conduit to the downstream connection of the valve housing of the second valve assembly; and setting a desired pressure limit for the second valve assembly using the user interface on the control system. The control system is configured to communicate with the valve actuation system of the second valve assembly to change a position of the valve.

**[0028]** The first and second valve assembly may be the same or may be different. That is, the first and/or second valve assembly may provide controlled pressure reduction within the fluid line, and the other of the first and/or second valve may provide rapid pressure decline in the same or a different fluid line. Moreover, when the system includes two controlled pressure reduction valve assemblies, the reduction in pressure may be the same or may be different.

**[0029]** According to certain aspects of the methods, the first, second, third, and fourth bypass conduits are all portions of a single bypass line having a connection to the fluid line. Alternatively, the first and second bypass conduits are portions of a first bypass line having a connection to the fluid line, and the third and fourth bypass conduits are portions of a second bypass line having a connection to a second fluid line. In this latter case, the method may further comprise attaching the pressure chamber of a second pressure sensor on the second fluid line such that an outward facing side of the diaphragm is in contact with a fluid in the second fluid line, wherein the control system is configured to receive a signal from the second pressure sensor

indicating a fluid pressure in the second fluid line, and communicate with the valve actuation system of the second valve assembly to change a position of the valve, such that when the fluid pressure in the fluid line reaches the desired pressure limit the valve is closed, and if the fluid pressure is desired to be zero the valve is maintained in the open position.

**[0030]** The present invention is also directed to methods for controlling pressure in a fluid line. The methods may comprise the steps of: monitoring a pressure in a fluid line; determining, using a controller, if the pressure in the fluid line exceeds a desired pressure limit, wherein, responsive to determining the pressure in the fluid line, if the pressure satisfies the desired pressure limit, controlling an actuator to move a valve of at least one valve assembly to an open or closed position; maintaining the valve in the commanded position for a specific amount of time; determining, using a controller, if the pressure in the fluid line is below a low pressure limit; and responsive to determining the pressure in the fluid line, if the pressure is below the low pressure limit, controlling the actuator to move the valve of the at least one valve assembly to a closed position. Controlling the actuator may comprise controlling a motor and/or hydraulic pump to supply or relieve a pressure in an actuation chamber. The pressure may be provided by a pressure sensor comprising a pressure chamber and at least one pressure transducer, or by user input.

#### BRIEF DESCRIPTION OF DRAWINGS

**[0031]** Aspects, features, benefits and advantages of the embodiments herein will be apparent with regard to the following description, appended claims, and accompanying drawings. In the following figures, like numerals represent like features in the various views. It is to be noted that features and components in these drawings, illustrating the views of embodiments of the present invention, unless stated to be otherwise, are not necessarily drawn to scale. The illustrative embodiments in the following drawings are not meant to be limiting; other embodiments may be utilized and other changes may be made without departing from the spirit or scope of the subject matter presented herein.

**[0032] FIG. 1** illustrates a block diagram of a valve system in accordance with certain aspects of the presently disclosed invention.

**[0033] FIG. 2** illustrates a perspective view of a valve system comprising two valves in accordance with certain aspects of the presently disclosed invention.

[0034] **FIG. 3** illustrates a side view of the valve system shown in **FIG. 2**.

[0035] **FIG. 4** illustrates a front view of the valve system shown in **FIG. 2**.

[0036] **FIG. 5** illustrates a perspective view of a valve system comprising three valves in accordance with certain aspects of the presently disclosed invention.

[0037] **FIG. 6** illustrates a remote user interface assembly in accordance with certain aspects of the presently disclosed invention.

[0038] **FIG. 7** illustrates a pressure sensor system in accordance with certain aspects of the presently disclosed invention.

[0039] **FIGS. 8A** and **8B** illustrate another pressure sensor system in accordance with certain aspects of the presently disclosed invention, wherein **FIG. 8A** shows a pressure bladder bonded within an inner bore of the pressure sensor and **FIG. 8B** shows the pressure bladder held in place with a c-ring.

[0040] **FIG. 9** illustrates a valve housing of a valve in accordance with certain aspects of the presently disclosed invention.

[0041] **FIG. 10** illustrates a cross-sectional view taken along line **A-A** of the valve housing of **FIG. 9** showing a valve configured for rapid pressure loss in accordance with certain aspects of the presently disclosed invention.

[0042] **FIG. 11** illustrates a cross-sectional view taken along line **A-A** of **FIG. 9** of an alternative valve configured for rapid pressure loss in accordance with certain aspects of the presently disclosed invention.

[0043] **FIG. 12** illustrates a close-up view of the ball and seat assembly of the valve shown in cross-section in **FIG. 10**.

[0044] **FIG. 13** illustrates a cross-sectional view taken along line **A-A** of the valve housing of **FIG. 9** showing a valve configured for controlled pressure decline in accordance with certain aspects of the presently disclosed invention.

[0045] **FIG. 14** illustrates a close-up view of the ball, seat assembly, and downstream flow restriction of the valve shown in cross-section in **FIG. 13**.

[0046] **FIG. 15A** illustrates a flow restrictor design for a valve configured for controlled pressure decline in accordance with certain aspects of the presently disclosed invention.

[0047] **FIG. 15B** illustrates a cross-sectional view taken along line **B-B** of **FIG. 15A** of another design for a flow restrictor design in accordance with certain aspects of the presently disclosed invention.

[0048] **FIG. 15C** illustrates a cross-sectional view taken along line **B-B** of **FIG. 15A** of a design for a two-piece flow restrictor in accordance with certain aspects of the presently disclosed invention.

[0049] **FIG. 16** illustrates a cross-sectional view taken along line **A-A** of **FIG. 9** of a valve configured for controlled pressure decline, wherein the downstream portion includes the removeable two-piece flow restrictor of **FIG. 15C**.

[0050] **FIG. 17A** illustrates the valve of **FIG. 11** including a downstream attachment containing a flow restrictor in accordance with certain aspects of the presently disclosed invention.

[0051] **FIG. 17B** illustrates a close-up view of the flow restrictor attachment of **FIG. 17A**.

[0052] **FIG. 18A** illustrates a flow restrictor attachment used to provide adjustable pressure decline for a valve in accordance with certain aspects of the presently disclosed invention.

[0053] **FIG. 18B** illustrates a cross-sectional view of a flow restrictor taken along line **C-C** of **FIG. 18A**.

[0054] **FIG. 19A** illustrates a cross-sectional view taken along line **C-C** of the flow restrictor shown in of **FIG. 18A** in the fully open state with fluid flow paths highlighted.

[0055] **FIG. 19B** illustrates a cross-sectional view taken along line **C-C** of the flow restrictor shown in of **FIG. 18A** in the fully closed state.

[0056] **FIG. 19C** illustrates a cross-sectional view taken along line **C-C** of the flow restrictor shown in of **FIG. 18A** in the open state, as in **FIG. 19A**, with hydraulic fluid lines highlighted.

[0057] **FIG. 19D** illustrates a cross-sectional view taken along line **C-C** of the flow restrictor shown in of **FIG. 18A** in the open state, as in **FIG. 19B**, with hydraulic fluid lines highlighted.

[0058] FIG. 20 illustrates a cross sectional view taken along line A-A of FIG. 9 of the valve housing of a bleed through valve system in accordance with certain aspects of the presently disclosed invention.

[0059] FIG. 21A illustrates an unbalanced poppet in accordance with certain aspects of the presently disclosed invention.

[0060] FIG. 21B illustrates a cross-sectional view taken along line D-D of the unbalanced poppet of FIG. 21A.

[0061] FIG. 22 is a schematic showing hydraulic control of the valve system actuation in accordance with certain aspects of the presently disclosed invention.

[0062] FIG. 23 is a schematic showing the relationship of major subassemblies of a valve system in accordance with certain aspects of the presently disclosed invention.

[0063] FIG. 24 is a schematic showing a valve system positioned to control the pressure contained within a hydraulic fracturing system in accordance with certain aspects of the presently disclosed invention.

[0064] FIG. 25 is a schematic showing a valve system positioned to control the pressure contained within a hydraulic fracturing system on a multiple well location in accordance with certain aspects of the presently disclosed invention.

[0065] FIG. 26 is a schematic showing a valve system positioned to provide rapid pressure loss within a hydraulic fracturing system in accordance with certain aspects of the presently disclosed invention.

#### DETAILED DESCRIPTION

[0066] In the following description, the present invention involves systems and methods for adjustment and control of pressure conditions in fluid lines. The above summary and drawings are not intended to describe or show each illustrated embodiment or every possible implementation of the presently disclosed systems and methods. Rather, various aspects of the systems and methods disclosed herein are described and illustrated with reference to one or more exemplary implementations. As used herein, the term “exemplary” means “serving as an example, instance, or illustration,” and should not necessarily be construed as preferred or advantageous over other variations of the devices, systems, or methods disclosed herein. "Optional" or "optionally" means that the subsequently described component, event, or circumstance may or may not occur, and that the description includes instances where the event

occurs and instances where it does not. In addition, the word “comprising” as used herein means “including, but not limited to”.

**[0067]** Various aspects of the systems disclosed herein may be illustrated by describing components that are coupled, attached, and/or joined together. As used herein, the terms “coupled”, “attached”, and/or “joined” are interchangeably used to indicate either a direct connection between two components or, where appropriate, an indirect connection to one another through intervening or intermediate components. In contrast, when a component is referred to as being “directly coupled”, “directly attached”, and/or “directly joined” to another component, there are no intervening elements shown in said examples.

**[0068]** Relative terms such as “lower” or “bottom” and “upper” or “top” may be used herein to describe one element’s relationship to another element illustrated in the drawings. It will be understood that relative terms are intended to encompass different orientations of aspects of the systems in addition to the orientation depicted in the drawings. By way of example, if aspects of a valve shown in the drawings are turned over, elements described as being on the “bottom” side of the other elements would then be oriented on the “top” side of the other elements as shown in the relevant drawing. The term “bottom” can therefore encompass both an orientation of “bottom” and “top” depending on the particular orientation of the drawing.

**[0069]** It must also be noted that as used herein and in the appended claims, the singular forms “a”, “an”, and “the” include the plural reference unless the context clearly dictates otherwise. For example, although reference is made herein to “a” valve, “an” actuator, or “the” user interface, one or more of any of these components and/or any other components described herein can be used.

**[0070]** “Substantially,” as used herein, is understood to mean to a great or significant extent, such as at least 80%, or 90%, or 95%, 96%, 97%, 98%, or even 99%. For example, when an object is described as having a property substantially the same as a comparative such as a diameter or shape, etc., the property will be within at least 80% of the value of the comparative.

**[0071]** Unless defined otherwise, all technical and scientific terms used herein have the same meanings as commonly understood by one of ordinary skill in the art.

**[0072]** The present invention provides valve assemblies and control systems which afford effective pressure adjustment, control, and/or relief in fluid lines or conduits, such as those used in the hydraulic fracturing industry or in wellbore completion activities. The valve assembly may

include individually controllable valves and associated actuators, and thus alleviates the problems associated with prior art single set-point systems. Moreover, the presently disclosed systems include valves that are placed in-line on a fluid line, such as a bypass conduit, and thus alleviate the problems associated with 90-degree valves (e.g., valves placed at right angles on high-pressure conduits). The systems also include unique valve designs that maintain the sealing face of the valve out of contact with the abrasive fluid flow.

[0073] The present invention is novel when compared with other known systems and controlled pressure loss solutions in that it provides at least two independently controlled valves that may monitor and adjust pressure conditions in the same or separate fluid lines, all in a convenient assembly having redundant sensors and controls to afford fail-resistant operation. The present invention is novel over prior art solutions in the overall system architecture, which provides a specific combination of elements that afford greater performance attributes to the valve assemblies, improved integration with current wellbore activities, enhanced designs for the valves and actuators, and better electronic control over the process and the data derived therefrom. Furthermore, the present invention places the valve assembly parallel with the fluid flow path, and provides unique valve internal geometry and materials selection that combat the harsh fluid environment during the adjustment and/or rapid pressure loss event (i.e., when the valve is open).

[0074] Referring now to the drawings, systems and methods according to the presently disclosed invention are shown in **FIGS. 1-26**. Like reference numbers are used to label similar or shared components in each of the figures. As such, reference to a component depicted in one figure, such as the pressure sensor **52** of **FIG. 1**, may also include reference to the pressure sensor and included components (**52-58**) in **FIG. 7**, and vice versa. As another example, reference to a valve **22** in **FIG. 1** may also be reference to a first valve and a second valve (**22a** and **22b**, respectively) in **FIG. 4**.

[0075] With reference to **FIG. 1**, a system **10** of the present invention includes a valve assembly **20**, a valve actuation system **30**, and a control system **40** configurable to execute a user defined control process. The system may include two or more valve assemblies **20** each comprising a valve **22** therein, such as a ball valve, wherein each valve **22** is individually regulatable. The valve actuation system **30** may include a source of actuation fluid **34**, such as a

gas or hydraulic fluid, and a drive means configured to open/close the associated valve, e.g., ball valve, such as an actuator **32** and a pump **33**.

[0076] According to certain aspects of the present invention, the actuator **32** may be a linear or rotary actuator, or an actuator that comprises a combined rotary and linear movement, e.g., scotch yoke, crank/slider, rack and pinion. The actuator **32** may be mechanically coupled to the valve **22**, wherein movement of the actuator may be assisted by a pump **33** which forces the actuator fluid **34** into a chamber of the actuator.

[0077] The control system **40** generally includes a user interface **42**, and a controller **44** including a processor and a memory. The control system **40** may be in communication with a pressure sensing device **52** and the valve actuation system **30** (electrical communications shown as dotted lines in **FIG. 1**) to provide electronic control over the opening and closing of the valve **22**.

[0078] During oil and gas operations, fluids are pumped at high pressures through various conduits. For example, during hydraulic fracturing operations, fluids are injected at high pressures through a wellbore into deep underground hydrocarbon formations. As a precursor to these fracturing operations, these conduits are pressure tested at significant pressures, i.e., at pressure often exceeding 10,000 psi. After a pressure test, the pressure in these conduits must be reduced or equalized to the pressures in the rest of the system, e.g., pressures in the wellbore. Prior art systems used for these activities generally require manual operation of a valve to slowly adjust the pressure in the lines by partially opening the valve. This not only places a human operator in harm's way, but also positions sealing faces of the valve in-line with the fluid flow, which frequently contained particulates. As discussed above, the abrasive fluid flow on the sealing face of the valve will reduce its sealing capabilities over time, and lead to the need for replacement of parts.

[0079] Moreover, during normal operation, high pressure pumps force fluid through these conduits into the wellbore for fracturing activities. In the event that a conduit becomes obstructed, an overpressure condition will develop within the conduits until the pumps are shut down, or until catastrophic failure occurs. As such, pressure relief valves are generally included on these conduits to provide a quick relief of these dangerous overpressure events. Typical prior art relief valves are either one-time use valves, or include valves that position sealing faces of the valve in-line with the fluid flow.

[0080] The systems and methods of the present invention improve upon the prior art valves discussed above by placing the valve in a bypass conduit (**5a**, **5b**) downstream from a connection **101** with a high pressure fluid conduit, i.e., main conduit **100**. This allows the valve **22** to be placed 180° with respect to the fluid flow, i.e., the open valve is parallel with the fluid flow, whereas the prior art valves were positioned at 90° to the fluid flow, i.e., the valve assembly was perpendicular to the fluid flow.

[0081] With reference to **FIG. 2**, an exemplary system **10** of the present invention is shown. The system **10** includes at least two valve assemblies and associated valve actuation systems. Shown in **FIG. 2** is a right side perspective view of a frame **102** which contains a hydraulics enclosure **3** containing at least the valve actuation fluid **34** and pump **33**. Also shown is an electronic control enclosure **4** which generally contains the power management system, and may further contain portions of the control system. Certain power management system components may be positioned on an outside face of the electronic control enclosure **4** so that they may be easily accessible by a user. For example, exemplary components include a power disconnect **46**, remote override input **47**, and charging input connections **48**. Furthermore, a local screen display **64**, a voltmeter **66**, a charging indicator lamp(s) **67**, and an indicator light stack **62** may also be included on the electronic control enclosure **4**.

[0082] As indicated above, the system **10** includes at least two valve assemblies **20**, each containing a valve **22** (shown in **FIG. 2** is a first valve **22a**), wherein the valve assemblies **20** includes an upstream connection point **6** and a downstream connection point **7**. In use, the system **10** may be placed in close proximity to a main conduit **100**. One end of a first bypass conduit (see **5a** of **FIG. 1**) may be attached to the main conduit **100** at a connection point **101**, and the other end may be attached to the upstream connection point **6** of the valve assemblies **20**. A second bypass conduit (see **5b** of **FIG. 1**) may be attached to the downstream connection point **7** of the valve assemblies **20**, and the other end may be placed in a collection reservoir. Exemplary collection reservoirs include at least an earthen pit, a collection pool, a tank, a portable tank such as on a truck, e.g., frac tank, etc.

[0083] The system **10** also includes a valve actuation system **30** to actuate (i.e., open and/or close) each valve **22**. As shown in **FIG. 2**, the valve actuation systems may be positioned in close association with the valves **22** within the frame **102** (i.e., valve **22a** may be actuated by actuator **32a**; valve **22b** may be actuated by actuator **32b**). Actuation of the valves by the valve

actuation system **30** may be triggered by a pressure event in the main conduit **100** detected by a pressure sensor **50** (*see* for example **FIG. 7**).

[0084] As shown in **FIG. 3**, the system **10** also includes a pressure input port **36** and a hydraulic output port **35** on the hydraulics enclosure **3**. The pressure input port **36** may connect to a pressure sensor **52**, as discussed in more detail below. As shown in **FIG. 1**, the pressure sensor **52** may be placed on a main conduit **100** or a bypass conduit **5**. The hydraulic output port **35** may provide connection for a fluid line that may pass the hydraulic fluid in a hydraulic fluid reservoir **34** positioned in the hydraulics enclosure **3** to the valve actuator **32** via a connection point **37** thereon (*see* **FIG. 2**). The indicator light stack **62**, valve **22**, and valve actuator **32** are labeled for reference. While actuation of the valve is discussed in connection with a hydraulic fluid, the actuator fluid **34** (as referenced in **FIG. 1**) could also include compressed gas.

[0085] A front view of the system **10** is shown in **FIG. 4**. Both valves (**22a** and **22b**) and valve actuation systems (**32a** and **32b**) are visible, as well as a case **103** that houses the hydraulics enclosure **3** and the electronic control enclosure **4**.

[0086] With reference to **FIG. 5**, a system **10** comprising three valve assemblies **20** is shown. Each valve assembly **20** comprises a valve (**22a**, **22b**, **22c**) and valve actuation (**32a**, **32b**, **32c**) housed within the frame **102**. As also shown in **FIGS. 2-4**, the system **10** of **FIG. 5** comprises a case **103** that houses a hydraulics enclosure and an electronic control enclosure, the latter of which may include power disconnect **46**, remote override input **47**, and charging input **48** connections in addition to other components (e.g., indicator light stack **62**, valve position sensor, pressure input port, a hydraulic output port, etc.).

[0087] Also shown in **FIGS. 2** and **5** are connection points on the system **10** that may assist in moving or placing the system at a job site. According to certain aspects, the system **10** may have an overall weight exceeding several thousand pounds, and an overall size exceeding 35 ft<sup>3</sup>. As such, heavy rigging and/or a forklift are commonly used to move the system **10** to or from a worksite. For example, attachment rings **105** or other connection points may be positioned on an upper surface or area of the frame **102** that are configured for attachment of rigging hooks for lifting the system **10** via a crane. Additionally, or alternatively, slots **104** may be positioned in a bottom portion of the frame **102** that are configured to provide insertion regions for the blades of a forklift. According to certain aspects, these slots **104** could also be positioned on a top of the frame **102**. This latter positioning may be favored for systems positioned at work sites having

soft ground, wherein slots **104** on a bottom region of the frame **102** could sink into the ground surface and become occluded.

[0088] With reference to **FIG. 4**, the case **103** may provide attachment for a user interface **42** portion of a control system **40** (see **FIG. 6**). Each of the valve actuation systems **30** may include a valve position sensor **74** configured to determine an open or closed position of the valve **22** and communicate with the control system **40**. For reference, the power disconnect **46**, remote override input **47**, charging input connections **48**, frame **102**, and indicator light stack **62** are also shown.

[0089] With reference to **FIG. 6**, each of these components may be controlled by control logic included as part of a control system **40** that includes a controller **44** (e.g., processor and memory, not shown) and a user interface **42**. The user interface **42** may include a display panel **118** and a keyboard interface **122** that provides a means for direct user input to the control system **40**. The user interface **42** may also include various ports for data import/export, and power input. For example, the user interface **42** may include a serial port output **116**, an Ethernet data output **114**, an input for user controller override (open) **112**, and a backup power input **110**.

[0090] While specific types of data connection and transfer are indicated in the description and figures, different connections and transfer means are within the scope of the present invention. For example, while specific types of wired data connections are shown, other means for wired and wireless data transfer are known and within the scope of the present invention. Moreover, while user input is shown to include a push button interface, a touch screen or other means for user input is also within the scope of the present invention (e.g., wireless transfer from another electronic or mobile device). For example, the control system **40** may include a user interface **42** that is attachable to the system **10**, such as on the case **103**, and/or that may be configured for remote use, such as when carried by a user or positioned remote from the frame **101** housing the main hardware of the system **10** (i.e., valve assemblies **20**, actuators **30**, etc.). In this latter scenario, the user interface **42** may include hardware and software components that enable wireless communication.

[0091] The control system **40** may monitor, interpret, control, and provide user interface or information feedback regarding performance of the system and values returned from the various sensors. Moreover, the system **10** as a whole may be configured in various control methodologies. For example, a singularly controlled valve may be controlled through

interpretation of a singular pressure sensing point. Alternatively, two separate valves may be controlled independently through interpretation of a singular pressure sensing point. Still further, two separate valves may be controlled independently through interpretation of two separate pressure sensing points. Still further, a singularly controlled valve may be controlled through interpretation of an input signal provided by a user. Still further, two separate valves may be controlled independently through interpretation of dedicated input signals provided by the user, such as through the user controlled override (112), or via a wireless signal sent from an external processor and remote communications interface. Where the operational control signal is supplied by others, the inherent on-board logic may act in a back-up manner to provide redundancy.

[0092] As such, the system 10 of the present invention can include a control system 40 to receive signals from the at least one pressure sensor 50, from the valve position sensors 74, and from the user interface 42. According to certain aspects of the present invention, the pressure registered by control system 40 may be received as a signal from an external input, such as a wired or wireless signal from a pressure sensor on another system that is reading pressure in the main conduit 100, a bypass conduit (e.g., 5a), or a user input value.

[0093] According to certain aspects of the present invention, the control system 40 includes a controller 44 that may process these signals, such as at least a processor and memory. The controller 44 may be a portion of a detachable user interface unit 42, an integrated, attached portion of the system 10 (i.e., a portion of the system 10 residing in or on the electronics enclosure 4), or a remote server. Alternatively, the control system 40 may include a controller 44 in one or more of the user interface unit 42, as a portion of the system 10 integrated in the electronics enclosure 4, and a remote server. It is to be appreciated that aspects of the control system 40 can be implemented by various types of operating environments, computer networks, platforms, frameworks, computer architectures, and/or computing systems.

[0094] According to certain aspects of the present invention, the control system 40 may include calibration algorithms for sensors that may be included as part of the system, or may allow user override of system registered values.

[0095] Implementations of the control system 40 are described within the context of a device configured to perform various steps, methods, and/or functionality in accordance with aspects of the described subject matter. It is to be appreciated that a control system such as a computing device or computer system can be implemented by one or more computing devices.

Implementations of the control system **40** can be described in the context of a “device configured to”, wherein the term configured may be taken to mean that the device can implement computer-executable instructions that are executed to perform various steps, methods, and/or functionality in accordance with aspects of the described subject matter.

**[0096]** In general, a computer system or computing device can include one or more processors and storage devices (e.g., memory and disk drives) as well as various input devices, output devices, communication interfaces, and/or other types of devices. A computer system or computing device can also include a combination of hardware and software. It should be appreciated that various types of computer-readable storage media can be part of a computer system or computing device. As used herein, the terms "computer-readable storage media" and "computer-readable storage medium" do not mean and unequivocally exclude a propagated signal, a modulated data signal, a carrier wave, or any other type of transitory computer-readable medium. In various implementations, the control system **40** may include a processor configured to execute computer-executable instructions and a computer-readable storage medium (e.g., memory and/or additional hardware storage) storing computer-executable instructions configured to perform various steps, methods, and/or functionality in accordance with aspects of the described subject matter.

**[0097]** Computer-executable instructions can be embodied and/or implemented in various ways such as by a computer program (e.g., client program and/or server program), a software application (e.g., client application and/or server application), software code, application code, source code, executable files, executable components, routines, application programming interfaces (APIs), functions, methods, objects, properties, data structures, data types, and/or the like. Computer-executable instructions can be stored on one or more computer-readable storage media and can be executed by one or more processors, computing devices, and/or computer systems to perform particular tasks or implement particular data types in accordance with aspects of the described subject matter.

**[0098]** The control system **40** can implement and utilize one or more program modules. Generally, program modules include routines, programs, objects, components, data structures, etc., that perform particular tasks or implement particular abstract data types.

**[0099]** The control system **40** can be implemented as a distributed computing system or environment in which components are located on different computing devices that are connected

to each other through network (e.g., wired and/or wireless) and/or other forms of direct and/or indirect connections. In such distributed computing systems or environments, tasks can be performed by one or more remote processing devices, or within a cloud of one or more devices, that are linked through one or more communications networks. In a distributed computing environment, program modules can be located in both local and remote computer storage media including media storage devices. Still further, the aforementioned instructions can be implemented, in part or in whole, as hardware logic circuits, which can include a processor.

**[0100]** The control system **40** can be implemented by one or more computing devices such as computers, PCs, server computers configured to provide various types of services and/or data stores in accordance with aspects of the described subject matter. Exemplary server computers can include, without limitation: web servers, front end servers, application servers, database servers, domain controllers, domain name servers, directory servers, and/or other suitable computers.

**[0101]** Components of the control system **40** can be implemented by software, hardware, firmware or a combination thereof. For example, the control system **40** can include components implemented by computer-executable instructions that are stored on one or more computer-readable storage media and that are executed to perform various steps, methods, and/or functionality in accordance with aspects of the described subject matter.

**[0102]** The control system **40** can include a controller **44**, i.e., a processor and memory, and additional hardware storage, input devices, and output devices. Input devices can include one or more of the exemplary input devices described above and/or other type of input mechanism and/or device. Output devices can include one or more of the exemplary output devices described above and/or other type of output mechanism and/or device.

**[0103]** The control system **40** can contain one or more communication interfaces that allow the control system **40** to communicate with other computing devices and/or other computer systems. The control system **40** can include and/or run one or more computer programs implemented, for example, by software, firmware, hardware, logic, and/or circuitry of the control system **40**. Computer programs can include an operating system implemented, for example, by one or more exemplary operating systems described above and/or other type of operating system suitable for running on computing device. Computer programs can include one or more applications.

[0104] As shown in FIG. 1, the system 10 may include one or more pressure sensors 52 that may be positioned on a main conduit 100 or on a bypass line (e.g., 5a). With reference to FIG. 7, an exemplary pressure sensor system 50 according to certain aspects of the invention is shown. The pressure sensor system 50 may include at least one pressure transducer (54a-c) and a pressure sensor 52. The pressure sensor 52 may include a diaphragm configured to sense an external pressure and deform to translate that external pressure to an internal pressure on a pressure fluid within a pressure chamber (i.e., pressure against the diaphragm pressurizes the pressure fluid within the pressure chamber). This pressurization of the pressure fluid is then registered by the at least one pressure transducer (54a-c) and converted to an electrical signal (e.g., piezo-resistive pressure sensor or silicon cell). The electrical signal 58 may then be communicated via a communication cable to the control system 40 where the signal may be calculated and utilized to control a pump operation of the valve actuation system 30.

[0105] According to certain aspects of the present invention, at least two pressure transducers are included as part of the pressure sensor system 50, and the signal from the pressure sensor system 50 received by the controller may comprise individual signals from the two pressure transducers. This allows the system to provide an almost instantaneous response to a pressure registered by the pressure sensor 52, such as an overpressure event. The individual signals may be received at a rate of at least 50 signals/second, such as 75 signals/second, or even 100 signals/second.

[0106] According to certain aspects of the present invention, three pressure transducers (54a-c) may be included as part of the pressure sensor system 50, and the signal from the pressure sensor system 50 received by the controller may comprise individual signals from the three pressure transducers. Such redundancy provides a near fail-safe system; should one transducer work improperly or fail, the readings from the failed transducer would differ from those of the other two transducers. The system would be configured to discard the “odd” third pressure reading from the failed transducer and register the correct readings from the other two transducers.

[0107] The presently disclosed system 10 may include other redundant aspects to protect overall operation, such as filters for the actuator fluid positioned in fluid lines both before and after a pressurization chamber, i.e., accumulator, and in fluid lines leading to a pressurized fluid storage tank. Additionally, each valve assembly may include an actuator, wherein the actuator

fluid may be independently pressurized in an accumulator (i.e., one accumulator for each valve assembly).

**[0108]** With continued reference to **FIG. 7**, the at least one pressure transducer (**54a-c**) may be any pressure sensor device capable of receiving and measuring physical pressure from the pressure fluid within a pressure chamber (i.e., chamber comprising the pressure fluid, wherein at least one wall or a portion thereof comprises the diaphragm that deforms with changes in an external pressure). A pressure passage **56/55** may be fluidly connected between the interior of the diaphragm and the at least one pressure transducer (**54a-c**) to transfer a pressure from the pressure fluid within the pressure chamber to the pressure transducer. The diaphragm may be comprised of a flexible and deformable structure so that an external pressure in the diaphragm causes a deformation that may be registered by the pressure fluid. Selection of the materials used for construction of the diaphragm may take into account the expected pressures to which the diaphragm may be exposed. For example, in the hydraulic fracturing industry, the pressures within conduits may be as high as 10,000 to 30,000 psi. As such, the diaphragm may be formed of a metal material capable of withstanding these high pressures yet flexible enough to deform with changes in the pressure.

**[0109]** The pressure sensor **52** may be positioned on a conduit so that the diaphragm comes into direct contact with the fluid in the conduit, and can respond to, or measure, a fluid pressure of the liquid within the conduit (**5** or **100**; external pressure). This external pressure on the diaphragm is translated via the pressure passages **55/56** to the at least one pressure transducer. One portion of the pressure passage **55** and the at least one pressure transducer (**54a-c**) may be housed in the hydraulics enclosure **3**. A second portion of the pressure passage **56** may be connectable via a port **36** on the hydraulics enclosure **3**, such as by a connector end **57** on the pressure passage **56**.

**[0110]** The diaphragm is sealed with respect to the at least one pressure transducer so that fluids in the conduit to which the sensor **52** is attached do not come into contact with the at least one pressure transducer (**54a-c**). This latter function is enabled by the design of the pressure sensor **52**. That is, the diaphragm contacts and retains a pressure fluid within the diaphragm (e.g., in a pressure chamber). The pressure fluid is preferably comprised of a relatively non-compressible and non-expandable fluid such as, but not limited to, oil to efficiently transfer the external fluid pressure applied to the diaphragm to the at least one pressure transducer (**54a-c**).

The pressure fluid preferably has no or a limited amount of air or other gases that can be compressed or expand based on temperature.

[0111] The pressure sensor **52** may include a pressure chamber which encloses the diaphragm and the pressure fluid. According to certain aspects of the present invention, the pressure chamber is preferably a hollow cylindrical structure, wherein the diaphragm is compressible based on the external fluid pressure. The diaphragm may have a substantially circular, square, or rectangular cross sectional area, and/or may be formed as a disk, a bellows, a cylindrical structure, or any other structure that may deform in a manner indicative of a fluid pressure in a conduit to which the diaphragm is attached.

[0112] For example, a pressure sensor system **50'** comprising a cylindrical diaphragm **59** is shown in **FIGS. 8A** and **8B**. The pressure sensor system **50'** may comprise a sensor body **52'** having an inlet end **72** and an outlet end **73** connectable inline on a conduit, and a longitudinal bore **68** therethrough defined by an internal cylindrical wall **65**. While shown in a specific orientation, the pressure sensor system **50'** could be positioned in an opposite orientation, i.e., having the inlet and outlet ends swapped, and function as described herein.

[0113] At least a portion of the internal cylindrical wall **65** of the sensor body **52'** may comprise a cylindrical diaphragm **59**. The diaphragm may be formed of a deformable material, so that when the sensor body **52'** is positioned in-line on a conduit, such as a main conduit **100** or a bypass conduit **5**, a pressure of the fluid flowing through the longitudinal bore **68** of the pressure sensor **52'** may push against an exterior wall of the diaphragm **59** causing it to deform inward. As shown in **FIG. 8A**, the pressure sensor further includes a pressure chamber **56** surrounding the diaphragm **59**, i.e., the diaphragm **59** forms one cylindrical wall of the pressure chamber **56**, the other wall being formed by an opposing surface **71** of the internal bore. The pressure chamber may further include pressure passages **55'** that provide communication of the pressure fluid in the pressure chamber **56** and the at least one pressure transducer (**54a-c**), thereby transferring a pressure of the pressure fluid within the pressure chamber to the pressure transducer.

[0114] The diaphragm may be any deformable material capable of responding to pressure within a user selected range. For example, as detailed above, the diaphragm may be a metal or polymer capable of registering pressure, i.e., reversible deformation, in the range of 10,000 psi to 30,000 psi. According to certain aspects, the diaphragm **59** may be formed of an elastomeric

polymer, such as polyurethane. Moreover, the fluid in the pressure chamber, i.e., pressure fluid, may be a relatively non-compressible fluid such as a hydraulic fluid.

[0115] As shown in **FIG. 8A**, the pressure sensor system **50'** may further include a charging port **61** for the pressure fluid in the pressure chamber **56**. The pressure chamber is thus a closed system, such that deformation of the diaphragm inward will increase a pressure of pressure fluid within the pressure chamber **56**, which is communicated via the pressure passages **55'** to at least one pressure transducer (**54a-c**). As discussed above, the pressure sensor system **50'** may comprise more than one pressure transducer, preferably three pressure transducers, to provide a nearly fail-safe system. The electrical signal(s) **58** from each pressure transducer may be communicated via a wired or wireless signal to the control system **40** where the signal may be received, converted to a registered pressure reading, and utilized to control a pump operation of the valve actuation system **30**.

[0116] Also shown in **FIGS. 8A** and **8B** are various connection means between cylindrical ends of the diaphragm **59** and the internal bore **65** of the sensor body **52'**. For example, shown in **FIG. 8A** are threaded ends **60** of the diaphragm **59** that may secure and seal the diaphragm within corresponding threads or grooves of the internal bore **68** of the sensor body **52'**. According to certain aspects, the threaded ends **60** may be bonded to the corresponding threads or grooves of the internal bore **68**. Alternatively, or additionally, an attachment ring **63** may be inserted, bonded, or molded into a thread of the threaded end **60** of the diaphragm **59**, as shown in **FIG. 8B**.

[0117] While specific embodiments of the pressure sensing system (**50, 50'**) have been described herein, others are possible and within the scope of the present invention.

[0118] With reference back to **FIGS. 2-5**, the valve assembly may include any type of actuator (**32a-32c**) configured to operate the valve (**22a-22c**) from the closed position to an open position, and then back to the closed position during each of a plurality of operation cycles. In some cases, each valve actuator (**32a-32c**) may be a solenoid actuator, a hydraulic actuator, a magnetic actuator, an electric motor, pneumatic actuator, and/or other similar or different types of actuators, as desired. According to certain embodiments, each valve actuator (**32a-32c**) may be a pneumatic or hydraulic actuator driven by an actuator fluid **34**. In preferred embodiments, each valve actuator (**32a-32c**) may be a hydraulic actuator driven by hydraulic fluid in a hydraulic fluid reservoir **34**. Such an embodiment may provide improved safety on extreme

worksites, such as those of a standard hydraulic fracturing or wellbore completion operation (e.g., exposure to extremes temperatures and weather).

[0119] With reference to **FIGS. 9-20**, various implementations of a valve assembly in accordance with aspects of the presently disclosed invention are shown. With specific reference to **FIG. 9**, the valve assembly generally comprises a valve assembly **20** having a longitudinal bore therethrough allowing a flow of fluids, such as in the direction shown by the arrow **2**. The valve assembly **20** generally includes an upstream connection **86** having an upstream connector **23** and a downstream connection **87** having a downstream connector **24** (also shown as **6** and **7**, respectively, in **FIG. 2**) that provide connection to sections of bypass conduit. While the downstream connector **24** is shown as an exterior threaded section on the downstream connection **87** and the upstream connector **23** is shown as in rotatable ring (e.g., having threads on an inside surface of the ring), these connectors may be switched or replaced by different means for connection to conduit lines.

[0120] Also shown in **FIG. 9** are an actuating stem **132a** that provides connection to the valve via a connection port **130a** (i.e., on ball valve **26** of **FIG. 12**) so that it may be opened or closed by the actuator (any of **32a-32c**). The ball valve shown in **FIG. 12** is a trunnion mounted ball valve having a trunnion **132b** and a trunnion cap **133** (see also **FIG. 10**), wherein the trunnion is attachable in a bottom connection port **130b** on the ball valve **26** (see **FIG. 12**). While the valve shown in the figures are trunnion mounted, which work practically well in conditions experiencing high velocity flow, other types of ball valves are within the scope of the presently disclosed invention.

[0121] **FIG. 10** shows a cross-sectional view of the valve assembly **20** taken along line **A-A** of **FIG. 9**. Contained within the valve assembly **20** is a valve **22** having a valve body. As shown, the valve may be a ball valve wherein the valve body comprises a ball **26** with a throughbore, wherein an open position of the ball **26** within the valve **22** provides flow-through alignment (see arrow **2**) of the throughbore with upstream and downstream connections (**23** and **24**, respectively) of the valve assembly **20**, and a closed position of the ball **26** provides an out of flow-through alignment of the throughbore with the upstream and downstream connections of the valve assembly.

[0122] With reference to **FIGS. 10** and **12**, the ball **26** of the valve **22** may be selectively rotatable within the valve **22** about an axis (line **9**) to the open and closed positions. The valve **22**

may further have a seat assembly comprising an upstream seat **27** and a downstream seat **28** positioned against the ball **26**, each having a longitudinal bore therethrough (arrow **2**; note, the ball **26** is shown in the closed position in **FIGS. 10** through **14** with the throughbore out of alignment with the longitudinal bore of the valve assembly and the upstream and downstream seats). Also shown are the actuating stem **132a** and connection port **130a** for the stem on the ball **26** (**132b** is a trunnion attachable in a bottom connection port **130b** on the ball **26**).

[0123] The upstream seat **27** of the ball **26** may include an outward facing surface **21a** positioned perpendicular to the longitudinal bore of the valve housing, such that a fluid pressure on the outward facing surface **21a** may force the upstream seat against a sealing face **29** of the ball **26**. Additionally, the upstream connection **86** of the valve housing may include a sloped section that reduces the diameter of the longitudinal bore such that fluid pressure is exerted on the upstream connection **86** and thus on the outward facing surface **21a** of the upstream seat **27**. Finally, the upstream connection **86** may also include an outward facing surface **21b** that may be exposed to a fluid flow, such that fluid pressure on the outward facing surface **21b** may force the upstream connection **86** against the upstream seat **27**, in turn forcing the upstream seat **27** against the sealing face **29** of the ball **26**. This acts to provide a dynamic seal for the ball **26** within the valve **22**, wherein increased fluid pressure within the conduit leads to dynamic increases in the sealing pressure applied on the sealing face **29**. Moreover, the unique arrangement of seats on the ball, and positioning of the ball within the valve housing, isolates the sealing face from the abrasive fluid flow in the conduits. When closed, no portion of the seal in the ball valve is exposed to the fluid flow, and when open, the sealing face on the ball is turned away from the fluid flow (out of alignment).

[0124] With reference to **FIG. 14**, the upstream seat **27** and downstream seat **28** may include gaskets **82a**, **82b** and **81a**, **81b**, respectively, that may further assist in providing a liquid tight connection between these upstream and downstream seats and the upstream and downstream connections (**86**, **87**), respectively.

[0125] The ball **26** may be connected to the valve actuator **32** via an actuating stem **132a**. According to certain aspects of the present invention, the valve actuator **32** may be any valve actuation system, such as an actuation system that uses linear, rotational, or a combination of rotary and linear movement, e.g., scotch yoke, crank/slider, and rack and pinion. In preferred embodiments, the actuator uses a combination of rotary and linear movement so that as the

actuator moves linearly within a housing, the actuating stem 132a connected between the ball 26 and the actuator 32 rotates and causes the ball 26 to rotate within the valve housing.

[0126] As example, when the actuator is configured as a scotch yoke, the actuating stem 132a may include a disk having a pin that interacts with a sliding yoke at one end of a piston of the actuator 32. Movement of the piston within an actuator chamber may provide linear movement of the yoke that is translated to a rotational movement of the stem 132a. Also shown in FIG. 10 are the trunnion cap 133 and bonnet 131 of the valve assembly.

[0127] According to certain aspects, the valve assembly may be configured to provide a rapid reduction in the pressure within a main conduit 100 or may provide a controlled reduction of the pressure in the main fluid conduit. When the valve assembly is configured to provide a rapid reduction in the pressure, i.e., rapid pressure loss, the valve actuation system may be configured to open the valve at a rate sufficient to reduce the fluid pressure in the main conduit by at least 50% within 1 second, or 70% within 1 second, or even 90% within 1 second. When the valve assembly is configured to provide a controlled reduction of the pressure, the valve actuation system may be configured to open the valve at a rate sufficient to reduce the fluid pressure in the main conduit by the controlled amount within 2 seconds, or within 1 second, or even within 0.5 seconds. Thus, opening such a valve assembly comprising restrictive regions or components may reduce the fluid pressure in the fluid line by at least 1% within 1 second, or 3% within 1 second, or even 5% within 1 second. Moreover, the controller may be configured to hold the valve open for a period when the user requires complete fluid pressure de-energization in the fluid line and, if/when the user desires, the controller may be configured to close the valve.

[0128] Moreover, the controller may be configured to hold the valve open for a set time period when the fluid pressure in the main conduit exceeds the user-defined high pressure limit, and if, after the set time period, the fluid pressure in the main conduit is at or below the user-defined low pressure limit, the controller is configured to close the valve.

[0129] Another design for the valve assembly 20' of the present invention is shown in FIG. 11, wherein a downstream connection 87' of the valve assembly 20' is configured as a one-component attachment to reduce the overall weight of the valve assembly 20'. As shown, the upstream connection 86, upstream connector 23, and upstream seat 27 may be substantially as described with reference to FIG. 10. The downstream region of the valve assembly 20' may be

configured as a single fixture directly attachable to a downstream side of the valve body, enclosing both the downstream seat 28 and the valve body (e.g., ball 26).

[0130] As shown in FIGS. 13 and 14, a downstream connection 87 of the valve assembly may include a portion having a reduced diameter 84 as compared to the diameter of the upstream connection 86, upstream seat 27, and/or throughbore of the ball 26, and may also include a portion having a graduated or sloped approach 85 to the reduced diameter section 84. These portions of the downstream connection 87 act to restrict the flow of fluid through the valve assembly 20 and thus provide a metered or controlled reduction of the pressure in the main conduit. Variation in the amount of diameter reduction in the downstream connection 87 provides an inverse variation in the amount of pressure reduction provided by opening the valve in the valve assembly (i.e., greater reduction in diameter of the downstream connection 87 leads to lesser pressure reduction on valve opening).

[0131] As shown in FIGS. 13-15, the reduced diameter section of the downstream connection 87 may be implemented using an insert 83 that includes the reduced diameter section 84. Alternatively, the downstream connection 87 may have a throughbore comprising the reduced diameter section 84.

[0132] According to certain aspects, the reduced diameter region may also be positioned in the upstream connection 86 as either a reduced diameter section or an insert (not shown).

[0133] According to yet further aspects, the reduced diameter region may also be positioned upstream or downstream from the valve assembly, such as in the bypass conduit (see 5a or 5b, respectively, in FIG. 1) distal from the upstream connection 86 or downstream connection 87. Moreover, the reduced diameter region may be positioned at any distal position, such as less than a millimeter downstream from the upstream connection 86 or downstream connection 87 to more than 500 meters from the upstream connection 86 or downstream connection 87 or more. When the fluid in the fluid lines contains particulate matter, it is preferable to position the reduced diameter region or insert downstream from the valve.

[0134] According to certain other aspects, controlled and/or variable reduction of the pressure in the main conduit 100 may be achieved through use of one or more flow restrictors. These flow restrictors may be positioned within the valve assembly, such as within the downstream connection 87. These flow restrictors may also be positioned downstream from the valve assembly, such as in the bypass conduit (see 5b in FIG. 1) distal from the downstream

connection 87. As with the reduced diameter regions, the flow restrictors may be positioned at any distal position, such as less than a millimeter downstream from the downstream connection 87 to more than 500 meters from the downstream connection 87 or more. Moreover, according to certain aspects, the flow restrictors may be positioned at any upstream position, such as within the upstream connection 86, or less than a millimeter upstream from the upstream connection 86 to more than 500 meters from the upstream connection 86 or more.

[0135] Any device configured to achieve restricted flow is within the scope of the present invention. For example, a flow restrictor may include a solid insert having one or more perforations or slots that act to reduce fluid flow through the insert. The insert may be a separate portion of the system, such as a separate portion of the downstream connection 87 as shown in FIG. 13 and 14 or may be an integral portion or region of the downstream connection 87. An exemplary configuration for a flow restrictor 83a according to the presently disclosed invention is shown in FIG. 15A, wherein the flow restrictor 83a may be an insert positionable within the downstream connection 87 (*see* FIG. 13 for reference).

[0136] FIG. 15B shows a cross-sectional view of another variation of a similar flow restrictor 83b taken along the line B-B of FIG. 15A. The sloped approach 85 to a set of one or more perforations 84a is shown. Another flow restrictor 83c design is shown in FIG. 15C, which includes a sloped approach 85 to a set of one or more perforations 84b, which may be included as part of an insert 99 at an end of the flow restrictor. As shown, the insert 99 may be held in place within the flow restrictor 83c with a set screw 88 and sealed against an inner surface of the flow restrictor 83c with an O-ring 89a. Additional O-rings 89b may be included to seal the flow restrictor 83c within the downstream connection 87. While O-rings are indicated to be used for the purpose of providing a seal between surfaces, specifically a liquid-tight seal, other means of providing a seal are known and within the scope of the presently disclosed invention.

[0137] According to aspects, the perforations of the flow restrictor limit the flow of fluids through the valve assembly and thus control the amount of pressure reduction in the main conduit provided by the valve assembly. The number, diameter, and length of the perforations may be adjusted to change the amount of fluid flow through the valve assembly.

[0138] FIG. 16 illustrates an exemplary valve assembly 20 including the flow restrictor 83c of FIG. 15C. As shown, the flow restrictor 83c may be positionable within the downstream connection 87 of the valve assembly 20. One advantage of configuring the flow restrictor (e.g.,

83a, 83b, or 83c) as a separate component of the downstream connection 87 is that it may be easily removed and replaced in the case of excessive wear or clogging with particulate matter.

[0139] The number, diameter, and length of the perforations, or of a reduced diameter section (i.e., diameter and length of the reduced diameter section) will dictate the amount of pressure reduction provided by the section or insert of the presently disclosed invention. As such, the amount of fluid flow through a valve assembly may be varied by exchanging the reduced diameter section or insert, and thus the amount of pressure reduction provided. Moreover, configuring this portion of the valve assembly as an insert such as shown in FIGS. 13-16 allows the fluid flow through the inventive valve assembly to be quickly changed by exchanging the insert. As such, the same overall architecture for the valve assembly may be used to provide a wide range of fluid flow rates therethrough.

[0140] Another exemplary valve assembly is shown in FIGS. 17A and 17B, which provides rapid changeout of the flow restrictor. As illustrated, the valve assembly 20' may be configured as shown in FIG. 11, wherein the downstream connection 87' is directly connectable to a downstream seat 28 of the valve body (ball 26). A flow restrictor attachment 90 may be connected to the downstream connection 87' via a joining means, e.g., via an attachment ring 92 having an internal thread configured to mate with the external thread of the downstream connector 24. The flow restrictor attachment 90 may further include a downstream joining means 91 configured for connection to a conduit. The flow restrictor attachment 90 may be designed to include an integral flow restrictor according to any of the designs disclosed herein (83a, 83b, 83c) or may be designed with a removeable flow restrictor insert (e.g., insert 99 shown in flow restrictor 83c), such as shown in FIGS. 14-16.

[0141] Alternatively, the flow restrictor attachment 90 may be connected to the upstream connection 86 via a joining means, e.g., via the attachment ring (upstream connector 23) having an internal thread configured to mate with the external thread of the downstream joining means 91.

[0142] FIG. 17B shows a close-up view of the flow restrictor attachment 90, wherein the flow restrictor 83c is included and held in place within attachment 90 by a threaded connector 93. While the threaded connector 93 is shown to have an exterior circumferential thread that mates with an internal circumferential thread on the flow restrictor attachment 90, other connection means are possible and within the scope of the presently disclosed invention.

Moreover, other means of securing the flow restrictor (any of **83a**, **83b**, **83c**, etc.) within the flow restrictor attachment **90** are possible and within the scope of the presently disclosed invention. Configuring the flow restrictor (e.g., **83a**, **b**, or **c**) to be part of an attachment, such as the flow restrictor attachment **90**, allows rapid changeout of the part when worn or damaged. Such a configuration also provides a means to achieve a wide range of fluid flow rates through the valve assembly (**20**, **20'**) through use of different flow restrictors and/or inserts (e.g., the insert **99** held in place with the set screw **88** of flow restrictor **83c**) designed to provide different flow volumes, i.e., simple exchange of the flow restrictor and/or insert in the flow restrictor attachment **90** to the valve assembly.

**[0143]** According to certain aspects, the flow restrictor attachment may be configured to provide a range of fluid flow adjustments without exchanging parts (i.e., flow restrictors **83a**, **83b**, **83c** and/or inserts **99** as described hereinabove). For example, a flow restrictor attachment may be configured to include at least two flow adjustment ports that may be individually opened or closed to vary the amount of fluid allowed to flow therethrough. The flow restrictor attachment may include three, four, or more ports evenly spaced about one or more outlet flow paths. As shown **FIG. 18A**, the flow restrictor attachment **90a** may include eight (8) flow adjustment ports configured as two sets of four (4) radially spaced ports about a circumference (two ports are labeled, **94a** and **94b**). Each set may be offset with respect to the other for ease of access.

**[0144]** The flow restrictor attachment **90a** may include an inlet end **97** and an outlet end **96**, connectable as described herein to a downstream or upstream connection of the valve assembly (**20**, **20'**) so that a fluid flow path shown by arrow **106** is provided. With reference to **FIG. 18B**, a cross-sectional view taken along line **C-C** of **FIG. 18A** of a flow restrictor attachment **90b** according to certain aspects of the presently disclosed invention is shown. Proximate the inlet end **97** of the flow restrictor attachment **90b** are longitudinally formed perforations **78** that terminate in ports **95** fluidly connectable with a passageway in the flow adjustment ports **94a**. When opened, the flow adjustment ports **94a** provide fluid communication between the perforations **78** and the flow path **79** via ports **95** and **43**, respectively.

**[0145]** As shown in **FIG. 18B**, the flow path is closed by the plunger **76**, which is rotated to a closed position in the bonnet **77**. Also shown is the locking nut **75** which maintains the bonnet **77** within the flow adjustment port **94a**. The locking nut further includes an overhang **45**

that acts as a stop for the plunger 76 so that it may not be completely unscrewed and removed from the bonnet 77. Flow through the flow restrictor attachment 90b may be adjusted by opening or closing individual flow adjustment ports, and/or by the degree to which each flow adjustment port is opened or closed (i.e., port may be partially opened to provide a portion of the flow allowable when fully opened).

[0146] With reference to FIG. 19A-19D, various flow paths are depicted in a flow restrictor attachment 90a that includes hydraulic actuation of a secondary flow adjustment port. Shown in FIG. 19A is a cross-sectional view taken along line C-C of FIG. 18A for the flow restrictor attachment 90a rotated 45° relative to the device shown in FIG. 18A (rotated about the longitudinal axis 69). The flow adjustment port 94b is shown, which includes a plunger 76 rotatably engaged within a bonnet 77 via matching threads. The bonnet 77 is likewise rotatably engaged within a port in a body of the flow restrictor attachment 90a via matching threads. Both the plunger 76 and the bonnet 77 are restricted from disengaging from the flow adjustment port 94b via a locking nut 75 having an overhang 45. As detailed above, the overhang 45 acts as a stop for the plunger 76 so that it may not be completely unscrewed and removed from the bonnet 77.

[0147] With continued reference to FIG. 19A, the plunger 76 is shown in an open position, i.e., unscrewed in a direction away from the central longitudinal axis 69 of the flow restrictor attachment 90a, thus providing fluid flow through the perforation 78 and flow path 79 as described above (i.e., through ports 95 and 43, respectively). As shown in FIG. 19B, directing the plunger 76 into the bonnet 77, i.e., by screwing the plunger inward toward the central longitudinal axis 69, closes the ports 95 and 43, thus stopping the flow of fluid through the perforation 78 and flow path 79. Individual flow adjustment ports 94b may be opened or closed to modulate the overall flow rate through the flow restrictor attachment 90a.

[0148] The unique two-part design of the flow adjustment port(s) (94a, 94b) disclosed herein provides a means to replace the bonnet and plunger when worn due to use, without requiring complete replacement of the flow restrictor attachment 90a.

[0149] Note that the cross-sectional view in FIG. 19B is rotated 45° relative to the device shown in FIG. 19A (rotated about the longitudinal axis 69). Also shown in FIG. 19B is a charging port 39 for hydraulic fluid (see also FIG. 18A).

[0150] With reference to FIGS. 19C and 19D, shown are cross-sectional views of the flow restrictor attachment 90a taken along line C-C of FIG. 18A, wherein the device is rotated 60° with respect to the device shown in FIG. 18A. The cross-sectional view is out of alignment with either of the flow adjustment ports 94a or 94b but is aligned with the charging port 39. As shown in FIG. 19D, hydraulic fluid may be injected through the charging port 39 to a charging pocket 53, forcing a stop 38 to close over a port 51, thus restricting fluid communication between a bypass perforation 78a and the flow path 79. When open, as shown in FIG. 19C, port 51 provides fluid communication between a bypass perforation 78a and the flow path 79. Also shown in FIG. 19D are positions of O-rings or other gaskets (8) that may be included on the stop 38 to provide a fluid tight seal within the flow restrictor attachment 90a.

[0151] When included on the system 10 of the present invention, the flow restrictor attachment 90a may be used to relieve pressure in a main conduit 100. The individual flow adjustment ports may be opened or closed to provide a specific flow volume through the valve to which the restrictor is attached, and thus may provide an adjustable amount of pressure relief from a conduit line when activated. Activation may be enable as discussed herein with respect to valve actuation of any of the previously discussed valves. As a high-pressure event is relieved, the pressure in the main conduit may drop to a point where flow is slowed (e.g., low pressure due to lack of strain on the metal pipes of the main conduit lines). In such a case, additional flow adjustment ports may be opened to drain the main conduit quickly when at lower pressures.

[0152] Moreover, port 51 may be opened to provide a free flow of fluid through the bypass perforation 78a and flow path 79. The bypass perforation 78a may be used to prime the pumps, and/or to drain the lines in a lower pressure scenario such as toward the end of a controlled depressurization. That is, as a high pressure in a main conduit is relieved and the pressure drops below a certain low-pressure limit, the amount of time required to fully drain a line may become increasingly long. In such a case, the bypass perforation 78a may be opened as described hereinabove to allow free flow of fluid from the lines, thus draining the lines much more quickly.

[0153] With reference to FIG. 20, a bleed through flow restrictor 200 is shown that may provide flow of fluid in either direction. In certain circumstances, high pressure fluid lines may be filled for longer term storage or to remove any air from the lines prior to use of the system (purge air from the system prior to activation of the pumps). As example, if left unused the lines

of a system may need to be either fully drained or filled with a salt solution so that they do not freeze. In such a case, a valve that may allow fluid to be pumped into the lines up to a preset pressure is desirable. Shown in FIG. 20 is a bleed through flow restrictor 200 having an upstream connection 92 and a downstream connection 205. The bleed through flow restrictor 200 may be connected to the downstream connection (e.g., 87' or 87) of a valve via a joining means, e.g., via an attachment ring 92 having an internal thread configured to mate with the external thread of the downstream connector 24. The bleed through flow restrictor 200 may further include a downstream joining means 205 configured for connection to a conduit. The bleed through flow restrictor 200 may be designed to include an integral flow restrictor according to any of the designs disclosed herein (83a, 83b, 83c) or may be designed with a removeable flow restrictor insert (e.g., insert 99 shown in flow restrictor 83c), such as shown in FIGS. 14-16.

[0154] Alternatively, the bleed through flow restrictor 200 may be connected to the upstream connection 86 of a valve via a joining means, e.g., via the attachment ring (upstream connector 23) having an internal thread configured to mate with the external thread of the downstream joining means 205. Also shown in FIG. 20 is a gasket 202 included on the upstream connection 92 that provides a liquid-tight seal on connection with any of the corresponding connection means detailed herein. Similar gaskets are shown in each of the upstream connections 92 shown in FIGS. 10, 11, 13, 16, 17A, and 17B.

[0155] The bleed through flow restrictor 200 includes a downstream connection 201 threadedly connectable to a flow restrictor attachment 204 that may hold any of the flow restrictors disclosed herein (83a, 83b, 83c) or may be designed with a removeable flow restrictor insert (e.g., insert 99 shown in flow restrictor 83c). The flow restrictor attachment 204 may further include an upstream seat 206 that seals against an inner surface of the flow restrictor attachment 204 and an end of an upstream valve plug 208 via gaskets 211 or the like. The upstream valve plug 208 may partially encase a spring 209 and a flow restrictor, such as any of the any of the flow restrictors disclosed herein (83a, 83b, 83c).

[0156] During standard operation, the bleed through flow restrictor 200 may provide flow in the direction of arrow 2 when a valve is opened, such as during any of the high-pressure events disclosed herein. However, the bleed through flow restrictor 200 further provides for flow of fluid opposite from the direction of arrow 2, such as into the fluid lines on which the restrictor

is attached (e.g., 100, 5, etc.). That is, fluid directed in a direction opposite of the arrow 2 may push against the upstream valve plug 208 forcing the spring 209 into a retracted position, and thus opening the space 210a surrounding the flow restrictor 83c to fluid flow. The fluid may then pass through ports 210b in the downstream plug 203 and into the downstream connection 201, and the fluid lines. Once the lines are filled, such as with a salt solution, the valve (26) may be closed to prevent fluid exit from the system (i.e., back in the direction of arrow 2).

[0157] With reference to FIGS. 21A and 21B, an unbalanced poppet 300 is shown that may be included as a safety measure for any of the systems disclosed herein. For example, the unbalanced poppet may be included on pressure lines on an outside wall casing of a down bore. Should an inner casing of the bore fail, the extremely high-pressure fluids contained therein will exit the system at near supersonic speeds. When attached to lines near the exit of the bore, the unbalanced poppet may provide an emergency safety pressure release that would not only save the wellhead but may reduce strain on all downstream equipment.

[0158] With specific reference to FIG. 21A, the unbalanced poppet 300 may be attached to a fluid line via a joining means, e.g., via an attachment ring 301 having an internal thread configured to mate with the external thread of the downstream connector. Alternatively, the connection may be via an external thread on an end of the unbalanced poppet 300 connectable to an attachment ring on the fluid line. As shown, the unbalanced poppet 300 comprises a main body 302 having an exit port 307 and a valve head 303.

[0159] With reference to FIG. 21B, which shows a cross-sectional view of the unbalanced poppet 300 taken along line D-D, the main body includes a main bore 306 and a bypass bore 305 to provide “unbalanced” flow of fluid therethrough. Within the main bore 306 lies a plug 308 that maintains the bore in a closed position so that no fluid may flow through the bore 306 and out the exit port 307. Additionally, flow of fluid through the bypass bore 305 pushes fluid through a port 304a in an upstream seat 304 that pressurizes a space behind plug 309, and thus maintains the plug 308 in the closed position as shown in FIG. 21B. As pressure in the line increases, such as during an extreme overpressure event or failure of a casing at a wellhead, the balance of pressure through the main and bypass bores changes so that the plug 308 may be pushed out of the way of the flow path 306-307 by compression of the spring 310 within the valve head 303.

[0160] While the unbalanced poppet 300 of FIGS. 21A and 21B has been described with reference to use in oil and gas drilling operations, it specifically as a safety measure useful in systems including any of the valves and/or valve systems disclosed herein, it may find use as a standalone component. Moreover, the unbalanced poppet 300 may be useful to vent overpressure events from any system under pressure, such as in municipal water treatment facilities. Additionally, while described as useful for system comprising fluid lines, the unbalanced poppet 300 may find use in systems that comprise gas under high pressure, such as on top of a gas separator, wherein the pressure release may vent gas to the atmosphere or as a gas flare.

[0161] According to certain non-preferred aspects, a reduced diameter portion of the system that could be used to provide metered or controlled pressure relief could be provided externally on the fluid line. For example, a reduced diameter portion of the system may be provided by an externally positioned valve, such as a pinch valve, that is automatically operated by a solenoid to compress or reduce the diameter of an upstream or downstream section of the bypass conduit (5b of FIG. 1). In this way, the amount of flow restriction through the bypass lines may be variable and controllable. Additional sensors, such as pressure and/or flow sensors, may be included to determine a change in the pressure and/or flow rate when the automatic valve is used, and this information may be transmitted to the control system 40 of the system 10. Alternatively or additionally, the externally positioned valve may be manually operated when positioned downstream (i.e., in scenarios when the fluid line is under zero pressure).

[0162] According to certain aspects of the presently disclosed invention, the valve assembly may be configured to provide a rapid reduction in the pressure within a main conduit 100. As shown in FIG. 10, the downstream connection 87 may have an internal bore diameter that is substantially the same as, or larger than the diameter of the throughbore on the ball 26 and the upstream connection 86. In this way, opening of the valve may provide nearly instantaneous reduction of pressure in a main conduit 100 to which the system is attached.

[0163] Alternatively, or additionally, the system 10 may include one or more valve assemblies that may be configured to provide a controlled or metered pressure relief, such as the valves having flow restrictors contained therein (e.g., 83a, 83b, 83c) or the flow restrictor attachments (e.g., 90a, 90b) or the bleed through flow restrictor 200.

[0164] The system may further include the unbalanced poppet **300** positioned adjacent the well head and configured to provide overpressure relief for extreme overpressure events, such as failure of an inner well casing.

[0165] The system may further include one or more batteries to power the control system **40** and the valve actuation system **30**. These batteries may be rechargeable battery cells. Further, the batteries may include a charge sensor configured to sense a charge state of the at least one battery cell, and a circuit electrically connected to the charge sensor for receiving a signal indicative of the charge state of the at least one battery cell. Additional sensors may be included which register a temperature, voltage, current, etc. of the at least one battery, and such information (data) may also be relayed via a circuit to the control system **40**, and may be shown visually on the voltmeter **66** and/or charging indicator lamp **67**. The battery may also indicate the charge status by an audible signal that may change (e.g., start at a certain charge state, grow louder and/or increase frequency of signal, etc.) as the battery is progressively discharged (for example an alarm as shown in **FIG. 6** at **120** on the control system **40**).

[0166] When more than one battery cell is included, each individual battery may include a charge sensor (and optionally additional sensors), which may communicate via individual circuits, or may communicate directly, to a battery management system. Such a system manages a rechargeable battery (cell or group of cells), such as by protecting the battery from operating outside its safe operating area, temperature, voltage, etc. and by monitoring its state, calculating secondary data, reporting that data, controlling its environment, authenticating it and/or balancing the usage of individual cells in a groups of cells.

[0167] The at least one battery may further include a connection means for an external power source which may provide for recharging of the at least one battery cell. For example, the external power source may be provided by AC power from a combustion engine generator equipped with a GFCI outlet, and the connection means may include a standard power cord. Alternatively, the external power source may be provided by a battery docking station which acquires power from an AC power source. The battery docking station may provide power to the battery via direct contact between one or more electrical charging contacts. The battery docking station may provide power to the battery wirelessly. Moreover, more than one means for recharging may be included on the battery.

[0168] As detailed above, according to certain aspects of the present invention, the system may include two or more valve assemblies, such as two or more ball valves actuated by two or more scotch yoke actuators, wherein each valve assembly includes a valve position sensor and an indicator light assembly. The system may further include a control system, and a source of actuation fluid and pumps to pressurize the actuation fluid. These components may be included in a frame which may be transportable, such as a road transportable frame. According to certain aspects of the invention, the system may further include at least one fluid catch tank to receive the fluid released when the relief valve system is opened, and at least one tank level probe to monitor a liquid level in the fluid catch tank. The system may also include tank mounted fluid diffusers that control input of fluid from either or both of the valve outlets (e.g., at the valve outlet, or at an end of a bypass line attached to the valve outlet – **5b**) to the fluid catch tank.

[0169] According to certain aspects, each valve assembly of the system may be the same or may be different. For example, a system according to the presently disclosed invention may include any of a valve configured for rapid relief of an over-pressure event in a conduit, a valve configured for controlled or metered pressure reduction, a valve configured to allow both forward and back-flow through the system, or any combination thereof.

[0170] The frame of the system may include a mount for the control system, and may optionally include vibration isolation on the mount to lessen the impact of vibrations from the valve assembly on the control system **40**. The control system **40** may provide electronic control of the hydraulic actuator (hydraulic control circuit), and receive feedback from each of the pressure sensors. In certain embodiments, up to four pressure sensing assemblies may be included, wherein each pressure sensor includes at least two pressure transducers, such as three pressure transducers. Thus, the control system may be configured to receive data from more than one pressure sensor (i.e., and pressure transducer).

[0171] The control system may be a remote electronic user interface that may provide control of the valves, such as by setting high and low pressure set-points. Moreover, the user interface may also provide instant interaction with the valves, such as opening and closing of the valves. The control system may store data related to the sensed pressures, valve opening and closings, etc., which may be output visually on a display panel of the control system or electronically (via direct wired or wireless connection) to another user device (remote).

[0172] The system may be powered via a direct AC or DC connection, such as via a rechargeable battery. The batteries may be used to power the control system, the sensors, and the hydraulic actuator. In certain instances, the batteries may also be used to power other optional components, such as fluid circulation pump circuits, throttles for the actuators, piping system heaters, and electrical lighting. Moreover, the control system may be electronically linked to each of these additional optional components to provide control for each.

[0173] The various components discussed hereinabove may be combined to create an architecture for the system that has complete independent control of both valves and their respective positions and may interpret two independent pressurized fluid conduits. The system may be incorporated into various high pressure conduits, such as those used in hydraulic fracturing or wellbore completions operations. For example, when included in such an operation to provide pressure adjustment and control for a single conduit, a first end of a first bypass conduit may be attached to the upstream connector **23** of the valve assembly **20** of a first valve assembly, and a second end of the first bypass conduit to the main conduit **100**, and a first end of a second bypass conduit may be attached to the downstream connector **24** of the valve assembly **20** of the first valve assembly. At least one pressure chamber **52** may be attached on the main conduit **100**, such as any of those disclosed herein.

[0174] If the valve is to be used to bleed or reduce the pressure in a main conduit **100**, such as after a pressure test, a valve connector or insert may be selected that includes a reduced diameter section or perforations as discussed hereinabove, i.e., any of the flow restrictors (e.g., **83a**, **83b**, **83c**) or the flow restrictor attachments (e.g., **90a**, **90b**) or the bleed through flow restrictor **200**. Selection may be based on the desired reduction of pressure in the line. As such, the control system **40** may initiate opening of the valve **26** so that fluid may exit the system through the bypass lines (**5a**, **5b** of **FIG. 1**) and through the selected valve connector or insert. Pressure may be tested both before and after opening of the valve, and these values may be recorded.

[0175] If the valve is to be used as a rapid pressure loss valve, high- and low-pressure limits may be set on the control system **40**. These may be set by the user, or may be preset based on a standard type of service on a standard type of high pressure conduit. Moreover, a user may start with present values and make changes thereto based on adaptations to the high pressure conduits, current environmental conditions, etc.

**[0176]** The high and low pressure limits may be those known in the industry of use. For example, in the hydraulic fracturing industry, the high pressure conduits can be rated to withstand fluid pressures of up to 10,000 psi, or up to 20,000 psi, or even up to as much as 30,000 psi. The high pressure limits may therefore be set based on the rating of the high pressure conduit for which the system may provide pressure loss, and may be set at the rated pressure limit, or below the rated pressure limit. Such settings are known to those of skill in the art. The low pressure limits may be adjusted to be at least 10% below the high pressure limit, such as at least 1,000 psi below the high pressure limit, or at least 2,000 psi below the high pressure limit, or at least 5,000 psi below the high pressure limit, or even 10,000 psi below the high pressure limit.

**[0177]** The control system will then receive signals from the at least one pressure sensor and pressure transducer indicating a fluid pressure in the high pressure conduit, and communicate with the valve actuation system of at least the first valve assembly to change a position of the valve, such that when the fluid pressure in the fluid line exceeds the high pressure limit the valve is opened, and when the fluid pressure in the fluid line falls below the low pressure limit the valve is closed. Alternatively, the signal related to a pressure in the high pressure conduit may be sent from an external device, such as from a pressure sensor of another control system positioned on the same high pressure conduit, or may be from user input.

**[0178]** According to certain aspects of the present invention, control logic is implemented by the control system that causes the valve to remain open until a downward trend is registered in the pressure reading(s) after the low pressure limit has been reached. For example, according to certain aspects of the present invention, at least the next pressure reading after the low pressure limit has been reached must also be below the low pressure limit, such as by an amount at least 10% below, or 30% below, or even 50% below the previous pressure reading, after which the valve may reclose. According to certain aspects of the present invention, the downward trend may include at least the next pressure reading after the low pressure limit has been reached, or the next two or more pressure readings after the low pressure limit has been reached.

**[0179]** Additional valve assemblies may be attached to provide pressure control or relief for the same high pressure conduit. That is, a first end of a third bypass conduit may be attached to the upstream connector of the valve housing of a second valve assembly, and a first end of a

forth bypass conduit may be attached to the downstream connector of the valve housing of the second valve assembly. The high pressure limit and low pressure limit for this second valve assembly may be set using the user interface on the control system, wherein the control system is configured to communicate with the valve actuation system of the second valve assembly to change a position of the valve. In this scenario, the first, second, third, and forth bypass conduits are all portions of a single bypass line having a connection to the same high pressure conduit.

**[0180]** Alternatively, the additional valve assemblies may be attached to provide pressure control or relief for a different high pressure conduit. In this scenario, the first and second bypass conduits would be portions of a first bypass line having a connection to a first high pressure conduit, and the third and fourth bypass conduits would be portions of a second bypass line having a connection to a second high pressure conduit.

**[0181]** In any of the methods discussed herein, additional pressure sensors may be used. As such, additional pressure chambers of a second, or third, or greater pressure sensor may be attached on the first or second fluid line such that an outward facing side of the diaphragm is in contact with a fluid in the fluid line, or inline on the first or second fluid line to provide flow-through pressure sensing on the lines. In this scenario, the control system may receive signals from each of the additional pressure sensors indicating a fluid pressure in the high pressure conduit to which it is attached. The control system may then use this data to control positions of the various valves in the system.

**[0182]** Hydraulic control of the valve actuation according to certain aspects of the present invention is shown in **FIG. 22**. The valve actuator **32** may be controlled by various components of a hydraulic control system **70**, which include one or more valves to control and direct communication between a motor driven pump **33**, a hydraulic fluid reservoir **34**, and the relief valve **22**. The one or more valves may include a solenoid valve, a check valve, and/or any other type of valve operable to open and close, or direct, the fluid circuits between the pump **33**, the hydraulic fluid reservoir **34**, and the relief valve **22**. The hydraulic control system **70** may include one or more gauges, such as a pressure transducer or gauge which can be visually inspected to monitor the pressure in the flow lines (note: this is a pressure transducer that registers pressure in the valve actuation chamber, and is not the same pressure transducer shown in **FIGS. 7 or 8** and labelled as **50/52** in **FIGS. 1, 7, 8, and 23-26**). According to certain aspects of the present invention, the pressure gauge may be configured to shut off the motor driven pump

33 when the pressure in the actuator 32 of the relief valve 22 reaches a pre-determined pressure setting. The one or more valves may also be controlled by the control system 40 as detailed above.

[0183] The relationship between major subassemblies of the present system according to certain aspects of the present invention is shown in FIG. 23. A fluid sensing point (50) which may include a pressure sensor comprising a diaphragm as detailed above, may be positioned on a secondary or bypass fluid line, wherein the bypass fluid line is attached at an upstream point to the main high pressure conduit. Also shown are the control system 40 and the remote user interface 42. The relief valve assembly (20/30) may also be positioned on the same or a different secondary or bypass fluid line. Another embodiment of the hydraulic control system 70 as detailed in FIG. 22 is shown, wherein a motor driven pump 33, hydraulic fluid reservoir 34, and solenoid valve are included. The solenoid valve assembly may be in communication with the control system 40 to control operation (e.g. open and close) of the valve assembly (20/30) to thereby control actuation of the valves as desired.

[0184] Various exemplary placements of the systems 10 of the present invention are shown within standard hydraulic fracturing or wellbore completion operations in FIGS. 24-26.

[0185] The following aspects are disclosed in this application:

[0186] Aspect 1. A system for pressure control in a fluid conduit, the system comprising: at least two valve assemblies, each valve assembly comprising: a valve actuation system including a source of actuation fluid, and a valve housing having a longitudinal bore therethrough, and including an upstream connection, a downstream connection, and a valve positioned therebetween, wherein the valve housing is positionable on a bypass conduit downstream from a connection point with a main conduit, and wherein at least one of the valve assemblies is configured to restrict flow of a fluid in the bypass line; and a control system in electronic communication with the valve actuation system and configured to receive an electronic signal related to a fluid pressure in the main conduit, wherein the control system is configured to open the valve of either or both valve assemblies.

[0187] Aspect 2. The system according to any previous aspect, wherein the control system is configured to open the valve of either or both of the at least two valve assemblies in response to a high-pressure condition, wherein the high-pressure condition may be user defined;

and/or wherein the system is configured to close the valve when the fluid pressure in the main conduit falls below a user-defined low-pressure limit.

**[0188]** Aspect 3. The system according to any previous aspect, further comprising a pressure sensor configured to detect the fluid pressure in the main conduit.

**[0189]** Aspect 4. The system according to any previous aspect, wherein the electronic signal related to the fluid pressure in the main conduit is received from the pressure sensor, from a pressure sensor on another system, from user input, or from a combination thereof.

**[0190]** Aspect 5. The system according to any previous aspect, wherein the control system opens the valve of at least one valve assembly upon receiving an initiation signal.

**[0191]** Aspect 6. The system according to any previous aspect, wherein the initiation signal is sent by a user from a remote system or input on an input device of the control system.

**[0192]** Aspect 7. The system according to any previous aspect, wherein the control system opens the valve of at least one valve assembly when the fluid pressure in the main conduit when signaled by the control system or by an external signal such as from a user input.

**[0193]** Aspect 8. The system according to any previous aspect, wherein the control system is configured to hold the valve of at least one valve assembly open for a set time period, and if, after the set time period, the fluid pressure in the main conduit is at or below the user-defined low pressure limit, the controller is configured to close the valve.

**[0194]** Aspect 9. The system according to any previous aspect, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor positioned in a portion of the bypass line downstream from the at least one valve assembly.

**[0195]** Aspect 10. The system according to any previous aspect, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor positioned in a portion of the bypass line upstream from the at least one valve assembly.

**[0196]** Aspect 11. The system according to any previous aspect, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor in the downstream connection.

**[0197]** Aspect 12. The system according to any previous aspect, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor in the upstream connection.

**[0198]** Aspect 13. The system according to any previous aspect, wherein the flow restrictor comprises a reduced diameter section, wherein the reduced diameter section has a diameter smaller than a diameter of the longitudinal bore of the valve housing.

**[0199]** Aspect 14. The system according to any previous aspect, wherein the flow restrictor comprises perforations that allow the restricted flow of the fluid to pass at a reduced flow rate.

**[0200]** Aspect 15. The system according to any previous aspect, wherein the flow restrictor comprises an insert positionable within the flow restrictor, wherein the insert comprises the perforations.

**[0201]** Aspect 16. The system according to any previous aspect, wherein the pressure sensor comprises: at least one pressure transducer positioned in a main housing of the system, and a pressure chamber having a deformable diaphragm contacting a pressure fluid within the pressure chamber, wherein the pressure fluid is fluidly connected to the at least one pressure transducer to transfer an external fluid pressure on the deformable diaphragm to the at least two pressure transducers, and wherein the pressure chamber is configured to be positioned on the main conduit line such that the fluid pressure in the main conduit line comprises the external fluid pressure on the diaphragm.

**[0202]** Aspect 17. The system according to any previous aspect, wherein the pressure sensor comprises: a sensor body comprising an inlet end, an outlet out, and central bore therebetween; a pressure chamber having a deformable diaphragm contacting a pressure fluid within the pressure chamber; and at least one pressure transducer fluidly connected to the pressure chamber, wherein the sensor body is positioned in-line on a conduit such the deformable diaphragm of the pressure chamber registers a fluid pressure in the conduit and transfers that fluid pressure to the at least one pressure transducer via the pressure fluid.

**[0203]** Aspect 18. The system according to any previous aspect, wherein the central bore of the sensor body comprises an inner wall between the inlet end and the outlet end, wherein the deformable diaphragm forms at least a portion of the inner wall.

**[0204]** Aspect 19. The system according to any previous aspect, wherein the deformable diaphragm forms all or a portion of an inner wall of the central bore of the sensor body.

**[0205]** Aspect 20. The system according to any previous aspect, wherein the pressure sensor comprises at least two pressure transducers.

**[0206]** Aspect 21. The system according to any previous aspect, wherein the pressure sensor comprises three pressure transducers.

**[0207]** Aspect 22. The system according to any previous aspect, wherein the signal indicating the fluid pressure in the main conduit is from the pressure sensor and comprises individual signals from the two or more pressure transducers, and wherein the individual signals are received at a rate of at least 50 signals/second.

**[0208]** Aspect 23. The system according to any previous aspect, wherein the pressure chamber is attachable on the main conduit such that the fluid pressure in the main conduit comprises the external fluid pressure on the diaphragm.

**[0209]** Aspect 24. The system according to any previous aspect, wherein the valve comprises a ball valve having: a ball having a throughbore, wherein an open position of the ball provides flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing, and a closed position of the ball provides an out of flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing, an upstream seat comprising an outward facing surface positioned perpendicular to the longitudinal bore of the valve housing, wherein a fluid pressure on the outward facing surface forces the upstream seat against a sealing face of the ball, and a downstream seat.

**[0210]** Aspect 25. The system according to any previous aspect, further comprising: a frame configured to contain the at least two valve assemblies, the at least one pressure transducer, and the controller.

**[0211]** Aspect 26. The system according to any previous aspect, wherein the valve actuation system comprises a valve actuator configured to fully open the valve in under 2 seconds, such as under 1 second.

**[0212]** Aspect 27. The system according to any previous aspect, wherein the valve actuation system comprises a biasing member in a valve actuation chamber which biases the valve to an open position, and wherein supply of the actuation fluid into the valve actuation chamber provides counterforce on the biasing member to move the valve to a closed position.

**[0213]** Aspect 28. The system according to any previous aspect, wherein the actuation system comprises a combined rotary and linear movement.

**[0214]** Aspect 29. The system according to any previous aspect, wherein the valve actuation system comprises a scotch yoke.

**[0215]** Aspect 30. The system according to any previous aspect, wherein the actuation fluid comprises a hydraulic fluid.

**[0216]** Aspect 31. The system according to any previous aspect, wherein the flow restrictor comprises two or more individually actuatable ports that open to provide fluid flow through the flow restrictor.

**[0217]** Aspect 32. The system according to any previous aspect, wherein the flow restrictor comprises two or more individually actuatable ports that open to provide fluid flow through the flow restrictor; and a hydraulic port that opens a main port to provide fluid flow that bypasses the individually actuatable ports.

**[0218]** Aspect 33. The system according to any previous aspect, wherein the flow restrictor allows fluid flow in either direction, wherein the fluid flow in a first direction is restricted by perforations that allow fluid to pass at a reduced flow rate, and the fluid flow in a second opposite direction is restricted by a valve plug and a spring such that fluid pressure on the valve plug forces compression of the spring and opening of the valve plug to allow fluid to flow in the second direction.

**[0219]** Aspect 34. A method for pressure control in a fluid line, the method comprising: providing a pressure control system according to any of one of the preceding aspects; attaching a first end of a first bypass conduit to the upstream connection of the valve housing of a first valve assembly, and a second end of the first bypass conduit to the fluid line; attaching a first end of a second bypass conduit to the downstream connection of the valve housing of the first valve assembly; attaching a pressure chamber of the pressure sensor on the fluid line such that an outward facing side of a diaphragm of the pressure sensor is in contact with a fluid in the fluid line; and setting a low-pressure limit for the first valve assembly using a user interface on the control system, wherein the control system is configured to receive an initiation signal and communicate with the valve actuation system of the first valve assembly to open the valve, and a pressure signal from the pressure sensor, such that when the pressure signal indicates that a fluid pressure in the fluid line is below the low pressure limit, the valve is closed.

**[0220]** Aspect 35. The method according to any previous aspect, wherein the initiation signal is sent by a user from a remote system or input on an input device of the control system.

[0221] Aspect 36. The method according to any previous aspect, the control system communicates with the valve actuation system to open the valve of the first valve assembly when the fluid pressure in the fluid line exceeds a user-defined high pressure limit.

[0222] Aspect 37. The method according to any previous aspect, further comprising: attaching a first end of a third bypass conduit to the upstream connection of the valve housing of a second valve assembly; attaching a first end of a fourth bypass conduit to the downstream connection of the valve housing of the second valve assembly; and setting a second pressure limit for the second valve assembly using the user interface on the control system, wherein the control system is configured to communicate with the valve actuation system of the second valve assembly to change a position of the valve.

[0223] Aspect 38. The method according to any previous aspect, wherein the first, second, third, and fourth bypass conduits are all portions of a single bypass line having a connection to the fluid line.

[0224] Aspect 39. The method according to any previous aspect, wherein the first and second bypass conduits are portions of a first bypass line having a connection to the fluid line, and the third and fourth bypass conduits are portions of a second bypass line having a connection to a second fluid line, wherein the method further comprises: attaching a pressure chamber of a second pressure sensor on the second fluid line such that an outward facing side of a diaphragm of the second pressure sensor is in contact with a fluid in the second fluid line, wherein the control system is configured to receive a signal from the second pressure sensor indicating a fluid pressure in the second fluid line and communicate with the valve actuation system of the second valve assembly to change a position of the valve.

[0225] Aspect 40. The method according to any previous aspect, wherein the control system is configured to receive a second initiation signal and communicate with the valve actuation system of the second valve assembly to open the valve, and a pressure signal from the pressure sensor, such that when the pressure signal indicates that a fluid pressure in the fluid line is below the second pressure limit, the valve is closed.

[0226] Aspect 41. The method according to any previous aspect, wherein the initiation signal is sent by a user from a remote system or input on an input device of the control system.

[0227] Aspect 42. The method according to any previous aspect, wherein the control system communicates with the valve actuation system to open the valve of the second valve assembly when the fluid pressure in the fluid line exceeds a user-defined high-pressure limit.

[0228] While specific embodiments of the invention have been described in detail, it should be appreciated by those skilled in the art that various modifications and alternations and applications could be developed in light of the overall teachings of the disclosure. Accordingly, the particular arrangements, systems, apparatuses, and methods disclosed are meant to be illustrative only and not limiting as to the scope of the invention. For example, while the systems and methods of the present invention have been described as useful for monitoring and adjusting pressure conditions of high pressure conduits, such as those used in the hydraulic fracturing industry and in wellbore completion activities, they may easily find use in other types of conduits and in other industries as would be understood by someone of ordinary skill in the art.

## CLAIMS

*What is claimed is:*

1. A system for pressure control in a fluid conduit, the system comprising:  
at least two valve assemblies, each valve assembly comprising:  
a valve actuation system including a source of actuation fluid, and  
a valve housing having a longitudinal bore therethrough, and including an  
upstream connection, a downstream connection, and a valve positioned  
therebetween,  
wherein the valve housing is positionable on a bypass conduit downstream from a  
connection point with a main conduit, and  
wherein at least one of the valve assemblies is configured to restrict flow of a  
fluid in the bypass line; and  
a control system in electronic communication with the valve actuation system and  
configured to receive an electronic signal related to a fluid pressure in the main  
conduit,  
wherein the control system is configured to open the valve of either or both valve  
assemblies.
2. The system of Claim 1, wherein the control system is configured to close the valve when  
the fluid pressure in the main conduit falls below a user-defined low-pressure limit.
3. The system of Claim 1, further comprising a pressure sensor configured to detect the  
fluid pressure in the main conduit.
4. The system of Claim 3, wherein the electronic signal related to the fluid pressure in the  
main conduit is received from the pressure sensor, from a pressure sensor on another  
system, from user input, or from a combination thereof.
5. The system of Claim 1, wherein the control system opens the valve of at least one valve  
assembly upon receiving an initiation signal.
6. The system of Claim 5, wherein the initiation signal is sent by a user from a remote  
system or input on an input device of the control system.

7. The system of Claim 1, wherein the control system opens the valve of at least one valve assembly when the fluid pressure in the main conduit exceeds a user-defined high-pressure limit.
8. The system of Claim 1, wherein the control system is configured to hold the valve of at least one valve assembly open for a set time period, and if, after the set time period, the fluid pressure in the main conduit is at or below the user-defined low pressure limit, the controller is configured to close the valve.
9. The system of Claim 1, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor positioned in a portion of the bypass line downstream from the at least one valve assembly.
10. The system of Claim 1, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor positioned in a portion of the bypass line upstream from the at least one valve assembly.
11. The system of Claim 1, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor in the downstream connection.
12. The system of Claim 1, wherein the restricted flow of the fluid in the bypass line is produced by a flow restrictor in the upstream connection.
13. The system according to any one of Claims 9 to 12, wherein the flow restrictor comprises a reduced diameter section, wherein the reduced diameter section has a diameter smaller than a diameter of the longitudinal bore of the valve housing.
14. The system according to any one of Claims 9 to 12, wherein the flow restrictor comprises perforations that allow the restricted flow of the fluid to pass at a reduced flow rate.
15. The system according to Claims 14, wherein the flow restrictor comprises an insert comprising the perforations.

16. The system according to any one of Claims 9 to 12, wherein the flow restrictor comprises two or more individually actuatable ports that open to provide fluid flow through the flow restrictor.
17. The system according to any one of Claims 9 to 12, wherein the flow restrictor comprises two or more individually actuatable ports that open to provide fluid flow through the flow restrictor; and a hydraulic port that opens a main port to provide fluid flow that bypasses the individually actuatable ports.
18. The system according to any one of Claims 9 to 12, wherein the flow restrictor allows fluid flow in either direction, wherein the fluid flow in a first direction is restricted by perforations that allow fluid to pass at a reduced flow rate, and the fluid flow in a second opposite direction is restricted by a valve plug and a spring such that fluid pressure on the valve plug forces compression of the spring and opening of the valve plug to allow fluid to flow in the second direction.
19. The system of Claim 3, wherein the pressure sensor comprises:  
at least one pressure transducer positioned in a main housing of the system, and  
a pressure chamber having a deformable diaphragm contacting a pressure fluid within the  
pressure chamber,  
wherein the pressure fluid is fluidly connected to the at least one pressure transducer to transfer an external fluid pressure on the deformable diaphragm to the at least two pressure transducers, and  
wherein the pressure chamber is configured to be positioned on the main conduit line such that the fluid pressure in the main conduit line comprises the external fluid pressure on the diaphragm.
20. The system of Claim 3, wherein the pressure sensor comprises:  
a sensor body comprising an inlet end, an outlet out, and central bore therebetween;  
a pressure chamber having a deformable diaphragm contacting a pressure fluid within the  
pressure chamber; and  
at least one pressure transducer fluidly connected to the pressure chamber,

- wherein the sensor body is positioned in-line on a conduit such the deformable diaphragm of the pressure chamber registers a fluid pressure in the conduit and transfers that fluid pressure to the at least one pressure transducer via the pressure fluid.
21. The system of Claim 20, wherein the central bore of the sensor body comprises an inner wall between the inlet end and the outlet end, wherein the deformable diaphragm forms at least a portion of the inner wall.
  22. The system of Claim 20, wherein the deformable diaphragm forms all or a portion of an inner wall of the central bore of the sensor body.
  23. The system of Claim 19 or 20, wherein the pressure sensor comprises at least two pressure transducers.
  24. The system of Claim 19 or 20, wherein the pressure sensor comprises three pressure transducers.
  25. The system of Claim 19 or 20, wherein the pressure chamber is attachable on the main conduit such that the fluid pressure in the main conduit comprises the external fluid pressure on the diaphragm.
  26. The system of Claim 23, wherein the signal indicating the fluid pressure in the main conduit is from the pressure sensor and comprises individual signals from two or more pressure transducers, and wherein the individual signals are received at a rate of at least 50 signals/second.
  27. The system of Claim 1, wherein the valve comprises a ball valve having:  
a ball having a throughbore, wherein an open position of the ball provides flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing, and a closed position of the ball provides an out of flow-through alignment of the throughbore with the upstream and downstream connections of the valve housing,

- an upstream seat comprising an outward facing surface positioned perpendicular to the longitudinal bore of the valve housing, wherein a fluid pressure on the outward facing surface forces the upstream seat against a sealing face of the ball, and a downstream seat.
28. The system of Claim 3, further comprising:  
a frame configured to contain the at least two valve assemblies, the at least one pressure transducer, and the controller.
29. The system of Claim 1, wherein the valve actuation system comprises a valve actuator configured to fully open the valve in under 2 seconds, such as under 1 second.
30. The system of Claim 1, wherein the valve actuation system comprises a biasing member in a valve actuation chamber which biases the valve to an open position, and wherein supply of the actuation fluid into the valve actuation chamber provides counterforce on the biasing member to move the valve to a closed position.
31. The system according to Claims 29 or 30, wherein the actuation system comprises a combined rotary and linear movement.
32. The system of Claims 29 or 30, wherein the valve actuation system comprises a scotch yoke.
33. The system of Claim 30, wherein the actuation fluid comprises a hydraulic fluid.
34. A method for pressure control in a fluid line, the method comprising:  
providing a pressure control system according to any of Claim 1 to 30;  
attaching a first end of a first bypass conduit to the upstream connection of the valve housing of a first valve assembly, and a second end of the first bypass conduit to the fluid line;  
attaching a first end of a second bypass conduit to the downstream connection of the valve housing of the first valve assembly;

- attaching a pressure chamber of the pressure sensor on the fluid line such that an outward facing side of a diaphragm of the pressure sensor is in contact with a fluid in the fluid line; and
- setting a low-pressure limit for the first valve assembly using a user interface on the control system,
- wherein the control system is configured to receive an initiation signal and communicate with the valve actuation system of the first valve assembly to open the valve, and a pressure signal from the pressure sensor, such that when the pressure signal indicates that a fluid pressure in the fluid line is below the low pressure limit, the valve is closed.
35. The method of Claim 34, wherein the initiation signal is sent by a user from a remote system or input on an input device of the control system.
36. The system of Claim 34, wherein the control system communicates with the valve actuation system to open the valve of the first valve assembly when the fluid pressure in the fluid line exceeds a user-defined high-pressure limit.
37. The method of Claim 34, further comprising:
- attaching a first end of a third bypass conduit to the upstream connection of the valve housing of a second valve assembly;
- attaching a first end of a fourth bypass conduit to the downstream connection of the valve housing of the second valve assembly; and
- setting a second pressure limit for the second valve assembly using the user interface on the control system,
- wherein the control system is configured to communicate with the valve actuation system of the second valve assembly to change a position of the valve.
38. The method of Claim 34, wherein the first, second, third, and fourth bypass conduits are all portions of a single bypass line having a connection to the fluid line.
39. The method of Claim 34, wherein the first and second bypass conduits are portions of a first bypass line having a connection to the fluid line, and the third and fourth bypass

conduits are portions of a second bypass line having a connection to a second fluid line, wherein the method further comprises:

attaching a pressure chamber of a second pressure sensor on the second fluid line such that an outward facing side of a diaphragm of the second pressure sensor is in contact with a fluid in the second fluid line,

wherein the control system is configured to receive a signal from the second pressure sensor indicating a fluid pressure in the second fluid line and communicate with the valve actuation system of the second valve assembly to change a position of the valve.

40. The method of Claim 39, wherein the control system is configured to receive a second initiation signal and communicate with the valve actuation system of the second valve assembly to open the valve, and a pressure signal from the pressure sensor, such that when the pressure signal indicates that a fluid pressure in the fluid line is below the second pressure limit, the valve is closed.
41. The method of Claim 40, wherein the initiation signal is sent by a user from a remote system or input on an input device of the control system.
42. The method of Claim 40, wherein the control system communicates with the valve actuation system to open the valve of the second valve assembly when the fluid pressure in the fluid line exceeds a user-defined high-pressure limit.

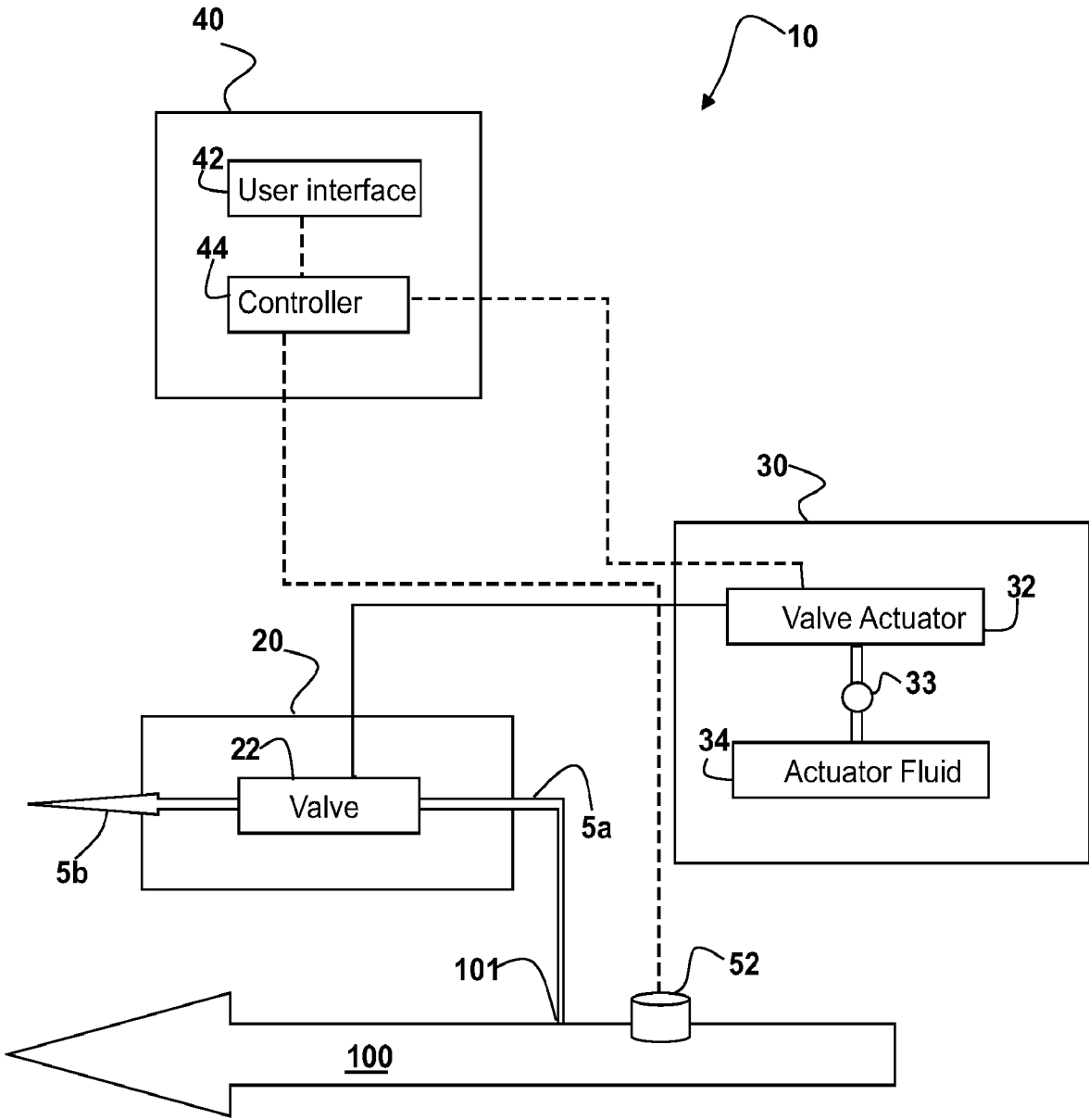


FIG. 1

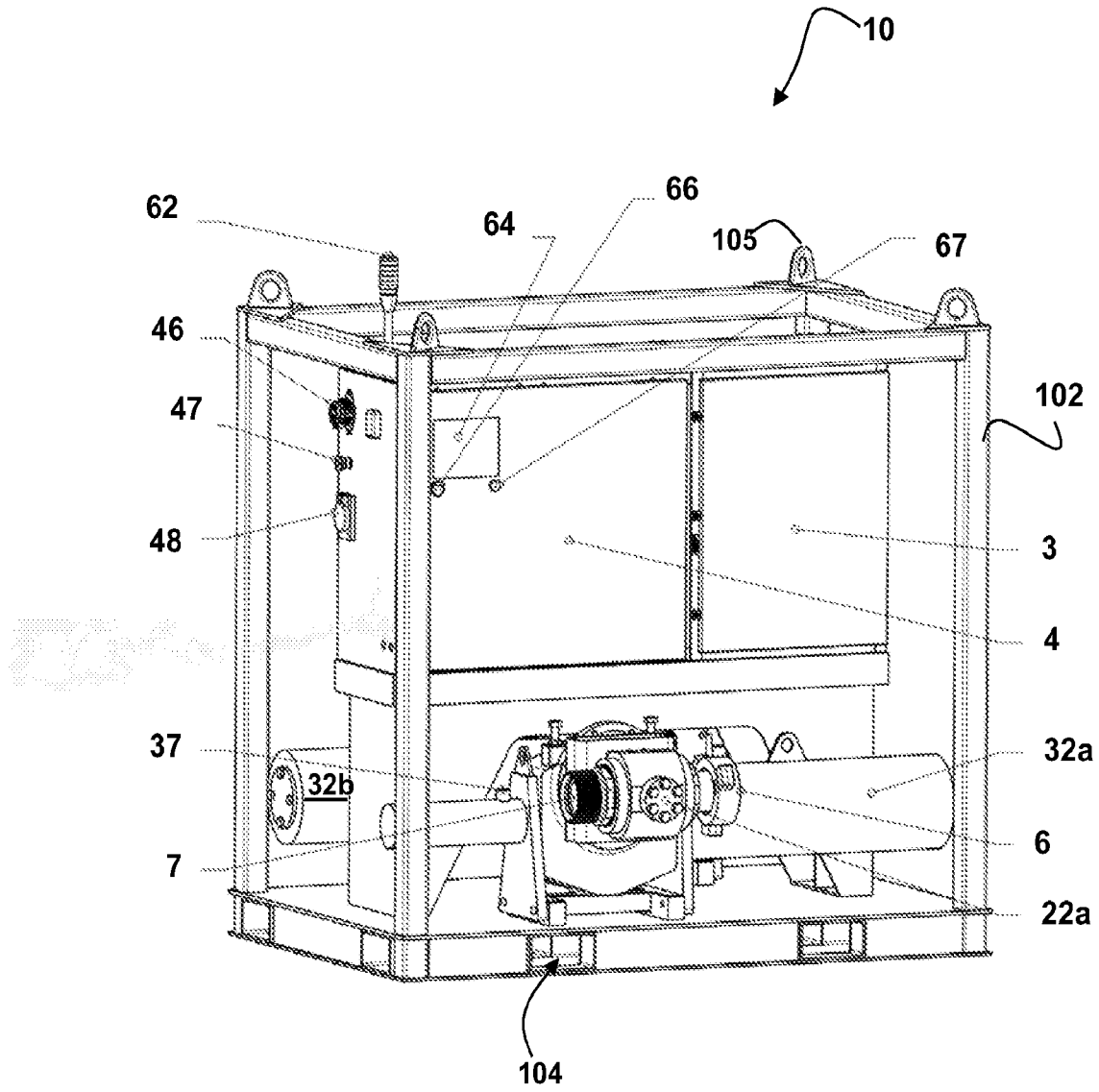


FIG. 2

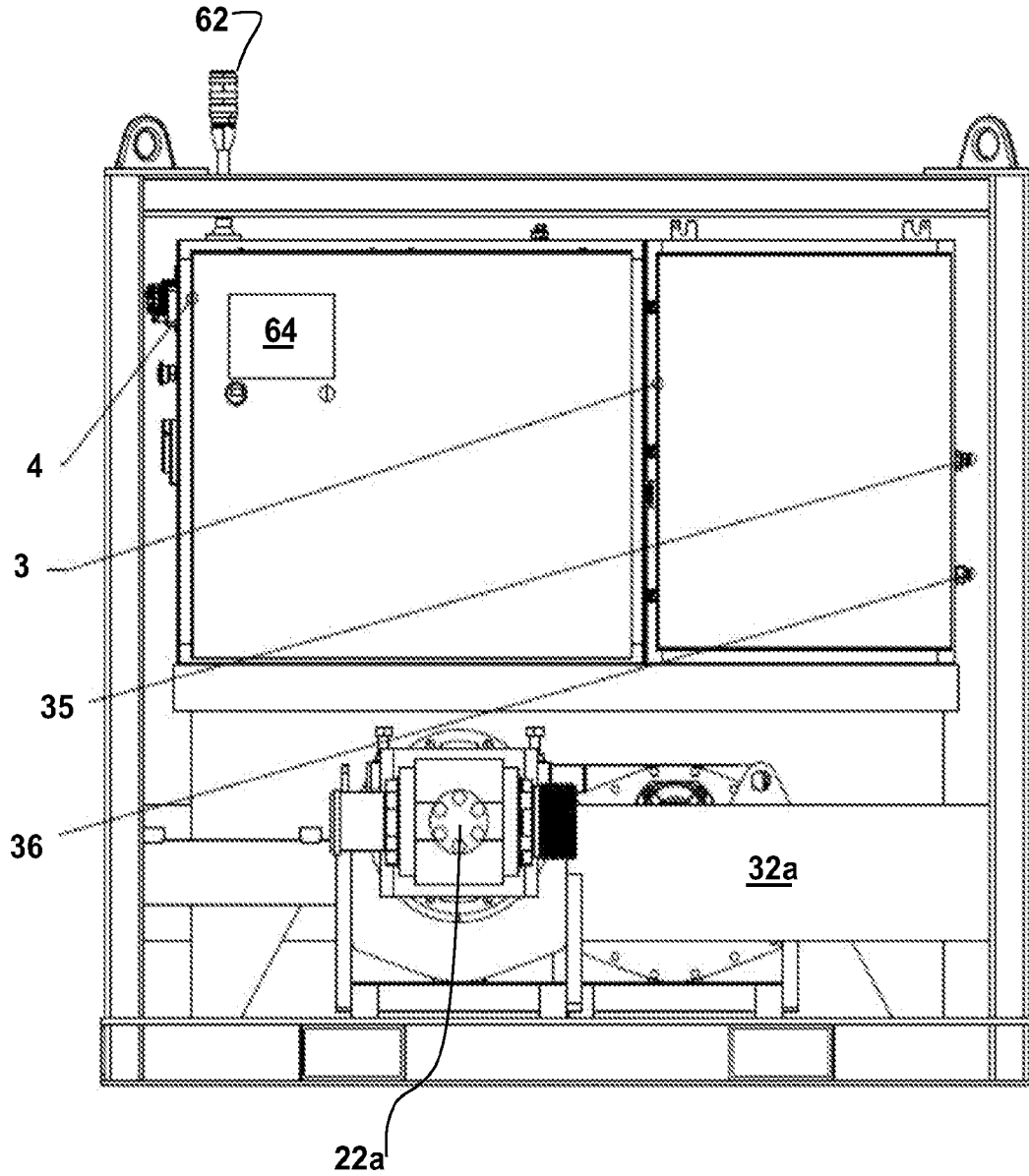


FIG. 3

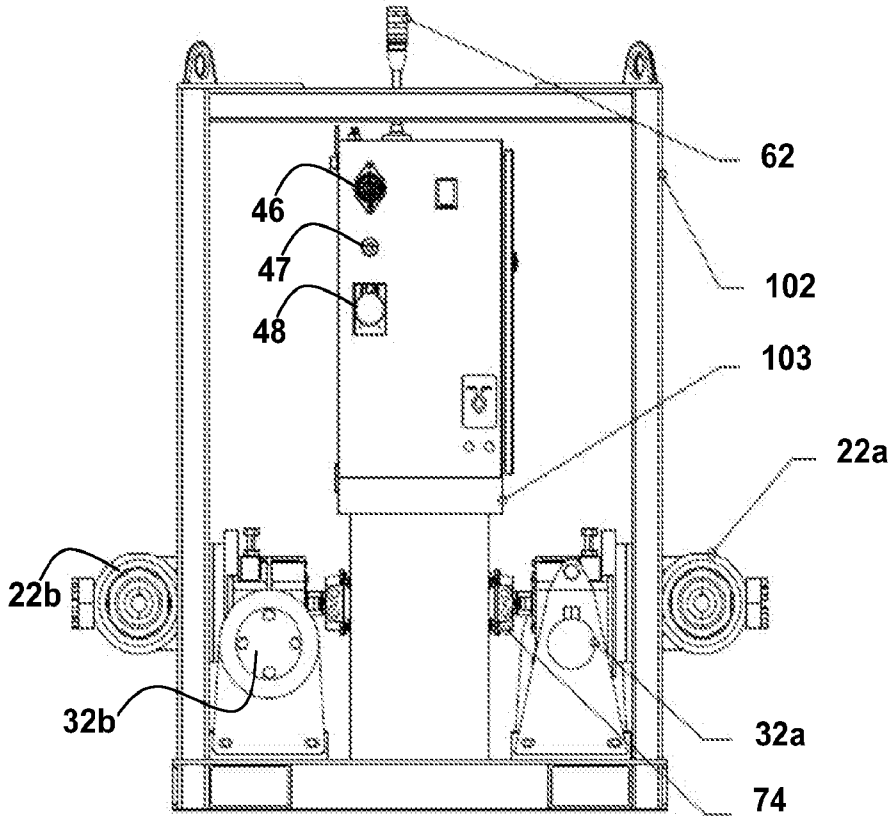


FIG. 4

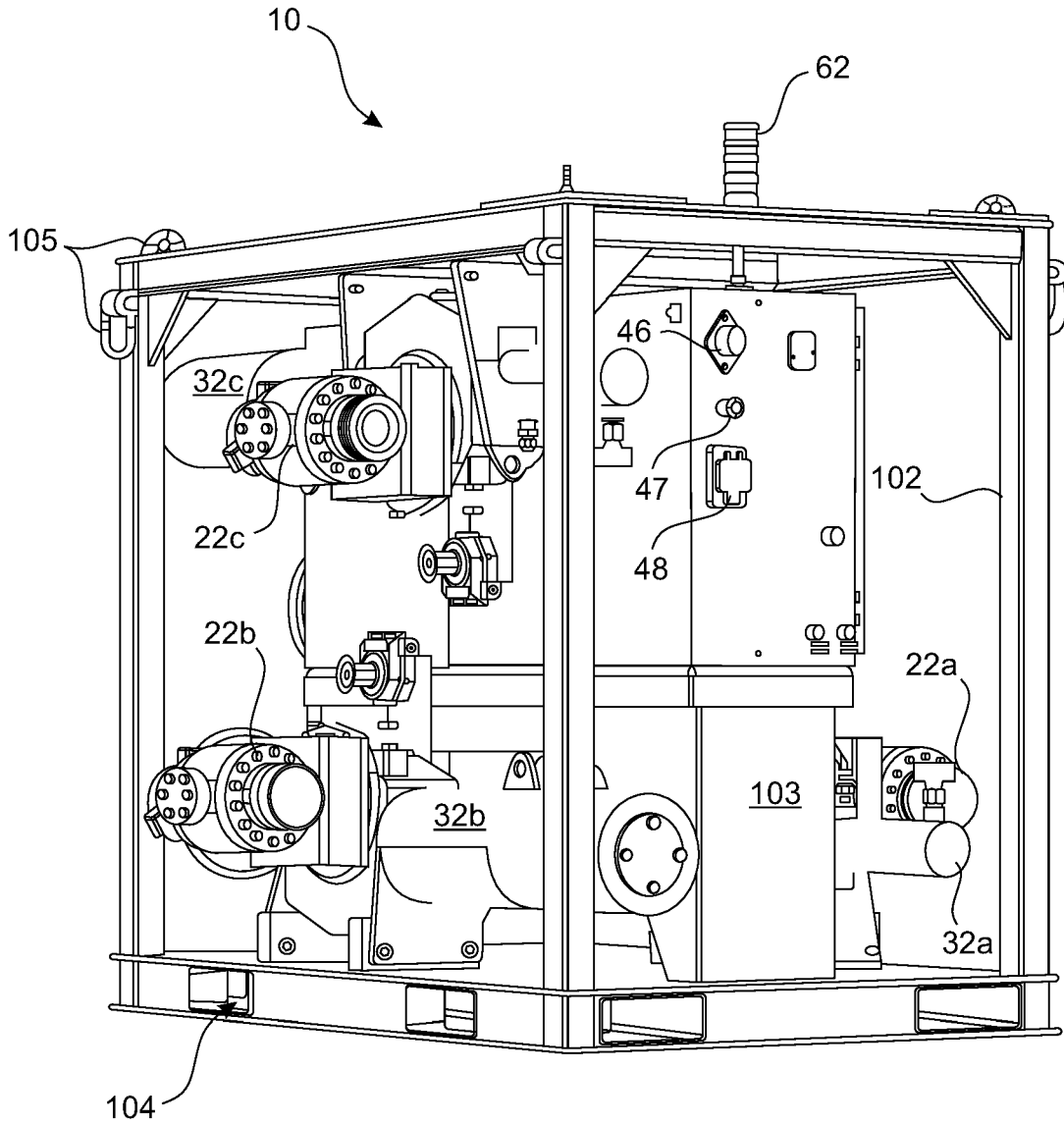


Fig. 5

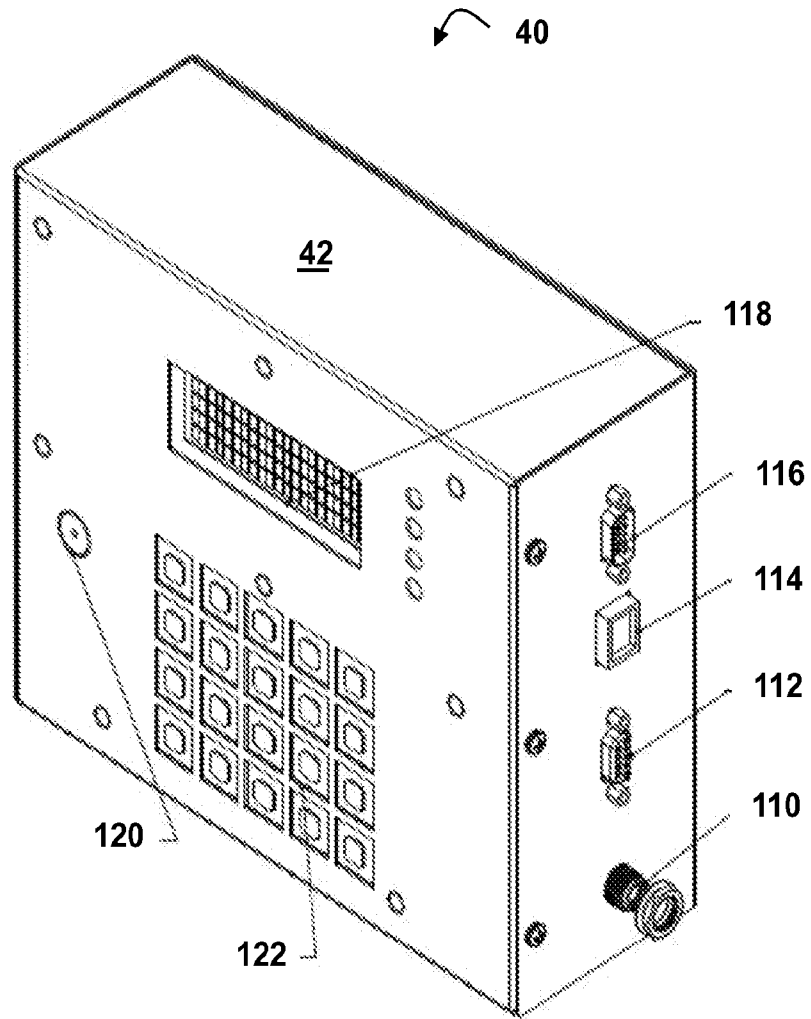


FIG. 6

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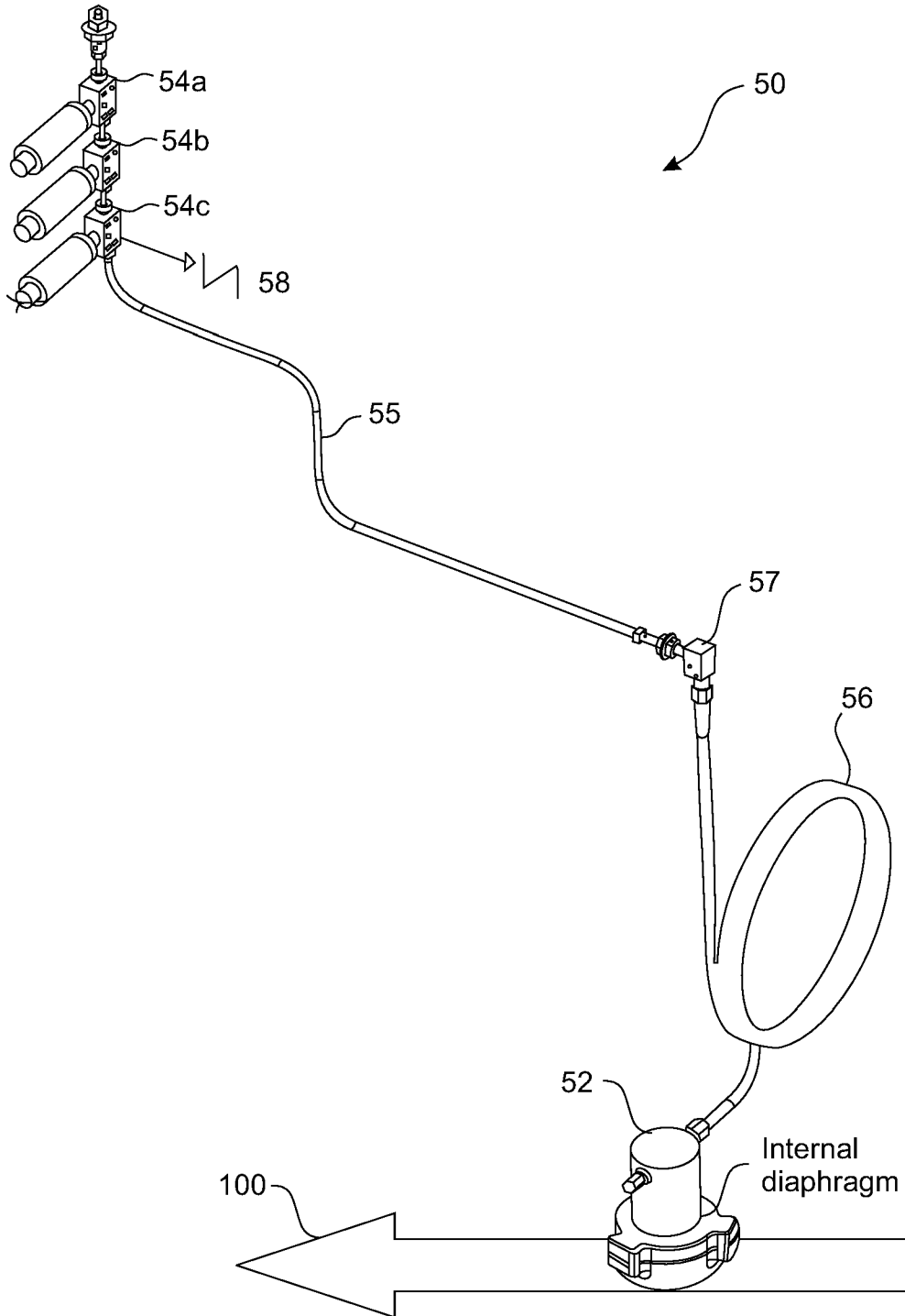


Fig. 7

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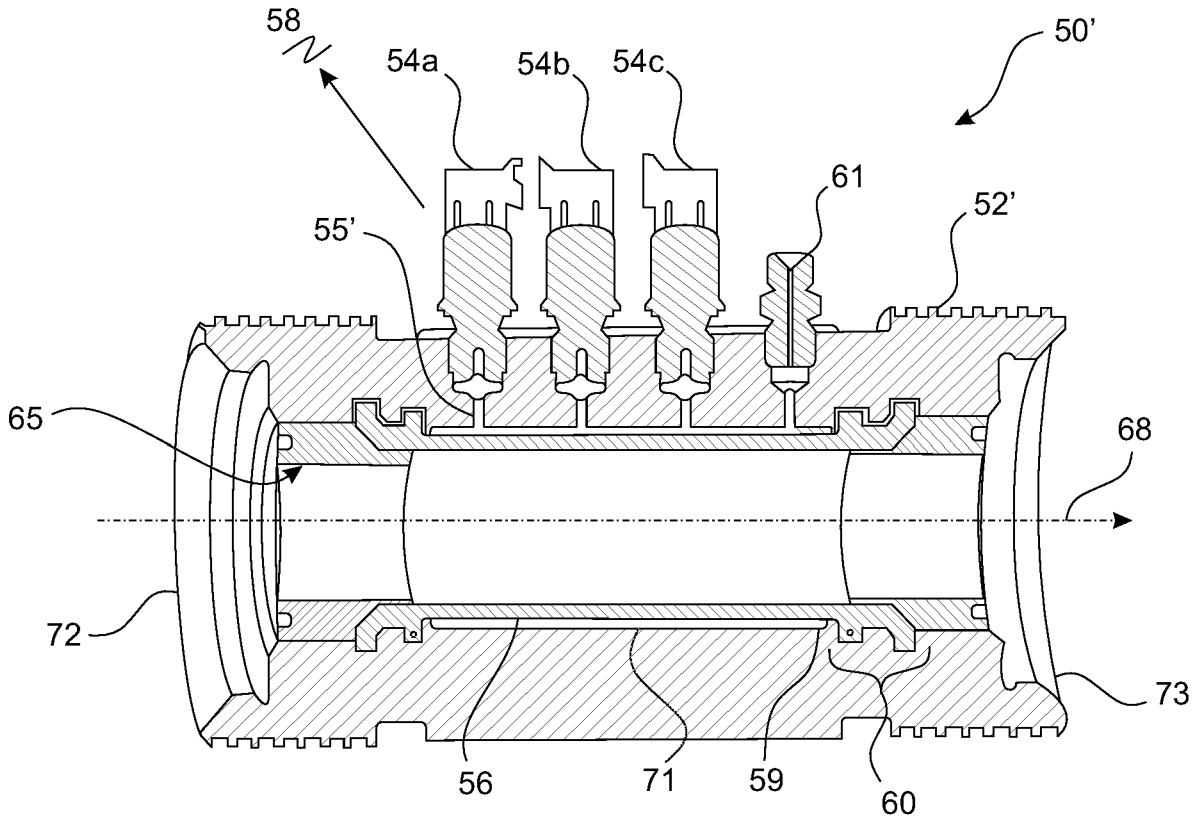


Fig. 8A

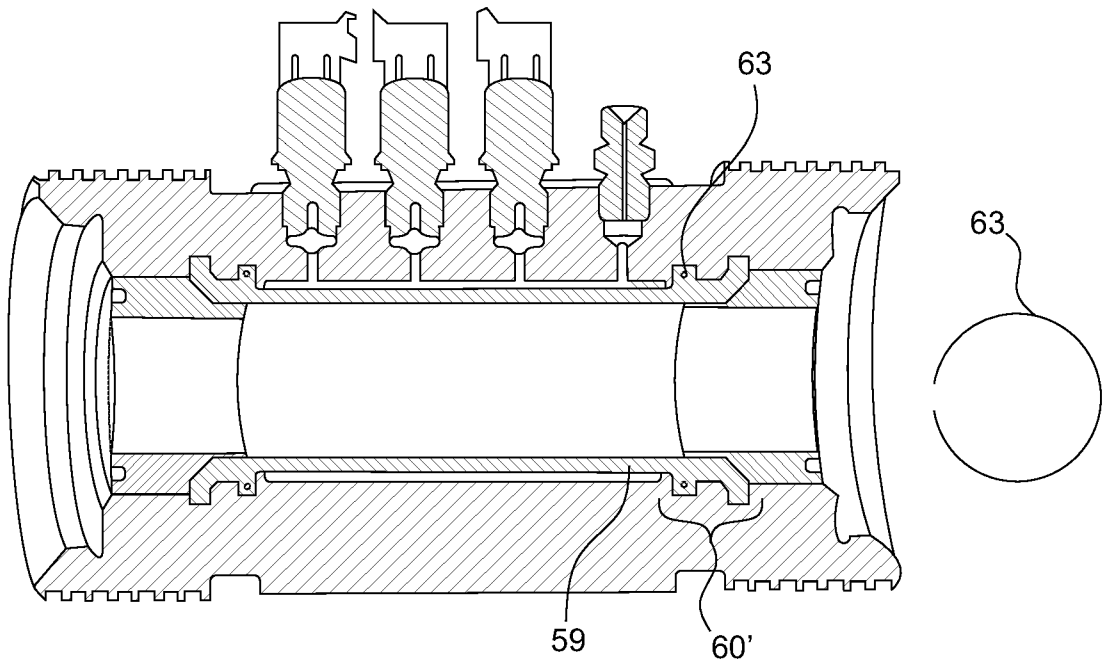


Fig. 8B

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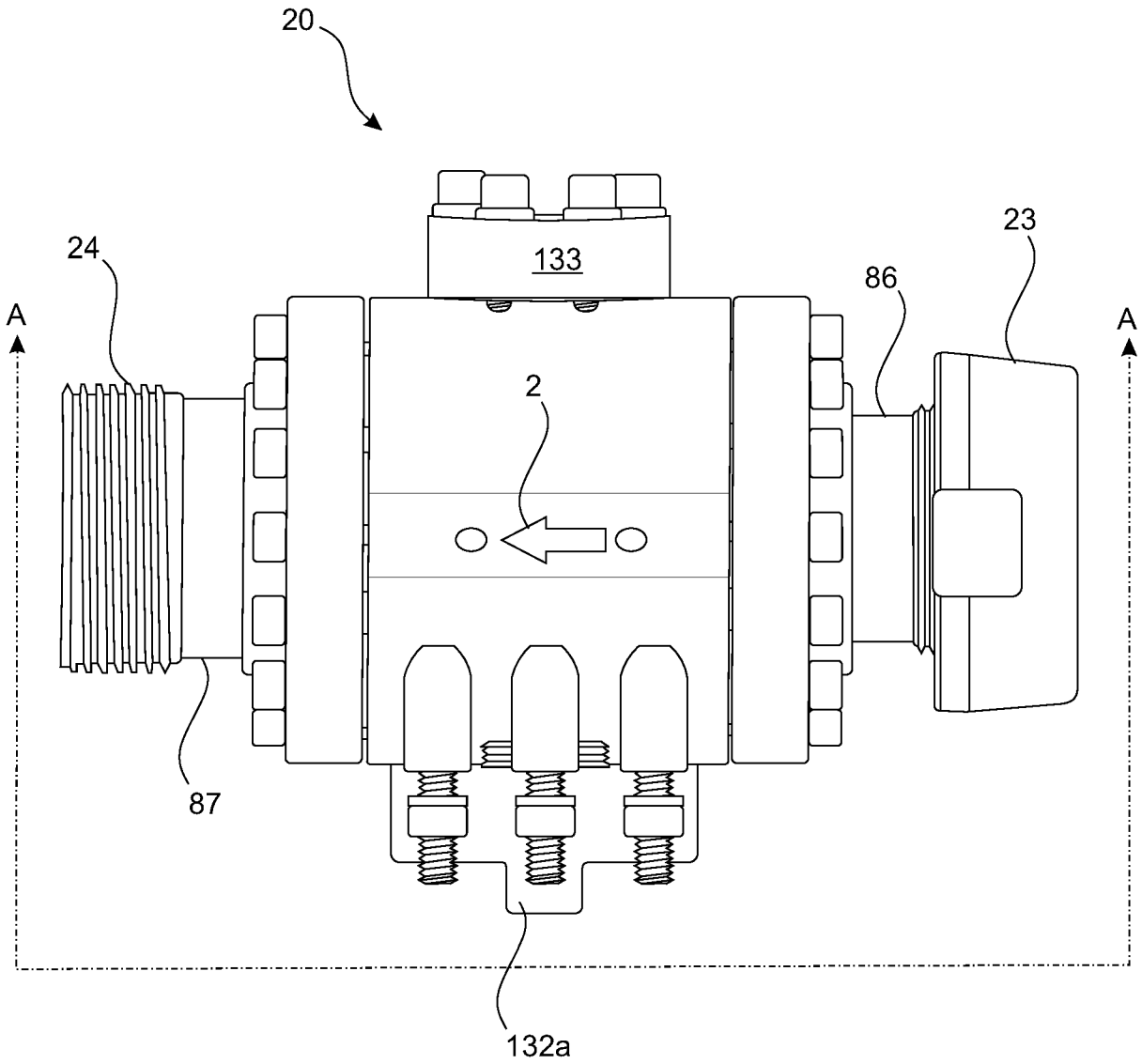


Fig. 9

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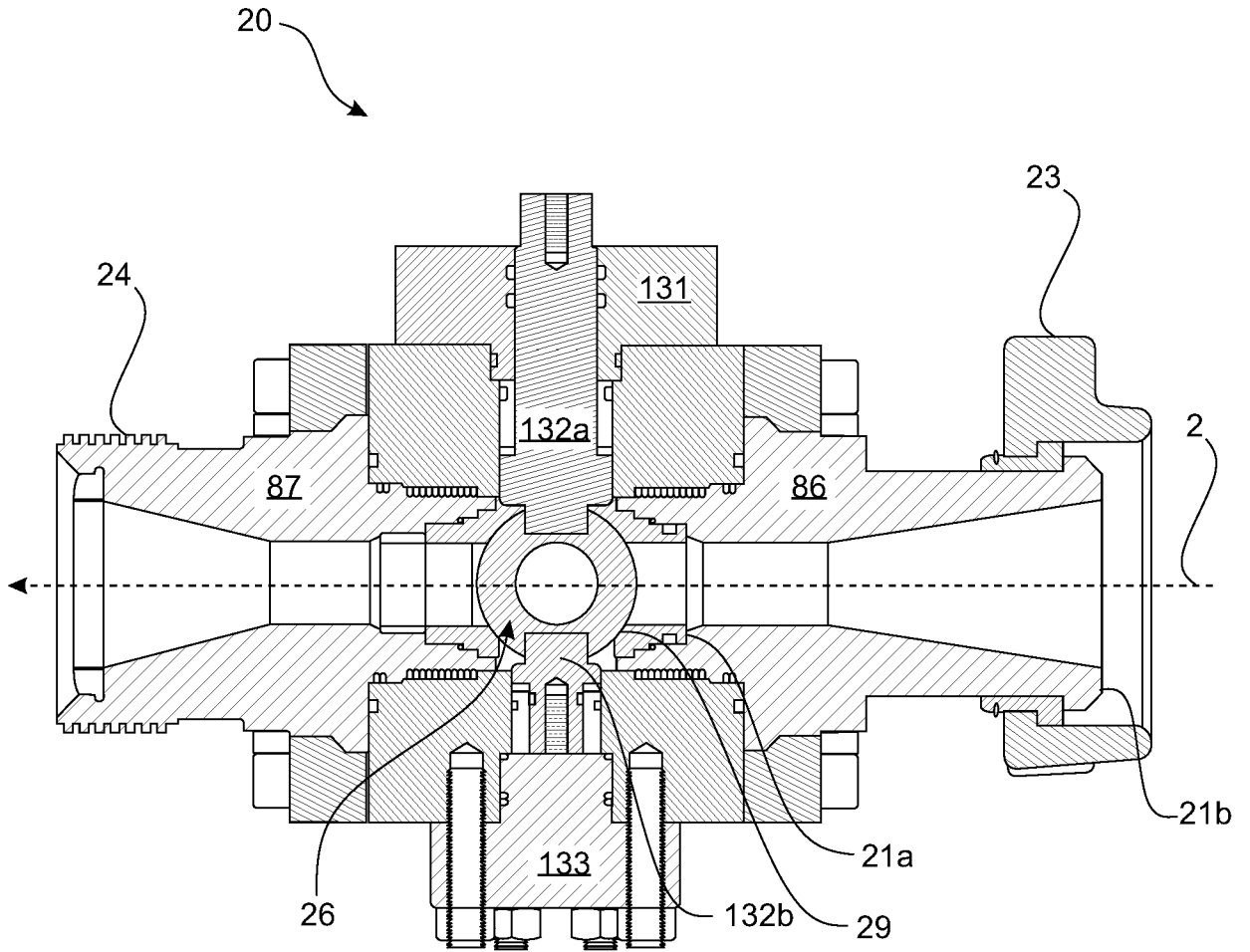


Fig. 10

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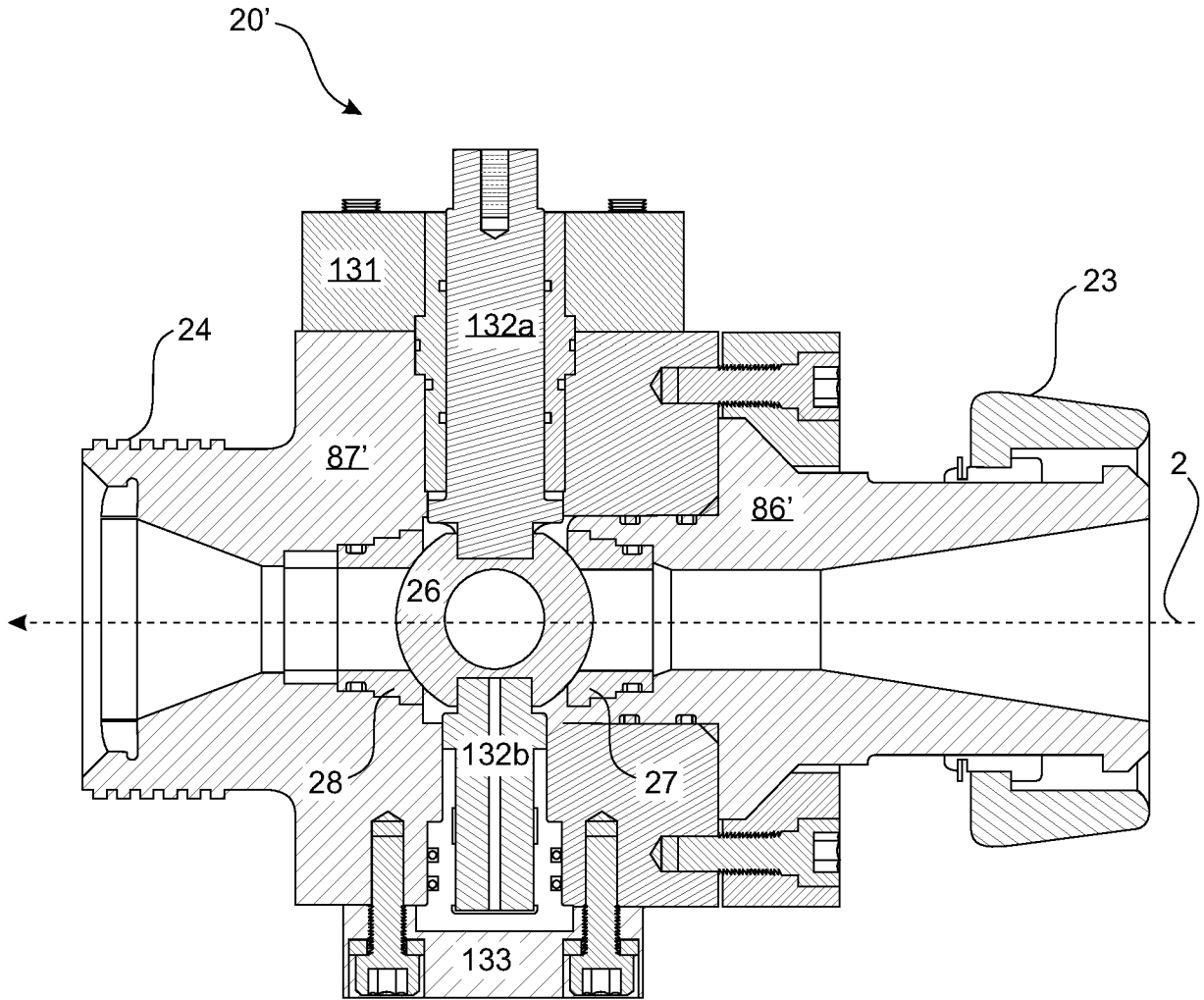


Fig. 11

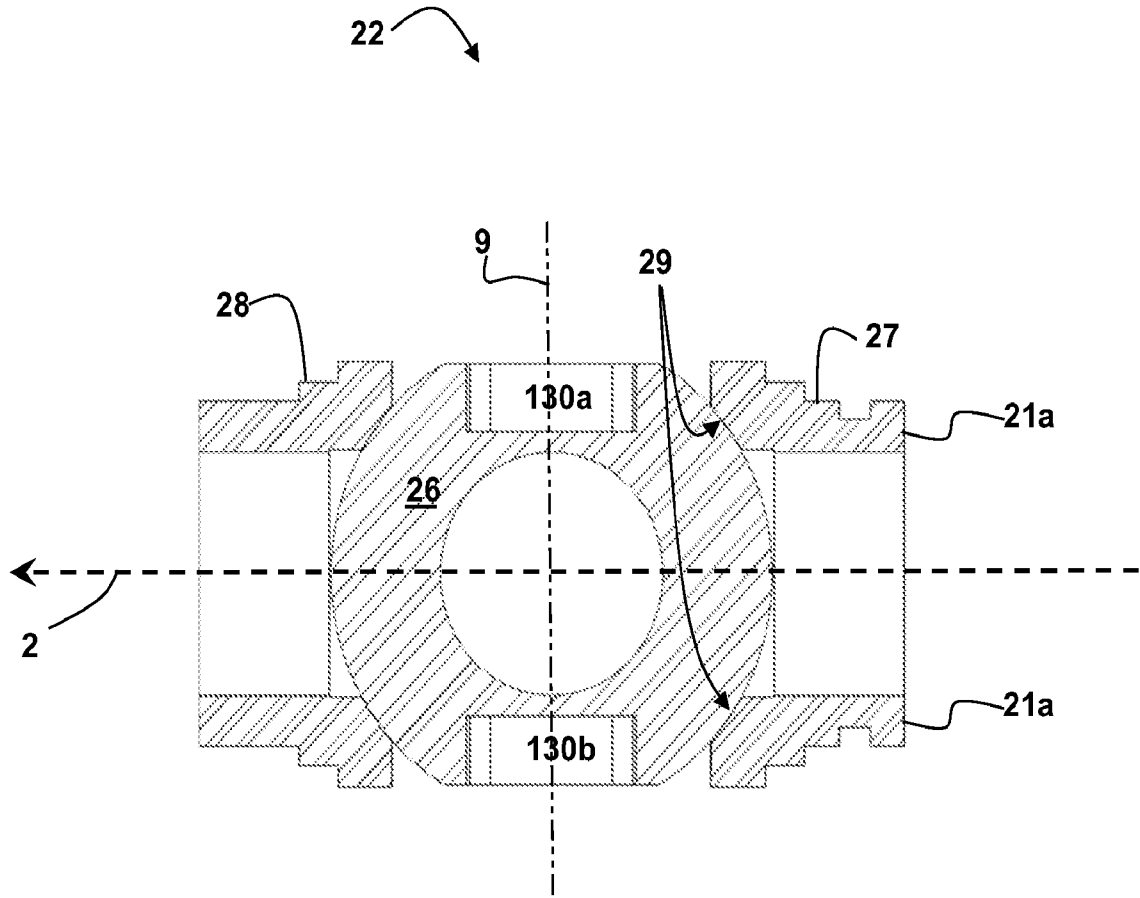


FIG. 12

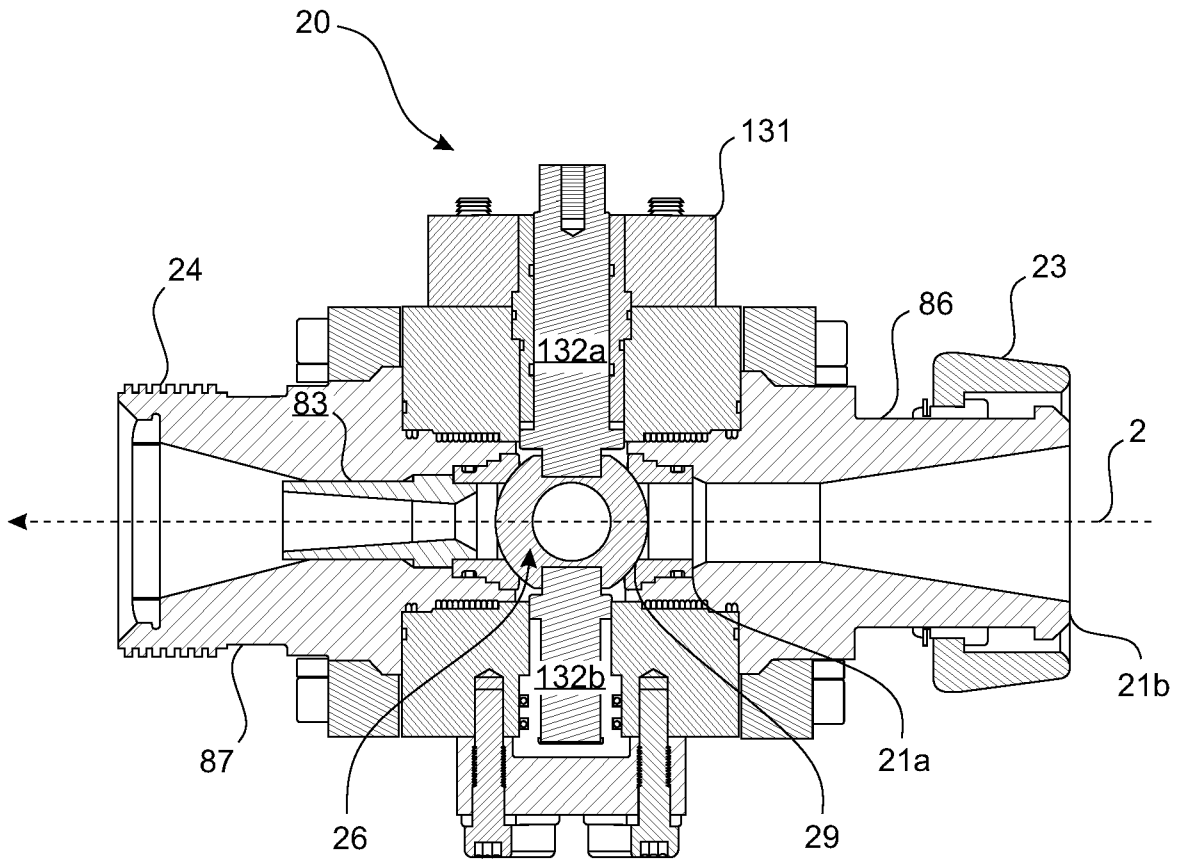


Fig. 13

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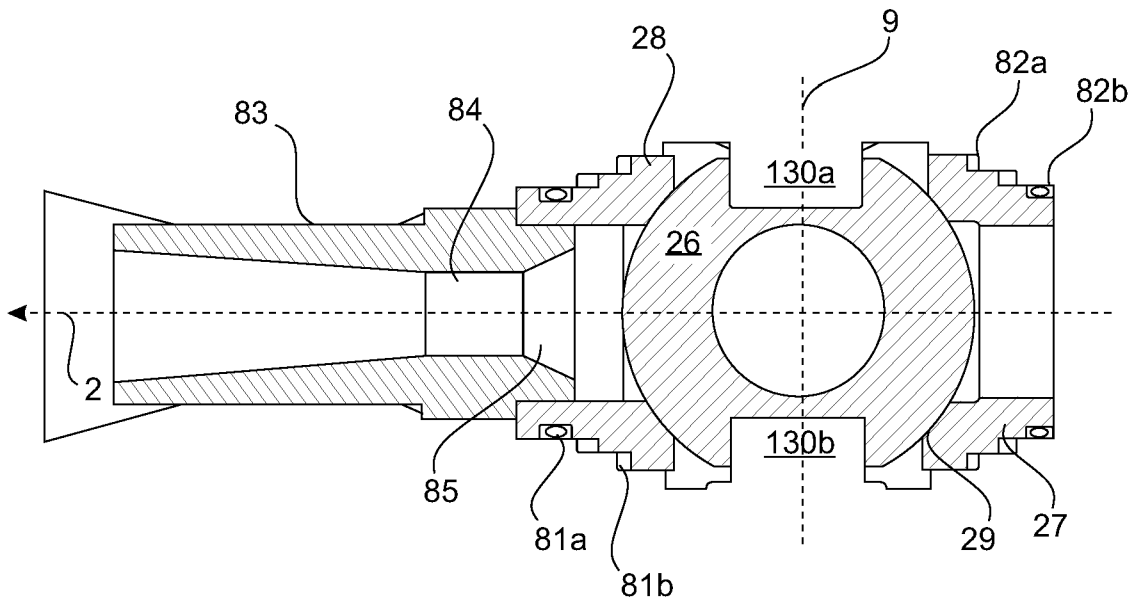


Fig. 14

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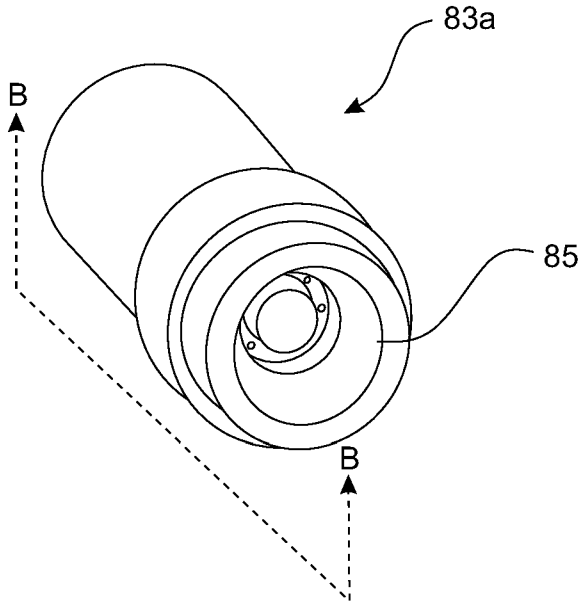


Fig. 15a

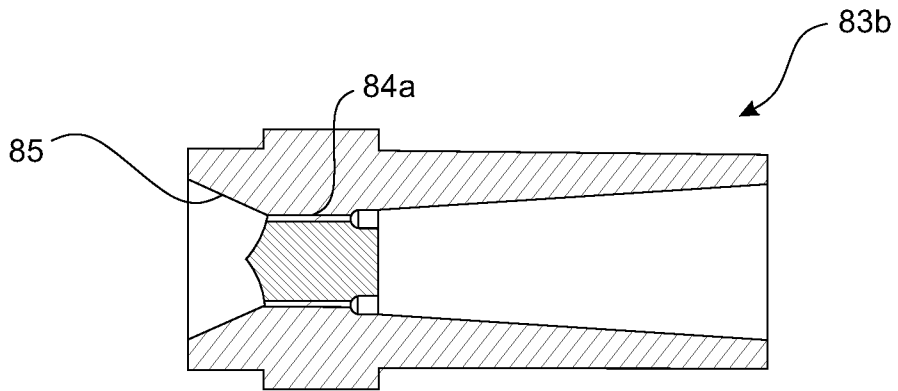


Fig. 15b

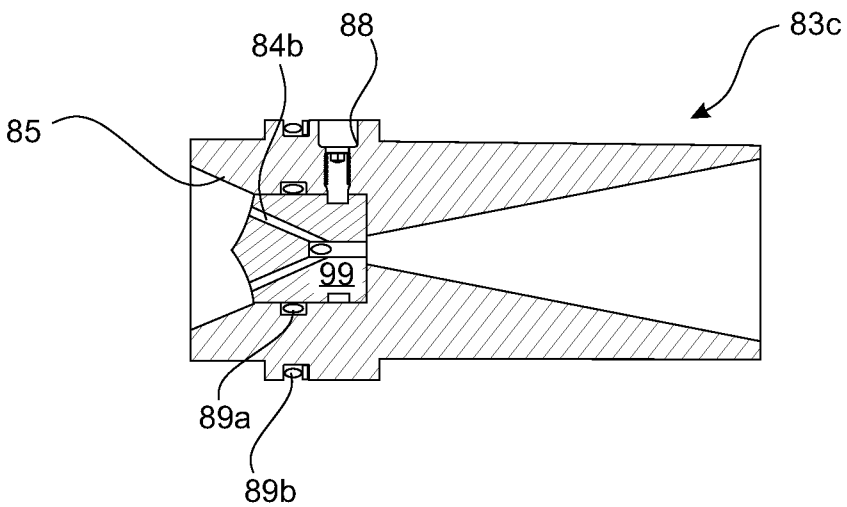


Fig. 15c

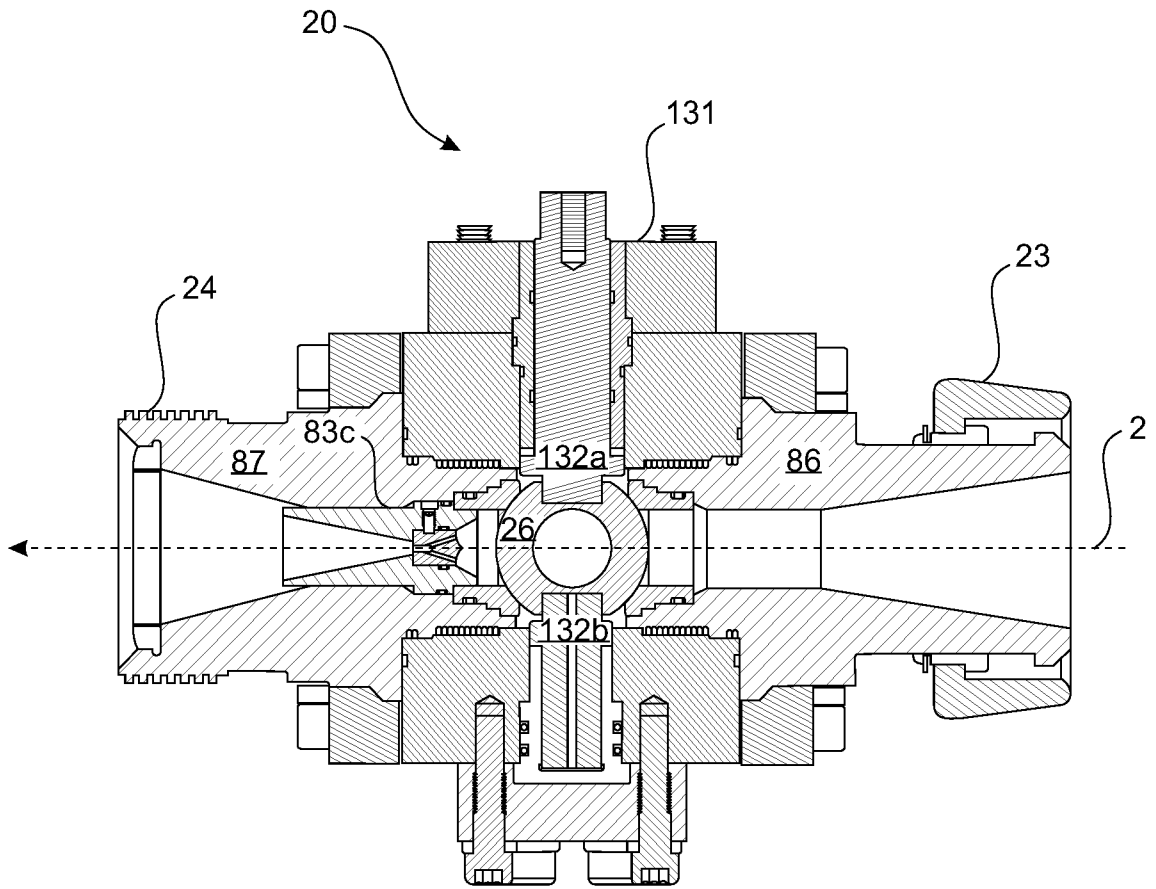


Fig. 16

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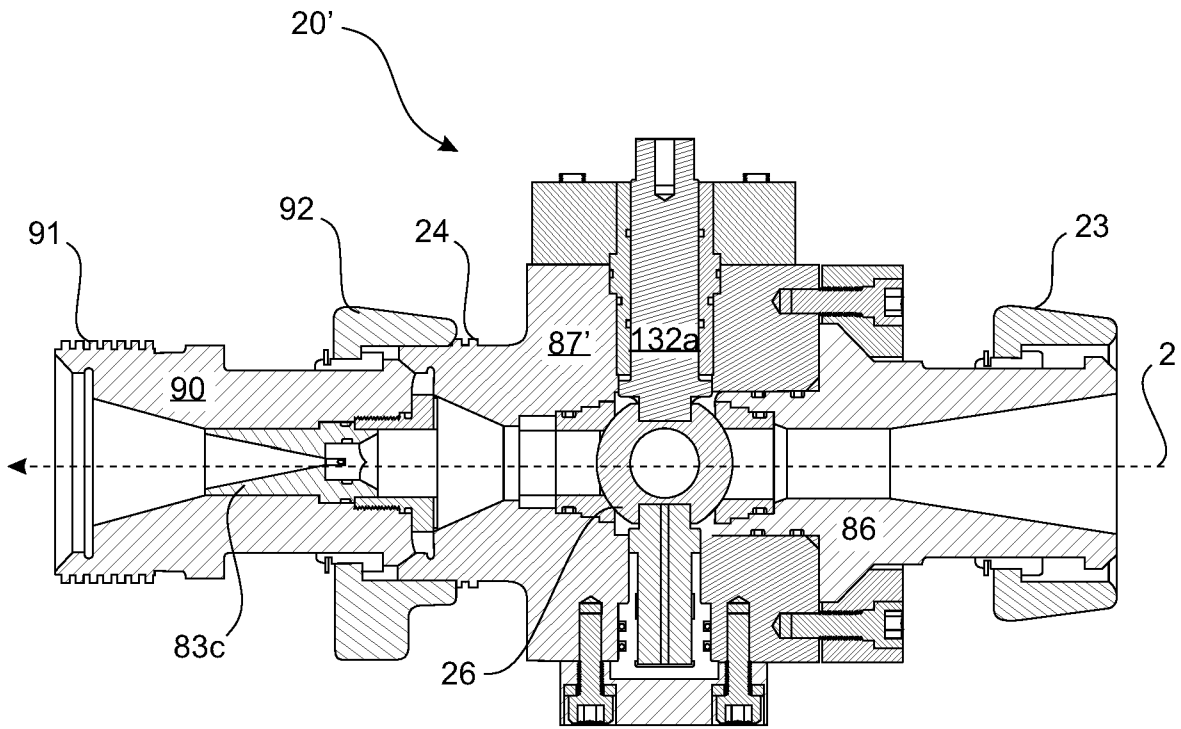


Fig. 17A

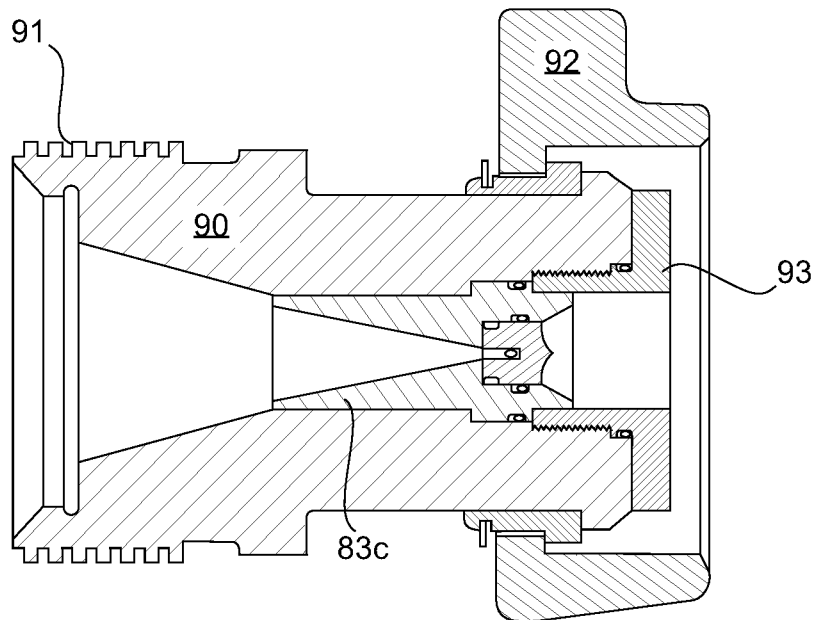


Fig. 17B

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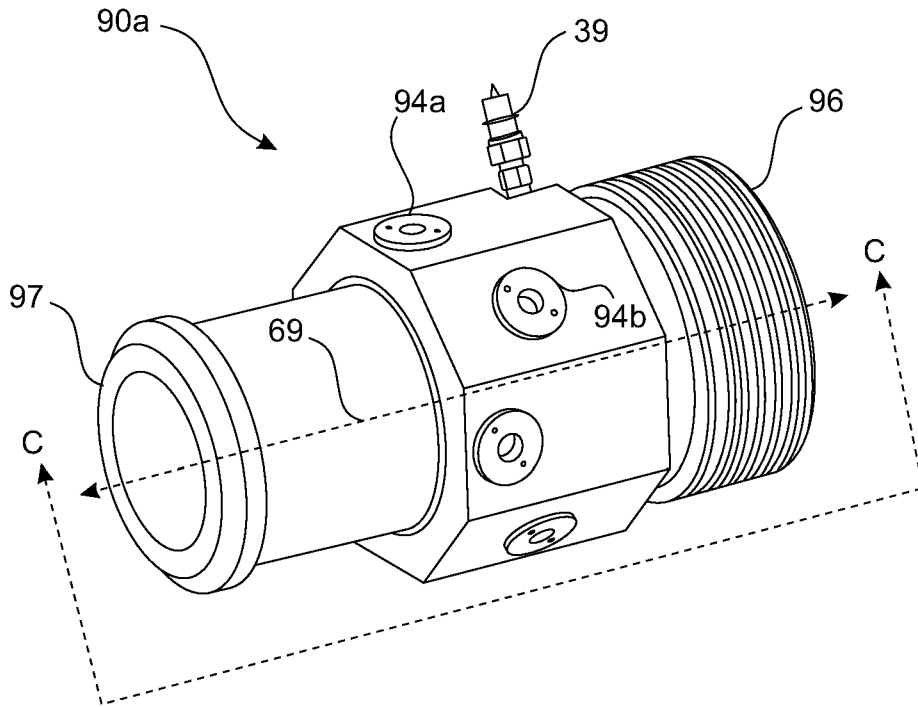


Fig. 18A

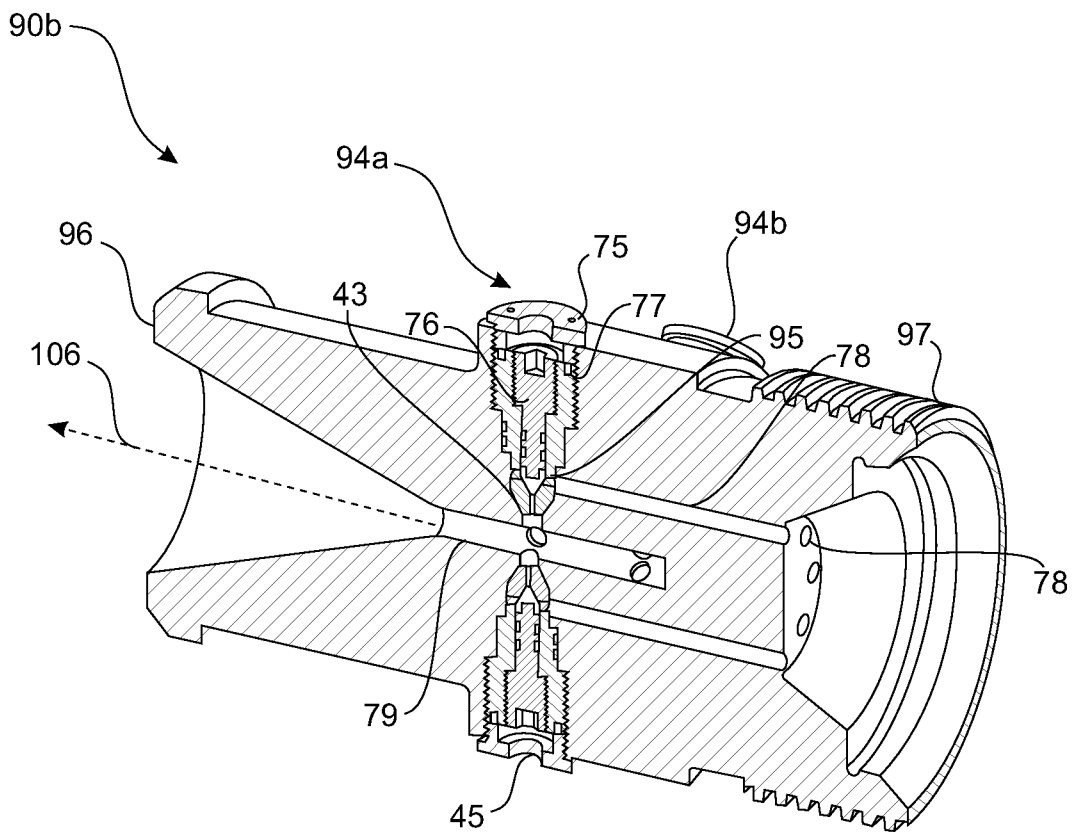


Fig. 18B

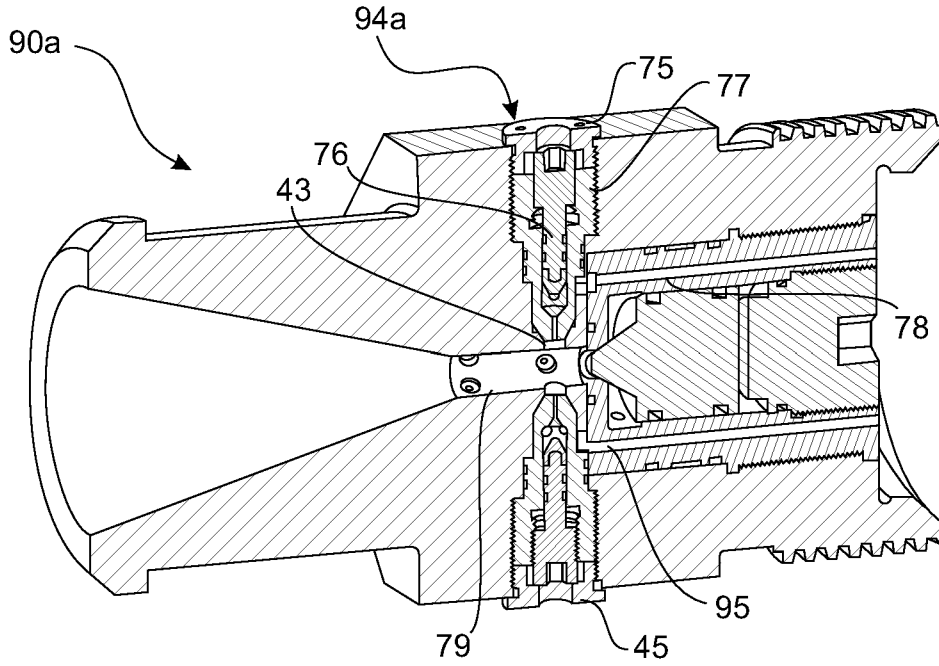


Fig. 19A

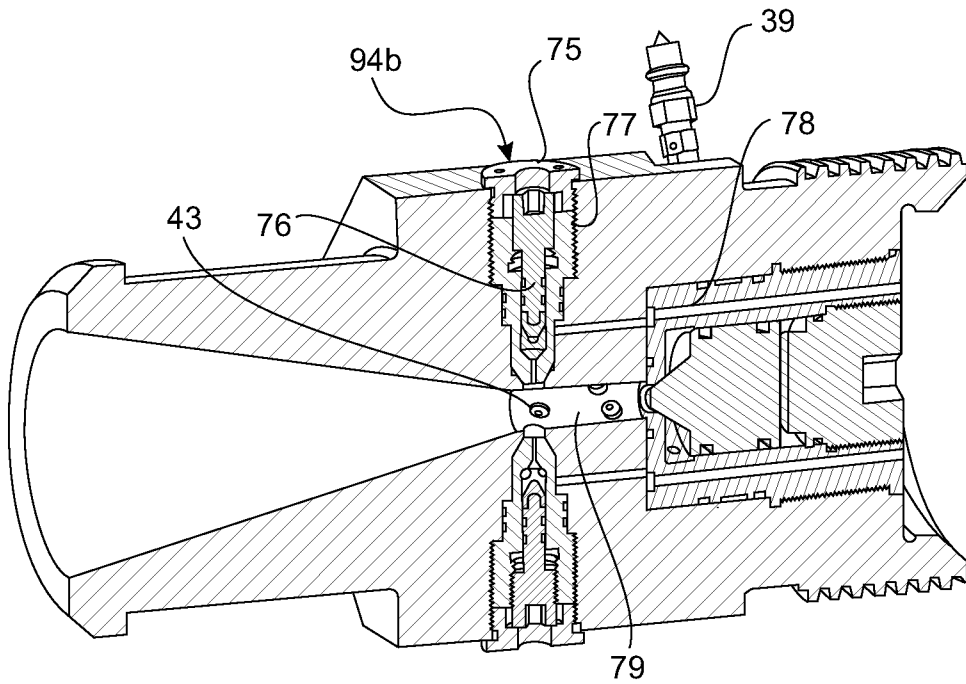


Fig. 19B

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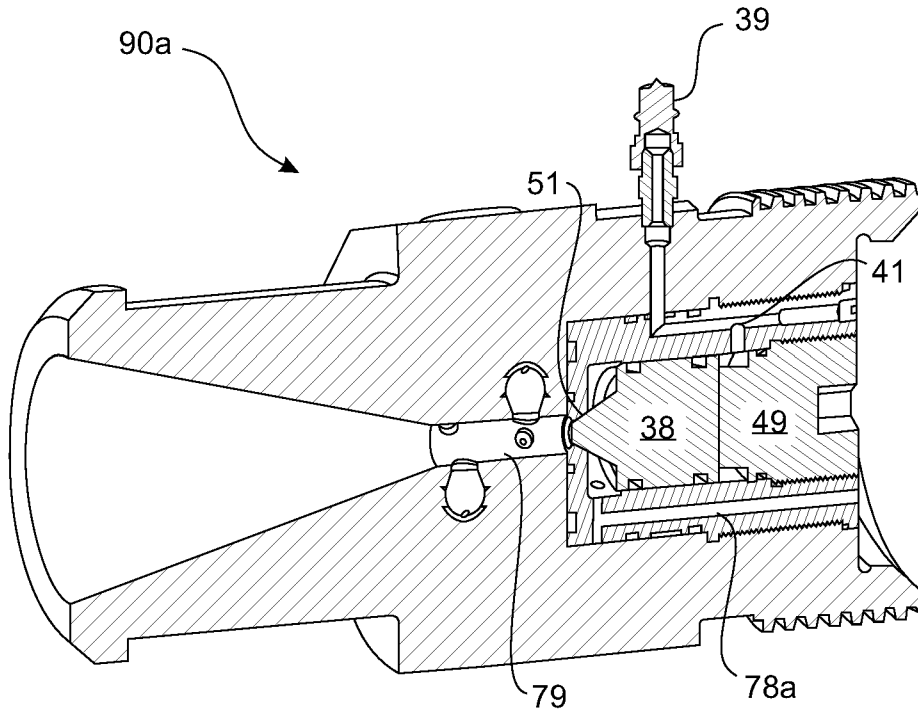


Fig. 19C

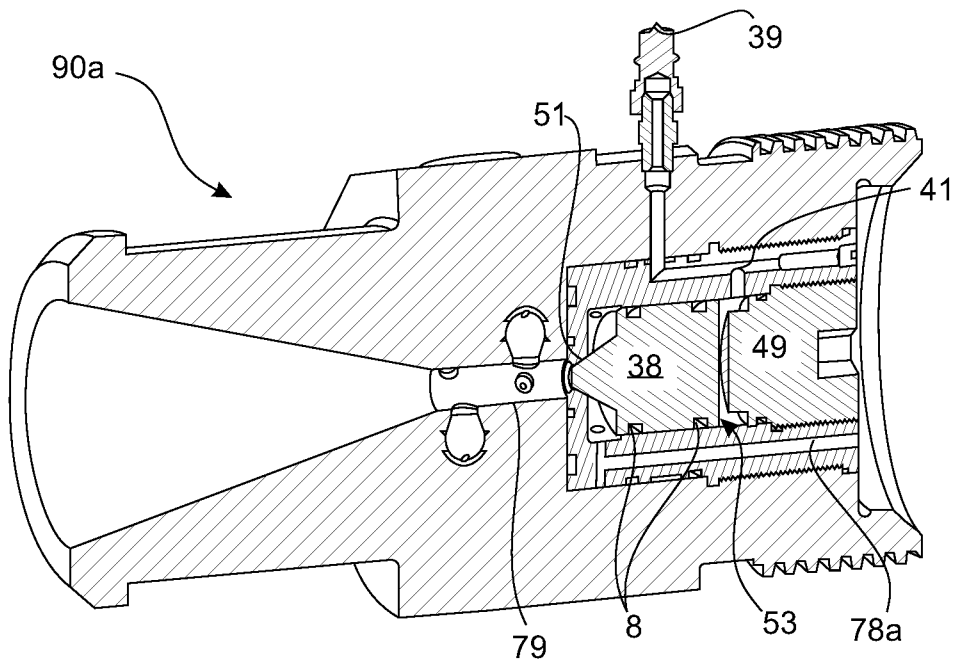


Fig. 19D

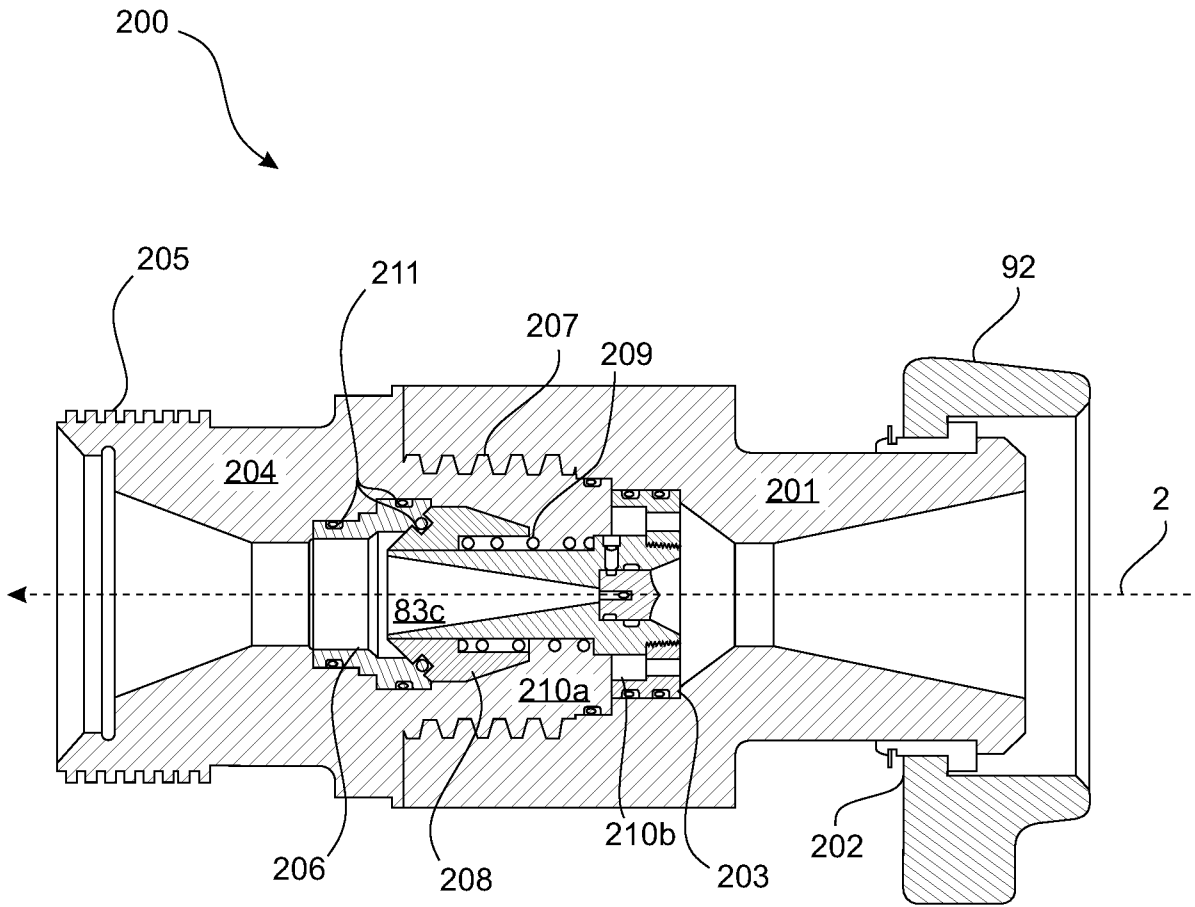


Fig. 20

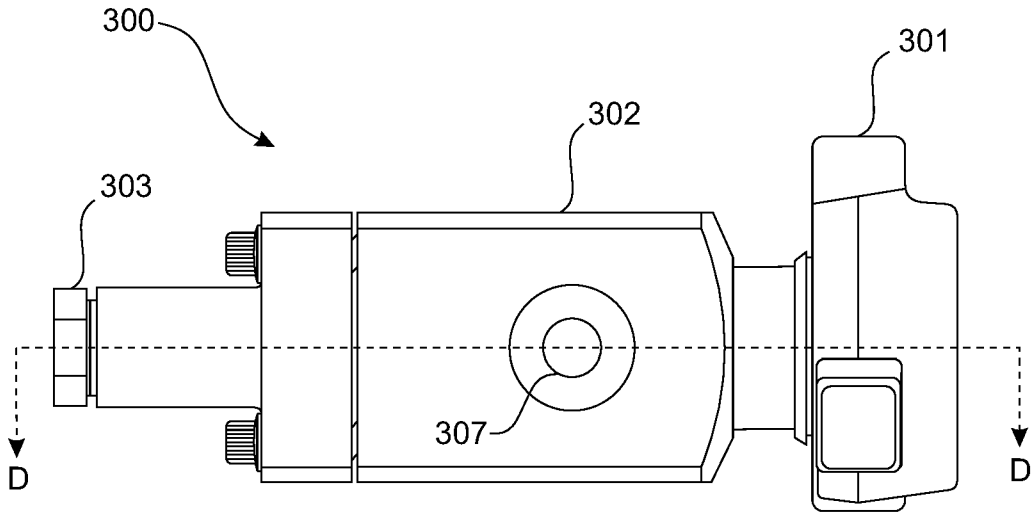


Fig. 21A

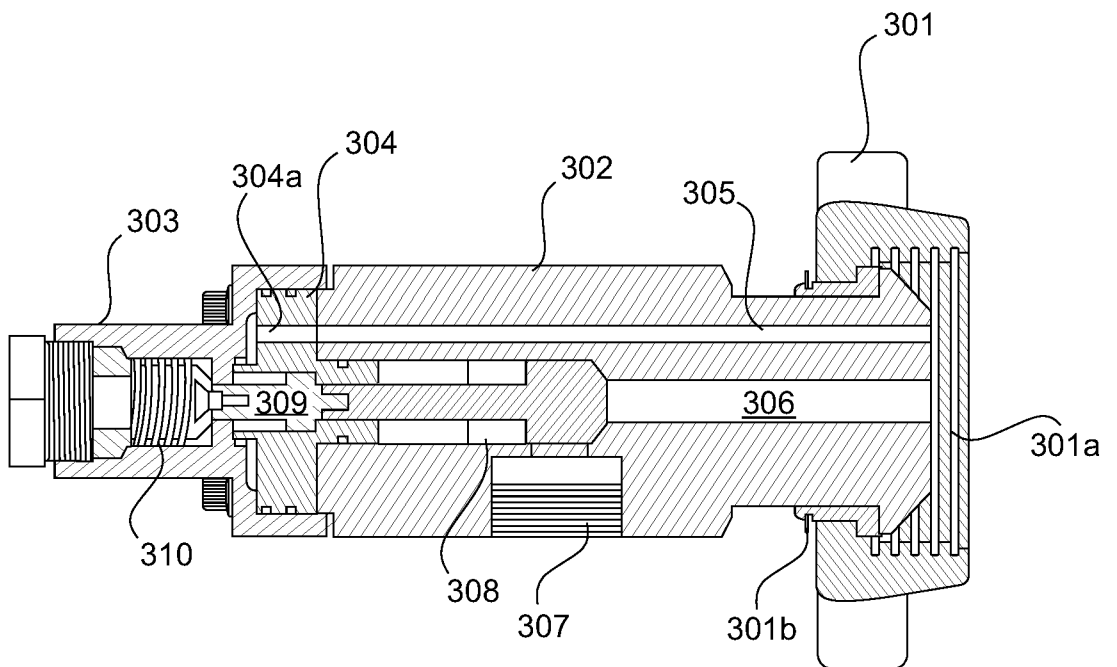


Fig. 21B

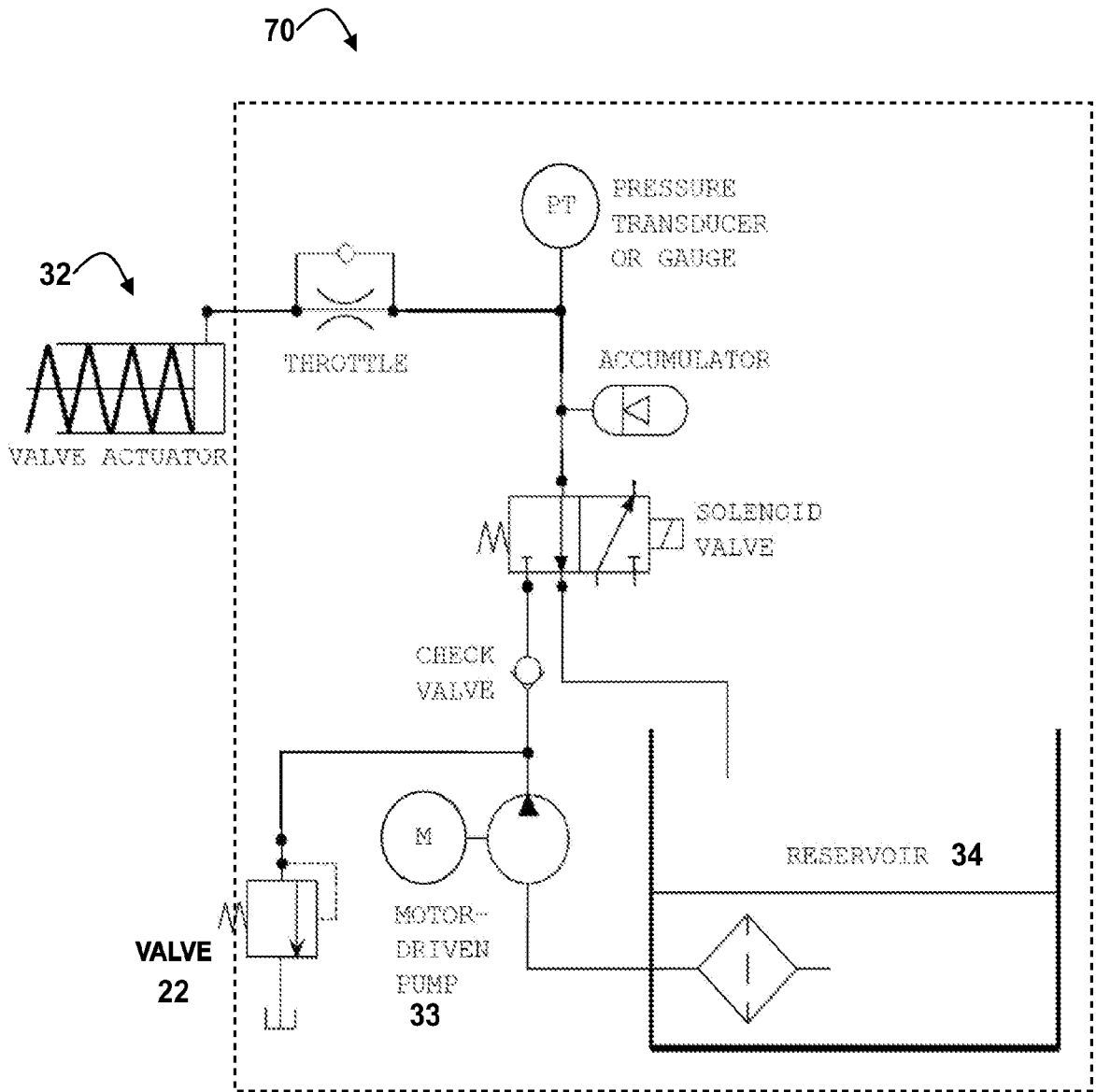


FIG. 22

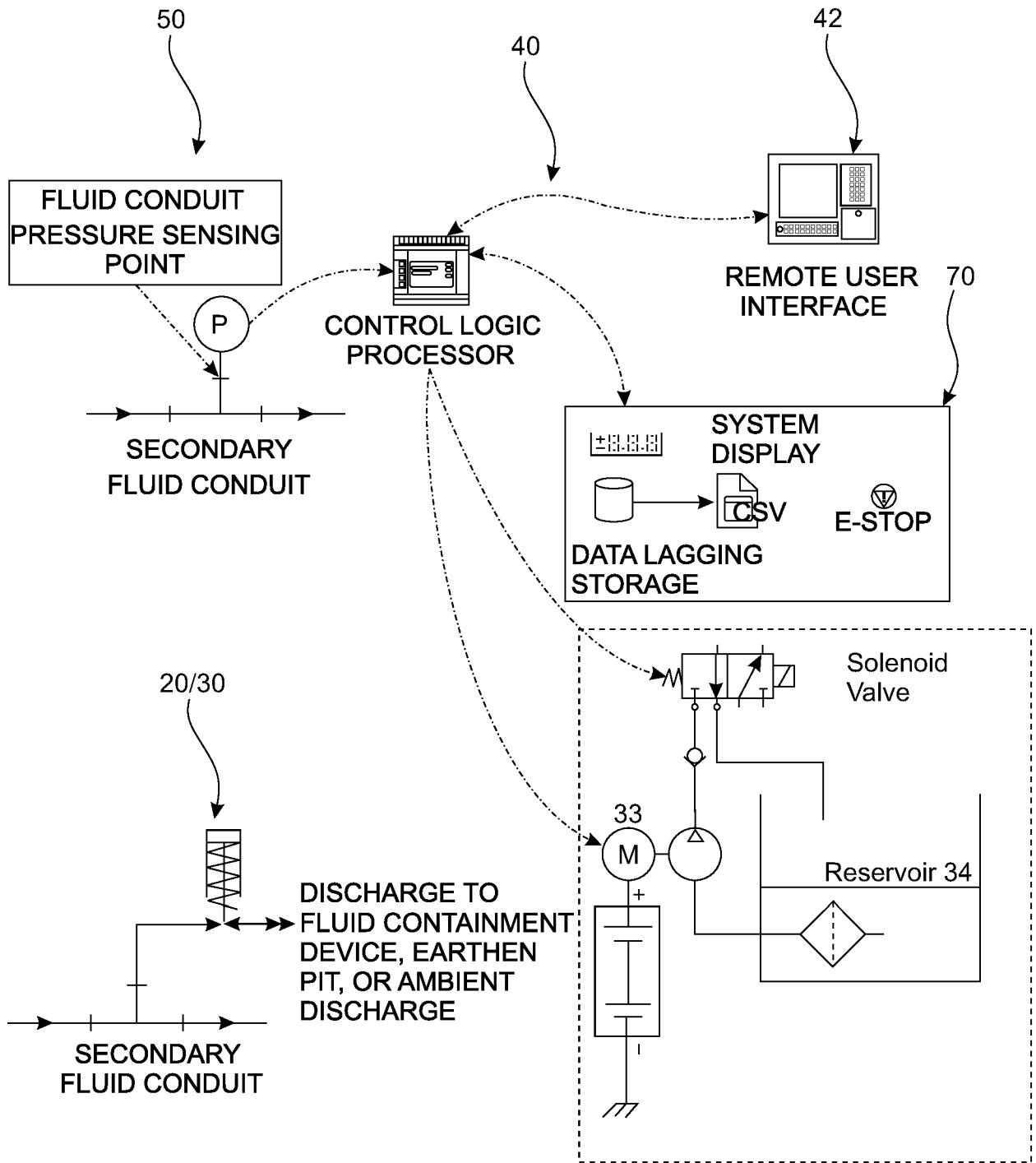
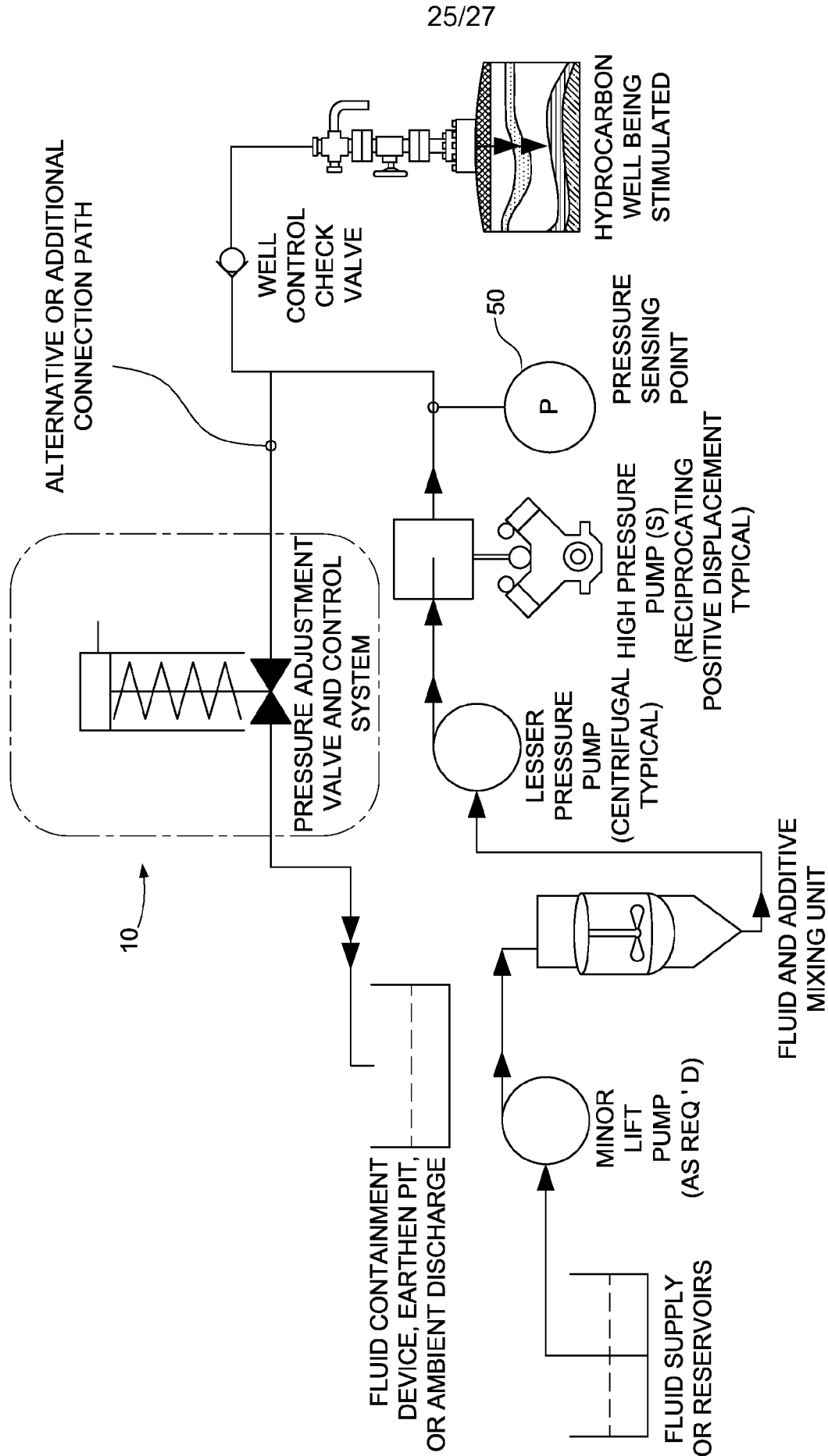


Fig. 23



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FIG. 24

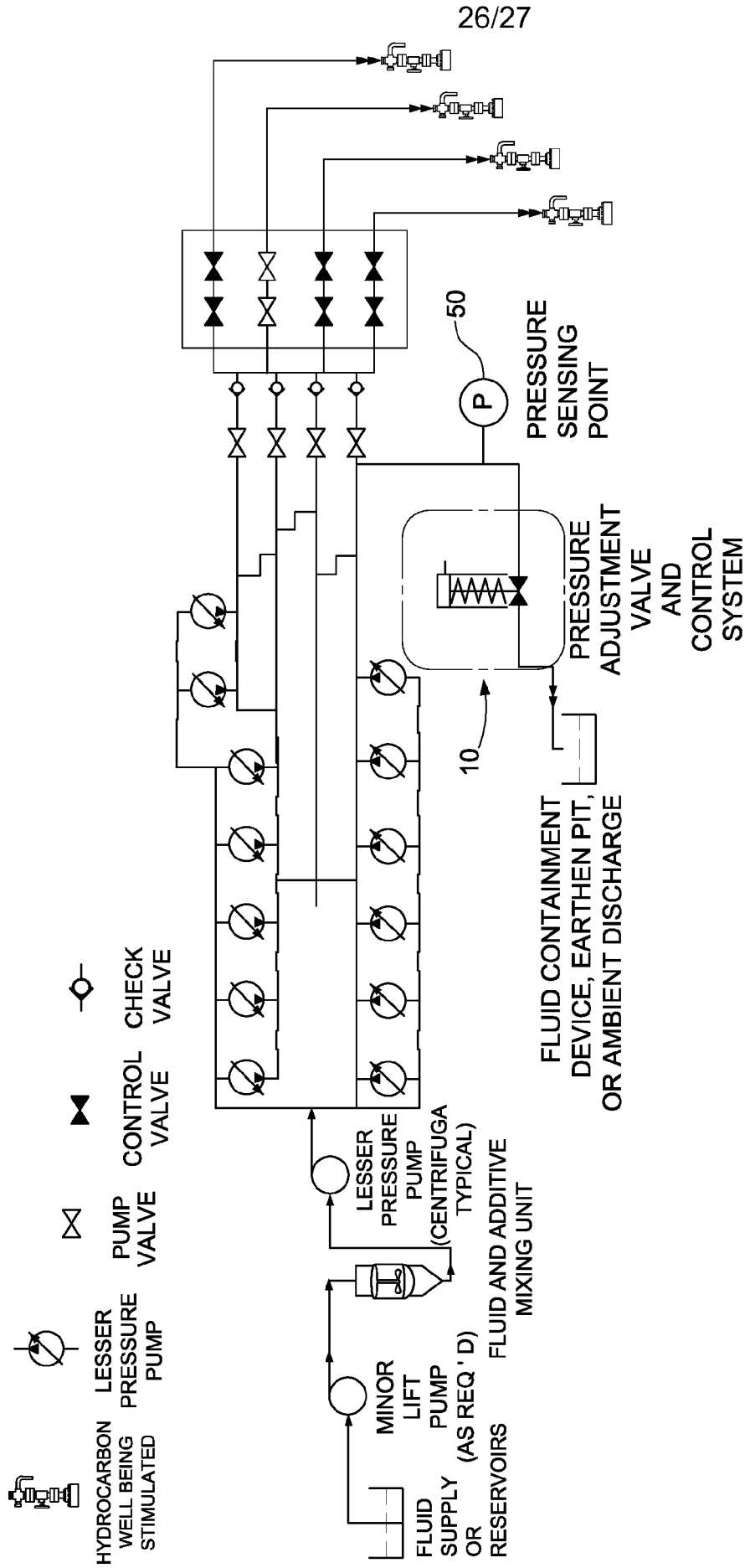


FIG. 25

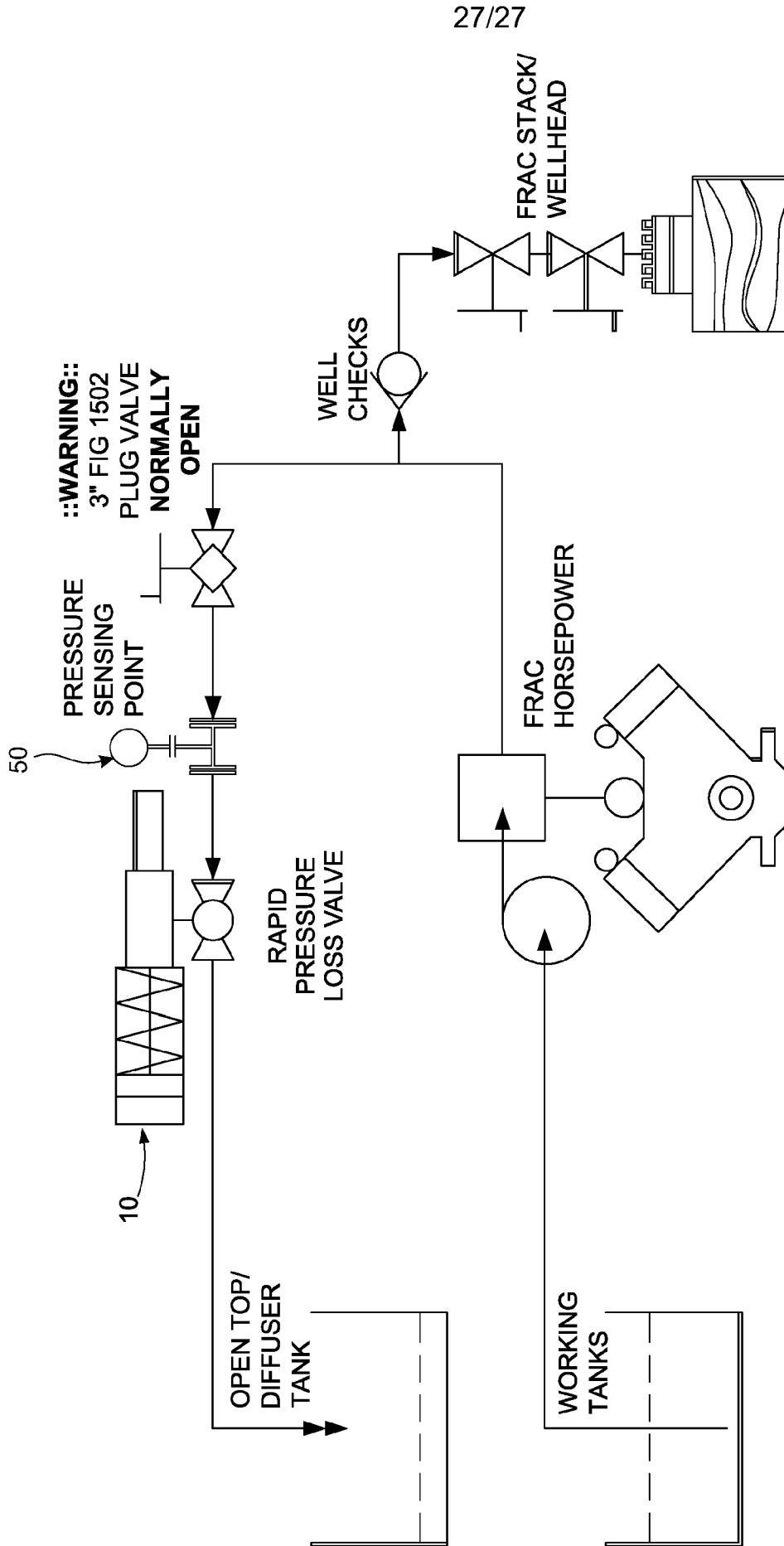
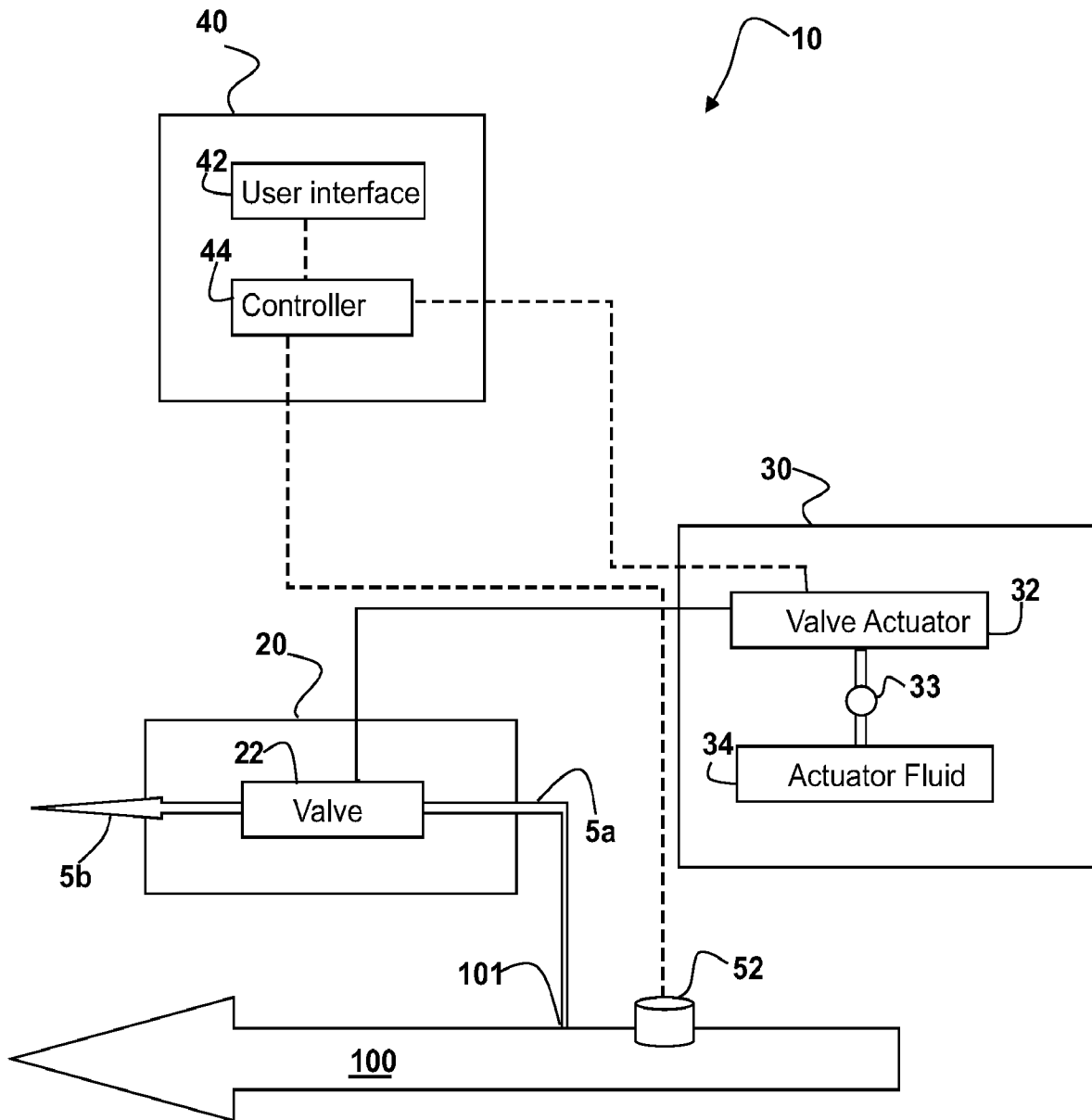


FIG. 26



**FIG. 1**