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BALANCED PRESSURE-REGULATING HYDRAULIC SERVO VALVE

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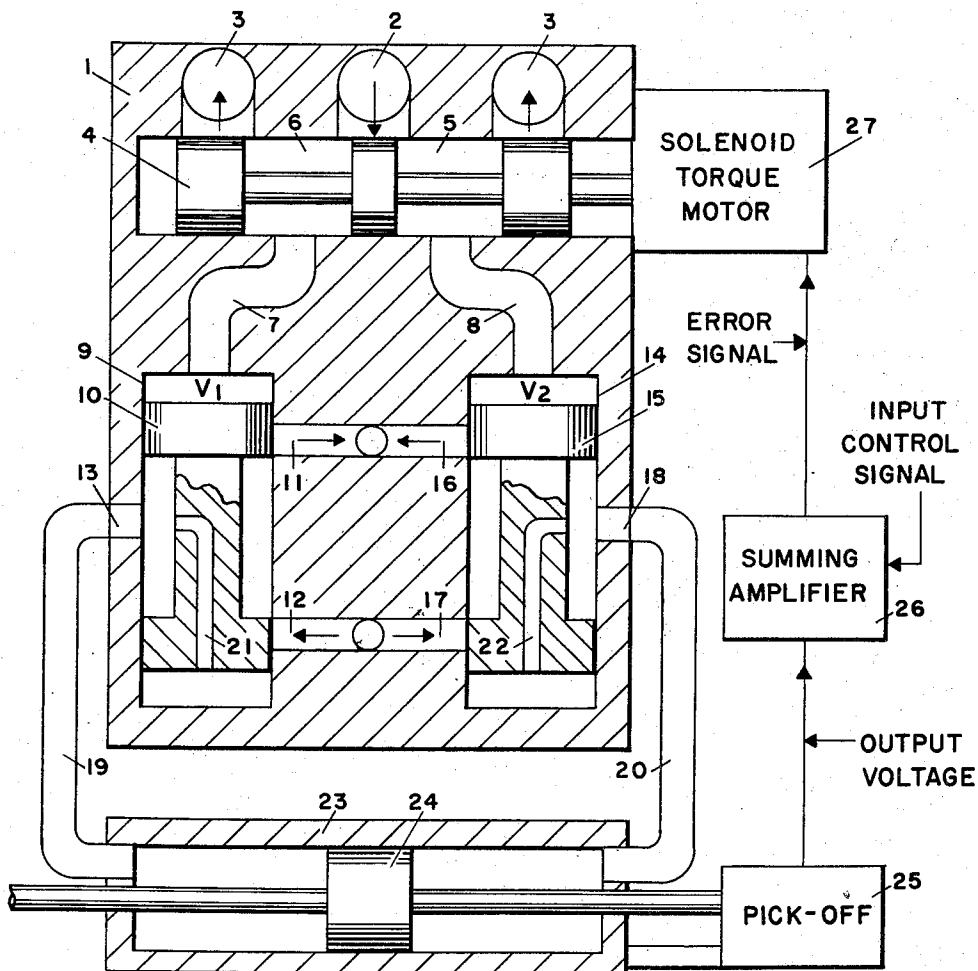


Fig. 1

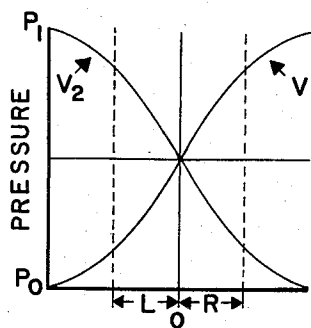


Fig. 2

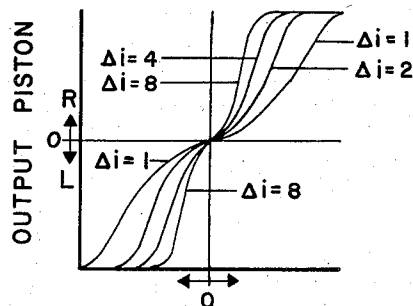


Fig. 3

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BALANCED PRESSURE-REGULATING HYDRAULIC SERVO VALVE

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This invention relates to the art of hydraulic control. More particularly, the present invention relates to hydraulic control apparatus such as is used in servo systems. More especially, the present invention relates to pressure-regulating, hydraulic servo valves.

In the prior art hydraulic amplifier valves have been especially difficult to operate because of the presence of foreign particles in the fluid. A typical prior art valve employs a pilot piston valve which completely disconnects a source of fluid under pressure from the piston valve when in a central or equilibrium position. The piston valve may be precluded from interrupting such a connection by foreign particles lodged between the piston valve and its surrounding cylinder. Relatively intricate filtering systems and various forms of mechanical feedback have been used in the prior art in an effort to solve this problem.

Hydraulic servo valves in the prior art are typically designed to provide a high degree of linearity between the physical displacement of a second stage spool valve and an input signal such as an electric current. The pressure drop across such prior art valves remains more or less constant and relatively high compared with the supply pressure. For example, typically the pressure drop across the valve is of the order of one-third of the supply pressure. In general, such valves are incapable of compensating for variations that occur in the loading or providing a constant pressure across an output loading device. It frequently turns out that it is far more important to maintain constant pressure across such a loading device in order, for example, to compensate for variations in the load, than to maintain precise linearity between an input signal and the physical displacement of a control spool valve in the second stage.

It is, therefore, an object of the present invention to provide an improved pressure-regulator, hydraulic servo valve capable of controlling the fluid pressure across an output device in accordance with an input control signal.

A further object of the invention is to provide an improved pressure-regulator, hydraulic servo valve capable of utilizing a greater proportion of the supply pressure across an output load device.

A still further object of the invention is to provide an improved pressure-regulator, hydraulic servo valve exhibiting a high degree of efficiency.

Another object of the present invention is to provide an improved hydraulic control apparatus which is reliable in operation and in which the need for intricate filtering systems and mechanical feedback is eliminated.

A still further object of the present invention is to provide an improved hydraulic control apparatus exhibiting rapid response to an input signal.

Other and further objects of the invention will be apparent from the following description of a typical embodiment thereof taken in connection with the accompanying drawings.

In accordance with the invention, there is provided a

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pressure-regulator, hydraulic servo valve adapted to control the application of fluid under pressure in accordance with an input control signal. The valve includes output conduit means and pressure responsive valve means coupled to the output conduit means for applying the fluid therethrough at an output pressure varying in accordance with an input control signal. Pilot means are coupled to the pressure responsive means for applying an input control signal. Output pressure feedback means couple the conduit and the pressure responsive means for controlling the pressure responsive means to oppose changes in pressure arising from the conduit means. In this manner, the valve is enabled to provide a differential output pressure substantially independent of the fluid-pressure changes in the output conduit, thereby tending to produce an increasing flow of fluid through the output conduit means.

In one embodiment of the present invention there is provided a balanced, pressure-regulator, hydraulic servo valve. The valve includes a source of fluid pressure and a pair of fluid passageways. A pilot valve is connected between the passageways in the source for varying the fluid pressure from the source acting through each of the passageways. The valve includes a pilot valve member having a center land for varying the opening of an inlet port and two end lands for varying the openings of discharge lands. The ports are normally partially open when the pilot valve member is in a central position. A first control valve is provided and has a cylinder, a movable piston valve within the cylinder and ports in the cylinder. A second control valve is also provided and has a second cylinder, a movable piston valve within the second cylinder and ports in the second cylinder. An end of each of the piston valves is connected to one of the passageways to enable the pilot valve selectively to apply pressures differentially to displace the piston valves. The piston valves each have two end lands, one for varying the opening of an inlet port and the other for varying the opening of a discharge port. The openings of the control valve are normally closed when the piston valves are in central position. A pair of output conduits are each connected to one of the end lands of each of the piston valves. The control valve is thereby connected in push-pull relation to the source and the conduits, selectively to control fluid flow therethrough. A pressure-equalizing passageway in each of the pilot valves connects the other end of each of the piston valves to one of the output conduits for equalizing the pressures tending to displace the piston valves to enable the apparatus to provide substantially a constant differential pressure producing an increasing flow of fluid through the output conduits.

Referring now to the drawings:

Fig. 1 is a schematic, cross-sectional view of a preferred embodiment of the present invention;

Fig. 2 is a graph of static pressure variations illustrating an aspect of the operation of the embodiment of Fig. 1; and

Fig. 3 is a graph of an output piston displacement as a function of time in the preferred embodiment.

More specifically, in Fig. 1 a source of fluid pressure is connected to an inlet port 2 and discharge ports 3 in a body 1 of a balanced, pressure-regulating, hydraulic servo valve. The valve is adapted to control the application of fluid under pressure in accordance with an input control signal as supplied, for example, electro-hydraulically by the pilot valve and a solenoid motor. The valve includes an output conduit means, such as the conduits 19 and 20. Pressure-responsive valve means such as the valves V_1 and V_2 are coupled to the output conduit means. A four-way pilot valve provides a pilot means coupled to the pressure-responsive means. The valves V_1 and V_2

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include output pressure-feedback means hydraulically coupling the conduit and the pressure-responsive means.

More particularly, the four-way pilot valve includes a piston member 4 which has end lands that vary the openings to the discharge ports 3 and a center land which varies the opening to the inlet port 2, as shown. The lands are underlapped to provide a restricted flow of fluid at all times from the inlet port 2 through the inside of the port cylinder to the discharge ports 3. In the preferred embodiment, when the pilot piston is in a central position the pressures in chambers 5 and 6 are each one-half the system pressure. The pilot valve then is connected between a pair of input pressure passageways 7 and 8 and the source for varying the fluid pressure from the source acting through each of the passageways. The passageway 7 is connected to a first pressure regulator control valve V_1 which has a cylinder 9, a movable piston 10 within the cylinder and ports 11, 12 and 13 in the cylinder.

The passageway 8 is connected to a second pressure regulator control valve V_2 which has a second cylinder 14, a movable piston valve 15 within the cylinder 14 and ports 16, 17 and 18 in the cylinder 14. Each of the piston valves has two end lands as shown, one for varying the opening of the inlet ports 12 and 17, and the other for varying the opening of the discharge ports 11 and 16. It is to be noted that the openings of the control valves are normally closed when the piston is in the central position as shown. A pair of output conduits 19 and 20 are each connected between the two lands of one of the piston valves 10 and 15 and an output actuator device which comprises a cylinder 23 and a reciprocating piston 24. The passageways 21 and 22 in each of the piston valves connect each of the other ends thereof to one of the output conduits 19 and 20 as shown.

A push-pull solenoid torque motor 27 in response to an error signal or differential current Δi causes the pilot piston member 4 to be displaced to the left or to the right. A pickoff device 25, such as a linear potentiometer, is connected between the cylinder 23 and the piston 24 and produces a voltage output in accordance with the motion of the piston 24. The output of the pickoff 25 is applied to a summing amplifier 26. The amplifier 26 produces in its output an error signal which is the algebraic sum of an input control signal and the pickoff output. The error signal is then applied to the torque motor 27. The inlet ports 2, 12 and 17 are, of course, connected together to the high pressure side of the fluid source and the discharge ports 3, 11 and 16 are connected together to the low pressure side of the fluid source, thus producing a resultant differential pressure acting through the conduits 19 and 20 and appearing across the land of the piston 24.

The operation of the preferred embodiment will now be considered with respect to an electric control signal which causes the solenoid torque motor to displace a pilot piston member 4 to the left. The valves V_1 and V_2 provide pressure-responsive valve means coupled to the output conduit circuit means for applying fluid there-through at an output pressure varying in accordance with an input control signal. The pilot valve is coupled to the pressure-responsive means for applying the input control signal. As noted above, the pressures in the chambers 5 and 6 are substantially one-half the system pressure when the piston 4 is centrally positioned. The piston valves 10 and 15 at this time are centrally positioned relative to the ports 11, 12, 16 and 17. Since the pressures acting on the bottom lands of the piston valves are equalized through the passageways 21 and 22, the control piston valves 10 and 15 and the output piston 24 are in static condition. The valves V_1 and V_2 include output pressure-feedback means hydraulically coupling the conduit and the pressure-responsive means for controlling the pressure-responsive means to oppose changes in pressure arising from the conduit means. The valve is thereby

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enabled to provide a differential output pressure substantially independent of the fluid-pressure changes in the output conduit and tends to produce an increasing flow of fluid through the output conduit means.

In Fig. 2 there is illustrated a graph of pressure operating on the valves V_1 and V_2 through passageways 7 and 8 versus pilot piston displacement wherein P_1 indicates maximum system pressure and P_0 the minimum system pressure. As shown in Fig. 2, motion of the pilot piston 4 to the left decreases the pressure in chamber 6 acting through passageway 7 on the control piston valve 10 in V_1 , while increasing the pressure in chamber 5 acting through passageway 8 on the control piston valve 15 in V_2 . Since the instantaneous pressures above and below the piston valves are now unequal, the piston valve 15 is depressed while the piston valve 10 is elevated thus providing "push-pull" operation. The term "push-pull" implies that when the motion of one of the control valves is opposite that of the other control valve, the pressure in the output conduit associated with one control valve tends to increase while the pressure in the output conduit associated with the other control valve tends to decrease. Thus, for example, when under the influence of a signal from the pilot valve, the piston valve 10 is urged downwardly and the piston valve 15 is urged upwardly. The pressure in the output conduit 19 increases because of flow from the input pressure port 12 while the pressure in the output conduit 20 decreases because of flow into the exhaust port 16. In this manner both control valves contribute to effecting a differential pressure across the output actuator piston 24. The downward motion of the piston 15 opens the inlet port 17 providing fluid flow under increased pressure through the output port 18 and output conduit 20 to act on the right side as shown of the cylinder land of the piston 24 and direct it to the left. The upward motion of the piston valve 10 opens the discharge port 11 to permit fluid return through the output port 13, output conduit 19, from the left side of the cylinder land of the piston 24 to increase the differential pressure directing the piston 24 to the left. The downward motion of the piston valve 15 continues until the pressure acting on the piston 24 is equal to the pressure acting on the piston 15 from the pilot valve. Inversely, the upward motion of the piston 10 continues until the reduced pressure acting on the piston 24 is equal to the reduced pressure acting on the piston 10 from the pilot valve.

In Fig. 3 the displacement of the output piston 24 is plotted as a function of time for open loop operation (no pickoff connection). The family of curves thus obtained illustrates the acceleration of the piston 24 for various arbitrary error signals (differential currents Δi) and, hence, for various displacements of the pilot valve member 4. The piston 24 accelerates continuously until the respective inlet port 12 or 17 is completely open. It may be seen that the equalizing pressures operating in the control valves V_1 and V_2 enable the apparatus to provide substantially a constant differential pressure between the conduits 19 and 20, producing an increasing flow of fluid in the conduits.

The motion of the piston 24 causes the pickoff 25 to produce a correction voltage which is applied to the summing amplifier 26 to cancel the input control signal, actuating the solenoid torque motor to restore the pilot piston 4 to its central or equilibrium position. Pressure in chamber 7 increases to restore the piston valve 10 to its central position and close the discharge port 11. The pressure in the passageway 8 decreases to restore the piston valve to its central position and close the inlet port 17. The pressures acting on the piston 24 are now equal and opposite so it stops.

Since the fluid flow in the pilot valve is continuous, those surfaces which might engage a foreign particle are continuously being flushed by the motion of the fluid. In the control valves the system pressure acts to free the

control piston valves in the event that a particle becomes lodged between the control piston valves and the cylinder. Since the system pressure is relatively very great, the shearing action of the control piston valve lands against the cylinders is sufficient to clear away a foreign particle which so inadvertently interrupts is operation.

From the above description it will be seen that the present invention greatly enhances the art of hydraulic control. This invention provides a degree of reliability which permits the advantages of hydraulic amplifier devices to be fully realized.

While there has been hereinbefore described what is at present considered a preferred embodiment of the invention, it will be apparent that many and various changes and modifications may be made with respect to the embodiment illustrated, without departing from the spirit of the invention. It will be understood, therefore, that all those changes and modifications as fall fairly within the scope of the present invention, as defined in the appended claims, are to be considered as a part of the present invention.

What is claimed is:

1. A balanced pressure-regulator hydraulic servo valve comprising a source of fluid pressure; a pair of fluid passageways; a pilot valve connected between said passageways and said source for varying the fluid pressure from said source acting through each of said passageways, said valve including a pilot valve member having a center land for varying the opening of an inlet port and two end lands for varying the openings of discharge ports, said ports being normally partially open when said pilot valve member is in a central position; a first control valve having a cylinder, a movable piston valve within said cylinder and ports in said cylinder; a second control valve having a second cylinder, a movable piston valve within said second cylinder and ports in said second cylinder, an end of each of said piston valves being connected to one of said passageways to enable said pilot valve selectively to apply pressures differentially to displace said piston valves; two end lands on each of said piston valves, one for varying the opening of an inlet port and the other for varying the opening of a discharge port, said openings of said control valves being normally closed when said piston valves are in a central position; a pair of output conduits each connected between the end lands of one of said piston valves, said control valves thereby being connected in push-pull relation to said source and said conduits, selectively to control fluid flow therethrough; and a pressure equalizing passageway in each of said piston valves connecting the other end thereof to one of said output conduits for equalizing the pressures tending to displace said piston valves to enable said apparatus to provide substantially a constant differential pressure producing an increasing flow of fluid through said output conduits.

2. A balanced, pressure-regulator, hydraulic servo valve comprising: a source of fluid under pressure; a pair of pressure-regulator valves each having a cylinder, ports in said cylinder, a reciprocating piston-valve within said cylinder having a pair of enlarged, annular, end lands for selectively controlling the opening of an inlet port and a discharge port, said inlet and discharge ports being closed when said piston valves are in a neutral position, said piston valves being adapted to provide an actuator chamber adjacent its actuator end land, a control chamber between said end lands, and a reaction chamber adjacent the other, reaction, end land and communicating with said control chamber; a pair of output conduits connecting said control chambers through output control ports in said cylinder to an output actuating device for reciprocally providing fluid flow therethrough; means connecting said pressure regulator valves in push-pull relation to said source and said output conduits selectively to control the flow of fluid through said output conduit means in response to signal and reaction pressures acting on said pressure-re-

sponsive members; and pilot means coupled to each of said actuator chambers for applying signal pressures differentially to said actuator end land through said actuator chamber, whereby the pressures in said reaction chambers tend to equalize said signal pressures to enable said servo valve to provide substantially a constant differential output pressure tending to produce an increasing flow of fluid through said output conduits.

3. A balanced, pressure-regulator, hydraulic servo valve comprising: a source of fluid under pressure; a pair of pressure-regulator valves having a cylinder, ports in said cylinder, a reciprocating piston-valve within said cylinder having a pair of enlarged, annular, end lands for selectively controlling the opening of an inlet port and a discharge port, said inlet and discharge ports being closed when said piston valves are in a neutral position, said piston valves being adapted to provide an actuator chamber adjacent its actuator end land, a control chamber between said end lands, and a reaction chamber adjacent the other, reaction, end land, and a passageway in said piston-valve connecting said reaction chamber to said control chamber; a pair of output conduits connecting said control chambers through output control ports in said cylinder to an output actuating device for reciprocally providing fluid flow therethrough; means connecting said pressure regulator valves in push-pull relation to said source and said output conduits selectively to control the flow of fluid through said output conduit means in response to signal and reaction pressures acting on said pressure-responsive members; and pilot means coupled to each of said actuator chambers for applying signal pressure differentially to said pressure-responsive members whereby the pressures in said reaction chambers tend to equalize said signal pressures to enable said servo valve to provide substantially a constant differential output pressure tending to produce an increasing flow of fluid through said output conduits.

4. A balanced, pressure-regulator, hydraulic servo valve comprising: a source of fluid under pressure; a pair of fluid passageways; a pair of pressure-regulator means each having a housing and a pressure-responsive, reciprocating member within said housing adapted to provide an actuating chamber, connected to one of said passageways, a control chamber isolated from said actuating chamber and a reaction chamber communicating with said control chamber; a pair of output conduits connecting said control chambers to an output actuating device for reciprocally providing fluid flow therethrough; means connecting said pressure-regulator means in push-pull relation to said source and said output conduits selectively to control the flow of fluid through said output actuator means in response to signal and reaction pressures acting on said pressure-responsive members; and a pilot valve connected between said passageways and said source for selectively varying the fluid under pressure acting through each of said passageways to apply signal pressures differentially to said pressure responsive members, whereby the pressures in said reaction chambers tend to equalize said signal pressures to enable said servo valve to provide substantially a constant differential output pressure tending to produce an increasing flow of fluid through said output conduits, said pilot valve including a pilot piston valve member having a center land for varying the opening of an inlet port and two end lands for varying the openings of discharge ports, said ports being normally partially opened when said pilot piston valve member is in a neutral position.

5. A pressure-regulator, hydraulic servo valve, comprising: a source of fluid under pressure; a pressure-regulator means having a housing and a pressure-responsive, reciprocating member within said housing adapted to provide a control chamber and a reaction chamber communicating with said control chamber; output conduit means for connecting said control chamber to an output actuating device; means connecting said pressure-regulator means to

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said source and said output conduit means for selectively controlling the flow of fluid through said output conduit means in response to signal and reaction pressures acting on said pressure-responsive member; and pilot means coupled to said pressure-regulator means for applying signal pressure to said pressure-responsive member, whereby the pressure in said reaction chamber tends to equalize said signal pressure to enable said valve to provide substantially a constant differential output pressure tending to produce an increasing flow of fluid through said output conduit means.

6. A balanced, pressure-regulator, hydraulic servo valve, comprising: a source of fluid under pressure; a pair of pressure-regulator means each having a housing and a pressure-responsive, reciprocating member within said housing adapted to provide a control chamber and a reaction chamber communicating with said control chamber; output conduit means for connecting said control chambers to an output actuating device; means connecting said pair of pressure-regulator means in push-pull relation to said source and said output conduit means for selectively controlling the flow of fluid through said output conduit means in response to signal and reaction pressures acting on said pressure-responsive members; and pilot means coupled to said pressure-regulator means for applying signal pressures differentially to said pressure-responsive members, whereby the pressures in said reaction chambers tend to equalize said signal pressures to enable said valve to provide substantially a constant differential output pressure tending to produce an increasing flow of fluid through said output conduit means.

7. A pressure-regulator, hydraulic, servo valve adapted to control the application of fluid under pressure in accordance with an input control signal, comprising: output conduit means; pressure-responsive valve means coupled to said output conduit means for applying said fluid therethrough at an output pressure varying in accordance with an input control signal; pilot means coupled to said pressure-responsive means for applying an input control signal; and output pressure-feedback means coupling said conduit and said pressure-responsive means for controlling said pressure-responsive means to oppose changes in pressure arising from said conduit means, thereby enabling said valve to provide a differential output pressure substantially independent of said fluid-pressure changes in said output conduit and tending to produce an increasing flow of fluid through said output conduit means.

8. A pressure-regulator, hydraulic, servo valve adapted to control the application of fluid under pressure in ac-

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cordance with an input control signal, comprising: output conduit means; pressure-responsive valve means coupled to said output conduit means for applying said fluid therethrough at an output pressure varying in accordance with an input control signal; pilot means coupled to said pressure-responsive means for applying an input control signal; and output pressure-feedback means hydraulically coupling said conduit and said pressure-responsive means for controlling said pressure-responsive means to oppose changes in pressure arising from said conduit means, thereby enabling said valve to provide a differential output pressure substantially independent of said fluid-pressure changes in said output conduit and tending to produce an increasing flow of fluid through said output conduit means.

9. A pressure-regulator, hydraulic, servo valve adapted to control the application of fluid under pressure in accordance with an input control signal, comprising: input conduit means for connection to a source of fluid under pressure; output conduit means; pressure-responsive valve means coupled to said output conduit means for applying said fluid therethrough at an output pressure varying in accordance with an input control signal; pilot means coupled to said pressure-responsive means for applying an input control signal; output pressure-feedback means coupling said conduit and said pressure-responsive means for controlling said pressure-responsive means to oppose changes in pressure arising from said conduit means, thereby enabling said valve to provide a differential output pressure substantially independent of said fluid-pressure changes in said output conduit and tending to produce an increasing flow of fluid through said output conduit means; and means coupling said pressure-responsive and said input conduit means together in push-pull relation to provide said output pressure independent of pressure variations arising from said source.

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