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(54) Electro-hydraulic actuator and method for controlling actuator position

(57) A fluid actuator (10) achieves precise placement without external feedback by employing a spool (44) slidable within a piston (20). The relative positions of the piston (20) and the spool (44) determine whether pressurized fluid is applied to extend the piston, to retract the piston, or to maintain the position of the piston. The spool (44) is positioned by balancing a spring (46) force on one end with a variable pressure force on the other end, the variable pressure fluid for providing the variable pressure force being supplied by a pulse width modulation valve (28) which is mounted in the actuator (10). The pressure of the fluid supplied by the modulation valve (28) is a function of an input such as an electrical signal received by the valve. The position of the piston (20) is determined by the position of the spool (44). In an exemplary embodiment, an actuator positions the vanes of a turbocharger of a motor vehicle engine. The pressurized fluid used is the crankcase oil of the engine.

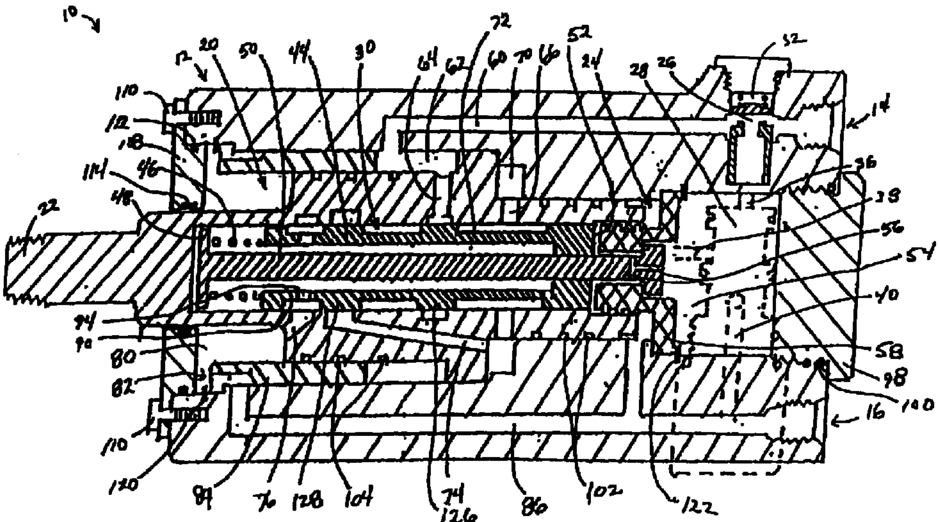

Fig. 1

EP 1 067 293 A2

Description

[0001] The invention relates generally to fluid actuators and, more particularly, to fluid actuators that may be controllably positioned, and to controlling such actuators.

[0002] In many circumstances it is desirable to control movement of a hydraulic actuator over a range of movement, for example by partially extending an actuator and holding it in place. Such partial extension may be accomplished by initiating hydraulic fluid flow to the actuator through a control valve, and by using information from an electronic sensor which senses the actuator position to determine when to shut off flow to the actuator.

[0003] However, electronic sensors are unsuitable for certain environments, such as where the actuator and the control valve will be subjected to high temperatures. Accordingly it will be appreciated that a means of accomplishing such partial actuation without use of electronic sensors would be desirable.

[0004] The present invention provides a fluid actuator including a valve member and a piston cooperatively configured to provide pressurized fluid to the piston to keep the piston in the same position relative to the valve member. That is, the piston may be controllably positioned by positioning the valve member operatively coupled to the piston.

[0005] In a preferred embodiment, a fluid actuator achieves precise positioning without external feedback by employing a spool slidable within a piston. The relative positions of the piston and the spool determine whether pressurized fluid is applied to extend the piston, to retract the piston, or to maintain the position of the piston. The spool is positioned by balancing a spring force on one end with a variable pressure force on the other end, the variable pressure force being provided by a variable pressure fluid preferably supplied by a pulse width modulation valve which is mounted in the actuator. The pressure of the fluid supplied by the modulation valve is a function of an input such as an electrical signal received by the valve. The position of the actuator is determined by the position of the spool.

[0006] In an exemplary application of the invention, the actuator positions the vanes of a turbocharger of a motor vehicle engine and a source of pressurized fluid is obtained from the crankcase oil of the engine.

[0007] According to one aspect of the invention, a fluid actuator includes a housing having a high pressure port and a low pressure port, a piston slidable within the housing, the piston and the housing defining a fluid chamber therebetween, and a valve member within the housing movable relative to the piston. The fluid chamber is in communication with one of the ports when the valve member is in an extended position relative to the piston, and the fluid chamber is in communication with the other port when the valve member is in a retracted position relative to the piston.

[0008] According to another aspect of the invention, a method of positioning a piston of a fluid actuator includes configuring the piston and a valve member for maintaining relative positions of the piston and the valve member, and positioning the valve member.

[0009] According to yet another aspect of the invention, a fluid actuator includes a housing, a piston slidable within the housing, the piston having pairs of piston passages therein, and a spool slidably mounted within the piston. The pairs of piston passages are selectively in communication with each other depending on the relative positions of the spool and the piston.

[0010] To the accomplishment of the foregoing and related ends, the invention comprises the features hereinafter fully described and particularly pointed out in the claims. The following description and the annexed drawings set forth in detail certain illustrative embodiments of the invention. These embodiments are indicative, however, of but a few of the various ways in which the principles of the invention may be employed. Other aims, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the drawings.

[0011] For a better understanding of the invention and to show how the same may be carried into effect reference is now made by way of example to the accompanying drawings in which:

Fig. 1 is a cross-sectional view of a fluid actuator of an embodiment of the present invention with a spool and a piston shown in a null relative configuration, and with the piston retracted;

Fig. 2 is an end view of the actuator of Fig. 1;

Fig. 3 is a plot of output pressure versus duty cycle open portion for a pulse width modulation valve such as that used in the actuator of Fig. 1;

Fig. 4 is a cross-sectional view of the fluid actuator of Fig. 1 with the spool and the piston shown in a relative configuration that provides pressurized fluid to extend the piston;

Fig. 5 is a cross-sectional view of the fluid actuator of Fig. 1 with the spool and the piston shown in a null relative configuration, and with the piston extended; and

Fig. 6 is a cross-sectional view of the fluid actuator of Fig. 1 with the spool and the piston shown in a relative configuration that provides pressurized fluid to retract the piston.

[0012] Referring now in detail to the drawings and initially to Figs. 1 and 2, a pressurized fluid actuator according to an embodiment of the invention is indicated generally at 10. The actuator 10 includes a housing 12 which has a pressure port 14 and a return port 16 for receiving respective high and low pressure lines (not shown). The housing 12 also contains other elements of the fluid actuator 10, most prominently a piston 20 which has a protruding rod end 22, and a control system 24 for selectively providing pressurized fluid for extending or retracting the piston 20. The preferred control system 24 includes a pressure reducing valve 26, a pulse width modulation valve 28, and a valve member subassembly 30.

[0013] The pressure reducing valve 26 provides fluid with substantially constant pressure as an input to the modulation valve 28, while at the same time allowing pressurized fluid to pass therethrough. The pressure reducing valve 26 includes a chamber 32 containing a spring. The chamber 32 is connected to return pressure via a passage (not shown). Such pressure reducing valves are well-known in the art.

[0014] The modulation valve 28 provides a pressure output which is a function of an electrical input. Preferably, the pressure output is a linear function of the electrical input for much or all of the input range. The pulse width modulation valve 28 cycles between being opened for a portion of a duty cycle, and being closed for the remainder of the duty cycle. The duty cycles occur at a rapid rate, for example at a frequency of 100 Hz. The pressure output from the pulse width modulation valve is a function of the amount of each duty cycle for which the valve is in an open configuration. An exemplary plot of output pressure versus duty cycle open portion is shown in Fig. 3. The pressure output plot of the pulse width modulation valve has a linear portion 34 wherein pressure varies linearly with increasing percentages of the duty cycle corresponding to the valve being in an "open" configuration. The response of the modulation valve 28 is largely independent of the viscosity of the fluid, the temperature of the fluid, as well as any contamination in the fluid or sluggishness in the valve. Details of a pulse width modulation valve having the above-described characteristics may be found in U.S-A-4538654, which is incorporated herein by reference in its entirety.

[0015] Pressurized fluid exiting from the pressure reducing valve 26 travels to the pulse width modulation valve 28 via an inlet duct 36 in the housing 12. Variable-pressure output from the pulse width modulation valve 28 exits the valve through an outlet duct 38. Return flow from the modulation valve 28 flows to the return port 16 via a return duct 40.

[0016] The variable-pressure fluid output of the modulation valve 28 is used in positioning a valve member such as a spool 44 which is part of the valve member subassembly 30 and which is within the piston 20. A spring 46 is provided between the spool 44 and an end plate 48 of a stem 50. As illustrated, the spring 46 biases the spool 44 and the stem 50 such that the spool 44 tends to be pushed away from the end plate 48. In positioning the spool 44 the spring force of the spring 46 is opposed by a pressure force acting on an end surface 52 of the spool 44. The pressure for providing this pressure force comes from the modulation valve 28. Fluid exiting the modulation valve 28 via the outlet duct 38 enters a variable pressure chamber 54 within the housing 12. The variable pressure chamber 54 is in communication with the region adjacent to the spool end surface 52 via stem flow passages 56 in the stem 50. Fluid from the region adjacent the spool end surface 52 can be vented to the return port 16 past a cylinder end seal member 58, the cylinder end seal member 58 also serving to keep the stem 50 in position. Thus varying the pressure output of the modulation valve 28 as described above varies the pressure force against the spool end surface 52, thereby varying the position of the spool 44 so that the pressure on the end surface 52 and spring force due to the spring 46 are in balance. Since the pressure output of the modulation valve 28 is a well-known function of an electrical input to the solenoid portion of the modulation valve 28, and since the characteristics of the spring 46 are known, it will be understood that the spool 44 may be reliably positioned relative to the housing 12.

[0017] It will be understood that a variety of known resilient biasing devices may be used in place of the coil spring shown in the illustrated embodiment. It also will be appreciated that the valve member may be other than within the piston, for example being slidable along an outside surface of the piston.

[0018] A housing pressure passage 60 is in communication with both the pressure port 14 and a piston retraction fluid chamber 62 on one side of the piston 20. The piston 20 has piston pressure passages 64 and 66 therein, the passages 64 and 66 respectively in communication with the piston retraction fluid chamber 62 and the piston extension fluid chamber 70. Depending on the relative positions of the piston 20 and the spool 44, the piston pressure passages 64 and 66 may be placed in communication with one another via a pressure flow passage 72 defined between an inner surface of the piston 20 and an outer surface of the spool 44. Placing the piston pressure passages 64 and 66 in communication with one another also places the fluid chambers 62 and 70 in communication with one another, thereby causing pressurized fluid to enter the piston extension fluid chamber 70 as well as the piston retraction fluid chamber 62. Placing pressurized fluid in the fluid chambers 62 and 70 on opposite sides of the piston 20 causes extension of the piston 20, since the surface area of the piston in contact with the piston extension fluid chamber 70 is greater than the surface area of the piston in contact with the piston retraction fluid chamber 62.

[0019] Similarly, the piston has piston return passages 74 and 76 therein. The piston return passage 74 is in communication with the piston extension fluid chamber 70 and the piston return passage 76 is in communication with a return chamber 80 at one end of the bore of the housing 12 which contains the piston 20. The return chamber 80 is in communication with the return port 16 via slots or openings 82 in a floating piston sleeve 84 between the piston 20 and a portion of the housing 12, and via a housing return passage 86 which connects the slots or openings 82 and the return port 16. Depending on the relative positions of the spool 44 and the piston 20, the piston return passages 74 and 76 may be in communication with one another through a return flow passage (groove) 90 defined between the spool 44 and the piston 20. When the piston return passages 74 and 76 are in communication with one another, the piston extension fluid chamber 70 is thereby in communication with the return port 16 of the housing 12. The region between the interior surface of the spool 44 and an outer diameter of the stem 50 is also in communication with the return port 16 via (in part) an annular recess 92 and holes 94 in the spool 44.

[0020] The various regions of the housing 12 are suitably sealed to prevent flow of fluid from one passage to another, as welt as to prevent leakage of flow exterior to the housing 12. To that end, an end cap 98 with a seal 100 prevents external leakage of fluid in the variable pressure chamber 54. Annular grooves 102 prevent excessive leakage of fluid along the sliding surface between the piston 20 and the housing 12. Similarly, annular grooves 104 prevent excessive internal leakage of fluid from the piston retraction fluid chamber 62 to the return chamber 80 along the sliding surface between the piston 20 and the floating sleeve 84. Where the protruding end 22 of the piston 20 protrudes from the housing 12, there is an end cover 108 attached to the housing by fasteners such as bolts 110, with a static seal 112 between the end cap 108 and the housing 12. In addition, there is a dynamic seal such as an O-ring seal 114 between the end cap 108 and the piston 12.

[0021] The O-ring seal 114 is the only dynamic seal in the illustrated pressurized fluid actuator 10. This seal is a low pressure seal in that it prevents leakage from the return chamber 80, the return chamber 80 being maintained at the return pressure of the hydraulic system. That the only dynamic seal of the actuator 10 is subjected only low pressure is beneficial in that high temperature conditions that the actuator may encounter make sealing more difficult, and this difficulty is compounded by increasing the pressure difference across the seal.

[0022] The floating sleeve 84 is held in place by a sleeve snap ring 120, and the cylinder end seal member 58 is held in place by an end seal snap ring 122.

[0023] In Fig. 1, the actuator 10 is shown in a fully retracted null position. That is, the piston 20 is fully retracted within the housing 12 and the spool 44 is positioned relative to the piston 20 such that the piston pressure passage 64 and the piston return passage 74 are blocked by respective covers or lands 126 and 128 which are part of the spool 44.

[0024] Figs. 4-6 illustrate operation of the actuator 10 to extend and retract the piston 20. In Fig. 4 an input signal has been sent to the modulation valve 28 to increase the pressure output through the outlet duct 38 of the modulation valve 28. This increase in pressure causes an increased force against the end surface 52 of the spool 44 thereby causing the spool 44 to move leftward as shown in Fig. 4 against the force exerted by the spring 46. This leftward motion of the spool 44 relative to the piston 20 causes the piston fluid chambers 62 and 70 to be in communication with one another via the piston pressure passages 64 and 66 and the pressure flow passage 72. Since the fluid in the extension fluid chamber 70 acts on a greater area of the piston 20 than does the fluid in the retraction fluid chamber 62, the net force acting on the piston 20 causes the piston to extend.

[0025] This extension of the piston continues until the piston 20 and the spool 44 are in the same relative position to one another that they were in Fig. 1 (the null position). Once the null position is again reached, the piston extension fluid chamber 70 is no longer in communication with the pressure port 14 because the cover 126 covers the piston pressure passage 64. This restored null position with the piston extended is illustrated in Fig. 5. Since the pressure port 14 is no longer in communication with the piston extension fluid chamber 70, there is no longer a net force on the piston 20 to cause further extension. However, since the covers 126 and 128 block fluid from entering or leaving the piston extension fluid chamber 70, the piston 20 is maintained at its extended position as long as the same pressure is exerted against the end surface 52 of the spool 44.

[0026] Fig. 6 illustrates a relative configuration of the piston 20 and the spool 44 that results in retraction of the piston 20. Compared to the configuration of Fig. 5, the position of the spool 44 has been changed by reducing the pressure against the end surface 52. This is done by sending a signal to the pulse width modulation valve 28 to reduce the percentage of the duty cycle for which the modulation valve 28 is open. Reduction of pressure against the end surface 52 causes the spool 44 to move away from the end plate 48 of the stem 50, this movement being rightward as shown in Fig. 6. This movement puts the piston return flow passages 74 and 76 in communication with one another via the return flow passage 90. This in turn causes the piston extension fluid chamber 70 to be in communication with the return port 16, which is at a relatively low return pressure. This reduction of pressure in the piston extension fluid chamber 70 causes an imbalance in the forces on the piston 20, thereby resulting in retraction of the piston 20. This retraction continues until the null relative positions of the piston 20 and the spool 44 are reached. For the fully rightward located spool shown in Fig. 6, this null condition would be the fully retracted piston configuration shown in Fig. 1.

[0027] It will be appreciated that the above actuator may be utilized to position the protruding rod end 22 of the piston 20 over a full range of positions from fully retracted to fully extended by controlling the pressure output by the modulation valve 28. There is a one-to-one correspondence between the position of the spool 44 and the position of the piston 20, movement of the spool 44 causing a corresponding movement of the piston 20 to re-establish the null condition. By controlling the position of the spool 44, position of the piston 20 may be precisely controlled.

[0028] It will be appreciated that there is hysteresis in the actuator 10 to the degree that the covers 126 and 128 are larger than their corresponding piston passages 64 and 74.

[0029] The main parts of the fluid actuator may be made of steel. Alternatively, the main parts may be made of other rigid materials suitable for the invention.

[0030] Preferably, a liquid is used as the pressurized fluid in the actuator. In an exemplary embodiment, the actuator is used for positioning the vanes of a turbocharger for a motor vehicle engine, and lubricating oil from the engine's crankcase is the source of pressurized fluid for moving the spool and the piston. The pressure reducing valve provides constant pressure for the pressure inlet to the modulating valve, compensating for fluctuations in the inlet pressure from the lubricating system. It will be appreciated that other pressurized systems may be employed to deliver pressurized fluid to the actuator.

[0031] It will further be appreciated that alternatives to the modulation valve may be used to deliver variable, controlled pressure to one side of the spool. The means for providing the variable, controlled pressure may be part of the actuator, or alternatively may be separate from the actuator, with suitable connections for transmitting the variable pressure fluid to the actuator. For example, the variable pressure fluid may be provided by a variable pressure pump.

[0032] Moreover, it will be understood that alternative means may be provided for positioning the spool, in response to an input signal. For example, the spool may be coupled to an armature which is positioned using force from a variable current solenoid valve, the current being selected so as to properly and accurately position the spool. Alternatively, the spool may be positioned by any of a variety of mechanical positioning mechanisms, for example by a system of gears coupled to the spool, the gears being moved by a mechanical linkage to vary the position of the spool.

[0033] The fluid actuator described above has the advantage of utilizing the full force of the pressurized fluid from the pressure port to move the piston. The reduced pressure output by the modulation valve is used to position the spool, and not for the force for moving the piston of the actuator. Thus the actuator is better able to overcome any external forces opposing movement of the piston.

[0034] From the above it will be understood that the actuator requires no sensor or other external feedback mechanism for detecting the position of the actuator in order to determine whether more high-pressure flow should be applied to extend the actuator, for example.

[0035] It will be appreciated that a non-linear pulse width modulation valve may alternatively be used, and any non-linearity in the modulation valve may be compensated for with electronics providing an input signal to the non-linear valve.

[0036] Although the invention has been shown and described with respect to a certain preferred embodiment or embodiments, equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described elements (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such elements are intended to correspond, unless otherwise indicated, to any element which performs the specified function of the described element (*i.e.*, that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one or more of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

Claims

1. A fluid actuator comprising:

> a housing having a high pressure port and a low pressure port;
> a piston slidable within the housing with a fluid chamber adjacent to the piston; and
> a valve member within the housing movable relative to the piston;
> wherein the fluid chamber is in communication with one of the ports when the valve member is in an extended position relative to the piston, and wherein the fluid chamber is in communication with the other port when the valve member is in a retracted position relative to the piston.

2. The actuator of claim 1, wherein the fluid chamber is not in communication with either of the ports when the valve member is in a null position relative to the piston, the null position being between the extended position and the retracted position.

3. The actuator of claim 1 or 2, wherein the piston has a bore and the valve member is a spool is slidably mounted within the bore.

4. The actuator of claim 3, wherein the piston and the spool define flow passages therebetween and movement of the spool relative to the piston selectively allows communication between the flow passages and the fluid chamber.

5. The actuator of any one of the preceding claims, further comprising a positioning mechanism for positioning the valve member.

6. The actuator of any one of the preceding claims, further comprising a spring coupled to the valve member and a variable pressure supply device, the spring and variable pressure fluid from the pressure supply device cooperating to position the valve member.

7. The actuator of claim 6, wherein the variable pressure supply device includes a pulse width modulation valve mounted in the housing.

8. The actuator of claim 6 or 7, further comprising a pressure reducing valve operatively coupled to the high pressure port and to the variable pressure supply device.

9. The actuator of claim 6, 7 or 8, further comprising a stem coupled to the spring and slidably mounted within the valve member.

10. The actuator of any one of the preceding claims, wherein a flow path for communication between the high pressure port and the fluid chamber includes another fluid chamber between the housing and the piston, the fluid chambers on opposite sides of the piston.

11. The actuator of any one of the preceding claims, further comprising a dynamic external seal between the piston and the housing which prevents external venting of fluid from a return chamber in communication with the low pressure port.

12. A method of positioning a piston of a fluid actuator, comprising:

configuring the piston and a valve member within a housing for maintaining relative positions of the piston and the valve member; and
positioning the valve member.

13. The method of claim 12, wherein the maintaining includes placing a fluid chamber adjacent to one end of the piston in communication with one of a pair of sources of pressurized fluid when the piston and the valve member are not in a null relative position, the sources having different pressures.

14. The method of claim 12 or 13, wherein the positioning includes providing a variable pressure fluid to one end of the valve member.

15. The method of claim 14, wherein the providing includes sending an input signal to a pulse width modulation valve to control pressure of the variable pressure fluid.

16. The method of claim 14 or 15, wherein the positioning further includes passing the variable pressure fluid through flow passages in a valve member.

17. A fluid actuator comprising:

a housing;
a piston slidable within the housing, the piston having pairs of piston passages therein; and
a spool slidably mounted within the piston;
wherein the piston passages of each of the pairs of piston passages are selectively in communication with each other depending on the relative positions of the spool and the piston.

18. The actuator of claim 17, wherein the spool and the piston define flow passages therebetween for selectively putting the pairs of piston passages are in communication with each other.

19. The actuator of claim 17 or 18, wherein the spool is slidable relative to a stem, and further comprising a spring between the spool and the stem.

20. The actuator of claim 19, wherein the stem has stem flow passages therein for allowing pressurized fluid to pass therethrough.

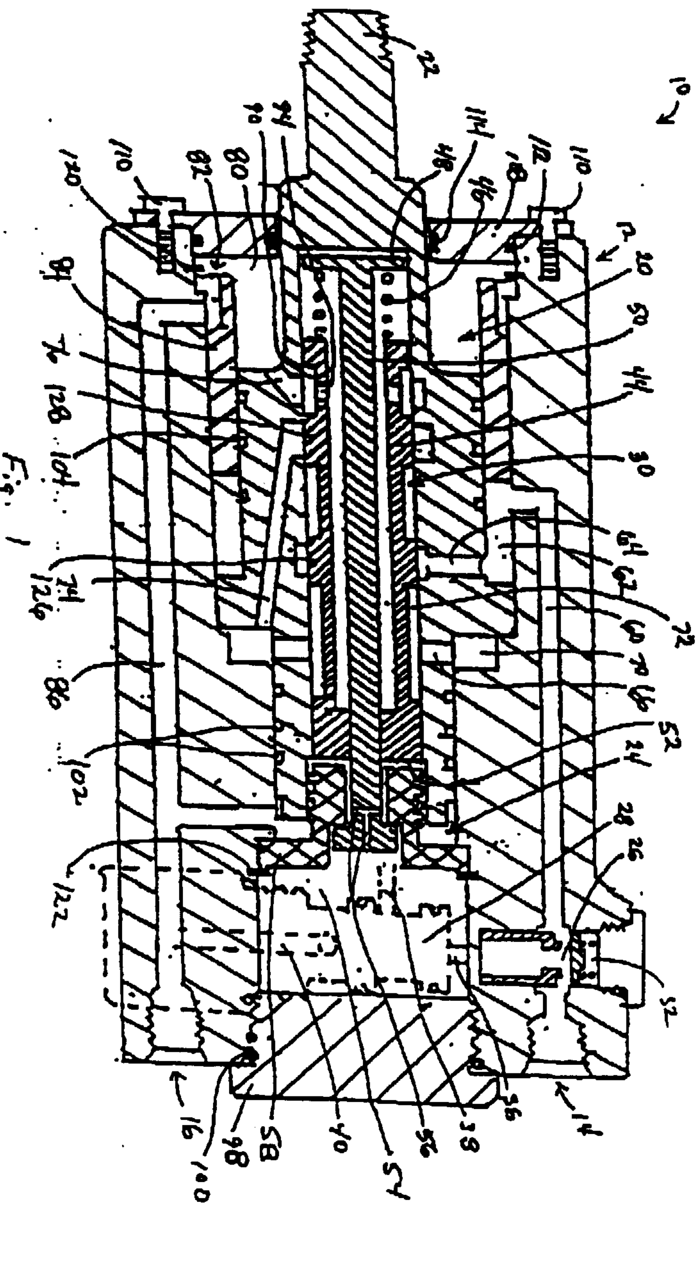

Fig. 1

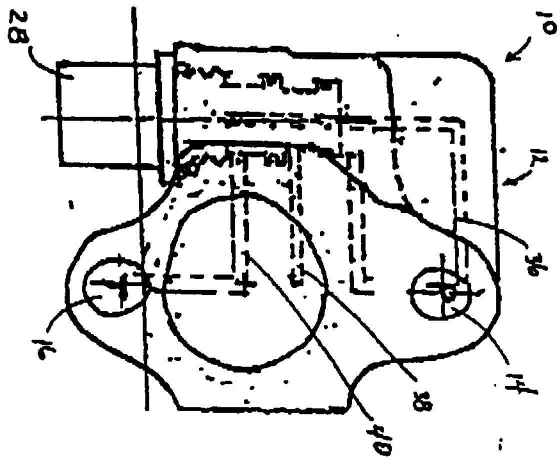

Fig. 2

PWM -VARIABLE PRESSURE
SOLENOID CARTRIDGE
PILOT VALVE

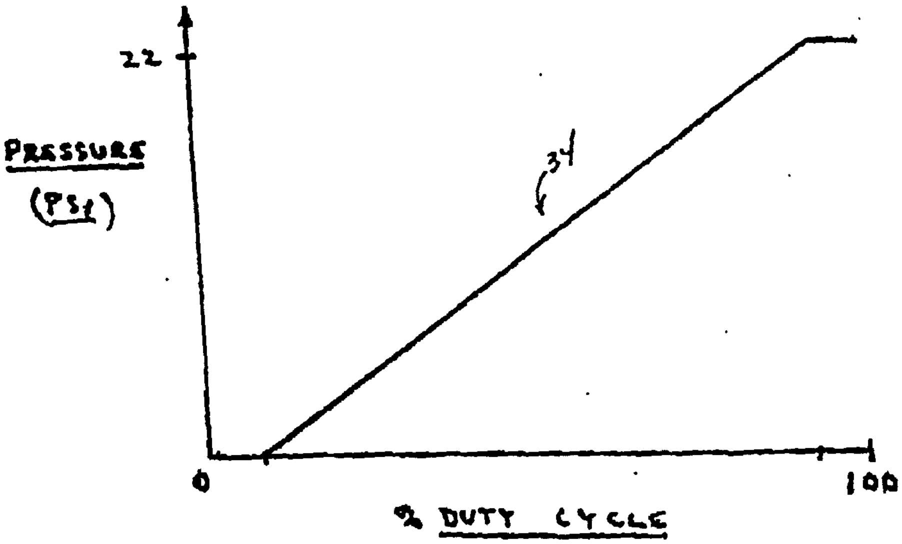

Fig. 3

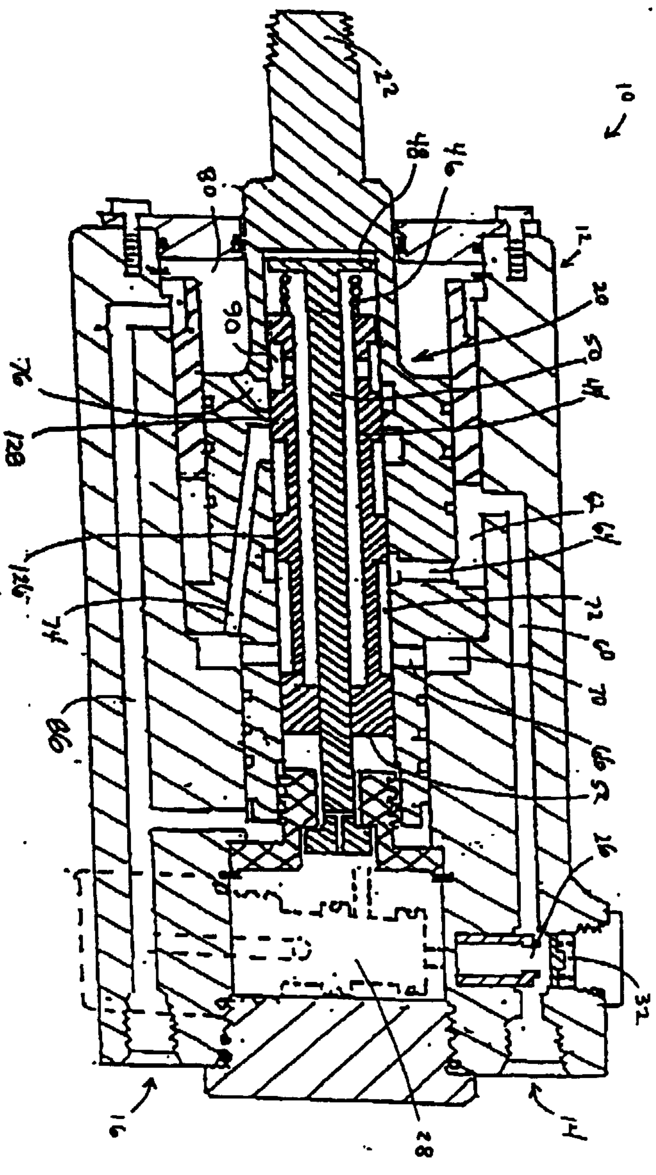

Fig. 4

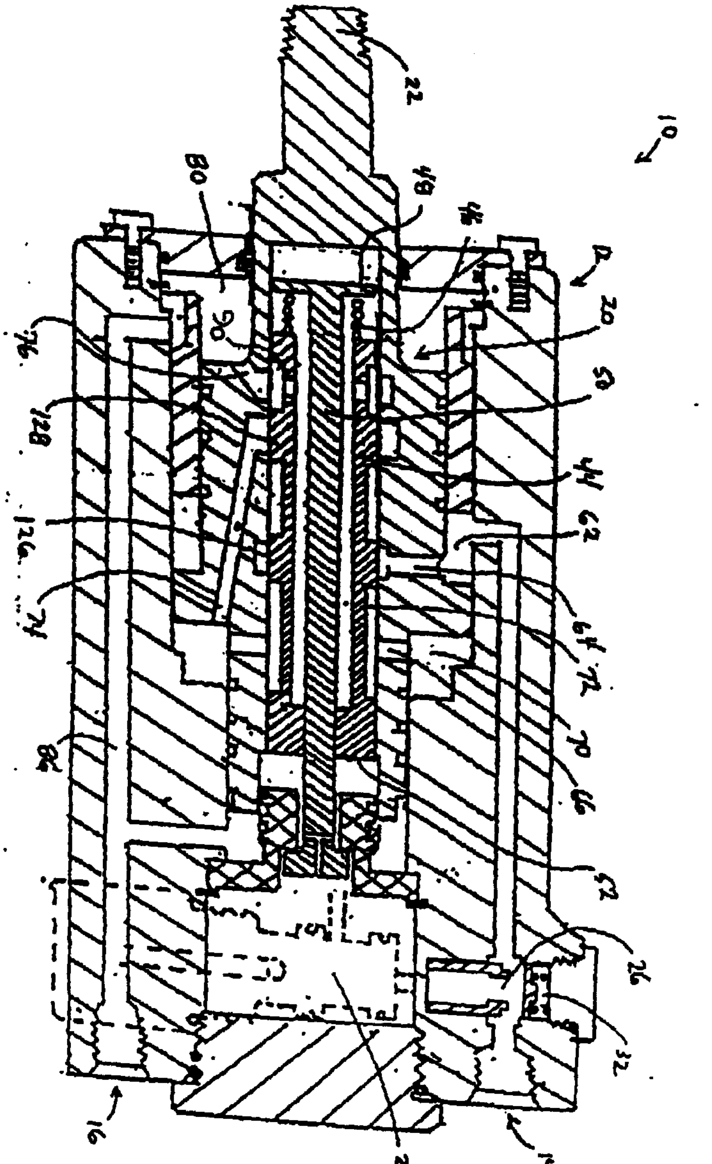

Fig. 5

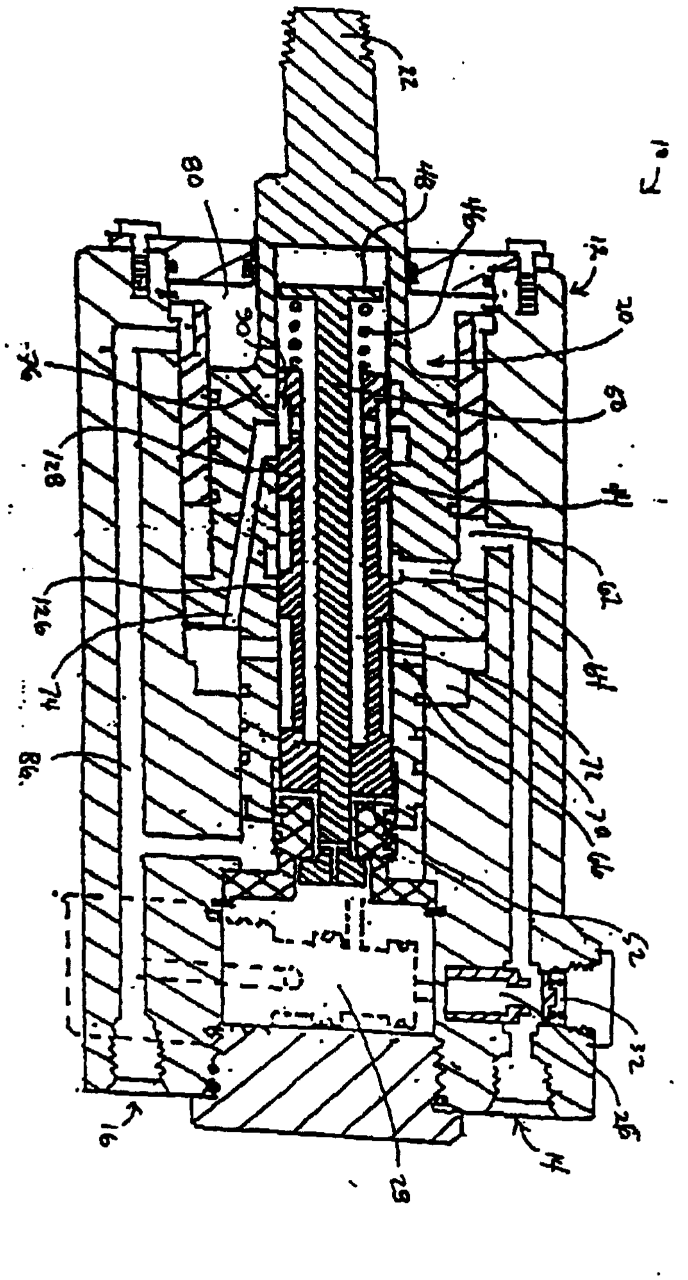
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Fig. 6