Aug. 18, 1953 H. W. AVERY 2,649,107

HYDRAULIC VALVE SYSTEM

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Fig. 1.

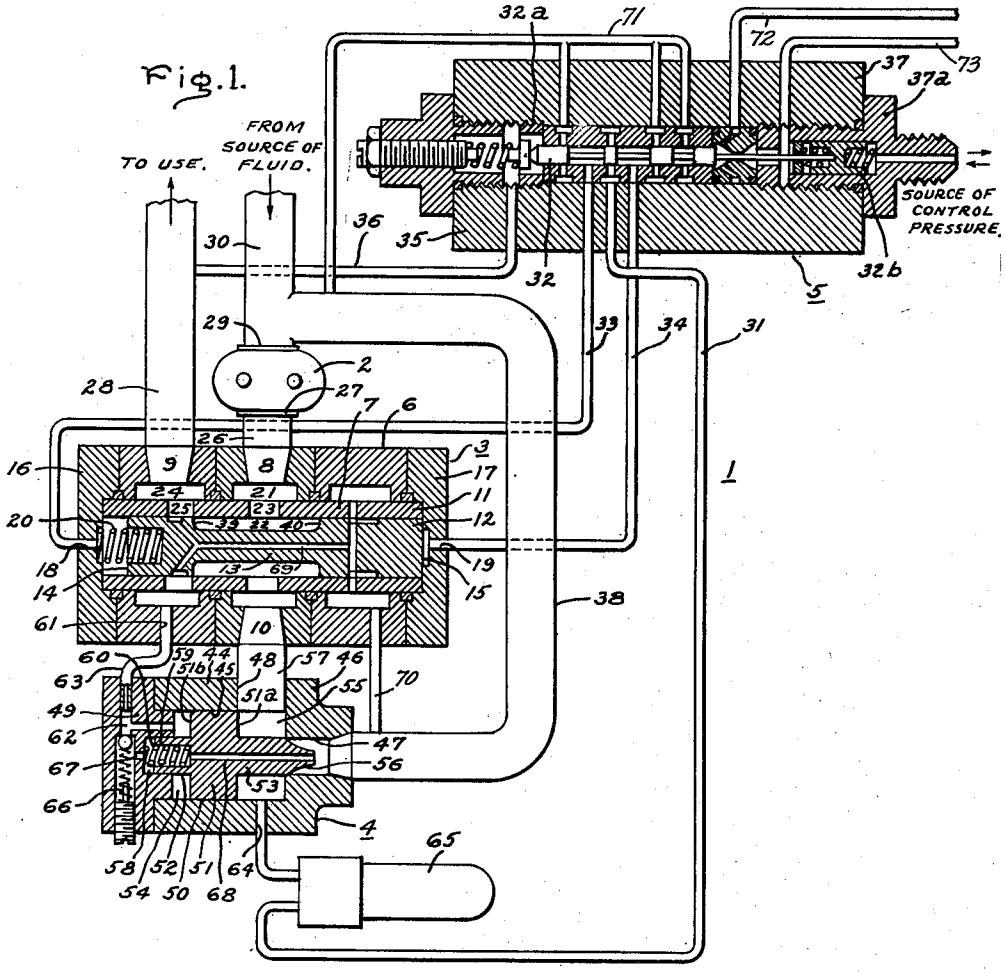
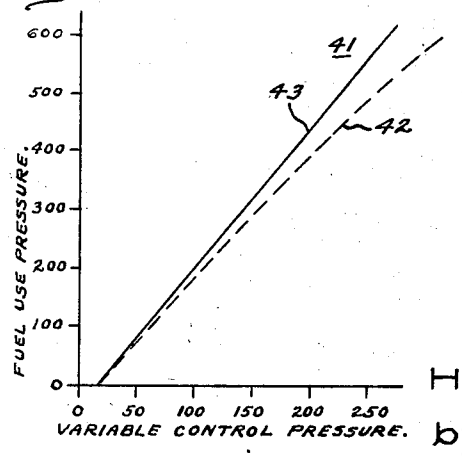



Fig. 2.




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## HYDRAULIC VALVE SYSTEM

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This invention relates to hydraulic valves and has for its object the provision of a system of cooperatively arranged hydraulic valves in which the fluid pressure drop of a throttle valve thereof is maintained substantially constant.

Another object is to provide a hydraulic control valve system to control the value of fluid pressure applied to a use from a fixed displacement type pump through a pressure drop throttle valve while maintaining a substantially constant pressure drop in the valve.

A further object is to provide means for maintaining a substantially constant pressure drop in a pressure drop throttle valve for variable fluid flow and fluid pressure in the valve.

In general, my invention comprises a pressure drop throttle valve, connections for connecting the throttle valve to a fixed displacement type pump and to a use to supply fluid under pressure to the use from the pump, means for actuating the throttle valve to control the fluid pressure to the use and means connected to the throttle valve and the actuating means to maintain a substantially constant pressure drop in the throttle valve under conditions of variable flow and fluid pressures.

For a complete understanding of my invention reference should be had to the following specification and the accompanying drawing in which Fig. 1 is a cross-sectional view of a hydraulic valve system illustrative of my invention and applied to a fixed displacement pump; Fig. 2 is a chart used to explain the operation and advantages of my invention.

The invention and apparatus to be disclosed herein is primarily intended for use in fuel service to aircraft gas turbines and will therefore be described with particular reference thereto with the understanding that the principles and advantages involved are applicable to other applications wherein a predetermined schedule of pump output pressure dependent upon a controlling pressure or force is desired.

Those skilled in the art will understand that fuel service to a jet engine of the gas turbine type can be provided by a variable displacement pump which has its delivery controlled by a fuel regulator responsive to the pilot's throttle position, local conditions and the ability of the turbine to satisfy the requirements of demand under the assumed conditions.

Although the above system operates satisfactorily, the variable delivery fuel pump is complicated, expensive and difficult to efficiently winterize for low ambient operating temperatures.

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A fixed displacement pump, on the other hand, is relatively simple in structure, inexpensive to manufacture and is unaffected by low ambient temperatures of the nature encountered in fuel service. However, the fixed displacement pump requires a separate means to regulate the amount of fuel delivered by the pump to the particular use.

In appreciation of the advantages to be obtained by the use of the fixed displacement type pump, attempts have been made to control the fluid delivery thereof by controllably bypassing a portion of the delivered fluid under the control of a throttle valve. However, this means for controlling the delivery from a fixed displacement pump to a use has not been satisfactory because, in accordance with Bernoulli's law, a variable pressure drop, dependent upon the rate of flow of fluid through the throttle valve to the use, results. Moreover, this variable pressure drop introduces a variable valve reactive force, as will be described in detail later, and for which compensation must be made in a regulator arranged to operate the throttle valve. The regulator is also burdened with a variable dependent upon the altitude of the airplane in which the jet engine is operating and difficulty is experienced in providing regulation with respect to the two variables.

Therefore, in accordance with my invention, I provide a hydraulic control valve system for a fixed displacement pump to regulate the amount of fluid delivered by the pump to the particular use without introducing a throttle valve pressure drop variable.

For example, referring to the drawing, in Fig. 1 thereof, I have shown in cross sectional view a hydraulic control valve system 1 illustrative of my invention and applied to a fixed displacement pump 2. The hydraulic control valve system comprises a pressure drop throttle valve 3, a bypass valve 4 and a pilot valve type actuating means 5 for the throttle valve 3. The throttle valve 3 comprises a housing 6 having a hollow cylindrical interior 7 and a plurality of spaced recesses extending from the outer periphery of the housing 6 in the direction of the hollow interior 7 thereof and forming an inlet passageway 8, a discharge passageway 9 and a return passageway 10. Throttle valve 3 comprises, in addition, a cylindrically spaced valve sleeve 11 having a hollow cylindrical interior 12, a cylindrically spaced valve element 13 having opposite ends 14 and 15 and slidably positioned in the valve sleeve 11. The throttle valve 3 comprises in further addition opposite housing ends 16 and

17 apertured respectively at 18 and 19 and spring means 20 arranged to engage the housing end 16 and the end 14 of the valve element 13 to bias the valve element 13 to closed position.

To provide for the passage of fluid from the inlet passageway 8 to the return passageway 10, cooperatively spaced annular grooves 21 and 22 are formed respectively in the housing 6 and the valve element 13 and a plurality of apertures 23 aligned with the grooves 21 and 22 are formed in the valve sleeve 11. To provide for the passage of fluid from the inlet passageway 8 to the discharge passageway 9 in quantity controlled by the valve element 13, an annular groove 24 communicating with the discharge passageway 9 is formed in the housing 6, and a plurality of apertures 25 in spaced relation to the annular groove 22 in the valve element 13 and communicating with the annular groove 24 of the housing 6 are formed in the valve sleeve 11. Thus, when the valve element 13 is in closed position, as shown in Fig. 1, apertures 25 and groove 22 are not aligned and therefore communication between passageways 8 and 9 is interrupted by the valve element 13. However, as the valve element 13 is moved to the left by means to be explained in detail later, the area of apertures 25 uncovered by the valve 13 and aligned with the groove 22 increases, thereby increasing the flow of fluid from inlet passageway 8 to discharge passageway 9. To control the delivery of fluid from the pump 2 to a use indicated, the inlet passageway 8 of the throttle valve 3 is connected by a tube 26 or other suitable means to a discharge side 27 of the pump 2 and the discharge passageway 9 of the throttle valve 3 is connected by a tube 28 or other suitable means to the use indicated. Fluid is supplied to an intake side 29 of the pump 2 through a tube 30 or other suitable means connected thereto.

To control the operation of the valve 3 to maintain the desired fluid pressure in the tube 28 dependent upon a separate actuating force means such as a fluid pressure regulator indicated, any suitable actuating means may be used. In the preferred embodiment of my invention, shown in Fig. 1, I provide the pilot valve 5. Pilot valve 5 is supplied with fluid under pressure from a supply line 31 connected through the bypass valve 4 to the return passageway 10 of the throttle valve 3 as will be described in detail later. The pilot valve 5 is provided with a slidable spring biased valve element 32 arranged to control the passage of fluid under pressure from the supply line 31 to one or the other of two delivery lines 33 and 34 connected respectively to the housing ends 16 and 17 to apply fluid under pressure through the apertures 18 and 19 thereof to the ends 14 and 15 of the valve element 13 and thereby control the operation of throttle valve 3 in response to operation of the pilot valve 5.

One end 35 of the pilot valve 5 is connected to the discharge passageway 9 of the throttle valve 3 through the discharge tube 28 and a control tube 36. The other end 37 of the pilot valve 5 is provided with an apertured coupling 37*a* to connect the pilot valve 5 to a source of control pressure indicated, such for example as a fluid pressure regulator, to admit fluid under pressure to the pilot valve 5 from the source of control pressure. Pilot valve 5 is operated in response to a first pressure differential established between the fluid pressure of the discharge passageway 9 applied to end 32*a* of the valve element 32 and the control pressure acting on an end 32*b* of the valve element 32. The valve element 13 of the throttle valve 3 is operated in response to the operation of the pilot valve 5 to maintain a fluid pressure in discharge passageway 9 dependent upon the control pressure applied to the pilot valve 5. Thus, the pilot valve 5 is operable in response to control pressure applied thereto to pass fluid under pressure to the right end 15 of the valve element 13 of the throttle 3. The valve element 13 is thereby moved to the left until a sufficient amount of fluid is being delivered to the discharge passageway 9 to raise the fluid pressure therein to a value sufficient to satisfy the desired ratio of control pressure to use pressure. At this particular position of the valve element 13 the first pressure differential becomes 0 and the pilot valve returns to the off position shown in Fig. 1. The throttle valve element 13 remains in the particular position mentioned to continue to the discharge passageway 9 a rate of fluid flow necessary to maintain the desired fluid pressure in discharge passageway 9. When control pressure is removed from the pilot valve 5, its valve element 32 is moved to the right by fluid pressure from passageway 9 of the throttle valve 3 and fluid under pressure is admitted through line 33 to the left hand end 14 of the throttle valve element 13 to close the throttle valve 3.

Thus the throttle valve 3 is operable to control the delivery of fluid from the fixed displacement pump 2 through the discharge passageway 9 of the throttle valve 3 to the use indicated. Assume for the moment that the remainder of the fluid delivered by the pump 2 and not required to maintain the desired fluid pressure in passageway 9, is returned to the intake side 29 of the pump 2 through a return tube 38 provided with a simple relief valve (not shown). In this case, a variable pressure drop results between fluid pressure in the inlet passageway 8 and discharge passageway 9 of the throttle valve 3 dependent upon the velocity of fluid flow through the apertures 25. Moreover, the fluid pressure drop above described is indicative of the reaction force acting on the valve element 13. That is, reaction forces on valve element 13 result in accordance with Bernoulli's law from the unequal velocity of fluid across opposite surfaces 39 and 40 of the groove 22, the greater velocity of fluid across the surface 39 diminishing the fluid pressure thereon as compared to the fluid pressure on surface 40. Thus, a variable reaction force tending to move the valve element 13 to the right is created. The effect of the variable reaction force acting upon the throttle valve element 13 is illustrated by the chart 41 shown in Fig. 2. In the chart 41 fuel use pressure, that is, the fuel pressure in discharge passageway 9 of throttle valve 3, is plotted against variable control pressure applied to the pilot valve 5 from the control pressure source indicated. Two curves numbered 42 and 43 are shown in the chart 41. The dotted curve 42 is typical of the nonlinear relationship of control and use pressures resulting from variable reactive forces caused by a variable pressure drop in the throttle valve 3. To operate under the condition of variable reactive force, compensation must be made in the control pressure through a compensated control pressure regulator (not shown). However, if a linear relation of fuel use pressure to variable control pressure, as indicated by curve 43 of chart 41, could be obtained, regulator compensation would not be required. Since the non-linear relation of con-

trol pressure to fuel use pressure is due to variation of reactive force, the elimination of such variation in reactive force is required to produce the desired linear relation shown in curve 43. To eliminate variation in reactive force, the fluid velocity across surface 39 must be made constant. However, the velocity of fluid across surface 39 is readily indicated by the pressure drop through the apertures 25, that is, the pressure drop between fluid pressures in the inlet passageway 8 and the discharge passageway 9. Thus, if means can be provided to maintain a constant pressure drop in the throttle valve 3 between the passageways 8 and 9 thereof, a constant reaction force results on the valve elements 13 and the relation of variable control pressure to fuel use pressure is made linear.

In accordance with my invention, I provide such a means in the form of the bypass valve 4. Valve 4 comprises a hollow housing 44 having a cylindrically shaped interior surface 45, a housing end 46 having a cylindrically spaced discharge aperture 47 centrally disposed therein and of smaller diameter than the diameter of the cylindrical surface 45 of the housing 44, an inlet passageway 48 communicating with the interior of the housing 44 and adjacent the end 46 thereof, and an opposite closed end 49. A valve element 50 having a cylindrically shaped body portion 51 and opposite ends 52 and 53 of reduced diameter is slidably positioned in the interior of the housing 44. The diameter of the body portion 51 of the valve element 50 is slightly less than the diameter of the interior surface 45 of the housing 44 to permit the surface 45 to form a guide for the valve element 50. The width of the body portion 51 is considerably less than the length of the interior of the housing 44 to allow the valve element 50 to divide the interior of the housing 44 into a closing pressure chamber 54 adjacent housing end 49 and an opening pressure chamber 55 adjacent housing end 46.

The end 53 of the valve element 50 which is aligned with the aperture 47 of the housing end 46, has a diameter slightly larger than the diameter of the aperture 47 of the housing end 46 and is tapered at its extremity as at 56 to provide for the control of fluid passing through the bypass valve 4 from the inlet passageway 48 to the discharge aperture 47 in response to the operation of the valve element 50. The bypass valve 4 is connected between the intake side 29 of the pump 2 and the return passageway 10 of the throttle valve 3 by the return tube 38 and a coupling tube 57, as shown in Fig. 1, to control the quantity of fluid bypassed from the discharge passageway 9 of the throttle valve 3 through the return passageway 10 thereof to the intake side 29 of the pump 2.

A recess 58 is formed in the housing end 49 of the bypass valve 4 to slidably accommodate the projecting end 52 of the valve element 50. The projecting end 52 of the valve element 50 is also recessed at 59 to accommodate a compression spring 60 engaging the housing end 49 and the valve element 50 to bias the valve element closed. A control passageway 61 is formed in the housing 6 of the throttle valve 3 to provide communication between the annular groove 24 of the throttle valve 3 and the exterior of the housing 6. A control passageway 62 is formed in the end 49 of the housing 44 of the bypass valve 4 to provide communication between the pressure closing chamber 54 and the exterior of the bypass valve 4. The passageways 61 of the throttle valve 3 and 62 of the bypass valve 4 are connected by a tube 63 to provide communication between the discharge passageway 9 of the throttle valve 3 and the closing pressure chamber 54 of the bypass valve 4.

In operation the pilot valve 5 is operated in response to a first pressure differential derived from fluid pressure in the discharge passageway 9 and fluid pressure from a control pressure source indicated. The pilot valve 5 in turn operates the valve element 13 of the throttle valve 3 to establish and maintain a desired fluid pressure in the discharge passageway 9. The valve element 50 of the bypass valve 4 is operated in response to a second pressure differential established in its pressure chambers 54 and 55. The second pressure differential is obtained from the difference in fluid pressure in the intake passageway 8 and the discharge passageway 9 of the throttle valve 3 and applied to the valve element 50 of the bypass valve 4 through the medium of the pressure chambers 54 and 55 to maintain a predetermined substantially constant pressure drop in the throttle valve 3. For example, when the valve element 13 of the throttle valve 3 is moved to the left by operation of the pilot valve 5 a pressure drop is established through the apertures 25 of the throttle valve 3 and evidenced by the difference in fluid pressures in the passageways 8 and 9. The difference in fluid pressures in passageways 8 and 9 I have called a second pressure differential to distinguish it from the first pressure differential obtained from the fluid pressure of passageway 9 and the fluid pressure from the separate control pressure source indicated.

The second pressure differential is applied to the valve element 50 of the bypass valve 4 to actuate the same in response to the value and direction of the pressure differential. That is, fluid under pressure in inlet passageway 8 of the throttle valve 3, passed through the annular groove 21 and return passageway 10 of the throttle valve 3 and through the coupling tube 57 to the pressure chamber 55 of the bypass valve 4 to act on a surface 51A of the valve element 50 to bias the valve element 50 of the bypass valve 4 to open position. Fluid under pressure in discharge passageway 9 is transmitted through annular groove 24 and control passageway 61 of the throttle valve 3, control tube 63, and control passageway 62 of the bypass valve 4 to the pressure chamber 54 of bypass valve 4 to act upon a surface 51B of the valve element 50 to aid the spring 60 in biasing the bypass valve 4 closed. Thus the valve means 50 of the bypass valve 4 is responsive to the second pressure differential to control the amount of fluid bypassed from the discharge side 27 of the pump 2 to the intake side 29 thereof. That is, neglecting reaction force in the bypass valve 4, which force is negligible, if the pressure drop in the throttle valve 3 is equal to the translated force of the closing spring 60 operating on the valve element 50 of the bypass valve 4, no change in position of the valve element 50 is effected. However, if the second pressure differential is greater than the force of the spring 60, that is, if the pressure in the opening pressure chamber 55 of the bypass valve 4 corresponding to the pressure in passageway 8 of the throttle valve 3 is sufficiently greater than the fluid pressure in the closing pressure chamber 54 corresponding to the fluid pressure in the discharge passageway 9 to overcome the closing pressure of the spring 60, the valve element 50 is moved to the

left to allow more fluid to be bypassed from the discharge passageway 9. When fluid is thus diverted from the discharge passageway 9 the fluid pressure in passageway 9 is lowered and the pilot valve 5 is actuated to move the valve element 13 of the throttle valve 3 to the left. Thus, the rate of flow of fluid to the passageway 9 is maintained to maintain the desired fluid pressure therein. However, the area of apertures 25 uncovered for the passage of fluid is increased to maintain a desired substantially constant pressure drop. Where the pressure drop is too low, the valve element 50 of the bypass element 4 is closed by the spring 60 to increase the supply of fluid to the discharge passageway 9. Fluid pressure in passageway 9 tends to rise. Pilot valve 5 is operated by the rise in fluid pressure in passageway 9 to move the throttle valve element 13 to the right, thereby increasing the pressure drop through the apertures 25 to maintain a substantially constant pressure drop in the throttle valve 3.

Therefore, in accordance with my invention, I have provided a hydraulic valve system in which the fluid pressure drop of a throttle valve, used to control the delivery of a fixed displacement pump to a use, is maintained substantially constant to eliminate a variable reactive force in the throttle valve which force is productive of undesirable operating conditions.

The supply line 31 connected to the pilot valve 5 is supplied with fluid under pressure by connecting the line 31 through an aperture 64 in the bypass valve 4 to the opening pressure chamber 55. If desired, a filter 65 is inserted in the line 31 to avoid clogging of the pilot valve 5.

An adjustable relief valve 66 is positioned in the bypassed valve housing end 49 to provide communication between the passageway 62 and aligned passageways 67 and 68 formed in the housing end 49 and valve element 50 to permit the exhaust of fluid under pressure from the discharge passageway 9 to the inlet side of the pump 2 in the event that such pressure should reach a predetermined undesirably high value likely to destroy the pump 2.

At times it may be desirable to stop all fluid flow through the outlet tube 28 by employment of such means as a stop cock (not shown) while continuing to maintain the pump 2 in operation and in readiness for resumption of delivery of fluid through the tube 28. Under such conditions an unusually high pressure may develop within the tube 28 due to leakage of fluid past the valve element 13 even though the throttle valve may be closed. In order to relieve this pressure a small central aperture 69 is provided through the center of valve element 13 which connects through suitable valve ports and a drain line 70 with the low pressure return tube 38. Pressure relieving drain lines 71, 72, and 73 are also provided for the pilot valve 5 in order to prevent unwanted pressure buildups within the valve bore which would otherwise interfere with the operation of this delicate pressure responsive device. Drain line 71 is shown to be connected to the low pressure return tube 38 and drain lines 72 and 73 may return to other appropriate portions of the hydraulic system such as a reservoir of hydraulic fluid (not shown). Drain line 73 is primarily for the relief of pressure fluid which may leak past the valve element 32b from the source of control pressure such as a hydraulic regulator (not shown). The drain line 73 therefore may be preferably connected back to casing of the regulator in order to provide compensation for changes in the ambient pressure within that casing.

While I have shown and described a particular embodiment of my invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from my invention in its broader aspects and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. In a valve control system for fluid delivery apparatus for providing a volume of fluid delivery variable in accordance with a variable control pressure, a pilot valve connected to measure the fluid delivery pressure as an indication of fluid flow and connected to measure said variable control pressure and positionable in accordance with a predetermined desired function of said pressures, a throttle valve connected to said pilot valve for positioning thereby, said throttle valve having a fluid flow control orifice variable in accordance with the position thereof, a by-pass valve connected between the input and discharge fluid connections of said throttle valve and operable in response to the pressure drop thereacross, said bypass valve including a connection for bypassing a portion of the fluid at the input side of said throttle valve to maintain a constant pressure drop and a constant fluid flow through said throttle valve for any given position thereof regardless of variations in input and discharge fluid pressures.

2. A control system for fluid delivery apparatus for providing a volume of fluid delivery variable in accordance with a variable control pressure comprising a pilot valve connected to measure the fluid delivery pressure as an indication of fluid flow and also connected to measure said variable control pressure and positionable in accordance with the difference between predetermined desired functions of said pressures, a throttle valve connected to said pilot valve for positioning thereby said throttle valve including an orifice variable in accordance with the position thereof through which the fluid is delivered, a bypass valve connected between the input and discharge fluid connections of said throttle valve and positionable responsive to the respective pressures thereof, said bypass valve including a bypass connection for maintaining a predetermined constant pressure drop across said throttle valve by by-passing a portion of the fluid at the input side of said throttle valve dependent on the position of said by-pass valve to maintain a constant fluid flow through said throttle valve for any given position thereof regardless of variations in input and discharge fluid pressures.

3. A system for controlling and regulating the flow from a fluid delivery apparatus in accordance with a variable control pressure comprising a pilot valve, a throttle valve, and a by-pass valve, each including a closed cylindrical housing and a valve piston reciprocably mounted therein, said pilot valve including connections for respectively conveying system fluid delivery pressure and a variable control pressure to the ends thereof, hydraulic fluid servo control connections from said pilot valve to the respective ends of said throttle valve for the positioning of said throttle valve in accordance with the control movements of said pilot valve, said throttle valve housing including a port, and said throttle valve piston including

a land defining a throttle valve orifice for controlling the system fluid delivery flow rate, connections from the input and discharge sides of said throttle valve orifice to the respective ends of said bypass valve piston for positioning thereof in accordance with the difference in pressure across said orifice, a biasing spring connected to bias said bypass valve in a direction assisting said delivery pressure, said bypass valve housing including a discharge port and said bypass valve piston including a piston valve element together defining a discharge orifice connected to the input side of said throttle valve and variable in



accordance with the position of said bypass piston to discharge fluid unneeded for delivery by said system.

HOWARD W. AVERY.

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