United States Patent

Usry

[15] **3,700,209**

[45] **Oct. 24, 1972**

[54] **BALANCED PINTLE VALVE**

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[21] Appl. No.: **102,570**

[52] **U.S. Cl.** 251/282

[51] **Int. Cl.** F16k 1/12

[58] **Field of Search** 251/282; 137/484.2, 484.4

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Assistant Examiner—David R. Matthews
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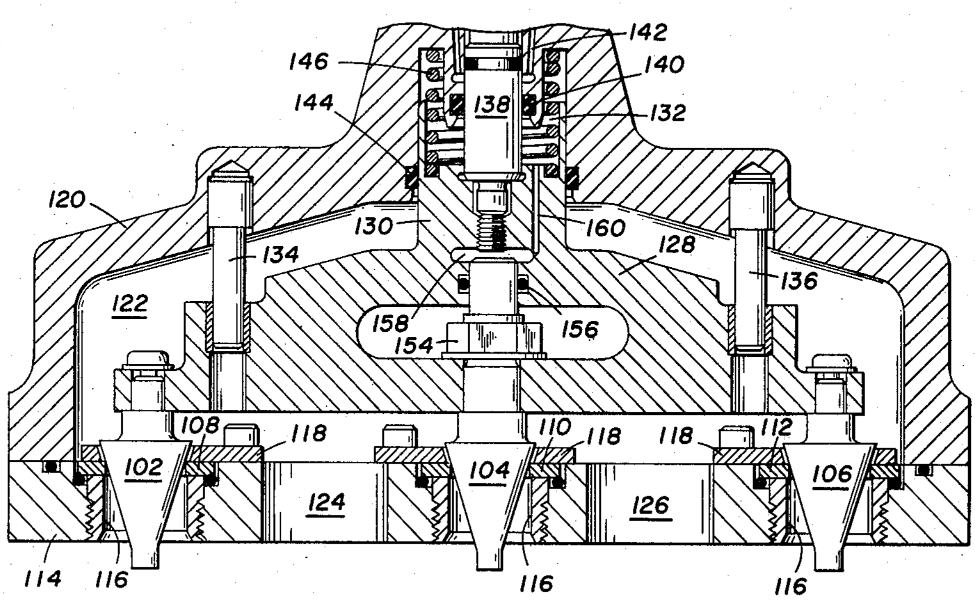
[57] **ABSTRACT**

To minimize actuation power requirements in a metering flow control valve, forces generated on the metering pintle are statically and dynamically balanced. To reduce actuation power, the mechanization of the flow control valve must be an integrated concept that combines valve geometry and balancing techniques. The pintle in either a throttling valve or an injector valve is dynamically balanced by a plurality of passages formed in the pintle. These passages are arranged to be successively withdrawn into the upstream pressure to balance forces generated by a fluid flowing past the pintle. As each succeeding passage is exposed to the upstream pressure, the pressure in a compensating chamber increases to produce a force that tends to balance the force produced on the pintle by fluid flowing through the valve. With a generally conical shaped metering pintle, the passages are displaced both longitudinally along and radially around the pintle.

11 Claims, 9 Drawing Figures



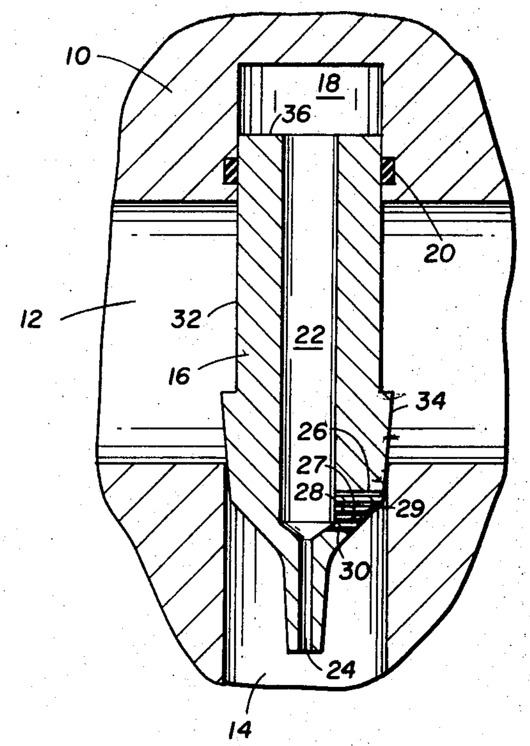


FIG. 1

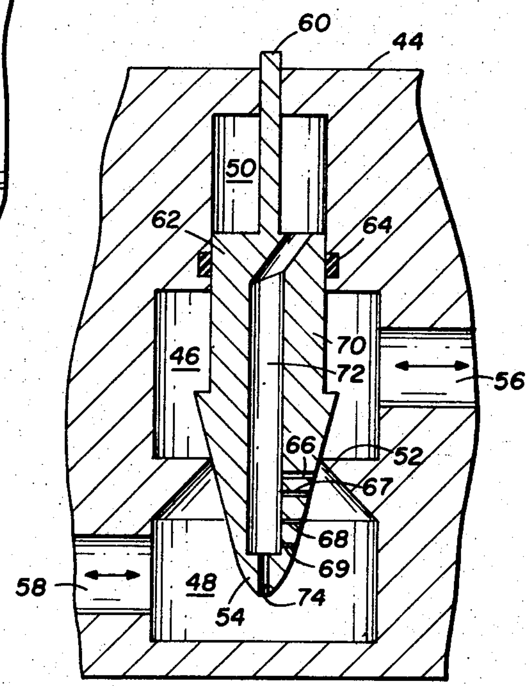


FIG. 5

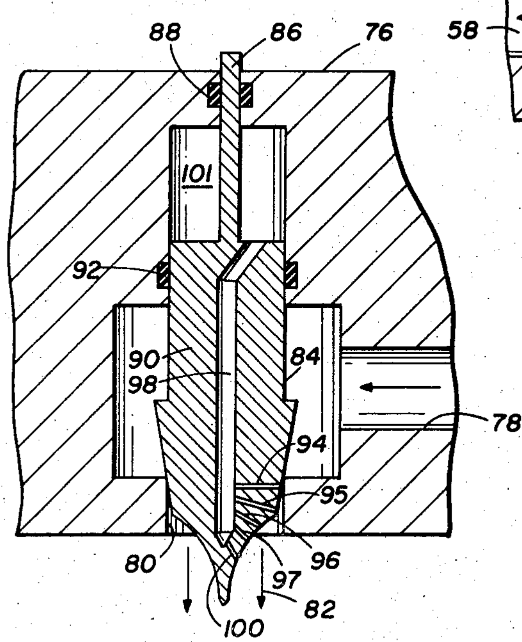


FIG. 6

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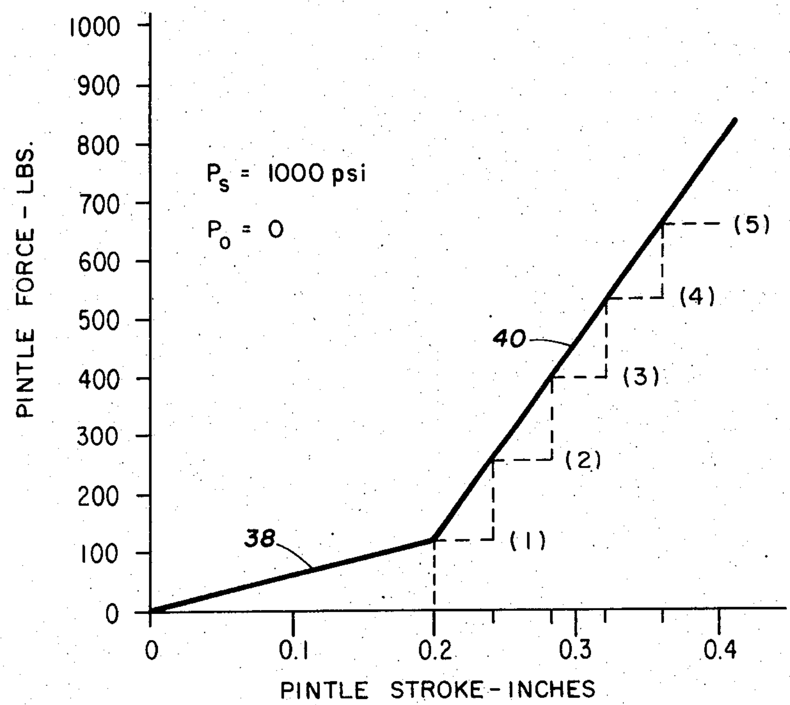

FIG. 2

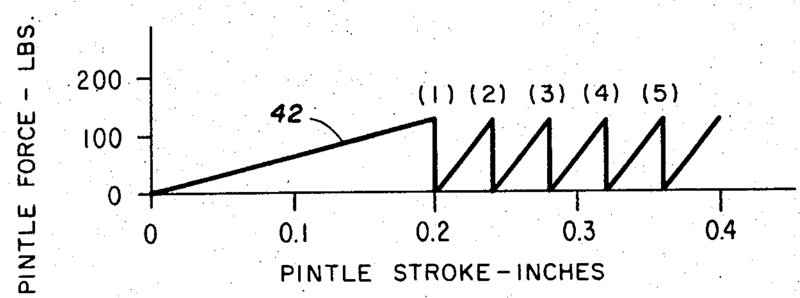

FIG. 3

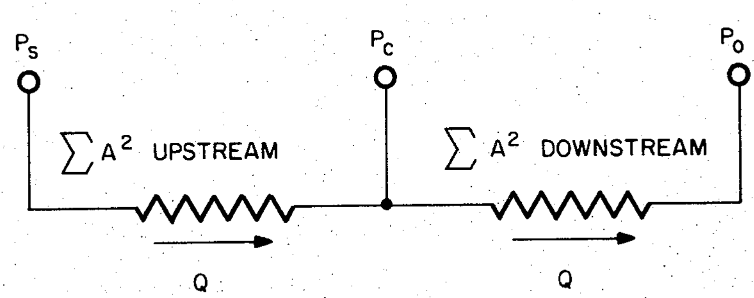

FIG. 4

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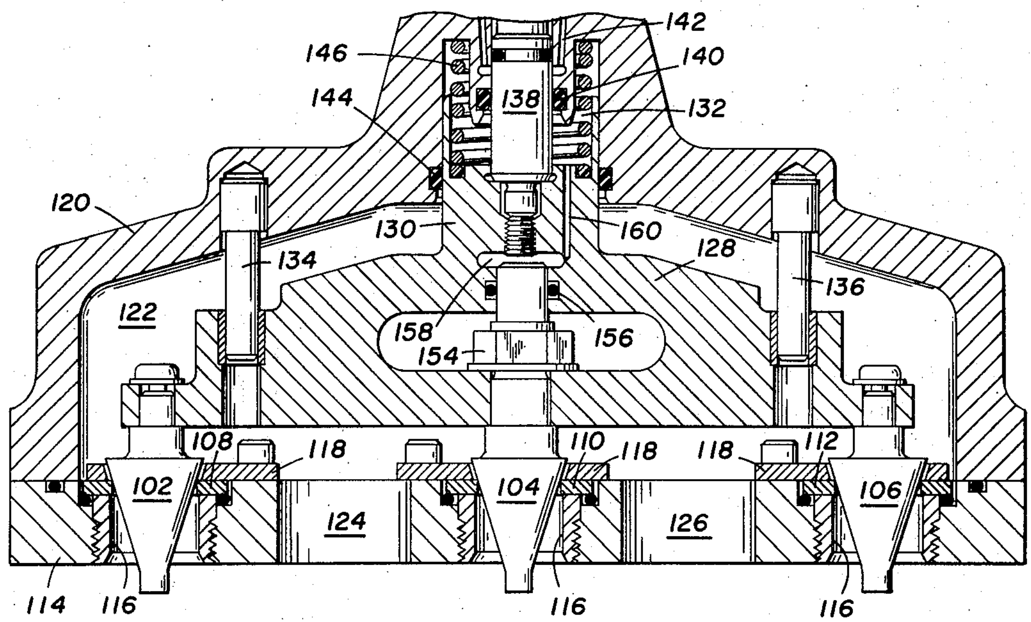

FIG. 7

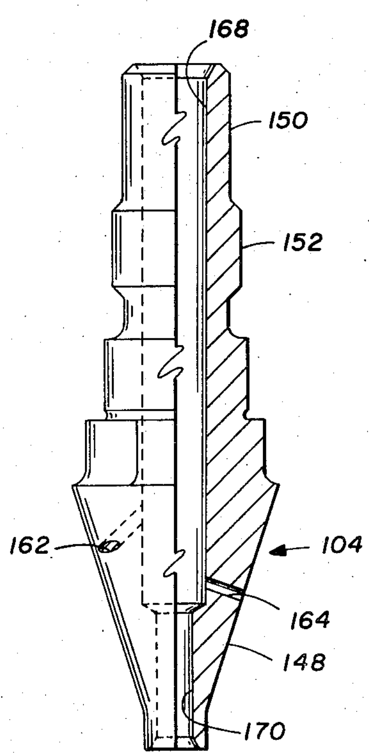

FIG. 8

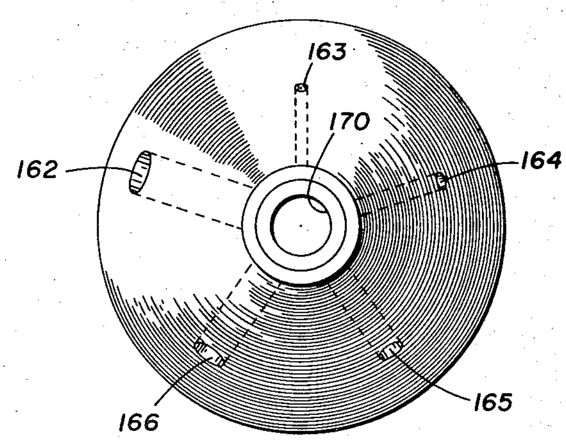

FIG. 9

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BALANCED PINTLE VALVE

This invention relates to a metering flow control valve, and more particularly to a statically and dynamically balanced pintle valve.

The balancing of a pintle valve usually consists of statically balancing the valve seat area with equal area pistons that oppose the pressure times area forces on the pintle plug. With such statically balanced valves, when the metering pintle is withdrawn from the valve seat the areas upstream and downstream of the metering area change and the static balance no longer holds. In addition to statically balanced valves, metering flow control valves have also been balanced at some intermediate point in the valve stroke by careful selection of the metering area. These valves, however, are not balanced at all flow rates or for various combinations of upstream and downstream pressures. This is primarily because the nature of the pintle valve geometry gives a variation of the forces on the pintle as it is withdrawn from its seat.

Heretofore, many attempts have been made to balance pintle valves (sometimes called globe valves) under both static and varying dynamic flow conditions. The techniques most often used to generate balancing forces are springs, Bernoulli pressures and flow momentum.

With the spring force balancing technique, the spring is used for balancing forces over the total stroke if the force versus stroke of the pintle valve is linear under expected conditions of pressure and flow. Some attempts have also been made to balance non-linear forces with non-linear springs. The spring force balancing method achieves a degree of balancing for only fairly constant operating conditions of upstream and downstream pressures.

Under some very selected conditions, it is possible to balance a valve with Bernoulli pressure forces generated against the side of the metering pintle. The limitation of this technique is the difficulty of configuring the three dimensional geometry of the pintle such that a balance is achieved for all flow conditions. Many times the pressure-flow-stroke requirements (such as flow-stroke requirements that require stepped pintles) are such that only a small reduction in forces can be achieved with realizable geometries. The Bernoulli technique has been found to be useful only when the back pressure operating conditions are well defined.

In the flow momentum technique, reaction forces of the high velocity metered fluid are used to counter the overbalance in the closing direction of a flow-to-open valve. This technique is difficult to analyze because of the three dimensional geometry that must be matched to some particular flow-pressure-stroke relation. Like the Bernoulli force balancing technique, this method is limited to valves with favorable force parameters that can be counteracted with realizable geometry.

An object of the present invention is to provide a balanced metering pintle valve under both static and dynamic conditions. Another object of this invention is to provide static and dynamic balancing of a metering valve for varying operating conditions of upstream and downstream pressures. A further object of this invention is to provide for static and dynamic balancing of a metering valve with realizable geometry under varying pressure-flow-stroke requirements. Still another object of this invention is to provide static and dynamic balancing of a metering pintle valve under varying back pressure operating conditions. A still further object of this invention is to provide static and dynamic balancing of a metering pintle valve by varying generated forces as the pintle is withdrawn from the valve seat.

In accordance with the present invention, a pintle valve is dynamically balanced by generating a prescribed pressure-ratio variation with stroke. The valve mechanism includes a valve body having an interior surface defining a chamber therein. The valve body includes means for defining an inlet and an outlet communicating with the chamber. A valve member movable within the defined chamber between a first position for closing off a flow of fluid through the chamber to intermediate positions for regulating the flow of fluid includes means for generating a force that increases with the flow of fluid through the defined chamber to balance the forces produced on the valve member. In one embodiment of the invention, the latter means includes a plurality of passages formed in the valve member.

A more complete understanding of the invention and its advantages will be apparent from the specifications and claims and from the accompanying drawings illustrative of the invention.

Referring to the drawings:

FIG. 1 is a sectional schematic view of a pintle valve balanced in accordance with the present invention;

FIG. 2 is a plot of an uncompensated force curve for the pintle valve of FIG. 1 with pintle forces in pounds given as a function of pintle stroke in inches;

FIG. 3 is a balanced force curve with pintle forces in pounds again plotted as a function of pintle stroke in inches;

FIG. 4 is an impedance representation of a plurality of passages formed in the pintle as they are withdrawn into the upstream pressure and vented to the downstream pressure;

FIG. 5 is a schematic technique of a throttling valve using the force balancing technique of the present invention;

FIG. 6 is a sectional schematic of an injector valve employing the force balancing technique of the present invention;

FIG. 7 is a sectional view of a three pintle injector valve wherein the dynamic forces are balanced by a plurality of passages in the center pintle;

FIG. 8 is an elevational view partially in section of the center pintle of the valve of FIG. 7; and

FIG. 9 is an end view of the center pintle of the valve of FIG. 7 showing the radial distribution of the plurality of compensating passages.

Referring to FIG. 1, the schematic illustrates a pintle valve wherein the inlet and outlet flow directions are at right angles to each other. In the valve shown, a housing **10** includes a plenum chamber **12** having an inlet passage (not shown) communicating therewith and an outlet passage **14** also in communication therewith. A metering pintle **16** moves axially within the housing **10** and forms a compensating chamber **18** opposite the outlet passage **14**. A seal **20**, located within an annular groove in the housing **10**, engages the pintle **16** to form a fluid seal between the compensating chamber **18** and the plenum chamber **12**.

Within the metering pintle **16** there is a longitudinal passage **22** communicating with the compensating chamber **18** and terminating in a restricted-flow passage **24** opening into the outlet passage **14**. Opening into the passage **22** is a plurality of longitudinally spaced compensating passages **26** through **30**.

In the illustration of FIG. **1**, the pintle has a cylindrical body section **32** terminating at a dual conical shaped metering area **34** terminating in a shaped surface for collimating a flow of fluid through the passage **14**. The configuration of the metering area **34** in FIG. **1** provides a desired flow pattern for an injector valve.

In the operation of the valve of FIG. **1**, the area of the section **32** and the metering area **34** are designed such that with the pintle in the closed position (as shown) the valve is statically balanced. That is, the forces tending to force the metering plug into a closed position substantially offset forces that tend to open or move the plug away from the closed position. As the pintle **16** moves to an intermediate position from the closed off position to establish a flow of fluid from the plenum chamber **12** through the outlet **14**, the plurality of compensating passages **26** through **30** are sequentially withdrawn into the high pressure upstream of the valve seat to generate a ratio of upstream to downstream pressure that varies with pintle position. This pressure is conducted to the compensating chamber **18** to generate a force on a piston **36** to counteract flow forces on the metering area **34**. Since the forces of the metering area are a function of the pressure drop across the valve, a reasonably good balance between the force on the piston **36** and the metering area **34** can be achieved for a wide variation of operating conditions. Further, the plurality of compensating passages for balancing dynamic forces is workable with a wide variation of total pintle geometry. A calculation of the diameters for the compensating passages **26** through **30** is made from the known uncompensated force curve.

As shown in FIG. **2**, the uncompensated force curve is given by the solid lines **38** and **40**. The section of this curve given by the line **40** can be compensated by a series of pressure steps introduced into the compensating chamber **18**. As the pintle **16** is stroked, a varying combination of orifice areas, as defined by the passages **26** through **30**, are presented to the upstream pressure (P_s) and the downstream pressure (P_o) to generate an intermediate control pressure (P_c). The generated control pressure P_c in the compensating chamber **18** is thus a function of the pintle position for a given relationship of upstream pressure P_s versus downstream pressure P_o. The control pressure P_c produces a force on the piston **36** to generate a force that is a function of stroke. For a balanced valve, the generated force on the piston **36** must be substantially equal and opposite to the force variation on the metering area **34**.

As an example of dynamic balancing, consider FIG. **1** to show a step injector pintle valve that has an uncompensated force curve versus pintle stroke as shown in FIG. **2**. To simplify this example, the area of piston **36** is 1 sq. in. and the upstream pressure P_s is 1,000 PSI. Using the passages **26** through **30**, five pressure steps are used to counteract the force curve given by line **40** of FIG. **2** to an acceptable limit, for example, below **200** lbs. as shown by curve **42** of FIG. **3**. As each of the passages **26** through **30** is opened to the upstream pressure P_s, with venting through the restricted flow passage **24**, an analog representation of the action of the balancing forces may be represented by the impedance diagram of FIG. **4**. If P_c = pintle force/1 sq. in., that is, the compensating pressure in the chamber **18** the following set of flow continuity equations can be written:

$$\Sigma Q_{up} = \Sigma Q_{down} \quad (1)$$

where

Q_{up} = the flow on the upstream side of the pintle, and

Q_{down} = the flow on the downstream side of the pintle.

This summation of flow continuity may also be written:

$$K \Sigma A_{up} \sqrt{P_s - P_c} = K \Sigma A_{down} \sqrt{P_c - P_o} \quad (2)$$

where

K = a system constant,

A_{up} = the area of the orifices (**26** through **30**) on the upstream side, and

A_{down} = the area of the orifices (**26** through **30**) on the downstream side.

Transporting equation (2) can be written as:

$$\sqrt{(P_s - P_c)/(P_c - P_o)} = (\Sigma A_{down} / \Sigma A_{up}) \quad (3)$$

When $P_o = 0$, that is when the valve is used in the injector flow mode, and using equation (3), the following equations for each of the steps given in FIG. **2** may be written:

$$\sqrt{(1000/125) - 1} = (A_2 + A_3 + A_4 + A_5 + A_0)/A_1 \quad (4)$$

$$\sqrt{(1000/250) - 1} = (A_3 + A_4 + A_5 + A_0)/(A_1 + A_2) \quad (5)$$

$$\sqrt{(1000/390) - 1} = (A_4 + A_5 + A_0)/(A_1 + A_2 + A_3) \quad (6)$$

$$\sqrt{(1000/525) - 1} = (A_5 + A_0)/(A_1 + A_2 + A_3 + A_4) \quad (7)$$

$$\sqrt{(1000/675) - 1} = A_0/(A_1 + A_2 + A_3 + A_4 + A_5) \quad (8)$$

where

A_0 = the area of the restricted flow passage **24**,

A_1 = the area of the passage **26**,

A_2 = the area of the passage **27**,

A_3 = the area of the passage **28**,

A_4 = the area of the passage **29**, and

A_5 = the area of the passage **30**.

Each of the above equations then reduces to:

$$2.65A_1 A_2 - A_3 - A_4 - A_5 - A_0 = 0 \quad (9)$$

$$1.73A_1\mathbf{a3.}\ 1.73A_2 - A_3 - A_4 - A_5 - A_0 = 0 \quad (10)$$

$$1.25A_1\mathbf{a3.}\ 1.25A_2 + 1.25A_3 - A_4 - A_5 - A_0 = 0 \quad (11)$$

$$0.95A_1\mathbf{a3.}\ 0.95A_2 + 0.95A_3 + 95A_4 - A_5 - A_0 = 0 \quad (12)$$

$$0.69A_1\mathbf{a3.}\ 0.69A_2 + 0.69A_3 + 0.69A_4 + 0.69A_5 - A_0 = 0 \quad (13)$$

Solving the equations simultaneously in terms of A_o gives:

$$A_1 = 0.671\ A_0 \quad (14)$$

$$A_2 = 0.227\ A_0 \quad (15)$$

$$A_3 = 0.191\ A_0 \quad (16)$$

$$A_4 = 0.167\ A_0 \quad (17)$$

$$A_5 = 0.193\ A_0 \quad (18)$$

This then yields the diameters for each of the passages **26** through **30** respectively in terms of D_o:

$$D_1 = 0.92\ D_0 \quad (19)$$

$$D_2 = 0.54\ D_0 \quad (20)$$

$$D_3 = 0.99\ D_0 \quad (21)$$
$$D_4 = 0.46\ D_0 \quad (22)$$
$$D_5 = 0.49\ D_0 \quad (23)$$

where

D_0 = the diameter of the restricted flow passage **24**,
D_1 = the diameter of the passage **26**,
D_2 = the diameter of the passage **27**,
D_3 = the diameter of the passage **28**,
D_4 = the diameter of the passage **29**, and
D_5 = the diameter of the passage **30**.

The diameters are based on D_0 which can be chosen based on contamination, allowable balancing flow and minimum drill sizes. The diameters can usually be large and still have insignificant flow compared to the valve flow rate.

As explained, the dynamic force balancing of the present invention may be used either in a throttle valve configuration or an injector valve configuration. Referring to FIG. **5**, there is shown a sectional schematic of a throttle valve including a valve housing **44** containing a first chamber **46**, a second chamber **48** and a third chamber **50**. Chambers **46** and **48** are separated by a valve seat **52** that engages a metering pintle **54** for controlling the flow of fluid between the first and second chambers. A passage **56** communicates with the first chamber **46** and a passage **58** communicates with the second chamber **48**.

A shaft **60** of the pintle **54** is slidably mounted by a bearing and seal assembly (not shown) that is disposed in a wall of the housing **44** so that the pintle moves coaxially relative to the seat **52**. The pintle has a solid cylindrical portion **62** with a diameter substantially equal to the diameter of the third chamber **50**. With the pintle **54** mounted as illustrated, the section **62** separates the first chamber **46** from the third chamber **50**. A seal **64**, mounted in an annular groove of the housing **44** and engaging the section **62**, forms a fluid-tight arrangement between the chambers **46** and **50**.

In the embodiment of FIG. **5**, a dynamic balancing of the pintle **54** is achieved by a plurality of compensating passages **66** through **69** formed within the generally cone-shaped section **70**. Passages **66** through **69** terminate at a longitudinal passage **72** that communicate with the third chamber **50**. The passage **72** terminates in a restricted flow passage **74**. For any given configuration and operating condition, equations (1) through (3) of the preceding example may be used to calculate the diameter of the passages **66** through **69** and passage **74**. For a throttle valve, the downstream pressure P_o is not zero but will be at some finite level, depending on the load into which the valve works. It will be noted, that with a throttle valve the upstream pressure P_s and the downstream pressure P_o can be generated in either the chambers **46** or **48**, depending on the flow through the valve.

Referring to FIG. **6**, there is shown a sectional schematic of an injector valve employing the principles of the present invention. A valve housing **76** has on one of its sides an inlet **78** for receiving liquid under high pressure from a supply line. The valve housing has a discharge orifice **80** located on an adjoining side to discharge a jet stream **82** in a direction perpendicular to the flow into the inlet **78**. An actuator (not shown) mounted to the housing **76** moves a metering pintle **84** within the housing. A shaft **86** couples the actuator motion to the pintle **84**. This shaft is slidably mounted by a bearing and seal assembly **88** that is disposed in the wall of the housing **76** so that the pintle is mounted coaxially relative to the valve seat at the discharge orifice **80**. The pintle **84** has a solid cylindrical portion **90** that engages a seal **92** to separate the housing chamber into first and second sections. The metering portion of the pintle **84** has a substantially conical shape.

To balance the dynamic forces on the pintle **84** for varying flow rates from the inlet **78** through the discharge orifice **80**, a plurality of compensating passages **94** through **97** are formed to the conical section of the pintle and communicate with a longitudinal passage **98**. The passage **98** also communicates with a discharge passage **100** to form an outlet from the section **101** of the housing chamber. Again, calculation of the diameter for each of the passages **94** through **97** and the passage **100** may be made by equations (1) through (3).

In a reduction to practice of the present invention, an injector valve having three metering pintles was provided for controlling fuel injection into a rocket engine. Referring to FIGS. **7** through **9**, there is shown a three metering-pintle injection valve. Each of the metering pintles **102**, **104** and **106** controls fluid flow by displacement from a valve seat **108**, **110** and **112**, respectively. Each of the valve seats is mounted in a manifold plate **114** and held in place between an orifice **116** and a holding plate **118**. The valve housing **120** is mounted to the manifold plate **114** and forms a plenum chamber **122** therewith. Fluid enters the chamber **122** through passages **124** and **126**.

The metering pintles **102**, **104** and **106** are supported on a yoke **128** that includes a cylindrical section **130** extending into the housing **120** to form a compensating chamber **132**. Guide pins **134** and **136**, mounted into the housing **120**, serve to orient each of the metering pintles with the respective valve seat. Linear motion is imparted to the yoke **128** through a ball-screw (not shown) coupled to a drive shaft **138**. The drive shaft **138** threadedly connects to the yoke **128**. The shaft **138** passes through the housing **120** and engages a seal **140** to form a fluid-tight seal between the compensating chamber **132** and the passage **142**. A seal **144**, engaging the cylindrical section **130** of the yoke **128**, forms a fluid-tight seal between the compensating chamber **132** and the plenum chamber **122**. A spring **146** biases the yoke **128** into a closed position. This spring may also serve to partially balance the forces on the metering pintles **102**, **104** and **106**.

The primary compensation force for the pintles **102**, **104** and **106** is accomplished by compensating passages in the metering pintle **104**. As shown in FIGS. **8** and **9**, the metering pintle **104** includes a generally conical section **148** and a cylindrical section **150**. The cylindrical section **150** terminates at a threaded section **152**. When assembled with the yoke **128**, a nut **154** engages the threaded section **152** to hold the metering pintle **104** in position. When in place, the section **150** engages an O-ring seal **156**. Section **150** terminates in a chamber **158** connected to the compensating chamber **132** by means of a passage **160**.

As illustrated in FIGS. **8** and **9**, a plurality of compensating passages **162** through **166** are formed in the conical section **148**. Each of these passages terminates in a longitudinal passage **168** that opens into the chamber **158**. The downstream portion of the passage **168** terminates in a restricted flow passage **170**. The passages **162** through **166** are both radially displaced about the conical section **148** and longitudinally displaced such that they will be subsequently withdrawn into the upstream pressure in the plenum chamber **122**.

The general conical shape of the metering portion of the pintle can be modified according to control characteristics desired. A preferred shape provides linear control; that is, the quantity of flow of liquid through each of the valve seats **108**, **110** and **112** varies in equal increments for equal changes in distance of travel of the metering pintles in the axial direction. When a collimated stream in an axial direction is not required for a low rate of fluid flow, the apex of the pintle need not be elongated to provide a pointed guide. Thus, the conical shape of the metering pintles described is not intended to limit the invention to such a configuration.

To calculate the diameters of each of the compensating passages **162** through **166** and passage **170**, the equations (1) through (3) of the example are employed. The calculations are independent of the use of three metering pintles instead of the one illustrated in FIG. 1.

While several embodiments of the invention, together with modifications thereof, have been described in detail herein and shown in the accompanying drawings, it will be evident that various further modifications are possible without departing from the scope of the invention.

What is claimed is:

1. A valve mechanism for regulating the flow of fluid comprising:

a valve body having an interior surface defining a chamber therein, said valve body having means for defining an inlet and an outlet communicating with said chamber,

a valve member movable within the defined chamber between a first portion for closing off a flow of fluid through said chamber to intermediate positions for regulating the fluid flow, and

means within said valve member cooperating with the valve body for generating a force on the valve member that varies with the pressure differential across the inlet and outlet of the defined chamber to balance the forces produced on said member.

2. A valve mechanism for regulating the flow of fluid as set forth in claim **1** wherein said means includes a plurality of compensating passages formed within said valve member to be successively withdrawn into the fluid flow through the inlet into the defined chamber.

3. A valve mechanism for regulating the flow of fluid as set forth in Claim **2** wherein said compensating passages are displaced longitudinally in said valve member.

4. A valve mechanism for regulating the flow of fluid as set forth in Claim **3** wherein said passages are radially distributed around said valve member.

5. A valve mechanism for regulating the flow of fluid comprising:

a valve body having an interior surface defining a first and second chamber, said valve body having means for defining an inlet and an outlet communicating with said first chamber,

a valve member movable within said first and second chambers between a first position for closing off a flow of fluid through said first chamber to intermediate positions for regulating the fluid flow, and

means within said valve member for producing a pressure in said second chamber to produce a compensating force on the valve member that varies with the pressure differential across the inlet and outlet of the first chamber to balance the forces produced on said valve member.

6. A valve mechanism for regulating the flow of fluid as set forth in claim **5** wherein said means includes a plurality of compensating passages formed within said valve member to be successively withdrawn into the fluid flow through said first chamber.

7. A valve mechanism for regulating the flow of fluid as set forth in claim **6** including a passage communicating with said plurality of passages, to said second chamber and the outlet of said valve body, and

restriction means in said passage to produce a controlled flow of fluid from said second chamber.

8. A valve mechanism for regulating the flow of fluid as set forth in claim **7** wherein said valve member has a generally conical configuration and said plurality of passages are displaced longitudinally through said conical section.

9. A valve mechanism for regulating the flow of fluid comprising:

a valve body having an interior surface defining a first chamber, a second chamber and a third chamber, said valve body having means for defining an inlet communicating with said first chamber and an outlet communicating with said second chamber,

a conically shaped valve member movable within said first and third chambers between a first position for closing off a flow of fluid through said first chamber to said second chamber to intermediate positions for regulating the flow of fluid between the inlet and outlet,

a longitudinal passage through said conically shaped valve member for forming a communicating path between said second chamber and said third chamber,

restriction means in said passage at the end toward said second chamber for controlling the flow of fluid through said longitudinal passage, and

a plurality of compensating passages formed within said valve member communicating with said first passage to be successively withdrawn into the flow of fluid through the inlet to generate a pressure in said third chamber that varies with fluid flow to balance the forces produced on said valve member.

10. A valve mechanism for regulating the flow of fluid as set forth in claim **9** wherein said plurality of compensating passages are displaced longitudinally in said conically shaped valve member.

11. A valve member for regulating the flow of fluid as set forth in claim **10** wherein said plurality of compensating passages are radially displaced around said conical shaped valve member.

* * * * *

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(5/69)

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,700,209 **Dated** October 24, 1972

Inventor(s) Joe D. Usry

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Col. 2, line 41, after "schematic" cancel "technique" and insert --sectional view--.

Col. 4, line 23, "Transporting" should be --Transposing--.
line 48, "$2.65A_1A_2-A_3-A_4-A_5-A_0= 0$" should be --$2.65A_1-A_2-A_3-A_4-A_5-A_0 = 0$--;

line 49, "$1.73A_1a3.1.73A_2-A_3-A_4-A_5-A_0 = 0$" should be --$1.73A_1 + 1.73A_2-A_3-A_4-A_5-A_0 = 0$--;

line 50, "$1.25A_1a3.1.25A_2+1.25A_3-A_4-A_5-A_0 = 0$" should be --$1.25A_1+1.25A_2+1.25A_3-A_4-A_5-A_0 = 0$--;

line 51, "$0.95A_1a3.0.95A_2+0.95A_3+95A_4-A_5-A_0 = 0$" should be --$.95A_1+.95A_2+.95A_3+ .95A_4-A_5-A_0 = 0$--;

line 52, "$0.69A_1a3.0.69A_2+0.69A_3+0.69A_4+0.69A_5-A_0 = 0$" should be --$.69A_1+.69A_2+.69A_3+.69A_4+.69A_5-A_0 = 0$--.

Signed and sealed this 13th day of March 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents