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Cook et al.

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(54) **EQUALIZATION OF PRESSURE IN AN ELECTRONICALLY CONTROLLED VALVE**

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(51) **Int. Cl.**
F15B 13/044 (2006.01)
F16K 31/02 (2006.01)

(52) **U.S. Cl.** **137/625.65**; 251/129.07

(58) **Field of Classification Search** 137/625.65; 251/129.07

See application file for complete search history.

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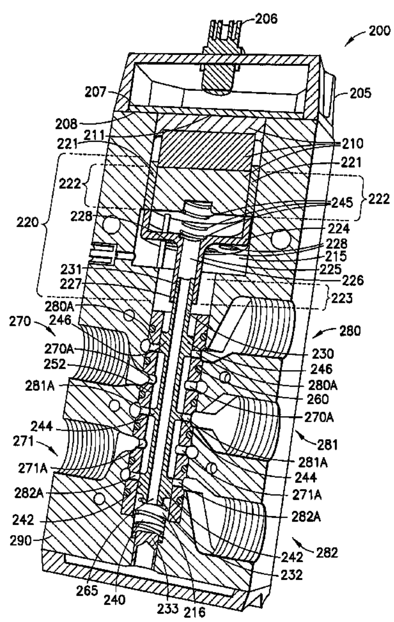
(57) **ABSTRACT**

Disclosed herein is an electronically controlled valve. The electronically controlled valve includes a valve body and a spool. The valve body includes at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity. The spool is disposed within the valve body. The spool includes a first end and an opening. The opening allows the lower cavity to be in fluid communication with the upper cavity.

18 Claims, 4 Drawing Sheets



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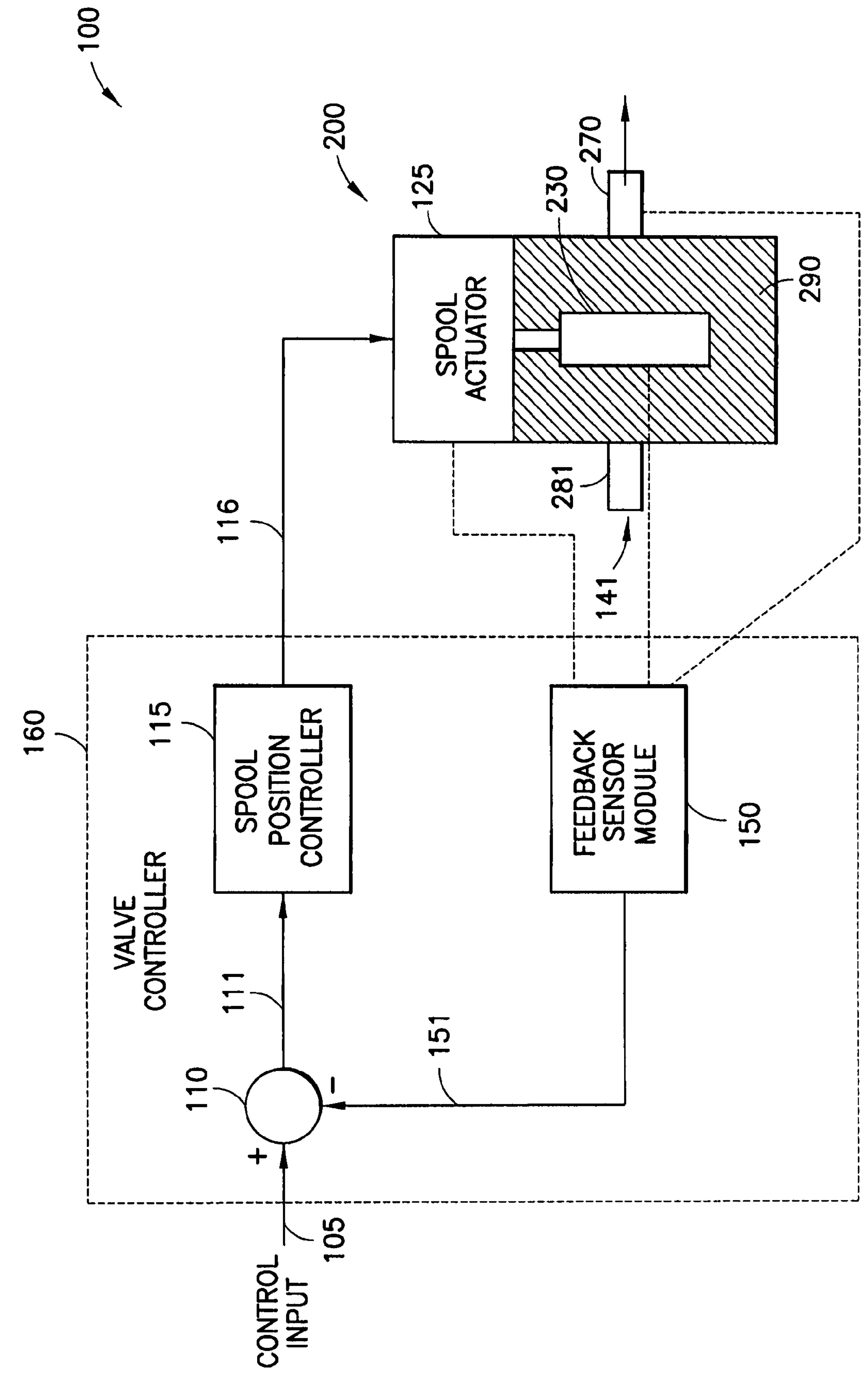
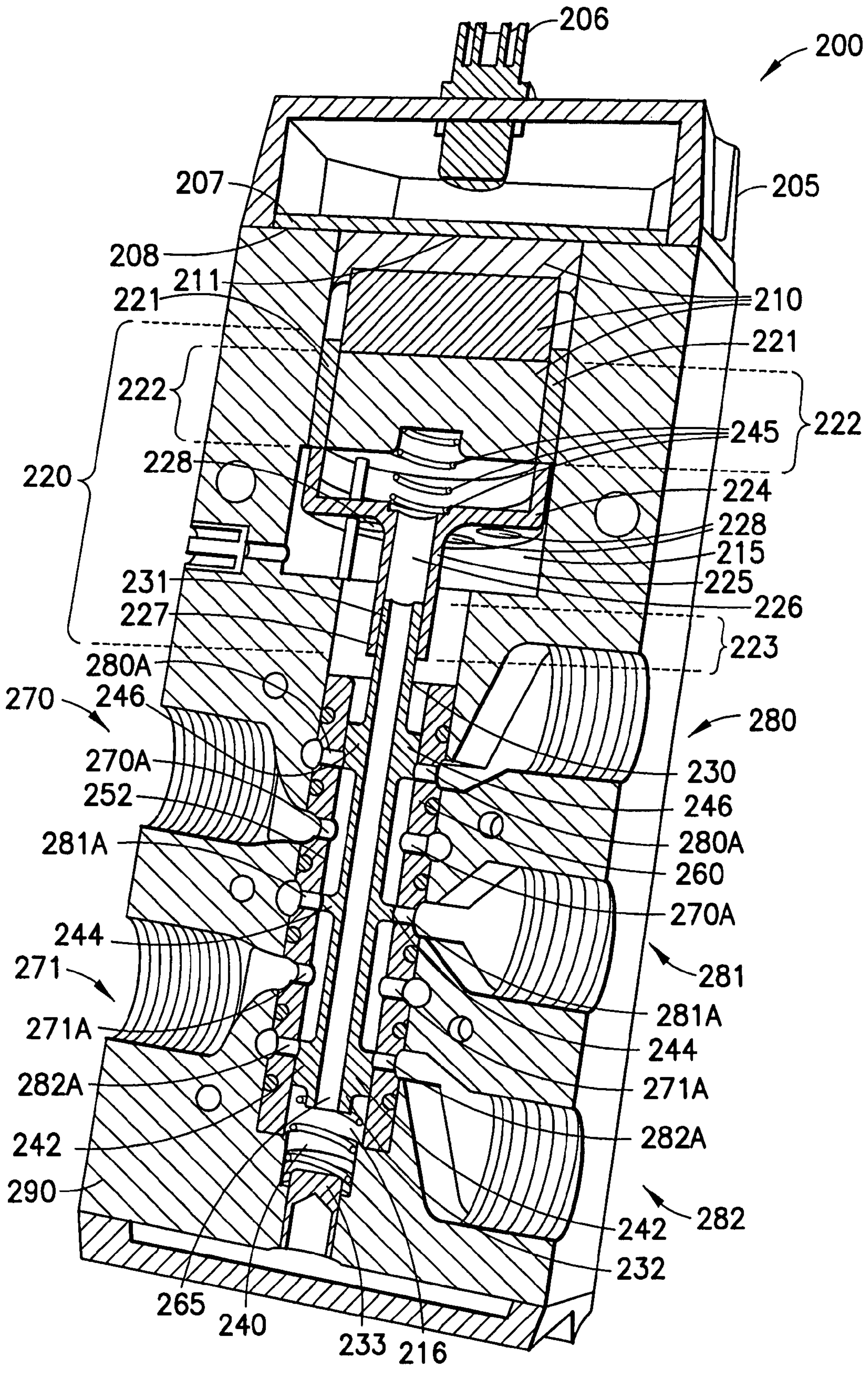

100
200
125
SPOOL ACTUATOR
230
270
290
281
141
116
160
115
SPOOL POSITION CONTROLLER
FEEDBACK SENSOR MODULE
150
VALVE CONTROLLER
111
151
110
+
-
105
CONTROL INPUT

FIG.1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280
270A
230
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281A
280A
260
270A
244
271
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271A
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282A
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232
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240
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216

FIG.2

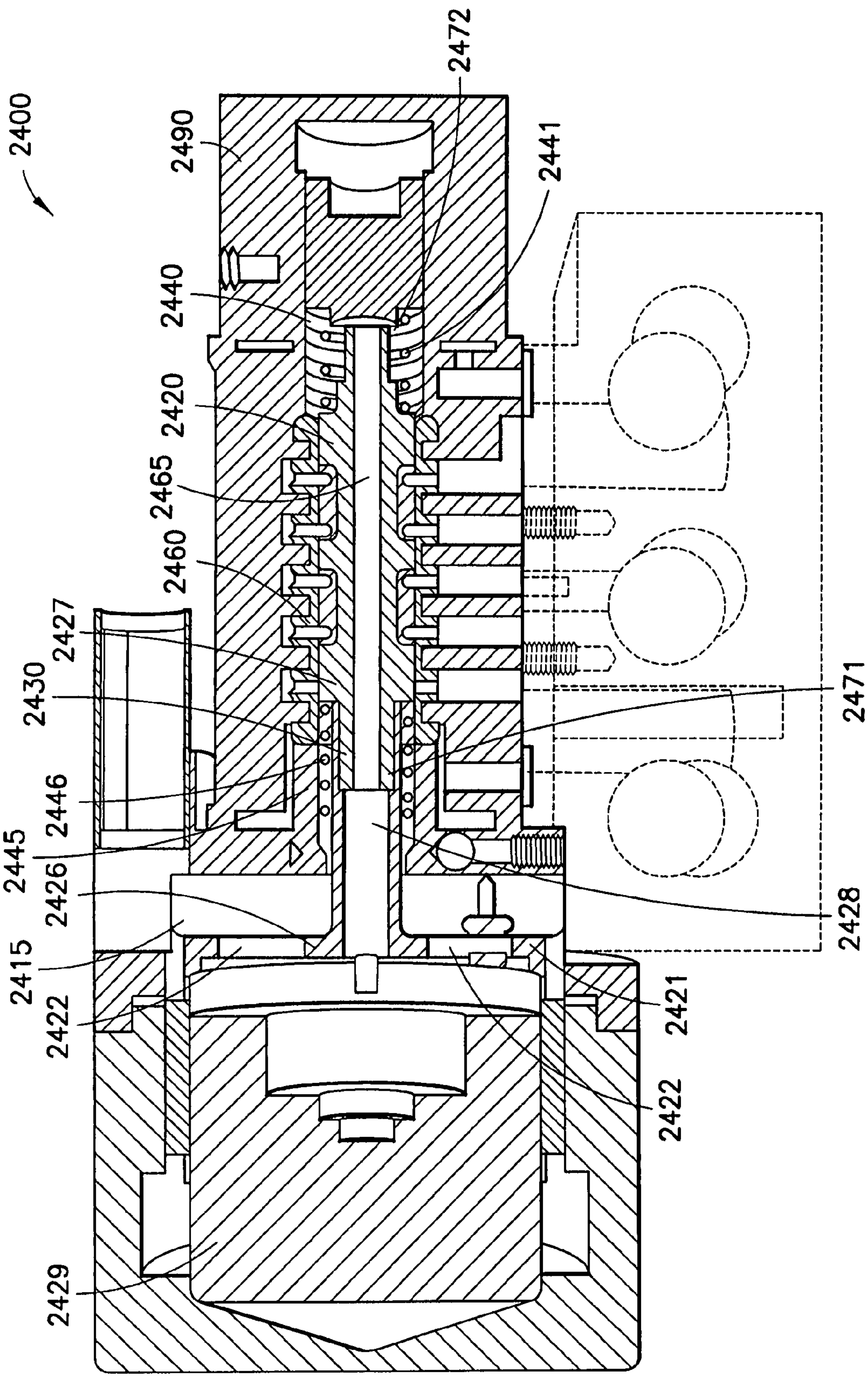
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FIG.3

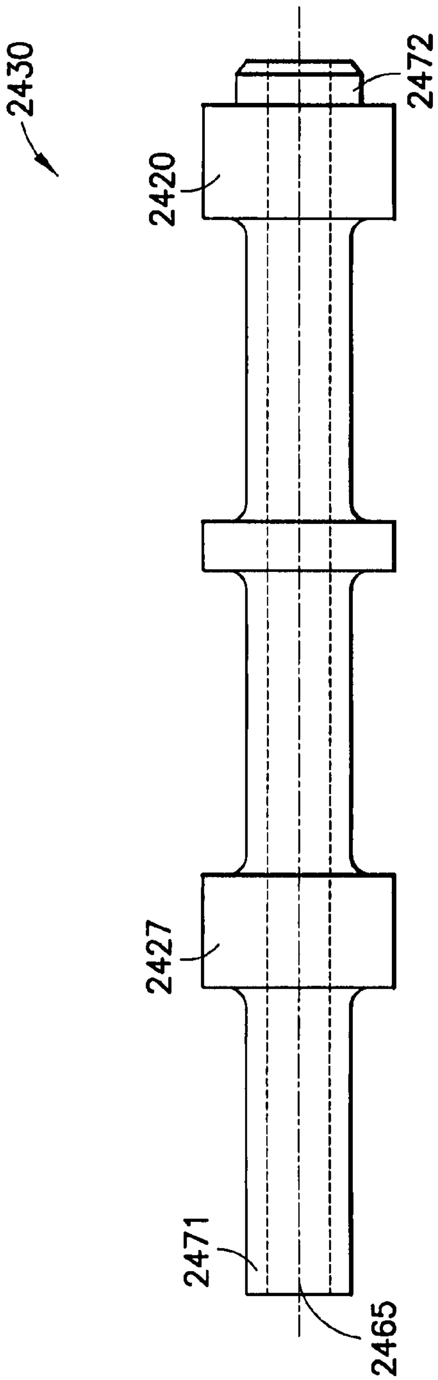

FIG.5

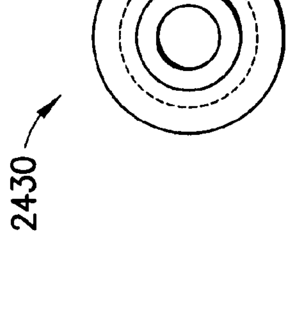

FIG.4

EQUALIZATION OF PRESSURE IN AN ELECTRONICALLY CONTROLLED VALVE

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. §119(e) to U.S. provisional patent application No. 60/854,562 filed Oct. 25, 2006 which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electronically controlled valve and, more particularly, to equalizing pressure within an electronically controlled valve.

2. Brief Description of Prior Developments

Control systems for electronically controlled valves control many different types of fluids for many different purposes. While control systems, their controllers, and the associated electronically controlled valves have many benefits, these control systems, controllers, electronically controlled valves and portions thereof may still be improved.

U.S. Pat. No. 5,960,831 discloses an electromechanical servo valve for controlling the operation of an associated fluid control valve. The electronically controlled valve comprises a valve body having inlet and outlet ports, wherein the valve body houses a spool valve member connected to a movable header. One drawback to conventional configurations is that fluid leakage within the valve body increases pressures proximate the spool valve member. These increased pressures can oppose operating forces within the system, which affects dynamic performance, reduces system efficiency, and may ultimately result in valve failure.

Accordingly, there is a need to provide an electronically controlled valve having equalized pressures within the valve body.

SUMMARY OF THE INVENTION

In accordance with one aspect of the present invention, an electronically controlled valve is disclosed. The electronically controlled valve includes a valve body and a spool. The valve body includes at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity. The spool is disposed within the valve body. The spool includes a first end and an opening. The opening allows the lower cavity to be in fluid communication with the upper cavity.

In accordance with another aspect of the present invention, a servo valve is disclosed. The servo valve includes a valve body, a valve actuator assembly, a sleeve, and a spool. The valve body includes at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity. The valve actuator assembly is disposed within the upper cavity. The valve actuator assembly includes a spool connecting portion. The spool connecting portion comprises an opening extending therethrough. The sleeve is between the upper cavity and the lower cavity. The spool is slidably disposed within the sleeve. The spool includes a fluid conduit extending from a first open end of the spool to a second open end of the spool. The first open end is received by the opening of the spool connecting portion. The second open end is at the lower cavity.

In accordance with yet another aspect of the present invention, a method of assembling an electronically controlled valve is disclosed. A valve body is provided. The valve body has at least one fluid inlet port, at least one fluid outlet port, an upper cavity, a lower cavity, and a sleeve. The sleeve is between the upper cavity and the lower cavity. A spool is installed within the sleeve. The spool includes an opening. The opening allows for fluid communication between the lower cavity and the upper cavity. A valve actuator assembly is connected to an end of the spool.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing aspects and other features of the present invention are explained in the following description, taken in connection with the accompanying drawings, wherein:

FIG. **1** is a block diagram of a system including a portion for controlling an electronically controlled valve and the electronically controlled valve;

FIG. **2** is a cutaway, perspective view of an exemplary pneumatic valve;

FIG. **3** is a side cross-sectional view of a pneumatic valve similar to the pneumatic valve of FIG. **2**;

FIG. **4** is an end view along the minor axis of a hollow spool for use in pneumatic valves such as shown in FIGS. **2** and **3**; and

FIG. **5** is a side view along the major axis of the hollow spool of FIG. **4**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. **1**, there is shown a block diagram of an exemplary system **100** having a portion for controlling an electronically controlled valve **200**. System **100** also includes in this example the electronically controlled valve **200** incorporating features of the present invention. Although the present invention will be described with reference to the exemplary embodiments shown in the drawings, it should be understood that the present invention can be embodied in many alternate forms of embodiments. In addition, any suitable size, shape or type of elements or materials could be used.

FIG. **1** is a simplistic, high-level view of a system **100** that includes a control input **105**, an adder **110**, a spool position controller **115**, the electronically controlled valve **200**, and a feedback sensor module **150** that takes an input from one or more feedback sensors (not shown) and that produces one or more feedback signals **151**. A valve controller **160** includes the adder **110**, the spool position controller **115**, and the feedback sensor module **150**. The electronically controlled valve **200** includes a spool actuator **125**, a spool **230**, a body **290**, an input **281**, and an output **270**.

The electronically controlled valve **200** controls fluid (e.g., gas, water, oil) **141** flow through the electronically controlled valve **200** by operating the spool **230**. The spool actuator **125** controls movement of the spool **230** based on one or more control signals **116** from the spool position controller **115**. The spool position controller **115** modifies the one or more control signals **116** based on the one or more input signals **111**, which include addition of the control input signal **105** and the one or more feedback signals **151**. The feedback sensor module **150** can monitor the spool actuator **125** (e.g., current through the spool actuator), a sensor indicating the position of the spool **230**, or sensors indicating any number of other valve attributes (e.g., pressure or flow rate of the fluid **141**) and/or spool actuator **125** or spool **230** attributes (e.g. temperature, acceleration, velocity, etc.). It should also be noted that the actuator **125** may be a non-pilot controlled actuator. Additionally, the actuator **125** may be internal or external to the valve body. It should also be understood that the actuator **125** may be electromagnetic. However, any suitable type of actuator may be provided.

Turning to FIG. **2** in addition to FIG. **1**, a cutaway, perspective view is shown of the exemplary valve **200** in accordance with a first embodiment of the present invention. The valve **200** includes an electronics cover **205**, a motor housing retainer **207**, a motor housing **210**, an upper cavity **215**, a lower cavity **216**, a valve actuator assembly **220**, a spool **230**, a sleeve **260**, a lower spring **240**, an upper spring **245**, external ports **270**, **271**, **280**, **281**, and **282**, circumferentially spaced internal ports **270***a*, **271***a*, **280***a*, **281***a*, and **282***a*, and a valve body **290**. At least one of the external ports **270**, **271**, **280**, **281**, **282** is a fluid inlet port, and at least one of the external ports **270**, **271**, **280**, **281**, **282** is a fluid outlet port, such as wherein external port **281** is a fluid inlet port, and external ports **270**, **271** are fluid outlet ports, for example. Additionally, it should be understood that the at least one fluid inlet port is connected to a suitable source of operating fluid such as a source for compressed air or hydraulic fluid, for example.

The valve actuator assembly **220**, which may be a coil header assembly for example, is disposed within the upper cavity **215** and includes a voice coil portion **222**, a base portion **224**, and a spool connecting portion **225**. The voice coil portion **222** extends from the base portion **224** and surrounds a portion of the motor housing **210**. The voice coil portion **222** includes a voice coil **221**. The base portion **224** comprises a plurality of circumferentially spaced holes **228** extending through the base portion **224**. The spool connecting portion **225** extends from the base portion **224** in an opposite direction to that of the voice coil portion **222**. The spool connecting portion **225** includes an opening **226** extending from an open end **227** through the axial length of the spool connecting portion **225** and through the base portion **224**. The spool connecting portion **225** further comprises an overlap portion **223** proximate the open end **227** that overlaps a portion of the spool **230** and connects the spool **230** to the coil header assembly **220**. The opening **226** receives a first end **231** of the spool **230**. The spool **230** is connected to the spool connecting portion **225** at the overlap portion **223** by any suitable fastening means, such as a threaded connection, or a press fit connection, for example. It should be noted that for the purposes of clarity, a simplistic view of the spool actuator **125** is shown in FIG. **1**. FIG. **2** illustrates the components forming the spool actuator which includes: the motor housing **210**, the coil header assembly **220**, the upper spring **245**, and the lower spring **240**. The upper spring **245** is disposed within the upper cavity **215** between the motor housing **210** and the coil header assembly **220**. One end of the upper spring **245** contacts the motor housing **210**. The other end of the upper spring **245** contacts the coil header assembly **220** proximate the intersection of the opening **226** and the base portion **224**. The lower spring **240** is disposed within the lower cavity **216** between the spool **230** and an adjustable set screw **233**. One end of the lower spring **240** contacts the adjustable set screw **233**. The other end of the lower spring **240** contacts a second end **232** of the spool **230**. The spool **230** is slidably disposed within the sleeve **260** between the two springs **240**, **245**. The sleeve **260** is disposed within the valve body between the upper cavity **215** and the lower cavity **216**. However in alternate embodiments, the sleeve **260** may not be a separate member and may instead be integral with the valve body **290**. The springs **240**, **245** exert a spring bias on opposing ends of the spool **230**. It is noted that at least a portion of the motor housing **210** is magnetized in order to be responsive to the voice coil **221**.

In this example, a top surface **211** of the motor housing **210** contacts a bottom surface **208** of motor housing retainer **207**. The motor housing **210** is therefore held in place by the motor housing retainer **207**, and the motor housing retainer **207** may be a printed circuit board. However, alternate embodiments may provide any suitable motor housing retainer. Additionally, it is to be noted that in alternate embodiments the valve **200** may comprise elements/components providing for features such as dead band elimination, variable frequency and amplitude dither, retaining mechanical elements having static or dynamic forces thereon, integration of electronics in a pneumatic valve body, mounting techniques for electronic modules in various products, closed loop current control of a voice coil using pulse width modulation drive elements, and/or techniques for control of an air loaded regulator and cascaded control loops, for example.

The exemplary spool **230** includes a passage **265**. The passage **265** has a number of purposes, including equalizing pressure between the upper cavity **215** and the lower cavity **216**, as described in more detail below. The passage **265** extends the entire length of the spool **230** between the top and bottom ends of the spool.

As also described below, the electronics cover **205** includes a connector **206** used to couple a spool position controller **115** to the voice coil **221** (or couple other useful signals from the valve internal to the control electronics) on voice coil portion **222**. The electronics cover **205** is one example of a cover used herein.

The valve **200** is similar to the valve shown in U.S. Pat. No. 5,960,831, which is hereby incorporated by reference in its entirety, and is assigned to the assignee of the present application. A description of exemplary operation of the valve **200** is included in U.S. Pat. No. 5,960,831. U.S. Pat. No. 5,960,831 describes, for instance, airflow through the external ports **270**, **271**, **280**, **281**, and **283** and the circumferentially spaced internal ports **270***a*, **271***a*, **280***a*, **281***a*, and **283***a*. It is noted that the springs **240**, **245** along with the coil header assembly **220**, motor housing **210**, and spool **230**, are configured such that the spool **230** blocks the ports **281**A when no power is applied to the voice coil **221**. Other portions of pneumatic valve **200** are also described in U.S. Pat. No. 5,960,831.

The spool **230** has several 'lands' **242**, **244**, and **246** that block flow from the ports **282**A, **271**A, **281**A, **270**A, and **280**A (collectively, "ports" herein) in the sleeve **260**. Miniature gaps between the lands **242**, **244**, and **246** and the inner surface **252** of the sleeve **260** may allow for fluid leakage within the valve body **290**. This fluid leakage may increase the pressure in portions of the valve body. The disclosed spool **230** provides for a technique for equalizing pressures in a pneumatic valve.

Referring now to FIG. **3** with appropriate reference to previous figures, a side cross-sectional view is shown of a valve **2400** in accordance with a second embodiment of the present invention. The valve **2400** is similar to the valve **200** of FIG. **2**. The discussion below regarding exhaust leakage also applies to the pneumatic valve **200** of FIG. **2**. The pneumatic valve **2400** includes a valve body **2490** (similar to the body **290**), a set screw chamber **2440** (similar to the lower cavity **216**), a voice coil chamber **2415** (similar to the upper cavity **215**), an upper spring **2446** (similar to the upper spring **245**), a coil header assembly **2421** (similar to the coil header assembly **220**), a lower spring **2441** (similar to the lower spring **240**), a sleeve **2460** (similar to the sleeve **260**) and a spool **2430** (similar to the spool **230**). One difference between the valve **2400** and the valve **200** is the location of the upper spring **2446**. The spring **2446** is disposed around a spool connecting portion **2426** (similar to the spool connecting portion **225**) of the coil header assembly **2421**. One end of the upper spring **2446** contacts a land **2427** (similar to the land **246**) of the spool **2430**. The other end of the upper spring **2446** contacts a sleeve retainer **2445**. The springs **2441**, **2446** exert a spring bias on opposing ends of the spool **2430**.

At higher operating pressures, air may leak past the exhaust land **2420** (similar to the land **242**) into a sealed chamber, set screw chamber **2440**. In a conventional configuration having a solid spool, the set screw chamber **2440** would build pressure and cause an offset in force to oppose operating forces in the system, placing the solid spool in an unpredictable position. Another effect of a sealed set screw chamber **2440** with a small volume in a conventional configuration is that solid spool displacement into the volume of the set screw chamber **2440** causes a slight increase in pressure (and vice versa). In conventional configurations this effect would add a non-linear spring effect that would affect dynamic performance. Additionally, conventional solid spools have a relatively large amount of mass that must be moved.

One conventional solution to the exhaust and non-linear spring problems is to vent the set screw chamber **2440** to atmosphere; however, this solution would likely compromise environmental sealing such as water tightness. Another conventional solution is external porting to connect the two chambers (set screw chamber **2440** and voice coil chamber **2415**) pneumatically. External porting would solve the exhaust and non-linear spring problems by ensuring that the chambers **2440**, **2415** remained at the same pressure; however, cross porting would be required as well as deep drilling operation, both of which add cost to the valve body **2490**.

An exemplary solution to the exhaust and non-linear spring problems is to manufacture the hollow spool element **2430** having open ends, which completely connects (in fluid communication) the voice coil chamber **2415** with the set screw chamber **2440**. FIG. **4** is an end view along the minor axis of the hollow spool **2430** for use in pneumatic valves such as shown in FIGS. **2** and **3**. FIG. **5** is a side view along the major axis of the hollow spool **2430** of FIG. **4**. The hollow spool **2430** contains a passage or fluid conduit **2465** sized and shaped to equalize pressure within the valve body **2490** during static leak and dynamic operation. Manufacturing the hollow spool **2430** ensures that the pressures on both ends of the spool **2430** are approximately equal under most or all conditions.

A first end **2471** of the spool **2430** is received by the spool connecting portion **2426**. The spool connecting portion **2426** comprises an opening **2428** (similar to the opening **226**). The connection between the spool connecting portion **2426** and the spool **2430** forms a fluid passage which allows the set screw chamber **2440** to be in fluid communication with the voice coil chamber **2415**. Clearance between a motor housing **2429** (similar to the motor housing **210**) and the coil header assembly **2421**, as well as base portion holes **2422** (similar to the holes **228**), allow for fluid communication between the opening **2428** and the voice coil chamber **2415**. A second end **2472** of the spool **2430** is open at the set screw chamber **2440** allowing for fluid communication therebetween.

It should be noted that although the figures illustrate the holes **2422** in the base portion aligned in a circular array, alternative embodiments may comprise any configuration, number, or orientation of holes suitable for fluid communication.

In an exemplary embodiment, the substantially uniform hole diameter used to form passage **2465** is chosen such that rapid spool motion will not restrict the displacement air flow required to keep air pressures approximately equal (as very small pressure differences may exist dependent on leak size and spool velocity) between the voice coil chamber **2415** and the set screw chamber **2440**. Since the hole diameter is a relatively large diameter for pneumatic purposes, the mass is reduced appreciably, which has an added benefit of increasing dynamic performance. It is noted that a number of possible hole diameters may be used, depending on, e.g., pneumatic and spool strength criteria. It should also be noted that although the figures illustrate the opening as a cylindrical opening, any suitable shape for equalizing pressure may be provided.

It should be understood that although portions of the disclosure are made with reference to a pneumatic valve, the disclosed electronically controlled valves may also be provided for controlling the operation of an associated fluid control valve such as a hydraulically operated valve for example.

In the past, conventional configurations having solid spools without a passage within the spool experience a pressure mismatch problem. This mismatch problem occurs when fluid leakage within the valve body causes the pressure at either the upper cavity or the lower cavity to increase. This increased pressure at one of the cavities applies a pressure force to the respective end of the spool which works against the normal spool actuation forces. The disclosed hollow spool solves the pressure mismatch problem by providing a fluid passage within the spool and between the upper cavity and the lower cavity to allow the pressures to be equalized. This provides for an improved valve having the advantages of increased efficiency, greater reliability, and improved dynamic performance.

It should be understood that the foregoing description is only illustrative of the invention. Various alternatives and modifications can be devised by those skilled in the art without departing from the invention. Accordingly, the present invention is intended to embrace all such alternatives, modifications and variances which fall within the scope of the appended claims.

What is claimed is:

1. A controlled valve comprising:
- a valve body comprising at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity;
- a spring at the upper cavity;
- a coil header assembly comprising a voice coil portion and a base portion having an opening, wherein the coil header assembly is at the upper cavity, wherein the spring is at one side of the base portion, and wherein a spool connecting portion extends from an opposite side of the base portion;
- a spool disposed within the valve body, wherein the spool comprises a first end and an inner passage, wherein the first end is connected to the coil header assembly at the spool connecting portion, and wherein the inner passage allows the lower cavity to be in fluid communication with the upper cavity through the opening in the coil header assembly; and
- a motor housing at the valve body, wherein the spring is disposed between the motor housing and the base portion.

2. The controlled valve of claim **1** wherein the valve is configured to be actuated directly by a non-pilot controlled actuator, and wherein the actuator is directly connected to the spool.

3. The controlled valve of claim **2** wherein the actuator is internal to the valve body.

4. The controlled valve of claim **3** wherein the actuator is electromagnetic.

5. The controlled valve of claim **4** wherein the valve is electronically controlled.

6. The controlled valve of claim **1** wherein the spool is slidably disposed within the valve body.

7. The controlled valve of claim **6** wherein the valve is configured to be actuated directly by a non-pilot controlled actuator, and wherein the actuator is directly connected to the spool.

8. The controlled valve of claim **7** wherein the actuator is internal to the valve body.

9. The controlled valve of claim **8** wherein the actuator is electromagnetic.

10. The controlled valve of claim **9** wherein the valve is electronically controlled.

11. A servo valve comprising:

a valve body comprising at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity;

a valve actuator assembly disposed within the upper cavity, wherein the valve actuator assembly comprises a base portion, a voice coil portion, and a spool connecting portion, wherein the base portion comprises a hole in fluid communication with the upper cavity, wherein the voice coil portion extends from a first side of the base portion, wherein the spool connecting portion is connected to the base portion, wherein the spool connecting portion extends from a second side of the base portion, wherein the spool connecting portion comprises an opening extending therethrough, and wherein the opening of the spool connecting portion extends through the base portion;

a sleeve between the upper cavity and the lower cavity;

a spool slidably disposed within the sleeve, wherein the spool comprises a fluid conduit extending from a first open end of the spool to a second open end of the spool, wherein the first open end is received by the opening of the spool connecting portion, and wherein the second open end is at the lower cavity; and

a motor housing and an upper spring, wherein the upper spring is disposed between the motor housing and the base portion.

12. The servo valve of claim **11** wherein the fluid conduit is configured to equalize pressure between the upper cavity and the lower cavity.

13. The servo valve of claim **11** wherein the base portion comprises a plurality of holes extending through the base portion.

14. The servo valve of claim **11** wherein an end of the upper spring is at the opening of the spool connecting portion which extends through the base portion.

15. The servo valve of claim **11** further comprising a lower spring disposed within the lower cavity, wherein a first end of the lower spring contacts the second open end of the spool.

16. The servo valve of claim **15** further comprising an adjustable set screw, wherein the adjustable set screw is connected to the valve body proximate the lower cavity, and wherein a second end of the lower spring contacts the adjustable set screw.

17. The servo valve of claim **11** further comprising an upper spring, wherein the spring is disposed around the spool connecting portion, and wherein one end of the upper spring contacts the spool.

18. A servo valve comprising:

a valve body comprising at least one fluid inlet port, at least one fluid outlet port, an upper cavity, and a lower cavity;

a spring at the upper cavity;

a valve actuator assembly disposed within the upper cavity, wherein the valve actuator assembly comprises a base portion, a voice coil portion, and a spool connecting portion, wherein the base portion comprises a hole in fluid communication with the upper cavity, wherein the voice coil portion extends from the base portion, wherein the spool connecting portion is connected to the base portion, and wherein the spool connecting portion comprises an opening therein;

a sleeve between the upper cavity and the lower cavity;

a spool slidably disposed within the sleeve, wherein the spool comprises a fluid conduit extending from a first open end of the spool to a second open end of the spool, wherein the first open end is received by the opening of the spool connecting portion, and wherein the second open end is at the lower cavity; and

a motor housing at the valve body, wherein the spring is disposed between the motor housing and the base portion.

* * * * *