United States Patent

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Continuation of application Ser. No. 688,771, Dec. 7, 1967, now abandoned.

[54] **CONTROL VALVE**
11 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **137/596.16,** 91/6, 91/459, 91/461, 137/625.64
[51] **Int. Cl.** **F16k 21/00,** F01b 23/02, F15b 13/043
[50] **Field of Search** 91/6, 461, 459, 418; 137/625.62, 625.61, 625.63, 625.64, 596.14, 596.16

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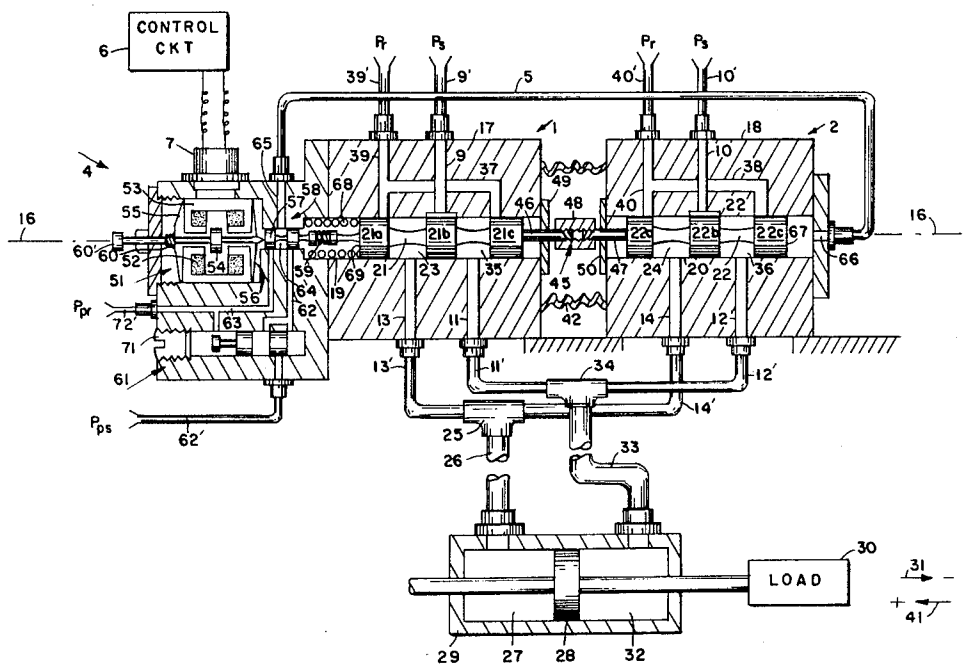
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ABSTRACT: A plurality of spool-type valves are cascaded in tandem so that the spools of the valves are connected and respond to an input control force derived from a control mechanism, which is applied to one spool which acts against a bias force exerted on another spool so that the spools are positioned in unison and one spool delivers position feedback to the control mechanism so that the valves uniformly meter fluid flow at substantially the same pressure to a power actuator, whereby a signal power actuator may receive the total flow from all of the valves.



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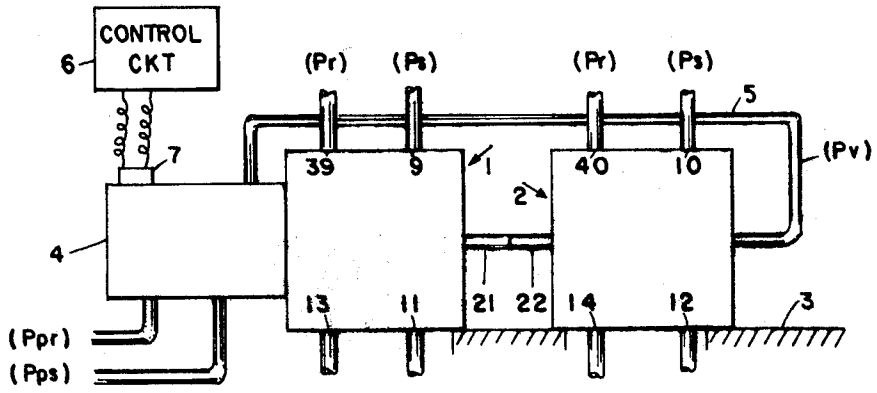


FIG. 1

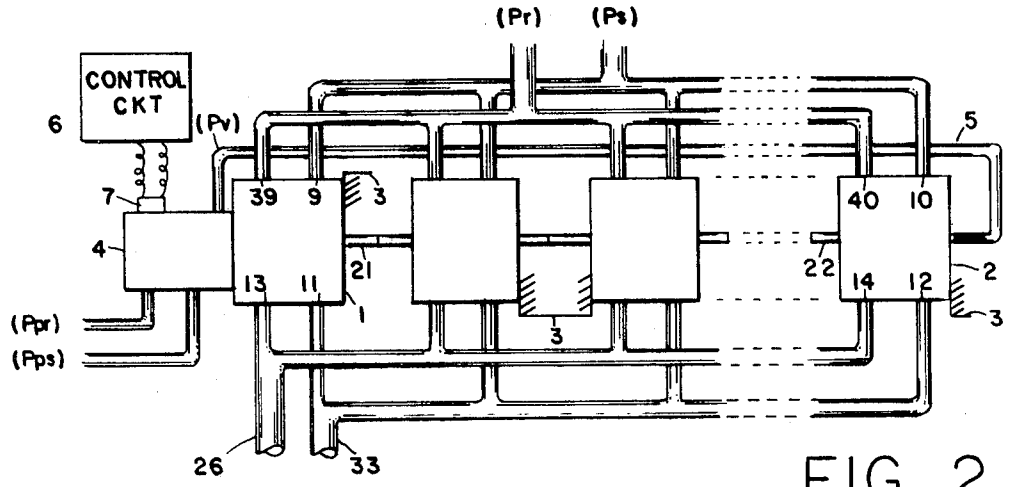


FIG. 2

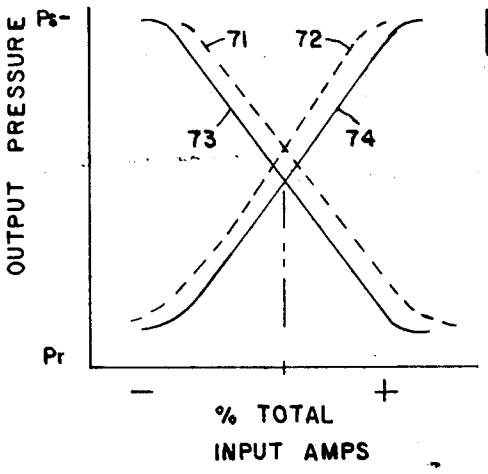


FIG. 3

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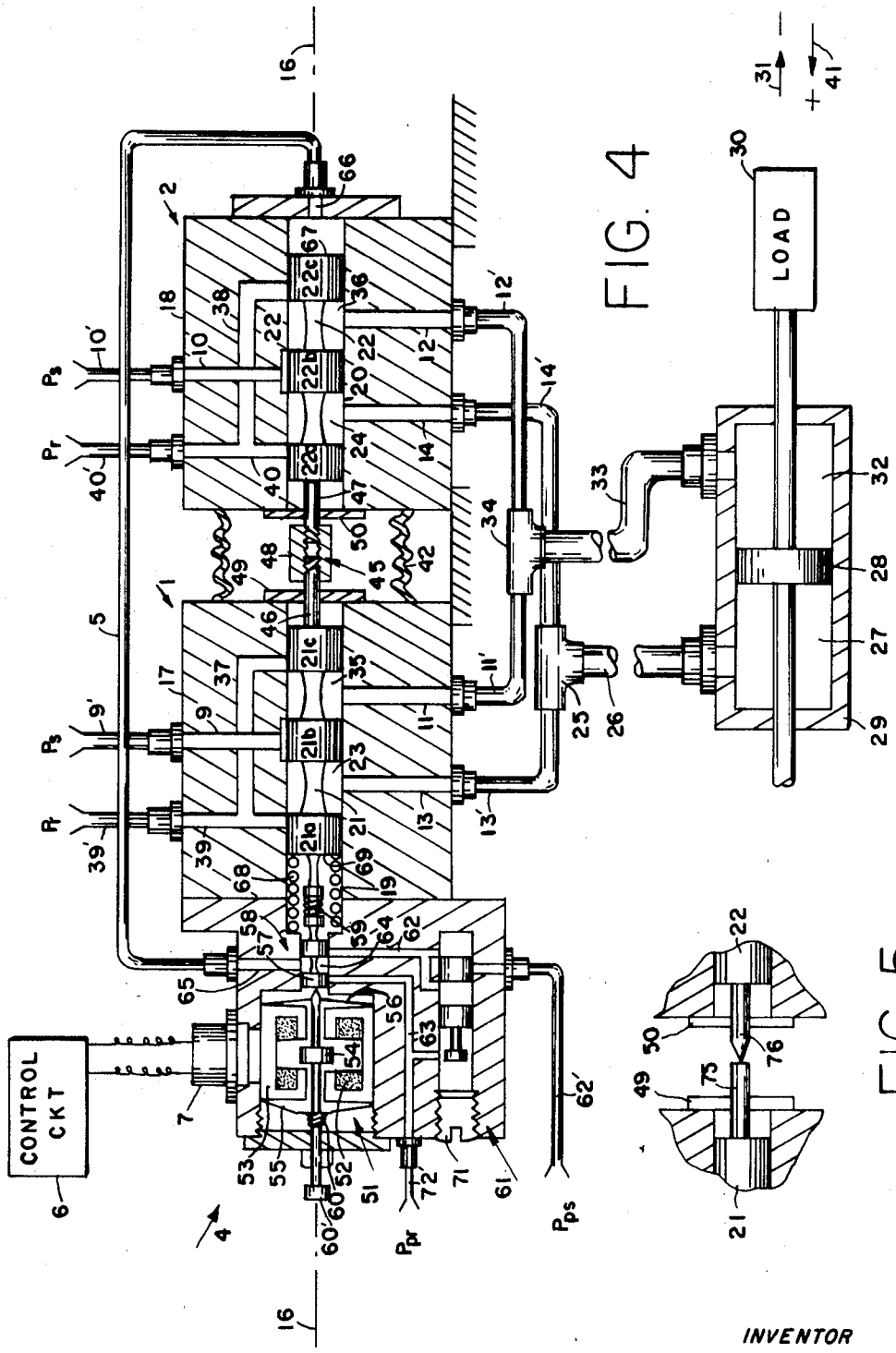


FIG. 4

FIG. 5

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CONTROL VALVE

This application is a continuation of application Ser. No. 668,771, filed Dec. 7, 1967, and now abandoned.

This invention relates to control valves and particularly to a relatively high flow hydraulic control valve including a plurality of stages in parallel all metering hydraulic fluid flow to a power actuator.

Heretofore, the high-flow requirements of large-power hydraulic actuators have been met by the use of multistage servo valves operated in series. In systems controlled by a relatively lower power electrical input signal, the electrical signal is converted by a small motor into a mechanical force which positions a small hydraulic valve. This small hydraulic valve in turn meters hydraulic fluid to control the position of a larger hydraulic valve which in turn meters hydraulic fluid to control the position of an even larger hydraulic control valve. Thus, hydraulic valves of increasing size are connected in series so that the last in the series is of a sufficient size to control the high flow of hydraulic fluid required by a large-power actuator.

The series cascaded hydraulic valve in the prior art is expensive and quite clearly meters a great deal of hydraulic fluid which never gets to the power actuator. Furthermore, it requires a separate feedback in each stage because the stages are of different size and have substantially different response rates.

It is one object of the present invention to provide a control valve providing high hydraulic fluid flow such as required by a large power hydraulic actuator and in which at least some of the disadvantages of the prior cascaded devices are avoided.

It is another object of the present invention to provide such a high-flow valve with a multitude of substantially equal size stages.

It is another object to provide such a valve in which the stages are modular in nature so that stages can be added or removed readily to increase or decrease the total metered hydraulic fluid flow from the valve.

It is another object to provide such a high-flow valve required but a single feedback to accommodate all stages thereof.

In accordance with one embodiment of the present invention, a plurality of substantially identical spool-type hydraulic fluid-metering valves are arranged in tandem with spools connected and with corresponding hydraulic inputs and outputs connected. Thus, the valves are connected mechanically in series and hydraulically in parallel. An input signal is converted to a control pressure which is applied to one end of the spool of one of the valves and acts against a spring engaging another one of the spools so that the spools move in unison and meter fluid at substantially the same flow rate and pressure to a power actuator.

Feedback for all of the valves is provided by a mechanical connection from a single one of the valve spools to the mechanism that determines the control pressure so that the control pressure depends on the position of the spool as well as the magnitude of the input signal.

Other objects and features of the invention will be apparent from the specific description of embodiments of the invention taken in conjunction with the FIGS. in which:

FIG. 1 illustrates a two-stage system of modular identical four-way spool-type valves connected mechanically in tandem or series so that the hydraulic outputs from the valves are of substantially equal flow and pressure;

FIG. 2 illustrates a similar system comprising more than two such modular units connected hydraulically in parallel;

FIG. 3 shows empirical curves of output hydraulic pressure versus percent total electrical input signal for a single valve and for the tandem combination shown in FIG. 1 for comparison of performance;

FIG. 4 is a sectional view of the tandem valve shown in FIG. 1 revealing the significant working parts thereof;

FIG. 5 shows another type of connection that can be used between the tandem stages of the valve assembly.

Turning first to FIG. 1 there is shown an arrangement of two four-way spool-type servo valves arranged in what is referred to herein as a tandem or mechanical series arrangement. The first valve **1** and the second valve **2** are preferably secured relative to each other by fixing each to a common platform **3** and the spools of each of these are connected in manners which will be described hereinbelow. In order to conveniently connect the spools in modular fashion, extensions **46** and **47** (see FIG. **4**) of the spools **21** and **22** extend beyond the valve bodies so that they can be connected externally of the valve bodies.

The valve bodies **1** and **2** may be substantially identical and the spools in these valves may also be identical except for some slightly different attachments made to the spool of valve **1** at assembly in the tandem arrangement. Thus, more than two such valves can be connected in tandem to provide the system of three, four or more valves shown in FIG. **2**.

In the tandem arrangement in FIG. **1**, a control mechanism **4** attaches to the body of valve **1**. This control mechanism **4** operates in conjunction with parts in valve **1** to produce in line **5** a hydraulic control pressure which is applied to one end of the spool in valve **2**. This control pressure, denoted P_c, is generated in response to an electrical input control signal form control circuit **6** which is fed to the control assembly **4** via an electrical connector **7**, and also in response to position feedback from the spool **21** in valve **1**. Thus, the pressure P_c reflects the input command signal and the positions of the valves **1** and **2**. More particularly, the input electrical signal initiates an action, and the position of the spool provides negative position feedback to produce the control pressure P_c. Furthermore, this negative feedback is the same for each of the valves **1** and **2** because the positions of the spools in these valves are identical. Thus, position feedback from a single spool to control mechanism **4** which produces control pressure P_c serves as proper feedback to insure stability of operation of both of the valves **1** and **2**.

In operation, hydraulic fluid at supply pressure P_s from a source, which is not shown, is fed to the valves **1** and **2** via lines **9** and **10**, respectively. The valves **1** and **2** simultaneously meter this high-pressure hydraulic fluid to control ports **11** and **12** or **13** and **14** of the valves **1** and **2**, respectively, depending on the sign and magnitude of the input signal from control circuit **6**. Since the valve are identical and operate in an identical manner, the high pressures simultaneously delivered to, for example, ports **11** and **12** are equal. Likewise when high-pressure hydraulic fluid is simultaneously delivered to ports **13** and **14** these pressures are also equal. This operation can be understood further by referring to the details shown in he sectional view of FIG. **4**.

FIG. **4** is a sectional view of the tandem assembly shown in FIG. **1** revealing the various parts thereof most of which define figures of revolution about the axis **16** of the assembly. The valves **1** and **2** are four-way spool-type valves and may be identical in structure except for attachments to the spools described hereinbelow. The bodies **17** and **18** of valves **1** and **2** contain substantially identical spool bores **19** and **20**, respectively, and the arrangements of fluid ports leading to bores **19** and **20** are substantially identical. Consequently, the spools **21** and **22** in valves **1** and **2** may be interchangeable.

The land areas on spool **21** are denoted **21***a*, **21***b* and **21***c* and the land areas on spool **22** are denoted **22***a*, **22***b* and **22***c*. In operation, land areas **21***b* and **22***b* move to the left or to the right in unison so as to meter fluid at pressure P_s from ports **9** and **10**, respectively, to one or the other of the output ports of their respective valves. For example, when the spools **21** and **22** move in unison to the right, high-pressure fluid is metered from the ports **9** and **10** through chambers **23** and **24** to the output ports **12** and **14** of valves **1** and **2**, respectively. The output flows from the ports **13** and **14** are combined at junction **25** and fed to a common conduit **26** which leads to one side **27** of the piston **28** of a high-power hydraulic actuator **29** causing the actuator to move the load **30** in the direction of arrow **31**.

When the actuator 29 moves the load in the direction of arrow 31, hydraulic fluid form the other side 32 of the power actuator is returned via line 33 and connection 34 to the ports 11 and 12 of the valves 1 and 2, respectively. The return hydraulic fluid flows through the chambers 35 and 36 in valves 1 and 2, through the uncovered ports 37 and 38 and out of the valves 1 and 2 via the return lines 39′ and 40′. The return lines 39′ and 40′ lead to a hydraulic fluid sump or well from which the fluid is taken at pressure P_r and charged to the pressure P_s by a suitable pump or other equivalent means, not shown.

On the other hand, when the pistons 21 and 22 move to the left, high-pressure hydraulic fluid at pressure P_s from lines 9′ and 10′ flows into chambers 35 and 36, respectively, and is fed via the ports 11 and 12 to line 33 which delivers the total flow to side 32 of the power actuator causing the piston 28 to move the load 30 in the direction of arrow 41. At the same time fluid from the other side, 27 of the actuator is returned via line 26 to the ports 13 and 14, through the chambers 23 and 24 and through uncovered ports 39 and 40 which lead to the return lines 39′ and 40′, respectively.

The valve spools 21 and 22 move to the right or left together to meter fluid flow to and from the power actuator 29 at substantially the same pressure or substantially the same pressure and flow rate. It is most convenient if the two valves are identical so that they deliver not only the same pressure of fluid to the power actuator 29, but also deliver the same flow rate. In order to insure this, the spools 21 and 22 are connected together so that they move precisely in unison and for this purpose a coupling mechanism 45 is provided. The coupling mechanism 45 is preferably adjustable so that the distance between the spools can be adjusted as necessary to account for the distance between the valves 1 and 2. As shown in FIG. 4, this mechanism consists of rods 46 and 47 which attach to the ends of the spools 21 and 22, respectively, and a coupling member 48 which threadably connects to each of these rods. In addition, seals 49 and 50 are provided over the ends of the valves 1 and 2, respectively, to prevent dirt and dust from entering the valve bores. A flexible dust cover 42 is provided enclosing the coupling assembly 45 to protect it from the environment. FIG. 5 illustrates another suitable coupling mechanism which will be discussed hereinbelow.

The input control assembly 4 includes a force motor 51 which is energized by an electrical current from control circuit 6. This electric current represents the input signal and is fed to the force motor coils 52 via the electrical connector 7. The coils when energized magnetize the stator magnet 53 which compels the force motor armature 54 to move left or right along the axis 16 of the device. The motion of the armature 54 is imparted to sealing diaphragms 55 and 56 at each end of the motor and through the diaphragm 56 to the spool 57 of the two-way pilot valve 58. This force applied by the armature to the pilot valve is opposed by a spring force exerted by pilot reference spring 59 between pilot valve spool 57 and spool 21 of valve 1. Thus, the pilot valve spool 57 moves to a position determined by a balance between the force imposed therein by the armature 54 and the force imposed by the spring 59 and the spring force is, in turn, determined by the position of the spool in valve 1 which of course represents the position also of the spool in valve 2. The position of armature 54 is biased by a spring 60 acting against diaphragm 55 and set by adjusting screw 60′.

The pilot valve 58 is a two-way spool valve type which meters the pressure of hydraulic fluid from the pressure regulator assembly 61. The pilot valve 58 meters fluid from the regulator in line 62 to the pilot return line 63 causing a pressure drop which is determined by the position of the pilot valve spool 57. As a result, the pressure in chamber 64 of the pilot valve, denoted herein as P_r is indicative of the position of the pilot valve spool 57 which in turn is indicative of the input electrical signal from circuit 6 combined with the position feedback from spool 21 via reference spring 59. This operation of the pilot valve is typical of two-way spool-type valves for producing a fluid pressure indicative of a mechanical position.

The chamber 64 in the pilot valve in which the control pressure P_r is produced connects to port 65 which feeds this pressure P_r through line 5 to port 66 to one end of spool 22 in valve 2. Thus, the pressure P_r acts against the end face 67 of spool 22 and forces both of the spools 22 and 21 to move to the left against the spool bias spring 68 acting against the end face 69 of spool 21. And so the position of the spools 21 and 22 is determined by the pressure P_r, because the spools assume a position which is a balance between pressure force P_r on the end of spool 22 and the force of spring 68 delivered against spool 21.

The pressure regulator 61 may be the well-known spring-loaded spool-type set by a screw such as screw 71 which loads a spring in the regulator. Thus, the regulator delivers a substantially constant fluid pressure to the port 62 even though the input to the regulator, P_{ps}, may vary. For example, if P_{ps} should drop, the spring-loaded piston in the regulator would move so as to decrease the pressure drop between line 62′ and port 62.

The control assembly 4 is shown as including the pressure regulator assembly 61. Quite clearly, this pressure may be included outside the control assembly or it may be eliminated in the system if a vary steady source of fluid pressure at the pressure P_{ps} (pilot supply pressure) is available by other means

In FIG. 4, the valves 1 and 2 are identical and this may be an advantage is some application, because it permits the addition of other stages by merely connecting more valves in tandem to provide a greater total output flow to a power actuator. In order to maintain modularity so that a valve unit can be placed any place in the tandem chain of such valves, the control valves such as 1 and 2 are preferably identical except for attachments to the spool 21 of the first valve to accommodate the pilot reference spring 59.

Inoperation, a positive control action applied to control circuit 6 produces an electric current in the force motor coils 52 which creates a magnetic field causing the armature 54 to move along the axis 16 to the right which in turn moves the pilot valve spool 57 to the right uncovering the port 62 into the pilot valve chamber 64 so that the pressure P_r, in chamber 64 increased. This increased pressure P_r is delivered against the face 67 of spool 22 causing the spools 22 and 21 to move to the left uncovering their supply pressure ports 9 and 10, respectively, so that fluid at supply pressure flows into chambers 35 and 56 and out through ports 11 and 12 of the valves 1 and 2, respectively. The flows from ports 11 and 12 are combined in line 33 and delivered to chamber 32 of power actuator 29 causing the piston 28 therein to move the load 30 in the direction of arrow 41 denoted herein as the positive direction. Meanwhile, since the spools 21 and 22 have moved to the left, the pilot reference spring 59 will exert force on the pilot valve spool 57 in opposition to the force exerted thereon by the armature 54 and when these forces on the pilot valve spool 57 are in balance, the control pressure P_r will be in equilibrium and a steady flow and pressure of hydraulic fluid will be delivered via line 33 to the power actuator 29. This manner of controlling the actuator 29 by a control action applied to the control circuit 6 is not proportional control as it does not include any position feedback from the load to the control circuit 6 or from the load to the control assembly 4. Other systems known in the art can be employed at this point to provided proportional control should it be desired.

FIG. 3 is a plot of output control pressure which can be fed to a power actuator as a function of the percent total input current applied to the force motor coils. In FIG. 3, the broken line curves 71 and 72 represent the pressures at output ports such as 11 and 13 of valve 1 as a function of percentage of total input current fed to the force motor coils. The solid line curves 73 and 74 are equivalent output pressures obtained with the tandem arrangement of two valves shown in FIGS. 1 and 4. These curves are taken form empirical tests of a single valve and a dual tandem valve constructed of identical parts, and reveal that pressure gain for the dual tandem valve combination is the same as the single valve and there is no cross-

talk in the operation of the dual tandem valve combination. Quite clearly, the flow rate for the dual tandem combination is substantially twice the flow rate for the single valve, while at the same time pressure, gain and stability are as good with the dual tandem arrangement as with a single valve.

FIG. **5** illustrates another coupling arrangement between the spools of adjacent control valves which can be substituted for the coupling assembly **45**. In FIG. **5**, for example, the coupling consists of pins **75** and **76** attached to the spools **21** and **22** which make point contact with each other.

The various embodiments of the present invention described herein, illustrate a tandem arrangement of a multitude of control valves in which the control valves are preferably identical so as to permit modular construction and interchange of the valves. It should be clearly understood, however that a multitude of such valves could be constructed in one unitary valve housing and that the individual spools shown and described herein with reference to the various embodiments could be formed as a single unitary spool with land areas arranged thereon to accommodate a plurality of separate valves. Such a structure would not deviate fundamentally from the modular structures described herein with reference to the FIGS. Accordingly, it is to be clearly understood that the foregoing illustrates but a few of the embodiments of the invention as set forth in the appended claims.

I claim:

1. A servo valve assembly comprising:

a plurality of substantially identical spool-type control valves positioned in a line with their spools coaxially aligned and in end-to-end engagement,

a source of fluid at supply pressure,

means for connecting said source to each of said valves,

means responsive to an input control signal for producing a control pressure varying therewith,

means for applying said control pressure to the outside end of the spool of that one of said control valves which is at one end of said line,

means for exerting a bias force on the outside end of the spool of that one of said control valves which is at the other end of said line,

whereby said exerted force opposes said applied control pressure and all of said spools move as a unit a distance which varies with the magnitude of said control signal, and

means for connecting the fluid outputs form each control valves to each other and to a common output.

2. A servo valve assembly in accordance with claim **1** in which said means for producing a control pressure includes a force motor and a pilot valve.

3. A servo valve assembly in accordance with claim **2** including means for providing position feedback from the spools of said control valves to said pilot valve.

4. A servo valve assembly in accordance with claim **3** in which said pilot valve is a spool-type valve and in which said means for providing position feedback includes a reference spring between said spool of said pilot valve and the spool of one of said control valves.

5. A servo valve assembly in accordance with claim **4** in which said pilot valve is a two-way valve and in which each of said control valves is a four-way valve.

6. A servo valve assembly comprising,

first and second substantially identical spool-type control valves positioned side-by-side with their spools coaxial,

means for mechanically coupling adjacent ends of said spools together,

means responsive to an input control signal for producing a control force varying therewith,

means for applying said control force to the end of the spool of said second control valve which is remote from said first valve,

means for exerting a bias force in opposition to said control force on that end of the spool of said first control valve which is remote form said second valve whereby said spools move as a unit a distance which varies with the magnitude of said input control signal, and

means for connecting the outputs of said valves together whereby the output fluid pressure and the rates of flow from said first and second control valves are substantially equal and vary with the magnitude of said input control signal.

7. A servo valve assembly in accordance with claim **6** in which said means for coupling includes a mechanism for adjusting the distance between adjacent spools.

8. A servo valve assembly in accordance with claim **6** in which said means for producing a control force includes a force motor responsive to said input control signal and a spool-type pilot valve responsive to the force exerted by said force motor.

9. A servo valve assembly in accordance with claim **8** including a reference spring between the spool of said pilot valve and the spool of one of said control valves for providing position feedback.

10. A servo valve assembly in accordance with claim **9** in which said pilot valve is a two-way valve and in which each of said control valves is a four-way valve.

11. A servo valve assembly in accordance with claim **10** in which the spools of said control valves are connected rigidly together.