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Johnson et al.

[11] **3,788,077**

[45] **Jan. 29, 1974**

[54] **OPEN CENTER CONTROL OF VARIABLE PUMPS**

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[21] Appl. No.: **271,303**

[52] **U.S. Cl.** **60/452,** 417/212

[51] **Int. Cl.** **F16h 39/46**

[58] **Field of Search** 60/452, 445; 417/212

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Attorney, Agent, or Firm—Donald W. Banner et al.

[57] **ABSTRACT**

Control of the displacement of a variable displacement pump is achieved by the use of a standard opencenter type of control valve and pump displacement controls that include a sensor valve. The control functions that are achieved include system standby at low pressure and minimum displacement thereby minimizing power loss and heat rise.

20 Claims, 6 Drawing Figures

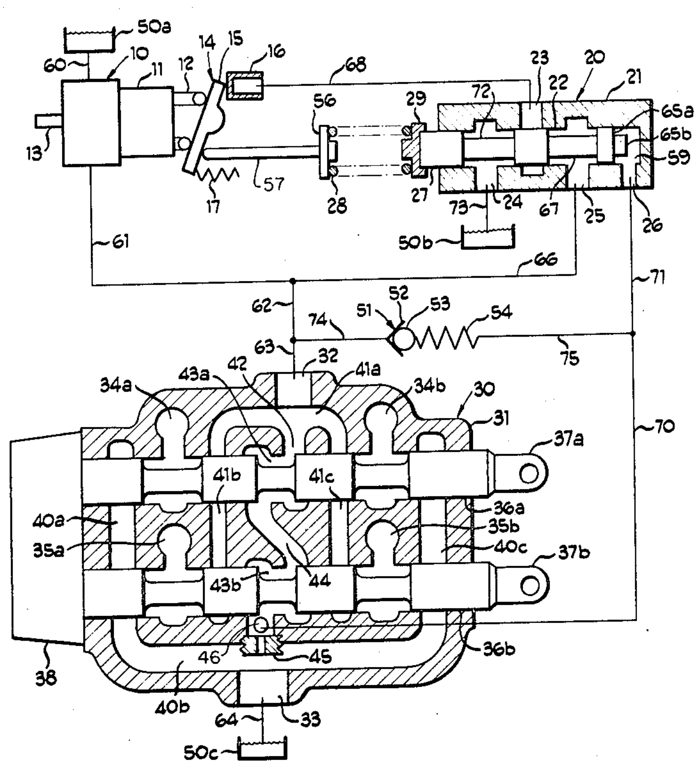

Fig 1

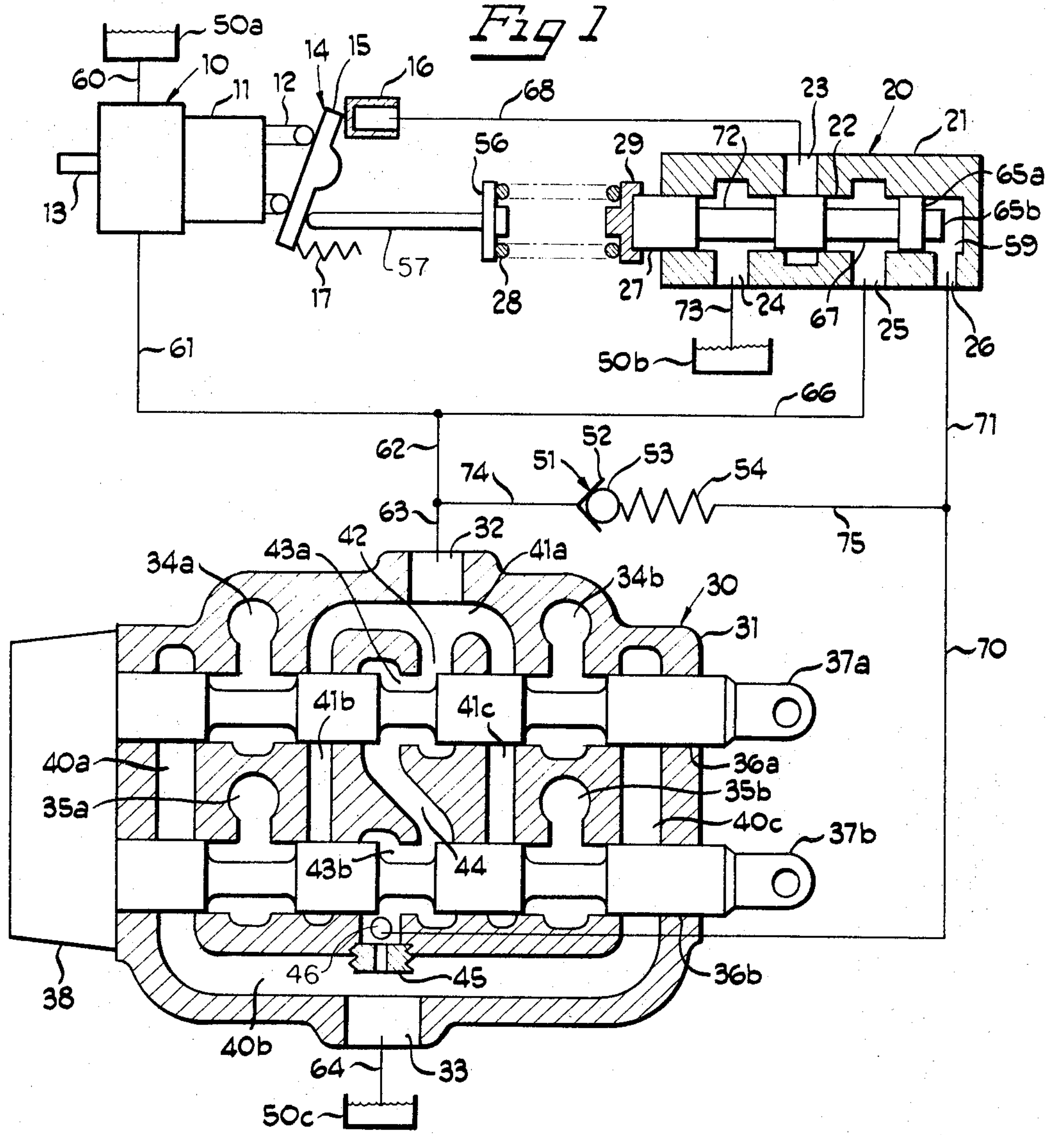
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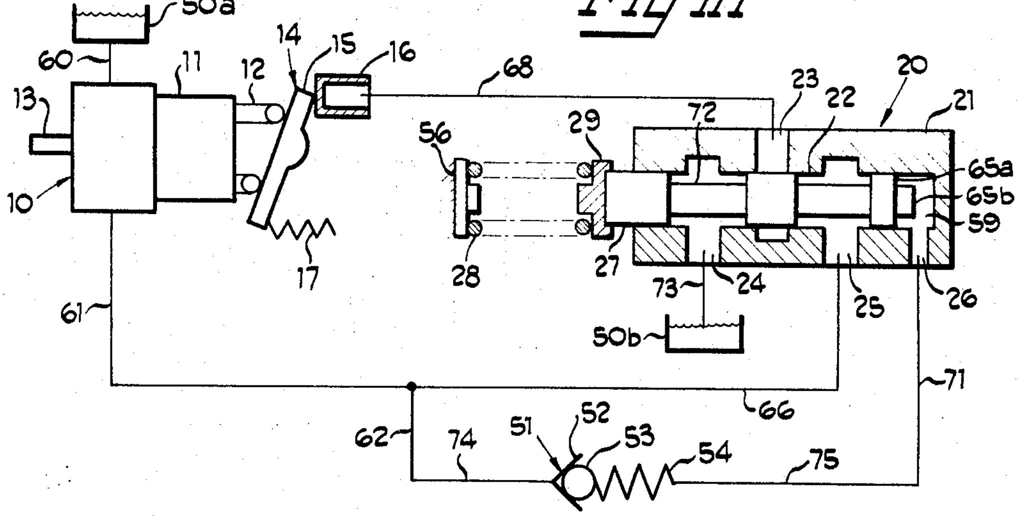
Fig 1A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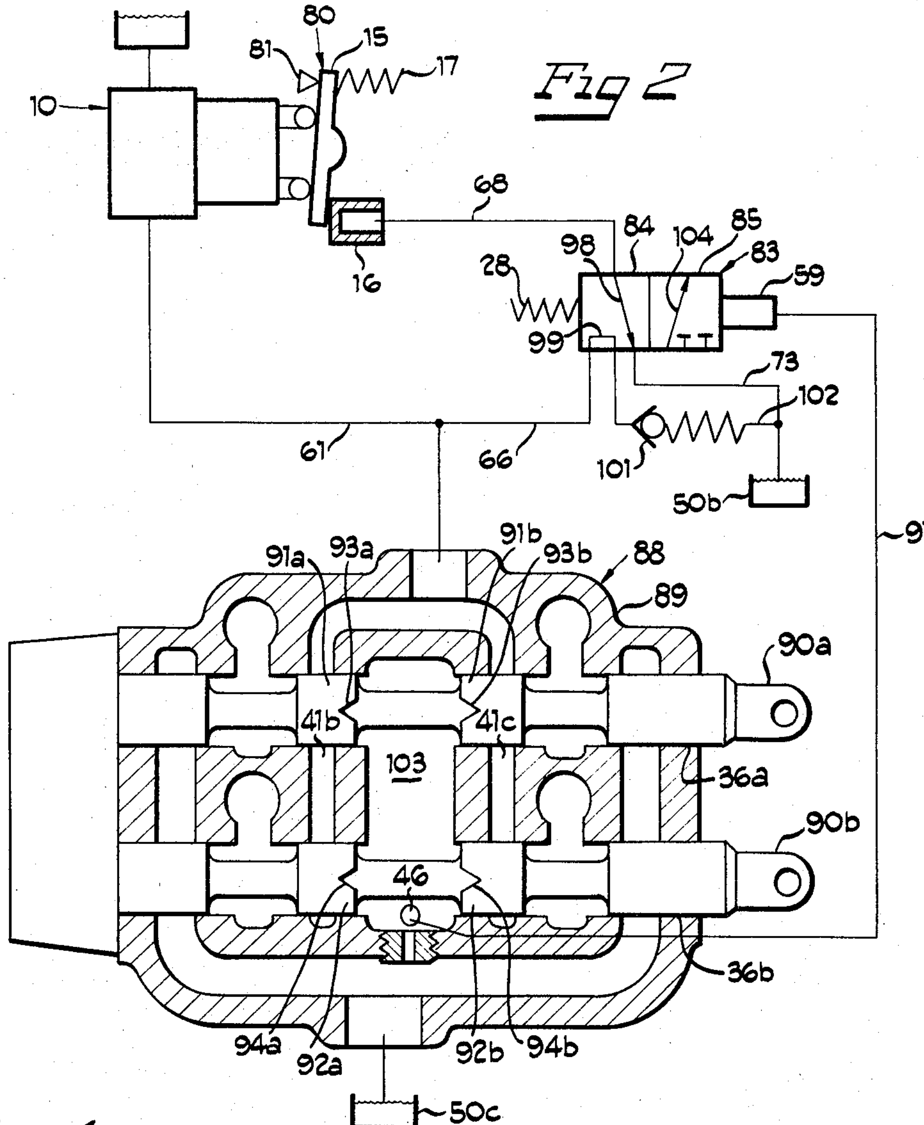
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91b
91a
93a
93b
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90a
41b
41c
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90b
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36b
94a
92a
92b
94b
50c

Fig 2

Fig 4

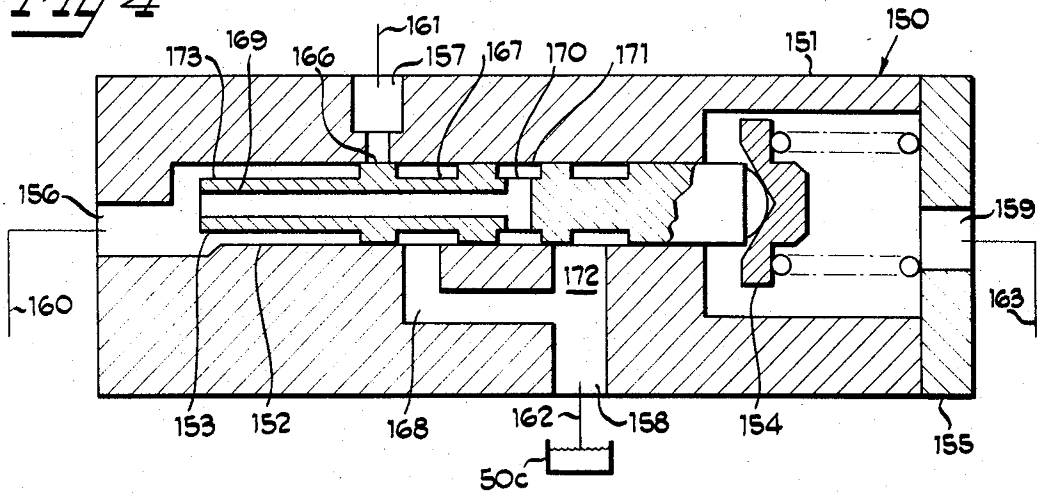
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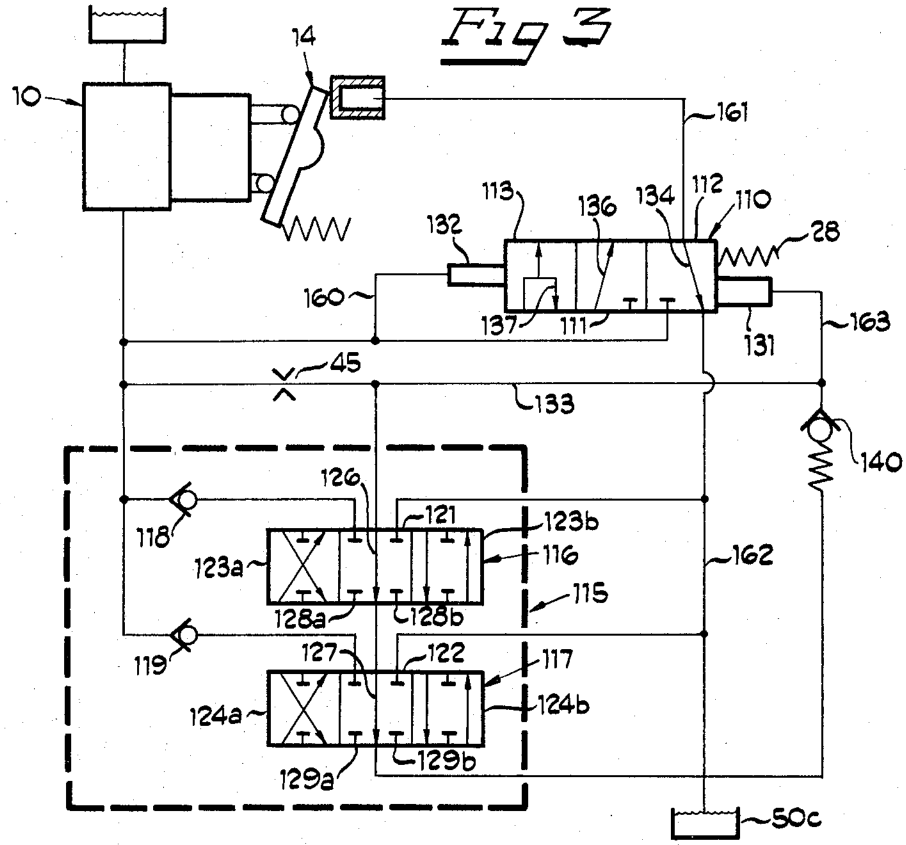
Fig 3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123b
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123a
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128a
128b
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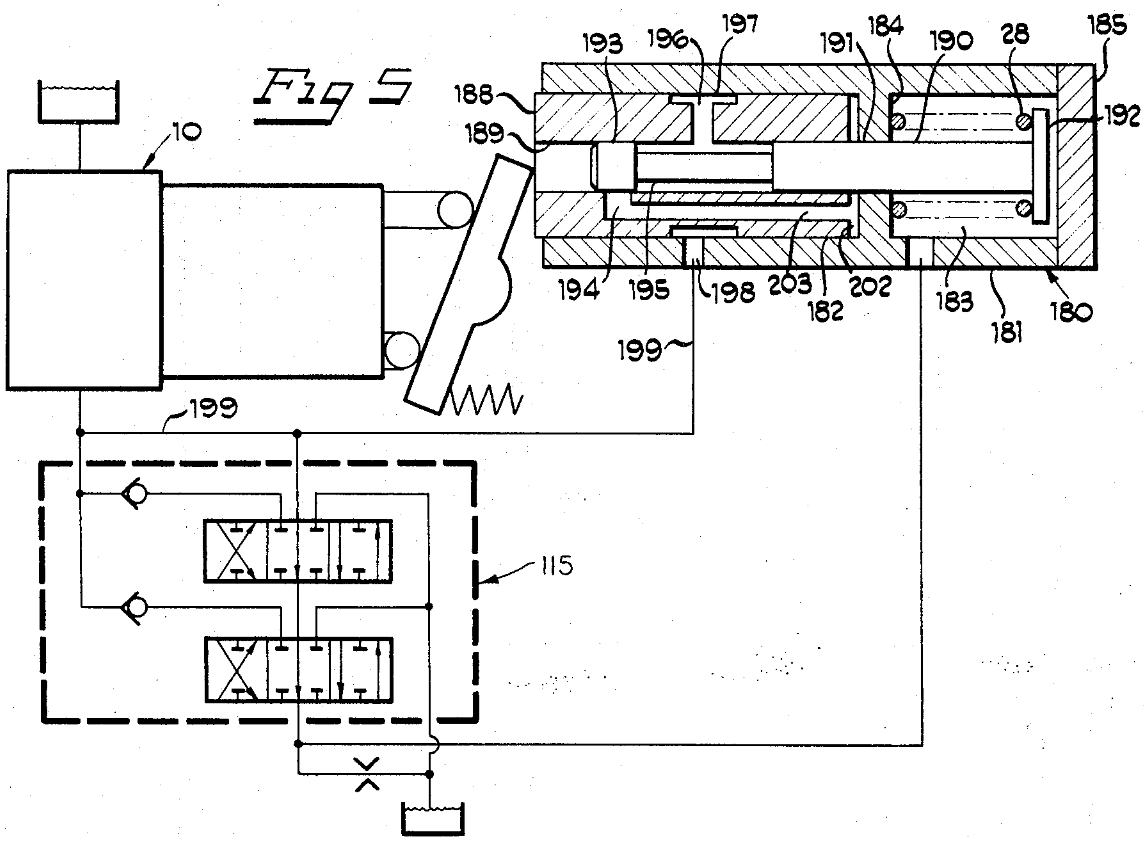
124a
124b
129a
129b
50c

Fig 5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OPEN CENTER CONTROL OF VARIABLE PUMPS

THE INVENTION

Hydraulic systems utilizing fixed displacement pumps and open center control valves are used extensively and have been for many years. Multiple spool control valves of this type include a neutral flow passage that connects the valve inlet port with the valve outlet port when all valve spools are in a neutral position. This provides a fluid path to convey all pump discharge from the valve inlet port to the valve outlet port and to the fluid sump or reservoir when no power is needed, thereby holding the fluid pressure, power at the pump increases as functions of both the number of valve spools and the flow rate, so that excessive neutral flow pressures, power losses, and heat rises are often encountered in system design.

Another disadvantage of the standard type of open center system utilizing a fixed displacement pump is that, when utilizing only a part of the pump displacement, the unused pump flow results in a power loss as a function of the percentage of flow that is bypassed and of the instantaneous working pressure of the system. Thus, it is not unusual to be wasting as much power as is being used at a given time.

Variable displacement pumps with pressure compensator controls have been used in an attempt to achieve better system efficiency. The disadvantages of this type of system are that: the standby pressure is the maximum system pressure; and operation of a fluid motor at low pressure and low flow involves the throttling of a large pressure drop across the valves which constitutes a large power loss.

Load-responsive systems are one solution to the inadequacies of both the open center and pressure compensated systems. An example of an advanced system of this type is disclosed in U.S. Pat. No. 3,526,247. A load responsive system has many advantages, but it includes the disadvantage of requiring a control valve of special design and increased complexity.

The system of the present invention overcomes the disadvantages of the open center system by providing low standby pressure at the minimum displacement of a piston pump, as well as at low pressure. Also, the excessive power loss during partial flow use of the open center system is eliminated because the system of the present invention produces only the flow that is required, that is, as long as only one valve spool is actuated at any one time.

The system of the present invention also overcomes the disadvantages of the pressure compensated system. The present invention achieves not only standby pressure at minimum pump displacement as does the pressure compensated system, but also it achieves standby pressure conditions at low system pressure. Also, the high power loss caused by throttling flow to a motor operating at low pressure and low flow, as experienced by pressure compensated systems, is eliminated by the present invention. In the present invention, only the necessary flow and pressure are pumped, as long as only one valve spool is actuated at any one time.

The system of the present invention also overcomes the disadvantage of the load responsive system, or an even less complex and less costly closed center valve can be designed especially for the system disclosed herein.

Included in the disclosed variations of the present invention are two designs that achieve greater precision of control of the pump displacement by the use of a mechanical feedback between the displacement control mechanism of the pump and the sensor valve that controls the displacement control mechanism. One of these variations utilizes a spring as a portion of the feedback mechanism, and the other includes a piston in the displacement control mechanism as a portion of a coaxial piston feedback mechanism. Both of these variations are adaptable for use with a standard open center valve having series connected neutral flow passages.

THE DRAWINGS

FIG. 1 is a schematic of the system that includes a cross sectional view of the sensor valve and a cross sectional view of an open center control valve.

FIG. 1A is a modification of the system shown in FIG. 1.

FIG. 2 is a schematic of the system that includes a cross sectional view of a closed center control valve having parallel connected control signal valves.

FIG. 3 is a schematic of the system in which the sensor valve includes a third or bypass position.

FIG. 4 is a cross section of a sensor valve that includes third and fourth bypass positions.

FIG. 5 is a schematic of the system that includes a cross section of a sensor valve having coaxial piston feedback.

Referring to FIG. **1**, a variable displacement pump **10** of the axial piston type includes a rotating cylinder barrel **11** containing a plurality of pistons **12** and rotated by a drive shaft **13**. The pump **10** also includes a fluid actuated displacement control mechanism **14** which is comprised of a variable inclination swash plate **15** mounted on trunnion bearings, not shown, and adapted to impart reciprocating movement to the pistons **12**, a control piston **16** adapted to impart a displacement decreasing movement to the swash plate **15**, and a spring **17** adapted to urge the swash plate **15** toward a higher displacement inclination.

The system of FIG. **1** also includes a sensor valve **20** which includes a body **21** having a plunger bore **22** and ports **23**, **24**, **25**, **26** and which also includes valve plunger **27** and and a bias force means or bias spring **28**.

An open center control valve **30** is also included in FIG. **1**. The control valve **30** includes a valve body **31** having an inlet port **32**, an outlet port **33**, work ports **34*a*** and **34*b***, work ports **35*a*** and **35*b***, and valve spool bores **36**a and **366**. Valve spools **37*a*** and **37*b*** are slidably fitted in the bores **36*a*** and **36*b*** and resiliently held in their neutral positions as shown by means of centering springs, not shown, which are included in cap **38**.

The control valve **30** of FIG. **1** includes return passages **40*a***, **40*b***, **40*c*** and pressure passages **41*a***, **41*b***, **41*c***. The control valve **30** also includes a neutral flow passage **42** which consists of control signal valves **43*a*** and **43*b*** which are series connected by means of a passage **44**.

Control signal valves **43*a*** and **43*b*** each are so constructed that movement of either of the spools **37** in either direction results in the closing of the control signal valve associated with the valve spool being moved.

Thus the control valve **30** is a standard type of open center control valve with the exception of the restrictor means or orifice **45** and the control signal port **46**.

The hydraulic system of FIG. **1** also includes a reservoir or fluid sump symbolized by the separate sumps **50***a*, **50***b* and **50***c* and includes a pilot relief valve **51** having a seat **52**, a poppet **53**, and a spring **54**.

Referring again to the sensor valve **20**, the bias spring **28** is adapted to urge plunger **27** to the right by means of a spring adapter **29**. The left end of spring **28** is held by a spring adapter **56** and a push rod **57** which is interposed between the spring adapter **56** and the swash plate **15**. However, the operation of the system will first be described without the pushrod **57** and with the adapter **56** rigidly fixed to the body **21** of the sensor valve **20** by a mechanical connection, as shown in FIG. 1A.

Operation of the FIG. 1A system is as follows: the pump **10** receives fluid from the sump **50***a* by a conduit **60**. Pressurized fluid is discharged from the pump **10** via conduits **61**, **62** and **63** to the inlet port **32** of the control valve **30** and through the control valve **30** to the sump **50***c* via the pressure passage **41***a*, the neutral flow passage **42** which is comprised of the control signal valves **43***a* and **43***b* and the passage **44**, the restrictor meanS **45**, the return passage **40***b*, the outlet port **33**, and a conduit **64**.

This flow of fluid from the pump **10** to the sump **50***c* via the restrictor **45** results in a pressure drop across the restrictor **45** which causes an increase in fluid pressure between the pump **10** and the restrictor **45**. This increase of pressure is applied to a fluid responsive area comprised of projected areas **65***a* and **65***b* of plunger **27** of the sensor valve **20** via the control signal port **46**, control signal conduits **70** and **71**, and the port **26**, so that the projected areas **65***a* and **65***b* cooperate with a portion of body **21** and the space therebetween to form a fluid actuator means **59** and to move the plunger **27** from the neutral position as shown, to the left against the bias force of the spring **28**. This movement of the plunger **27** to the left to a second operating position is effective to connect pump pressure from the pump **10** to a control piston **16** via the conduits **61** and **66**, the port **25**, a reduced plunger portion **67**, the port **23**, and a conduit **68**. Thus the increase in pump pressure as caused by fluid flow across the orifice **45** is used as a control signal pressure and it is effective to move the plunger **27** to the left, to direct pump flow to the piston **16**, to decrease the inclination of the swash plate **15**, and to decrease the displacement of the pump **10** whenever the force developed by the fluid actuator means **59** is sufficient to overcome the bias force of the spring **28**.

This reduction in displacement as caused by neutral flow of fluid through the control valve **30** occurs in the standby condition of the apparatus. That is, the valve spools **37***a* and **37***b* are in their neutral positions, as shown, and they are blocking the work ports **34***a*, **34***b*, **35***a* and **35***b* from both the pressure passages **41** and the return passages **40** so that fluid actuated devices or fluid motors attached to the work ports **34** and **35** are not being actuated. In this standby condition, the displacement of the pump **10** is low, that is, the output of the pump **10** is only what is required to cause a pressure rise across the restrictor **45** that will cause a force large enough to overcome the spring **28**.

When either valve spool **37***a* or **37***b* is actuated in either direction, the respective control signal valve **43***a* or **43***b* is closed or restricted. The closing or restricting of a control signal valve is effective to reduce the fluid pressure that is applied to the fluid actuator means **59** because of the reduction or the elimination of flow from the pump **10** and across a control signal valve **43** and thus the reduction or elimination of flow across the orifice **45**. A reduction in fluid pressure in the fluid actuator means **59** allows the spring **28** to move the plunger **27** to the right to a first operating position and to force fluid from the fluid actuator means **59** to the sump **50***c* via the port **26**, the conduits **71** and **70**, the control signal port **46**, the restrictor **45**, the passage **40***b*, the outlet port **33** and the conduit **64**.

This movement of the plunger **27** to the right establishes a flow path across the sensor valve **20** and allows the spring **17** to increase the displacement of the pump **10** by increasing the inclination of the swash plate **15**, by moving the piston **16** to the right, and by discharging fluid from the piston **16** to the sump **50***b* via the conduit **68**, the port **23**, a reduced portion **72** of the plunger **27**, the port **24**, and a conduit **73**.

Thus it can be seen that actuation of either of the valve spools **37***a* or **37***b* is effective not only to connect a work port **34** or **35** to a pressure passage **41** but also to increase the displacement of the pump **10**.

A buildup in fluid pressure beyond that required by a fluid motor attached to a work port **34** or **35** is prevented by designing the valve spools **37***a* and **37***b* so that less movement of the valve spools **37***a* and **37***b* is required to connect a work port **34** or **35** to a pressure passage **41** or to a return passage **40** that is required to restrict or to block a control signal valve, **43***a* or **43***b*, sufficiently to cause an increase in the displacement of the pump **10**.

The relief valve **51** is connected to the pump **10** by conduits **61**, **62** and **74** and to the fluid actuator means **59** by conduits **75** and **71** and the port **26**. Pump pressure above a predetermined value is effective to move the poppet **53** away from the seat **52** in opposition to the spring **54**, sending fluid to actuator **59**, moving the plunger **27** to the left establishing a flow path across the sensor valve **20**, directing pump outlet fluid to the control piston **16**, and decreasing the displacement of the pump **10**.

Referring to FIG. **1**, operation of the system with the push rod **57** included is the same as previously described, except that, inclusion of the push rod **57** provides mechanical feedback to the sensor valve **20**.

The movement of the swash plate **15** is used to change the bias force of the spring **28** through the connection formed by the push rod **57** and the adapter **56**, so that a change in displacement of the pump **10**, as called for by change in control signal pressure applied to the actuator **59** and the movement of the plunger **27**, results in a change in bias force which opposes this movement of the valve plunger **27** that has been caused by the change in control signal pressure. This results in a proportional relationship between control signal pressure and pump displacement. Operation of the FIG. **1** configuration includes movement of spool or valving element **37***a* or **37***b* from the neutral position as shown in FIG. **1** and is effective to reduce the conductance or flow path opening of control signal valve **43***a* or **43***b* proportional to the movement of valving element **37***a* or **37***b*, thereby restricting fluid flow and reducing the fluid flow rate from the pump **10** and the conduit **61** to the sump **50***c* via the restrictor means **45** in proportion to the movement of spool **37***a* or **37***b* and in proportion to the reduction in conductance of a control signal valve **43***a* or **43***b*.

This reduction of fluid flow rate across the restrictor **45** results in a decrease in the pressure drop across the restrictor **45** which is proportional to this change in flow rate and which is also proportional to the movement of valve spool **37***a* or **37***b*, so that the fluid pressure or control signal pressure at the control signal port **46** decreases proportional to the movement of a valve spool **37***a* or **37***b*.

The valve plunger **27** or the sensor valve **20** is designed to move a distance that is proportional to the control signal pressure applied to the responsive areas **65***a* and **65***b* so that the movement of the valve plunger **27** is proportional to both the control signal pressure and to the movement of valve spool **37***a* or **37***b* which controls the control signal pressure.

This proportional response of the valve plunger **27** to control signal pressure is the result of the fluid responsive areas **65***a* and **65***b* developing a force proportional to the control signal pressure and to the bias means or spring **28** which produces a force to resist the movement of the valve plunger **27** that is proportional to movement of the valve plunger **27**.

Thus there is a first level or magnitude of control signal pressure that will move the valve plunger away from a first position in which the surface of the area **65***b* is butted against the right end of the housing **21** and there is a second and higher level of control signal pressure that is required to move the valve plunger **27** to the neutral position as shown in FIG. **1** and also there is a third level of control signal pressure that is required to move the valve plunger to the left of the neutral position and to the second operating position wherein the port **23** is communicated with the port **25** via the reduced plunger portion **67**.

A feedback means is included in FIG. **1** that is effective to change the level or magnitude of control signal pressure that is required to move the valve plunger **27** to the neutral position and to the other positions. This feedback means consists of the push rod **57** and its translating of a change in displacement of the pump **10** is the result of movement of the displacement control mechanism **14** which is movable from minimum to maximum displacement limits and which results in a change in the inclination of the swash plate **15**.

A change in displacement is proportional to a change in the inclination of the swash plate **15** and a change in the inclination of swash plate **15** moves the push rod **57** and the spring adapter **56** proportional to this change in displacement so that the load of the spring **28** and the control signal pressure required to move the valve plunger **27** to a given position are both changed proportional to a change in the displacement of the pump **10**.

Thus a movement of valve spool **37***a* or **37***b* results in a control signal pressure and in a movement of the valve plunger **27** that are both proportional to the movement of valve spool **37***a* or **37***b*, and the movement of the valve plunger **27** to a position on either side of neutral results in fluid flow into or out of the control piston **16** and a resultant change in the displacement of the pump **10**. This change in displacement continues until the push rod **57** is moved by the swash plate **15** sufficiently to change the control signal pressure that is required to move the valve plunger **27** to the neutral position to be equal to the control signal pressure being produced by the movement of valve spool **37***a* or **37***b*.

That is, the valve plunger **27** moves to the neutral position as shown and locks the displacement of the pump **10** and the inclination of the swash plate **15** to control the displacement of the pump **10** proportional to movement of valve spool **37***a* or **37***b* and the magnitude of the control signal pressure.

Referring now to the FIG. **2** embodiment, a variable displacement pump **10** has a displacement control mechanism **80** which includes: a swash plate **15**, a control piston **16** that is adapted to increase the displacement of the pump **10**, a spring **17** that is adapted to decrease the displacement of the pump **10** and a minimum displacement stop **81**.

The system of FIG. **2** includes a sensor valve **83** that is symbolically represented and that includes first and second operating positions which are represented by boxes **84** and **85**. The sensor valve **83** is operated to the first operating position **84** by a bias force or spring **28** and to the second operating position **85** by a fluid actuator **59**.

The FIG. **2** configuration also includes a closed center control valve **88** which includes a body **89** and valve spools **90***a* and **90***b*. The operation of control valve **88** is the same as that of control valve **30**, except that, the body **89** and the spools or movable valving members **90***a* and **90***b* have been modified to provide control signal value lands or valves **91***a*, **91***b*, **92***a* and **92***b* which are parallel-connected and which are normally closed, whereas the control signal valves **43***a* and **43***b* of the FIG. **1** configuration were connected in series and were normally open.

The control signal valves **91***a* and **91***b*, **92***a* and **92***b* are comprised of the notches **93***a*, **93***b*, **94***a* and **94***b* and of the valve spool bores **36***a* and **36***b* where they intersect the pressure passages **41***b* and **41***c*. Thus each of the control signal valves **91***a*, **91***b*, **92***a* and **92***b* includes a first port which is a portion of a passage **41** and all of these first ports are interconnected by the passage **41** and each of the control valves **91***a*, **91***b*, **92***a* and **92***b* includes a second port comprised by a control signal pressure chamber **103**.

In standby operation the valve spools **90***a* and **90***b* are held in their neutral positions as shown, and all of the control signal valves **91** and **92** are closed, so that the fluid pressure in the control port **46** is approximately the same as the fluid pressure in the sump **50***c*, and the fluid pressure in conduit **97** and actuator **59** is also equal to sump pressure.

The spring **28** is capable of moving the sensor valve **83** to the first operating position **84** because of the low pressure in the actuator **59**, and a fluid path **98** connects the control piston **16** to the sump **50***b* via conduits **68** and **73**, thereby allowing the spring **17** to move the swash plate **15** to the minimum displacement position as limited by the stop **81**.

The displacement of the pump **10** at standby conditions is limited by the minimum displacement stop **81**, and the pump pressure at standby conditions is limited by a standby path **99** in the first position **84** of the sensor valve **83** and a standby relief valve **101** which cooperate to discharge the standby pump flow from the pump **10** to the sump **50b** via conduits **61, 66,** and **102.**

In actual design practice, as will be apparent to those familiar with the art, the fluid path **98** would be established before the standby path **99** is established as the sensor valve **83** is actuated from the second operating position **85** to the first operating position in which the displacement of the pump **10** would be reduced by flow from the piston **16** to the sump **50***c* without loss of fluid from pump **10** through the standby path **99** and the standby relief valve **101**.

The movement of either of the valve spools **90***a* or **90***b*, in either direction from the neutral position to an operating position, is effective to open a fluid path from a notch **93** or **94** to a pressure passage **41***b* or **41***c*, thereby pressuring the control signal pressure chamber **103**, the port **46**, the conduit **97**, and the actuator **59** to move the sensor valve **83** to the second operating position **85** and thus to increase the displacement of the pump **10** by flow of pump fluid from the conduit **66** to the conduit **68** and the piston **16** via a flow path **104**.

Another type of sensor valve is shown in FIG. **3**. The system of FIG. **3** includes a pump **10** and a displacement control mechanism **14** that are similar to the FIG. **1** configuration, a symbolical representation of a bypass type sensor valve **110** that includes a third operating position **113**, and a symbolical representation of a control valve **115** that includes working sections **116** and **117**.

The working sections **116** and **117** are provided with pump flow via load checks **118** and **119** which are common to the art. Each of the working sections has a neutral position **121** or **122** and operating positions **123***a* and **123***b* or **124***a* and **124***b*. The working sections **116** and **117** may be operated to their respective operating positions by any suitable means.

The working sections **116** and **117** include work ports **128***a*, **128***b*, **129***a* and **129***b* which are adapted to be connected to first and second fluid actuated devices and which correspond to work ports **34***a*, **34***b*, **35***a* and **35** of the control valve **30** of FIG. **1**.

The control valve **115** also includes a neutral flow passage which is comprised of two series-connected control signal valves which are symbolized by flow paths **126** and **127**.

Referring again to FIG. **3**, the sensor valve **110** has a first operating position **111**, a second operating position **112**, and a third operating or bypass position **113**. The sensor valve **110** is operated to these three positions by first and second fluid actuators **131** and **132** which may have equal or unequal fluid responsive areas. The sensor valve **110** may optionally include a bias force means or spring **28**.

Operation of the system of FIG. **3** which includes equal areas in the actuators **131** and **132** and which includes the spring **28** is as follows: actuation of either working section, **116** or **117** toward an operating position is effective to restrict or to block a flow path **126** or **127**. The restricting or blocking of a flow path **126** or **127** is effective to increase the fluid pressure or control signal pressure in conduit **133** because the flow paths **126** and **127** control flow from the conduit **133** to the sump **50***c*, and so flow across restrictor means or orifice **45** is effective to build up the pressure in the conduit **133** and in the actuator **131**.

The sensor valve **110** is actuated to the second operating position **112** whenever the total force of actuator **131** and spring **28** is sufficient to overcome the force developed by the pressure of pump outlet pressure in the actuator **132**. In the second operating position **112**, pump displacement is increased by discharging fluid from the piston **16** to the sump **50***c* via a flow path **134**.

When the force developed by the actuator **132** overcomes the force developed by the actuator **131** and the spring **28** then the sensor valve **110** is moved to the first operating position **111** wherein the displacement of the pump **10** is decreased by flow of fluid from the pump **10** into the piston **16** via flow path **136**, or, a greater force developed by the actuator **132** will move the sensor valve **110** to the bypass position **113** wherein the flow path **136** is maintained to decrease the displacement of the pump and an additional or bypass flow path **137** is established. Thus, the bypass position **113** and its bypass flow path **137** cooperate with the displacement control mechanism **14** and the piston **16** to control the effective output of the pump **10**.

The operation of the FIG. **3** configuration with the actuator **131** larger than the actuator **132** is as previously described except that a lower fluid pressure in the actuator **131** is able to overcome the force developed by the actuator **132** so that the control signal valves in the working sections **116** and **117**, as symbolized by the flow paths **126** and **127**, operate at lower fluid pressures,

A pilot relief valve **140** is connected to the actuator **131** and to the sump **50***c* and is effective in limiting the fluid pressure and the force of the actuator **131**, so that pumping pressures above a predetermined value are effective to develop a force in the actuator **132** that overcomes the force of the actuator **131** and moves the sensor valve **110** to the first operating position **111** or even on to the bypass condition **113**. Thus the pilot relief valve **140** adds the function of pressure compensation to the hydraulic system.

The sensor valve **150** of FIG. **4** shows a preferred configuration of a sensor valve that is adapted for use in the system of FIG. **3**.

The sensor valve **150** includes a body **151** having a bore **152**, a plunger **153** in the bore **152**, a spring adapter **154**, a spring **28**, and a cap **155**. The body **151** of FIG. **4** includes ports **156**, **157**, **158** and **159** which are connected by conduits **160**, **161**, **162** and **163** as shown in FIG. **3**.

Referring again to FIG. **4**, plunger **153** is in a neutral position between positions one and two and the port **157** is blocked by plunger land **166**. In a second operating position, the plunger **153** is to the left of the position shown, the land **166** is not blocking the port **157**, and fluid from the piston **16** is free to flow to the sump **50c** via the conduit **161**, a reduced diameter portion **167**, a passage **168**, the port **158** and the conduit **162**.

In a first operating position, the plunger **153** is to the right of the position shown and fluid can flow from the conduit **160** and the port **156** to the port **157** and the piston **16** via a reduced diameter portion **173** thereby reducing the pump displacement.

In a third or bypass position, the plunger **153** is moved further to the right than for the first operating position, so that excess pump flow is delivered to the sump **50c** via the port **156**, a longitudinal passage **169**, a cross drilled hole **170** and an annular groove **171** in the plunger **153**, and a passage **172** in the body **151**.

In a fourth or supplementary bypass position, the plunger **153** is moved yet further to the right opening a supplementary bypass path from the conduit **160** and the port **156** to the port **158** and the sump **50***c* via the reduced diameter portion **173** and the passage **168.**

The advantage of the FIG. **4** construction is that the third position achieves bypass flow with a minimum movement of the plunger **153** from the first operating position; and then additional movement to the fourth operating position is effective to establish a bypass flow path having additional and larger flow capacity.

The system of FIG. **5** is the same as the FIG. **1** configuration, except that, the feedback mechanism consisting of the push rod **57** and the spring **28,** the sensor valve **20,** and the control piston **16** of FIG. **1** are all combined into a coaxial piston sensor valve **180,** and except that, the control valve **30** of FIG. **1** is replaced by the control valve **115** of FIG. **3.**

The coaxial piston sensor valve **180** includes a housing or body **181** which has a piston **182,** a spring cavity **183,** a partition **184** and a cap **185.**

A piston **188** is slidably fitted in the bore **182** and includes a plunger bore **189.** A valve plunger **190** is slidably fitted in bore **189** of piston **188** and cooperates with piston **188** to form first and second relatively movable elements of a sensor valve.

One end of the plunger **190** extends through a hole **191** in the partition **184** into the cavity **183** and thereby cooperating with the cavity **183** to form a fluid actuator means having a fluid responsive area equal to the area of the plunger **190** at the place where it extends through the hole **191.**

A spring **28** placed in compression between the partition **184** and an integral shoulder **192** on the plunger **190** provides a bias force urging plunger **190** to the right.

In operation, the control signal pressure from the port **46** and a conduit **71** is applied to the spring cavity **183** and to the projected area of the plunger **190** forcing the plunger **190** to the left against the force of the spring **28.**

Movement of the plunger **190** to the left moves a plunger land **193** to the left exposing a port **194** to a reduced diameter portion **195** of the plunger **190,** to a cross hole **196** and an annular groove **197** in the piston **188,** and to a port **198** which is connected to pump pressure by a conduit **199.**

Connection of pump pressure to the port **194** is effective to pressurize chamber **202** which exists between the piston **188** and the partition **184** because of the flow path provided by a longitudinal hole **203.**

Pump pressure supplied to the chamber **202** is effective to move the port **194** to the left thereby cooperating with the land **193** to stop additional fluid flow to the chamber **202.** Thus it can be seen that the plunger **190,** the spring **28,** the piston **188** and the swash plate **15** all cooperate to form a mechanism in which the displacement of the pump **10** is controlled to be inversely proportional to the magnitude of the control signal pressure supplied to the spring cavity **183.**

In like manner, a decrease in fluid pressure in the spring cavity **183** allows the spring **28** to move the plunger **190** to the right opening chamber **202** to a sump, not shown, via the longitudinal hole **203,** the port **194,** the exposed left end of the land **193** and the bore **189.**

The systems that have been described provide a superior method of controlling the output of any pump that includes a pressure actuated means of controlling either the actual displacement of the pump or the effective output of the pump. Thus it should be understood that the term variable displacement is used to include pumps having any control that regulates the quantity of fluid that is discharged through the pressure port.

Various features of the invention have been particularly shown and described; however, it should be obvious to one skilled in the art that modifications may be made therein without departing from the scope of the invention.

What is claimed is:

1. A hydraulic system including a variable displacement pump having a fluid actuated displacement control mechanism adapted to control the displacement of said pump, a sump, a control valve having a neutral position and an operating position and being adapted to control a fluid actuated device, and a fluid actuated device all operatively connected, the improvement which comprises:

a sensor valve connected to said pump, to said sump, and to said displacement control mechanism and being adapted to establish, to block, and to control fluid communication paths from said pump to said displacement control mechanism and from said displacement control mechanism to said sump as said sensor valve is actuated to first and second operating positions;

sensor valve actuating means adapted to provide an operating force to actuate said sensor valve from one of said operating positions to the other of said operating positions in response to a control signal pressure applied to said sensor valve actuating means;

control signal valving means and restrictor means connected in series between said pump and said sump and being adapted to receive and to control fluid pressure from said pump for use as said control signal pressure, said control signal valving means being operatively connected to and controlled by said control valve as said control valve is moved to said positions to control said fluid actuated device;

and control signal conduit means connected between said control signal valving means and said restrictor means to receive said control signal pressure and operatively connected to said sensor valve actuating means to apply said control signal pressure thereto;

whereby said control signal valving means and said restrictor means cooperate to provide and to control said control signal pressure, to actuate said sensor valve to said operating positions and to control the displacement of said pump in response to the movement of said control valve to said positions.

2. The hydraulic system as claimed in claim **1** in which said control valve includes first and second working sections adapted to be actuated to control first and second fluid actuated devices;

said control signal valving means includes a first control signal valve operatively connected to said first working section for actuation thereby and a second control signal valve operatively connected to said second control valve for actuation thereby;

said restrictor means and said control signal valves being operatively connected together and interposed between said pump and said sump;

whereby the actuation of either of said working sections is effective to control said control signal pressure and to increase the displacement of said pump.

3. The hydraulic system as claimed in claim **2** in which said control signal valves are connected in series with each other and with said restrictor means;

and closing of either one of said control signal valves is effective to control said control signal pressure and to increase the displacement of said pump.

4. The hydraulic system as claimed in claim **2** in which each of said control signal valves includes two ports;

each of said control signal valves has one of said ports in fluid communication with said pump and has the other of said ports in fluid communication with said sump;

and opening either one of said control signal valves is effective to control said control signal and to increase the displacement of said pump.

5. The hydraulic system as claimed in claim **1** in which said restrictor means is located between said pump and said control signal valving means.

6. The hydraulic system as claimed in claim **1** in which said restictor means is located between said control signal valving means and said sump.

7. The hydraulic system as claimed in claim **1** which includes a pilot relief valve connected to said pump and to said sensor valve actuating means and adapted to move said sensor valve to a displacement decreasing position by increasing thP fluid pressure applied to said sensor valve actuating means.

8. The hydraulic system as claimed in claim **1** in which said first operating position of said sensor valve is effective to control said paths to increase the displacement of said pump;

said sensor valve is effective in said second operating position to control said communication paths to decrease said displacement of said pump;

and said sensor valve includes a third operating position in which fluid communication paths are controlled to decrease said displacement and said sensor valve establishes a bypass communication path between said pump and said sump;

whereby said bypass communication path cooperates with said displacement control mechanism to control the effective output of said pump.

9. The system as claimed in claim **1** in which said sensor valve actuating means includes bias force meanS and fluid actuator means.

10. The system as claimed in claim **9** in which said sensor valve includes a sensor valve body having a bore therein and a valve plunger slidably fitted in said bore;

said fluid actuator means includes the projected end area of said valve plunger;

and a spring comprises said bias force means.

11. A hydraulic system including a variable displacement pump having a fluid actuated displacement control mechanism adapted to control the displacement of said pump, a sump, a control valve having a neutral position and an operating position and being adapted to control a fluid actuated device, and a fluid actuated device all operatively connected, the improvement which comprises:

a sensor valve connected to said pump, to said sump, and to said displacement control mechanism and being adapted to establish, to block, and to control fluid communication paths from said pump to said displacement control mechanism and from said displacement control mechanism to said sump as said sensor valve is actuated to first and second operating positions;

sensor valve actuating means including first and second fluid actuators adapted to provide operating forces to actuate said sensor valve to said first and second operating positions in response to fluid pressures applied to said fluid actuators;

control signal valving means and restrictor means connected in series between said pump and said sump and being adapted to receive and to control fluid pressures from said pump to provide control signal pressures, said control signal valving means being operatively connected to and controlled by said control valve as said control valve is moved to said positions to control said fluid actuated device;

first control signal conduit means connected between said control signal valving means and said restrictor means to receive said control signal pressures and operatively connected to one of said fluid actuators to apply said control signal pressures thereto;

and second control signal conduit means connected between said pump and the other of said fluid actuators to apply fluid pressures from said pump for use as control signal pressures for said other fluid actuator;

whereby said control signal valving means and said restrictor means cooperate to provide control signal pressures applied to one of said fluid actuators, to actuate said sensor valve to said operating positions and to control the displacement of said pump in response to the movement of said control valve to said positions.

12. The hydraulic system as claimed in claim **11** which includes a pilot relief valve connected to said one fluid actuator and to said sump and effective to limit the control signal pressures applied to said one fluid actuator;

whereby pump pressures applied to said other actuator are effective to reduce the displacement of said pump by forcing said sensor valve toward a displacement decreasing position thereby forcing fluid from said one actuator to said sump whenever said pump pressures exceed a predetermined value.

13. The hydraulic system as claimed in claim **11** in which said sensor valve includes a sensor valve body having a bore therein and a valve plunger slidably fitted in said bore;

said first and second fluid actuatros include the use of the projected end areas of said valve plunger for use as fluid responsive areas;

and said valve plunger is movable to a third or bypass position wherein fluid connections are made to decrease the displacement of said pump and to bypass excess pump flow from said pump to said sump.

14. The hydraulic system as claimed in claim **11** which includes fluid actuators having unequal fluid responsive areas.

15. The hydraulic system as claimed in claim **11** in which said sensor valve actuating means includes a bias spring.

16. A hydraulic system including a variable displacement pump having a fluid actuated displacement control mechanism operably connected to said pump and movable to control the displacement thereof, a control valve having a valving element movable from a neutral position to an operating position and to intermediate positions therebetween, a fluid actuated device operatively connected to said control valve for actuation thereby, and a fluid sump all operatively connected, the improvement which comprises:

a sensor valve having a body, a valve plunger, and a sensor valve actuating means and being connected to said pump, to said sump, and to said displacement control mechanism;

said valve plunger being operable to first, neutral, and second positions and being adapted to cooperate with said body to establish, to block and to control fluid communication paths between said pump and said displacement control mechanism and between said displacement control mechanism and said sump to increase the displacement of said pump, to decrease the displacement of said pump, and to maintain the displacement of said pump at any given value as a function of the relative position of said valve plunger to said valve body;

said sensor valve actuating means consisting of bias force means and fluid actuator means and being operatively connected to said valve plunger and being adapted to move said valve plunger relative to said body in response to a control signal pressure applied to said fluid actuator and in proportion to the magnitude of said control signal pressure, whereby there exists a first proportional relationship between the magnitude of said control signal pressure and the relative position of said valve plunger to said body;

control signal valving means and restrictor means being connected in series between said pump and said sump to control the flow of pressure fluid between said pump and said sump, being adapted to provide a control signal pressure in the juncture between said control signal valving means and said restrictor means, and being adapted to control the magnitude of said control signal;

control signal conduit means being connected to said juncture between said control signal means and said restrictor means to receive said control signal pressure and being connected to said fluid actuator means to apply said control signal pressure thereto;

said control valving means being operatively connected to said valving element to receive movement therefrom and being adapted to control the magnitude of said control signal pressure proportional to the position of said valving element from said neutral position, whereby a second porportional relationship exists between the position of said valving element, the magnitude of said control signal pressure and the relative position of said valve plunger to said body;

said feedback means operatively interconnecting said sensor valve and said displacement control mechanism and being adapted to modify said second proportional relationship in proportion to the movement of said displacement control mechanism and the displacement of said pump;

whereby there exists a proportional relationship between the position of said valving and the displacement of said pump.

17. The hydraulic system as claimed in claim **16** in which said bias force means includes a spring;

and said feedback means includes said spring as a part of said means interconnecting said displacement control mechanism and said sensor valve.

18. The hydraulic system as claimed in claim **17** in which said pump is of axial piston type and said displacement control mechanism includes a variable inclination swash plate;

said fluid actuator means includes the projected area of one end of said valve plunger;

and said feedback means includes said spring interposed between said valve plunger and said swash plate, one end of said spring being adapted to receive motion from said swash plate as the displacement of said pump is changed and the other end of said spring being adapted to apply force to the other end of said valve plunger.

19. The hydraulic system as claimed in claim **16** in which said valve plunger and said body comprises first and second relatively movable valving parts;

one of valving parts being operable to first and second positions by said bias force and said fluid actuator means;

and the other of said valving parts being operatively connected to said displacement control mechanism to receive feedback movement therefrom.

20. The hydraulic system as claimed in claim **19** in which said displacement control mechanism includes a control piston, said one valving part is coaxial with said control piston, and said other valving part is connected to said control piston to receive feedback movement therefrom.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 3,788,077 Dated January 29, 1974

Inventor(s) Raymond E. Johnson et al.

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

Column 11, line 5, Claim 7, "thP" should read -- the --.

Column 13, line 31, "pressure" should read -- pressures --.

Signed and sealed this 25th day of June 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents