Dec. 7, 1971 L. R. HERNDON, JR 3,625,007

HYDRAULIC SYSTEM INCLUDING FLOW STABILIZATION MEANS

Filed Feb. 7, 1969 2 Sheets-Sheet 1

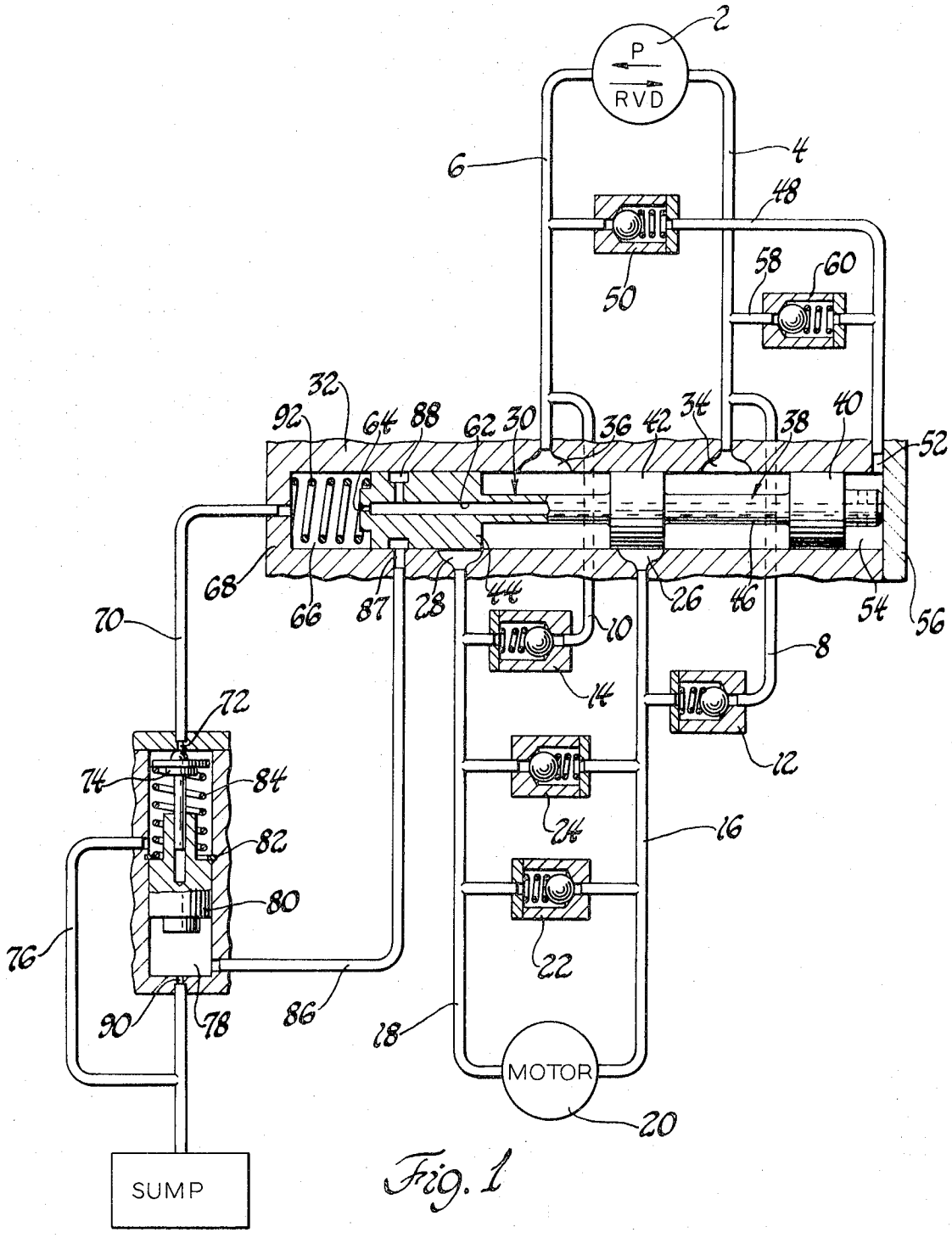


Fig. 1

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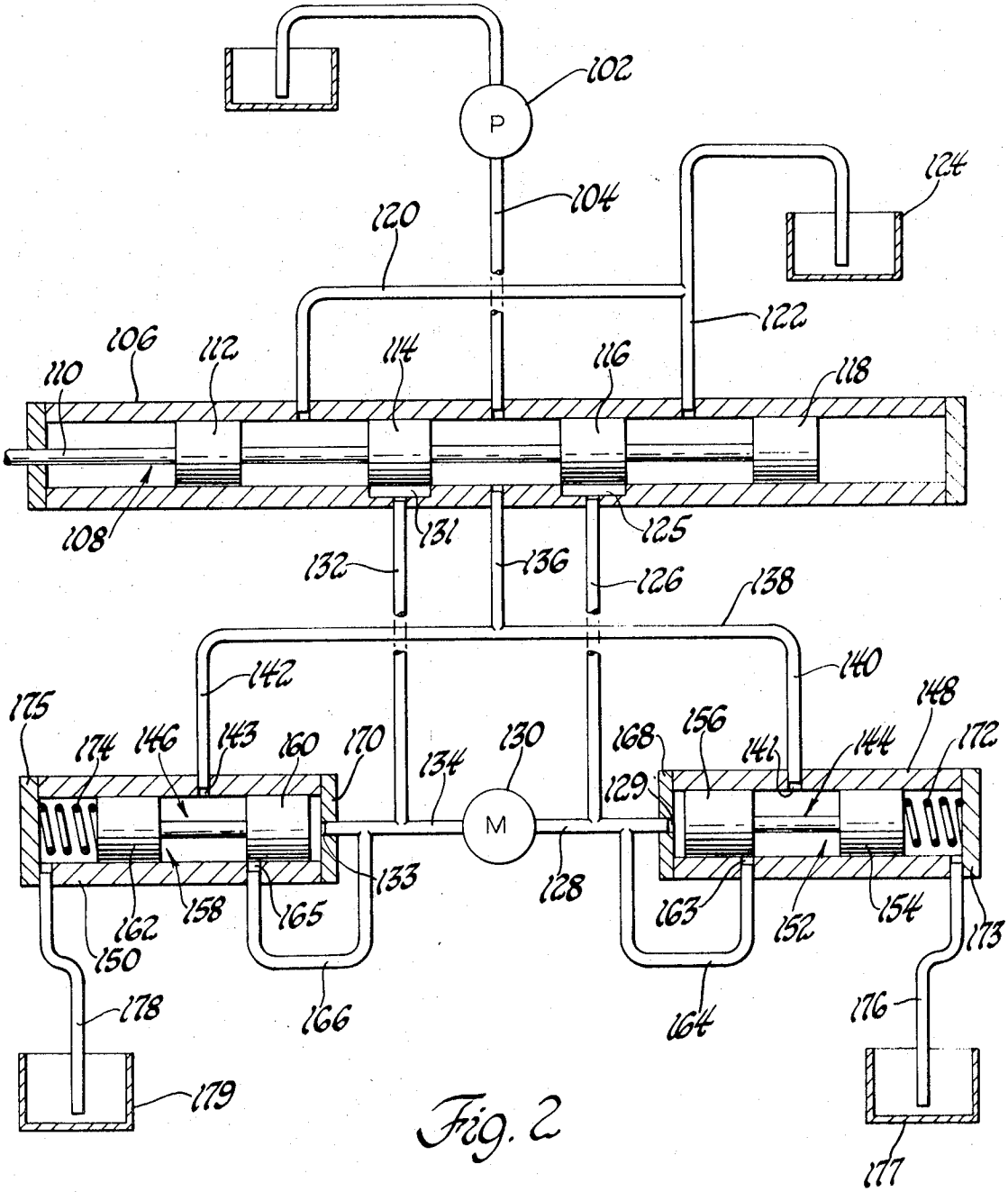


Fig. 2

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HYDRAULIC SYSTEM INCLUDING FLOW STABILIZATION MEANS

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ABSTRACT OF THE DISCLOSURE

A hydraulic system including a hydraulic motor with means for controlling the pressure in the intake line of the motor to prevent cavitation and elastic compression of the hydraulic oil when the load on the motor increases.

This invention relates to hydraulic systems, and is particularly concerned with hydraulic systems including a hydraulic motor driven by flow of hydraulic fluid from a source such as a variable displacement pump, and having means for stabilizing the flow through the motor such that both cavitation and the effects of elastic compression of the hydraulic fluid are avoided.

In such hydraulic systems it is necessary to maintain a minimum pressure on the intake side of the hydraulic motor for preventing cavitation which can occur due to the tendency of the inertial forces on the motor to cause the motor to run away in the event that there is a reduction in the amount of hydraulic oil available to the motor. When cavitation occurs, the motor runs faster than called for by the oil supply due to inertia and attempts to pull oil through the motor faster than it is being supplied to the motor. In order to prevent cavitation, it is necessary to maintain a minimum pressure on the intake side of the motor so that sufficient hydraulic fluid is available to the motor corresponding to the actual speed of the motor.

Another frequently recurring problem in such hydraulic systems is that of power loss due to compression of the hydraulic fluid on the intake side of the hydraulic motor when there is a load increase on the motor. The load increase may momentarily slow the motor which tends to cause a pressure increase on the intake side of the motor. In hydrostatic transmissions of the type including a variable displacement pump for driving a constant displacement motor, it is desirable to maintain the speed of the output shaft of the motor in accordance with the displacement of the pump. When the pump displacement increases, there should be a corresponding increase in the speed of the motor shaft. However, when the load on the motor increases, a back pressure occurs between the intake side of the motor and the output side of the pump which can, due to the length of the passages involved, cause a substantial elastic compression of the hydraulic oil with the result that there is a lag in the speed of the motor shaft, and the motor speed no longer corresponds to the displacement of the pump. The amount of lag, or loss in r.p.m., increases with the length of the passageways between the pump and the motor due to the greater amount of compression that is possible.

One of the objects of this invention is to reduce the likelihood of the occurrence of cavitation in a hydraulic system having a hydraulic motor driven by the flow of hydraulic fluid through the motor.

Another object of this invention is to prevent compression of hydraulic oil on the intake side of a hydraulic motor caused by increases in the load on the motor.

A more specific object of this invention is to provide a hydraulic system having a source of hydraulic fluid

for supplying hydraulic fluid to a hydraulic motor with means defining a path of flow from the source to the motor including an intake line for the motor and means defining a path of flow from the motor including an output line for the motor with means for maintaining the pressure in the intake line at a normal value including flow control means controlling one of the paths operable in response to pressure changes in the intake line to change the pressure in said one path until the intake pressure returns to normal.

Another object of this invention is to prevent cavitation in a hydraulic system including a hydraulic motor by connecting the intake line of the hydraulic motor with an auxiliary path of flow from a source when the pressure in the intake line decreases below a minimum.

Still another object is to prevent elastic compression of the hydraulic oil on the intake side of a hydraulic motor by decreasing the pressure in the output line from the motor when the pressure on the intake side of the motor increases.

Yet another object is to prevent cavitation and elastic compression in the intake line of a hydraulic motor by maintaining a constant pressure in the intake line.

The foregoing, and other objects, are achieved by the provision of a hydraulic system including a hydraulic motor with means defining a path of flow from a source of hydraulic fluid to the motor including an intake line for the motor and means defining a path of flow from the motor including an output line for the motor. Flow control means is operable in response to pressure changes in the intake line from a normal value to vary the pressure in one of the paths until the intake pressure returns to the normal value. A port in one of the paths is controlled by flow control means in such a manner that the port is open and closed in accordance with the position of the flow control means relative to the port, and the flow control means is movable in response to pressure changes in the intake line to open and close the port.

In one embodiment of the invention a spool valve increases and decreases the size of a discharge port for the output line of the hydraulic motor in accordance with changes in the pressure in the intake line. The spool valve is urged in a direction to increase the size of the discharge port by the intake pressure and is urged in a direction to decrease the size of the discharge port by a pilot pressure. When the load on the motor increases, the resulting increase in the pressure in the intake line causes the spool valve to increase the size of the discharge opening to correspondingly reduce the pressure in the output line of the motor until the pressure in the intake line returns to normal.

In another embodiment of the invention, a hydraulic motor has its intake line connected with a source of hydraulic fluid through a primary path of flow. The intake line of the motor is also connected in an auxiliary path of flow which is controlled by a modulating spool valve which operates to connect the intake line with the auxiliary path of flow from the source when the pressure on the intake side of the motor decreases below normal, or the minimum pressure required to prevent cavitation. Thus, when the pressure on the intake line to the motor decreases to a point where cavitation might occur, the spool valve connects the intake line with the auxiliary path of flow from the source to supply additional oil to the intake line and restore the intake pressure to normal.

Other objects, advantages and features of the invention will become apparent from the following description taken in connection with the accompanying drawings in which:

FIG. 1 is a schematic diagram of a first embodiment of the invention; and

FIG. 2 is a schematic diagram of a second embodiment of the invention.

In FIG. 1, reference numeral 2 designates a variable capacity pump for providing a source of hydraulic fluid. Hydraulic lines 4 and 6 extend from opposite sides of pump 2. Pump 2 may be reversible, and when the pump is driven to deliver through hydraulic line 4, line 6 serves as a return line to the pump, and vice versa. Hydraulic lines 8 and 10 each have one of their ends respectively connected with lines 4 and 6 and their other ends respectively connected with lines 16 and 18. Check valves 12 and 14 prevent flow of hydraulic fluid from lines 16 and 18, respectively, to lines 8 and 10. Lines 16 and 18 are connected with opposite sides of a hydraulic motor 20 of conventional construction to be driven by fluid delivered from pump 2. Hydraulic motor 20 is reversible so that when the pump delivers in one direction, line 16 serves as an intake line for the motor and line 18 serves as an output line for the motor, and vice versa. Reference numerals 22 and 24 indicate high pressure relief valves for relieving excessive pressure in lines 16 and 18, respectively.

Lines 16 and 18 communicate with discharge ports 26 and 28, respectively, in a cavity 30 defined in a valve casing 32. Lines 4 and 6 communicate with return ports 34 and 36, respectively, in the cavity 30. Slidably received in the cavity 30 is flow stabilization or control means in the form of a spool valve designated generally by reference numeral 38 and formed with lands or pistons 40, 42 and 44 projecting from a stem 46.

The hydraulic line 6 is connected through a line 48 with an inlet port 52 for an inlet chamber 54 defined by land 40 and the end wall 56 of cavity 30. A check valve 50 in line 48 prevents flow from line 48 to line 6 but permits flow in the opposite direction. Line 4 is connected with line 48 through a line 58 controlled by a check valve 60 which permits flow only from line 4 into line 48. It is apparent that the inlet chamber 54 is subjected to the higher of the pressures from lines 4 and 6.

A central passage 62 extends through the stem 46 of spool valve 38 and communicates through a restricted port or orifice 64 with a pilot chamber 66 defined by land 44 and end wall 68 of cavity 30. Pilot chamber 66 has an exhaust port which communicates through a line 70 with a port 72 in a pilot valve casing, and port 72 in turn is controlled by a pilot valve 74. When the pilot valve 74 is opened to permit flow from line 70 through port 72, the fluid flows around valve 74 through an exhaust line 76 to sump. The closing force on pilot valve 74, and thus the pressure in pilot chamber 66, is determined by the pressure in a pilot valve chamber 78. Pilot valve chamber 78 has a pressure responsive movable wall in the form of a piston member 80 which slidably supports the pilot valve 74 and is engageable with a stop member 82. Pilot valve 74 has a stem slidably mounted in a cylindrical bore formed in piston 80 and is biased into engagement with port 72 by a spring 84. When piston 80 engages stop 82, spring 84 applies a maximum closing force on the pilot valve 74, which in turn determines the maximum pilot pressure. Increases in pressure in pilot valve chamber 78 thus increase the closing force on valve 74 and correspondingly cause an increase in the pressure in pilot chamber 66. The pilot valve chamber 78 receives fluid from a line 86 connected with a port 87 in cavity 30. Port 87 registers with a peripheral groove 88 in land 44 which in turn is in communication with passage 62. Thus, fluid flows from the inlet chamber 54 through passage 62 in the groove 88, and from groove 88 through port 87 and line 86 into the pilot valve chamber 78. Pilot valve chamber 78 is connected with exhaust through a restricted port 90. A spring 92 urges the spool valve 38 toward the right in FIG. 1.

Assuming that pump 2 is driven to deliver hydraulic fluid through line 4, the pump constitutes a source of hydraulic fluid and lines 4 and 8 as well as the intake line 16 defines a path of flow from the pump to motor 20, and a path of flow from motor 20 including output line 18 is defined by the space between lands 42 and 44 and line 6. The flow control means or spool valve 38 is operable in response to pressure changes in the intake line to change the pressure in the path of flow from the motor 20 by increasing and decreasing the size of the discharge port 28 through which the fluid flows along the path of flow from the motor until the intake pressure is returned to normal. The discharge port 28 is controlled by the flow control means 38 in such a manner that port 28 is opened and closed in accordance with the position of land 44 of the flow control means relative to the port 28. The flow control means, or spool valve 38 is movable in response to pressure changes in the intake line to open and close port 28. The flow control means is urged toward the left by the pressure in the intake line, which is the same as the pressure in the inlet chamber 54, and is urged in a direction to close discharge port 28 by the pilot pressure in pilot chamber 66. The pilot pressure is determined in accordance with the position of the spool valve 30 is determined by the rate of flow from the pump 2 since the pilot valve chamber 78 has communication with the path of flow from the source through the port 87. The pilot valve 74 controls communication between the pilot chamber and exhaust, and the pilot valve is urged to a closed position against the pilot chamber pressure through line 70 by the pressure in the path of flow from pump 2, which is the same as the pressure in the pilot valve chamber 78.

The flow control means, which comprises the spool valve 38, is received in cavity 30 in such a manner that the first land 40 cooperates with the end wall 56 of cavity 30 to define the inlet chamber 54, and the second land 44 cooperates with the second end wall 68 of cavity 30 to define the pilot chamber 66.

When the pump starts into operation, hydraulic fluid is delivered through line 4 to line 8 and past check valve 12 into the intake line 16 from motor 20. The hydraulic fluid flows through the motor into the output line 18 and from output line 18 through discharge port 28 into the space between lands 42 and 44, and through return port 36 and return line 6 to pump 2. The pressure in the inlet chamber 54 is the same as the pressure in line 4 and this pressure urges the spool valve toward the left to uncover the discharge port 28 sufficiently to permit fluid to be discharged from output line 18 into cavity 30 between lands 42 and 44. The fluid from inlet chamber 54 also passes through passage 62 into the pilot valve chamber 78 through groove 88 and line 86, and through the restricted port 64 into the pilot chamber 66. Since the pilot valve chamber 78 has restricted communication only with sump through port 90, the pressure in pilot valve chamber 78 is substantially the same as that in the inlet chamber 54 and in the path of flow from the source 2 to the motor 20. An increase in the load on motor 20 will cause a pressure rise in intake line 16 which in turn will cause a corresponding increase in the pressure in line 8 and inlet chamber 54. The increased pressure in inlet chamber 54 will move the spool valve 38 to the left to increase the size of the opening through discharge port 28 and thus correspondingly reduce the resistance to flow from output line 18 and thus the pressure in line 18. The drop in pressure in output line 18 will thus cause a corresponding reduction in pressure in intake line 16 to thereby maintain a constant pressure in line 4 to prevent the occurrence of elastic compression of the hydraulic oil in the path of flow from pump 2 to motor 20.

When it is desired to run the motor at high speeds, the pressure in the line 4 will tend to rise sufficiently to cause the pressure in inlet chamber 54 to urge valve 38 toward the left sufficiently to move the groove 88 out of registry with port 87 so that flow from output line 18 will have the minimum amount of resistance. However, for low speeds, the groove 88 will be in communication with port 87 throughout the range of movement of valve 38 caused by variations in the pressure in the intake line. Thus at

low speeds, the pilot valve chamber **78** will be in communication with groove **88** and the pilot valve will be maintained at its high setting due to the engagement of piston **80** with stop **82**. At high speeds, groove **88** will move to the left out of communication with port **87** and piston **80** will seat on the lower wall of chamber **78** to reduce the spring force on pilot valve **74** and place the pilot valve **74** at its low pressure setting. The spool valve **38** controls cavity **30** to thus constitute flow stabilization means for preventing elastic compression of hydraulic fluid in the intake line of the hydraulic motor by decreasing the pressure in the output line of the hydraulic motor in response to increases in the pressure in the intake line above a predetermined maximum pressure.

When the pump **2**, and hence motor **20** is reversed, line **6** will become the delivery line, line **4** will become the return line for the pump, and line **18** will become the intake line for motor **20** and line **16** will become the output line for the motor **20**. In this case, a discharge port **26** will be under the control of land **42** and will be opened and closed in accordance with changes in the pressure in inlet chamber **54**. The pressure in inlet chamber **54** will be the same as the pressure in the delivery line **6**.

With reference to the embodiment of FIG. 2, reference numeral **102** designates a pump having a delivery line **104** which is connected with a servo valve casing **106** having a cavity receiving a servo valve **108**. The servo valve **108** includes a stem **110** and lands **112**, **114**, **116** and **118**. A return line **120** communicates with the servo valve cavity between lands **112** and **114**, and a return line **122** communicates with the cavity between lands **116** and **118**, and with a sump or reservoir at **24**. The return line **120** communicates with the return line **122**.

One end of a line **126** is connected with a port **125** controlled by land **116**, and the other end of line **126** is connected with a line **128** extending from one side of a hydraulic motor **130**. Similarly, one end of a line **132** communicates with a port **131** controlled by land **114** and the other end of line **132** is connected with a line **134** extending from the opposite side of the hydraulic motor **130**. A line **136** has one end connected with a port communicating with the space between lands **114** and **116**, and the other end of line **136** is connected with a line **138** having one end portion **140** connected with a valve cavity **144** in a valve casing **148**, and the other end **142** communicating with a valve cavity **146** defined by a valve casing **150**. Slidably received in the valve cavity **144** is a flow control means in the form of a spool valve **152** having lands **154** and **156**. Similarly, a spool valve **158** is slidably received in cavity **146** and includes lands **160** and **162**.

One end of a line **164** is connected with a port **163** communicating with cavity **144**, and the other end of line **164** is connected with line **128**. Similarly, one end of a line **166** is connected with a port **165** in cavity **146**, and the other end of line **166** is connected with line **134**. Line **128** communicates with a port **129** in the end wall **168** of casing **148**, and line **134** is connected with a port **133** in the end wall **170** of casing **150**. Valve **152** is urged toward the left of FIG. 2 by a spring **172** seated between land **154** and the end wall **173** of casing **148**, and a similar spring **174** seated between land **162** and the end wall **175** of casing **150** urges the spool valve **158** toward the right in FIG. 2. The space between land **154** and end wall **173** is connected with an exhaust line **176** to a sump or reservoir at **177**. Similarly, an exhaust line **178** connects the space between land **162** and end wall **175** of casing **150** with the exhaust at **179**.

Pressure source **102** delivers hydraulic fluid through delivery line **104** into the space between lands **114** and **116**. The fluid flows from line **136** to the cavities **144** and **136**. When the servo valve **108** is shifted to the right in FIG. 2, the hydraulic fluid flows through port **125** to line **126** and line **128**, and the fluid flows from the motor through lines **134** and **132** to port **131** and from port **131** into the space between lands **112** and **114** to return line **120**. In this condition, line **128** is the intake line for motor and line **134** is the output line for motor **130**. The pressure in the intake line **128** acts against land **156** of the spool valve **152** to urge the valve toward the right in FIG. 2 and close port **163**. The pressure in line **128** tends to close port **163** and spring **172** tends to urge the valve **152** in a direction to open port **163** and connect line **128** with the flow from line **140** through line **164**.

In the FIG. 2 embodiment, the path of flow from the source, i.e., pump **102**, to motor **130** includes a primary path of flow through line **126** to the intake line **128**, and an auxiliary path of flow through lines **136**, **138**, cavity **144** and line **164** to the intake line **128**, with port **163** located in the auxiliary path of flow and being controlled by the flow control means in the form of spool valve **152**. Port **163** connects the valve cavity with the intake line through line **164** and constitutes an outlet port for valve cavity **144**. The spool valve **152** controls communication between the outlet port **163** and the inlet port **141** communicating with the line **140**. Port **129** connected with the end of intake line **128** constitutes a sensing port communicating with the intake line, the land **156** being exposed to the pressure of the sensing port on a side opposite the second land **154**. The port connecting line **176** with the cavity **144** constitutes a reference port to provide a fixed reference pressure or force, together with spring **172** acting on land **154** so that the spool valve is movable in the cavity in response to changes in the pressure in the intake line.

When the system is operating normally, port **163** is closed and the intake line **128** is supplied through the primary path from line **126** past the land **116** of the servo valve **108**, which is in a fixed position. If for any reason the pressure in the intake line **128** should fall, the pressure at port **129** will correspondingly decrease and spool valve **152** will shift to the left and open port **163** to change the pressure in the path of flow from the source by increasing the area through which fluid flows from the pump **102** to the motor **130** and supplying additional oil to intake line **128**. When port **163** is opened, fluid flows from the auxiliary path into the intake line **128** to increase the pressure in line **128** and prevent cavitation.

The system is reversed by shifting the servo valve **108** toward the left so that fluid is supplied to the motor through line **132** from port **131** instead of through line **126**, and is exhausted or returned to sump **124** through line **122** instead of through line **120**.

It is, of course, within the scope of the invention to provide a separate source of hydraulic fluid for the auxiliary path of flow through lines **136**, **138**, casings **148** or **150** and lines **164**, **166**. Moreover, lines **164** and **166** may both be connected to a single valve through a common line connected with the outlet port **163** or **165**, with check valves preventing reverse flow from the lines **128** or **133** having the higher pressure.

The hydraulic system of FIG. 2 thus includes a hydraulic motor **130** having an intake line **128** (or **134**) and an output line **134** (or **128**). Means **126** or **128** defines a primary path of flow to the intake line **128** or **134**, respectively. Line **136** is connected with a source of hydraulic fluid defined by pump **102**. Means **136**, **138**, **140** and **164**, or **136**, **138**, **142** and **146** defines an auxiliary path of flow to the intake line, which, in the illustrated embodiment, is connected with the source of hydraulic fluid defined by pump **102**. Obviously, line **136** could be connected with a separate source of hydraulic fluid independent of pump **102**. Flow control means **144** is responsive to the pressure in the intake line **128** and is operable to shut off communication between the intake line **128** and the auxiliary path of flow defined by lines **136**, **138**, **140** and **164** when the pressure in the intake line is above a predetermined minimum necessary to prevent cavitation and provide an uninterrupted stream of fluid to the motor. The flow control means **144** is operable to connect the intake line with the auxiliary path of flow

when the pressure in the intake line falls below the minimum. The flow control means includes means **148** defining a valve cavity **152** having an inlet port **141** and an outlet port **163** connected in the auxiliary path of flow the outlet port **163** communicating hydraulically with the intake line **128**; and the pressure responsive valve **144** controlling communication between the inlet port **141** and the outlet port **163** in response to pressure changes in the intake line **128**. Valve **144** is slidable in cavity **152** such that one land **156** of the valve controls the outlet port **163**, and the inlet port **141** communicates with the space between the spaced lands **154** and **156** such that the inlet port **141** communicates with the outlet port **163** when land **156** uncovers the outlet port. A port **129** connects cavity **152** with the intake line to subject land **156** to the intake pressure and spring **172** engages the other land **154** to oppose the intake pressure such that the intake pressure urges the spool valve **144** to close the outlet port **163**, and spring **172** urges the spool valve to open the outlet port against the intake pressure.

While specific forms of the invention have been illustrated and described in the foregoing specification and accompanying drawings, it should be understood that the invention is not limited to the exact construction shown but various alternatives in the construction and arrangement of parts is possible without departing from the scope and spirit of the invention.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A hydraulic system comprising: a source of hydraulic fluid; a hydraulic motor; means defining a path of flow from said source to said motor including an intake line for said motor; means defining a path of flow from said motor including an output line for said motor; means for maintaining the pressure in the intake line at a normal value including flow control means controlling one of said paths and operable in response to pressure changes in the intake line to change the pressure in said one path until the intake pressure is returned to normal; and means providing a pilot pressure; said one path including a port in said output line controlled by said flow control means in such a manner that said port is opened and closed in accordance with the position of the flow control means relative thereto; said flow control means being urged in one direction by pressure in the intake line and in the other direction by the pilot pressure; said means providing a pilot pressure comprising a pilot chamber having restricted communication with the path of flow from said source, a pilot valve controlling communication between said pilot chamber and exhaust, said pilot valve being urged to a closed position by a force that varies in accordance with variations in the rate of flow from said source, a cavity, and wherein said flow control means comprises a spool valve received in said cavity and having a first land cooperating with one end wall of said cavity to define an inlet chamber, and a second land cooperating with a second end wall of said cavity to define said pilot chamber.

2. A hydraulic system comprising: a variable displacement pump for providing a source of hydraulic fluid; a constant displacement hydraulic motor; means defining a path of flow from said pump to said motor including an intake line for said motor; means defining a path of flow from said motor including an output line for said motor; a port in said output line; a flow control valve controlling said port and movable in one direction to open said port and decrease the resistance to flow through said output line from said motor and movable in the opposite direction to close said port and increase the resistance to fluid flow through said output line from said motor; means providing a pilot pressure independent of the pressure in said output line that increases and decreases in response to increases and decreases, respectively, in the pressure in said intake line, said flow control valve being urged in said one direction by the pressure in said intake line and in said opposite direction by said pilot pressure to thereby maintain the speed of said motor proportional to the displacement of said pump, said last named means including a pilot chamber having restricted communication with said intake line, a pilot valve chamber, and a pilot valve controlling communication between said pilot chamber and exhaust and urged to a closed position by the pressure in said pilot valve chamber, and means connecting said pilot valve chamber with said intake line.

3. A hydraulic system as claimed in claim **1** wherein said inlet chamber communicates with the path of flow from said source and further including a passage formed in said spool valve having one end communicating with said inlet chamber and its other end in restricted communication with said pilot chamber.

4. A hydraulic system as claimed in claim **2** further including means defining a pilot valve chamber having a pressure responsive movable wall, said pilot valve being carried by said pressure responsive movable wall such that increases in the pilot chamber pressure increases the closing force on said pilot valve.

5. A hydraulic system as claimed in claim **3** further including a restricted exhaust port in said pilot valve chamber and a pilot valve chamber inlet conduit connecting said pilot valve chamber with said cavity.

6. A hydraulic system as claimed in claim **4** further including a peripheral groove in said second land communicating with said passage in the spool valve, said groove being normally in communication with said pilot valve chamber inlet conduit for conducting flow from said inlet chamber to said pilot valve chamber.

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