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[54] **HYDRAULIC SYSTEM FAILURE DETECTORS**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 889,197, Dec. 30, 1969, abandoned.

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[58] **Field of Search** ..... 91/363 A, 448, 411 R, 91/459, 452, 421, 447, 451; 92/86

[56] **References Cited**

UNITED STATES PATENTS

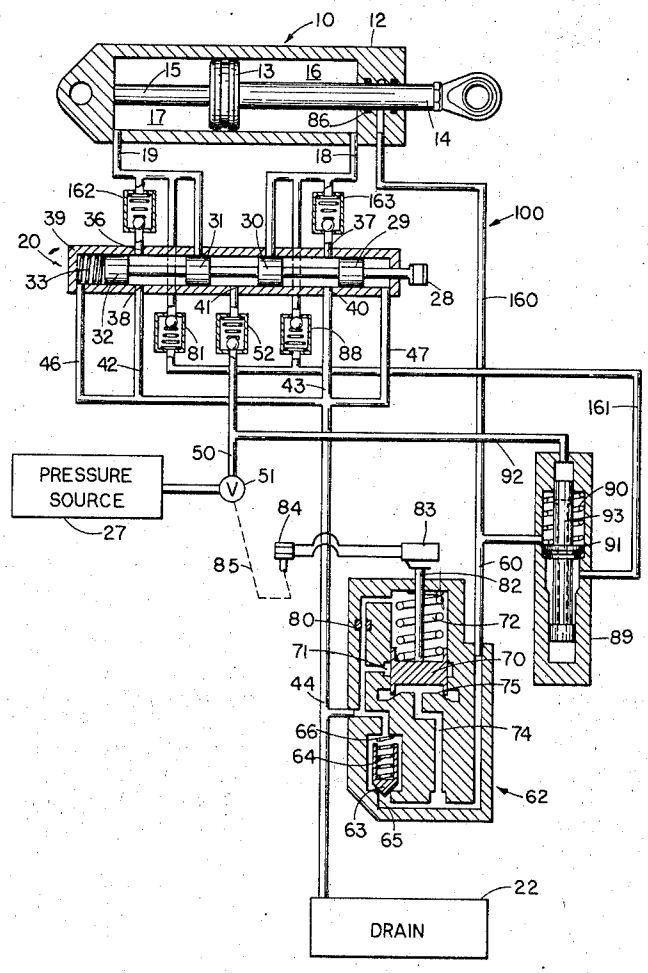
3,470,792	10/1969	Darling	91/421
3,631,761	1/1972	Rumsey	91/421
2,597,419	5/1952	Westbury et al.	91/363 A
2,766,731	10/1956	Brandes et al.	91/363 A
3,190,185	6/1965	Rasmussen	91/363 A

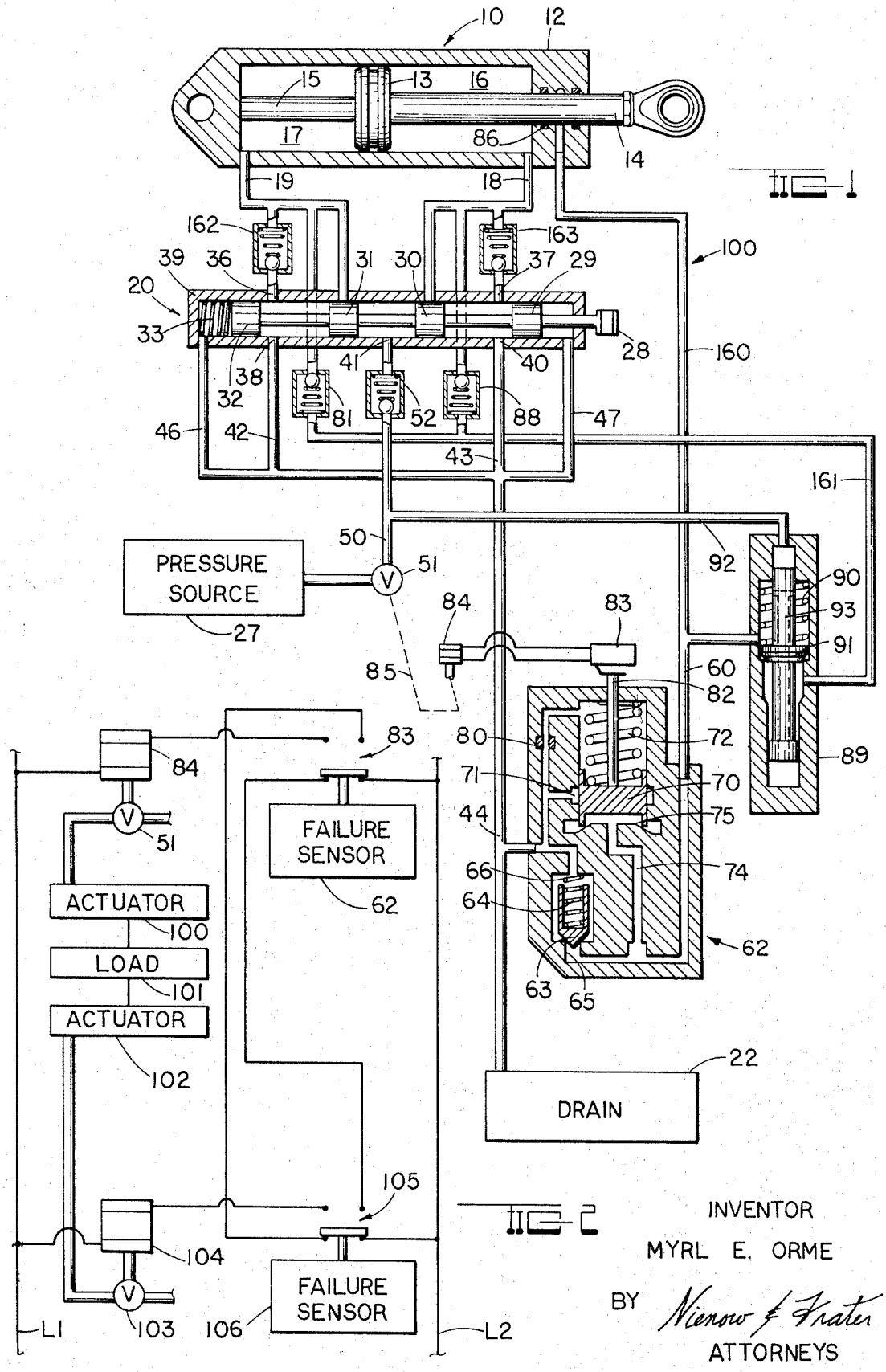
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[57] **ABSTRACT**

Hydraulic system failure detector including a sensor in a high pressure drain line connected between possible sources of excessive pressure or flow and a drain. The sensor includes a restriction capable of passing limited flows and of relieving limited pressures. It also includes a damped, pressure-operated bypass valve in parallel with the restriction. Relief valves in branches of the high pressure drain line isolate the failure sensor from normal high pressure in those lines until the occurrence of overpressure resulting from a failure thus to permit detection of failures characterized by widely differing fluid pressures while permitting calibration of the detector at the pressure of the lowest failure pressure.

6 Claims, 2 Drawing Figures





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HYDRAULIC SYSTEM FAILURE DETECTORS

This invention relates to improvements in failure detection apparatus for fluid powered control systems. The application is a continuation-in-part of application Ser. No. 889,197 filed Dec. 30, 1969, now abandoned.

It is a general object of the invention to provide an improved failure detection apparatus. The invention is applicable to fluid systems, both pneumatic and hydraulic, in a wide variety of circuits, configurations and forms in which some sort of actuator is employed to position an output element in accordance with operation of a control valve to vary the routing of fluid to and from the actuator. It is an object to provide failure detection apparatus capable of such wide application.

There is a need in such systems to detect a variety of failure conditions including excess leakage around seals, gross mismatch between actual actuator position and the position that the control element dictates that it should have, and any kind of failure of the control mechanism and the actuator to operate in unison. An object of the invention is to provide an improved and novel apparatus for detecting failures of this kind. A related object is to provide a failure detection apparatus capable of detecting failures of a kind which result in generation of system pressures above supply pressures while simultaneously detecting and indicating failures which result in the generation of fluid pressures no greater than the supply pressure.

While the invention is applicable to fluid control systems of the type having a single actuator and control element, it is especially useful in applications in which several hydraulic fluid control systems are operated in parallel in the sense that the actuators of several hydraulic systems are connected to a common load. It is another object of the invention to provide a failure detection system for use in this circumstance. An example is found in systems employed in operating the control surfaces of aircraft where individually controlled actuators are connected to the same elevator or rudder or other flight control surface. A separate control system is provided for each actuator in order to achieve the greater reliability provided by redundancy. Even if one control valve becomes broken or jammed so that it cannot move or if the seals of one actuator begin to leak excessively or if there is a disconnection or a breakage of control linkages, the actuator of the defective system will nonetheless be moved by the other actuators in unison with them. In that case, the failures may not be obvious. Incorporation of a failure detection apparatus in the system may be essential to avoid serious consequences. The fact that there is a defect may not become obvious until after irreparable harm is done to the system so that it is necessary to provide a failure detection system which can detect the problem and take corrective action promptly.

There are certain circumstances in which the load element is subjected to external forces that are sufficiently great so that all of the actuators become grossly mismatched from their respective pressure flow and control elements. This can happen when a heavy gust of wind forces an aircraft flight control surface to alter position independently of the fluid control system elements. That special circumstance must also be detected for the corrective action is different than that required when there is a failure in a single one of several systems. It is an object of the invention to provide a failure

detection system which will detect failure in an individual one of such parallel systems and which can distinguish individual failure from the apparent failure of all systems.

The failure detection apparatus provided by the invention is capable of performing a "snubbing" function in that it can be employed as a system to resist actuator movement in response to external forces until those forces reach a value at which further resistance might result in damage to the control element or to the system elements. At that point the task of the snubbing apparatus is to yield. Wind gust snubbing while the aircraft is on the ground and all aircraft systems and pumps are shut down, is also provided. The provision of these snubbing functions is another of the objects of the invention.

These several objects and advantages of the invention, and others which will hereinafter appear, are realized in part by the provision of apparatus for incorporation in an hydraulic system which includes an hydraulic fluid flowpath section for connection from a pressurized fluid circuit to a drain, and a restriction in that flowpath section for limiting the permissible flow rate through the flowpath, and by the provision of a sensing means responsive to a predetermined minimum pressure drop across the restriction for increasing the permissible flow and for providing a signal indicative of that condition.

In the drawings:

FIG. 1 is a schematic diagram of a failure sensor embodying the invention incorporated in an hydraulic control system; and

FIG. 2 is a schematic diagram illustrating how several failure sensors are combined to accomplish corrective action in a corresponding number of hydraulic systems.

The system shown in FIG. 1 includes an actuator **10** in the form of a cylinder **12**, a piston **13**, a ram **14** and a balance tube **15**. The piston **13** is mounted for reciprocal movement within the cylinder **12**. The ram **14** extends through one end wall of the cylinder to a fixed connection with the piston. The ram is hollow to accommodate the balance tube **15** which is fixed to the opposite end of the cylinder **12** and extends along the cylinder axis through the piston and into the ram. The ram occupies a substantial portion of the volume within the cylinder at the left of the cylinder **13**. In the absence of the balance tube or extension of the ram, there would be substantial disparity in the volumetric change in the spaces at the right and at the left of the piston as the latter was made to reciprocate. Use of the balance tube permits overcoming that problem in a large degree without the need to have the piston shaft or ram extend through both end walls of the cylinder. The invention is not limited to this arrangement but is also applicable to completely balanced, unbalanced actuators and to actuators in which the body, rather than the piston, is the moving element.

The space within the cylinder at the right of piston **13** is designated by the reference numeral **16** whereas the space at the left is designated by the reference numeral **17**. Fluid is introduced to the spaces **16** and **17**, and is discharged from those spaces, through conduits **18** and **19**, respectively. A control valve **20** is provided with a number of ports and a spool whose lands cooperate with those ports to permit the flow of pressurized fluid to lines **18** and **19** from a pressure source **27** and from those lines to a drain **22**. The control valve also permits

flow through lines 18 and 19 from one of the spaces 16 and 17 to the other.

The spool comprises a central shaft 28 which carries four lands 29, 30, 31 and 32, respectively. The spool is biased spring by a valve biasing 33 in selected direction to overcome play in the ocntrol linkages. It is shown in mid-position in the valve casing 39 in FiG. 1. In that position lands 31 and 30 seal ports 36 and 37 respectively. A first drain port 38 opens at a point between the lands 31 and 32. Port 40 opens at the interior of casing 39 at a point intermediate lands 29 and 30. The fluid inlet port 41 opens at the interior of the casing at a point between lands 30 and 31. Ports 38 and 40 are connected by conduits 42 and 43 respectively, to a common drain line 44. The end spaces within the control valve casing are also connected to the primary drain line 44. The space at the left is connected thereto by a line 46 and the space at the right is connected thereto by a line 47. The primary drain line 44 empties to a drain or sump 22. In most cases, fluid reaching the drain 22 is pressurized and returned to the system at the pressure source 21 but, because this is not essential, no connection has been shown in FIG. 1 between the drain and pressure source.

Correction means may be incorporated in the system for accomplishing corrective action in the event of a failure. Fluid from the pressure source 27 is permitted to flow to a pressurized supply line 50 by a supply valve 51. Fluid flowing through the valve into supply line 50 must flow through a check valve 52 to reach the inlet port 41. Valve 51 is one system element by which corrective action may be taken upon the occasion of a failure. In some systems, as in the system shown, it may comprise a simple shut-off valve. In other systems it may serve another function and have a different form. The invention does not depend upon its form. The purpose of element 51 is to protect the system with which it is associated or the apparatus with which the system is associated and the symbol 51 represents whatever structure will perform that function. Element 51 may be eliminated if desired by letting other actuators overpower the failed actuator. A signal then would be transmitted to the pilot who may make the decision to use area isolation valves, or if area isolation valves are not used, the signal may be simply used to apprise the pilot of the problem and that hinge moment and rate capability have been degraded.

The invention does embrace an apparatus for detecting a failure in the system and it envisions the provision of a signal upon the occurrence of a failure which can be made the occasion for rendering some protective means 51 effective to perform its task.

The numeral 60 designates a second high pressure drain line. That high pressure line incorporates the failure sensing structure generally designated 62. This structure may have any of a variety of forms. It includes a means for detecting flow rates greater than a selected rate and for signalling that the selected rate has been exceeded. A preferred structure has been selected for illustration in the drawings. That structure includes a restriction in the line. In preferred form the restriction comprises a spring closed, pressure opened valve advantageously of the double acting type. The head portion 63 of that valve is biased by a spring 64 in a direction to seal an upstream seat 65, and open a downstream seat 66. When the pressure at the upstream side of the drain line is sufficiently great, the head 63 will be forced against the bias of spring 64 in a direction to open the valve at seat 65. However, flow is limited because the forces that tend to open the valve at seat 65 tend to close it at seat 66 whereby the flow rate through the restriction, and the pressure that can be relieved through it, are limited. At some value of pressure differential across the double acting valve, it will shut off at seat 66. More specifically the valve is initially opened by pressure on the head. The degree of valve opening is controlled by differential pressure across the head 63 resulting from flow through the inlet opening. Once the head reaches seat 66 it is held closed by line pressure. Thus it is responsive to flow rate and serves as a flow limiter.

In this embodiment, the failure detection apparatus includes a second valve comprising a head 70 and a seat 75. This valve is pressure opened and spring closed. The spring is designated by the reference numeral 72. The head 70 reciprocates as a piston within a bore or chamber. The spring 72 is disposed in the chamber in back of the valve head, above it in FIG. 1. This space, the valve port 71, and the valve port 66 of the double acting valve, are all connected by flowpaths to the primary drain line 44. Pressure is applied to the valve head 70 by a line 74 which extends from the high pressure drain line 60 to the chamber below valve head 70. When the pressure in line 74 is sufficiently great, fluid passing through it will lift the head 70 from a secondary seat 75 and permit the application of pressurized fluid to a larger area of the valve head, lifting it abruptly against the spring 72 and insuring that the valve will not chatter. When the pressure at line 74 is sufficiently great, the valve head 70 will be lifted to clear the port 71 and flow will be permitted from the high pressure drain line 60, or from the relief valve or both should that mode of failure occur, through line 74 to the cavity that contains head 70 and out the outlet ports 71 to the primary drain line 44. To insure that this valve 70 does not respond to pressure spikes of short duration in the second drain line, action of the valve is damped. Any convenient damping means may be employed. Advantageously, as in this embodiment, that damping means comprises a restriction 80 in the line from the valve cavity to the primary drain.

It is not essential that the double acting valve completely shut off flow at port 66 before the valve head 70 be moved to clear its seat. Moreover, it is not essential that the valves 70 open at the same pressure at which the double acting valve closes. It is permissible, and usual, for the double acting valve to close at a pressure lower than that at which the valve 70 is opened. The fact that the operating pressures are not critical is one of the advantages of the invention and makes it possible to use a relatively inexpensive failure detection device.

In this embodiment a shaft 82 carried by the piston head 70 extends through the casing of the unit and becomes the actuator for a switch 83 which controls the application of power to a solenoid 84. The solenoid armature is operatively connected as at dashed line 85 to the corrective action apparatus 51.

The symptom of failure which is detected by the failure detection apparatus is pressure above a selected pressure level. The restriction and bypass valve arrangement of the apparatus 62 is capable of detecting excessive flow rate without blocking flow. It detects increased pressure in terms of flow rate greater than a preselected rate in that the double acting valve 63, 65,

66 remains open when the flow rate is below the preselected value. To enable the detection of failures which are characterized by the development of substantially different pressures, the high pressure drain line is provided with branches including pressure relief valves which isolate the failure sensor from the higher pressures in those branches until they are subjected to overpressure upon the occasion of a failure. This is illustrated in FIG. 1 where the high pressure drain line 60 is divided into two branches designated 160 and 161 respectively. Line 160 includes no relief valve. It extends from the region of the low pressure side of a seal 86 surrounding the actuator ram 14 where it emerges from the cylinder 12. If the seal 86 permits excessive leakage of hydraulic fluid, that fluid will be conducted by line 160 to the failure sensor 62 which will operate as previously described to actuate the switch 83 and provide a signal for initiating corrective action.

The other branch of the high pressure drain line extends from line 60 through a valve 89 to the cavities 16 and 17 within cylinder 12. It is connected to cavity 17 through a check valve 81 and it is connected to cavity 16 through a check valve 88. The function of these check valves is to prevent fluid from bypassing from cavity 17 to cavity 16 while providing a path for discharge of fluid from actuator 10 in the event of a failure that prevents operation of valve 20 and in which actuator 10 is forced to move by other actuators. Line 161 includes relief valve 89. This valve compares the pressure at the upstream side of line 165 with the sum of the supply pressure and the bias of a valve closing spring 90. The valve head 91 is mounted on a piston which moves in a cylinder to which the supply pressure is applied by a line 92.

Valve 89 is ordinarily held closed by the bias spring 90 and the pressure applied by line 92 at the upper end of the piston and head assembly 91. That assembly includes two pistons, one above the head and one extending below. A passageway 93 (shown in dotted lines) through the assembly connects the space above the head with the space below the lower piston. The space above the piston is ported to the high pressure drain line 60 so that the value of that pressure has no effect on valve operation. The bias of spring 90 and pressure in line 92 holds the valve head and piston assembly downward so that the head engages a lower seat such that less than the total head area is subjected to pressure in line 161 until the head has been lifted from its seat. At that time the greater head area is exposed to line 61. This feature prevents chattering of the valve at opening. The flow of pressurized fluid through line 161 lifts the head of the head and piston assembly 91 until it clears the outlet port which is connected to the high pressure drain line 60.

The diagram of FIG. 2 illustrates how two hydraulic systems are interconnected when both include a failure sensor and both are connected to output elements which serve a common load. The symbols L1 and L2 represent a source of electrical power. The failure sensor of FIG. 1 is shown as a block in FIG. 2 where it is labeled 62. The switch 83 is a double pole, single throw unit which is actuated by the failure sensor. Solenoid 84 operates the valve 51 which is in the supply line to the box marked actuator and designated 100. This box represents the remainder of the hydraulic system of FIG. 1 and it is connected to a load 101. A similar hydraulic system is connected to the load 101. It includes an actuator 102 to which fluid is supplied through a valve 103. The valve is operated by a solenoid 104 whose operation is controlled by a switch 105 under the control of a failure sensor 106 similar to failure sensor 62. The switches 83 and 105 are arranged so that neither of the solenoids 84 or 104 is energized in the absence of a failure and the switches are in the condition shown. If a failure is detected in sensor 62, switch 83 is actuated to open the lower contact and to close the upper contact whereby a circuit is completed from line L2 through the lower contacts of switch 105 and the upper contacts of switch 83 to the solenoid 84 and line 1. Conversely, if no failure is sensed by sensor 62 so that switch 83 occupies the condition shown and a failure is sensed by sensor 106 so that its switch is actuated to open its lower contacts and close its upper contacts, then current can flow from line L2 through the lower contacts of switch 83 and the upper contacts of switch 105 to energize solenoid 104. If a failure is sensed at both sensors, both switches will be actuated so that their upper contacts are bridged and their lower contacts are open in which condition no current can flow to either solenoid. Thus it is that the system of FIG. 2 is capable of providing a correction action in that hydraulic system which has experienced a failure provided that a failure is not indicated in all systems.

As previously described, the failure sensor may have other forms in that it may employ other kinds of flow rate detectors and pressure detectors and other kinds of check and release valves. The embodiment selected for illustration has the several advantages described above and is the preferred form. In addition to those advantages already described, the sensor 62 is advantageously employed because its flow valves serve as check valves in the event of pressure loss on the high pressure side. For example, in the case of a complete failure of the cylinder seal that prevents fluid from escaping past actuator arm 14 the head 63 will be seated against seat 65 to prevent loss of fluid from the drain circuit.

In addition to the elements heretofore described the system of FIG. 1 advantageously includes an anti-cavitation check valve 162 connecting the space between lands 31 and 32 with line 18. A similar anti-cavitation check valve 163 is connected from the space between lands 29 and 30 with line 19. In both cases these check valves prevent flow from the cavities 16 and 17 to the drain line while permitting flow from the drain line into cavities 16 and 17 should the pressure in either cavity fall below drain pressure. These valves serve to prevent cavitation when the actuator is powered by external forces such as wind gusts on the ground. Such cavitation could unseat the seal 86 and result in excessive leakage.

I claim:

1. For incorporation in a position control system of the kind in which an output element is controlled by plural hydraulic systems each of which includes an hydraulic actuator and an associated control valve for controlling hydraulic fluid flow from a pressurized source to the actuator and from the actuator to a system drain, improved failure detection and control apparatus, comprising, in each hydraulic system:

a supply line valve connected in the supply line between said source and said actuator;

a high pressure drain line connected between the actuator and the drain;

failure sensing means in said drain line and normally closing said drain line for providing a failure signal when pressure in said drain line exceeds some preselected value and for opening said drain line when pressure therein exceeds some preselected value;

supply line valve closing means for closing said supply line valve in response to said failure signal;

said drain line comprising a check valve at a point between the actuator and the failure sensing means which check valve opens toward the failure sensing means

said control valve including means for completing direct connection from the actuator to the drain; and

means for collecting leakage fluid from said actuator and introducing it into the drain line associated therewith at a point between the check valve and the failure sensing means.

2. For incorporation in a position control system of the kind in which an output element is controlled by plural hydraulic systems each of which includes an hydraulic actuator and an associated control valve for controlling hydraulic fluid flow from a pressurized source to the actuator and from the actuator to a system drain, improved failure detection and control apparatus, comprising, in each hydraulic system:

a supply line valve connected in the supply line between said source and said actuator;

a high pressure drain line connected between the actuator and the drain;

failure sensing means in said drain line and normally closing said drain line for providing a failure signal when pressure in said drain line exceeds some preselected value and for opening said drain line when pressure therein exceeds some preselected value;

supply line valve closing means for closing said supply line valve in response to said failure signal;

in which the drain line includes means in the form of a differential pressure relief valve upstream from the failure sensing means for discharging fluid from the actuator only when its pressure exceeds supply pressure by a given amount, the relief valve being sensitive to the difference between drain line pressure and supply line pressure.

3. The invention defined in claim **2** which further comprises means for collecting leakage fluid from said actuator and introducing it into the drain line at a point between the relief valve and the failure sensing means.

4. For incorporation in a position control system of the kind in which an output element is controlled by plural hydraulic systems each of which includes an hydraulic actuator and an associated control valve for controlling hydraulic fluid flow from a pressurized source to the actuator and from the actuator to a system drain, improved failure detection and control apparatus, comprising, in each hydraulic system:

a supply line valve connected in the supply line between said source and said actuator;

a high pressure drain line connected between the actuator and the drain;

failure sensing means in said drain line and normally closing said drain line for providing a failure signal when pressure in said drain line exceeds some preselected value and for opening said drain line when pressure therein exceeds some preselected value; and

supply line valve closing means for closing said supply line valve in response to said failure signal; and

in which said failure sensing means comprises:

a first spring closed, pressure responsive valve in series with the drain;

a less sensitive and damped pressure opening and spring closed valve in parallel with the first valve; and

means for providing said failure signal upon opening of the less sensitive valve.

5. The invention defined in claim **4** which further comprises a check valve in the drain line upstream from said failure sensing means.

6. For incorporation in a position control system of the kind in which an output element is controlled by plural hydraulic systems each of which includes an hydraulic actuator and an associated control valve for controlling hydraulic fluid flow from a pressurized source to the actuator and from the actuator to a system drain, improved failure detection and control apparatus, comprising, in each hydraulic system:

a supply line valve connected in the supply line between said source and said actuator;

a high pressure drain line connected between the actuator and the drain;

failure sensing means in said drain line and normally closing said drain line for providing a failure signal when pressure in said drain line exceeds some preselected value and for opening said drain line when pressure therein exceeds some preselected value;

supply line valve closing means for closing said supply line valve in response to said failure signal;

in which the supply line valve closing means of each hydraulic system is ineffective to close the supply line to its respectively associated actuator when a failure signal is provided by the respectively associated failure sensing means of the other hydraulic systems of said position control system.

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