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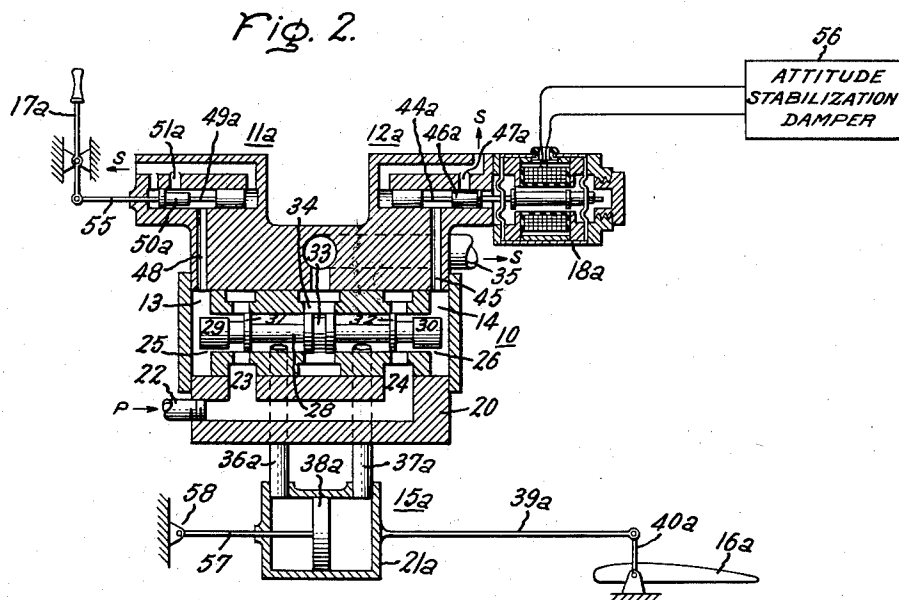
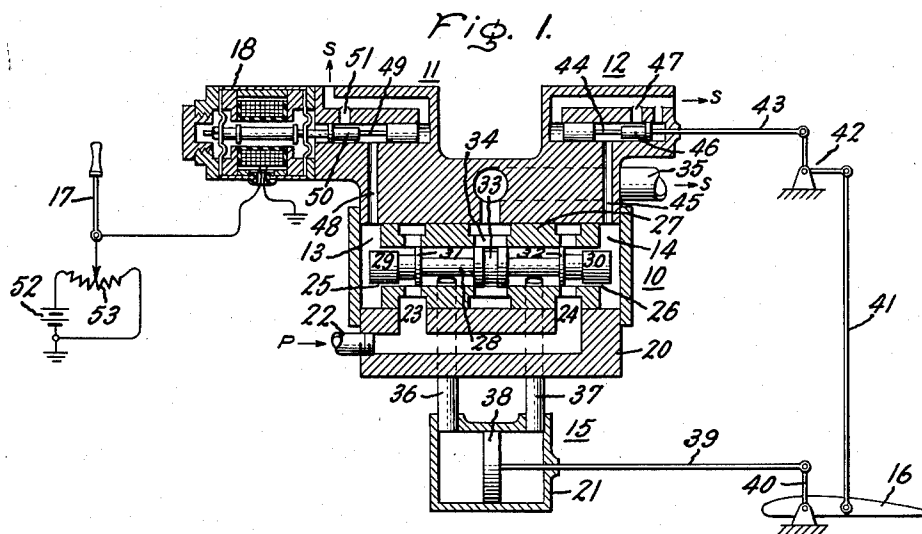
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2,970,575

MULTIPLE INPUT HYDRAULIC AMPLIFIER

Filed Dec. 30, 1954

2 Sheets-Sheet 1



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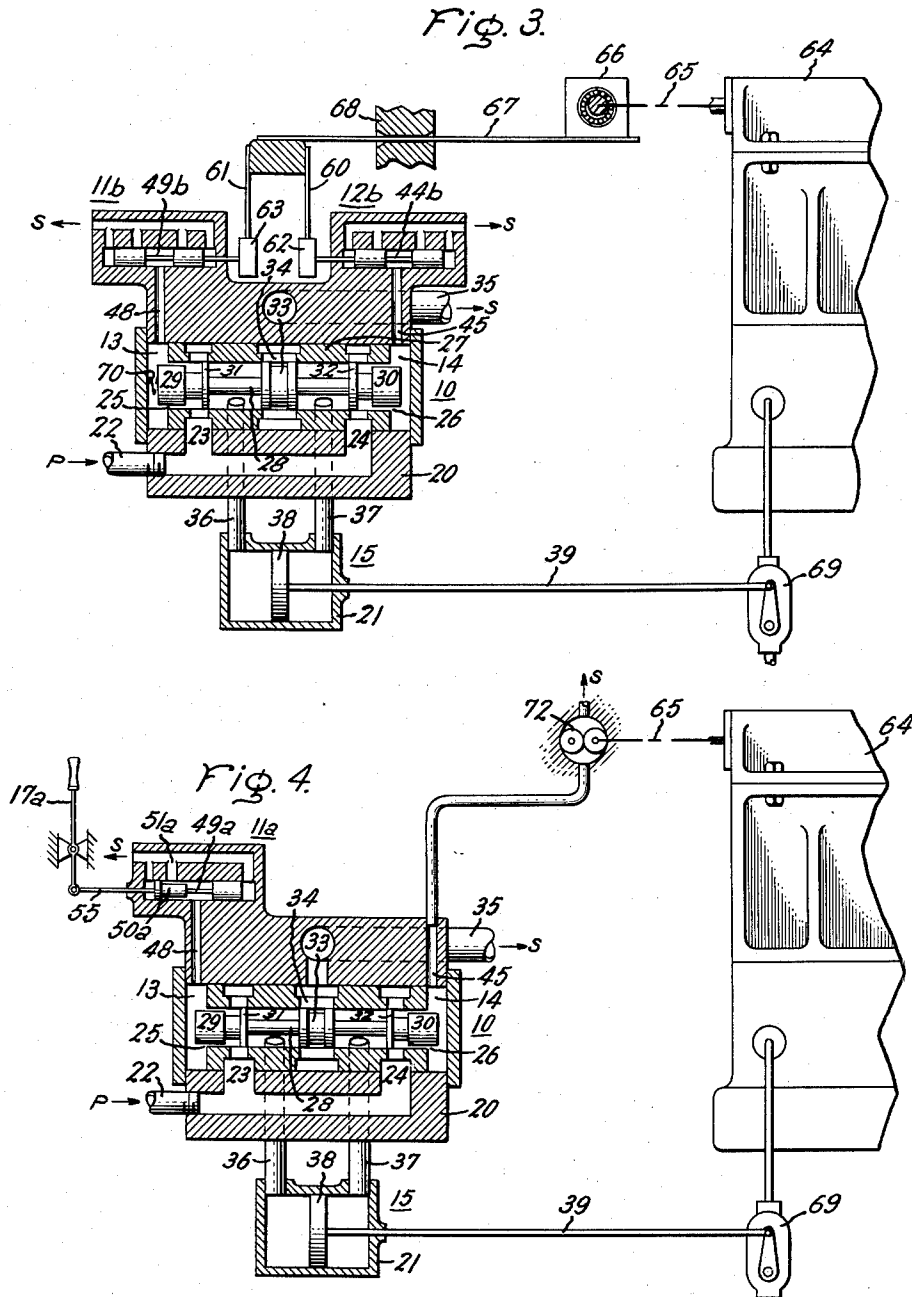
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2,970,575

MULTIPLE INPUT HYDRAULIC AMPLIFIER

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5 Claims. (Cl. 121-41)

This invention relates to hydraulic amplifier devices and systems and more particularly to hydraulic apparatus for amplifying forces or positional movements and having provision for control operation in response to two or more input signals.

In hydraulic control systems, it has been common in the past to employ a pilot valve which controls the flow of hydraulic liquid under pressure to a hydraulic motor for positioning or driving apparatus to be controlled. When hydraulic amplification of the control forces is required, a so-called two-stage hydraulic servo control system or hydraulic amplifier has been employed in which a pilot valve controls the position of a second-stage control valve which in turn controls the supply of hydraulic pressure liquid to the hydraulic motor. Co-pending patent application Serial No. 301,444, filed July 29, 1952 by Howard W. Avery for a "Hydraulic Amplifier," now Patent No. 2,709,421, issued May 31, 1955, and assigned to the same assignee as the present application contains a disclosure and claims directed to an improved two-stage hydraulic control system of this type. In these prior systems, provision has not generally been made for the introduction of more than one control signal by a single pilot valve. However, it is frequently desired that several independent control signals may be introduced into the system.

Accordingly, it is one object of the present invention to provide a hydraulic control system in which two or more independent control signals may be introduced and in which the operation is carried out in response to a combination of these control signals. Prior hydraulic control systems of the type described above have generally been subject to control by the position of a pilot piston and thus controllable primarily in accordance with a position signal and not directly in terms of a speed signal. However, it is often desired that a hydraulic control system should be controllable in response to speed signals or other signals not primarily dependent upon a relatively static position measurement.

Accordingly, it is another object of this invention to provide a hydraulic control system which is controllable in response to signals other than relatively static position signals.

Further objects and advantages of this invention will be apparent from the following specification and the accompanying drawings.

In carrying out the above objects of this invention in one preferred embodiment thereof, a hydraulic control valve is provided for controlling the operation of a hydraulic motor. The control valve includes a housing enclosing control pressure chambers at the respective ends of the control valve piston for positioning of the piston in response to pressure differences therein. A continuous flow of hydraulic pressure liquid is provided through the control pressure chambers. Flow restrictive members at each end of the control valve piston provide flow restrictions for the supply of hydraulic liquid to the pressure chambers by amounts which vary

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inversely in response to a given control valve piston movement. And individual separate flow restrictive devices are connected to control the discharge of liquid from each of the chambers in accordance with control signals.

For a more complete understanding of the invention, reference should be made to the following specification and the accompanying drawings, which are as follows:

Figure 1 is a schematic diagram of one preferred embodiment of the invention which is incorporated in a steering control system for a dirigible craft.

Figure 2 is a schematic diagram of a modified form of the invention employed in a steering system for a dirigible craft in which provision is made for the introduction of both a manual control signal and an automatic stabilization signal.

Figure 3 is a schematic diagram of a modified form of the invention incorporated in a control for the motive fluid and speed of an engine. This specific form of the invention comprises a portion of the subject matter which is described and claimed in my concurrently filed copending patent application Serial No. 478,665, now Patent No. 2,879,467, for a "Vibratory Control Apparatus" which is assigned to the same assignee as the present application, and

Figure 4 is a schematic diagram of another modified form of the invention which is incorporated in a motive fluid control system for controlling the speed of an engine.

Referring more particularly to Figure 1, there is shown a hydraulic control valve 10 which is positionable in response to signals introduced by pilot valves 11 and 12 controlling the pressures within control pressure chambers 13 and 14 to thus control the movement of a hydraulic motor 15. Motor 15 is connected to position a steering control surface 16. The control operation is accomplished by positioning of the pilot valve 11 in response to movement of a manual control lever 17 through the medium of an electrical solenoid 18 and an energizing circuit therefor. A "follow-up" control signal is provided at the pilot valve 12 by means of a mechanical linkage which connects this pilot valve to follow changes in the position of the steering member 16.

The control valve 10 includes a housing 20 which may be integral with the housing 21 of the hydraulic motor 15. Within the housing 20 there is a high pressure inlet for the reception of high pressure hydraulic liquid at 22. This inlet as well as other inlets for high pressure hydraulic liquid shown in the drawings for this patent application is identified also by the letter symbol P and an inwardly directed arrow. Similarly, the low pressure return lines or conduits which are intended for connection to a reservoir or sump of hydraulic liquid at low pressure are indicated by the letter symbol S and an outgoing arrow. It will be understood that a conventional reservoir and source of hydraulic pressure liquid may be employed. For purposes of simplicity and clarity in the drawings, these components are not shown.

The inlet 22 is the casing 20 forms a fluid pressure manifold which terminates at ports 23 and 24 connecting to the bore of the control valve 10. From the ports 23 and 24, hydraulic pressure fluid is supplied through capillary passages indicated at 25 and 26 to the respective control pressure chambers 13 and 14. Valve 10 includes a sleeve member 27 which may be considered as a portion of the housing 20 and which defines a cylinder bore within which the control valve piston 28 is reciprocally mounted. The capillary passages 25 and 26 are formed by cooperating portions of sleeve member 27 and end lands 29 and 30 of piston 28 which are of slightly reduced diameter with respect to the cylinder

bore diameter. The remainder of the valve 10, between the end lands 29 and 30, is in the general configuration of a conventional three-land control valve having outer lands 31 and 32 and a center land 33. Center land 33 is connected to control the opening of a port 34 which connects with a low pressure discharge manifold 35. The valve lands 31, 32 and 33 therefore control the entrance and discharge of hydraulic pressure fluid to motor conduits 36 and 37 to control the movement of the piston 38 of the hydraulic motor 15.

From the piston 38 there extends a connecting rod 39 which is pivotally connected to a crank 40 for movement of the steering control surface 16. Resulting movement of the steering control surface 16 is transmitted through a connecting rod 41, a bell crank 42, and a connecting rod 43 to piston 44 of pilot valve 12.

The cylinder bore of the pilot valve 12 is connected to the control pressure chamber 14 by means of a fluid passage 45. One of the valve lands of control valve piston 44 includes a reduced diameter section at 46 which forms a capillary passage within the valve bore for controlling the discharge of hydraulic pressure liquid through a port 47. Similarly, the bore of pilot valve 11 is connected with control pressure chamber 13 by a hydraulic fluid passage 48, and the piston 49 of pilot valve 11 is provided with a reduced diameter portion indicated at 50 forming a capillary passage for control of the discharge of hydraulic pressure fluid through a port 51. The position of the piston 49 of the pilot valve 11 is determined by the energization of the solenoid 18. This solenoid may be energized from a battery 52 across which there is connected a potentiometer 53. A portion of the battery voltage appearing across the potentiometer 53 may be selected by the control lever 17 for application to the solenoid 18. Solenoid 18 may preferably be constructed in accordance with the teachings of Boynton et al. Patent 2,435,817 for an "Electromagnet with Plunger" which is assigned to the same assignee as the present application.

In operation, if the control lever 17 is moved so as to change the energization of solenoid 18, the piston 49 of pilot valve 11 is thus shifted in position to change the length of the capillary passage provided by the piston portion 50 at port 51 and thereby change the resistance to flow offered by the capillary passage. The flow of hydraulic fluid through control pressure chamber 13 is thus altered and the resulting unbalance of pressures in chambers 13 and 14 causes the control valve 10 to move to one side to re-establish pressure balance between chambers 13 and 14. This re-establishment is accomplished by virtue of changes in resistance to liquid flow offered by the capillary passages 25 and 26, such that the pressure drop through the passage 25 at the new flow established by passages 25 and 50 is equal to the pressure drop through capillary passage 26 at the new flow established by passage 26 in cooperation with passage 46. Movement of the control valve 10 will actuate the motor 15 to shift the steering member 16. As described above, movement of the member 16 will result in a movement of the piston 44 of the pilot valve 12. This movement will be in such a direction as to readjust the balance of pressures between chambers 13 and 14 so that control valve 10 will return to the centered position shown and no further movement of the motor 15 and the steering control surface will occur. More specifically, for instance, if the movement of pilot valve piston 49 is to the left to shorten the capillary passage connecting with discharge port 51, the discharge of hydraulic liquid from the control pressure chamber 13 will be increased and the pressure within this chamber will therefore drop with respect to the pressure within chamber 14. The piston 28 of control valve 10 will therefore move to the left. This movement will continue until the pressure in chamber 13 is equal to that in chamber 14 by virtue of the shortening of the length of passage 25. This motion

to the left in the diagram provides a high pressure fluid connection through port 23 and conduit 36 to the left end of the hydraulic positioning motor 15. Positioning motor piston 38 will therefore move to the right to rotate the steering control surface 16 in a clockwise direction. The clockwise movement of steering control surface 16 will result in a movement to the right in the diagram of piston 44 of pilot valve 12. This movement of the pilot valve piston 44 will reduce the length of the capillary passage at 46 connecting with the discharge port 47 to increase the discharge of hydraulic fluid from control pressure chamber 13 and 14 at a lower level. This rebalancing will cause the return of the control valve piston 28 to the centered position shown and no further control operation will occur. It will thus be seen that for any position which is given to the control lever 17, the system will provide a corresponding new position for the steering control surface 16 which will be automatically held. Although a manual position input control is shown for this steering control surface positioning system, it will be obvious that the electrical energization of solenoid 18 could be obtained from automatic electrical control apparatus such as an automatic pilot. Although pilot valves 11 and 12 have been illustrated as employing capillary flow control elements at the reduced sections 50 and 46, it will be appreciated that more conventional valves without these reduced sections may be employed to vary associated orifice openings.

It will be obvious, of course, that the input pilot piston 49 of pilot valve 11 may be manually positionable. This is illustrated in the embodiment of Figure 2 in which the input control lever 17a positions the pilot piston 49a of the pilot valve 11a through the medium of a connecting rod 55. In the modification of the system shown in Figure 2, the right-hand pilot valve 12a includes a piston 44a which is positioned by a solenoid 18a. The solenoid 18a is energized by an attitude stabilization damper which may include a conventional rate gyro and an electrical amplifier to provide attitude stabilization signals for the dirigible craft which is to be controlled by the system. Figure 2 thus particularly illustrates how the present invention may be employed to mix two control input signals such as the manual control signal from the lever 17a and the electrical signal from the attitude stabilization damper 56 to obtain a positioning control system which is operable in response to the mixture of signals. In this embodiment of the invention, a "follow-up" signal is obtained by a method which has been employed in prior art systems. The entire casing 20 of the control valve, and the casing 21a of the hydraulic motor 15a which is integral therewith are movable upon actuation of the motor 15a. The piston 38a of the hydraulic motor 15a includes a connecting rod 57 which is pivotally mounted to the frame of the dirigible craft to be controlled as indicated at 58. It will be seen therefore that the piston 38a remains relatively fixed and the casing 21a must move when the motor 15a is activated. This motion is transmitted through the connecting rod 39a to the steering control surface 16a. Since the control valve housing 20 is integral and movable with the housing 21a of the motor 15a and houses the pilot valve 11a when the motor 15a causes motion of these housings in response to an initial movement of the control lever 17a, the repositioning of the housing causes an immediate relative repositioning of the housing and the pilot piston 49a to provide the desired "follow-up" operation.

In the embodiments of the invention shown in Figures 1 and 2 and described immediately above, the two pilot valves controlling the discharge of fluid from the control pressure chambers 13 and 14 have been statically positionable to various control positions in order to accomplish the control function. This control function may also be accomplished by causing the control valve pistons to open intermittently, the amplitude or the frequency

of the intermittent opening action will then provide an average discharge rate which will control the flow and the resulting pressures in the chambers 13 and 14. An example of a system employing this principle is shown in the modification of Figure 3. In this form of the invention, the pilot valve pistons 44b and 49b are respectively vibrated by separate spring-mass systems including leaf spring members 60 and 61 and the associated masses 62 and 63. These spring-mass systems are designed with natural vibration frequencies respectively above and below a vibration excitation frequency which is to be controlled. In the system of Figure 3, the apparatus of the invention is incorporated in a speed control system for an engine 64 and the excitation frequency of the spring-mass systems including the spring members 60 and 61 is proportional to the speed of the engine 64. This speed signal is transmitted through an output shaft 65 to an eccentric device 66 from which a translational vibration is transmitted to a connecting rod 67 and thus to the spring members 60 and 61. The connecting rod 67 may be supported as shown at 68.

In this system, the output shaft 39 of the power piston 38 is connected to position a motive fluid valve 69 to control the flow of motive fluid to the engine 64 in order to maintain the engine speed which is determined by the natural vibration frequencies of the spring-mass systems including the spring members 60 and 61. A starting spring 70 may preferably be provided to bias the control valve 10 in the direction which will provide for increase in motive fluid flow to the engine 64 when the engine speed is below the range at which the spring-mass systems are effective. The system shown in Figure 3 and described in this and the preceding paragraph forms a portion of the subject matter described and claimed in my concurrently filed and co-pending patent application Serial No. 478,665, now Patent No. 2,879,467, for a "Vibratory Control Apparatus" which is assigned to the same assignee as the present application.

It will be realized, of course, that the control devices such as pilot valves 11 and 12 not only may be operated by either mechanical or electrical signals as illustrated in Figures 1 and 2, or by vibratory mechanical signals such as illustrated in Figure 3, but flow control devices other than valve elements may be used on either one or both sides of the control system of this invention. For instance, in the modification of Figure 4, the pilot valve 12 is replaced by a small low-flow positive displacement pump 72. In this embodiment, the pump 72 is employed to provide a speed signal to indicate the speed of the engine 64 as determined by the rotation of the shaft 65. Thus, the manual control lever 17a may be positioned to shift the pilot valve piston 49a to a position corresponding to a desired speed of the engine 64. The system then operates to adjust the setting of motive fluid valve 69 to change the speed of the engine 64 to a point at which the fluid flow provided by the pump 72 corresponds to the flow permitted by the valve 11a and the pressures within control pressure chambers 13 and 14 are thereby balanced.

It will be apparent that there are many possible combinations of separate flow control devices which may be employed to control the pressures within the control pressure chambers 13 and 14, and the modifications of the invention shown and described above are illustrative only of a few of the possibilities. For instance, fluid pumps such as the pump 72 in Figure 4 could be employed on both sides of the system and the system could thus be employed to match the speeds of two machines. The speed of machine 64 would be altered or controlled by the valve 69 to follow the speed of another machine which would rotate a pump similar to the pump 72 to control the pressure within control pressure chamber 13.

A particularly notable feature of the invention is that with two separately operable pilot valves or other flow control signal input devices, the number of possible input

signals is at least doubled over the conventional hydraulic servo system in which a single pilot valve is employed. Thus, in a conventional piloted positioning system, two input signals may be employed by movements respectively of the pilot valve piston and of the cylinder or cylinder sleeve within which that piston is supported. Although the movable cylinder sleeve structure has not been disclosed in this patent application, it is well known, and the principle of movement of the cylinder supporting the pilot valve is illustrated in Figure 2 as described above. Obviously, by the employment of sleeves, the pilot valves could both provide for the reception of two input signals to make a total of four input signals which would be "hydraulically" mixed in the control system. This feature of the invention whereby a plurality of control input signals may be mixed hydraulically is particularly important and advantageous because many control systems require a multiplicity of input signals and the present methods of combining those signals are often very unsatisfactory. The present methods are very generally by means of lever systems, or systems employing differential gears or other mechanical connections for combining position signals before introduction to the hydraulic pilot valve. These prior systems have the basic disadvantage not existent in the present invention that the mechanical connections are likely to include "play" or lost motion because of assembly requirements and because of mechanical wear after a period of use. Such lost motion can be disastrous in a positioning control system, particularly where the amplification is high, for extreme lack of precision in the control system is likely to result, and even more seriously, unstable operating conditions may be encountered.

In contrast, the present invention provides a system in which signals may be combined very precisely within the hydraulic system itself and without the necessity for mechanical interconnections between the separate sources of input signals. This lack of interconnection is also a very important advantage since the transmission of mechanical disturbances from one signal source to another, commonly present in prior art systems, may be completely avoided.

The following claims are intended to define the valid scope of this invention over the prior art and to cover all changes and modifications falling within the true spirit and valid scope of the invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A steering control system for a dirigible craft comprising a steering member to be positioned, a hydraulic motor connected to position said steering member, a valve connected to control said positioning motor, said control valve comprising a housing enclosing two separate control pressure chambers and a piston reciprocally mounted within said housing between said chambers, said piston including reduced diameter end portions defining capillary passages for the admission of hydraulic pressure fluid into said chambers respectively associated therewith, said capillary passages being inversely variable in length and flow resistance upon piston movement, a first variable flow valve connected to control the discharge of fluid from one of said chambers in accordance with a control signal, a second variable flow valve connected to control the discharge of fluid from the other of said chambers, and a mechanical linkage connection with said steering member for positioning said second variable flow valve to provide a follow-up signal.

2. Apparatus for the control of the flow of motive fluid to an engine having a motive fluid valve, a hydraulic motor adapted to position said valve, a control valve connected to control the operation of said positioning motor, said control valve including a housing and a piston reciprocally mounted therein for movement in either direction away from a central null position during control operation, said housing including control pressure cham-

ber enclosures at the respective ends of said piston, the portion of said housing supporting said piston comprising a sleeve member of a length shorter than said piston and having a cylinder bore therethrough, said piston including ends protruding through the ends of said sleeve and comprising end lands of reduced cross section to provide circumferential capillary passages with the inner surface of said sleeve, said respective capillary passages being inversely variable in length for a given piston movement, said sleeve including inlet connections for supplying hydraulic pressure fluid through said capillary passages to said chambers, and at least two flow control devices separated from said piston but arranged to control flow through said chambers, said flow control devices being operable in response to independent control signals from said engine.

3. A hydraulic positioning apparatus comprising a double input hydraulic amplifier including a housing enclosing two separate control pressure chambers each arranged for continuous flow of hydraulic pressure fluid therethrough, a first pilot valve arranged for positioning in accordance with a desired output position of the apparatus and connected to control the flow of fluid through one of said chambers, a second pilot valve arranged for positioning in accordance with the actual output position of the apparatus and connected to control the flow of fluid through the other of said chambers, said first and second pilot valves being operative in response to independent signals of unlike kind, a control valve piston reciprocally mounted within said housing between said control pressure chambers for positioning in accordance with pressure differences therebetween, said control valve piston including end portions forming capillary passages with associated portions of said housing, said capillary passages at said respective chambers being inversely variable in length for a given movement of said control valve piston, said housing including connections for the supply of high pressure hydraulic fluid through said capillary passages to said respective chambers, and a hydraulic positioning motor connected for operation by said control valve.

4. A double input hydraulic amplifier for an engine speed control system comprising a housing enclosing two control pressure chambers adapted for continuous flow of hydraulic pressure fluid therethrough, a liquid flow control device connected to control the flow of liquid through one of said chambers in accordance with a control signal, a liquid pump arranged to be driven by the engine which is to be controlled as an indication of the speed thereof and connected to the other of said chambers for controlling the liquid flow therethrough, a control valve piston reciprocally mounted within said housing between said control pressure chambers and arranged for positioning in accordance with pressure differences therebetween, the respective ends of said piston adjacent to said chambers including members forming capillary passages with associated portions of said housing, said pas-

sages being variable in length upon piston movement, said housing including hydraulic pressure liquid inlet connections for supply of hydraulic pressure liquid through said capillary passages to said chambers, a hydraulic positioning motor connected for positioning by said control valve, said motor being adapted for connection to a device for controlling the flow of engine motive fluid for the control of the speed thereof.

5. A multiple input hydraulic amplifier for a hydraulic control system providing for control operation in response to two or more independent control signals, comprising a housing, a reciprocable piston mounted in the housing and dividing it into two control pressure chambers, flow receiving and discharging means associated with each chamber and adapted for connection to a source of hydraulic liquid under pressure, flow restrictive means associated with opposite sides of said piston for restricting flow through each chamber, additional flow restrictive means responsive to a first control signal and acting to restrict flow through one of said chambers, and further additional flow restrictive means responsive to a second control signal independent from and unlike said first control signal, said second signal acting to restrict flow through the other of said chambers, said control pressure chambers and said flow restrictive means being so constructed and arranged that the piston position and operation is governed by the resultant of the flow restrictive forces generated by said first and second control signals.

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