April 25, 1961

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HYDRAULIC ACTUATOR CONTROL

2,981,237

Filed Oct. 14, 1958

2 Sheets-Sheet 1

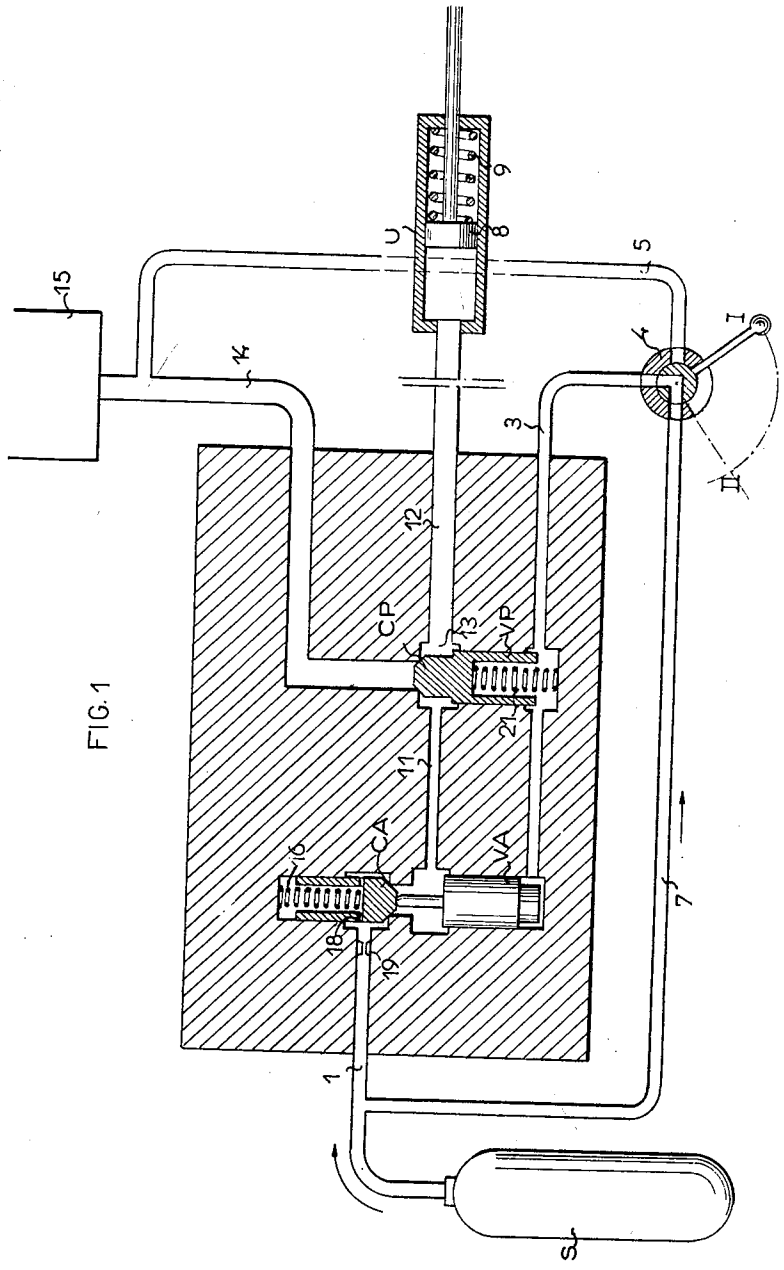

FIG. 1

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2 Sheets-Sheet 2

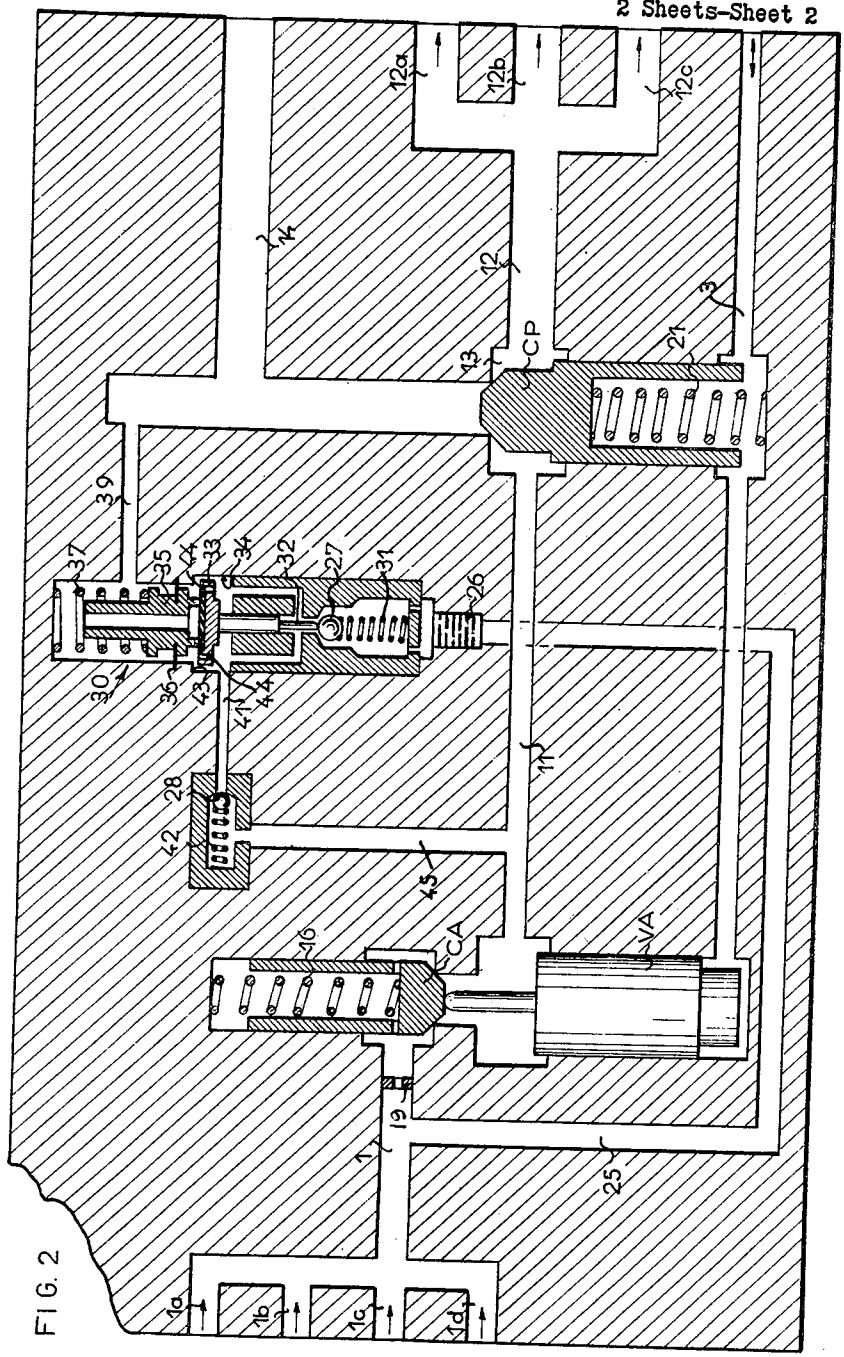

FIG. 2

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HYDRAULIC ACTUATOR CONTROL

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This invention relates to apparatus for controlling hydraulic actuators, such as single-acting hydraulic jacks, and more particularly to actuators for operating electrical circuit-breakers, for which immediate, rapid and positive response to control actions or signals is essential.

For various reasons such as, for example, the need for remote control or to keep the dimensions of the liquid passages of the control means within reasonable limits, hydraulic relays must usually be incorporated into the control apparatus; but conventional hydraulic relays are apt to impose unacceptable delay in the response to control actions or signals and/or to impede the acceleration of the movable member of the controlled actuator, or to reduce the maximum speed it can attain when a movement thereof has been initiated. In the case of a single-acting actuator whose exhaust stroke, effected by spring means or the like (e.g., a weight) opens a circuit-breaker, any such delay in initiating the movement or slowing-down of the movement when initiated is especially objectionable.

An object of the invention is to provide an improved apparatus comprising hydraulic relays for controlling the feeding, from a suitable source of hydraulic liquid under pressure, and the exhausting of a hydraulic actuator, so constructed, arranged and operative as to insure that, in response to the appropriate control action or signal, exhaustion of the actuator is initiated with no measurable delay, and that no resistance is imposed on the actuator capable of appreciably retarding its acceleration or limiting its maximum speed, once its exhaust stroke has been initiated.

A further object of the invention is to provide an apparatus as defined in the preceding paragraph comprising an admission valve and an exhaust valve, both of which are of the poppet type having the smallest possible travel between their seated and fully unseated positions and are controlled by separate valve actuating members having a common feed and exhaust line selectively connectible to a source of hydraulic pressure or to exhaust by a selector cock or equivalent selector means, the power stroke of the "admission" member serving to unseat the admission valve, which is seatable by a spring, and the power stroke of the "exhaust" member serving to seat the exhaust valve (which may also have a light seating spring, though this is not absolutely essential).

A yet further object of the invention is an apparatus as above described in which the hydraulic pressures acting on the admission valve when unseated are completely balanced and that, so long as flow is taking place through the admission valve, its valve actuating member is subjected to a hydraulic-pressure effort sufficient to enable it to hold the valve unseated against the counter-effort of its seating spring, whereas when flow through the valve ceases, the hydraulic pressures acting on its valve actuating member are in equilibrium and no unseating effort is applied to the valve, which therefore is at once re-seated by its seating spring.

The last-mentioned object may be achieved by feeding

the working chamber of the "admission" member directly (through the selector means) from a source of pressure and feeding the admission valve itself from the same source of pressure through a restrictor, the pressure on the downstream side of the valve-seating being constantly applied to the valve actuating member in the sense opposing the pressure in its working chamber and the areas on which those opposed pressures act being equal.

Still another object of the invention is an arrangement of the exhaust valve of the apparatus such that it is subjected to the pressure subsisting in the controlled actuator in the sense to unseat it, said pressure acting on a smaller area than that on which the pressure applied to the working chamber of the "exhaust" member acts in the sense to seat the valve.

An additional object of the invention is the incorporation in the control apparatus of automatic means for compensating leakages, and thermal changes of specific volume of the hydraulic liquid and, more generally, for keeping the whole system of ducts, chambers and members of which the apparatus is composed completely full of liquid at all times. A preferred form of such automatic means is hereinafter described.

The foregoing objects of the invention, together with others as may hereinafter appear, and how they may be achieved in a practical way, will be more fully understood from the following detailed description, having reference to the accompanying drawings and given by way of example only, without implied limitation of the scope of the invention.

In the drawings:

Figure 1 is a partly sectional, schematic view of the apparatus; and

Figure 2 is a similar view, on an enlarged scale, of a modified form of the apparatus illustrated in Figure 1, further including means for compensating leakage.

The function of the apparatus illustrated in Figure 1 is to bring about, alternatively, the feeding of liquid, such as oil, under pressure, from a source such as an accumulator S, and the exhaustion to a reservoir 15 of a hydraulic actuator, such as a hydraulic jack U. The latter is connected to the source S by ducting 1, 11, 12, and to the reservoir 15 by ducting 12, 14. In the run of the ducting 1, 11, 12, between the parts 1 and 11, thereof, is a poppet type admission valve CA, normally held on to its seating by a spring 16; and in the run of the ducting 12, 14 is a poppet type exhaust valve CP normally held on to its seating by a spring 21.

The admission valve is controlled by a reciprocable valve actuating member VA whose piston acts directly on the admission valve CA in the sense to unseat it; and the exhaust valve CP is controlled by a reciprocable valve actuating member VP, whose piston is integral with the exhaust valve. The working chambers of the cylinders of the members VA and VP are both connected by a duct 3 with a selector cock, which can connect the duct 3, either with a source of hydraulic pressure, which in the illustrated example is the source S, via a duct 7, or with the reservoir 15 via a duct 5.

In the illustrated example, the controlled actuator U is a single-acting hydraulic jack, whose piston 8 is movable (to the right as seen in the figure) by hydraulic pressure against the counter-effort of a spring 9. The portions of ducting 11, 12 are connected by a chamber 13 in which the exhaust valve CP is situated and in which is formed the seating of the exhaust valve leading to the exhaust duct 14.

The admission valve CA is extended to form a hollow piston which slides in a blind cylinder in which the spring 16 is located and the interior of this cylinder communicates with the admission duct 1 through ports 18 formed in the skirt of the piston part of valve CA. Consequently, when the valve CA is seated the pressure in duct 1 sup-

plements the effort of spring 16 in holding the valve seated; but when the valve is unseated the pressure downstream of a restrictor 19 in duct 1 is applied over equal areas to both faces of the valve CA so that the hydraulic pressures applied to the valve in the unseating and seating senses are in equilibrium.

The resistance 19 serves not only to insure a steady build-up of pressure on the piston 8 of the jack U and to prevent surging during the admission phase, but also to unbalance the pressures acting, during this phase, on opposite faces of the piston of the member VA as, and for the purpose, hereinafter explained.

When the selector cock 4 is in the position I as shown in the figure, the pressure of the source S is transmitted via ducts 7 and 3 to the operative chambers of the valve controlling members VA and VP. The piston of member VA, whose area is considerably greater than that of the seating of valve CA, therefore unseats the valve CA against the efforts of spring 16 and the hydraulic pressure exerted on the valve in the sense to seat it. The pressure of source S is thereupon transmitted, via duct 11, to the chamber 13, thus equalizing the pressures in chamber 13 and in the working chamber of the member VP. Consequently, there is no need for the piston of member VP to have a fluid-tight fit in its cylinder. Since, however, the area of the piston of the valve CP subjected to the pressure in chamber 13 is less by the area of the valve seating than that on which the pressure in the working chamber of the member acts on the piston of the valve CP, the net hydraulic effort exerted on the valve CP supplements that of the spring 21 in holding the valve on to its seating. These conditions persist as long as the cock 4 in position I.

The apparatus operates as follows:

In the normal rest position the selector cock 4 is in position II connecting the ducts 3 and 5 and shutting off the duct 7. The piston 8 of the controlled jack U is at the left-hand end of its stroke (as seen in the figure) and all the ducts 1, 11, 12, 14, 3, 5 and 7 are full of liquid. The pressure in ducts 1, 7 is that of the source S, and that in ducts 14, 5 and 3 is a low pressure due only to the head corresponding to the depth below the liquid level in the reservoir 15 of any point of the duct system 14, 5, 3. The valves CA and CP are both closed and the pressure in the jack U and ducts 11, 12 is likewise low corresponding to the residual pressure in the jack U at the end of the preceding exhaust stroke.

To effect the power stroke of the controlled jack U, the cock 4 is moved to position I, shutting off the duct 5 and connecting the duct 3 to the pressure-source S via the duct 7. The source pressure is thus applied to the working chamber of the member VP and thus supplements the effort of spring 21 in holding the valve CP on its seating. The source pressure is likewise applied to the working chamber of the member VA causing its piston to unseat the valve CA as previously explained, thereby admitting the source pressure, less the reduction due to the loss of head through the restrictor 19, to the jack U via the ducts 11 and 12. Since the system is full of liquid to start with there is no measurable delay between the throwing over of cock 4 to position I and the opening of valve CA and the beginning of movement of the jack piston 8, the theoretical delay between the instant of throwing over the cock 4 and the commencement of movement of the piston 8 being the time taken for sound to travel through the liquid column enclosed between the cock 4 and the piston 8.

As soon as the valve CA is unseated the pressure downstream of the restrictor 19 acts on both faces of the valve which are of the same area and consequently the valve is only subjected to the effort of the spring 16. The same hydraulic pressure also acts on the upper face of the piston of member VA, but owing to the loss of head through the restrictor 19 this pressure is less than the source pressure applied, via duct 3, to the lower face of the piston which is therefore subjected to a net upward

hydraulic effort, which, by suitable selection of the area of the piston of member VA, of the characteristic of the restrictor 19 and of the strength of spring 16, is sufficient to overcome the effort of spring 16 and hold the valve CA unseated as long as flow is taking place through the restrictor 19.

When the piston 8 reaches the limit of its power stroke (to the right as seen in the figure) and its movement ceases, flow through the restrictor 19 ceases too and consequently the pressure in the ducts 11, 12 (and in the jack U itself) becomes equal to the source pressure, with the result that the pressures acting on the opposite faces of the piston of member VA are equalized, thus enabling the spring 16 to reseat the valve CA. The liquid thus trapped between the valve CA and the piston 8 of jack U therefore constitutes a hydraulic lock which holds the piston 8 in its "end of power stroke" position.

The return stroke of the jack U is effected by throwing-over the cock 4 into position II causing the duct 3 and working chambers of the members VA, VP to be promptly exhausted through duct 5. The pressure which is maintained in the jack U and in the ducts 12 and 11 by the spring 9 and acts on the annular surface of valve CP exposed in chamber 13, overcomes the effort of spring 21 and unseats valve CP, thus connecting the jack U to exhaust via ducts 12, 14 and allowing spring 9 to return piston 8 to its initial position of rest. The dynamic pressure of the liquid escaping past valve CP suffices to hold this valve fully unseated until the exhaust stroke of piston 8 is complete, whereupon, with cessation of flow past the valve CP the spring 21 returns this valve to its seating, thus returning the system to its initial rest condition.

Referring now to Figure 2 illustrating a modified form of the embodiment shown in Figure 1, elements common to both the embodiments illustrated respectively in Figures 1 and 2 are identified by the same reference characters in both figures.

In the embodiment illustrated in Figure 2 the supply duct 1 has four branches 1*a*, 1*b*, 1*c*, 1*d*, for connection to four alternative sources of supply (not shown in Figure 2), but each corresponding to the source S of Figure 1. Further, the continued feed and exhaust duct 12 has three branches 12*a*, 12*b*, 12*c* for connection to three hydraulic actuators (not shown in Figure 2) but each corresponding to the actuator U of Figure 1. (The three actuators may be arranged for simultaneous operation or for selective operation by means of suitable selector cocks.) The reservoir 15, the ducts 5 and 7 and the cock 4, which are not shown in Figure 2, are arranged as in Figure 1.

The embodiment of Figure 2 further includes an automatic device for keeping the whole system full of liquid in all circumstances and serving to compensate (*a*) possible leakages, especially past the exhaust valve CP; (*b*) thermal changes of specific volume of the liquid; and (*c*) partial voids that can be produced, at the instant at which the exhausting phase ends, in the controlled actuators themselves or in the exhaust duct in their neighbourhood, owing to the speed acquired by the liquid at the end of the exhausting phase.

This automatic "refilling" device comprises a duct 25 branched from the supply duct 1 upstream of the restrictor 19 and connected, via a flow-restrictor 26, with a pressure reducing device 30, which in turn is connected, via a duct 41, a non-return valve 28 loaded by a spring 42, and a duct 45, with the duct 11 connecting admission valve CA with the chamber 13 of the exhaust valve CP. In the illustrated example the flow-restrictor 26 comprises a series of mutually staggered calibrated orifices.

The pressure reducing device 30 comprises a valve constituted by a ball 27 situated on the upstream side of its seating and seatable by a spring 31. The ball 27 is unseatable by a push-rod 32 formed integrally with a

plate 33, which slides in a cylinder 34. The interior of cylinder 34 below the plate 33 communicates with the seating of the ball 27 and with the duct 41. Upward travel of plate 33 is limited by a shoulder 43. Above the plate 33 is a tubular member 35 supported by an elastic diaphragm 36 which partitions the cavity in which the member 35 is situated into two chambers of which the upper one communicates with the exhaust duct 14, via a duct 39, and the lower one comprises the part of cylinder 34 above the plate 33 and communicates with the part of cylinder 34 below plate 33, via perforations 44 in plate 33, even when the latter is in engagement with the shoulder 43. On the upper face of plate 33 is a sealing disc which forms a seating for the lower end of member 35. The chamber above and below the diaphragm 36 intercommunicates through the tubular member 35 when the latter is clear of its seating. Member 35 is urged towards it seating by a spring 37, whose calibration determines the pressure reduction through the ball valve 27, since the pressure in cylinder 34 exerts an upward effort on plate 33 owing to the difference between the whole area of the lower face of plate 33 and the annular area of its upper face surrounding the member 35, both of which areas are subjected to the pressure in cylinder 34. Consequently when this upward effort overcomes the opposed effort of spring 37 (plus any contribution from the diaphragm 36) the plate 33 rises and allows the ball 27 to be re-seated.

The refilling device operates as follows:

If at the conclusion of the exhausting phase of the controlled actuators(s) leakage occurs, e.g. past the exhaust valve CP, towards the exhaust reservoir from the column of liquid contained, between the piston(s) of the controlled actuators, the non-return valve 28 and the admission valve CA, in the ducts 12 (12*a*, 12*b*, 12*c*) 11, 45 and chamber 13 or if partial voids occur in this column of liquid, due either to the speed of the liquid at the inclusion of the exhausting phase or to thermal contraction of the liquid, the pressure in ducts 11 and 45 will be correspondingly reduced. The spring-loading of the non-return valve 28 being quite light, this valve will not sustain any substantial excess of pressure in duct 41 over that in duct 45 and consequently the pressure in duct 41 and cylinder 34 will be correspondingly reduced until the upward effort of the pressure on plate 33 is overcome by the opposed effort of spring 37, thus causing the valve ball 27 to be unseated, whereupon additional liquid is admitted, via duct 25 and restrictor 26, cylinder 34, duct 41, non-return valve 28 and duct 45 to the duct system 11, 13, 12 until the latter is completely refilled with liquid substantially at the pressure subsisting in duct 41 which is determined by the characteristics of the pressure reducing device 30.

If for any reason an excessive pressure is generated in the cylinder 34, e.g. due to defective fluid-tightness of the valve 27 allowing a continual flow to take place through the "refilling" channel, or to defective fluid-tightness of the non-return valve 28, no damage will be sustained by the pressure-reducing device 30, since the net upward effort of this excess of pressure on the plate 33 will lift it until it is arrested by the shoulder 43. The excess pressure transmitted through the perforations 44 will then continue to act on the diaphragm 36 and the annular area of member 35 surrounding its seating and will unseat the member 35 from its seating on the plate 33 allowing excess liquid to escape through the central bore of member 35 into the exhaust duct 14, via duct 39.

The flow-restrictor 26 protects the valve 27 more especially against erosion of its seating by too rapid a flow of liquid.

In practice, the admission and exhausting phases will usually be initiated, not by throwing over a hand-operated cock, such as cock 4 (Figure 1) but by equivalent automatic means, actuated e.g. electrically, for selectively connecting duct 5 to duct 7 or duct 3 in response to predetermined signals.

It should further be noted that the exhaust valve CP, formed and arranged as described and illustrated, acts as a safety valve in that its spring 21 is so rated that it will yield and allow the valve CP to be unseated if the pressure in the liquid column 11, 13, 12, which acts on the valve in the unseating sense, exceeds a safe value. Such excessive pressure may be generated when the apparatus is in the rest position after completion of the exhaust stroke of the controlled actuator by thermal expansion of the liquid column (11, 13, 12) trapped between the admission valve CA and the actuator piston 8 (Figure 1).

It is to be understood that the invention includes all such modifications, adaptations and variations of detail and arrangement within the scope of the appended claims as may be required for any contemplated application thereof and are within the competence of those skilled in the art.

What is claimed is:

1. Hydraulic control apparatus, for selectively connecting a controlled hydraulic actuator to a source of hydraulic pressure and to exhaust respectively, and comprising an admission duct connecting the said source to said actuator, an exhaust duct connected to said actuator, an admission valve including a valve seat in said admission duct and a movable valve member cooperating with said seat, spring means operative to seat said movable member of the admission valve, a reciprocable valve actuating member associated with said movable member of the admission valve and operative to unseat it, an exhaust valve including a movable valve member controlling the connection of said actuator with the exhaust duct, a reciprocable valve actuating member associated with said movable member of the exhaust valve and operative to seat the same, a combined feed and exhaust line common to both said valve actuating members, the pressure subsisting in said line being operative on said valve actuating members for unseating said movable member of the admission valve and seating said movable member of the exhaust valve respectively, a controllable device for selectively connecting said common feed and exhaust line to exhaust and to a source of hydraulic pressure respectively, means operative to equilibrate hydraulic pressures acting on the valve actuating member of the admission valve when the admission valve is open and no flow through it is taking place, thus allowing said spring to re-seat said movable member of the admission valve, and said valve actuating member of the exhaust valve having a form such that the pressure subsisting in the actuator acts thereon to unseat the movable member of the exhaust valve thereby causing it to be unseated as soon as the said common line is connected to exhaust.

2. Hydraulic control apparatus, for selectively connecting a controlled hydraulic actuator to a source of hydraulic pressure and to exhaust respectively, and comprising an admission duct connecting the said source to said actuator, an exhaust duct connected to said actuator, a poppet type admission valve in said admission duct, spring means opertaive to seat said admission valve, a reciprocable valve actuating member associated with said admission valve, a poppet-type exhaust valve controlling the connection of said actuator with the exhaust duct, a reciprocable valve actuating member associated with said exhaust valve and operative to seat it, a combined feed and exhaust line common to both said reciprocable valve actuating members, the pressure subsisting in said line being operative on said reciprocable valve actuating members for unseating the admission valve and seating the exhaust valve respectively, a controllable device for selectively connecting said common feed and exhaust line to exhaust and to said source of hydraulic pressure respectively, said apparatus further including

a cylindrical chamber in which the admission valve is slidably mounted and which encloses said spring means, a restrictor in the admission duct upstream of the admission valve, means for equalizing the pressure in said cylindrical chamber with the pressure in the admission duct between said restrictor and the admission valve, the reciprocable valve actuating member associated with the admission valve including a piston having one face subjected to the pressure subsisting in said common feed and exhaust line and an opposite face of equal area is communication with the admission duct downstream of the admission valve, said piston being adapted to unseat the admission valve when the first-mentioned face thereof is subjected to a greater pressure than the second-mentioned face thereof; and the reciprocable valve actuating member associated with the exhaust valve including a piston operatively connected with the exhaust valve, and having a smaller face on which the pressure subsisting in the controlled actuator acts to unseat the exhaust valve and a larger opposite face subjected to the pressure subsisting in said common feed and exhaust line.

3. Apparatus as defined in claim 2, including a chamber in which the exhaust valve is located and in which the smaller face of the piston of the reciprocable valve actuating member of the exhaust valve is exposed, said chamber communicating with the controlled actuator and with the part of the admission duct downstream of the admission valve and having an opening which constitutes the seating of the exhaust valve and communicates with the exhaust duct.

4. Apparatus as defined in claim 2, further including spring-means operative to hold the exhaust valve seated.

5. In an apparatus as defined in claim 1, means for compensating leakages and voids in liquid columns contained between the admission and exhaust valves and the controlled actuator, said means comprising a refilling channel constantly fed with hydraulic liquid under pressure and connected to the admission duct downstream of the admission valve, and in said channel a pressure reducing device; and spring means operative to hold the exhaust valve seated.

6. In an apparatus as defined in claim 1, means for compensating leakages and voids in liquid columns contained between the admission and exhaust valves and the controlled actuator, said means comprising a refilling channel constantly fed with hydraulic liquid under pressure and connected to the admission duct downstream of the admission valve, and in said channel a pressure reducing device and a non-return valve downstream of said pressure reducing device; and spring means operative to hold the exhaust valve seated.

7. In an apparatus as defined in claim 1, means for compensating leakages and voids in liquid columns contained between the admission and exhaust valves and the controlled actuator; said means comprising a refilling channel constantly fed with hydraulic liquid under pressure and connected to the admission duct downstream of the admission valve, and in said channel a pressure reducing device and a flow-restrictor upstream of said pressure reducing device; and spring means operative to hold the exhaust valve seated.

8. In an apparatus as defined in claim 1, means for compensating leakages and voids in liquid columns contained between the admission and exhaust valves and the controlled actuator, said means comprising a refilling channel constantly fed with hydraulic liquid under pressure and connected to the admission duct downstream of the admission valve, and in said channel a pressure reducing device including means responsive to development of excess pressure in the part downstream thereof of said refilling channel for venting said part of the refilling channel to exhaust; and spring means operative to hold the exhaust valve seated.

9. Apparatus as defined in claim 2 and further including re-filling means comprising a duct branched from the admission duct upstream of the said restrictor, a flow-restrictor in said branch duct, a pressure reducing device fed by said branch duct through said flow-restrictor, a passage connecting the low-pressure side of said pressure reducing device to the admission duct downstream of the admission valve and a non-return valve in said passage; said pressure reducing device comprising a lightly spring-loaded ball valve, a chamber downstream of said ball valve communicating with said passage, a floating plate slidable in said last-mentioned chamber and operative to unseat said ball valve when moved towards it, a shouldering in said last-mentioned chamber limiting movement of said plate away from the ball valve, said plate being provided with perforations communication between opposite faces of the plate when engaged with said shouldering, a flexible diaphragm closing the end of said last-mentioned chamber remote from the ball valve, a tubular member sealed into the center of said diaphragm and providing communication between the last-mentioned chamber and the exhaust duct, said member being seatable on the face of said plate remote from the ball valve so as to seal off said last-mentioned communication, and spring means operative on said member to seat it on said plate and to move the latter towards the ball valve to unseat the latter.

10. In a fluid power transmission system comprising a single acting fluid motor, a source of fluid under pressure, and a reservoir, control valve means including a first valve chamber having a fluid inlet port communicating with said source, a fluid outlet port communicating with said motor, a valve seat disposed toward said inlet port, a spring loaded movable valve member cooperating with said seat, and a first reciprocable valve actuating member having two pressure faces one of which is exposed to fluid pressure in said first valve chamber past said seat, a second valve chamber having a fluid inlet port communicating with said motor, a fluid outlet port communicating with said reservoir and forming a second valve seat, a second movable valve member cooperating with said second seat, and a spring loaded second reciprocable valve actuating member to urge said second movable valve member normally towards said second seat, said second valve actuating member having two pressure faces one of which is exposed to fluid pressure in said second valve chamber, a selector valve operable to connect the other pressure face of said first valve actuating member and the other pressure face of said second valve actuating member selectively to either said source or to said reservoir, and means operative to equilibrate fluid pressures acting on said first valve actuating member when the movable valve member of said first valve is open and no fluid flow through it is taking place.

11. In a fluid power transmission system comprising a single acting fluid motor, a source of fluid under pressure, and a reservoir, a control valve assembly including a first valve chamber and a second valve chamber, said first chamber having a fluid inlet port communicating with said source and a fluid outlet port communicating with said second chamber, and said second chamber having an operating port communicating with said motor and an exhaust port communicating with said reservoir, a valve seat disposed in said first chamber intermediate said inlet and outlet ports thereof, a spring loaded movable valve member in said first chamber cooperating with said seat, a reciprocable valve actuating member in said first chamber adapted to open said movable valve against the action of the spring, said valve actuating member having two pressure faces one of which is exposed to fluid pressure past said seat, a second movable valve member in said second chamber adapted to close said exhaust port thereof and having two pressure faces one of which is exposed to fluid pressure in said second chamber, resilient means in said second chamber to urge said second movable valve member towards closed position, means to connect the other pressure face of said valve actuating member and

the other pressure face of said second movable valve member selectively to said source and to said reservoir, and means effective to balance the fluid pressures acting on both pressure faces of said valve actuating member when the latter has raised the movable valve member in said first chamber from its seat and no fluid flow is taking place through said first chamber.

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