June 28, 1960 D. J. GAFFNEY 2,942,581

HYDRAULIC OPERATOR

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FIG. 1

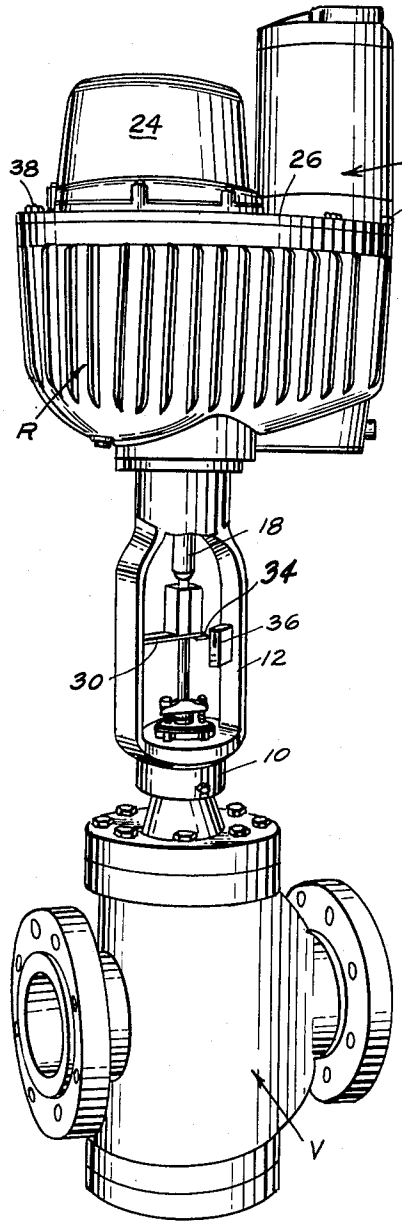
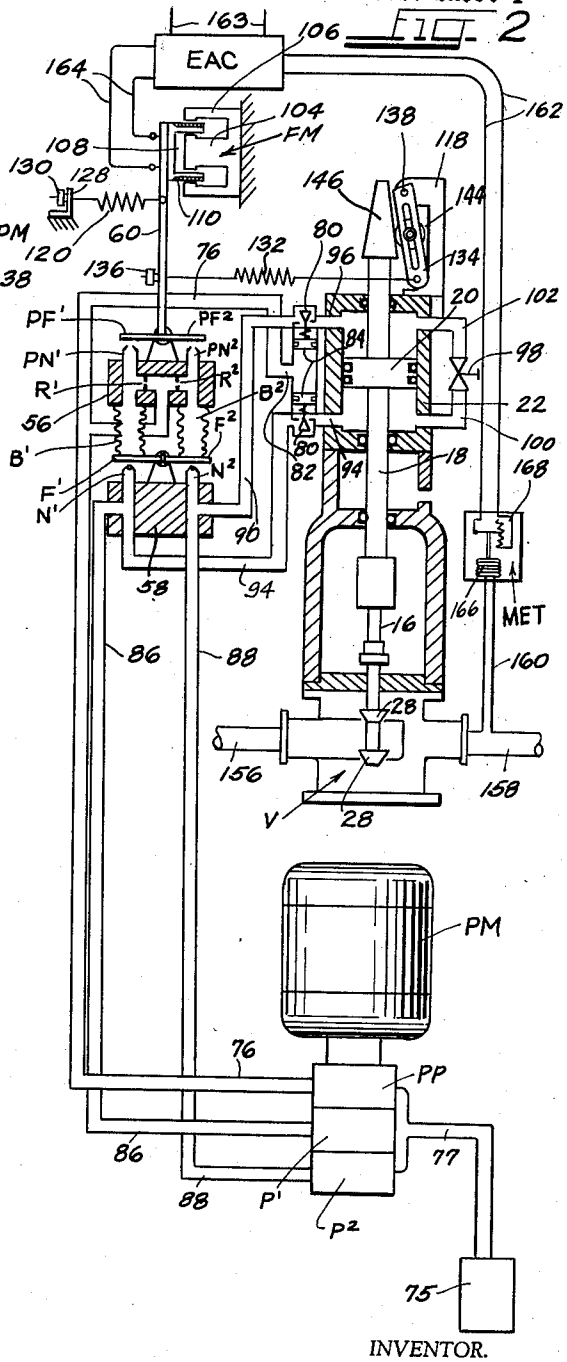


FIG. 2



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FIG. 3

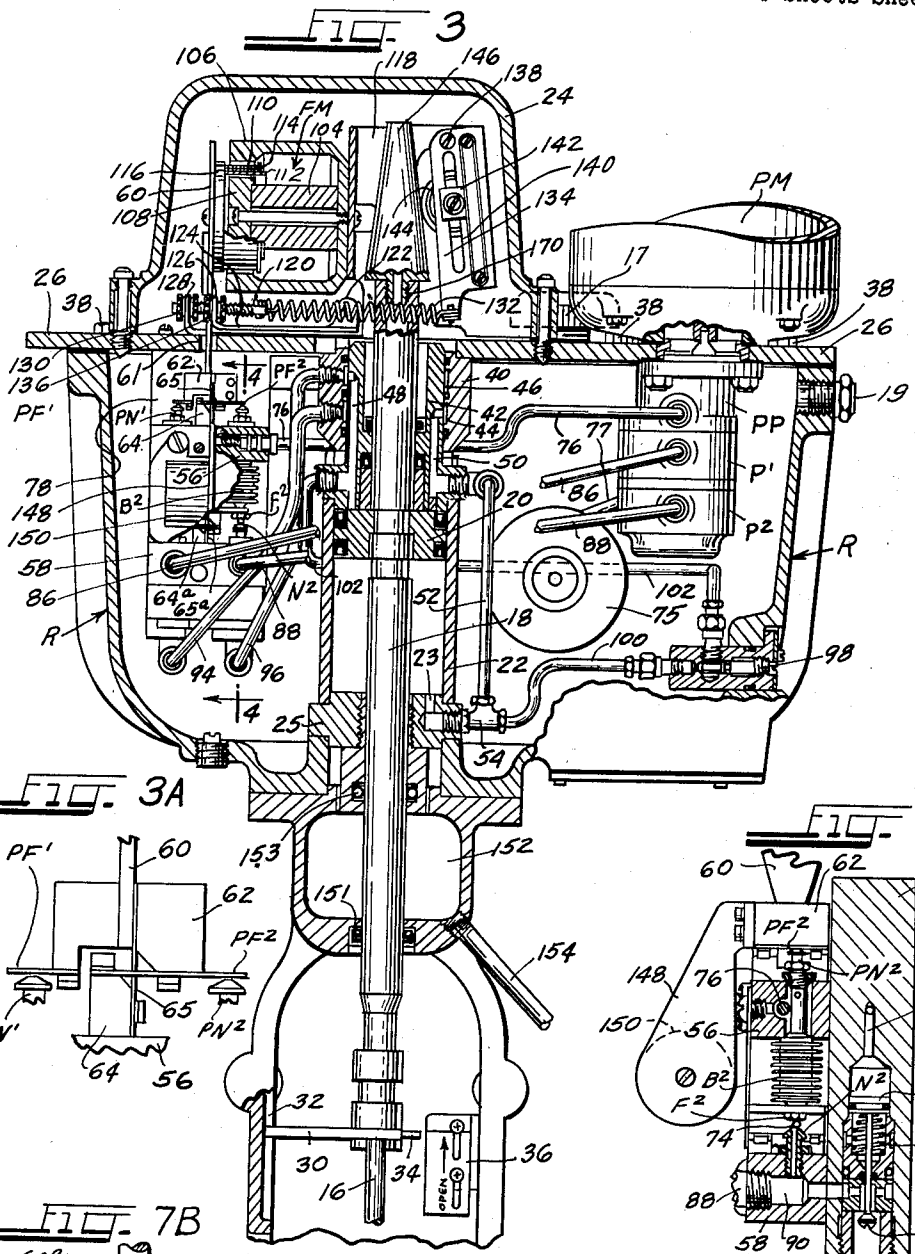


FIG. 3A

FIG. 4

FIG. 7B

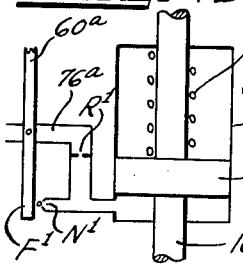
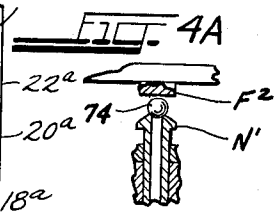


FIG. 4A



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FIG. 5

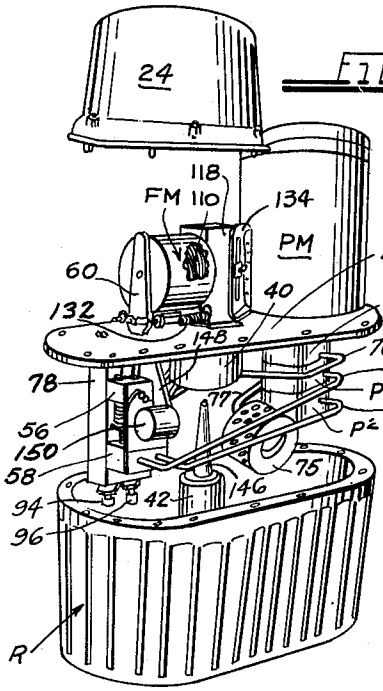


FIG. 7

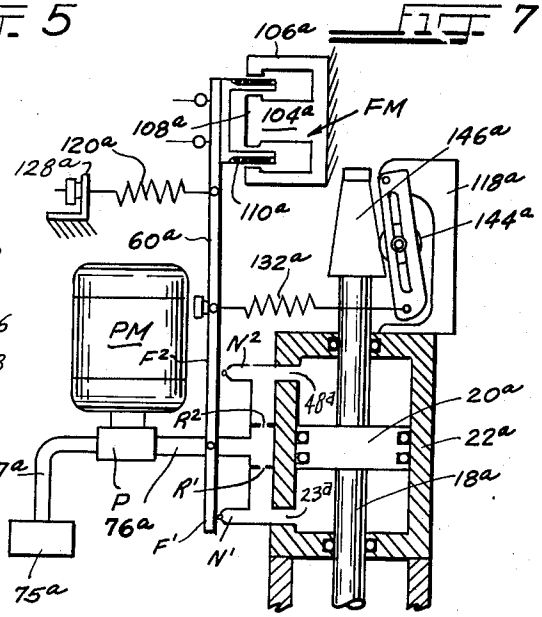


FIG. 6

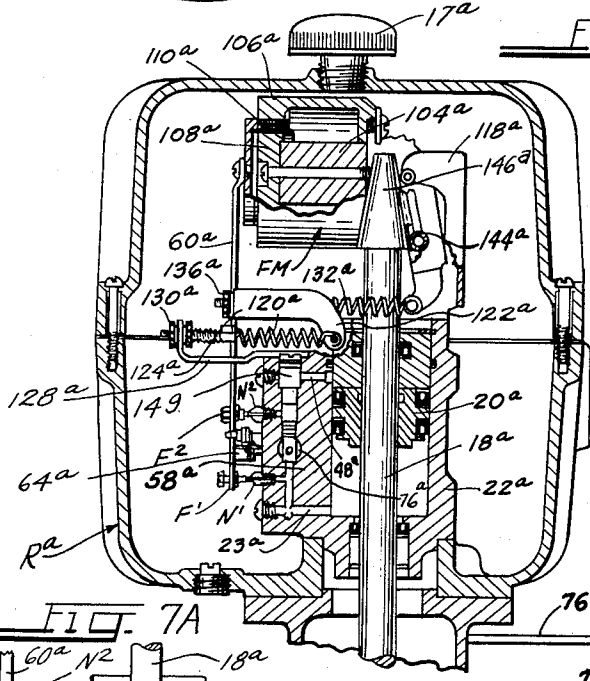


FIG. 8

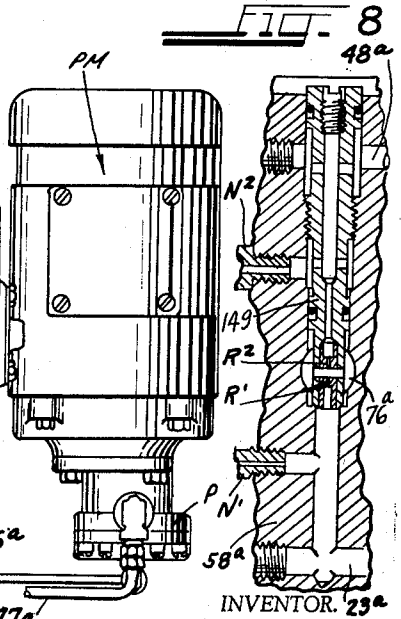
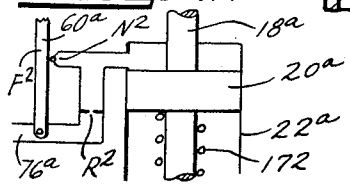


FIG. 7A



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2,942,581

HYDRAULIC OPERATOR

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Filed Mar. 12, 1958, Ser. No. 720,838

13 Claims. (Cl. 121—41)

This invention relates to an electrically controlled hydraulic operator for valves and the like wherein hydraulic pressure is the actuating medium for the valve and is controlled by an electric command signal in such manner as to proportion the positioning of the valve in relation to the requirements of a condition such as the pressure in the downstream side of the valve.

One object of the invention is to provide hydraulic means to position the final control element utilizing electric current such as used for lighting to produce the hydraulic energy. The hydraulic system lends itself readily to proportioning control, producing high forces where necessary. A hydraulic system using a relatively high fluid pressure together with a small actuating piston, when used with a suitable pilot system, makes it possible to obtain relatively high frequency response characteristics because of the low mass of the system, as compared with an electric motor-gear train system.

Another object is to provide electric control for the hydraulic system to eliminate the necessity for a compressed air supply system consisting of compressors, dehydrators, filters and standby equipment. Without appropriate dehydrators and filters pneumatic systems can be troublesome in cold climates where air line "freeze-ups" can occur, resulting in interruptions of service. Further, it is possible to transmit electric control signals over long distances with better frequency response than with pneumatic control signals over comparable distances.

Still another object is to provide a high performance controller utilizing an electric control loop with or without the use of electronic amplification and utilizing only a simple force motor to control a hydraulic pilot which in turn controls the hydraulic system that actuates the operator, and in which the pilot system incorporates no close fitting parts such as sliding plates or spool valves but uses instead simple nozzle-flapper combinations to control the flow of hydraulic fluid.

A further object is to provide an hydraulic actuator in which the hydraulic system including the motor-pump combination can be removed from the actuator itself with the exception of the hydraulic cylinder and piston so that for periodic maintenance or for replacing a malfunctioning actuator the pilot and motor-pump assembly can be removed as a unit and may be replaced with a standby unit in a matter of minutes, thereby resulting in very little down-time.

Still a further object is to provide nozzle valves for controlling the flow of hydraulic fluid in the system which nozzle valves are controlled by a simple force motor consisting of a coil suspended in the magnetic field of a permanent magnet to which direct current from a controller flowing through the coil produces a force which moves the coil through the magnetic field, and the magnitude of the coil current determines the thrust of the force motor, thereby proportionally controlling the pilot valves if used and nozzle valves, and through them and the hydraulic system, controlling the corresponding position

of a main valve or other final actuated element being controlled.

An additional object is to provide a hydraulic pilot circuit that controls the pressure to the actuating cylinder for the main valve in response to movement of the force motor coil caused by input current change from an electric controller and the pilot varies the pressure in pilot nozzles and bellows connected therewith and actuated by relatively low pressure so that the bellows then serve to actuate power nozzles that control the flow of hydraulic fluid at greater pressure to the actuating cylinder for the main valve, the pilot stage acting as a hydraulic amplifier and making possible the operation of the power nozzles with the small force available from the force motor, and the power nozzles controlling the pressure and/or flow applied to the hydraulic piston which actuates the main valve stem.

Another additional object is to provide feed back from the position of the valve to the force motor in which a feed-back cam of a shape to secure the desired operating characteristic relationship between input signal and main valve area may be used and is readily interchangeable with cams of other shapes, while at the same time the main valve itself may always be of linear type thereby simplifying the changing of its operating characteristics by making it unnecessary to break into the main flow line with the attendant inconvenience and protracted down-time. In the prior art several types of main valves had to be on hand to give the required characteristics such as linear, parabolic or percentage types.

A further additional object is to provide a "plug-in" arrangement whereby it is possible to remove the motor pump and all pilot parts from the main valve and its actuating means without disconnecting any fluid line, the pump and motor being bolted to a cover plate as is the pilot and second-stage assemblies and the force motor. In case of a failure of any pilot parts, the coil or magnet parts of the force motor, or the pump and motor, the plant personnel can remove the bolts holding the cover plate down, lift the entire unit comprising the plate with its attachments, disconnect the signal wires, remove the entire top and replace with a standby unit. Thus maintenance and down-time are reduced to a minimum. The plug-in feature includes a sealed telescoping sleeve connection for two of the hydraulic connections so that no hydraulic connections need be disconnected when changing units.

Yet another object is to provide a three-pump system furnishing a separate supply of hydraulic fluid to produce an individual constant pressure source for each nozzle at all times.

Still a further additional object is to provide a shut-off valve feature in which shut-off valves are actuated by the pump to open position whenever the operator is in operation but which, in case of power, motor or pump failure, automatically reclose under the action of springs, and close the lines leading to the cylinder chambers above and below the actuating piston, thereby maintaining the piston in the last position it assumed prior to the power, motor or pump failure. By means of a by-pass valve included in the operator it is possible to open fluid passages to both cylinder chambers, thereby making it possible to manually position the piston and main valve by manually operated mechanical means.

Other objects of the invention are to provide good shut-off characteristics without vibration, objectionable noise and wear in the flapper-nozzle combinations for the hydraulic power circuit of the actuator by the use of balls between the nozzles and flappers, the use of a counterweight for the beam of the pilot valve to prevent vibrations from the main pipe line being transmitted to the coil of the force motor and sympathetic vibration at

common frequencies or harmonics of motors, turbines, etc. that might be imparting vibrations to the main valve itself, and a means to take care of any oil leakage such that the leakage fluid can be directed away from the valve body structure which in many cases is in an extremely high ambient temperature and could cause a fire hazard should leakage fluid contact the hot surfaces.

I also contemplate the provisions of a modified form of the operator which is simplified by the elimination of pilot circuits where close and accurate control is not paramount, and my operator can thereby be manufactured at lower cost but operates on the same general principle of electric force motor control of flapper-nozzle valves which in turn control the flow of hydraulic actuating fluid for the actuator of the operator.

With these and other objects in view, my invention consists in the construction, arrangement and combination of the various parts of my hydraulic operator, whereby the objects above contemplated are attained, as hereinafter more fully set forth, pointed out in my claims and illustrated in detail on the accompanying drawings, wherein:

Fig. 1 is a perspective view of an hydraulic operator embodying my present invention;

Fig. 2 is a diagrammatic view thereof to show the operation and includes a main valve controlled by the operator in a fluid flow controlling system, and an electric circuit responsive to the pressure in the system and controlling a force motor of the operator;

Fig. 3 is an enlarged vertical sectional view through my operator;

Fig. 3A is a further enlarged view of a flapper pivot thereof;

Fig. 4 is an enlarged sectional view on the line 4—4 of Fig. 3.

Fig. 4A is a further enlarged fragmentary view of a portion of Fig. 4 to show a flapper-nozzle construction;

Fig. 5 is a perspective view of my operator with the motor-pump and all pilot parts of the unit supported on the flat plate cover being removed from the reservoir and actuating cylinder for replacement, the cover for the force motor also being removed;

Fig. 6 is a vertical sectional view similar to Fig. 3 showing a modified construction which does not use pilot valves;

Fig. 7 is a diagrammatic view thereof similar to Fig. 2 to show the operation;

Figs. 7A and 7B are similar diagrammatic views of modifications of Fig. 7; and

Fig. 8 is a sectional view of a passageway and restriction fitting used in the form of my invention shown in Figs. 6 and 7.

On the accompanying drawings I have used reference characters to indicate in general several of the important elements of my operator as follows:

- B^1—bellows to control N^1
- B^2—bellows to control N^2
- EAC—electronic amplifier controller
- F^1 and F^2—power flappers for N^1 and N^2
- FM—force motor
- MET—measuring element transmitter
- N^1 and N^2—valve controlling or power nozzles
- P^1 and P^2—Nozzle pumps for N^1 and N^2
- PF^1 and PF^2—pilot flappers for PN^1 and PN^2
- PM—pump motor
- PN^1—pilot nozzle for N^1
- PN^2—pilot nozzle for N^2
- PP—pilot pump for PN^1 and PN^2
- R—reservoir provided with cooling fins
- R^1—restriction for PN^1
- R^2—restriction for PN^2
- V—main valve being operated

The valve V, as shown in Fig. 1, has a head **10** to which an adapter yoke **12** is suitably secured so that the yoke is supported on the valve and in turn may support my operator contained in the reservoir R. Most of the mechanism of the operator and the pump motor PM are mounted on a mounting plate **26**, the element **24** being a force motor cover. The valve V has a valve stem **16** extending therefrom and connected with a valve actuating piston rod **18** as also shown diagrammatically in Fig. 2.

The rod **18** extends from an actuating piston **20** in cylinder **22** located in the reservoir R as shown in Fig. 3. The cylinder has a lower head **25**. The adapter yoke **12** incorporates an anti-spin arrangement since usually there is torsional force on the stem **16** caused by the fluid flowing through the valve V acting on the valve elements **28** (Fig. 2) therein, and it is necessary to prevent this rotation to avoid wear of seals, piston cylinder and cams, etc. for which purpose an arm **30** slides vertically in a slot **32** (Fig. 3). A suitable pointer **34** and scale **36** serve to show the position of the valve.

The mounting plate **26** is adapted to be removably secured to the upper end of the reservoir R by means of cap screws **38** and has a centrally located sleeve **40** that telescopes over a sleeve extension **42** from the upper end of the cylinder **22** with suitable O-ring seals to isolate annular passageways **44** and **46** from each other and seal them against leakage as between the sleeve **40** and the sleeve extension **42**. The element **42** also serves as an upper head for the cylinder **22**.

The annular passageway **44** communicates with the cylinder **22** below the piston **20** therein by means of a passageway **50** in the sleeve extension **42** and a conduit **52** leading to a T fitting **54** threaded into the lower head **25** of the cylinder **22** and communicating with a passageway **23** therein. The annular passageway **46** communicates with the cylinder **22** above the piston **20** therein through a passageway **48** in the sleeve extension **42**.

Valve blocks **56** and **58** are mounted on a supporting block **78** and are thereby rigidly suspended from the mounting plate **26**. The pilot nozzles PN^1 and PN^2 are mounted in the block **56** while the nozzles N^1 and N^2 are mounted in the block **58**. The pilot flappers PF^1 and PF^2 coact with the nozzles PN^1 and PN^2 and consist of thin sheet metal strips as shown in Fig. 3*a*. The strip PF^2 is in the horizontal plane and also serves as a support and pivot for a force motor arm **60** secured to a block **62** to which the strips PF^1 and PF^2 are secured, the strip PF^2 being also secured to a stationary block **64**. A strip **65** (which is similar to the strip PF^2 except in the vertical plane) is also connected to the blocks **62** and **64** so that the flexure of the strips PF^2 and **65** between their points of securement to the blocks **62** and **64** serve as a rotating pivot or flexure strip connection to eliminate hysteresis in the control system. The strip PF^2 is bifurcated and the strip **65** is located between the two arms thereof to provide a mechanically balanced connection.

A pair of actuating bellows B^1 and B^2 communicate with the pilot nozzles PN^1 and PN^2 respectively and are mounted on a centrally pivoted bar constituting the flappers F^1 and F^2 for cooperation with the valve controlling nozzles N^1 and N^2. The pivot of the bar F^1—F^2 is preferably the same type (Fig. 3A) as provided for the flappers PF^1 and PF^2. Two of the elements thereof are shown at 64^a and 65^a in Fig. 3.

The power nozzles N^1 and N^2 are advantageously provided with balls covering the nozzles as shown in Fig. 4A to accomplish two purposes. First, the balls make it possible to obtain very good shut-off which is necessary to provide maximum cylinder pressure and/or flow with the minimum loss of hydraulic energy. Second, regardless of the angle of the flapper beam F^1–F^2 which rotates about the flexure strip center, the orifice can be completely covered. It will also be found that a flat surface covering an orifice containing hydraulic fluid at 500 p.s.i. tends to vibrate and cause objectionable noise and wear, and the balls change the flow pattern such that as shut-off position is approached, there are no detrimental effects. The noz-

zles are so adjusted in relation to the flappers that the balls, even at maximum opening of the combination as shown in Fig. 4A, cannot become dislodged from the nozzles by the oil flow.

A conduit **76** leads from the pilot pump PP to the valve block **56** for supplying hydraulic fluid under low pressure (such as 50 p.s.i.) to the valve block and through the restrictions R^1 and R^2 to the nozzles PN^1 and PN^2 and the bellows B^1 and B^2 as shown diagrammatically in Fig. 2. Shut-off valves **80** as detailed in Fig. 4 are located in the supporting block **78** and are supplied with hydraulic fluid from the conduit **76** by means of a passageway **82** in the block **78** which passageway is also shown diagrammatically in Fig. 2. Each shut-off valve **80** has a piston **84** and is normally closed under the action of a spring **86**. When pressure is exerted on the pistons **84** from the passageway **82**, the shut-off valves **80** are opened as shown in Figs. 2 and 4 for operation of the system. This arrangement permits automatic reclosure of the shut-off valves **80** for a purpose which will hereinafter appear when the pressure in the passageway **82** fails for any reason.

All three pumps PP, P^1 and P^2 receive oil from the reservoir R through a filter **75** and a conduit **77**. The nozzle pumps P^1 and P^2 are higher (such as 500 p.s.i.) than the pilot pump PP and deliver hydraulic pressure through conduits **86** and **88** to the valve block **58** and thereby to the power nozzles N^1 and N^2 respectively. As shown in Fig. 4 and diagrammatically in Fig. 2, passageways **90** provide branch paths leading to the shut-off valves **80** which are controlled by the pressure in **90** with the outlets from the valves **80** (one of which is shown at **92** in Fig. 4) communicating by means of conduits **94** and **96** with the annular passageways **44** and **46** respectively in the sleeve **40**. Thus communication is established between the nozzle N^1 and the lower end of the cylinder **22** and between the nozzle N^2 and the upper end of this cylinder.

The lower and upper ends of the cylinder **22** are connected together by conduits **100** and **102** with a by-pass valve **98** interposed between the two conduits (see Fig. 2), and this valve is normally closed but is adapted for manual opening for a purpose which will hereinafter appear. The upper end of the conduit **102** taps into the passageway **48** as shown in Fig. 3 whereas the lower end of the conduit **100** is connected into the **T** fitting **54** and thus communicates with the cylinder **22** below the piston **20** therein by means of the passageway **23** in the lower head **25** of the cylinder.

The force motor FM comprises a permanent magnet **104** having a pole disc **108** and a pole cup **106** which provide an annular flux gap for a control coil **110** wound on a sleeve **112** having a washer **114** at one end of the coil and a disc **116** at its other end. The parts **112**, **114** and **116** are non-magnetic. The disc **116** is secured to the force motor arm **60** and floats in the annular flux gap in such manner that increase and decrease of direct current in the coil **110** will move the arm **60** in one direction or the other as will hereinafter be explained. The pole cup **106** is supported on a bracket **118** connected to the mounting plate **26**.

A bias spring **120** has one end connected to an ear **122** of a bracket **124** that has an anchored end **126** secured to the force motor arm **60**. The other end of the bias spring **120** is connected with a spring tension adjusting screw **130** supported by a stationary bracket **128** secured to the top of the mounting plate **26**.

A feed-back spring **132** has one end connected to a lever **134** and its other end connected to a spring tension adjusting screw **136** that is carried by the anchored end **126** of the bracket **124**. The lever **134** is pivoted at **138** to the bracket **118** and has a slot **140** in which a roller carrying block **142** is adjustable. A roller **144** is rotatable on the block **142** and is held in contact with a cam **146** by the feed back spring **132**. The force motor cover **24** encloses the force motor FM and the cam mechanism **134—144—146** so that when removed as disclosed in Fig. **5** the parts are exposed for repair, replacement or adjustment.

The force motor arm **60** is advantageously provided with an extension **148** downwardly from the block **62** as shown in Figs. 3 and 4 to which a counterweight **150** is secured to help prevent vibrations from the main pipe line of the valve V being transmitted to the force motor FM, and prevents the assembly from vibrating sympathetically at common frequencies or harmonics of motors, turbines and the like, connected with the piping for the valve V.

With respect to the form of invention shown in Figs. 6 and 8 and diagrammatically in Fig. 7, many of the parts correspond to those described in connection with the first five figures of the drawings and have been given the same reference numerals with the distinguishing characteristic *a* added. In this modified form of the invention a single pump P is provided and the flappers F^1 and F^2 for the nozzles N^1 and N^2 are directly actuated by the force motor arm **60***a* rather than through a pilot arrangement as in the first described form of the invention. The modified form is therefore considerably simpler in construction and lower in cost although it does not have the fine control characteristics of the first described device but there are some installations where this is not important. Also, the high pressure such as 500 p.s.i. used in the first described device need not be used but some lower pressure such as 250 p.s.i., and of course a single pressure instead of a plurality of pressures that reduces the overall cost of the operator. This form of invention includes a passageway and restriction fitting **149** shown in elevation in Fig. 6 and in cross-section in Fig. 8.

Another feature of my present invention is associated with the prevention of oil leakage. The adapter yoke **12** has a chamber **152** formed therein and located under the reservoir R, which chamber is supplied at the top with a high-pressure oil-tight seal **153**, and at the bottom with a combined oil tight seal and felt wiper ring **151**. Any oil leakage past the high pressure seal **153** is retained by the lower ring **151** so that it does not run down the stem **18** where it would be exposed to atmosphere. The chamber has a tapped hole near the lower end so that the oil can be directed away from the valve body structure as through a drain-off conduit **154** to a remote point where there is no fire hazard as in many cases the valve V is operating at extremely high ambient temperature and could cause a fire hazard should leakage oil contact the hot surface thereof.

The valve actuating rod **18** constitutes a movable actuating element and may control the valve V or any other modulating type of device and the force motor FM may be responsive to pressure or the like as disclosed or to any other condition. The reservoir R is filled with oil through a suitable filler plug **17** of the mounting plate **26** up to a level indicator **19**. Thus, nozzles N^1, N^2, PN^1 and PN^2 are submerged in the oil for quiet operation and to avoid spraying and the accompanying result of oil foaming and subsequent oxidation. In the foam of invention shown in Figs. 6, 7 and 8, the pump motor PM and the pump P are mounted externally relative to the reservoir R.

Practical operation

In the operation of my hydraulic operator reference is made to Fig. 2 as a typical installation wherein the valve V serves as a pressure-reducing valve between a supply line **156** at a given pressure and a downstream line therefrom **158** in which it is desired to maintain a predetermined lower pressure regardless of the pressure in the supply line **156**. The system includes the measuring element transmitter MET connected as by conduit **160** to the downstream line **158** to sense the pressure thereof and the transmitter is wired at **162** to the electronic amplifier controller EAC which is supplied with readily available house lighting current such as 110 v. A.C.

through wires **163**. By way of example, the transmitter MET may have a bellows **166** responsive to the pressure in the line **158** and controlling a rheostat **168** which varies the current to the controller EAC wherein the variations of current may be amplified and supplied through wires **164** to the control coil **110** of the force motor FM, or in some instances the rheostat **168** or an equivalent device may be directly connected with the control coil of the force motor since an input command signal change of small magnitude is sufficient in the type of force motor shown for varying the force motor thrust throughout its entire range. The force of the arm **60** is proportional to a change in the command signal and usually is very small in magnitude such as from 3 to 5 ounces' change in force on the force motor arm **60** for a 1 to 5 milliamp. input change.

The pumps PP, P^1 and P^2 are of the constant pressure type having the necessary built-in relief valves set for the pressures desired. With the pump PP providing constant pressure of 50 p.s.i. supplied to the first or pilot stage of the system, I have in effect a hydraulic amplifier in that it makes it possible to operate the large power nozzles N^1 and N^2 with many pounds of flapper force from only a few ounces force available at the force motor. The restrictions R^1 and R^2 and the nozzles PN^1 and PN^2 are sized so that when the nozzle N^1 is closed by the force motor, the bellows B^1 has a pressure of 50 p.s.i. and the bellows B^2 has a pressure approximating 10 p.s.i. When the force motor flapper is horizontal as illustrated in Figs. 2 and 3, i.e. equally covering N^1 and N^2, pressure in each bellows is approximately 30 p.s.i.

When the nozzle N^1 is closed by the bellows B^1 the full capacity of the pump P^1 is applied to the under side of the piston **20** forcing it upwardly and exhausting the upper end of the cylinder **22** through the orifice of the nozzle N^2. This nozzle is sized so that it will exhaust the cylinder and also pass the flow from the pump P^2 with a minimum of back pressure. When the piston has traveled all the way up and contacts the upper end of the cylinder, the nozzle N^2 is then passing only the volume pumped by the pump P^2 at which condition pressure in the nozzle N^2 and the line **90** leading thereto, and in the upper cylinder chamber is approximately 50 p.s.i.

The balls **74** contribute to silent operation of the device during the opening and closing of the nozzles N^1 and N^2. The counterweight **150** is used to reduce instability caused by main pipe line vibrations by virtue of its weight and moment arm counterbalancing that of the coil assembly **110, 114, 116**.

Since the magnet assembly of the force motor FM is composed of magnet **104**, the inner pole **108** and the outer annular pole **106** surrounding the pole **108**, there is created thereby a concentration of magnetic field between the poles thus formed. The coil **110** is positioned within the gap between the poles and is caused to be urged right or left, depending on the direction of current flow in the coil **110**.

The opposite action can be had when required, depending on the type of installation, by reversing the leads to the coil **110** (the current in **164** being D.C.) or the action of the rheostat **168** can be reversed. When the coil **110** and the arm **60** move toward the left, the flappers PF^1 and PF^2 tend to close nozzle PN^1 and open nozzle PN^2 as obvious in the diagram Fig. 2 so that pressure will increase in the bellows B^1 and decrease in the bellows B^2, thus resulting in a counterclockwise rotation of the flapper F^1—F^2 attached to the lower end of the bellows. This results in a closing of the nozzle N^1 and a corresponding opening of the nozzle N^2 resulting in an increase in pressure under the piston **20** and a decrease thereabove. The piston and feed-back cam **146** will move up which causes the feed-back lever **134** to move to the right, thereby increasing the feed-back spring load on the arm **60** until a balance with the bias spring **120** is reached and the main piston stem will continue to move until the resulting increase in this feed-back spring load balances the force resulting from the current in the force motor coil modified by the bias spring at which time the flappers PF^1, PF^2, F^1 and F^2 will assume their neutral positions.

The normal range of input signal is usually from 1 to 5 milliamps. so that the main valve should start to move at 1 milliamp. and complete its stroke when the signal is at 5 milliamps. To start the system moving at 1 milliamp. the bias spring **120** is adjusted so that there is sufficient unbalance between the force motor and the feed-back spring to allow the force motor beam to slightly close one nozzle and to slightly open the other.

Normally, the feed-back cam is machined with a straight surface as disclosed which results in a linear relationship between the input signal and the valve stem movement. In other words when the input signal is plotted on rectangular coordinates against stem position, the resulting curve is a straight line. If the main valve is a linear type valve (i.e. flow area plotted against travel is a straight line on rectangular coordinate paper), it can be seen that the flow area for the valve elements **28** will change linearly with the input signal change.

It is possible with my arrangement to always use a linear type valve element **28** and to provide the proper shape of cam **146** for the desired characteristic relationship between input signal and valve element **28** area, thereby making it unnecessary to break into the main flow line with the subsequent inconvenience and protracted down-time. This cam may have any required shape as dictated by the plotting of flow area against valve travel, the surface of the cam being curved inwardly or outwardly or a compound curve as may be found necessary. Such an arrangement permits the changing of the operating characteristics of the valve V by merely removing the force motor cover **24** and replacing the cam **146** with another of the desired shape, the cam being mounted on the upper end of the actuating rod **18** by screw threading it thereto. The thread is shown at **170** in Fig. 3.

With reference to the "plug-in" feature previously referred to, attention is drawn to Fig. 5 wherein the cover plate **26** is shown disconnected and elevated for removing the pumps, motor, force motor and flapper-nozzle valve mechanism as a unit so that it can be replaced by another unit in case of malfunctioning or for other reasons. The ease with which the pilot and motor-pump combination can be removed from the actuator is obvious. Every part except the hydraulic cylinder and piston may be removed as one unit. For periodic maintenance the entire unit may be replaced with a standby assembly in a matter of minutes resulting in very little down-time. It is unnecessary to break or make any hydraulic connections since, as illustrated, all the piping remains intact and the only two hydraulic connections that are necessary are those to the upper and lower ends of the cylinder **22** which are automatically taken care of by the telescoping plug-in connection **40—42**.

In Fig. 5 the force motor cover **24** is also shown removed and elevated from the plate **26** to gain access to the force motor itself.

Summarizing the operation, the hydraulic pilot controls the pressure to the cylinder **20** in response to movement of the force motor coil caused by a change of input current from a controller. The beam and flappers of the pilot are attached to the coil of the force motor and are used to vary the pressure in the pilot nozzles and bellows. The pilot stage is a hydraulic amplifier making possible the operation of the power nozzles that control greater pressures and/or flow with the small force available from the force motor.

The power stage of the controller controls the pressure and/or flow applied to the hydraulic piston which actuates the valve stem. Each power nozzle is connected to a high pressure pump section and also to one side of the hydraulic cylinder. When the nozzle N^1 is closed the full

pressure of the pump section P^1 is applied to the underside of the piston. The nozzle N^2 is sized so when open it will exhaust the upper side of the cylinder and also pass the flow from the lower pump section with minimum back pressure. When the nozzle N^2 is closed the reverse of the above is true. The pilot utilizes simple durable flapper-nozzle combinations. Flappers F^1 and F^2 have hardened stainless steel buttons at points of greatest wear. All orifices and restrictions are ample size for minimizing chance of failure from dirt in the oil.

With respect to the three-pump system disclosed for furnishing separate supplies of hydraulic fluid to produce an individual constant pressure source for each nozzle N^1 and N^2, it is possible to eliminate the use of restrictions such as R^1 and R^2 in connection with the pilot nozzles PN^1 and PN^2 as when a single source of pressure is provided as I do for the pilot system. If one pump supplied both nozzles N^1 and N^2, much of its output would be lost when one or the other of the nozzles is open.

The chief advantage of this system is the ability to prevent excessive heating of the oil. When the main valve V is in some throttling position, the flapper systems are in a nearly neutral position with approximately 30 p.s.i. in each bellows, the flapper beam F^1—F^2 being nearly horizontal and the nozzles N^1 and N^2 open nearly equal amounts. In that case the pressures from pumps P^1 and P^2 are approximately 100 p.s.i. each because nozzles N^1 and N^2 are sized to more than handle the capacity of their respective pumps. When the valve is in throttling position, the pumps P^1 and P^2 are operating at less than maximum pressure, the motor is not operating at maximum load and consequently energy in the form of heat is reduced. Lower temperature operation increases greatly the life of the hydraulic fluid and the life of the pumps.

Prior actuators of somewhat similar type use spool valves or sliding plate valves which, when not called upon to deliver oil to either side of the piston, close off the pump supply so that the pump relieves its flow through the relief valve maintaining full set pressure on the pump, in most cases, 500 p.s.i. The motor is therefore expending more power and develops more heat than with my system.

My disclosed operator uses maximum horsepower input and heats the hydraulic fluid the most when the command signal calls for the main valve to be fully closed or fully open, in which case one or the other of the nozzles N^1 and N^2 is closed creating a back pressure of 500 p.s.i. on the one that is closed, approximately 75 p.s.i. on the one that is fully open and 50 p.s.i. on the pump PP which supplies the pilot system.

The spring-closed shut-off valves 80 are automatically held in the open position by hydraulic pressure while the pump is operating. The close upon pump failure and thus provide a safety lock-up feature because the hydraulic fluid is locked in the cylinder 22 for holding the valve V in position until the cause of the failure is corrected. The by-pass valve 98 provides means of equalizing the pressure across the piston so that the actuator stem 18 may be manually positioned if desired (not illustrated). Upon resumption of power, normal automatic functioning of the operator in response to the force motor is restored.

While I have disclosed a bias spring 120, it is quite possible to arrive at equal performance without it. It is used for two reasons: (1) It is possible to adjust the starting point for operation of the force motor without jarring the coil beam 60 and (2) it is used to give an opposing load to the feed back spring 132 so that the feed back spring is loaded sufficiently to separate its coils. On the other hand, a light feed back spring with separated coils can be provided thereby eliminating the need of the bias spring 120. It is evident, therefore, that the bias spring is not an essential element of my operator.

While I have illustrated and described an electric force motor FM, a comparable pneumatic force motor could be substituted and the novel features of my invention could be equally well incorporated in a unit in which the command signal could operate a bellows by air pressure. It is to be understood, therefore, that reference to a force motor in my claims could be for one that is operated electrically, pneumatically or otherwise. I prefer the electrical type as having advantages herein before referred to.

In the operation of the device shown in Figs. 6, 7 and 8 the power nozzles N^1 and N^2 are the only ones used and the restrictions R^1 and R^2 cooperate to control them from a single source of oil under pressure in the same manner as the pilot nozzles are controlled in Fig. 2 whereas the nozzles of Figs. 6, 7 and 8 control flow directly from this single source to and from the ends of the cylinder 22*a* without a pilot stage as in Fig. 2. Otherwise the operation is substantially the same. Instead of a double acting piston 20*a* as disclosed in Figures 6, 7 and 8 a single acting one may be used in which a spring 172 normally opens the valve V and only the upper nozzle N^2 and the restriction R^2 are used to control the flow of oil to and from the upper end of the cylinder as disclosed in Fig. 7A. Conversely, the valve V may be normally closed under the bias of a spring 174 and only the lower nozzle N^1 and the restriction R^1 used as shown in Fig. 7B. The operation of these types are responsive to the command signal supplied to the force motor FM in a manner similar to the double acting piston type.

Some changes may be made in the construction and arrangement of the parts of my hydraulic operator without departing from the real spirit and purpose of my invention, and it is my invention to cover by my claims any modified forms of structure or use of mechanical equivalents which may reasonably be included within their scope.

I claim as my invention:

1. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, and a cam operable by said movable actuating element to vary the load of said feedback spring proportional to the position of said actuating element, a reservoir in which said cylinder, piston and nozzles are located and from which said pressure supplying means receive oil, a cover plate on said reservoir, said nozzles and force motor being mounted thereon for removal from the reservoir as a unit with said cover plate, a plug-in sleeve connection between said plate and cylinder, said sleeve connection including passageways leading from said power nozzles, and passageways communicating therewith and leading to the opposite ends of said cylinder.

2. In a hydraulic operator for a movable actuating element, a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions

and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, separate means for individually supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of the piston in the cylinder in response to the pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the tension of said feed-back spring proportional to the position of said actuating element, a reservoir in which said cylinder, piston and nozzles are located and from which said pressure supplying means receive oil, and balls located between said power nozzles and said power flappers to coact with said nozzles under action of said flappers for proportioning the oil flow.

3. In a hydraulic operator for a movable actuating element, a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, said power nozzles and flappers having balls between them for seating on the nozzles by pressure from the flappers, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of the cylinder whereby said second nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor having a force arm operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a command signal change supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, and a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element.

4. In a hydraulic operator for a movable actuating element, a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, said power nozzles and flappers having balls between them for seating on the nozzles by pressure from the flappers, separate means for supplying oil under higher pressure to each of said power nozzles individually and to opposite ends of the cylinder whereby said second nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor having a force arm operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor from a condition responsive device, a counterweight on said force arm of said force motor to prevent the vibrations of said operator being transmitted to the force motor, a feed-back spring connected with said force motor, and a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element.

5. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, and a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, said feed-back cam being readily replaceable with cams of other shapes.

6. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to one of said power nozzles and to one end of said cylinder, means for supplying oil under similar pressure to the other of said power nozzles and to the other end of said cylinder independent of said first means whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the tension of said feed-back spring proportional to the position of said actuating element, and a drain-off chamber below said cylinder adapted to receive leakage oil from the cylinder and having a drain-off connection to a remote point to prevent fire hazard.

7. A hydraulic operator for a movable actuating element comprising a piston, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with the pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and said bellows-actuated power flappers control the position of the piston in the cylinder in response to the pilot flapper, said power nozzles and flappers having balls between them for seating on the nozzles by pressure from the flappers, a force motor operatively connected with said pilot flapper for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a command signal change supplied to said force motor, a feed-back spring con-

nected with said force motor, and a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, said feed-back cam being replaceable with cams of other shapes.

8. A hydraulic operator for a movable actuating element comprising a reservoir, a cylinder therein, a piston in said cylinder for moving said actuating element, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations in said reservoir, said pilot nozzles receiving oil under one pressure through restrictions and said bellows being connected with said pilot nozzles for having their pressures controlled thereby and being actuated by said flappers for said power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and said bellows-actuated flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, a cover plate on said reservoir, said nozzles and force motor being mounted thereon for removal from the reservoir as a unit with said cover plate, a plug-in sleeve connection between said cover plate and said cylinder, said sleeve connection including passageways leading from said power nozzles, and passageways communicating therewith and leading to the opposite ends of said cylinder.

9. A hydraulic operator for a movable actuating element comprising a reservoir, a cylinder therein, a piston in said cylinder for moving said actuating element, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations in said reservoir, said pilot nozzles receiving oil under one pressure through restrictions and said bellows being connected with said pilot nozzles for having their pressures controlled thereby and being actuated by said flappers for said power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and said bellows-actuated flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, and a cover plate on said reservoir, said nozzles and force motor being mounted thereon for removal from the reservoir as a unit.

10. A hydraulic operator for a movable actuating element comprising a reservoir, a cylinder therein, a piston in said cylinder for moving said actuating element, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations in said reservoir, said pilot nozzles receiving oil under one pressure through restrictions and said bellows being connected with said pilot nozzles for having their pressures controlled thereby and being actuated by said flappers for said power nozzles, separate means for supplying oil under higher pressure and individually to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and said bellows-actuated flappers control the position of said piston in said cylinder in response to said pilot flappers, said power nozzles and their flappers having balls between them for seating on the nozzles by pressure from the flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, a cover plate on said reservoir, said nozzles and force motor being mounted thereon for removal from the reservoir as a unit with said cover plate, a plug-in sleeve connection between said cover plate and said cylinder, said sleeve connection including passageways leading from said power nozzles, and passageways communicating therewith and leading to the opposite ends of said cylinder.

11. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, and a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element.

12. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating element, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for separately supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal supplied to said force motor from a condition responsive device, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, and a reservoir in which said nozzles are located and from which said pressure supplying means receive oil.

13. A hydraulic operator for a movable actuating element comprising a piston for moving said actuating ele-

ment, a cylinder in which said piston is movable, a hydraulic system for controlling the movement of said piston comprising pilot nozzle-flapper combinations and bellows-actuated power flapper-nozzle combinations wherein the pilot nozzles receive oil under one pressure through restrictions and the bellows are connected with said pilot nozzles for having their pressures controlled thereby and actuate the flappers for the power nozzles, means for supplying oil under higher pressure to each of said power nozzles and to opposite ends of said cylinder whereby said power nozzles and the bellows-actuated power flappers control the position of said piston in said cylinder in response to said pilot flappers, a force motor operatively connected with said pilot flappers for moving one pilot nozzle toward open position and moving the other one toward closed position and vice versa in response to a control signal change supplied to said force

motor from a condition responsive device, a feed-back spring connected with said force motor, a cam operable by said movable actuating element to vary the load of said feed-back spring proportional to the position of said actuating element, a reservoir in which said cylinder, piston and nozzles are located and from which said pressure supplying means receive oil, and a cover plate on said reservoir, said nozzles and said force motor being mounted thereon for removal from the reservoir as a unit with said cover plate.

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