March 30, 1965 R. W. ZEIGLER 3,175,500

ELECTRO-HYDRAULIC ACTUATOR

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Fig. 1

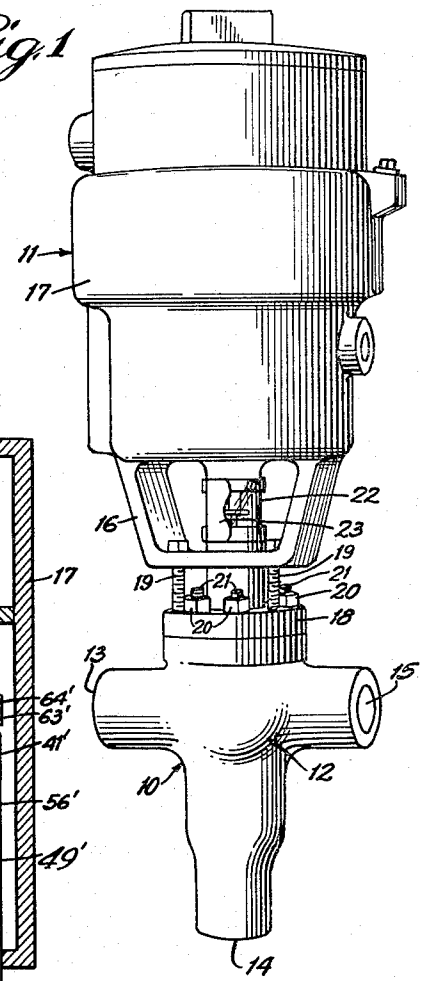
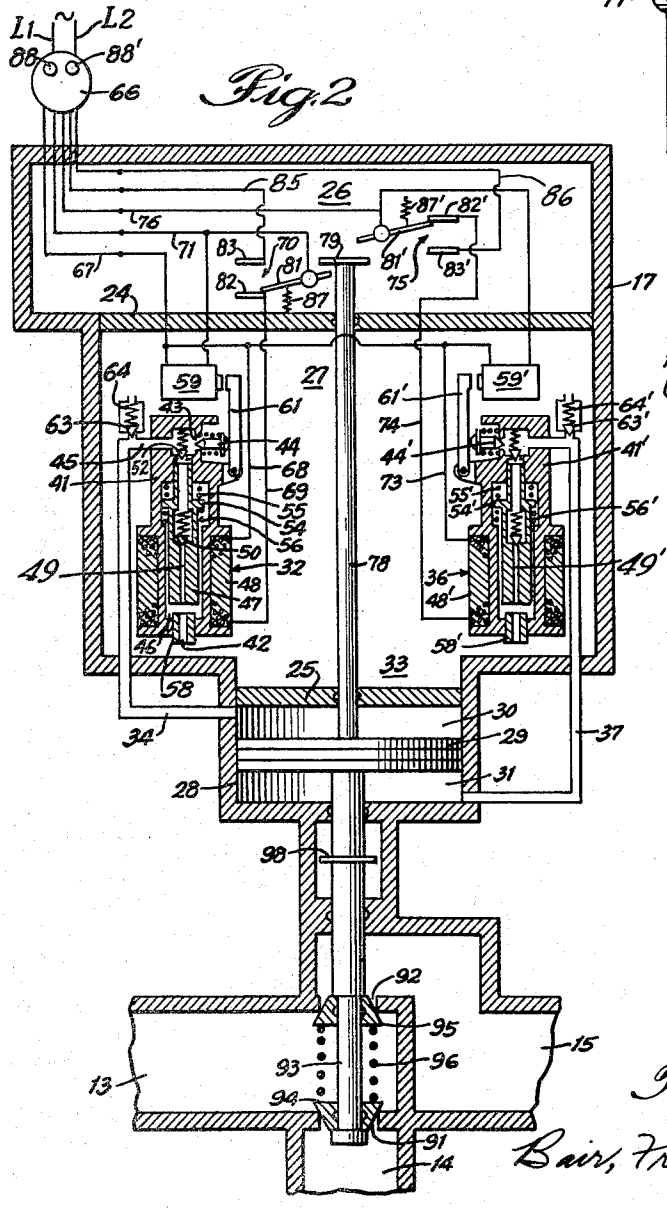


Fig. 2



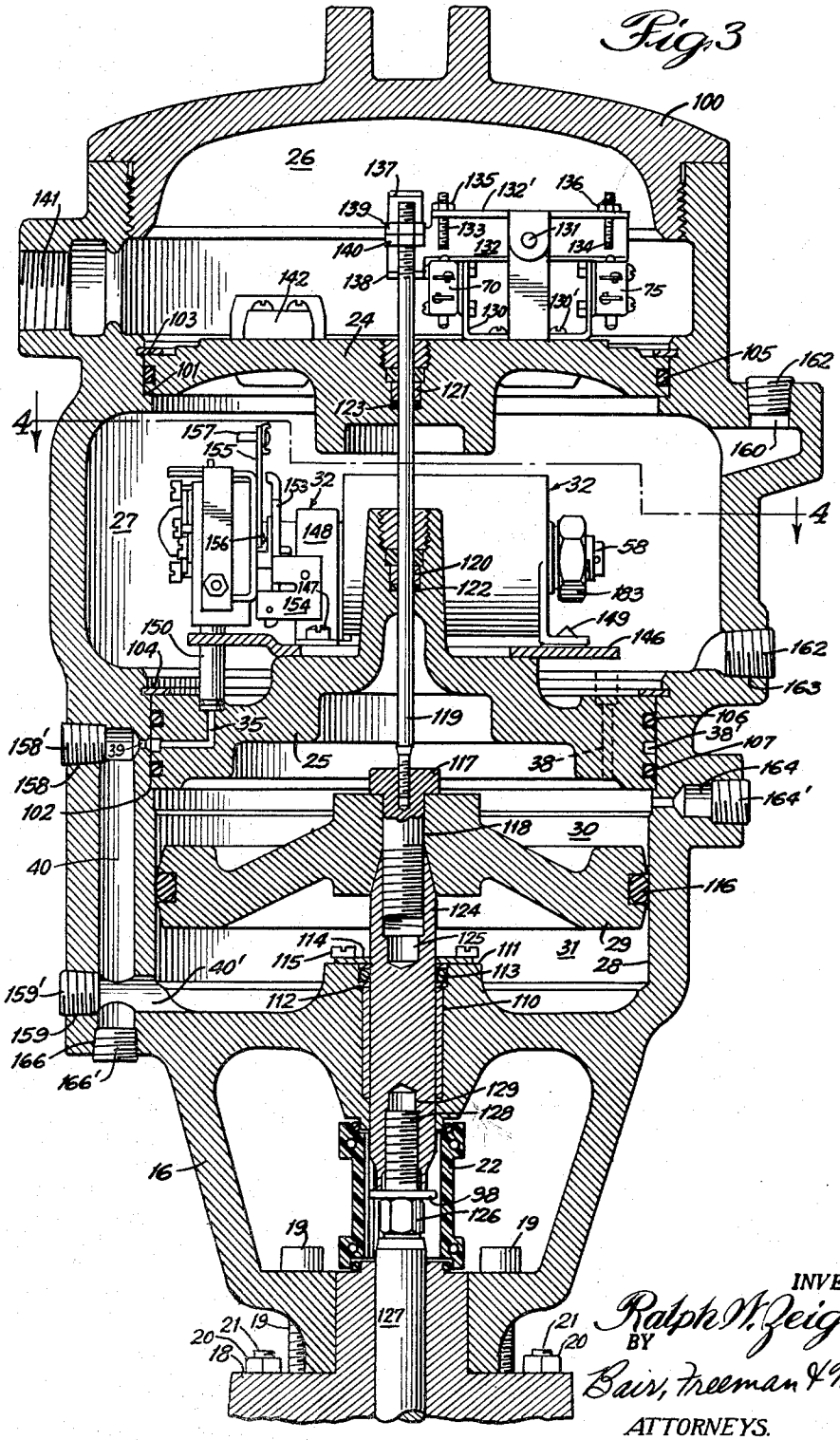
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Fig. 3



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Fig. 4

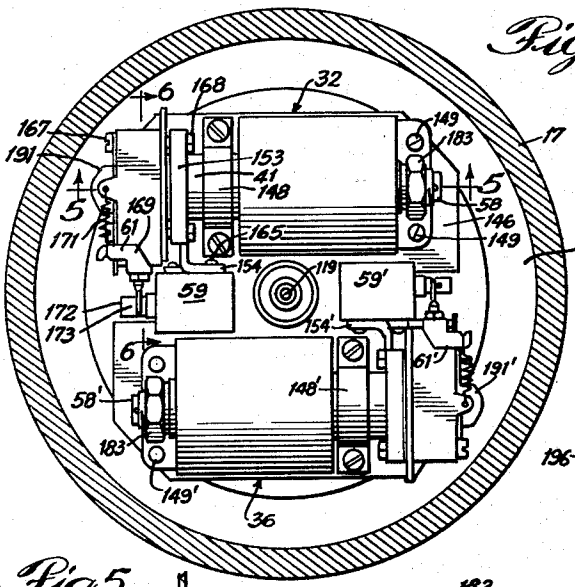


Fig. 6

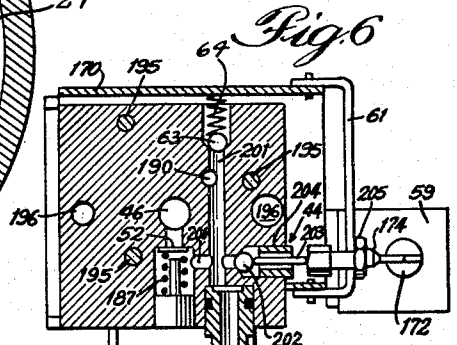


Fig. 5

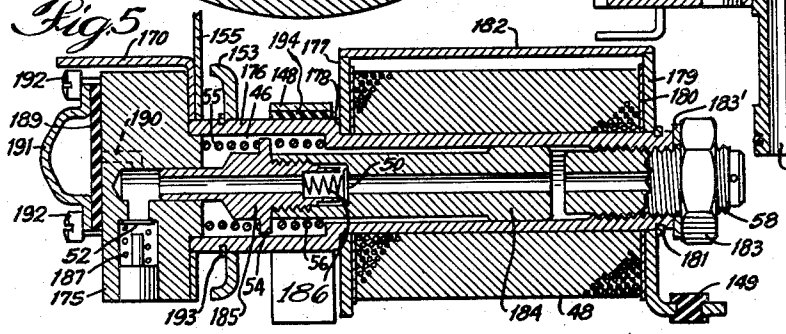
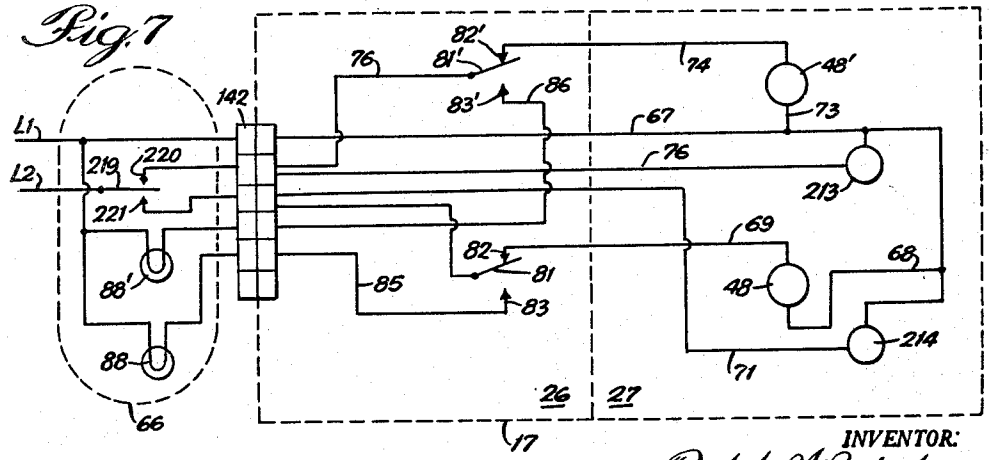


Fig. 7



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ELECTRO-HYDRAULIC ACTUATOR

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Fig. 9

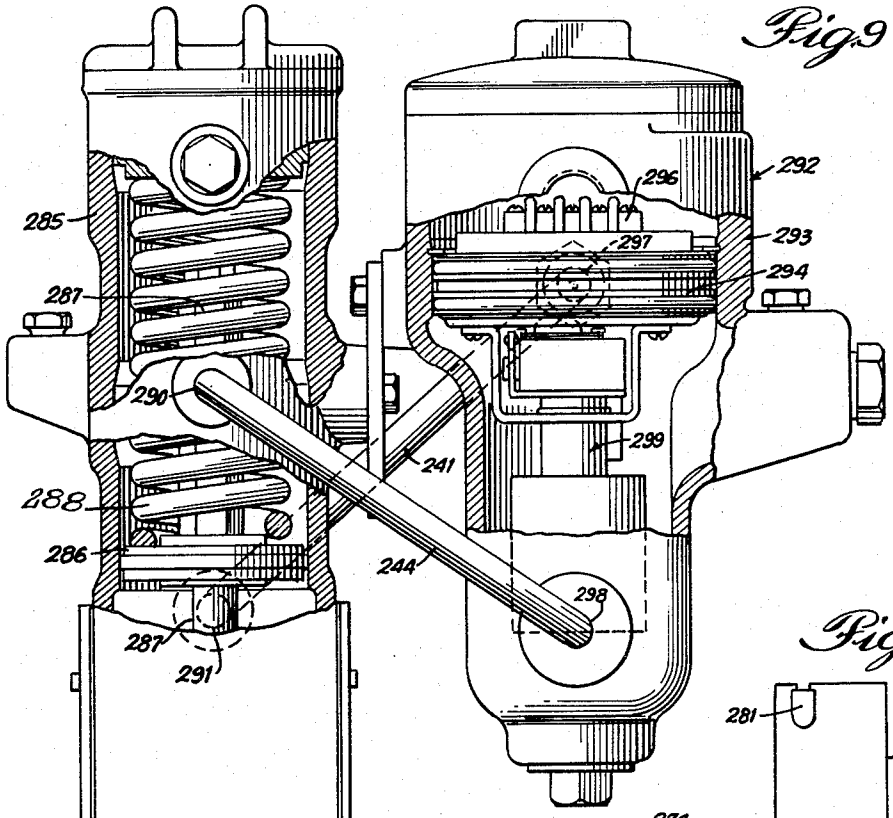
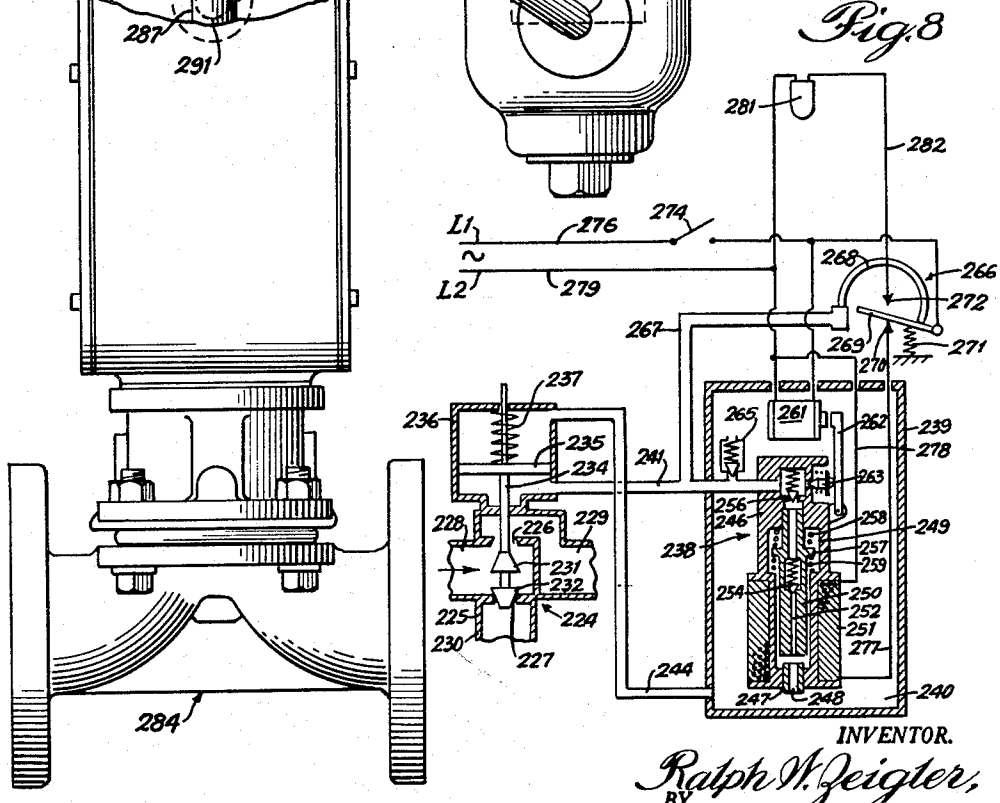


Fig. 8



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3,175,500

ELECTRO-HYDRAULIC ACTUATOR

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Filed May 14, 1962, Ser. No. 194,504
6 Claims. (Cl. 103—53)

This invention relates to an electro-hydraulic actuator and more particularly, to an electro-hydraulic actuator incorporating vibrator pump means for actuating a power member.

An object of the present invention is to provide an improved electro-hydraulic actuator.

Another object of the present invention is to provide an electro-hydraulic actuator for a control element, the actuator comprising a power member adapted to be connected to the control element for moving the same and vibrator pump means for actuating said power member.

Another object of this invention is to provide an improved electro-hydraulic actuator comprising a power piston adapted to be connected to a movable element, and a pair of vibrator pumps for imposing control pressure selectively on one side or the other of the power piston to actuate the same.

It is another object of this invention to provide an improved electro-hydraulic actuator comprising a power piston adapted to be connected to a movable element, a vibrator pump for imposing control pressure on one side of the power piston to move the piston in one direction, and means for urging the power piston in an opposite direction.

Still another object of this invention is to provide an improved vibrator pump for use in an electro-hydraulic actuator, the pump being immersed in oil to prevent oil seal problems.

A further object of this invention is to provide an improved vibrator pump for use in an electro-hydraulic actuator, the vibrator pump incorporating a surge damper to smooth out the pulsations in the discharge pressure from the pump.

These and other objects of the invention which will become hereafter more apparent are attained by the provision of an electro-hydraulic actuator for a control mechanism.

In one application of the invention, the control mechanism comprises a valve. The electro-hydraulic actuator comprises a power member for moving the valve and vibrator pump means for actuating the power member. Such vibrator pump means are constructed in a simple and economical manner so as to prolong the reliability and life of the pump means. The pump means may comprise a pair of vibrator pumps acting upon opposite sides of the power member or a single vibrator pump for urging the power member in one direction and means for urging the power member in the opposite direction. A solenoid connected to a source of alternating current is utilized to actuate a plunger within the vibrator pump to displace hydraulic control fluid from a reservoir and discharge it against one side of the power member. The solenoid cooperates with a spring means to reciprocate the plunger and cause flow of the hydraulic control fluid. Also incorporated in the vibrator pump is a surge damper for smoothing out the pulsations in the discharge pressure.

The specific structural details and their mode of functioning will be made most manifest and particularly pointed out in clear, concise and exact terms in conjunction with the accompanying drawings wherein:

FIGURE 1 is a perspective view of a valve mechanism utilizing an electro-hydraulic actuator of the present invention;

FIGURE 2 is a schematic view partially in cross-section of the valve mechanism of FIGURE 1 illustrating the power piston for actuating the valve, the pump means for moving the power piston comprising a pair of vibrator pumps, and the electrical controls therefor;

FIGURE 3 is a cross-sectional view of the electro-hydraulic actuator of FIGURE 1 on an enlarged scale;

FIGURE 4 is a cross-sectional view of the electro-hydraulic actuator taken generally along the line 4—4 of FIGURE 3;

FIGURE 5 is a longitudinal cross-section of a vibrator pump of the present invention;

FIGURE 6 is a transverse cross-section of a vibrator pump taken generally along the line 6—6 of FIGURE 4;

FIGURE 7 is a schematic wiring diagram of the electrical controls for the electro-hydraulic actuator;

FIGURE 8 is a schematic view partially in cross-section of a modification of the present invention illustrating an electro-hydraulic actuator comprising a single vibrator pump for urging a power member in one direction and means for biasing the power member in an opposite direction; and

FIGURE 9 is a front view partially in cross-section of a modified valve mechanism utilizing the electro-hydraulic actuator of FIGURE 8.

Referring now more particularly to the drawings, like numerals in the various figures will be taken to designate like parts.

Considering FIGURE 1, there is shown a valve mechanism **10** utilizing an electro-hydraulic actuator **11**. The valve mechanism comprises a valve body **12** having an inlet **13** adapted to be connected to a pipeline, an outlet **14** and an outlet **15**, each outlet adapted to be connected to a pipeline.

The actuator housing or casing **17** has formed integrally with the bottom thereof an adapter yoke **16**. The yoke **16** is secured to a joint or connection member **18** by suitable bolts or cap screws **19**. The connection member **18** is in turn secured to the valve body **12** by a suitable fastening means as for example, studs **21** and nuts **20**.

An indicator housing **22**, which is suitably made from clear plastic for viewing the position of a movable indicating means, is provided on the actuator housing **17**. A suitable indicia plate **23** may be placed on the housing **22**. To prevent dirt and moisture from entering housing **22**, a clear plastic cover may be placed around the housing **22**.

Referring now to FIGURE 2, there is shown schematically a cross-section of the valve mechanism of FIGURE 1. The actuator housing **17** comprises a one-piece housing divided into three compartments **26**, **27** and **28** by means of end plates **24** and **25**. Within compartment **26** are contained the electrical components and limit switches. Disposed within compartment **27** of the actuator housing **17** are vibrator pump means of the present invention. Compartment **28** contains the power piston **29** which separates the compartment into a chamber **30** and a chamber **31**.

One vibrator pump means **32** displaces hydraulic fluid from the reservoir or sump **33** formed by the end plate **25** and the interior walls of casing **17** and discharges such fluid through line **34** into power piston chamber **30**.

The second vibrator pump means **36** displaces hydraulic fluid from reservoir **33** and discharges the hydraulic fluid through line **37** into the power piston chamber **31**.

The pump means are constructed and arranged to be operated alternatively so that when one pump means is operative, the second pump means is idle. For convenience of reference the pump means **32** is designated as the "down" pump means, and pump means **36** is designated as the "up" pump means. Thus when the pump means **32** is operative to force liquid into chamber **30**, the power piston **29** will be moved downwardly and fluid will be displaced from chamber **31** to the sump or

reservoir 33 in a manner to be hereinafter described. Similarly, when the pump means 36 is operative and the pump means 32 is idle, hydraulic fluid will be discharged into chamber 31, forcing the power piston upwardly and displacing the fluid from chamber 30 back to the reservoir 33 in a manner to be later described.

One of the pump means will now be described in further detail. Inasmuch as the pump means 32 and 36 are identical in construction, only pump means 32 will be described in detail and the corresponding elements of pump means 36 will be designated by primed numerals. The pump means 32 is of the vibrator type which employs an alternating current to generate a flow of hydraulic control fluid. Secured within the housing 41 of the pump means 32 is a core 58 having an inlet opening 42 therethrough communicating with the reservoir 33. A second opening 43 in the housing is regulated by solenoid-actuated valve means 44. Also formed in the housing 41 is an outlet 45 communicating with the power piston chamber 30 via line 34. Disposed in the longitudinal bore 46 in the housing 41 is a plunger 47 adapted to be moved downwardly as viewed in FIGURE 2 upon energization of the coil 48 in a manner as will be later explained.

Extending through the plunger 47, which is suitably made from magnetic material, as for example Type 416 Stainless Steel, is a passage 49 having an inlet check valve 50 therein spring-biased to the closed position. At the outlet from the longitudinal bore 46 there is an exhaust check valve 52 spring-urged to the closed position. Formed on the plunger 47 is a flange 54 which bears on one side upon a spring 55 and upon the other side on a spring 56. The springs are preferably fabricated from steel, which may be cadmium plated to prevent rusting in stock before assembling the pump means.

The coil 48, concentrically disposed about a portion of housing 41, will be energized from a suitable source of alternating current and on each half cycle of the voltage wave the plunger 47 is attracted to the core 58 which is preferably made from a magnetic material, as for example Type 416 Stainless Steel, and defines the inlet opening. The top of core 58 forms a stop against which the plunger 47 may abut. For most efficient operation and minimization of noise, it is preferred that the plunger 47 closely approach core 58 but not contact the core. The attraction of the plunger 47 to the core 58 results from the magnetic flux passing through the two parts. Spring 55 expands and spring 56 is compressed. As the current flow through the coil diminishes at the end of the half wave, the magnetic attraction decreases and compressed spring 56 expands, urging the plunger away from core 58 to its starting position. As none of the parts in the magnetic circuit are permanent magnets, the attraction between the core 58 and the plunger 47 occurs equally on both halves of the voltage cycle. Therefore, the cycle of movement of the plunger 47 will occur twice for each complete voltage cycle, and a voltage cycle frequency of 60 cycles per second will result in a plunger movement frequency of 120 cycles per second.

Valve means 44 are operative to close opening 43 in response to energization of solenoid 59. The mechanism for moving valve means 44 to the closed position includes rocker arm 61 pivoted with respect to housing 41. The free end of the rocker arm is attracted to the solenoid 59 upon energization thereof. Upon deenergization of solenoid 59, valve means 44 are biased open.

Means are provided for relieving excessive discharge pump pressure to the reservoir. Such means comprise a ball-type relief valve 63 urged to the closed position by spring 64.

Alternating current supplied to the coil 48 from a suitable source via lead L_1 and L_2 and controller 66 energizes the coil upon completion of a circuit including common line 67, line 68, line 69, down limit switch 70 and down line 71. The circuit for energizing coil 48' of pump means 36 comprises common line 67, line 73, line 74, up limit switch 75 and up line 76. Secured to the upper end of piston rod 78 is a flange 79 adapted to actuate limit switches 70 and 75, respectively, upon movement of the piston 29 to the upper and lower limit positions, respectively.

Each limit switch comprises a pivoted arm 81, 81' movable from engagement with a contact 82, 82' to engagement with a contact 83, 83'. When the pivot arm 81 engages the contact 82 and the controller 66 has completed the down circuit, the coil 48 and solenoid 59 are energized. Similarly, when the pivot arm 81' is in engagement with contact 82', and the controller 66 has completed the up circuit, the coil 48' and the solenoid 59' are energized. Each of the pivot arms 81, 81' is biased into engagement with contact 82, 82', respectively, by spring means 87, 87', respectively.

When the power piston 29 reaches the lower limit of movement during operation of pump means 32, pivot arm 81 is pivoted into engagement with the contact 83 to break the circuit to pump means 32, thus terminating operation of the pump means 32 and completing a circuit via line 71, switch 70, and line 85 to signal light 88, which indicates that the power piston 29 has reached the lower limit of movement. The solenoid 59 remains energized in order to lock the power piston 29 in its lowermost position.

Considering operation of up pump means 36, when the power piston 29 reaches the upper limit of movement, flange 79 on the piston rod 78 engages the pivot arm 81' and moves said arm into engagement with contact 83'. The circuit to the coil 48' is broken, inactivating the pump means 36 and completing a circuit to signal light 88' via line 76, switch 75, and line 86. It will be noted that the solenoid 59' remains energized to lock the power piston 29 in position.

In one disclosed embodiment of the invention, the control element moved by the actuator comprises a valve body 12 within which are disposed a port 91 between inlet 13 and outlet 14, and a port 92 between inlet 13 and outlet 15. Movably mounted on valve stem 93, which is secured to piston rod 78, are valve plugs 94 and 95. The valve plugs are biased to the closed position by spring 96 concentrically mounted on the valve stem 93 between the two valve plugs.

To provide an indication of the position of the power piston, an indicator washer 98 is secured to piston rod 78, and the housing surrounding the indicator washer is clear plasic to permit viewing of the indicator washer.

Referring now to FIGURE 3, there is shown a cross-sectional view of an actuator of the present invention. The top of actuator housing 17 is closed by a cover 100 which is threadingly engaged with the housing. It is readily apparent that the housing is otherwise integrally formed with the adapted yoke 16. The interior of the housing is divided into separate compartments by the end plates or cover plates 24 and 25 respectively, each of which is in abutting relation with a shoulder 101 and 102, respectively provided in the interior of the actuator housing 17. Each of the plates 24 and 25 is held in position by means of a retaining ring 103, 104 respectively. Preferably, the retaining rings are formed from cadmium-plated steel. O-ring 105, made from synthetic rubber or like material, is provided in an annular groove in the end plate 24 to seal compartment 26 from compartment 27.

Similarly, O-rings 106 and 107 are provided in annular grooves in the end plate 25 to seal compartment 27 from compartment 28 and provide a flow channel from one pump means to the lower side of the piston 29.

A guide bushing or bearing insert 110 is provided in a counterbore in the housing 17 to guide the reciprocating movement of the piston rod 78. The means for retaining the bearing insert in position and sealing around the sleeve member 124 comprises a first backup washer

111 and a second backup washer 112 between which there is provided an O-ring seal 113. Retaining plate or washer 114 which is held in position within the chamber 28 by machine screws 115, maintains the washers 111, 112, O-ring 113 and bearing insert 110 in position.

The power piston 29 is provided with an O-ring 116, which may be suitably made of synthetic rubber, to prevent undesirable flow of control fluid from chamber 30 to chamber 31 during operation of the power piston.

Piston rod extension 119 is secured to the power piston by means including a piston bolt 117 disposed in a bore 118 through the power piston 29. The externally threaded end of piston rod extension 119 engages with the female threads in the top of piston bolt 117. Provided in the plates 24 and 25 respectively are guide bushings 120 and 121, which provide bearing surface for the piston rod extension 119. O-ring seals 122 and 123, respectively, are placed between each guide bushing and the associated end plate to seal the respective chambers.

Connected to the lower end of piston bolt 117 is a sleeve member 124 having therein an internally threaded bore 125 which engages with the external threads on piston bolt 117. The peripheral surface of the sleeve is slidable within the bearing insert 110.

Piston rod extension 127, which is adapted to be connected to the control element, in this case the valve stem 93 upon which the valve plugs are mounted, has at the top thereof a threaded end 128 which interlocks with the internally threaded bore 129 in sleeve 124. It will be noted that the indicator washer 98 is disposed between the hexagon-shaped portion 126 of the extension 127 and the sleeve 124.

Within the upper compartment 26 are housed the electrical components for the pump means. The limit switches 70 and 75 are secured to a bracket 130, which is in turn suitably affixed to the end plate 24, as for example, by machine screws 130'. Pivotally supported on pin 131 affixed to bracket 130 is a plate 132. Extending from a flange 132' on plate 132 are adjustable actuating screws 133 and 134 for actuating the limit switches 70 and 75 respectively. Each actuating screw is provided with a lock nut 135, 136 for maintaining the actuating screw in the selected adjusted position. Also formed on plate 132 are upper and lower contact ears 137 and 138. The contact ears are adapted to be engaged by nuts 139 and 140 adjustably supported on the upper end of piston rod extension 119. Thus it is apparent that upon movement of the piston rod extension 119 to the uppermost position, nut 139 will engage contact ear 137, pivoting plate 132 about pin 131 to actuate limit switch 75. In a like manner, upon movement of the piston rod extension 119 downwardly to its lowermost position, nut 140 will engage contact ear 138 to pivot plate 132 causing actuating screw 134 to actuate limit switch 70.

The electrical wires enter the actuator housing through inlet opening 141 and are connected to a terminal strip or block 142 provided in the compartment 26. For purposes of clarity, the electrical wires connecting the terminal block to the controller and a suitable source of alternating current and the electrical wires connecting the terminal block to the limit switches are not shown.

Each of the pump means are secured to a support or base plate 146, which is affixed to the end plate 25 in compartment 27 by cadmium-plated machine screws or bolts 147. These bolts also secure bracket members 148, which is disposed about the housing 41. Provided between one end of the housing and the support plate 146 are vibration dampeners or grommet bumpers 149. The housing 41 is further supported within the compartment 27 by a cylindrical pump tube 150 which extends through an opening in the support plate 146 and engages plate 25. For clarity the solenoid has been omitted to better show the mounting bracket 153 upon which the solenoid is secured. Such solenoid mounting bracket 153 includes an upright portion secured to the housing and support ears 154 to which the solenoid is ordinarily connected.

Also secured to the housing 41 by suitable fastening means, as for example, machine screws 156, is a terminal plate assembly 155. Electric wires (not shown) connected at one end to termianl strip 142 extend through a suitable opening in end plate 24 and are connected at the other end to terminal lugs 157.

Oil may be supplied to the reservoir 33 through the fill opening 160 in the housing 17. The opening is normally closed by plug 161. Drain plug 162 normally closes opening 163 in the housing 17.

The line 34 is formed by a vertical hole 38 extending through the end plate 25. The line 37 is formed by a vertical and a horizontal passage 35, annular groove 38', holes 39, passage 40, and bore 40'. Access openings 158, 159 and 166 are closed by suitable plugs 158', 159' and 166'. Upon removal of plug 164', which normally closes opening 164, a pressure gauge may be installed.

Referring now to FIGURE 4, there is shown a cross-sectional view of compartment 27 taken generally along the line 4—4 of FIGURE 3. Each pump means 32, 36 is secured to the support plate 146. The solenoids 59 and 59' are secured to the support ears 154 of the mounting members or brackets 153, 153' respectively by suitable fastening means 165, for example, machine screws. The mounting member 153 is secured to the housing 41 by means including bolts or machine screws 167 and machine screw nuts 168. Fastened to the housing 41 by the screws 156 is a pivot support bracket 170. The rocker arm 61 is supported on the pivot pins 169 secured to the pivot support bracket 170. Tension spring 171 affixed between an end of the rocker arm 61 and the pivot support bracket 170 biases the rocker arm clockwise as viewed in FIGURE 4.

Solenoid 59 comprises a solenoid plunger 172 having a projection 173 thereon adapted to engage a solenoid pin 174 secured to the rocker arm 61, for moving the rocker arm in opposition to the bias of spring 171.

Referring now to FIGURE 5, there is shown a cross-sectional view of a vibrator pump taken generally along the line 5—5 of FIGURE 4. The pump housing comprises a body 175 and a coil support 176 within which is defined the longitudinal bore 46. Abutting a shoulder 178 on the coil support 176 is a coil washer 177. The back flange 179 engages the coil 48 and retains the same in position. The retaining ring 181 is utilized to stake the back flange 179 in position on the coil support 176. Insulating washers 180 are provided at each end of coil 48. Provided about the coil 48 there is a cover 182. It should be noted that vibration isolators or grommet bumpers 149 are supported in openings in the back flange 179.

Core 58, which is externally threaded, engages the internal threads in an end of the coil support 176. The core has an opening therein which defines the inlet opening 42 to the housing. The core is adjusted with respect to the coil support and is then locked in place by the lock nut 183 and lock washer 183'.

The plunger is preferably comprised of two parts, a main plunger 184 which has a plurality of longitudinally extending slots in the periphery thereof, and a piston 185. The actuating spring 55 acts between the flange 54 of piston 185 and the pump body 175. Actuating spring 56 acts between the flange 54 and an internal shoulder of coil support 176.

The inlet check valve 50 is biased to the closed position by the check valve spring 186, and the exhaust check valve 52 is biased to the closed position by the check valve spring 187

Means are provided within the pump means for damping the surge pressure created during operation of the pump means. The damping means comprise a membrane 189, preferably made from synthetic rubber or the like. Passage 190 communicates one side of membrane 189 with oil under pressure. The other side of the membrane

189 communicates with a supply of air trapped between dome 191 and the membrane or diaphragm 189. Suitable fastening means, for example, bolts or machine screws 192, are utilized to secure the dome 191 to the pump body 175.

It can be seen that movement of the mounting member 153 is restrained by retaining ring 193. Also, it should be noted that a rubber pad 194 is provided between the coil support and the bracket member 148 to further assist in minimizing the vibration emanating from the pump means.

Referring now to FIGURE 6, there is shown a transverse cross-sectional view of the pump means taken generally along the line 6—6 of FIGURE 4. Provided within the pump body 175 is a longitudinal passage 46 which communicates with a vertical passage 201 by means of an internal bore 200. Passage 201 communicates with the relief valve 63 through which pressure may be returned to the sump 33 in the event of excessive discharge pressure to prevent damage to the actuator. The passage 190 communicates passage 201 with one side of the membrane 189.

It will be noted that pump tube 150, which is generally cylindrical, has a bore 151 therethrough which communicates with the passage 201. During operation of the pump 32, oil will be forced through bore 151, passage 35, (FIGURE 3) holes 39, passage 40 and bore 40' into chamber 31 to actuate piston 29 upwardly. During operation of pump 36, oil will be forced through the pump tube (not shown) and hole 38 into the chamber 30 to actuate piston 29 downwardly.

The valve means 44 comprises a ball valve 202 adapted to be retained in the closed position by valve plug stem 203, which stem is guided in pin bushing 204. The pin bushing 204 has a plurality of slots therein to permit return of oil to the sump 3 when the ball valve 202 is open. Upon energization of the solenoid, pin 174 is actuated, pivoting rocker arm 61 and forcing the solenoid operated valve 202 to be closed. Upon deenergization of solenoid 59, tension spring 171 pivots rocker arm 61, thereby urging solenoid 174 to actuate valve plug stem 203 and open solenoid operated valve 202. The solenoid pin 174 may be adjustably secured with respect to the rocker arm 61 by means of lock nut 205.

The machine screws 192 engage the threads within the openings 195 to secure the dome 191 to the valve body.

Machine screws 167 pass through the openings 196 in the valve body.

Referring now to FIGURE 7, there is shown an electrical wiring schematic of the electrical components for actuating the vibrator pumps. The solid black dotted line represents the actuator housing 17 within which are defined compartment 26 for the electrical components and compartment 27 for the hydraulic components. A suitable source of alternating current, which for purposes of illustration may be 117-volt, 60-cycle, is supplied to the controller 66. Within controller 66 there is a single pole double throw switch 219 movable from a neutral, off position into engagement with either up contact 220 or down contact 221. Also included in the controller 66 are appropriate signal lights 88 and 88'. The wires extending from controller 66 are connected to terminal strip or block 142 in the actuator housing. The common line 67 supplies current to each of the coils 48, 48', 213 and 214. Coil 48 is in the "down" pump means 32, coil 48' is in the "up" pump means 36, coil 213 is contained within the "up" solenoid 59', and coil 214 is contained within the "down" solenoid 59. The line 85 connects the contact 83 of "down" limit switch 70 to the terminal strip 142 and the line 86 connects the contact 83' of "up" limit switch 75 with the terminal strip 142.

Referring now to FIGURE 8, there is illustrated schematically a modified form of the present invention. The valve mechanism 224 comprises a valve body 225 containing therein a first port 226 and a second port 227. The port 226 communicates the inlet 228 with the outlet 229 and the port 227 communicates the inlet 228 with the outlet 230. Provided within the valve mechanism 224 are valves 231 and 232 for selectively closing the ports 226 and 227. Each of the valves is connected adjacent one end of a rod or stem 234. Proximate its upper end, stem 234 is connected to a power member 235, which may take the form of either a piston, as illustrated, or a diaphragm. Disposed between the power housing 236 and the upper side of the power member 235 is a spring 237, which urges the power member 235 and the valves 231 and 232 downwardly to unseat valve 231, opening port 226, and seat valve 232, closing port 227.

Pump means 238 are provided for urging the power piston 235 upwardly to close port 226 and to open the port 227. The pump means 238 are disposed within a casing 239, the bottom portion of which defines a reservoir 240 for fluid. The pump means 238, which are similar to the pump means previously described, force liquid from the reservoir 240 through the line 241 to the underside of the power piston 235 for urging the power piston upwardly. It will be noted that a line 244 communicates the chamber above the power piston 235 with the reservoir 240.

The pump means 238 comprises a housing 246 in the lower end of which is provided a core 247 which defines therethrough an inlet opening 248. Provided in the longitudinal bore 249 in the housing 246 is a plunger 250. Disposed about the exterior of a portion of the housing 246 is a coil 251, which is adapted to be energized to actuate the plunger 250.

Extending through the plunger 250 is a passage 252. Within an enlarged portion of the passage 252 there is an inlet check valve 254. An exhaust check valve 256 is disposed in the housing 246 proximate the outlet from the passage 252.

Circumferentially formed on the plunger 250 is a flange 257. A spring 258 acts between an internal shoulder in housing 246 and the flange 257 to urge the plunger downwardly as viewed in FIGURE 8, and spring 259 acts on the oposite side of the flange to move the plunger 250 in opposition to the spring 258.

Also provided in the casing 239 is a solenoid 261 which is adapted to pivot the free end of the rocker arm 262 to the left in FIGURE 8 upon energization of the solenoid to close the valve means 263. Upon deenergization of the solenoid 261, the spring in the valve means 263 will cause the valve means to open.

A suitable relief valve 265 is provided in the casing 239 to prevent actuator damage due to excessive discharge pressure.

Cooperating with the pump means 238 is a pressure switch 266, which functions to terminate operation of the pump means when the power piston reaches the uppermost position of movement. At such time, the pressure within the lines 241 and 267 rises, causing the free end of pressure member or bourdon-type tube 268 to expand or raise upwardly, relieving the force on switch arm 269 and permitting the switch arm to move from engagement with the contact 270 into engagement with the contact 272 by means of the bias spring 271. A suitable switch 274 is provided to close the circuit to the pump means 238 when the actuation of the valve mechanism is desired. It can be seen that the coil 251 in the pump means will be energized upon closing of the switch 274. A circuit will be completed via lead L_1, line 276, switch 274, pressure switch 266, line 277, coil 251, line 278, line 279, and lead L_2. On each half cycle of the voltage wave, the plunger 250 will be attracted to the core 247, which defines the inlet opening 248, compressing the spring 259. The attraction of the plunger to the core results from the magnetic flux passing through the two parts. As the current flow through the coil 251 diminishes at the end of each half wave, the magnetic attraction decreases and the compressed spring 259 expands, causing

the plunger 250 to move away from the core 247 to its initial position. As none of the parts in the magnetic system are permanent magnets, the attraction between the core and the plunger occurs equally on both halves of the voltage cycle. Therefore, the cycle of movement of the plunger 250 will occur twice for each complete voltage cycle and a voltage cycle frequency of 60 cycles per second will result in a plunger movement frequency of 120 cycles per second. Inasmuch as the solenoid 261 is also energized upon energization of the coil 251, the rocker arm 262 will be pivoted to close the valve means 263. Thus, upon reciprocation of the plunger, oil will be drawn from the reserovir 240 in the casing 239 and pumped through line 241 to the underside of the power-piston 235, causing the piston to be moved upwardly as seen in FIGURE 8.

When the power piston 235 reaches its uppermost position, the pressure will build up in line 241, causing actuation of the pressure switch 266. When contact 272 is engaged by switch arm 269 a circuit will be completed via lead L_2, line 279, signal light 281, line 282, pressure switch 266, switch 274, line 276, and lead L_1 to energize the indicating light 281.

Inasmuch as the solenoid 261 remains energized as long as switch 274 is closed, the power piston will be locked in its uppermost position until switch 274 is opened. Then the circuit to solenoid 261 will be broken, deenergizing the solenoid and permitting valve means 263 to open bleeding fluid from line 241 to the reservoir 240.

Turning now to FIGURE 9, there is illustrated another form of the present invention. A valve mechanism 284 is affixed to a power housing 285, within which is provided a piston 286 connected to a piston rod 287 for actuating the valve within the valve mechanism, and a spring 288 for urging the piston 286 downwardly within the power housing 285. It will be readily apparent to those persons having ordinary skill in the art that the valve mechanism may contain a valve means similar to that shown in FIGURE 8 or that the valve means may be of the simple open or closed type.

Operatively connected to the power housing 285 is a power pack 292. The power pack 292 comprises a housing 293 containing a vibrator pump and the electrical elements for controlling the operation of the vibrator pump. Suitably fixed in place in the housing 293 is end plate 294. Within the upper compartment in the housing 293 are provided certain of the electrical components, including a terminal strip or block 296. A vibrator pump 299 of the present invention is provided in the lower compartment in the housing 293. It will be understood that the vibrator pump 299 will draw fluid from the reservoir defined within the housing 293 and discharge it through outlet 297, line 241 and opening 291 into the chamber beneath the power piston 235. The line 244 communicates the opening 290 in housing 285 with the inlet opening 298 in housing 293.

As shown in FIGURE 8, the spring 237 urges piston 235 downwardly and discharge pressure from pump 238 urges the piston upwardly. The parts are constructed and arranged so that spring 237 may be positioned to bias piston 235 upwardly and the ends of lines 241 and 244 may be interchanged in openings 290 and 291. In this latter construction, fluid under pressure passing through line 241 from the pump 299 urges piston 235 downwardly against the bias of spring 237.

The mechanism illustrated in FIGURE 9 is considered to be fully illustrative of another form of the invention and inasmuch as the details thereof are comparable to those previously described, it is believed that further explanation is not needed.

From the foregoing, it is clear that the electrohydraulic actuator of the present invention may have different forms and may be used to control a variety of valve mechanisms, as well as other control mechanisms.

Operation

The operation of the electro-hydraulic actuator of the the present invention will best be understood by reference to FIGURES 2 and 8. Considering first FIGURE 2, it is seen that the electro-hydraulic actuator comprises a pair of vibrator pumps, one designated an "up pump" and the other designated a "down pump," and a power piston actuated thereby. The vibrator pump 32 may be energized in response to a signal sense in the controller 66. Upon actuation of the controller 66 to the down position, a circuit is completed via lead L_1, line 67, solenoid 59, line 71 and lead L_2 to energize the solenoid 59 and pivot the rocker arm 61 to close the valve means 44. Simultaneously a circuit is completed energizing the coil 48 of the valve means 32. Such circuit is completed via lead L_1, line 67, line 68, coil 48, line 69, down switch 70, line 71, and lead L_2. The plunger 47 is attracted to the core 58 during each half cycle of the voltage wave and as the magnetic attraction decreases, the spring 56 urges the plunger 47 from the core 58, causing the plunger 47 to be reciprocated within the longitudinal bore of the housing 41. As the plunger 47 moves downwardly fluid will be drawn into the passage 49 through the open inlet check valve 50 and as the plunger 47 moves upwardly the check valve 50 will be closed and the fluid will be expelled through the exhaust check valve 52 and discharged through the line 34 into the chamber 30 above the power piston 29. The pressure increase in chamber 30 causes the piston 29 to move downwardly, seating the valve 94 in port 91 and causing the valve 95 to open the port 92.

When the power piston 29 reaches the lower limit of operation, the flange 79 on the upper end of the piston rod 78 pivots the switch arm 81 into engagement with contact 83. At this time the circuit to the coil 48 is broken, deenergizing the coil to terminate operation of vibrator pump 32, and the circuit to the indicator light 88 is completed, energizing the light to indicate that the piston 29 has attained its lowermost position. Solenoid 59 remains energized, holding valve means 44 closed, thus locking the power piston 29 in the lowermost position.

Assuming that the controller 66 is actuated in response to a predetermined control to close the "up" circuit, solenoid 59 will be deenergized, and a circuit is completed via lead L_1, line 67, solenoid 59', line 76 and lead L_2 energizing the solenoid 59'. At the same time, a circuit is completed via lead L_1, line 73, coil 48', line 74, switch 75, line 76 and lead L_2 energizing coil 48' of the vibrator pump means 36. The vibrator pump means will draw fluid from the reservoir 33 and discharge it through the line 37 to the chamber 31 beneath the power piston 29, causing movement of the piston 29 and piston rod 78 upwardly, moving valve 95 to close the port 92 and moving valve 94 to open the port 91 to permit the flow of fluid from the inlet 13 of the valve mechanism 12 to the outlet 14 thereof. When the piston 29 attains the upper extremity of movement the flange 79 on the upper end of the piston rod 78 will contact the arm 81' of the "up" limit switch 75, causing the arm 81' to move from engagement with contact 82' into engagement with 83'. A circuit is completed energizing the indicator light 88' and the circuit to the coil 48' is broken, deenergizing the vibrator pump 36. Solenoid 59' remains energized, thus holding valve means 44' closed and maintaining the power piston 29 in place.

In the event that an undesirable pressure buildup occurs in line 34 during operation of pump 32, the relief valve mechanism 63 will open, relieving the pressure to the reservoir 33. Similarly, excessive discharge pressure in the line 37 created during operation of pump 36 will be bled to the reservoir 33 by means of relief valve mechanism 63'.

Referring now to FIGURE 8, it is apparent that the electro-hydraulic actuator differs principally in that a single vibrator pump is utilized to move the power piston in

one direction and that a spring is utilized to move the power piston in the opposite direction. To effectuate the desired operation, a pressure switch 266 is provided to indicate termination of the operation of the vibrator pump 238. Upon closure of the switch 274 in response to a predetermined demand, a circuit is completed via lead L_1, line 276, switch 274, switch 266, line 277, coil 251, line 278, line 279 and lead L_2 energizing the coil and causing reciprocation of the plunger within the housing 246. Fluid will be drawn from the reservoir in housing 239 by pump 238 and forced through the line 241 to the underside of the power member or piston 235. The piston 235 moves upwardly until valve 231 closes the port 226, permitting flow of fluid from the inlet 228 to the outlet 230 of valve mechanism 224. The pressure will build up within the line 241 as the piston 235 reaches its uppermost position and this increase in pressure will cause expansion or straightening of the bourdon tube 268. Switch arm 269 will be biased by spring 271 from engagement with the contact 270 into engagement with the contact 272, breaking the circuit to the coil 251, de-energizing vibrator pump 238 and closing the circuit to the signal light 281, thus energizing the signal light.

Upon opening the switch 274, the circuit to the solenoid 261 will be broken, thus permitting the spring in valve means 263 to pivot rocker arm 262 and to open the valve means 263. Thus pressure within the line 241 will be bled back to the reservoir in casing 239 and the spring 237 will move the power piston 235 downwardly to the position indicated in FIGURE 8.

By the present invention applicant has provided a novel electro-hydraulic actuator incorporating vibrator pump means therein. The electro-hydraulic actuator may be utilized to control a variety of control elements. Within the electro-hydraulic actuator is provided a novel vibrator pump mechanism which is simple in construction and thus requires little maintenance.

From the foregoing it is apparent that the present invention accomplishes the designated objects intended therefor.

While there has been shown and described particular embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and, therefore, it is intended in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. For use with control mechanism including an electrohydraulic actuator comprising a power member adapted to be connected to move a control member and means for biasing the power member in one direction, the improvement comprising vibrator pump means for actuating the power member in a second direction, said vibrator pump means comprising a housing having an outlet and a longitudinal bore therein, an elongated reciprocable plunger movable in said longitudinal bore and having a passage therethrough, a core defining an inlet opening into said housing, said inlet opening communicating with said longitudinal bore and said passage, a coil adapted to be connected to a source of alternating current, said plunger, said core, and said coil defining a magnetic circuit for moving said plunger in one direction, means for biasing said plunger in an opposite direction, said plunger being reciprocable at twice the frequency of the source of alternating current, and check valve means cooperating with said plunger to control movement of fluid through the housing to one side of the power member.

2. Vibrator pump means as in claim 1 wherein said vibrator pump includes a surge damper for smoothing out pulsations in the discharge pressure.

3. In an electro-hydraulic actuator of the type including a generally cylindrical casing having a power member movable therein, said power member defining a first chamber and a second chamber in said casing, and pump means for actuating said power member, the improvement comprising a vibrator pump including a housing having an inlet adapted to communicate with a reservoir of control fluid, a first outlet communicating with one of said chambers, a second outlet adapted to communicate with a reservoir of control fluid, a reciprocable plunger in said vibrator pump having a plurality of longitudinally extending slots in the periphery thereof, magnetic means for actuating said plunger in one direction, spring means for biasing said plunger in an opposite direction, and check valve means cooperating with said plunger for moving control fluid through the housing.

4. Vibrator pump means comprising a housing having an inlet adapted to communicate with a reservoir of control fluid, a first outlet adapted to communicate with said reservoir and a second outlet adapted to communicate with a pressure chamber, solenoid-actuated valve means responsive to actuation of the vibrator pump means for closing said first outlet, means defining a bore in said housing communicating said inlet and said outlets, a reciprocable plunger movable in said bore in said pump means, magnetic means adapted to be connected to a source of alternating current for actuating said plunger in one direction, spring means biasing said plunger in an opposite direction, and inlet and exhaust flow control check valve means cooperating with said plunger for regulating the movement of control fluid through the housing, said magnetic means comprising a core in said housing and a coil adapted to connect to a source of alternating current for passing magnetic flux through said core and said plunger, whereby as the current flow through the coil increases the core and plunger are attracted to one another and as the current flow through the coil decreases, the spring means bias the plunger and core apart.

5. Vibrator pump means comprising a housing having an inlet adapted to communicate with a reservoir of control fluid, a first outlet adapted to communicate with the reservoir for control fluid and a second outlet adapted to communicate with a pressure chamber, first valve means responsive to actuation of the vibrator pump means for closing said first outlet, means defining a bore in said housing communicating said inlet and said outlets, a magnetizable plunger reciprocably disposed in said bore, said plunger having a passage therethrough, magnetic means adapted to be connected to a source of alternating current for actuating said plunger in one direction, means for biasing said plunger in an opposite direction, inlet valve means in said plunger and cooperating with said passage in said plunger for regulating the flow of control fluid from said passage into said bore downstream of said plunger, and exhaust valve means in said housing for controlling the discharge of control fluid from said bore.

6. Vibrator pump means as in claim 4 wherein said core is adjustable in said housing with respect to said plunger for optimizing performance of the pump means.

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