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(71) Applicant
Copperweld Robotics Inc
1401 East 14 Mile Road
Troy
Michigan 48084
United States of America

(72) Inventors
Jerry Kirsch
Kerry Frank Kirsch

(74) Agents
J A Kemp & Co
14 South Square
Gray's Inn
London WC1R 5EU

(54) Electro-hydraulic robot positioning system

(57) An electro-hydraulic control includes a closed loop hydraulic system comprising a reciprocating pump (55) which forces hydraulic liquid under pressure into the system and hydraulic actuators e.g. 60, 62 which are operated by hydraulic pressure in the system to perform some kind of useful work. A valveing arrangement (58) in the system directs hydraulic liquid from the pump always to the delivery side of the system and also directs the movement of the hydraulic actuators in accordance with the particular work operation to be performed An electric servomotor 10 controlled by eg a computer (Fig. 1, not shown) rotates a thread 14 to move a carriage 37 connected to a reciprocating piston 48 in a final cylinder 50 of the pump 55. An accumulator 82 controls minimum pressure in the system.

FIG. 3.

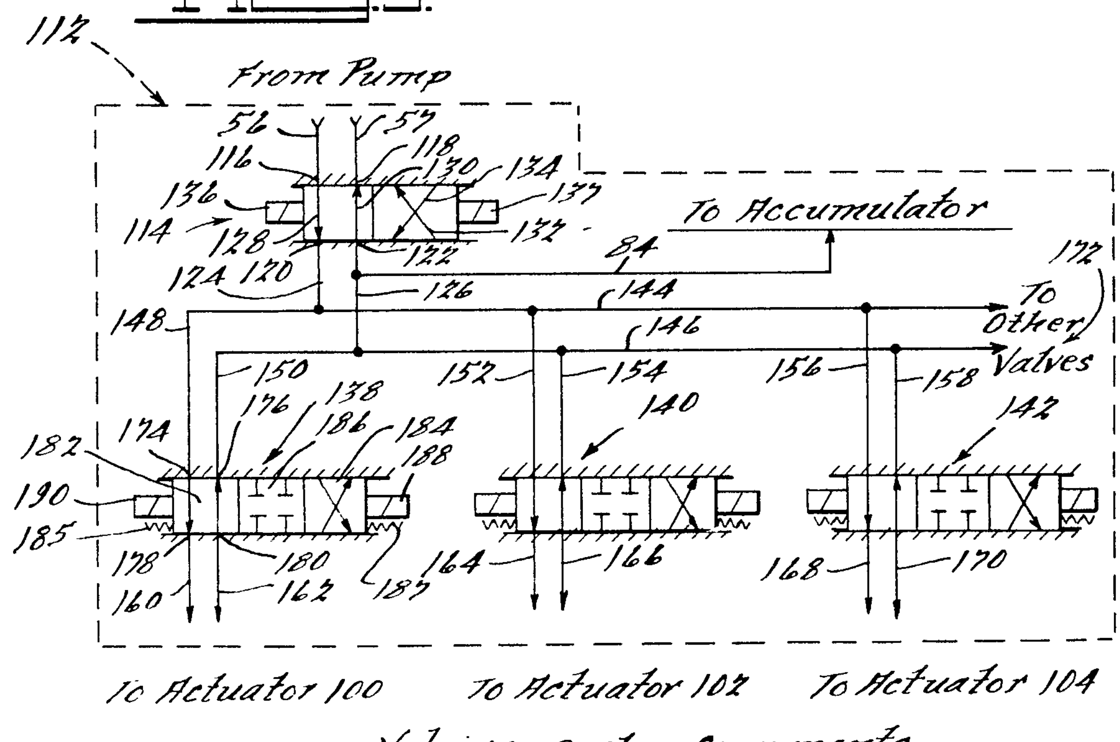

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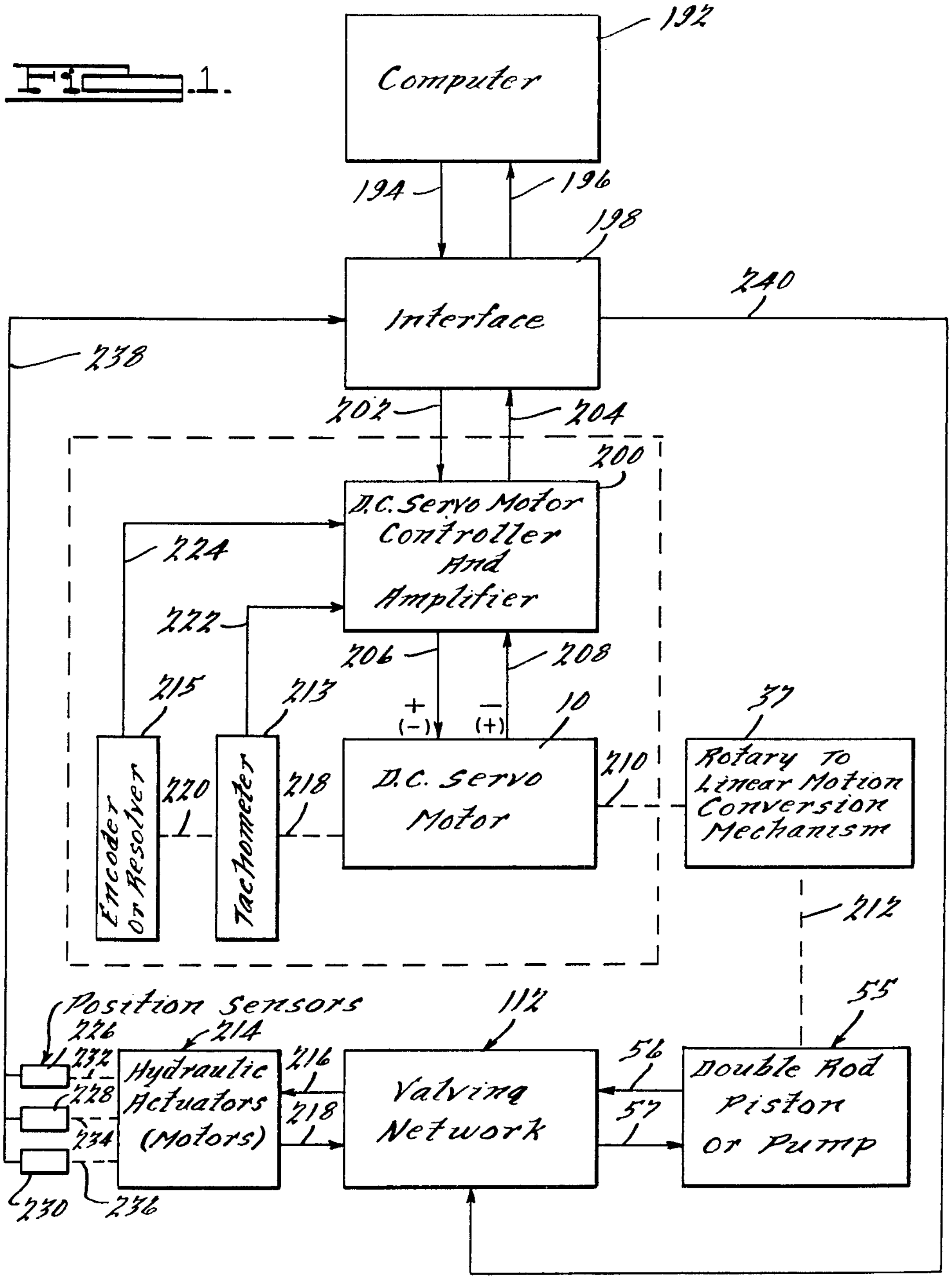
FIG. 1.



Computer
192
194
196
198
Interface
240
238
202
204
200
D.C. Servo Motor Controller And Amplifier
224
222
206
208
215
213
+ (−)
− (+)
10
37
Encoder Or Resolver
220
Tachometer
218
D.C. Servo Motor
210
Rotary To Linear Motion Conversion Mechanism
212
Position Sensors
112
55
226
214
232
Hydraulic Actuators (Motors)
216
Valving Network
56
Double Rod Piston Or Pump
228
218
57
234
230
236

Fig. 2.

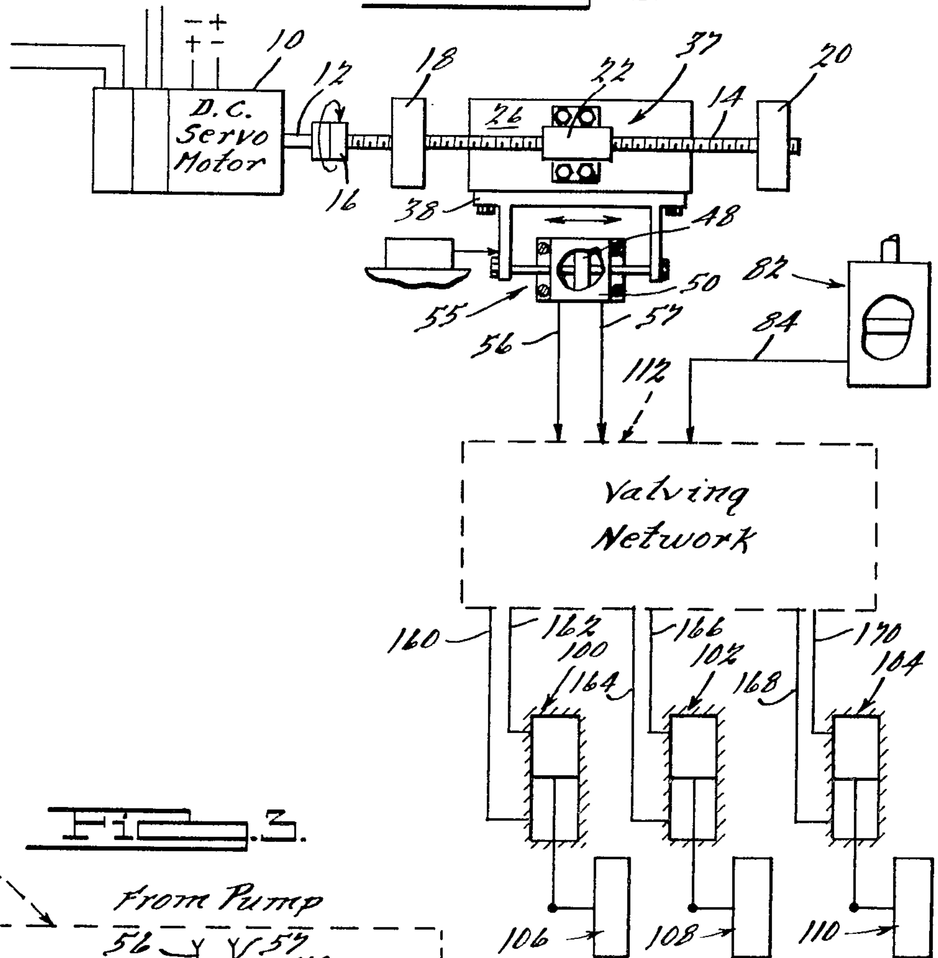
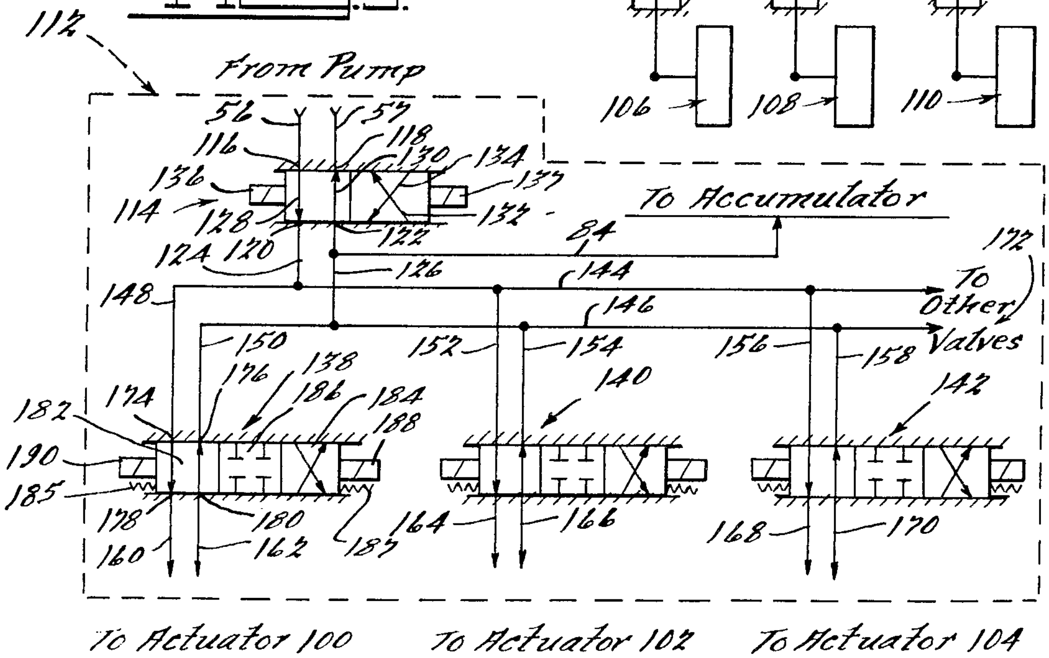
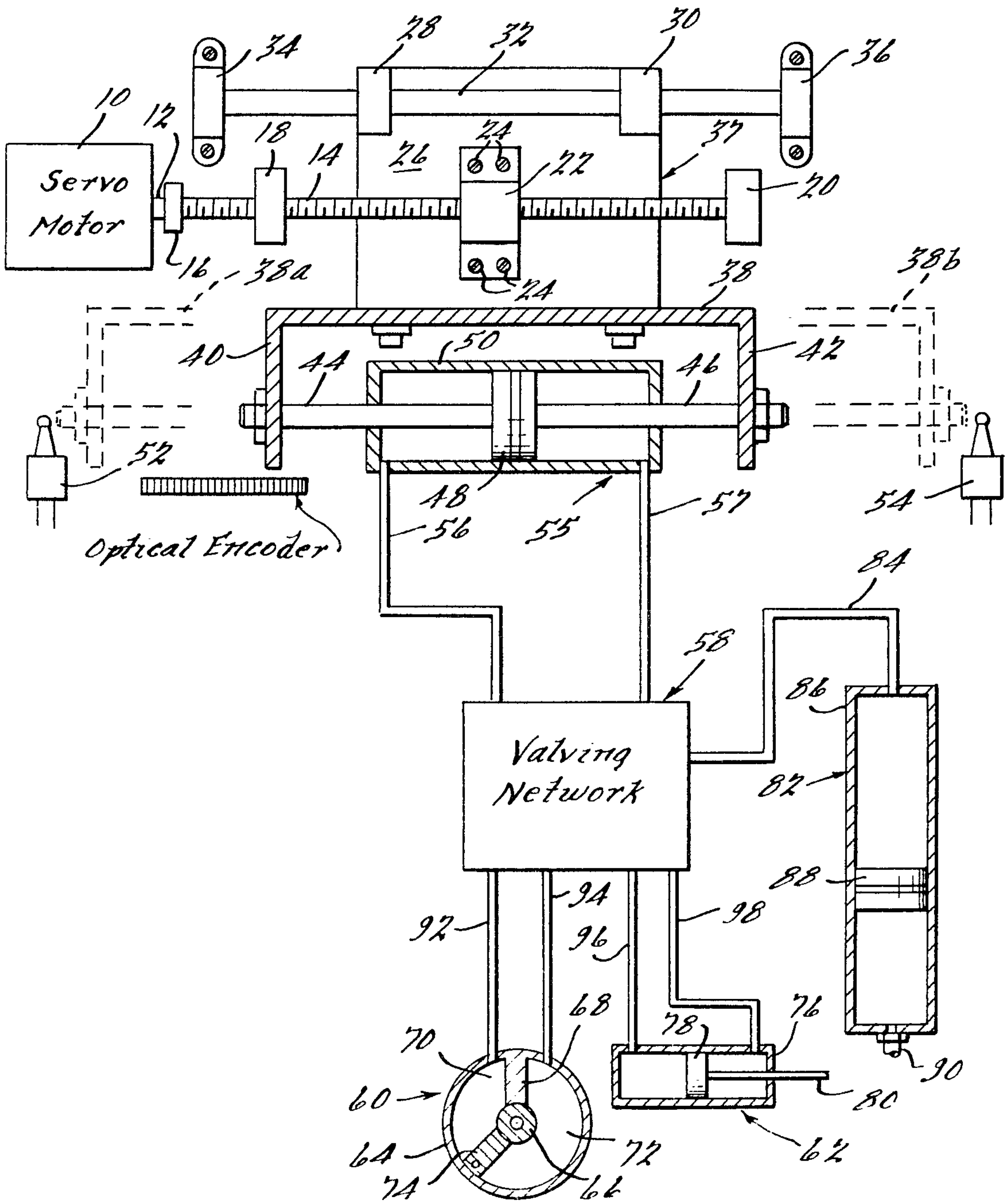


Fig. 3.



Valving System Componants

FIG. 4.


Servo Motor
10
12
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16
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38a
38b
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42
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Optical Encoder
58
Valving Network
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62
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SPECIFICATION

Electro-hydraulic robot positioning system

Background to the Invention

This invention relates to new and useful improvements in electro-hydraulic control systems adapted and intended primarily for use with robot devices of the type having one or more work actuating members.

The robot device disclosed in U.S. patent No. 3,406,837 dated October 22, 1968 is typical of the robot devices with which the system of this invention is adapted to be used.

Brief Summary of the Invention

Briefly, the control system of this invention comprises a plurality of hydraulic actuators each adapted to be operatively connected to a work actuating means of the robot and operative in use to impart different motions to the work actuator member or members. More specifically, a closed-loop hydraulic circuit having delivery and return sides is connected to the hydraulic actuators, and a servomotor preferably acting through a suitable speed reducer is operatively connected to the position of a power cylinder which is connected to and is a part of the hydraulic circuitry and functions as a hydraulic pump to force hydraulic liquid through the circuit. Reversing valve means provided in the hydraulic circuit between the power cylinder and the hydraulic actuators directs hydraulic liquid being pumped to the circuit always to the delivery side of the circuit, and control valves provided in the circuit in operative association with the hydraulic actuators control operation of the latter in response to operating conditions in the system so that the hydraulic actuators can be held stationary or operated selectively individually and in predetermined sequence to move the robot work actuating means in accordance with a predetermined program. Suitable means such as a piston type accumulator is operatively connected to the return side of the hydraulic circuit to maintain a predetermined hydraulic pressure therein and to accommodate variations in the amount of hydraulic liquid in the return side of the system occurring in use for some reason as by movement of the hydraulic actuators.

An important object of the present invention is to provide an electro-hydraulic servo control system for robot devices and the like that is more efficient than existing servo systems and which operates at significantly lower sound levels.

Another object of the invention is to provide an electro-hydraulic servo control system which operates by positive displacement of hydraulic liquid in the system, that is capable of generating relatively high pressure in the hydraulic portion of the system to assure accurate and readily controllable movements of the robot work actuating members, and in which the pressure can be easily regulated by selective operation of the servo actuator.

Still another object of the invention is to provide an electro-hydraulic servo control system of the type referred to above in which temperature of the hydraulic liquid in the system remains relatively low due to lack of rest position turbulence typical particularly of vane type hydraulic pumps conventionally used in existing systems.

More particularly, the servo control system of this invention is adapted to position a mechanical load being handled by the robot machine through a robot actuator in response to digital commands. The system is specifically designed to utilize a non-contacting digital shaft encoder in conjunction with control logic to develop position feedback information. CMOS circuitry can be used throughout the control logic to provide for low power consumption and low heat generation. The interrelationships between the various components of the system is such that interfacing can be kept simple by limiting the control commands to a minimum number of inputs. The control commands can be generated by computer, by digital control logic or by electro-mechanical contact closures. The electro-mechanical servo actuator for the system preferably includes a permanent magnet, direct current motor, a velocity feed-back tachometer, and a position feed-back shaft encoder together with an external amplifier and power supply. These components form a complete positioning means for the system and for the work actuating member or members of the robot machine.

Brief Description of the Drawings.

In the drawings:

Figure 1 is a block diagram showing a servo control system embodying the invention;

Figure 2 is a diagrammatic view showing the servo actuator means that forms a part of the control system of Fig. 1 and particularly illustrating the manner in which the electro-hydraulic actuator pumps hydraulic liquid into the hydraulic circuit and illustrating also a plurality of hydraulic actuators in and forming a part of the circuitry operatively connected to work actuating means with which robot machines of the type involved here are conventionally equipped;

Figure 3 is a diagrammatic view showing the hydraulic circuitry which is a part of the electro-hydraulic actuator means illustrated in Fig. 2; and

Figure 4 is a diagrammatic view showing in greater detail the electro-hydraulic servo drive means for the hydraulic motors that operate the robot work actuating members.

Description of the Preferred Embodiment

Reference is first had to Fig. 4 which shows a conventional direct current, reversible, servomotor 10 having a drive shaft 12 drivingly connected to an externally threaded shaft 14 by a coupler 16. Both the motor 10 and the shaft 14 are held longitudinally stationary in any suitable or conventional manner, but the motor drive shaft 12 and the screw 14 as well as the connecting coupling 16 are mounted so as to be freely rotatable. In this connection, it will be observed that the shaft 14 is here shown suitably supported by a pair of spaced bearings 18 and 20. A nut 22 is mounted on and threadably engaged with the screw 14 and also attached by screws 24 to a suitable carriage 26 which in turn is slidably supported by bearings 28 and 30 on a guide rod 32 carried by and fixed to suitable end supports 34 and 36.

In use, the motor 10 rotatably drives the screw 14 and this causes the nut 22 to move either to the right or to the left as shown in the drawing depending upon the direction of rotation of the screw. Preferably, the screw 14 and the nut 22 are in the form of a conventional ball nut to minimize frictional resistance to movement of the nut on the shaft and to minimise also lost motion between these two elements. The carriage 26 moves on the guide rod 32 together with the nut 22. Manifestly, the mechanism described is capable of reciprocally actuating the nut 22 and the carriage 26 back and forth on the shaft 14 and thus serves as a means for translating rotary motion of the motor drive shaft 12 into rectilinear reciprocatory motion of the carriage 26, and it also serves as a speed reducer designated generally by the numeral 37 for moving the carriage at a much slower rate of speed than the motor drive shaft 12.

Mounted on and movable with the carriage 26 is a generally U-shaped bracket 38 the two arms 40 and 42 of which are connected to the two rod portions 44 and 46 of a double-rod piston 48 which is mounted for reciprocation in a stationary hydraulic cylinder 50. From the foregoing, it will be readily apparent that the bracket 38 moves with and at the same rate as the carriage 26 and that, as it moves in this manner, the bracket reciprocally actuates the piston 48 within the cylinder 50. In Fig. 4, the parts referred to are shown in full lines with the piston 48 at approximately the middle of the cylinder 50. The extreme position of the bracket 38 to the left as viewed in Fig. 4 is shown at 38a and the extreme position of the bracket to the right as viewed in Fig. 4 is shown at 38b. Travel of the bracket 38 both to the right and to the left is suitably controlled during normal operation by a controller shown schematically at 200 in Fig. 1 under instructions from a computer shown at 192, and the extent of movement of the bracket is adjusted in accordance with the exigencies of the particular situation by modification of the computer program. It is contemplated, however, that the piston 48 not travel the full distance permitted by the cylinder 50, and a pair of limit switches 52 and 54 are suitably connected in the control circuit of the servomotor 10 so that the direction of rotation of the latter is reversed for over-travel safety in the event the bracket 38 should for some reason engage one of the limit switches 52 and 54 at the extreme limit of its travel in one direction or the other.

The piston 48 and the cylinder 50 collectively define a pump 55 that is part of a closed-loop hydraulic circuit in which the pipes 56 and 57 extending from the cylinder 50 at opposite ends thereof provide communication between the cylinder chambers at opposite sides of the piston 48 and a valve arrangement or network shown diagrammatically at 58 in Fig. 4. The valving network 58 directs hydraulic liquid from the pump 55 to hydraulic actuators 60 and 62 for one or more movable work actuators which are part of a robot device or the like as hereinabove described. As suggested, it is intended that the electro-hydraulic control system of this invention be used with a mechanical robot device and that the hydraulic actuators be suitably connected to a movable part or parts of the device such as, for example, a work transfer arm.

The hydraulic actuator 60 here shown by way of illustration is a rotary actuator comprising a cylinder 64 having an axially disposed rotatable shaft 66 therein. A fixed radial vane extending from the cylinder 64 to the shaft 66 separates the cylinder into two chambers 70 and 72, and a vane 74 on and rotatable with the shaft 66 and extending radially to the cylinder moves the shaft and whatever part of the robot device is attached thereto either clockwise or counterclockwise depending on which of the chambers 70 and 72 is connected to the delivery side of the hydraulic circuit by the valving network 58.

The hydraulic actuator 62 is a different form of actuator comprising a cylinder 76 having a piston 78 mounted for reciprocation therein with the piston rod 80 extending from one end of the cylinder. A typical use for the hydraulic actuator 42 in robot devices of the type referred to above would be for the piston rod 80 to reciprocally actuate some movable part of the robot device.

The movable robot part referred to with respect to both hydraulic actuators 60 and 62 may be the same part or two different parts. In the robot device shown in U.S. patent No. 3,406,837 previously referred to herein, the lifting and swinging transfer arm identified in the patent by the numeral 70 provides a typical setting for work actuators of the type shown here at 60 and 62. The arm 70 is adapted to lift and swing a vacuum cup shown in the patent at 74 and, in adapting the control system of this invention to the patented device, it would be well within the skill of an ordinary mechanic to attach the piston rod 80 of the hydraulic actuator to the arm 70 or one of its adjuncts so as to lift the arm and it would be equally within the skill of an ordinary mechanic to attach the shaft 66 of the hydraulic actuator 60 to the arm 70 or one of its adjuncts so as to impart a turning or swinging movement to the arm. In connection with the foregoing, however, it will be readily appreciated that, while a pair of turning and reciprocable actuators are here shown by way of example, any desired number or kind of actuator or combination of actuators can be used in the system of this invention and it is contemplated also that the system be used in any environment or situation where such control circuits have utility.

In use, it is contemplated that the piston 48 of the pump 55 force hydraulic liquid under relatively high pressure into the closed loop hydraulic circuit during both strokes of the piston. Thus, when the piston 48 moves to the left, as shown in Fig. 4, it forces hydraulic liquid under pressure into the pipe 56. Contrariwise, when the pump piston 48 moves to the right, as viewed in Fig. 4, it forces hydraulic liquid under pressure into the pipe 57. It is important in the operation of the electro-hydraulic control system of this invention that the closed loop hydraulic circuit have a delivery side through which hydraulic liquid flows to the work actuators here shown by way of example at 60 and 62 and that the hydraulic circuit have a return side through which hydraulic liquid flows from the work actuators back to the pump.

It is important also that the control system of this invention have an accumulator that serves to maintain a predetermined minimum pressure in the return line of the hydraulic circuit and that compensates for variations in the amount of hydraulic liquid in the line which occurs when piston-type actuators of the type shown at 62 are used. In this latter connection, a piston-type accumulator 82 is here shown connected to the return side of the hydraulic circuit by a pipe 83. The accumulator 82 comprises a cylinder 86 having a free-floating piston 88 mounted therein. Hydraulic liquid from the return side of the circuit is free to flow through pipe 84 to and from the portion of the cylinder 86 above the piston 88 so that the hydraulic liquid in the upper portion of the cylinder 86 is at the same pressure as the hydraulic liquid in the return side of the circuit. An inert gas such as nitrogen or the like is supplied from any suitable source through an inlet pipe 90 to the cylinder 86 below the piston 88. The gas pressure in the lower portion of the cylinder 86 may vary depending upon the pressure of hydraulic liquid in the return side of the hydraulic circuit. A gas pressure of about 50 psi is suitable in most instances, but it will be readily appreciated that in any particular installation the gas pressure should be sufficiently high to hold the piston 88 normally approximately midway in the cylinder 86 so that the gas in the cylinder serves as a cushion against which the piston 88 moves when hydraulic pressure in the circuit increases and which acts against the piston to move it upwardly in the cylinder when the pressure of hydraulic liquid in the circuit decreases.

In the control system shown in Fig. 4, hydraulic liquid passes from the valving network 58 to and from the work actuator 60 at opposite sides of the fixed vane 68 through pipes 92 and 94, and it does so independently of liquid flow to and from the work actuator 62. Similarly, hydraulic liquid passes from the valving network 58 to and from the work actuator 62 through pipes 96 and 98 at opposite sides of the piston 78 independently of the actuator 60. It is contemplated that in use the valving network 58 be operative to connect the delivery side of the hydraulic circuit selectively to either of the pipes 92 and 94 which supply the work actuator 60. Similarly, it is contemplated that the valving network 58 be operative to supply hydraulic liquid from the delivery side of the circuit to the work actuator 62 selectively through either of the pipes 96 and 98. Manifestly, if high pressure hydraulic liquid is supplied to the work actuator 60 through the pipe 92 at the same time the pipe 94 is connected to the return side of the hydraulic circuit, the movable vane 74 will move counterclockwise in the cylinder 64 as shown in the drawing, and if hydraulic liquid at relatively high pressure is supplied to the cylinder 64 at the other side of the fixed vane 68 under similar circumstances, the movable vane 74 will move clockwise. In the suppositious robot installation shown in U.S. patent No. 3,406,837 referred to hereinabove by way of example, movement of the vane 74 acts to swing the transfer arm 70 disclosed in the patent either to the right or to the left depending on the direction of movement of the vane. Similarly, in this suppositious installation, the piston 78 and its piston rod 80 are either advanced or retracted in the cylinder 76 depending upon whether high pressure hydraulic liquid is supplied to the cylinder through the pipe 96 or the pipe 98. In any event, however, movement of the piston rod 80 can be used either to lift or to lower the transfer arm 70 shown in the patented environment by proper manipulation of the valve in the valving network 58 that controls flow of hydraulic liquid to the pipes 96 and 98.

Fig. 2 illustrated a control system similar to the one shown in Fig. 4 but adapted to serve 3 hydraulic actuators shown diagrammatically at 100, 102 and 104 all of which are piston-type actuators of the type shown at 62 in Fig. 4. Also, in Fig. 2, each of the hydraulic actuators 100, 102 and 104 is illustrated diagrammatically as being connected to separate work actuators 106, 108 and 110, respectively. In the modified control system shown in Fig. 2, hydraulic liquid under relatively high pressure is supplied to the valve network 112 alternately through pipes 56 and 57 as in the form of the invention first described. Also, the valving network 112 is modified to accommodate the three hydraulic actuators 100, 102 and 104. Otherwise, the two control systems shown in Figs. 2 and 4 are the same and they function in a similar manner.

Reference is now had to Fig. 3 which illustrates diagrammatically a typical valving network 112 for three work actuators. It will be readily apparent from a detailed description of the valving network 112 how the latter can be modified to provide a valve arrangement such as the one shown at 58 in Fig. 4 which serves only the two hydraulic actuators 60 and 62. Similarly, it is believed that it will be equally apparent from a description of the valving network 112 how the latter can be modified to serve substantially any number or kind of hydraulic actuators that would normally be involved in a robot mechanism or similar device.

More particularly, the valving network 112 comprises a solenoid valve 114 having inlet ports 116 and 118 to which the two pipes 56 and 57 are connected. The solenoid valve 114 also has two outlet ports 120 and 122 to which pipes 124 and 126 are connected. In one position of the valve spool, through passages 128 and 130 connect the inlet ports 116 and 118 with respective outlet ports 120 and 122. In another position of the valve spool, passages 132 and 134 connect the inlet ports 116 and 118 with outlet ports 122 and 120, respectively, to maintain delivery flow of hydraulic liquid in the pipe 124; viz., always away from the valve 114 and toward the valves 138, 140 and 142 that serve the hydraulic actuators 100, 102 and 104. The valve 114 here shown is a conventional type wherein the valve spool is moved to the left; viz., to the position shown, by energization of the solenoid 136 and deenergization of the solenoid 137 to connect pipe 56 to pipe 124 and pipe 57 to pipe 126 through passages 128 and 130, respectively, and wherein the valve spool is moved to the right by energization of the solenoid 137 and deenergization of the solenoid 136 to connect pipe 56 to pipe 126 and pipe 57 to pipe 124 through ports 132 and 134, respectively. In practice, the solenoids 136 and 137 are connected together with the servomotor 10 in electrical circuits having suitable electric controls and interlocks that position the valve 114 as shown in Fig. 3 when the pump piston 48 moves to the left as shown in Fig. 2 and that positions the valve with the ports 132 and 134 in register with pipes 56, 126 and 57, 124 respectively, when the pump piston 48 moves to the right. Thus, the pipe 124 always delivers high pressure hydraulic liquid to the work actuators 138, 140 and 142 regardless of the direction of movement of the pump piston 48. By the same token, as will be hereinafter apparent, hydraulic liquid in the pipe 126 will always flow away from the control valves 138, 140 and 142 and toward the pump 55. In this latter connection, as previously suggested, it is important that the accumulator 82 be connected always to the return side of the closed loop hydraulic circuit now being described, and it will be observed that the pipe 84 from the accumulator is here shown connected to the liquid return pipe 126.

The three hydraulic actuators 100, 102 and 104 are served by three-position solenoid valves 138, 140 and 142, respectively. The delivery and return pipes 124 and 126 connect with the main hydraulic pipes 144 and 146, respectively, and the latter are connected to the three-position valves 138, 140 and 142 by respective pairs of pipes 148, 150; 152, 154 and 156, 158. Hydraulic liquid from the three-position valves 138, 140 and 142 pass to and from the hydraulic actuators 100, 102 and 104 through respective pairs of pipes 160, 162; 164, 166 and 168, 170 (Fig. 2).

If the valving network were adapted to serve only two hydraulic actuators such as the ones shown at 60 and 62 in Fig. 4, the main pipes 144 and 146 would terminate at the valve supply pipes 152 and 154. In this event, the three-position valve 138 would serve the hydraulic actuator 60 through pipes 92 and 94 and the three-position valve 140 would serve the hydraulic actuator 62 through pipes 96 and 98. Similarly, if the valving network were adapted to serve three hydraulic actuators, such as the ones shown at 100, 102 and 104 in Fig. 2, the main supply lines 144 and 146 would terminate at the pipes 156 and 158. In this latter event, the three-position valves 138, 140 and 142 would serve the hydraulic actuators 100, 102 and 104, respectively. On the other hand, if the valve network was required to serve more than three hydraulic actuators the main lines 144 and 146 would be extended as shown at 172 in Fig. 3 and similarly connected to additional hydraulic actuators.

The three solenoid valves 138, 140 and 142 are identical in construction and operation and a detailed description of valve 138 therefore will suffice. As shown in the drawing, the valve 138 has inlet ports 174 and 176 which connect with the pipes 148 and 150, respectively, and outlet ports 178 and

180 connected to the pipes 160 and 162. The sliding spool of valve 138 has a straight-through position indicated diagrammatically at 182, a reversing position indicated diagrammatically at 184, and an intermediate blocking position indicated diagrammatically at 186. Counterbalancing springs indicated generally at 185 and 187 hold the valve spool normally in the intermediate blocking position. A solenoid 190 at one end of the valve 138, when energized, moves the spool to the straight-through position shown in the drawing, and a solenoid 188 at the other end of the valve 138, when energized, moves the spool to the reversing position 184. As in the case of the valve 114, the solenoids 188 and 190 are adapted to be electrically connected and interlocked in a conventional manner with suitable control means that program operation of the valves 138, 140 and 142 in accordance with the mechanical requirements of the work actuators and of the robot device of which they are a part.

In the case of the three-position valve 138 which serves the hydraulic actuator 100 and the work actuator 106 (Fig. 2), it will be readily appreciated that when the valve is in the normal blocking position 186, the supply of hydraulic liquid to the hydraulic actuator 100 is cut off and the work actuator 106 is stationary. However, when the valve 138 is in the straight-through position 182, high pressure hydraulic liquid flows from the reversing valve 114 through pipes 124, 148 and 160 to the lower portion of the hydraulic actuator 100 to retract its piston and to lift the work actuator 106. As the piston in the hydraulic actuator 100 retracts, hydraulic liquid in the upper portion of the actuator flows through pipes 162, three-position valve 138, pipes 150, 126 and 57 back to the pump 55. On the other hand, when the three-position valve 138 is in the reversing position 184 and the valve 114 is positioned as shown in Fig. 3, high pressure hydraulic liquid from the three-position valve 138 passes to the upper portion of the hydraulic actuator 100 through the pipe 162 to advance the piston in the hydraulic actuator and to lower the work actuator 106.

In connection with the foregoing, it will be readily appreciated that all of the three-position valves 138, 140 and 142 function similarly to control the operation of their respective hydraulic actuators 100, 102 and 104 and thus the work actuators 106, 108 and 110. It will be appreciated also that the three-position valves 138, 140 and 142 can be individually selectively positioned to operate their respective work actuators 106, 108 and 110 in either the straight-through or the reversing position and that this can be done in either position of the main valve 114. Furthermore, each of the three-position valves 138, 140 and 142 can be individually selectively maintained in the blocking position to hold its respective work actuator stationary for a predetermined interval of time regardless of what the other work actuators are doing.

From the foregoing, it will be readily appreciated that the valve arrangement here shown permits constant monitoring and control of the work actuators at all times and permits the work actuators to be selectively operated in accordance with a predetermined program. This is made possible by the present control system which supplies hydraulic liquid from the pump 55 relatively constantly and under relatively high pressure to the hydraulic circuit at all times during operation of the servomotor 10. Energization of the servomotor 10 and consequently movement of the drive nut 22 and the piston 48 can be accurately controlled within extremely close limits. This in turn permits the movements of the work actuators 106, 108 and 110 to be individually controlled within equally close limits at least in part because the higher pressure hydraulic liquid that operates the work actuators is supplied from a closed loop system. The entire system operates with a minimum of noise and generates relatively little heat. Further, the need for preheaters and coolers normally required by hydraulic systems of the type involved here is eliminated. The temperature of the hydraulic liquid in the circuit remains relatively low due to lack of rest-position turbulence in the system.

It is a special feature of the instant electrohydraulic control system that it can be readily incorporated into a larger system that can be controlled for automatic operation under the direction of a computer using means and techniques well known in the art. As shown diagrammatically in Fig. 1, the numeral 192 designates a computer having a closed loop connection indicated at 194 and 196 with an interface 198 which in turn is suitably connected to the direct current, reversible servomotor 10 through a controller and amplifier unit 200 as indicated at 202, 204 and 206, 208. As previously described, the motor 10 has a direct driving mechanical connection 210 with the rotary-to-linear motion conversion mechanism 37 which reduces the speed of the motor drive shaft and reciprocally actuates the pump 55 as indicated at 212. Suitable speed and motion monitoring and control devices, such as the tachometer 213 and the encoder or resolver indicated generally at 215, are mechanically driven by the motor 10, as indicated at 218 and 220, and in turn are suitably electrically interconnected with the motor controller and amplifier unit 200 as indicated generally at 222 and 224 to provide speed and position feed-back information to the motor controller so that the latter can regulate the travel of the pump piston and the position of the piston within the pump cylinder in accordance with the requirements of the system. The connections between the pump 55 and the valving network 112 are indicated diagrammatically at 56 and 57 in Fig. 1, and the hydraulic actuators shown at 60 and 62 in Fig. 4 and at 100, 102 and 104 in Fig. 2 are shown diagrammatically in Fig. 1 and designated collectively by the numeral 214. The hydraulic connections between the valving network 112 and the hydraulic actuators 214 are indicated diagrammatically at 216 and 218. Movements of the hydraulic actuators 214 are controlled by suitable position sensors such as limit switches or the like. It is contemplated that each hydraulic actuator will be individually served by its own position sensor or set of sensors, and for the purpose of this description it is assumed that the hydraulic actuators shown diagrammatically and collectively at 214 in Fig. 1 comprise the three hydraulic actuators 100, 102 and 104 shown in Fig. 2. To this end, three position sensors or sets of sensors 226, 228 and 230 are here shown one for each of the hydraulic actuators 100, 102 and 104. The connections between the position sensors 226, 228 and 230 and their respective hydraulic actuators are shown schematically at 232, 234 and 236. The position sensors 226, 228 and 230 are also electrically connected as indicated generally at 238 with the interface 198, and the latter in turn is electrically connected as indicated at 240 to the solenoids of the control valves 114, 138, 140 and 142, as shown in Fig. 3.

In operation, the servomotor 10 is programmed by the computer 192 to reciprocate the piston 48 in the middle portion of the cylinder 50 with the length of the piston stroke determined in the environment here shown by way of example by the particular motion requirements of the robot actuators 106, 108 and 110, and in carrying out the operation the interface 198 translates control signals from and provides feed-back to the computer. For example, if the program calls for operation of the servomotor 10 for a time corresponding to 300 continuous wave pulses, it sends out appropriate instructions to this effect and the interface 198 sets direction on the servomotor controller and emits a pulse train of 300 pulses via conductor 202 and then checks the controller for a "done" signal transmitted back via conductor 204. The interface 198 also translates position sensor data received through the conductor 238 into a form understandable by the computer 192. This would involve analog to digital conversion if the position sensors 226, 228 and 230 are potenteometer-type sensors or it would be necessary to count pulses if the sensors are encoders. The interface 198 also functions to convert coded computer signals to A.C. voltage levels and transmits these voltages through the conductor 240 to the appropriate solenoid valves 138, 140 and 142 to establish a desired passageway for hydraulic liquid to the proper hydraulic actuator 100, 102 and 104.

The complete system shown in Fig. 1 provides program capability for configuring individual actuation of axes movement of any of several work actuators in a robot device, for example. A positive driving force for robot motion is supplied by hydraulic fluid in such a way that the rate and extent of movement in every instance can be precisely controlled, and the precision of movement required for accurate placement of a workpiece by work actuators that are part of the robot mechanism is served particularly well by the direct current servomotor and the rotary-to-linear motion conversion effected by the speed reducer 37, the pump 55 and the combination of these two devices as well as their unique association with the servomotor 10 since the latter can be precisely controlled by the computer 192 to move the pump piston 48 back and forth in the cylinder 50 in response to a micro processor that receives feed-back information of position, velocity and oil-volume from the electro-hydraulic control system. The piston-cylinder pump device 55, when coupled with a direct current servomotor of the type shown at 10, converts motor shaft torque to fluid pressure in a particularly efficient and readily controllable manner to move the robot actuators. Also, the unique correlation of the rotary-to-linear motion conversion mechanism shown at 37 and the particular pump mechanism shown at 55 permits movement of the pump piston 48 within the cylinder 50 to be carefully controlled and normally positioned at or about the middle portion of the cylinder so that complete movements of the robot work actuator mechanisms are assured during any single stroke of the piston. This is singularly important when a control system of the type here shown is adapted for operation of a robot mechanism since the middle portion of the pump cylinder 50 represents the useful area of piston movement. When the piston 48 is too near either end of the cylinder, complete steps of robot movement cannot occur. Thus, the micro-computer control system must cycle the servomotor which actuates the pump 55 forwardly and backwardly so that movement of the pump piston 48 is kept near the middle portion of the pump cylinder 50. The particular arrangement and correlation of parts that drive the pump 55 also permits optical encoders or equivalent means to be coupled to the servomotor 10, as shown at 220, to feedback information to the processor for position orientation, and a tachometer can be similarly coupled to the servomotor as indicated at 218 to produce a velocity feed-back signal for velocity orientation of the robot work actuating mechanism. Since the computer 192 controls the direction of flow of the hydraulic liquid and also the volume of liquid moving in the closed loop hydraulic circuit, flow control means can also be connected to the output lines of the pump 55 to produce velocity feedback to the computer for volume orientation.

CLAIMS

1. Electro-hydraulic control system for robot devices of the type having work actuating means comprising

a closed-loop hydraulic circuit having a liquid delivery side and a liquid return side,

means for pumping hydraulic liquid into the delivery side of said circuit while simultaneously receiving hydraulic liquid from the return side thereof, and

a plurality of hydraulic actuators operatively connected to the delivery and return sides of said hydraulic circuit through individually controlled valve means and adapted to be connected to said work actuating means to actuate the same, said valve means being independently operable to move said work actuating means selectively in either of two directions or to hold said work actuating means stationary.

2. In an electro-hydraulic control system for robot devices of the type having work actuating means, the improvement comprising

a self-contained, closed-loop hydraulic circuit having a pair of separate conduit means through which hydraulic liquid flows in the circuit and including a plurality of hydraulic motor means each having a cylinder and a movable actuator in said cylinder dividing the latter into separate chambers,

said conduit means being connected to respective chambers of said hydraulic motor means and permitting flow of hydraulic liquid between said hydraulic motor means,

at least one of said hydraulic motor means comprising drive motor means and said drive motor means being operative to pump hydraulic liquid at relatively high pressure alternately into said conduit means,

other of said hydraulic motor means comprising driven motor means operative by the pressure of liquid from said drive motor means to manipulate the work actuating means of said robot device,

main valve means connected to said conduit means between said drive motor means and said driven motor means operable to direct hydraulic liquid from said drive motor means always to one of said conduit means for delivery to said driven motor means, whereby the other of said conduit means between said main valve means and said driven motor means returns hydraulic liquid to said drive motor means,

control valve means connected to said conduit means between said main valve means and said driven motor means for controlling the flow of hydraulic liquid to and from said driven motor means, and

accumulator means connected to said return conduit means between said main valve means and said driven motor means for maintaining a predetermined minimum pressure in said hydraulic circuit and operative to accommodate variations in the amount of hydraulic liquid in the delivery and return sides of said hydraulic circuit due to operation of said hydraulic motor means.

3. The invention as defined by claim 2 including actuator means, and speed reducer means driven by said actuator means, and wherein said drive motor means comprises a cylinder and a piston mounted for reciprocation in said cylinder, said piston having rods extending through both ends of said cylinder connected to and actuated by said speed reducer means.

4. The invention of claim 2 including a direct current servomotor having a drive shaft operatively connected to said drive motor means.

5. The invention of claim 2 wherein the actuator of said drive motor means is in the form of a reciprocable piston, and including a reversible, direct current servomotor having a rotatable drive shaft, and speed reducing means having a driven connection with the shaft of said servomotor and a driving connection with the piston of said drive motor means, said speed reducing means being operable to translate rotary motion from said servomotor to reciprocatory travel of said piston.

6. The invention of claim 2 wherein the actuator of said drive motor means is in the form of a reciprocable piston, and including a reversible, direct current servomotor having a rotatable drive shaft, and speed reducing means having a drive screw connected to the drive shaft of said servomotor, and a carriage-connected to the piston of said drive motor means including nut means on and movable linearly along said drive screw.

7. The invention of claim 2 wherein the actuator of said drive motor means is in the form of a reciprocable piston, and including a reversible, direct current servomotor having a rotatable drive shaft, and means operable by said servomotor for translating rotary motion of said servomotor drive shaft into reciprocatory motion of said drive motor means.

8. The invention as defined in claim 2 wherein said hydraulic circuit is provided with a plurality of said driven motor means each having a cylinder and a movable actuator in said cylinder, and wherein said delivery conduit means is connected to the cylinder of each driven motor means at one side of the actuator in said cylinder and said return conduit means is connected to the cylinder of each driven motor means at the other side of the actuator in said cylinder.

9. The invention as defined by claim 8 including a plurality of said control valve means, one for each of said driven motor

means, each of said control valve means being operatively connected to a respective one of said driven motor means and operable individually to connect said delivery conduit means selectively to the cylinder of its respective driven motor means at either side of the actuator in said cylinder or to block the flow of hydraulic liquid completely to said cylinder, whereby said driven motor means can be selectively actuated individually and successively in predetermined sequence.

10. An electro-hydraulic control for a robot device of the type having a movable work actuating member comprising

at least one hydraulic actuator means having individual chambers separated by a movable actuator element, said actuator element adapted to be connected to said work actuating member to operate the latter in use,

a reversible, direct current servomotor,

a stationary cylinder normally filled with hydraulic liquid,

a double rod piston mounted for reciprocation in said cylinder,

means driven by said servomotor operatively connected to said piston to slidably actuate the latter in one direction or the other in said cylinder depending on the direction of rotation of said motor, and

a closed loop hydraulic system having delivery and return sides connected to said stationary cylinder at opposite sides of said piston and to respective chambers of said hydraulic actuator means at opposite sides of said movable actuator element.

11. The invention as defined in claim 10 including flow diverter valve means connected to the delivery and return sides of said hydraulic system operative to establish communication between said stationary cylinder at either side of said double rod piston and the chambers of said hydraulic actuator means.

12. The invention as defined by claim 10 including piston-type accumulator means connected to the return side of said hydraulic system for assuring a relatively constant pressure in said hydraulic system and for accommodating variations in volume of hydraulic liquid in said system due to actuation of said movable actuator element.

13. An electro-hydraulic control for a robot device of the type having a movable work actuating means comprising

a plurality of hydraulic actuators individually operable to impart different predetermined motions to said work actuating means, each of said hydraulic actuators having pressure chambers separated by a movable actuator element adapted to be operatively associated with and connected to said work actuating means,

a reversible electric drive motor,

a power cylinder normally filled with hydraulic liquid,

a piston mounted for reciprocation in said cylinder defining individual pressure chambers at opposite sides thereof,

connecting means driven by said motor operatively connected to said piston to slidably actuate the latter in one direction or the other depending on the direction of rotation of said motor, and

a closed loop hydraulic system normally filled with hydraulic liquid and through which hydraulic liquid passes between said power cylinder and said hydraulic actuators, said hydraulic system having delivery and return sides connected to the pressure chambers of said power cylinder and to the individual pressure chambers of said hydraulic actuators, and valve means for connecting the pressure chamber into which said piston is moving always to the delivery side of said hydraulic system and for blocking flow of hydraulic liquid to said hydraulic actuators or for connecting the delivery side of said system selectively to the pressure chamber at one side or the other of the movable actuator element of each hydraulic actuator.

14. The invention as defined by claim 13 wherein said drive motor is a direct current servomotor.

15. The invention as defined by claim 13 or claim 14 wherein said connecting means comprises a speed reducer.

16. The invention as defined by claim 13 wherein said drive motor is a direct current servomotor having a rotatable drive shaft, and wherein

said connecting means comprises a rotary-to-linear motion conversion mechanism interconnecting the drive shaft of said servomotor and said piston.

17. The invention as defined by claim 13 wherein said drive motor is a direct current servomotor having a rotatable drive shaft, and wherein

said connecting means comprises a ball screw speed reducer mechanism including a screw shaft having a driven connection with the drive shaft of said servomotor, a ball nut advanceable and retractable on said screw shaft depending on the direction of rotation of said drive shaft, and a carriage connected to and movable with said nut having a driving connection with said piston and operable in use to reciprocably actuate the same in said cylinder, whereby to pump hydraulic liquid alternately from said cylinder at opposite sides of said piston to the delivery side of said hydraulic system.

18. The invention as defined by claims 13 or 17 wherein said valve means includes a plurality of control valves operably associated with said plurality of hydraulic actuators for controlling the flow of hydraulic liquid thereto and being selectively operable individually in predetermined sequence to impart their respective motions to said work actuating means.

19. An electro-hydraulic control system for robot devices, such control system being constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

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