Dec. 23, 1969 CHUN HYUNG CHO 3,485,256

ELECTROHYDRAULIC ACTUATOR

Filed Jan. 22, 1968 2 Sheets-Sheet 1

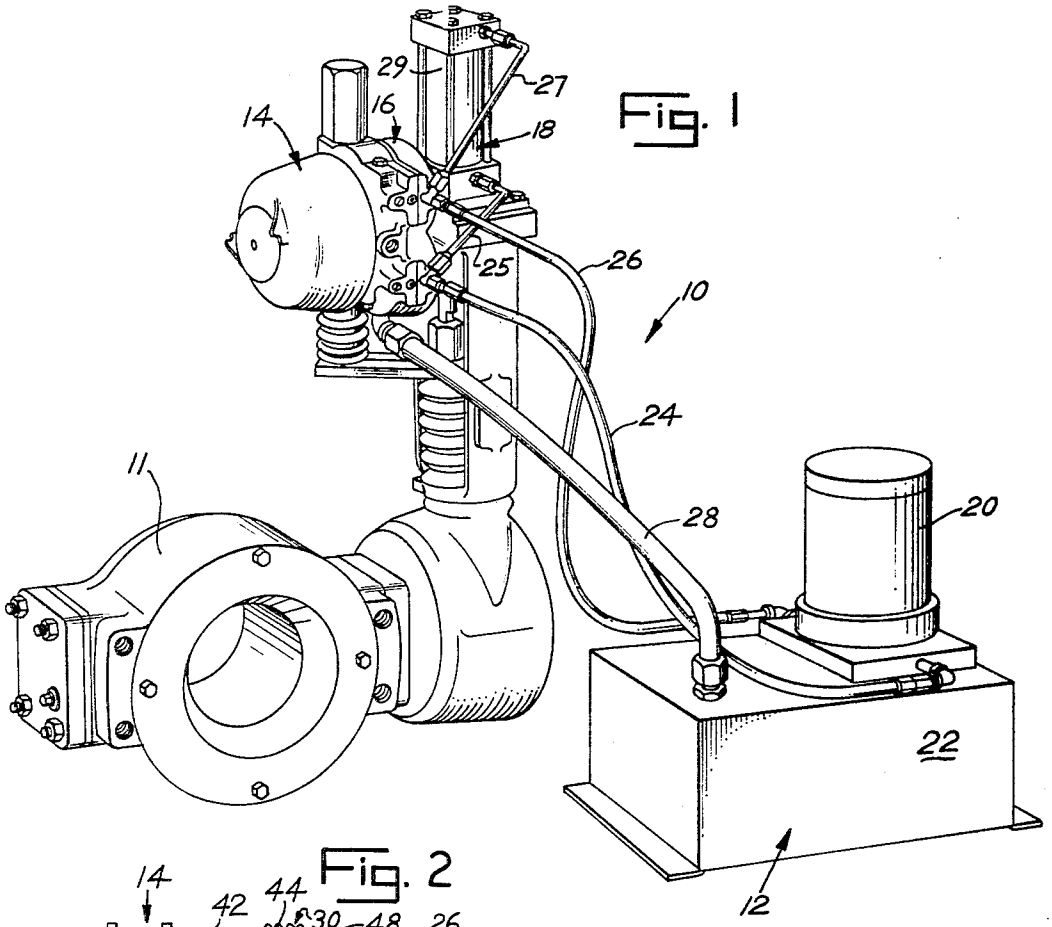

Fig. 1

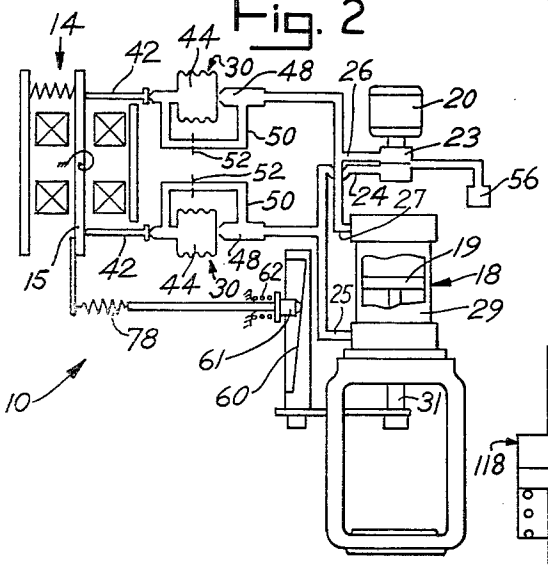

Fig. 2

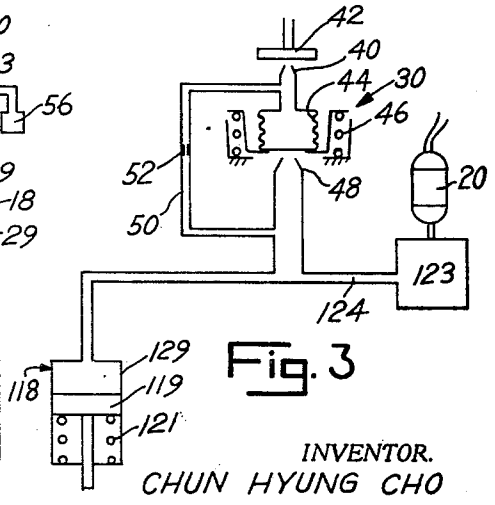

Fig. 3

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Fig. 4

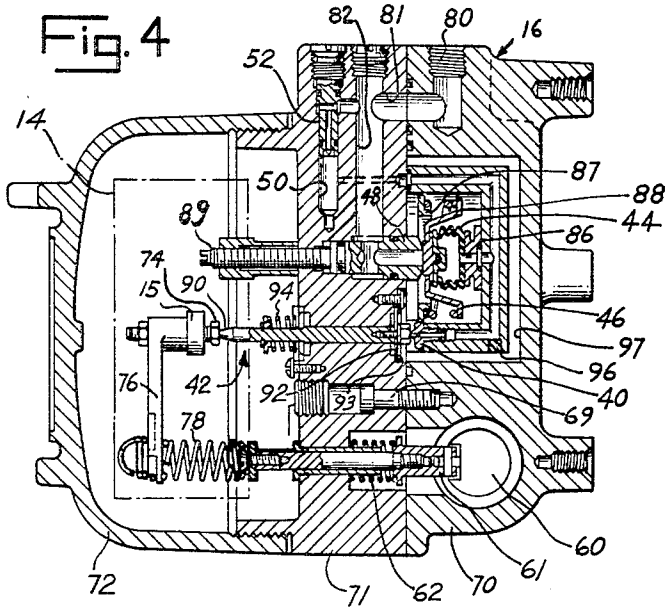
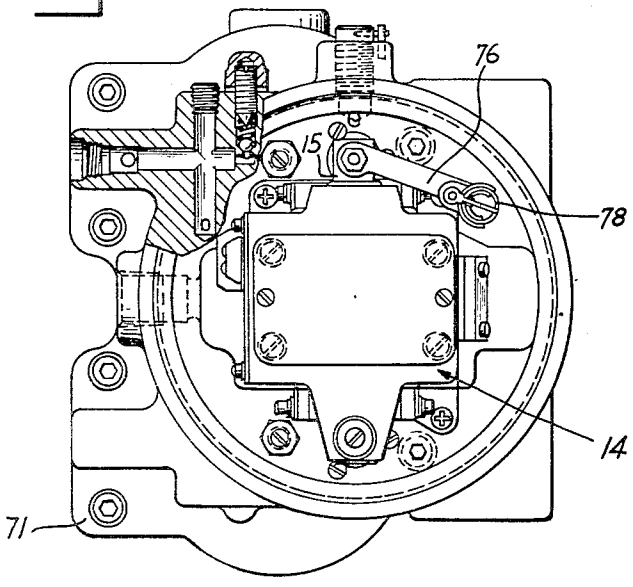


Fig. 5



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ELECTROHYDRAULIC ACTUATOR

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ABSTRACT OF THE DISCLOSURE

For use in an actuator mechanism which includes an input element, a power supply, and an actuator for a controllable element, for example, a valve, a novel regenerative servo amplifier including first and second nozzles, a movable element operative by said input element cooperating with the first nozzle to control discharge of fluid therefrom, bellows means responsive to pressure at said first nozzle and cooperating with the second nozzle to control discharge of fluid therefrom, and conduit means having a restriction therein communicating the pressure adjacent the outlet of said second nozzle with that adjacent the outlet of said first nozzle, whereby increase or decrease in the flow rate across the restriction in said conduit means due to change in pressure at the second nozzle effects a positive feedback to the first nozzle.

Background of the invention

This invention relates to electro-hydraulic actuator means and more particularly to improved electro-hydraulic actuator means incorporating a unique fluid power amplifier.

An electro-hydraulic actuator means is comprised basically of four major components. These are an electro-mechanical input element, a fluid power amplifier, a power source which conveniently may be a pump and motor unit, and a ram and its cylinder. One of the deficiencies in prior electro-hydraulic actuator systems is the relatively high steady-state power consumption which is due to the fact that prior arrangements often depend upon a regulated usually high supply pressure. In some prior arrangements, the input element was a force motor which in cooperation with prior fluid power amplifiers was incapable of producing the relatively high gain characteristics necessary for desired static accuracy of the electro-hydraulic actuator system.

An object of the present invention is to provide an improved actuator means incorporating a unique fluid power amplifier.

A further object of this invention is to provide a unique regenerative fluid power amplifier capable of providing very high loop gain at low cost. Another object of this invention is to provide improved actuator means operable on a constant fluid flow rate from a power source rather than a regulated, generally high supply pressure, whereby the power to the actuator of the actuator means is governed by load demand and the steady-state power losses are kept at a minimum.

Yet a further object of this invention is to provide a novel regenerative fluid amplifier for receiving motion input from an electro-mechanical element and delivering a modulated fluid power to a ram and cylinder or like actuator to provide a required valve stem thrust with high gain and at relatively low cost. Other objects and advantages of the present invention will be made more apparent hereafter.

Brief description of the drawing

The attached drawing illustrates a preferred form of the present invention, in which like numerals designate like parts in the various views and in which:

FIG. 1 is a perspective view of electro-hydraulic actuator means embodying the present invention operatively connected to a valve member for actuating same;

FIG. 2 is a schematic view of the electro-hydraulic actuator means of FIG. 1;

FIG. 3 is a schematic illustration of the basic regenerative servo amplifier system;

FIG. 4 is a cross-sectional view of the electro-mechanical element and the regenerative fluid amplifier of FIG. 1; and

FIG. 5 is a plan view with the cover removed of the electro-mechanical element and the regenerative fluid amplifier of FIG. 1.

Description of the preferred embodiment

Referring to FIG. 1, there is illustrated actuator means **10** embodying the present invention for operating a valve mechanism **11**. Though a ball valve is illustrated, it will be apparent that the actuator means **10** can be used to control different valves or like controllable mechanisms.

The actuator means **10** is comprised of four basic parts—power supply **12**, a transducer **14**, fluid power amplifier **16** and actuator **18**. The power supply **12** comprises an electric motor **20** driving a pump within reservoir **22** for supplying fluid under pressure through conduits **24**, **25** and **26**, **27** to the fluid power actuator means **16** and to the actuator **18**. Fluid is returned to the reservoir **22** through conduit **28**. The novel actuator means of this invention utilizes a fluid power source supply at a constant flow rate. The advantages of such arrangement will become more apparent hereafter. Though a hydraulic power supply source is used in one presently preferred form of the invention, a pneumatic arrangement could be used in its place.

The transducer or input element **14** is, in the illustrated form of the invention, an electro-mechanical device, a torque motor. Such torque motor may be generally of the type shown and described in the copending application of Paul G. Borthwick, Ser. No. 479,935 filed Aug. 16, 1965, now Patent No. 3,334,641 granted Aug. 8, 1967, and assigned to the same assignees as the instant application. The torque motor provides the input signal to the amplifier **16**. A torque motor is preferred to a force motor because it is relatively insensitive to vibration and has a high gain as compared to a force motor. Though a torque motor is employed in a presently preferred actuator mechanism embodying the present invention, other input elements can be utilized.

The actuator **18** illustrated includes a cylinder **29** having a piston or ram reciprocable therein. A stem or rod is connected at one end to the piston and at the other end to the valve or like controllable mechanism.

Turning now to FIGS. 2 and 3, there is better illustrated the fluid power amplifier means or regenerative servo amplifier means of this invention. In the application shown in FIG. 2 (which corresponds to FIG. 1), the fluid power amplifier means **16** includes a pair of like amplifier devices **30**, whereas in FIG. 3, there is shown the basic amplifier device **30**. For clarity, the function of the amplifier of this invention will be described just by reference to FIG. 3 and then the operation of the device of FIG. 1, employing dual amplifier devices will be described by reference to FIG. 2. Since the basic amplifier device is the same in each case, the reference numerals used in FIG. 3 for the amplifier device will likewise be used in FIG. 2.

Essentially, the amplifier **30** is a two-stage device employing fluid supplied at a constant flow rate from constant flow rate pump **123**. The pump **123** is adapted to be driven from a suitable motor drive, for example, an electric motor **20**. The amplifier includes a first-stage nozzle **40** cooperating with a movable element **42** which con-

trols the discharge from nozzle 42. The movable element 42 may be a beam of a suitable transducer, for example, an electro-mechanical input element or torque motor. Nozzle 40 communicates with bellows or compressible member 44, which is compressed by bellows spring 46. Acting beneath bellows 44 is a second-stage nozzle 48. Pressure is supplied to nozzle 48 from pump 123 through conduit 124. At the same time the pressure is communicated to one side of the piston 119 to urge the piston or ram in one direction. The piston 119 is urged in the opposite direction by spring 121.

Bypass conduit 50 communicates nozzles 40 and 48. Provided in conduit 50 is a restriction 52 which is primarily responsible for the amplifier gain. The restriction 52 may be adjustable to obtain a desired amplifier gain or it may be a fixed restriction sized for optimum gain in a particular application.

Consider now the operation of the amplifier 30 of FIG. 3. The input signal to the amplifier is a change in the position of movable element 42. As element 42 moves toward nozzle 40, the pressure increases within bellows 44 and the bellows 44 moves toward nozzle 48, thereby increasing the pressure upstream of the nozzle 48. The loading pressure on piston 119 is increased, thus moving the piston and stem connected thereto downwardly as shown in FIG. 3 to reposition the controllable element secured to the piston stem or piston rod.

If element 42 moves away from nozzle 40, pressure is reduced in bellows 44. The change in pressure moves the bellows 44 away from nozzle 48, reducing the pressure above piston 119 in cylinder 118 and permitting spring 121 to bias the piston 119 upwardly as viewed in FIG. 3.

The term regenerative or positive feedback arises from the fact that an increase or decrease in the flow rate across the restriction 52 due to change in pressure at the second-stage contributes a positive flow feedback to the first-stage nozzle. An important advantage of this amplifier system is that the positive flow feedback compensates for the negative force feedback to the movable element 42 due to the first-stage nozzle area and its pressure. By proper selection of the first-stage and second-stage nozzle sizes, the restriction 52, the bellows and the operating pressure ranges of the first-stage and second-stage, it is possible to attain a high gain amplifier with the minimum staging for power amplification.

The actuator means 10 of FIGS. 1 and 2 includes a pair of identical regenerative servo amplifiers 30 operatively connected in push-pull fashion to the torque motor 14. Fluid under pressure is applied to the amplifiers 30 and to the opposite sides of piston 19 by a two-section positive displacement constant flow rate pump 123. Fluid (in the illustrated device, oil) is withdrawn from the reservoir through filter 56 and forwarded under pressure to the amplifiers 30 via lines or conduits 24, 26 and to the cylinder 29 via lines 25 and 27. The fluid is returned from the amplifier housing to the reservoir 22 via conduit 28.

The torque motor 14 is electrically connected to an input source of DC current. To the armature 15 of the torque motor are secured a pair of push rod elements 42 which cooperate in push-pull fashion with the first-stage nozzles 40 of amplifiers 30. The position of stem 31 is fed back to the torque motor 14 by means including cam track 60 secured to the stem 31, cam follower 61 and spring 78 to provide a force balance. With the high gain amplifier in the system, it is possible to obtain a high degree of static accuracy.

In operation, clockwise rotation of armature 15 will cause increase of pressure in the upper bellows 44 and decrease of pressure in the lower bellows 44. The upper bellows 44 moves towards its associated nozzle 48, increasing the pressure upstream thereof, thereby increasing the loading pressure above piston 19 within cylinder 29. At the same time, lower bellows 44 moves away from its associated nozzle 48, decreasing the pressure upstream thereof, thereby decreasing the loading pressure below the piston 19. The piston 19 moves downwardly, the piston rod 31 and cam track or cam member 60 carried thereon will be moved, resulting in feedback of the piston rod position to the torque motor 14 through follower 61 and spring 78.

It will be understood that counterclockwise rotation of the armature 15 in FIG. 2 will result in upward movement of piston 19.

The amplifier system of the present invention can easily be adapted for use with an electro-hydraulic transducer, instead of an electro-hydraulic actuator. For the general purpose electro-hydraulic input application, it is only required to have one side of the power amplification system of FIG. 2. The input to the electro-hydraulic transducer would be a standard DC current signal and the output would be a pressure signal. The pressure signal would be a loading pressure for an actuator. Such pressure would also be fed back to the armature of the torque motor through a bellows or diaphragm to provide a force balance. The actuator would include a piston urged in one direction by the loading pressure and spring biased in the opposite direction for fail close or valve open operation depending upon the requirement of the particular process system.

Referring to FIGS. 4 and 5, there is shown further detail of the torque motor 14 and regenerative servo amplifier 16. The housing for the torque motor and amplifier is comprised of two casing parts 70, 71 suitably machined and joined to one another, as, for example, by bolts 69, and a cover 72 detachably secured to casing part 71. The torque motor 14 is suitably affixed to the casing part 71.

The torque motor 14 includes an armature 15 having a bolt 74 adjustably secured thereto and abutting the input element 42 which cooperates with the first-stage nozzle 40 to control the discharge of fluid therefrom. A connecting beam 76 is affixed to the armature 15. Feedback tension spring 78 is disposed between connecting beam 76 and cam follower and feedback rod 61. The feedback spring 78 determines the travel or output stroke of the actuator ram or piston rod of the actuator. Cam follower 61 is maintained in operative engagement with cam 60 by cam spring 62.

Supply pressure from the constant flow source enters casing part 70 through inlet 80. The supply fluid passes from inlet 80 through internal passages 81 and 82 to the power nozzle or second stage nozzle 48. Adjustment means 89 are provided for adjusting the position of the nozzle 48 with respect to the bellows 44, so as to adjust second-stage nozzle pressure.

Conduit 50, which has a fixed restriction 52 secured therein, is defined by passages formed in casing parts 70 and 71 and communicates supply pressure from passage 82 to nozzle 40. Pressure is communicated from conduit 50 to the bellows 44 through passage 86.

The bellows 44 is biased in opposition to the pressure applied through passage 86 by bellows spring 46, which is operative between supports in casing part 70. Support 87 is fixed in casing part 70 and support 88 is affixed to the bellows 44 and movable therewith. The input element 42 for controlling discharge of fluid from the first-stage nozzle 40 is comprised of an input rod 90 which abuts bolt 74 at one end and carries a bolt 91 at the opposite end having a head which cooperates with the first-stage nozzle 40. Bolt 91 secures a diaphragm seal 92 to the end of the rod 90 for preventing fluid, in this case, oil, from entering the torque motor compartment. Seal 92 is retained adjacent its periphery by retaining ring 93. Pusher spring 94 urges the input rod 90 out from the casing part and biases the input rod 90 away from the nozzle 40.

Seal 96 is disposed in casing part 70 to seal between passage 50 and return passage 97 which communicates with the supply reservoir for returning hydraulic fluid

from the regenerative servo amplifier 16 to the reservoir. Suitable seals are also provided where necessary between the mating surfaces of casing parts 70 and 71.

There has been provided by the present invention a unique regenerative servo amplifier adaptable for use in a variety of actuator means. The basic amplifier is compatible to all conditions, provided that the nozzles and bellows are matched with respect to the flow rate of the constant flow rate pump. The amplifier is readily adapted to relatively large cylinders (on the order of six inches diameter), long stroke (on the order of eight inches) push-pull type systems and to low cost, spring-biased general purpose process actuators. Though a hydraulic amplifier construction has been shown, it will be appreciated by those skilled in the art that the principles of the novel amplifier will apply equally to a pneumatic amplifier.

One of the important advantages realized from the use of the present invention in a hydraulic actuator system, as compared to most general hydraulic actuator systems, is the low steady-state power consumption of the motor in the power supply. This is due to the fact that the operation of the present system depends on a constant flow rate, rather than a regulated, generally high supply pressure. Therefore, the power to the system is governed by the load demand. The steady-state power loss is kept at a minimum with relatively low steady-state first stage and second stage nozzle pressure.

While I have shown a presently preferred form of the invention, it will be understood that the invention is not limited thereto, since it may be otherwise embodied within the scope of the following claims.

I claim:

1. A fluid power amplifier including an input element, a first-stage nozzle, a second-stage nozzle, pressure responsive means communicating with said first nozzle, means for supplying fluid pressure to said second nozzle and conduit means having restriction means therein communicating said first nozzle with said second nozzle, the input element being movable to control the fluid flow from said first nozzle, the pressure responsive means being responsive to change in pressure at the first nozzle to control the fluid flow from the second nozzle, the change in pressure at the second nozzle effecting a positive feedback through said conduit means to the first nozzle.

2. A fluid power amplifier as in claim 1, wherein the supplying means includes a constant flow rate pump means.

3. A fluid power amplifier as in claim 1, wherein the pressure responsive means comprises bellows means and a spring for biasing the bellows means in opposition to the pressure force from the first nozzle applied to said bellows means.

4. A fluid power amplifier as in claim 3, wherein the bellows means is adjacent the outlet from the second nozzle and the input element is adjacent the outlet from said first nozzle.

5. In an electro-hydraulic actuator mechanism comprising an input element, a fluid power amplifier, a power source, and actuator means for moving a controllable element, the improvement characterized by said fluid power amplifier including a first-stage nozzle, and a second-stage nozzle, means for communicating fluid pressure from said power source to said second-stage nozzle, conduit means for communicating fluid pressure from said power source to said first stage nozzle, said conduit means having a restriction therein, pressure responsive means communicating with said first-stage nozzle operative to control fluid discharge from said second nozzle, said input element cooperating with said first-stage nozzle to control fluid discharge from said first-stage nozzle, the change in fluid pressure at the second-stage nozzle effecting a positive flow feedback through said conduit means to the first-stage nozzle.

6. An electro-hydraulic actuator mechanism as in claim 5, wherein the input element comprises a torque motor having an input rod operatively connected to the armature thereof for controlling the fluid discharge from the outlet of said first-stage nozzle.

7. An electro-hydraulic actuator mechanism as in claim 5, wherein the pressure responsive means in the fluid power amplifier includes a bellows communicated to the first stage nozzle, said bellows being expansible to restrict the fluid flow from the outlet of said second-stage nozzle, and spring means for biasing the bellows to operate within the designed travel range.

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U.S. Cl. X.R.

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