March 29, 1960 S. YANDO 2,930,360

SERVO MECHANISMS

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FIG. 1.

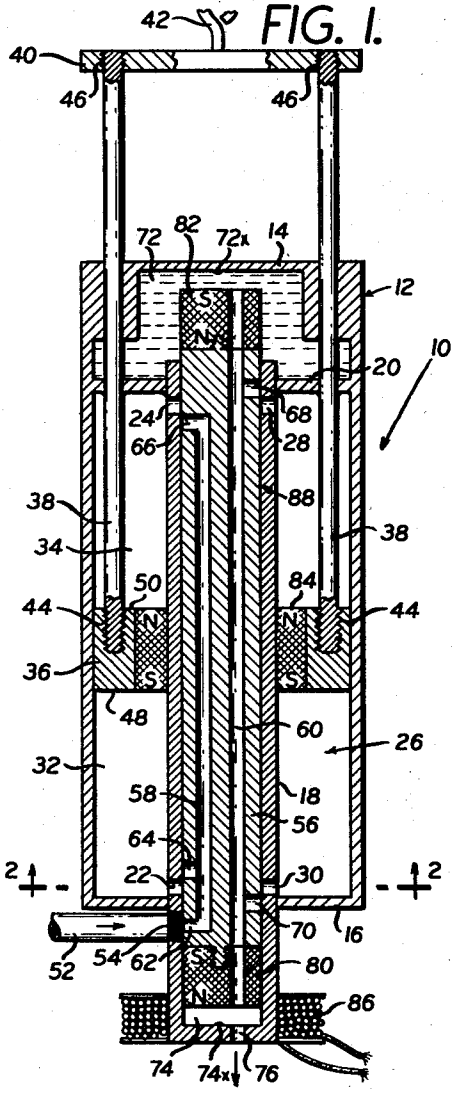


FIG. 2.

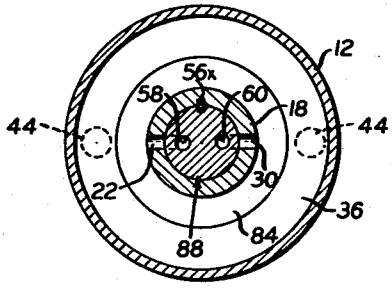


FIG. 3.

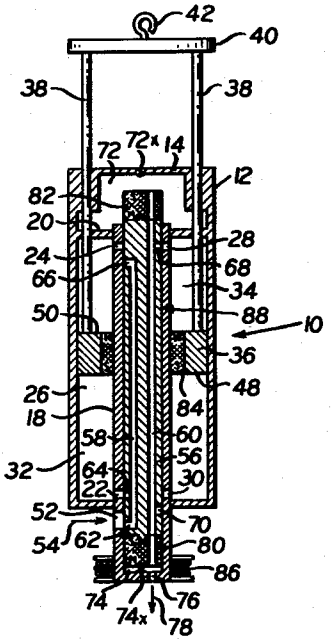
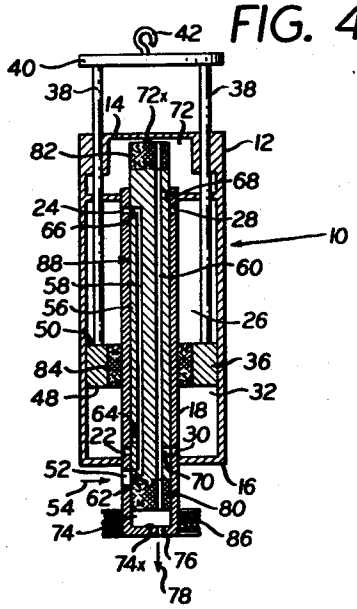


FIG. 4.



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FIG. 5.

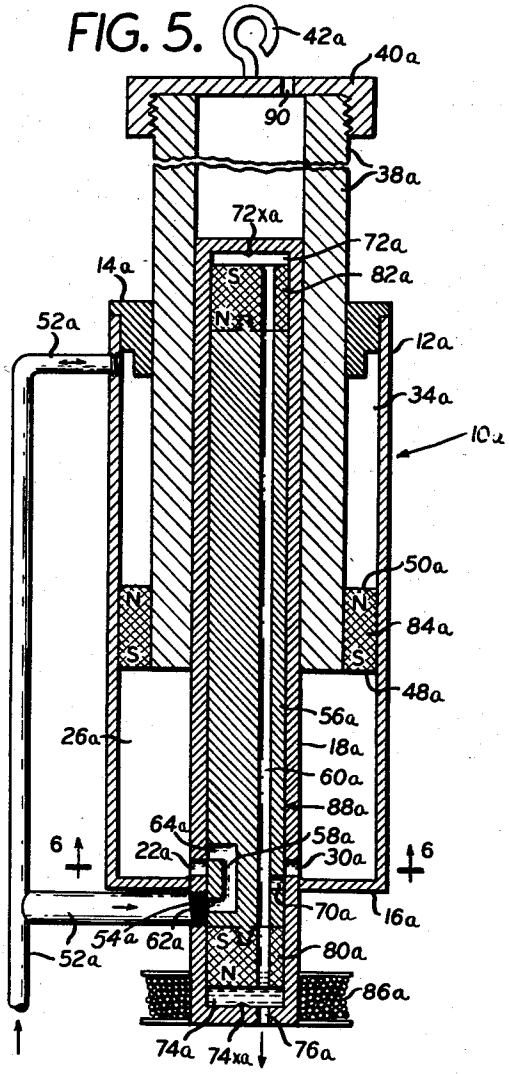


FIG. 6.

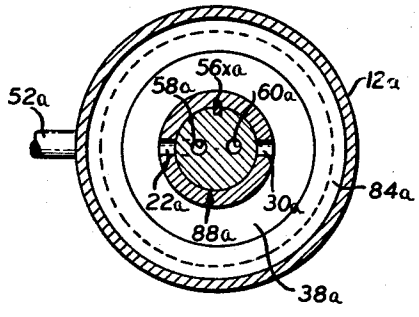


FIG. 7.

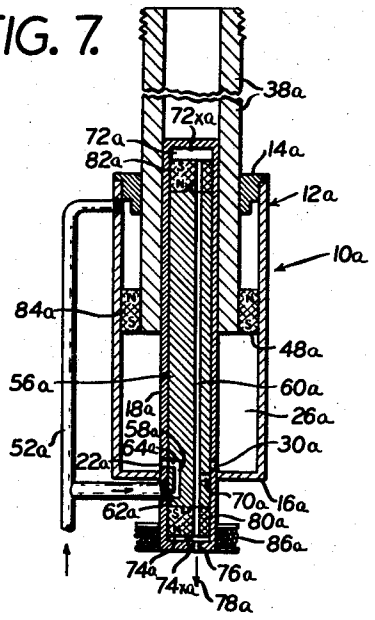
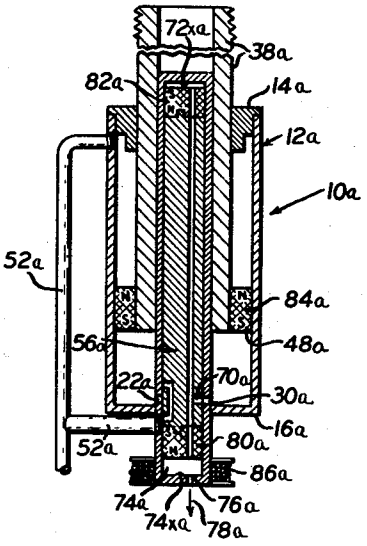


FIG. 8.



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United States Patent Office 2,930,360 Patented Mar. 29, 1960

2,930,360

SERVO MECHANISMS

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Application March 28, 1958, Serial No. 724,683

20 Claims. (Cl. 121—41)

This invention relates to servo mechanisms. Servo mechanisms are designed to make large forces and massive equipment sensitively and accurately responsive to light control forces. They have many valuable uses including, for example, power brake and power steering control in automobiles, the management of aircraft controls, and the programmed control of massive mechanisms in which a power output member is caused precisely and dependably to assume and strongly maintain a definite position for each different operated condition of a light and sensitive control member.

In the conventional electro-fluid form of servo-mechanism, an electromagnetic control member is commonly provided for a fluid valve unit. The valve unit controls the delivery of pressure fluid to a fluid actuator and the discharge of fluid from the actuator. The purpose is to cause a powerful and relatively massive output member, strongly driven by the fluid actuator in either of two opposite directions from a zero position, to assume a position uniquely characteristic of the measure and sense of the input control voltage supplied from a control station. The output member is accordingly arranged to control a feedback voltage unit in such a way that the feedback voltage is always opposite in sense to the input voltage and is caused to increase progressively in absolute value as the displacement of the output member from the zero position increases, until the feedback voltage cancels out the input voltage, causing the net voltage applied to the electromagnetic control member to be zero, and thereby causing the valve to be restored to the neutral condition in which fluid can neither enter nor leave the fluid actuator. An organization of this kind involves a number of distinct operating units of considerable aggregate weight and cost, each subject to its own infirmities, and a rather complex and elaborate circuitry.

It is the primary object of the present invention to provide a servo mechanism capable of performing the services outlined above in an improved way, which mechanism is reduced to a very simple electrical or other effective control means, together with a single composite unit comprising a control valve, a power actuator and an output member.

Important advantages of the invention reside in the reduction of cost due to simplicity of organization, parts and assembly, reduction of space required, lightness of construction adapting the mechanism to be airborne, ruggedness, dependability, precision of response, and stability under load.

It is an important object of the invention to provide a feedback system which acts, not to eliminate the application of the yielding control force to the valve when the desired position of the output member has been attained, but rather to develop automatically, as a function of the extent of displacement of the piston, a force which will balance the control force and return the valve to the neutral condition when the extent of output

operation characteristic of the applied control force has been attained.

It is a further important object of the invention to provide a valve balancing system, devoid of wiring and of electrical circuits, which is capable of automatically opposing a progressively increasing resistance to the control force, through the valve, as the displacement of the output member progresses, causing the control force to be balanced and the valve to be returned to, and stably maintained in, the neutral or non-operating relation by said balanced forces.

To these ends, and in accordance with a preferred illustrative embodiment of the invention, it is a feature that provision is made of a ported cylinder, a piston in the cylinder, a slide valve associated with the cylinder and normally occupying a neutral position relative to the ports so that fluid under pressure can neither enter nor leave the cylinder, magnetic means carried by the valve and by the piston and arranged to cause the valve normally to occupy a neutral position, and control means operable yieldingly to displace the valve, the construction and arrangement being such that the piston is caused to be operated in a direction opposite to that in which the valve has been displaced, and is effective magnetically to repel either end of the valve which it approaches with progressively increasing force until the net effect of the force exerted by the piston on the valve becomes equal to the yieldingly applied control force, returns the valve to neutral position over the resistance of said control force, and thereby establishes a stable condition of the output member, free from substantial hunting effects, with the output member in a definite position uniquely characteristic of the magnitude and direction of the control force acting on the valve.

It is not essential that the feedback means utilize permanent magnets, since electromagnets or other field producing means may be utilized. The number and arrangement of the field producing means may also be varied, as can the valve arrangement and various other features of construction. The mechanism may be contrived to cause the feedback forces to operate according to any desired law in relation to the extent of piston displacement. With permanent magnets, each magnet operates according to a square law, the repelling force increasing in inverse relation to the square of the distance between the piston carried and valve carried poles under consideration. This is advantageous because of the stability which the system is caused to have in various operated conditions.

Other objects and advantages will hereinafter appear.

In the drawing forming part of this specification,

Fig. 1 is a longitudinal section of an illustrative fluid servo device embodying features of the invention, the parts being shown in a neutral condition;

Fig. 2 is a transverse sectional view, taken on the line 2—2 of Fig. 1, looking in the direction of the arrows;

Fig. 3 is a reduced longitudinal section similar to Fig. 1 wherein a slide valve is shown in a position to establish fluid connections for driving the piston upward;

Fig. 4 is a view similar to Fig. 3 wherein the slide valve is shown in a position to establish connections for driving the piston downward;

Fig. 5 is a longitudinal section of another illustrative form of fluid servo device, embodying features of the invention, the parts being shown in a neutral condition;

Fig. 6 is a transverse sectional view taken along line 6—6 of Fig. 5, looking in the direction of the arrows;

Fig. 7 is a reduced section similar to Fig. 5 wherein the slide valve is shown in a position to establish fluid connections for driving the piston upward; and

Fig. 8 is a view similar to Fig. 7 wherein the slide valve

is shown in a position to establish fluid connections for driving the piston downward.

An illustrative electro-hydraulic servo device **10** embodying features of the invention is disclosed in Figs. 1 to 4, inclusive. The device **10** comprises an elongated housing **12**, shown as of cyclindrical configuration. The housing **12** is fluid-tight, being closed at its upper end by a wall **14** and at its lower end by a wall **16**. The lower end wall **16** is provided with an opening in which there is mounted an inner valve sleeve **18**. The valve sleeve **18** forms an integral part of the housing **12**, being secured thereto at its upper end through a radial wall **20**, and at its lower end through the wall **16**.

The valve sleeve **18** is provided with a plurality of inlet ports **22** and **24**, adjacent the walls **16** and **20**, respectively. The ports let into annular space **26** that is defined between the sleeve **18** and the outer wall of the housing **12**. Inlet port **22** provides for fluid entrance into the lower portion of the longitudinally extending fluid space **26**, while inlet port **24** serves as a fluid inlet at the upper end of the fluid space **26**.

To provide for the discharge of fluid longitudinally spaced fluid exhaust or outlet ports **28** and **30** are provided in the valve sleeve **18**, adjacent, respectively, to the walls **20** and **16**. The outlet port **28** permits the discharge of fluid from the upper portion of the longitudinal space **26**, while the lower outlet port **30** permits the discharge of fluid from the lower portion of the space **26**.

The annular fluid space **26** is provided into lower and upper working chambers **32** and **34** by the interposition of an output member in the form of a fluid actuated piston **36**. The piston **36**, which is the initial member of a power output mechanism, is suitably secured through slide rods **38** for transmitting motion of the piston to any external output member such as a crossbar **40** and an eye member **42** which is unitary therewith. Although, in the instant embodiment, members **38** are shown in the form of rods threaded at their lower ends **44** to the piston **36** and at their upper ends **46** to the crossbar **40**, it will be understood that they may take any other convenient and practical shape.

The piston **36** is selectively moved in the working space **26** of the cylinder by the introduction of fluid under pressure to either one of the chambers **32**, **34** and the simultaneous discharge of fluid from the other of said chambers. For this reason, a conduit **52** is provided as a means for supplying fluid under pressure from any suitable external source of energy such as a hydraulic pump (not shown) to the interior of the sleeve **18** through an opening **54**, the opening **54** being formed in an end portion of the valve sleeve **18** which projects beyond the lower end **16** of the housing **12**. The fluid under pressure is transmitted selectively either to chamber **32** or to chamber **34** by a slide valve **56**.

The slide valve **56** has a snug but free sliding fit in the valve sleeve **18**. A spline **56***x* is provided which prevents rotation of the slide valve **56** but does not restrain the desired sliding motion. It is provided with inlet and exhaust passages **58** and **60**. The inlet passage **58** has an entrance port **62** that is in constant communication with the inlet aperture **54** and the pressure fluid supply means or conduit **52**. The pressure fluid is therefore in constant communication with the inlet passage **58**. The passage **58** is provided with a fluid port **64** for alignment with the inlet port **22** of the valve sleeve **18**, and with a fluid port **66** for alignment with the inlet port **24** of the sleeve **18**, so that fluid under pressure may be selectively transmitted to the chamber **32** or the chamber **34** under the control of the slide valve **56**. Normally, however, the valve occupies a neutral position like that shown in Fig. 1, in which the passage **58** communicates neither with the port **22** nor with the port **24**.

The discharge passage **60** of the slide valve **56** is provided with side passages or ports **68** and **70** for cooperating, respectively, with the discharge ports **28** and **30**. In the neutral relation of Fig. 1, however, the passage **60** is not in communication with either the port **28** or the port **30**.

It is to be noted that unlike the inlet passage means **58**, the exhaust passage **60** extends the complete length of a comparator **88** (to be more fully described and explained presently) of which the valve **56** forms a part, opening at its upper end into a fluid receiving pressure equalization chamber **72** defined in the upper end of the housing **12** between the end wall **14** and the impermeable transverse wall **20** thereof. The lower end of exhaust passage **60** opens into a fluid pressure equalization chamber **74** defined in the projecting end of the sleeve **18**. Stops **72***x* and **74***x* are provided at the ends of the chambers **72** and **74**, respectively, for keeping the passage **60** in free communication with the chambers and for limiting the stroke of the valve **56**. An outlet opening **76** is provided in the projecting end of the sleeve **18** to permit the discharge of fluid in the direction of the arrow **78** from the device **10** to a receiving or recirculating chamber, not shown. Valve means, not shown, may be provided in a discharge line (not shown) for assuring the presence of fluid under predetermined limited pressure at all times in the passage **60** and in both the chambers **72** and **74**.

The position of the piston **36** and its related output member **40** is precisely determined and maintained by the unique comparator **88** which serves as a novel feedback means. The comparator **88** comprises the slide valve **56** and a plurality of field responsive members, illustratively shown as permanent bar magnets. These include bar magnets **80** and **82** fixedly carried and mechanically joined by the slide valve **56** beyond the opposite ends of the range of piston travel. The magnets **80** and **82** are, themselves, field producing, but since the comparator with its magnets **80** and **82** is designed to yield to magnetic and electromagnetic forces, the magnets **80** and **82** are referred to as field responsive. A further bar magnet **84**, fixedly secured upon the piston **36**, constitutes a further field producing means and serves as one input to the comparator, the other input being an arbitrarily produced displacing force yieldingly applied to the comparator as will be more fully explained. The magnets **80**, **82** and **84** all have their axes disposed parallel to the axis of cylinder **32**. The magnets **80** and **82** both have their north poles disposed in one direction and their south poles disposed in the opposite direction, but the arrangement of the magnet **84** is the reverse of that of the magnets **80** and **82**.

In the absence of other forces acting on the comparator **88**, this magnetic polar relationship causes the slide valve **56** to assume the neutral relation of Fig. 1 when the piston is in its median or zero position, as shown in Fig. 1.

Selective controlled operation and displacement of the piston **36** away from the zero output position is produced by applying an extraneously produced, yielding displacing force to the comparator **88** through a displacing force applying means. The displacing force may be applied mechanically or in any other suitable manner. As illustrated an electromagnetic coil **86**, adapted to be energized selectively by current flow of any selected value and in either direction desired, is fixed on the protruding end of the sleeve **18** in position to have the magnet **80** received within it to a greater or lesser degree. Displacement of the valve **56** from neutral is effected in one direction by the flow of current in one direction through the coil **86** and in the opposite direction by the flow of current in the opposite direction through the coil **86**, the comparator being attracted by the action of the coil on the magnet **80** in one case and repelled by the action of the coil on the magnet **80** in the other.

Since the valve balancing forces exerted upon the comparator magnets **80** and **82** in the zero position of the

piston 36 are light forces, even a light yielding force applied to the valve 56, mechanically or through the coil 86, will suffice to disturb the balanced condition of the comparator and the neutral relation of the valve to the cylinder ports.

If the comparator 88 is yieldingly pulled downward, a condition like that of Fig. 3 will be produced in which inlet port 22 and outlet port 28 are rendered active by the valve 56. The piston will be displaced in an upward direction, causing the magnet 84 to approach the comparator magnet 82 and repel it with increasing force, and to separate from the comparator magnet 80 and repel the magnet 80 with diminishing force.

Since the net effect of magnet 84 on the comparator system will be the vector sum of these two forces, an increasing force tending to move the comparator, including the valve 56, in an upward direction toward the neutral position is developed. When this developed force becomes sufficient to balance the control force yieldingly applied to the comparator 88, as by the coil 86, the valve is restored to the normal, neutral relation of the valve to the ports of sleeve 18 illustrated in Fig. 1. If the pressure fluid employed is hydraulic fluid, and it preferably is for most purposes, the piston 36 will be positively locked in a precise, predetermined position which is characteristic of the control force yieldingly applied to, and maintained upon, the comparator 88 by the coil 86. With this kind of arrangement the position of the valve is stably maintained and this, in turn causes the position of the piston 36 to be stably maintained.

Should the downwardly acting control force be increased, the same valve ports, 22 and 28, will be uncovered and a further action like the one already described will be effected to carry the piston further upward and lock it in a new position characteristic of the increased control force.

A diminution of the downward control force applied to the valve 56, or reversal to an upward force applied to the valve will cause the valve to be moved upward to a condition like that shown in Fig. 4. This causes the inlet port 24 to be at least partially uncovered for admitting pressure fluid to chamber 34 for driving the piston 36 downward, and the discharge port 30 to be simultaneously uncovered at least part way for permitting escape of fluid from the chamber 32. The valve will again be closed and the piston locked, when the net force exerted on the comparator magnets is exactly equal in absolute value, but opposite in direction, to the control force yieldingly applied and maintained by the coil 86.

In practice it frequently happens that the device 10 is subjected to sudden stresses caused, for example, by change of speed or direction of the body on which the device is carried. Since these stresses are unavoidably applied to all parts of the servo mechanism, including the hydraulic fluid and the comparator 88, it is important that measures be taken to avoid displacement of the valve through inertia effects. To this end the average density of the comparator 88 is made equal or substantially equal to that of the hydraulic fluid. With this arrangement there will be no tendency for hydraulic fluid to flow between the chambers 72 and 74, and since the chambers 72 and 74 are filled with hydraulic fluid at all times, the comparator 88 is compelled to move in unison with, and not relative to, the fixed parts of the servo-mechanism such as the housing 12 and the sleeve 18. This equality of densities may be achieved by employing a hydraulic fluid of comparatively high density and a valve 56 which consists of magnesium or aluminum or an alloy of one or both of these metals, hollowed out to whatever extent may be necessary for achieving the stated purpose.

In Figs. 5 to 8, inclusive, another practical and advantageous illustrative form of servo-mechanism 10*a* embodying features of the invention is disclosed. The device 10*a* has many features in common with the device 10 of Figs. 1 to 4. It differs chiefly in the fact that the chambers at opposite sides of the piston differ substantially in their cross-sectional dimensions, that the chamber of smaller cross-section is constantly and freely in communication with the pressure fluid supplying means, and that the valve controls admission and discharge of fluid to and from the chamber of larger cross-section only. This arrangement is illustrative of the fact that control of a single cylinder chamber is sufficient to provide adequate and effective servo operation. The same end can be achieved in a variety of ways, as by the use of spring means opposed to the fluid pressure of the lower chamber.

Since the structure of Figs. 5 to 8 may be largely duplicative of the structure of Figs. 1 to 4, corresponding reference characters have been applied to corresponding parts with the subscript *a* added in each instance, and the description and explanation will be substantially confined to specific differences.

Instead of the slide rods 38 and the cross bar 40 of Figs. 1 to 4, a thick walled output sleeve 38*a* and a cap member, screwed thereon, are made unitary with the piston which, in this instance, constitutes in its entirety a bar magnet 84*a* of annular form. A hole 90 is provided in cap member 40*a* to avoid pressure and suction effects. The sleeve has the effect of reducing the cross-sectional area of the upper chamber 34*a* and the upper piston surface 50*a* very materially as compared with the cross sectional area of the lower chamber 26*a* and the lower piston face 48*a*, desirably to a ratio of substantially 1 to 2.

The conduit 52*a* is a branched conduit, one branch leading to port 54*a* and the other being connected to communicate freely with the chamber 34*a* at all times. The end wall 14*a* is thickened and circumferentially rabbeted, the reduced end extending below the adjacent inlet of conduit 52*a* to prevent cutting off of the port by the piston, while maintaining a clear passage between conduit 52*a* and the upper cylinder chamber 34*a*.

The sleeve 18*a* is extended at its upper end beyond the housing 12*a* and within the output sleeve 38*a*, being closed at its upper end to provide the pressure equalizing chamber 72*a*. The sleeve 18*a* includes ports 22*a* and 30*a* for admitting pressure fluid to the chamber 26*a* and discharging it therefrom, respectively, but no ports corresponding to the ports 24 and 28 of Figs. 1 to 4, are provided.

The comparator valve 56*a* includes an intake passage 58*a* having ports 62*a* and 64*a* for cooperating with the ports 54*a* and 22*a*. A discharge passage 60*a* extends through the comparator 88*a* from equalizing chamber 72*a* to equalizing chamber 74*a*, and has a port 70*a* for cooperating with discharge port 30*a*.

The action of the comparator magnets 80*a* and 82*a*, piston magnet 84*a*, and the coil 86*a* and their effects upon the valve 56*a* are as previously described. The hydraulic action, however, requires a word of explanation. When the valve is pulled downward from the position of Fig. 5 to a position like that of Fig. 7, pressure fluid is admitted to the chamber 26*a*. Since the force of the fluid pressure against the lower face of piston 84*a* is greater than that against the upper face of the piston, because of the difference of areas, the piston moves upward, forcing fluid in the upper chamber 34*a*, which is under the same pressure, back into the pressure supply conduit 52*a*. This action continues until the valve 56*a* has been restored to the neutral relation of Fig. 5 in the manner already explained in connection with Figs. 1 to 4.

Movement of the valve upward from the neutral position connects the chamber 26*a* through the port 30*a* with the outlet passage 60*a*, causing the pressure of the fluid in the chamber 26*a* to drop sharply. The pressure fluid from conduit 52*a* then flows into chamber 34*a*, forcing the piston downward, and driving the pressure fluid out

of chamber 26*a* until the comparator forces balance the control force, closing the valve and leaving the piston in a new position characteristic of the magnitude and direction of the control force maintained upon the valve.

While certain preferred embodiments of the invention have been illustrated and described in detail, it is to be understood that changes may be made therein and the invention embodied in other structures. It is not, therefore, the intention to limit the patent to the specific construction illustrated, but to cover the invention broadly in whatever form its principles may be utilized.

I claim:

1. A servo mechanism comprising, in combination, means supplying fluid under pressure, a ported, chambered housing, a fluid actuated piston in the housing, a slide valve normally maintained in a neutral relation to the housing ports but movable relative to the housing ports to control admission and discharge of fluid to and from at least one chamber of the housing, field producing means, causing fields to be established at opposite ends of the slide valve, field producing means carried by the piston and acting to apply a progressively increasing repelling force to either end of the slide valve toward which the piston is moved, and control means associated with the slide valve for yieldingly urging the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be fluid operated in the direction opposite to that in which the valve is displaced to a definite position uniquely characteristic of the direction and magnitude of the control force applied to the valve, and in which the valve is restored to the neutral relation through a counterbalancing of the control force.

2. A servo mechanism comprising, in combination, means supplying fluid under pressure, a ported cylinder, a fluid actuated piston in the cylinder, a slide valve normally maintained in a neutral relation to the cylinder ports but movable relative to the cylinder to control admission of fluid from said supplying means to the cylinder and discharge of fluid from the cylinder, field responsive means carried by the slide valve at opposite ends thereof, field producing means carried by the piston and acting to repel either end of the slide valve toward which the piston is moved, and control means associated with the slide valve and operable yieldingly to urge the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be fluid operated in the direction opposite to that in which the valve is displaced to a definite position uniquely characteristic of the direction and magnitude of the control force applied to the slide valve.

3. A servo mechanism comprising, in combination, means supplying fluid under pressure, a ported cylinder, a fluid actuated piston in the cylinder, a slide valve normally maintained in a neutral relation to the cylinder ports but movable relative to the cylinder to control admission and discharge of fluid to and from the cylinder, magnetic means carried by the slide valve at opposite ends thereof, magnetic means carried by the piston and acting to repel either end of the slide valve toward which the piston is moved, and electromagnetic means associated with the slide valve and energizable yieldingly to urge the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be fluid operated in a direction opposite of the valve displacement, to a definite position uniquely characteristic of the direction and magnitude of the control force applied to the slide valve.

4. A servo mechanism comprising, in combination, means supplying hydraulic fluid under pressure, a ported cylinder, a fluid actuated piston in the cylinder, a slide valve normally maintained in a neutral relation to the cylinder ports but movable relative to the cylinder to control admission and discharge of hydraulic fluid to and from one chamber, at least, of the cylinder, field producing means providing opposite polarities in confronting relation to the piston at opposite ends of the slide valve, field producing means carried by the piston and acting to exert a repelling force upon either end of the slide valve toward which the piston is moved, and control means associated with the slide valve for applying yielding force to urge the slide valve in either of two opposite direction from the neutral relation, the construction and arrangement being such that the piston will be hydraulically operated in a direction opposite to that in which the valve is displaced until the valve is compelled, against the resistance of said yielding force and while said force is still maintained, to reassume the normal relation to the cylinder ports, so that the piston will be caused to assume a definite position uniquely characteristic of the direction and magnitude of whatever control force may be applied to the slide valve.

5. A servo mechanism comprising, in combination, means supplying fluid under pressure, a cylinder, a fixed ported sleeve extending into the cylinder and throughout the major portion of the length thereof, a fluid actuated piston in the cylinder, a slide valve having a snug sliding fit within the sleeve and normally maintained in a neutral relation to the ports, but movable relative to the sleeve and cylinder to control admission and discharge of hydraulic fluid to and from the cylinder, field responsive means providing opposite poles in confronting relation to the piston at opposite ends of the slide valve, field producing means carried by the piston and acting to exert a progressively increasing repelling force upon either end of the slide valve toward which the piston is moved, and control means associated with the slide valve for yieldingly urging the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be fluid operated in a direction opposite to that in which the valve is displaced by the control force until the valve is compelled, against the resistance of said yielding control force and while said force is still maintained, to reassume the normal relation to the cylinder ports, so that the piston is caused to assume a definite position uniquely characteristic of the direction and magnitude of whatever control force, within the limits of the mechanism, may be applied to the slide valve.

6. A servo mechanism as set forth in claim 5 in which the slide valve has intake and discharge passages therein, and segregated chambers are provided in which opposite ends of the slide valve play, the discharge passage of the valve being extended completely through the valve from end to end thereof in free communication with both chambers, whereby suction effects tending to interfere with the free and intended operation of the valve are avoided.

7. A servo mechanism as set forth in claim 6 in which the fluid is hydraulic and the hydraulic fluid and the slide valve are of equal density, whereby the slide valve is rendered immune to acceleration effects acting on the mechanism as a whole.

8. A servo mechanism as set forth in claim 5 wherein the field responsive and field producing means referred to consists of permanent magnets carried, respectively, by the opposite ends of the slide valve and by the piston, the valve carried magnets having like poles disposed in the same direction lengthwise of the valve, and the piston carried magnet having its poles reversely disposed.

9. A servo mechanism as set forth in claim 5 in which the sleeve and the slide valve extend beyond the cylinder at one end, and in which the control means comprises a coil surrounding a protruding portion of the sleeve and adapted to be variably energized by current flow of varied strength in either direction.

10. A servo mechanism as set forth in claim 5 in which the fluid is hydraulic and sufficient clearance is provided between the sleeve and the slide valve to cause

a thin film of hydraulic fluid to be maintained continuously between the sleeve and the valve for lubricating purposes.

11. A servo mechanism comprising, in combination, means supplying hydraulic fluid under pressure, a cylinder, a fixed ported sleeve extending into the cylinder and throughout the major portion of the length thereof, a fluid actuated piston dividing the cylinder into two opposed working chambers, a slide valve having intake and discharge passages therein, and having a snug sliding fit within the sleeve and normally maintained in a neutral relation to the ports, but movable relative to the sleeve and cylinder selectively to effect admission of hydraulic fluid to either chamber and simultaneous discharge thereof from the other, field responsive means providing opposite poles in confronting relation to the piston at opposite ends of the slide valve, field producing means carried by the piston and acting to exert a progressively increasing repelling force upon either end of the slide valve toward which the piston is moved, and control means associated with the slide valve for yieldingly urging the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be hydraulically operated in a direction opposite to that in which the valve is displaced by the control force until the valve is compelled, against the resistance of said yielding control force and while said force is still maintained, to reassume the normal relation to the cylinder ports, so that the piston will be caused to assume a definite position uniquely characteristic of the direction and magnitude of whatever control force within the limits of the mechanism, may be applied to the slide valve.

12. A servo mechanism comprising, in combination, means supplying fluid under pressure, a cylinder, a fixed ported sleeve extending into the cylinder and throughout the major portion of the length thereof, a fluid actuated piston dividing the cylinder into opposed working chambers, output means of substantial cross-section connected to the piston and extending through an end of the cylinder, said output means having the effect of cutting down the working area of the piston in said chamber by a substantial amount as compared with the working area of the piston in the other chamber, said supplying means being directly and freely connected at all times with said one chamber, a slide valve having a snug sliding fit within the sleeve and normally maintained in a neutral relation to the ports, but movable relative to the sleeve and cylinder to control admission and discharge of fluid to and from said other chamber, field responsive means providing opposite poles in confronting relation to the piston at opposite ends of the slide valve, field producing means carried by the piston and acting to exert a progressively increasing repelling force upon either end of the slide valve toward which the piston is moved, and control means associated with the slide valve for yieldingly urging the slide valve in either of two opposite directions from the neutral relation, the construction and arrangement being such that the piston will be fluid operated in a direction opposite to that in which the valve is displaced by the control force until the valve is compelled, against the resistance of said yielding control force and while said force is still maintained, to reassume the normal relation to the cylinder ports, so that the piston will be caused to assume a definite position uniquely characteristic of the direction and magnitude of whatever control force, within the limits of the mechanism, may be applied to the slide valve.

13. A servo mechanism as set forth in claim 12 in which the working area of the piston in said one chamber is substantially one-half the working area of the piston in said other chamber.

14. A hydraulic servo mechanism comprising, in combination, an outer housing, a hollow sleeve in said housing radially spaced therefrom, a piston longitudinally movable in said radial space in response to fluid pressure acting thereon, a slide valve movable longitudinally in said sleeve, said slide valve having passages adapted respectively to admit and exhaust fluid under pressure, fluid ports in said sleeve communicable with the respective valve passages to admit and exhaust fluid under pressure to and from said radial space, field responsive means on said valve and field producing means on the piston cooperating normally to cause said valve to close the fluid communication between said valve and sleeve, and yieldable control means associated with said valve for yieldingly moving the valve in either of two opposite directions from the normal, communication closing position, the construction and arrangement being such that the piston will be hydraulically operated in the direction opposite to that in which the valve is displaced, to a definite stable position uniquely characteristic of the direction and magnitude of the control force applied to the slide valve.

15. A hydraulic servo device comprising a source of fluid under pressure, inner and outer longitudinally extending radially spaced members, a piston operable longitudinally in said radial space in response to the fluid pressure acting thereon, valve means movable in said inner member to communicate fluid pressure to said piston, said piston including field producing means, a comparator including the valve as a unitary part thereof and providing longitudinally spaced fields at opposite sides of the piston and in constant cooperation with said piston field producing means, and yieldable control means operable to yieldingly displace said comparator in either of two opposite directions from the normal communication closing position, the construction and arrangement being such that the piston will be hydraulically operated in the direction opposite to that in which the valve is displaced, to a definite stable position uniquely characteristic of the direction and magnitude of the control force applied to the comparator.

16. A fluid operated servo mechanism comprising, in combination, means providing a supply of pressure fluid, a housing chamber, an output piston movable in said chamber in response to fluid pressure acting thereon, a valve movable to control communication between said housing chamber and said fluid supply means, force field producing means on said piston, comparator force field responsive means on said valve, said piston and valve force field producing and responsive means coacting with progressively increasing force as the piston approaches either end of the valve to move said valve to close said communication, and control means yieldingly operable to move the valve away from closing position over the opposition of the piston carried force field producing means and to maintain the valve open until, through movement of the piston, the valve closing effect of the piston carried force field producing means upon the comparator means is sufficiently increased to offset the yielding force exerted by the control means upon the comparator means.

17. A fluid operated servo mechanism comprising, in combination, an output piston controllably movable in either of two opposite directions in response to fluid pressure acting thereon, a housing in which the piston operates, supply means for fluid under pressure, valve means between said housing and said pressure fluid supply means operable to vary the communication therebetween and to control the direction of application of the fluid pressure on said piston, said piston having magnetic means, a comparator including the valve means and magnetic means predeterminately spaced on said valve means at opposite sides of the piston and cooperable with said piston magnetic means normally to move said valve to close said communication, and electromagnetic control means operable on said valve, and variably energizable to cause selective movement of said valve, the construction and arrangement being such that the piston is caused to

assume a position uniquely characteristic of the energization of the control means.

18. A hydraulic servo device comprising, in combination, a housing having a longitudinally extending working space therein, a piston movable in said space and dividing said space into two chambers, a pressure fluid supply means, valve means movable in one direction to admit pressure fluid from said supply means to one of said chambers, and in the opposite direction to discharge fluid from the same chamber, a comparator including the valve means and magnetic means on said valve means, said piston including magnetic means coacting with said comparator to bias said valve means toward closed position, yielding control means operable to shift the valve in one direction to admit pressure fluid to said one chamber and to shift the valve in the opposite direction to discharge fluid from said one chamber, the arrangement being such that the comparator means acts progressively to balance the force of the piston magnetic means against the control force and close the valve in response to piston movement, and means acting on the piston continuously to exert yielding force on the piston in the direction opposite that in which the piston is moved by the admission of pressure fluid to said one chamber.

19. A servo mechanism comprising, in combination, an output member possessing field producing means, a control member also possessing field producing means, the field producing means of the output member and of the control member being arranged to interact with one another, means for applying small displacing forces yieldingly in either of two opposite directions to the control member, and an external source of energy for applying operating power to the output member in response to displacement of the control member from a neutral position by said displacing force applying means, the construction and arrangement being such that with no displacing force applied to the control member the output member will be maintained in a normal or neutral position with the control member balanced by the field producing means in a neutral position, but that when the control member is displaced in either direction from neutral by the displacing force applying means, the output member will be operated powerfully in the direction

opposite to that in which the control member is displaced until the output member has been moved to a position characteristic of the magnitude and direction of the comparatively small displacing force applied to the control member, in which position the field producing means will have supplied a net feed-back force to the control member through the field producing means of the output member and the control member sufficient to counterbalance the applied displacing force, thereby to return the control member to its neutral position and arrest the output member.

20. A servo mechanism comprising, in combination, an output member possessing field producing means, a control member also possessing field producing means, the field producing means of the output member and of the control member being arranged to interact with one another, means for applying small displacing forces yieldingly to the control member, and an external source of energy for applying power to the output member in response to displacement of the control member by said displacing force applying means, the construction and arrangement being such that with no displacing force applied to the control member by the displacing force applying means the output member will be maintained in a normal position and the control member held in a normal condition, but that when the control member is displaced from its normal condition to an operating condition by the displacing force applying means, the output member will be operated powerfully in the opposite direction until the output member has been moved to a position characteristic of the magnitude of the comparatively small displacing force applied to the control member, in which position the field producing means will have supplied a net feed-back force to the control member sufficient to drive the control member against the resistance of the displacing force to a neutral position.

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