

[54] **PUSH-PULL LINEAR MOTOR**

[76] Inventor: **Samuel A. Gray**, 10201 Falun Dr.,
Sun Valley, Los Angeles, Calif.
91352

[22] Filed: **Aug. 14, 1972**

[21] Appl. No.: **280,405**

[52] U.S. Cl. **137/625.65, 251/129**

[51] Int. Cl. **F16k 11/02**

[58] Field of Search..... 137/625.65; 251/129,
251/132, 282; 335/259, 264

[56] **References Cited**

UNITED STATES PATENTS

3,538,954 11/1970 Fagerlie 137/625.65
3,570,806 3/1971 Sturman..... 251/129 X

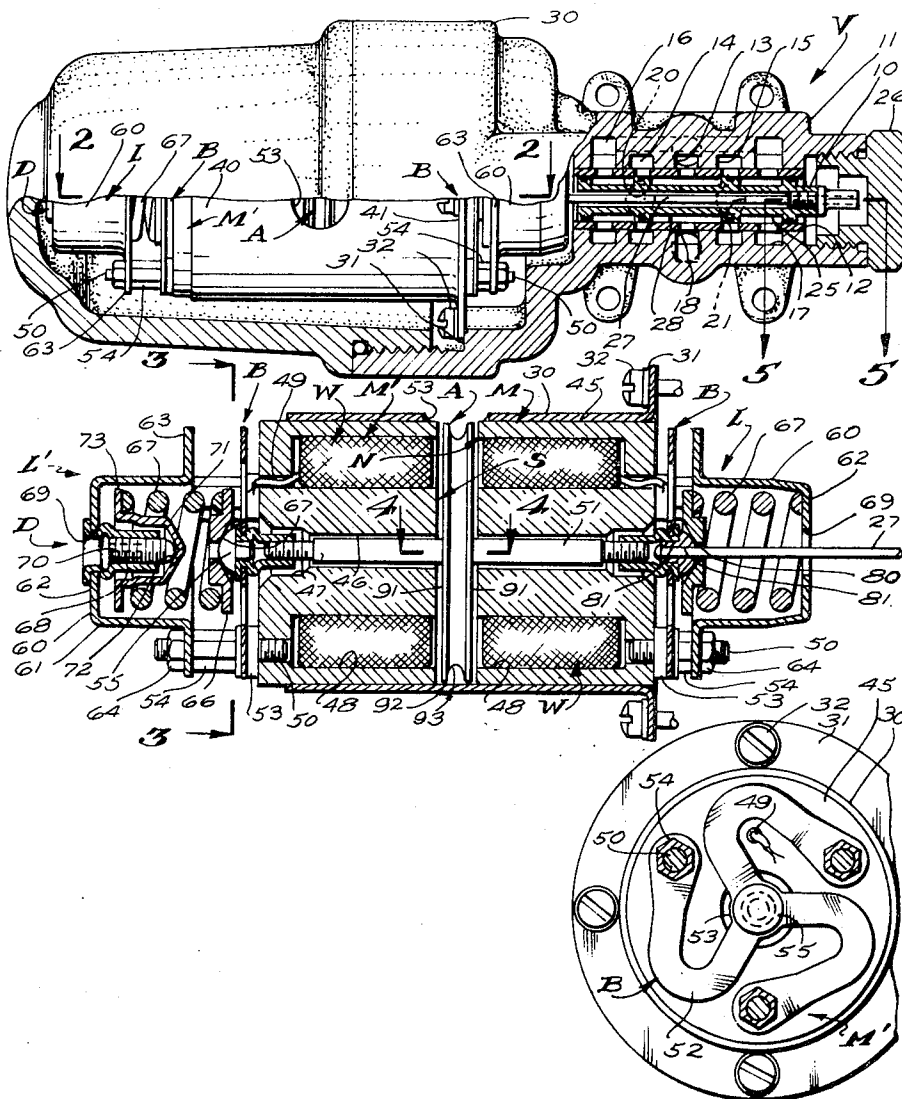
Primary Examiner—Henry T. Klinksiek
Assistant Examiner—Robert J. Miller
Attorney—Georges A. Maxwell

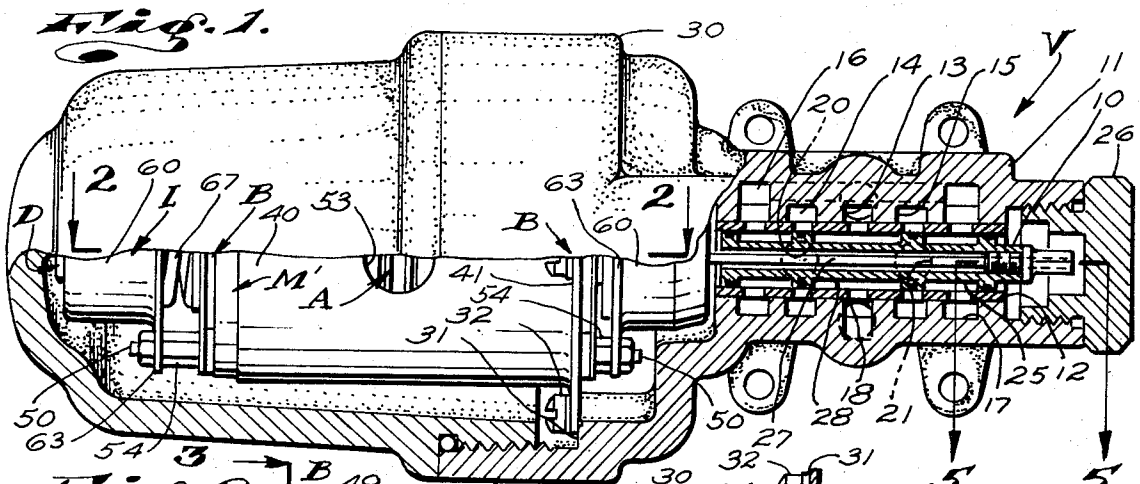
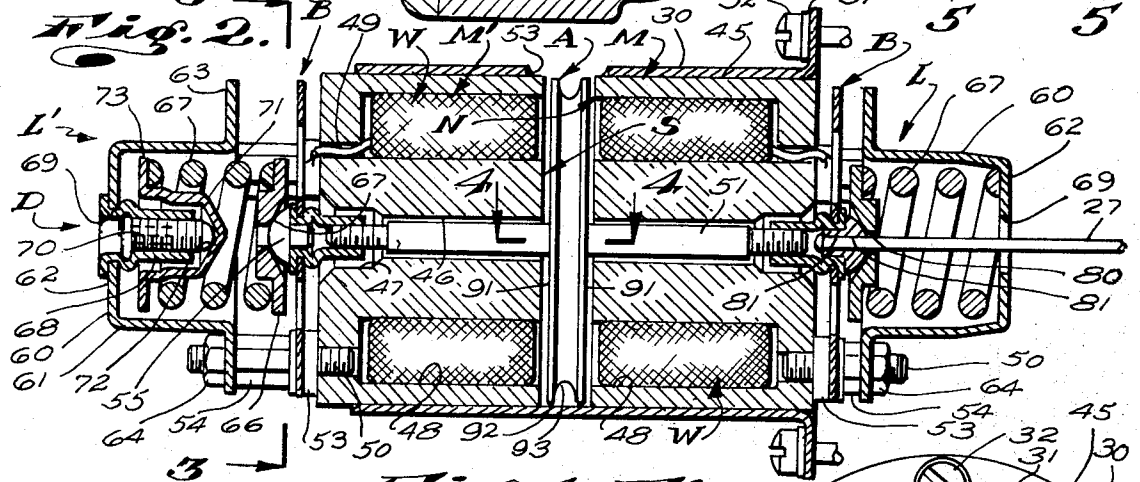
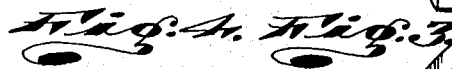
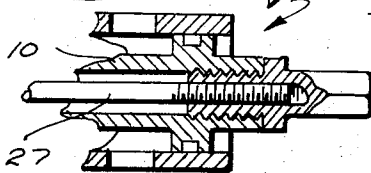
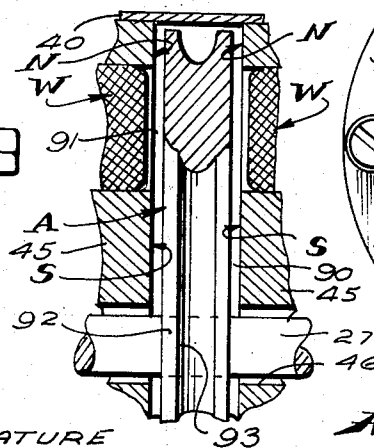
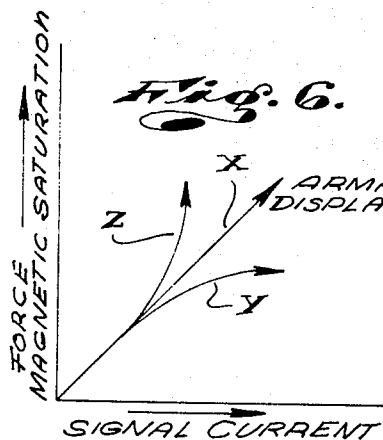
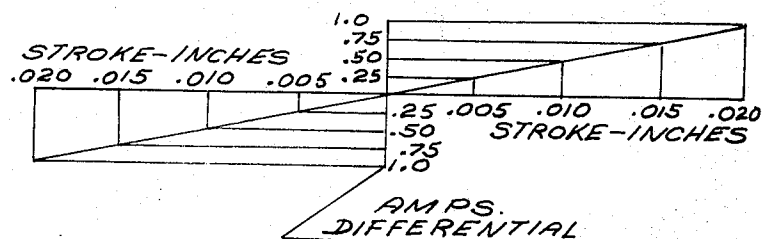
[57]

ABSTRACT

An electro-hydraulic servo valve means comprising a four-way spool-type valve and a push-pull type linear motor for operating an axially shiftable valve member, said motor comprising a single armature arranged between a pair of spaced, axially aligned, opposing, energized field coils whereby the armature is magnetically biased at all times and subject to instant response to changes in variations in the flux field of said coils created by differentials in signal currents to said fields; said armature having shaped magnetically saturable portions related to each coil whereby magnetic saturation is effected proportionately with respect to linear motion and current differentials; said motor including equal and oppositely disposed spring means at the opposite ends of the armature yieldingly maintaining the armature in a mean position between the coils.

10 Claims, 7 Drawing Figures





PUSH-PULL LINEAR MOTOR

This invention has to do with servo-mechanisms and is more particularly concerned with a novel electro-magnetically operated fluid valve for use in hydraulic control systems and the like.

Throughout the arts, hydraulic motors, actuators and like devices are widely used to move and/or effect the operation of related mechanical mechanisms and devices and to effect work which is to be performed. The operation of such hydraulic devices is effected by selected and controlled flow of fluid, under pressure, to and from said devices by suitable control valve structures.

While in some instances the control valve means for hydraulic devices can be manually operated, it is often necessary and required that such valve means be capable of being operated or controlled by means separate and oftentimes remote from the valve means. To make possible such operation of control valves, it is common practice to provide the valve structures with electrically operated drive means within closed servo loops. Such means have included solenoids, torque motors, moving coil motors and the like. Such electro mechanically controlled valve structures are commonly referred to and classified as electro-hydraulic servo valves.

The valve structures in most electro-hydraulic servo valves provided by the prior art are costly and complex structures and are such that in order to drive the valving means with those high forces required for accurate and dependable operation, hydraulic amplification is employed. Such amplification requires complicated and delicate structures such as electrical force motors driving flappers relative to nozzle means or such motors deflecting jet pipes relative to receivers.

One of the most common and widely used class of valve structures found in the art of electro-hydraulic servo mechanisms are four-way spool-type valves. Such spool-type valves have an elongate, axially shiftable spool-like valve member arranged in a cylindrical bore in a suitably chambered and ported fluid conducting body, with which the various fluid supply delivery and return lines are connected.

The electric drive means provided for the last noted class and type of valve is generally a push-pull type of electro mechanical drive means connected or coupled with the valve member.

One form of push-pull type of electro mechanical drive means provided to operate servo control valves of the character referred to above and in combination with suitable amplifying means comprises an elongate armature with one end coupled with the valve member and spring means normally yieldingly holding the armature and the valve member in a central, normal, closed position and a field coil, with a permanent magnet, polarizing core related to and about the armature. The field coil is adapted to receive control signal currents of one polarity or the other whereby a flux field is generated which moves the armature and the valve member axially, against the resistance of the spring means, as desired.

By varying the strength of the signal current, the force of the field is varied and the extent to which the armature and its related valve member is moved by the field against the resistance of the spring means, is varied to effect metering of the fluid flowing therethrough.

While the above form and/or class of push-pull type electro mechanical drive means or motors for servo valve mechanisms appears sound in principle and while it might be adequate and serviceable in some situations, they have been found to be wanting and inadequate where immediate or high response to control signals is required and where great accuracy in metering capability is demanded.

It is a general object and feature of the present invention to provide an electro-hydraulic servo valve means which requires no hydraulic amplification but which falls within that class of such valve means which can only employ and require the provision and use of hydraulic amplification means.

Another object of this invention is to provide an electro magnetically operated servo valve including a push-pull type linear motor drive means which exerts a high spool valve operating force on the order of 100 pounds and having a natural frequency of 500 Hertz to variations in the input signal to the motor without the required use or reliance upon hydraulic amplification.

It is a further object of my invention to provide a means or structure of the character referred to wherein movement of the motor armature and resulting movement of a relative valve member is substantially linear with respect to changes in an input signal throughout the full operating range of the means or structure.

It is an object and feature of my invention to provide a push-pull type linear motor for operating an axially shiftable valve member in which a single armature is arranged between a pair of spaced, axially aligned, opposing, energized field coils, whereby the armature is magnetically biased at all times and subject to instant response to changes in variations in the flux fields of said coils and a motor including opposing spring means at the opposite ends of the armature which serve to normally yieldingly urge and maintain the armature in a mean position between the field coils.

It is another object and feature of the present invention to provide a motor of the character referred to having an armature of novel configuration and design whereby portions thereof become magnetically saturated in uninterrupted progression as the armature moves toward one or the other of the field coils in response to increases and decreases in the magnetic fields generated, whereby the force exerted in and through the armature is substantially linear and the displacement or movement of the armature is likewise substantially linear.

It is an object and feature of the instant invention to provide a means and structure of the character referred to above which is easy and economical to manufacture, assemble and maintain, a structure and means which is rugged, durable and both highly effective and dependable in operation.

The foregoing and other objects and features of the present invention will be apparent and understood from the following detailed description of a typical preferred form and carrying out of the invention throughout which description reference is made to the accompanying drawings, in which:

FIG. 1 is a side view of my invention with portions broken away and shown in sections to illustrate certain details of the construction;

FIG. 2 is an enlarged detailed sectional view of a portion of the structure shown in FIG. 1 and taken as indicated by line 2—2 on FIG. 1;

FIG. 3 is a detailed view taken as indicated by line 3—3 on FIG. 2;

FIG. 4 is an enlarged detailed sectional view of a portion of the structure shown in FIG. 2;

FIG. 5 is an enlarged detailed sectional view taken substantially as indicated by line 5—5 on FIG. 1;

FIG. 6 is curves illustrating certain operating characteristics; and

FIG. 7 is a chart illustrating certain other operating characteristics.

Referring to FIG. 1 of the drawings, the servo valve structure provided includes a valve means V and drive means D for operating the valve means.

The valve means V is shown as a four way fluid metering spool type valve including an elongate, axially shiftable valving member 10 and the drive means D is a push-pull type electro-magnetic, linear motor structure adjacent to the valve means in axial alignment with the valve member 10 and coupled with one end of said valve member.

The valve means V, in addition to the valve member 10, includes an elongate body 11 with front and rear ends, a central longitudinal opening 12 with five axially spaced, annular, radially inwardly opening channels 13, 14, 15, 16 and 17 and four fluid conducting passages 18, 19, 20 and 21 communicating with certain of the channels and opening to the exterior of the body to connect with suitable fluid supply, bypass and delivery lines (not shown). The means V further includes an elongate tubular sleeve 22 extending longitudinally in the opening 11 in the body, closing the inner opening sides of the channels and having axially and circumferentially spaced, radial ports communicating with the channels and the interior of the sleeve. The valve member 10 is cylindrical and is slidably engaged in the sleeve 12.

The valve member 10 is provided with three radially outwardly opening annular grooves 23, 24 and 25 of considerable longitudinal extent and which serves to establish and close communication between the ports communicating between the interior of the sleeve and adjacent channels, upon axial shifting of the valve member in the sleeve.

The passage 18 is a fluid inlet passage communicating with the channel 13 which occurs centrally of the means V and is adapted to be communicated with a fluid supply line extending from a suitable source of fluid, under pressure. The passage 19 is a fluid outlet passage which communicates with the channel 13 and is connected with the channels 16 and 17, which occur at the opposite end portions of the body, by means of a longitudinal tunnel 26 in the body.

The ports in the sleeve communicating with the channels 13, 16 and 17 normally establish communication with the grooves 23, 24 and 25 in the valve member and so that the channels are filled with fluid at all times and in such a manner that the valve member is hydraulically balanced within the sleeve and is not subject to being urged axially therein by the fluid pressures to which it is subjected.

The channels 14 and 15 occur between the channels 13 and 24 and the channels 13 and 25, respectively, and the ports in the sleeve communicating therewith are normally closed by the portions of the valve member 10 at the opposite ends of the central groove 23 therein. The passages 20 and 21 communicate with the channels 14 and 15 and are adapted to connect with

fluid conducting lines extending to related fluid openings in a hydraulically operated motor, actuator or other device with which my construction is related to control the operation thereof.

Upon shifting the valve member 10 forwardly, to the right in FIG. 1 of the drawings, the port to the channel 15 is open to the groove 23 and fluid is therefor conducted through the passage 21 and to the related hydraulic device. The port to channel 18 is open to groove 24 and fluid from the device is free to flow back into the valve, through the groove 24, channel 16 and out through the passage 13. It will be apparent that upon shifting of the valve member rearwardly from its normal or closed position, as shown, a reversed flow pattern from that which is described above is effected.

It is to be noted and it is important to understand that metering and controlling the volume of fluid conducted to and from the device with which the valve means is related is effected by controlling the extent of axial movement of the valve member and the extent to which the ports communicating with the channels 14 and 15 are opened.

The valve structure described above is a typical four-way fluid metering spool type valve structure and its construction and mode of operation is well known to those skilled in the art.

In the case illustrated, the front end of the valve body is closed by a cap 26 screw threaded into a socket opening in that end of the body and so that free access to the interior of the body and to the valve member, for purposes of assembly, service and/or adjustment can be readily had.

In the form of the invention illustrated, the valve member 10 has a central, longitudinal bore to freely accommodate an operating rod 27 extending from the drive means D. The front end of the rod is coupled with the front end of the member 10 in axial driving relationship by means of a coupler 28 threaded into the front end of the bore in the member 10 and into and through which the front end of the rod is threaded. The coupler 28 is accessible in the socket in the front end of the body and is so arranged that coupling of the member and rod and axial adjustment thereof can be easily made. The body can, as shown, be provided with suitable mounting means, such as apertured flanges through which mounting screw fasteners can be engaged.

The rear end of the body 11 is provided with an enlarged, rearwardly opening bell-shaped housing portion 30 with an annular, rearwardly disposed mounting shoulder 31 to accommodate a portion of the means D and in which the means D is secured or mounted. The rear end of the housing portion 30 is internally threaded as at 32 and the forward end of an elongate, forwardly opening cup-like closure 33 is engaged therein. The closure 33 freely surrounds and protects that portion of the means D which projects rearwardly from the portion 30 of the body 11, as clearly illustrated in the drawings.

The drive means D, as noted above, is a push-pull type electro-magnetic, linear motor structure.

The means D, while particularly designed and constructed for operating the valve means V here provided, or a valve means of similar nature, it is such that it can be advantageously used or employed in many other situations and to operate other means or devices

where push-pull type prime mover or drive means are required.

In the form of the invention illustrated, the means D includes an elongate, cylindrical, tubular support barrel 40 with front and rear open ends and having a radially outwardly projecting mounting flange 41 at its front end. The flange 41 engages and stops against the shoulder 31 in the bell portion 30 of the body 11 and is secured thereto by fasteners 32.

The barrel 40 supports and carries a pair of like, oppositely disposed electro magnet units, there being a front unit M and a rear unit M'.

Each of the units M and M' include an elongate cylindrical core 45 in fixed position in an end portion of the barrel and having an outer end disposed axially outwardly from its related end portion of the barrel and a flat, radially extending, axially inwardly disposed inner end. Each core is further characterized by a central longitudinal bore 46 with an enlarged socket 47 opening at its outer end and an annular, axially inwardly opening coil recess 48 entering the inner end and defining inner and outer annular pole faces N and S at said inner end of the core.

The coil recess in each core has a cylindrical inner and outer walls and a flat bottom and cooperatively receives and holds a field winding W.

Suitable openings are provided in the outer end of each core to accommodate the leads or conductors for the winding W, as illustrated at 49.

In addition to the above, each core 45 is provided with a plurality (3) of circumferentially spaced threaded studs 50 projecting axially outwardly from the outer end of the core. The studs 50 are shown threadedly engaged in suitable openings provided in the core.

It is important to note that the wall thickness of the core occurring radially outward of the socket 45 is less than the wall thickness of the core occurring radially inward of the socket 45 whereby the cross-sectional areas of the core, radially inward and outward of the socket 45 are equal and the areas of the pole faces N and S are equal.

The structure provided next includes an elongate armature shaft 51 extending longitudinally and freely through the bores 46 in the cores of the units M and M' and bridging the space between said units.

The ends of the shaft 51 terminate in the socket openings 47 in the outer ends of the cores 45 and are threaded.

The shaft 51 carries an armature A intermediate its ends which armature is a flat, radially extending, disc-shaped part and projects radially, freely and in spaced relationship between the pole faces N and S of the units M and M'.

The special form and nature of the armature will be fully described and considered later in this disclosure.

The structure next includes axially shiftable support means B to support and maintain the shaft 51 and the armature A concentric in and with the units M and M'.

The means B includes two, like, support springs 52 coupled with the opposite ends of the shaft 51 and with the outer end of the units M and M' related thereto. The springs 52 have central hub portions 53 and a plurality (3) of circumferentially spaced, radially outwardly projecting, substantially U-shaped spring arms 54 with apertured terminal ends engaged on and about the studs 50 of their related units M and M', as clearly illustrated in FIGS. 2 and 3 of the drawings. The springs

52 are spaced from the cores of their related units M and M' by washers 53 and are secured in fixed relationship by holding units 54 on the studs outward of the springs.

The hub portions 53 of the springs 52 are provided with tubular axial tubes 54 which project axially inwardly into the sockets 47 in the cores 45 of the units M and M' and which threadedly receive and couple with the ends of the shaft 51 related thereto.

The threaded connections between the springs 52 and ends of the shaft 51 permit for axial shifting and adjusting of the shaft and the armature A thereon. Such axial adjustment can be effected by engaging and rotating the armature through an access opening 53 provided in the central portion of the sleeve 40, as shown in FIG. 1 and FIG. 2 of the drawings.

The springs 52 are flat, normally radially extending parts and are normally unbiased. When in their normal position, the central radial plane of the armature A on the shaft is midway between the opposing pole faces of the units M and M' and the opposite, flat, radially extending axially disposed surfaces of the armature A are in equal predetermined spaced relationship from said pole faces.

The axial parts of the springs are further provided with axially outwardly projecting bearings 55, in the nature of semi-spherical protuberances.

The structure next includes spring loading means L and L' at the front and rear ends of the means D which loading means are similar in nature and serve to exert equal and opposite, axially directed forces onto and through the armature shaft 51.

The means L', at the rear end of the means D, includes an axially inwardly opening cup 60 with a cylindrical side wall 61, a flat bottom 62 at its outer end and a radially outwardly projecting mounting flange 63 at its inner end. The flange is apertured to receive the outer end portions of the studs 50 on the unit M' and is secured in fixed relationship on or with the unit M' by lock nuts 64 on the studs 50, outward of the flange and holding the flange tight against the nuts 54 on the studs.

The means L' next includes a substantial disc-shaped radially extending spring seat 66 with a central bearing socket 67, axially outward of the spring 52 and in which the bearing 55 related to the rear end of the shaft 51 is seated.

The means L' next includes an elongate, axially extending helical compression load spring 67 within the cup with a front end seated on the seat 66 and axially adjustable setting means D carried by the bottom 62 of the cup and engaging the rear end of the spring 67. The means D includes an internally threaded tubular stem 68 fixed in a central opening 69 in the bottom 62 of the cup 60, an axially adjustable setting screw 70 in the stem 68, to project axially forwardly therefrom and a follower 71 engaged by the screw 70 and engaged with the rear end of the spring 67. The follower 71 is an elongate, rearwardly opening, cup-like part which extends axially into the spring 67 and occurs about the stem 60 and screw 70; has a conical bottom 72 at its front end in which the screw is seated and stopped and has a radially outwardly projecting seat flange 73 at its rear end engaged with the rear end of the spring 67.

With the means L' set forth above, it will be apparent that the extent to which the spring 67 is biased can be easily and conveniently adjusted.

The screw 70 is shown as an Allen screw engaged in the stem 68 and accessible from the open rear end of the stem.

The means L includes a cup 60, similar to the cup 60 of the means L', mounted and fixed relative to the front end of the unit M in the same manner that the cup 60 of the means L' is related to the means M', except that the nuts 54 related to the means L are shorter than the nuts 54 related to the means L'. The means L includes a spring seat 66 and a compression load spring 67 identical with the seat 66 and spring 67 of the means L'. In the means L, the means D provided in the means L' is not provided and the front end of the spring 67 sits directly on the bottom 62 of the cup 60.

With the means L and L' set forth above, it will be apparent that upon axial adjustment of the means D in the means L', the springs 67 of both the means L and L' are adjusted equally and at the same time.

In practice, the springs 67 of the means L and L' are compressed and biased or preset to an axial extent greater than the maximum axial movement of the armature A and rod 51 and act equally and oppositely at and upon the opposite ends of the rod 51 to normally yieldingly hold the rod 51 and the armature A in their normal central position, as shown in FIG. 2 of the drawings.

The load springs 67 are of considerable strength with respect to the mass of the rod 51 and armature A and are therefor such that the spring rate of said springs governs the operation of the construction as regards its natural frequency.

The operating rod 27 coupled with and extending rearwardly through the valve member 10 of the valve means V, projects rearwardly from the valve means V, through the opening 69 of the bottom 62 of the cup 60 by means L, extends through a central opening 80 provides in the spring seat 66, thence through a central opening 81 in the bearing 55 of the means L and to or with which it is fixed. In practice the rear end of the rod is threaded in the opening 81 and is fixed thereon as suitable stacking the rearmost threads thereof.

With the structure set forth above, it will be apparent that the means V and D are suitable coupled and housed to establish a neat, compact, easy and economical to make, assemble and maintain servo valve construction.

It will be further apparent that with and by means of the several axially shiftable threaded couplings and means provided, accurate adjustment of the springs and position of the armature and the valve member can be easily and conveniently made.

The armature A, as previously noted, is a flat radially extending disc-shaped body of magnetic material and is characterized by flat forwardly and rearwardly disposed end faces 90 and 91, which oppose the inner sides of the units M and M' and the pole surfaces N and S thereof, a cylindrical, radially outwardly disposed exterior surface 92 and a radially outwardly opening annular groove 93 in the surface 92. The central plane of the groove 93 is on the central plane of the armature and has axially and radially inwardly parabolically curved side surfaces which cooperate with their adjacent end portions of the armature to define peripheral edge portions of diminishing cross-section adjacent and about the outer portion of each surface 90 and 91. The edge portions of diminishing cross-section at and about the outer periphery of the surfaces 90 and 91 of the ar-

mature A are so formed that as the portion of the armature with which they are related is subjected to increased magnetic field forces, the edge portions become saturated from the exterior and radially inwardly at a predetermined rate.

In operation, the coils or windings W of the means M and M' are normally energized by equal, signal currents and so that the outer circumferential poles N of the, for example, units are north and the inner poles S are south. The lines of flux between the poles of the units M and M', in the air gap, are conducted, from north to south, through the half of the armature A which opposes the poles of those units and occurs at the opposite ends or sides of the central vertical plane of the armature. The quiescent currents are such that the armature material is magnetically biased, that is, it is magnetized to that extent that it will accommodate additional lines of flux freely and without the conducting of added or extra current to the field windings to effect magnetizing of the armature.

It is important to note that while the armature A is normally magnetically biased as set forth above, the motive effect on the magnetic fields of the units M and M' thereon is equalized one by the other and the armature remains in its central, normal position with the surfaces 90 and 91 thereof spaced equal distances from their opposing related poles of the units M and M'.

Upon an increase of current to the winding W of one unit, and a decrease of current to the other winding, the normal balance of the fields acting on and through the armature is upset and the armature is urged towards said one unit, away from the other unit.

As the armature A moves towards said one unit the saturable portion of the armature related to that unit, that is the peripheral portion of diminishing cross-section at the end of the armature adjacent that unit becomes progressively magnetically saturated in a predetermined ration between the force of the field of that unit and the diminishing distance between the armature and said one unit, and so that the effect of that field on and through the armature is to cause motion of the armature which is linear with respect to the differential of the input currents.

The armature A and the units M and M' are designed, balanced and related to each other so that the axial movement of the armature between the units M and M' is linear with the differential in currents supplied to the units M and M'.

With the drive means D provided, it will be apparent that the means D is energized and in full operating condition at all times and that the mechanical movement to be effected thereby, be it right or left of center, occurs instantly in direct linear response to differentials established in the currents to the field units M and M'.

In FIG. 6, line X indicates the linear displacement of my new armature with respect to differentials in signal current. Line Y indicates the nature of saturation of the armature A in response to current differentials and displacement of the armature. Line Z indicates the performance characteristics of an armature in the instant drive means which is not grooved or provided with the saturable portions here provided.

In the chart shown in FIG. 7 of the drawings, the performance characteristics of one embodiment of my new construction is illustrated. It is to be noted that the differentials in amperes is that differential which is brought about by current added and subtracted to the

normal quiescent currents to the units M and M' which quiescent currents can be whatever current is required to effect the desired magnetic biasing of the unit cores and those portions of the armature related thereto.

Having described only one typical preferred form and application of my invention, I do not wish to be limited or restricted to the specific details herein set forth, but wish to reserve to myself any modifications and/or variations that may appear to those skilled in the art to which this invention pertains.

Having described my invention, I claim:

1. A servo valve having an elongate valving member with front and rear ends and shiftable axially forwardly and rearwardly from a central normal position; drive means to shift the valve member forwardly and rearwardly to and from its central normal position comprising an elongate armature shaft with front and rear ends, coupling means connecting the front end of the shaft with the valving member, an armature with forwardly and rearwardly, axially outwardly disposed surfaces carried by the shaft between the ends thereof, front and rear electro magnet field units arranged forwardly and rearwardly of the armature, respectively, and having axially inwardly disposed north and south poles in normal predetermined spaced and opposing relationship with the front and rear surfaces of the armature related thereto, support means at the ends of the shaft and maintaining the shaft on a common axis and spring loading means at the opposite ends of the shaft biased to exert equal and opposing forces axially inwardly at the ends of the shaft and normally yieldingly holding the shaft with the armature in its normal position, said field units normally energized by quiescent currents and establishing equal and opposite magnetic fields intersecting the armature whereby the armature is normally magnetized and held in its normal position by the fields, said armature and shaft being shifted axially toward one field unit upon an increase of current thereto and a decrease of current to the other field unit, resulting in increase and decrease in the magnetic fields of the units acting on the armature, the armature having progressively magnetically saturable portions related to each surface thereof and to the field unit related thereto whereby the saturable portion of the armature to a field unit towards which it is moved saturates progressively with respect to its linear longitudinal movement and linear differentials in the currents to the field units.

2. A structure as set forth in claim 1 wherein the field units include elongate axially aligned, axially spaced cylindrical cores with central openings through which the shaft freely projects, flat axially inwardly opposing inner ends, annular, axially inwardly opening grooves opening at said inner ends and defining axially inwardly disposed radially spaced annular pole faces and field coils engaged in the grooves, said armature being a flat, radially extending disc-shaped part on the shaft extending freely between the inner end of the field units and having an outer cylindrical side with a radially outwardly opening shaped channel defining said magnetically saturable portions related to the surfaces at the opposite ends thereof, and means engaged with and between the cores to maintain the units in fixed relationship with each other.

3. A structure as set forth in claim 2 wherein said support means for the shaft includes axially yielding radially non-yielding spring units mounted in fixed spaced

position from axially outwardly disposed ends of the field units and means connecting each spring unit with an end of the shaft.

4. A structure as set forth in claim 3 wherein said spring loading means includes spring seats, bearing support means between the seats and the ends of the shaft, axially force exerting springs with inner and outer ends, said inner ends engaging the spring seats and spring stops engaging the outer ends of said springs.

5. A structure as set forth in claim 3 wherein said spring loading means includes spring seats, bearing support means between the seats and the ends of the shaft, elongate, axially extending helical compressing springs with inner ends engaging the spring seats and spring stops engaging the other outer ends of the compression springs, the spring stops related to one spring being in fixed position relative to the field units and the other spring stop having a part in fixed position relative to the field units, an axially moveable part and axially shiftable screw means between the parts whereby the moveable part can be moved axially to bias the springs.

6. A structure as set forth in claim 3 wherein the field units include elongate axially aligned, axially spaced cylindrical cores with central openings through which the shaft freely projects, flat axially inwardly opposing inner ends, annular, axially inwardly opening grooves opening at said inner ends and defining axially inwardly disposed radially spaced annular pole faces and field coils engaged in the grooves, said armature being flat, radially extending disc-shaped part on the shaft extending freely between the inner ends of the field units and having an outer cylindrical side with a radially outwardly opening shaped channel defining said magnetically saturable portions related to the surfaces at the opposite ends thereof, and means engaged with and between the cores to maintain the units in fixed relationship with each other and including an elongate barrel with open ends and in which the cores are engaged and held, said barrel having a mounting flange projecting therefrom to engage a related support structure.

7. A structure as set forth in claim 6 wherein said support means for the shaft includes axially yielding radially non-yielding spring units mounted in fixed spaced position from axially outwardly disposed ends of the field units and means connecting each spring unit with an end of the shaft.

8. A structure as set forth in claim 7 wherein said spring loading means includes spring seats, bearing support means between the seats and the ends of the shaft, elongate, axially extending helical compressing springs with inner ends engaging the spring seats and spring stops engaging the other outer ends of the compression springs, the spring stops related to one spring being in fixed position relative to the field units and the other spring stop having a part in fixed position relative to the field units, an axially moveable part and axially shiftable screw means between the parts whereby the moveable part can be moved axially to bias the spring.

9. A structure as set forth in claim 7 wherein said spring loading means includes spring seats, bearing support means between the seats and the ends of the shaft, elongate, axially extending helical compressing springs with inner ends engaging the spring seats and spring stops engaging the other outer ends of the compression springs, the spring stops relate to one spring being in fixed position relative to the field units and the other spring stop having a part in fixed position relative to the

11

field units, an axially moveable part and axially shift-
able screw means between the parts whereby the move-
able part can be moved axially to bias the springs, said
coupling means connecting the support springs to the
ends of the shaft including threaded portions on the
ends of the shaft and threaded parts carried by the
spring and engaged with said threaded portions
whereby the longitudinal position of the armature can
be adjusted by rotating the armature and shaft to ad-
vance the threaded portions in the threaded parts.

10. A structure as set forth in claim 7 wherein said
spring loading means includes spring seats, bearing sup-
port means between the seats and the ends of the shaft,
elongate, axially extending helical compressing springs
with inner ends engaging the spring seats and spring
stops engaging the other outer ends of the compression

12

springs, the spring stops related to one spring being in
fixed position relative to the field units and the other
spring stop having a part in fixed position relative to the
field units, an axially moveable part and axially shift-
able screw means between the parts whereby the move-
able part can be moved axially to bias the springs, said
coupling means connecting the support springs to the
ends of the shaft including threaded portions on the
ends of the shaft and threaded parts carried by the
spring and engaged with said threaded portions
whereby the longitudinal position of the armature can
be adjusted by rotating the armature and shaft to ad-
vance the threaded portions in the threaded parts, said
barrel having an access opening for engaging the arma-
ture to rotate said armature and shaft.

* * * * *

20

25

30

35

40

45

50

55

60

65