(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 198 635**
A2

(12) # EUROPEAN PATENT APPLICATION

(21) Application number: **86302507.8**

(51) Int. Cl.[4]: **F16K 31/06** , F15B 13/043

(22) Date of filing: **04.04.86**

(30) Priority: **04.04.85 GB 8508803**

(43) Date of publication of application:
22.10.86 Bulletin 86/43

(84) Designated Contracting States:
DE FR GB IT

(71) Applicant: **FAIREY HYDRAULICS LIMITED**
Cranford Lane Heston Hounslow
Middlesex, TW5 9NQ(GB)

(72) Inventor: **Smith, John Denis**
37, Spindlebery Grove Bramblewood Gate
Nailsea Bristol, BS19 1QF(GB)
Inventor: **Davis, Peter James**
43 Wemberham Crescent
Yatton Avon, BS19 4BD(GB)

(74) Representative: **Ashmead, Richard John et al**
KILBURN & STRODE 30 John Street
London, WC1N 2DD(GB)

(54) **Fluid valves.**

(57) An electrohydraulic servo valve (10) comprises a pair of electric motors (11) mounted on the body - (13) of a linear hydraulic spool valve (12) and driving a common motor shaft (77) whose rotation is transmitted directly to the valve spool (20) by a pivoted lever (90), one end of which is engaged in a cross-bore (89) in the motor shaft (77) and the other end of which is engaged in a cross-bore (30) in the valve spool (20). The lever (90) is pivotally suspended by two integral rectangular-section thin steel strips projecting at right angle from opposite sides of the lever and secured by screwed-down integral mounting blocks (107) at their outer ends. The strips are arranged with their widths transverse to the length of the lever (90), and twist resiliently about their lengths as the lever pivots about a pivotal axis (92) coincident with the lengths of the strips (105,106) providing a frictionless pivotal suspension for the lever with a resilient centering action.

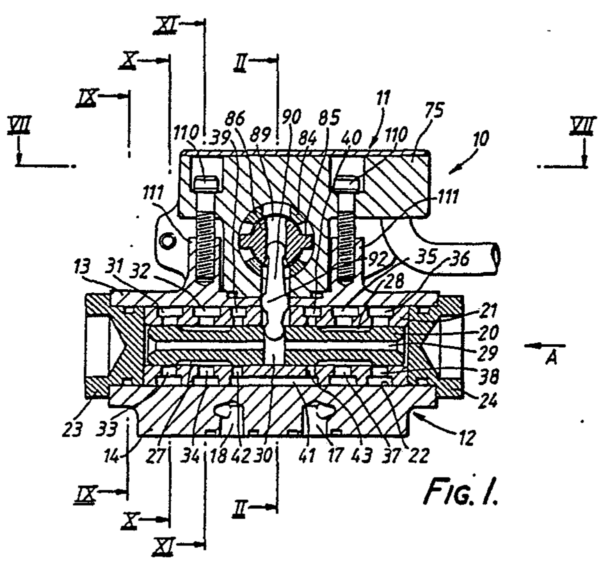

FIG. 1.

EP 0 198 635 A2

FLUID VALVES

This invention relates to fluid valves, and is particularly although not exclusively applicable to electrohydraulic servo valves, for example of the linearly-movable spool type.

In its broadest concept, the present invention comprises means whereby the drive of an actuating means for a fluid valve is transmitted to the movable valve member directly through a pivoted lever for valve operation, in which the pivoting of the lever is by distortion, of its suspension or other support, for example resiliently by flexure, or by twisting.

It is known, in an electrohydraulic servo valve, to transmit the drive of the electric actuator motor to the movable valve member directly through a pivoted lever whose pivotal movement by the motor thus operates the valve.

In such known arrangements a pivot bearing for the lever is provided, which requires some form of spring means for centering the lever and the movable valve member in valve-closed position.

According to the present invention from another aspect, in a fluid valve (for example although not necessarily an electrohydraulic servo valve of spool type) which comprises a ported valve housing, a movable valve member, actuating means for the valve, and a pivotally supported lever for transmitting movement of the actuating means directly to the movable valve member for causing movement of the valve member relative to the ported housing so as to alter the valve porting, the pivoting of the lever is by distortion of its suspension or other support.

For example the suspension or other support may be distorted resiliently e.g. by twisting, from a datum condition.

This arrangement has the advantage that the centering bias for the lever is contributed directly by its pivotal suspension or support, obviating the need for additional spring means. Moreover the pivoting action is frictionless and free of hysteresis on account of the resilient or elastic distortion of the suspension or support.

From yet another aspect, the present invention comprises a hydraulic spool valve including a ported valve housing, a valve spool slidably movable in the housing to control the valve porting, actuating means for the valve, and a pivotally-supported lever which by pivoting about its suspension or other support transmits the drive of the actuating means directly to the valve spool to move the spool in the housing for valve operation, in which the pivoting of the lever is by distortion of its suspension or support.

From yet another aspect, the present invention comprises an electrohydraulic servo valve including a ported valve housing, a movable valve spool slidable in the housing to control the valve porting, electric motor actuating means mounted on the valve housing, and a pivotally-supported lever which by pivoting about its suspension or other support transmits the drive of the output member of the electric motor directly to the valve spool to move the spool in the housing for valve operation, and in which the pivoting of the lever is by distortion of its suspension or support.

In one form of the invention, from any of the last three aspects referred to, the lever may be pivotally supported by elongate torsion spring means arranged to yield resiliently by twisting about its length as the lever pivots. For example, the lever may be suspended by thin strip spring means extending transversely to the length of the lever and arranged to yield resiliently by twisting about its length as the lever pivots.

Thus in a preferred arrangement, the lever may be suspended at an intermediate point of its length between adjacent ends of two aligned elongate thin spring strips which are fixedly mounted at their other ends, and are arranged to yield resiliently by twisting in opposite directions about their respective lengths as the lever pivots.

The thin strips are preferably of rectangular cross-section, and in their untwisted and unloaded state may be straight and may be arranged with their lengths and their widths extending at right angles to the length of the lever. At least the thin strips may be made of alloy steel.

It is preferred that the thin spring strips shall be integral with the lever itself.

Where the electric motor (or other actuating means for the valve) has a rotary output shaft, this may be arranged to extend at right angles to the axis of movement of the valve member and may be formed with a transverse bore in which one end of the lever is trapped as a sliding fit, the pivotal axis of the lever being parallel to the shaft axis, and the other end of the lever being trapped as a sliding fit in a recess in the movable valve member, whereby rotation of the shaft causes pivotal movement of the lever which in turn causes movement of the movable valve member to operate the valve.

In a further form of the invention the lever may be attached to, that is to say affixed or formed integral with, a lever support member for example a lever support plate, the plate in turn preferably being provided with means by which the plate and consequently the lever may be attached to the valve case or housing. The lever is preferably formed integrally with the valve plate, the lever axis being substantially at right angles to the plane of the valve plate. The elongate torsional spring means is preferably provided by cuts, grooves or other discontinuities in the valve plate on either side of the lever, the cuts etc., extending fully through the plate and leaving between them areas of material of the plate which function as the thin strip spring means referred to above.

In this form of the invention the lever plate is preferably provided with fluid seal means to prevent passage of valve fluid through the said grooves, cuts etc., for example from the valve case or housing into the motor case or housing. These seal means may preferably comprise a rubber or other resilient material affixed to the underside of the plate about the lever and extending at least over the area of the plate in which the said grooves, cuts etc., appear. The fluid seal may be formed in situ for example by moulding of settable resilient material within a formation or formations on or attached to the plate or the seal may be fabricated separately and attached to the plate by appropriate means, for example adhesion.

In a further form of the invention an arrangement as set out in any of the above defined aspects of the invention may comprise a fluid seal provided between the lever and the valve housing, to prevent passage of valve fluid e.g. from the valve case or housing to the motor assembly.

The electric torque motor preferably comprises a rotor and a stator, one of which has magnets while the other has coils for defining magnetic poles when electrically energised by a command signal, which poles then react with the magnets to produce torque. The motor may have any one or more of the following features either alone or in any combination.

The magnets -which may be permanent magnets -may be arranged in pairs which are radially spaced in relation to the torque axis to define between them a space for iron for the magnetic poles. Usually the iron for the magnetic poles will be in a space defined between a south pole on one magnet and a north pole on another magnet of the pair.

In a double arm arrangment there may be two pairs of magnets on either side of the torque axis and on a common diameter, and then each pair will define a gap for different parts of the iron for magnetic poles.

The iron for the magnetic poles can be in the form generally of a figure of revolution but with two parallel spaced cores on either side of the torque axis. The cores can be on either side on the magnets radially with respect to the torque axis and/or circum ferentially with respect to that axis.

The rotor and the stator may each be of multi-U form for assembly together by relative movement towards each other along the torque axis.

The coils may be separately wound coils on individual formers which are then fitted over cores preferably of laminated material where the magnetic pores are to be defined.

A sealing gland for enabling conductors to be led into the motor through a hole in the body may have an internal helical thread of a form corresponding to the external form of a helical covering of the conductors which can be threaded into the gland to effect the necessary seal between the atmosphere on the one hand and the space within the covering and within the body on the other hand.

The invention may be carried into practice in various ways, but specific embodiments will now be described by way of example only and with reference to the accompanying drawings, in which:

FIGURE 1 is a sectional elevation of an electrohydraulic servo valve assembly, taken on the line I-I in Figure 2 in a plane through the longitudinal axis of the valve spool;

FIGURE 2 is a view in section on the line II-II in Figure 1, in a plane through the longitudinal axis of the common electric motor shaft;

FIGURE 3 is a sectional plan view taken on the line III-III in Figure 2;

FIGURES 4 and 5 are underneath sectional plan views taken respectively on the lines IV-IV and V-V in Figure 2;

FIGURE 6 is an end view of the assembly as seen in the direction of the arrow A in Figure 1;

FIGURE 7 is a sectional plan on the line VII-VII in Figure 1;

FIGURE 8 is a scrap section on the line VIII-VIII in Figure 7;

FIGURES 9, 10 and 11 are scrap sections taken on the lines IX-IX, XII-XII and XI-XI respectively in Figure 1;

FIGURES 12, 13 and 14 are views in three mutually-perpendicular projections, on a larger scale, of the pivoted driving lever and its flexible mounting which is an important feature of the present invention, and which lever transmits the assembly motor drive directly to the valve spool;

FIGURES 15, 16 and 17 show diagrammatically the relative angular positions of the electric motor driving shaft and the pivoted driving lever, respectively in the neutral or closed position of the valve and in its two opposite extreme open positions:

Figure 18 shows a view in section of a valve casing and spool valve corresponding to that shown in Figure 2 with an alternative form of pivoted driving lever;

Figure 19 shows in plan view the driving lever support plate assembly of Figure 18;

FIGURES 20 and 21 show the assembly of Figure 19 at right angle sections to one another;

Figure 22 is a section generally corresponding to that of Figure 1 of the improved motor which is taken on the line V-V in Figure 23 which is itself a section on the line X-X in Figure 24;

Figure 24 is a view taken from the same direction as Figure 22 with the end cap of the motor removed;

Figure 25 is a section on the line Y-Y in Figure 24;

Figure 26 is a plan and Figure 27 is an elevation in section of the stator housing of the motor;

Figure 28 is a plan of the stator iron and windings for mounting in the housing of Figures 26 and 27;

Figures 29 and 30 are an elevation and plan of the rotor of the motor;

Figure 31 is a plan view of the assembled rotor and stator with the rotor being at the null position at the left-hand side of the centre line and being at an inclined position at the right side of the centre line;

Figure 32 is a sectional elevation of the assembled rotor and stator; (Figures 31 and 32 are effectively enlarged views of parts of Figures 24 and 23);

Figure 33 is a sectional elevation of a sealing gland for leading the conductors into the motor housing; and

Figure 34 is a detail of Figure 33.

In the illustrated embodiments the invention is applied to an electrohydraulic servo valve assembly generally indicated at 10 and intended to be mounted upon a double-acting hydraulic jack (not shown) for controlling the position and movement of the jack plunger in accordance with electrical input signals to duplicated electric motors 11 of the assembly. The motors 11 drive a hydraulic spool valve 12 whose valve body 13 has a ported hydraulic interface 14 intended to be bolted to a correspondingly-ported face on the body of the jack. The interface 14 contains an inlet port 15 - (Figure 2) for high-pressure hydraulic fluid from a supply to a corresponding high-pressure port in the jack body, with which the inlet port 15 is in register when the valve body is bolted to the jack body; a return port 16 which is then in register with a low-pressure return line in the jack body; and a pair of operating ports 17 and 18 (Figure 1) which are then in register with ports in the jack body communicating with the jack cylinder on opposite sides of the jack piston. The valve 12 is operated by the axial displacement of its spool 20 to connect its delivery ports 17 and 18 respectively to the pressure and return ports 15 and 16, or vice versa, so as to supply pressure fluid to either selected end of the jack cylinder whilst connecting the opposite end of the jack cylinder to the low pressure return.

As seen in Figures 1 and 4, the valve spool 20 is a sealing and sliding fit in the bore of a tubular liner sleeve 21 located in a bore 22 in the valve body 13, the bore 22 being closed at its opposite ends by end plugs 23 and 24, each secured to the valve body 13 by four screws 25. The plugs 23 and 24 located the sleeve accurately in the bore 22 by abutting against the respective ends of the sleeve, a small axial adjustment range of 0.127 mm (0.005 inch) being provided. The valve spool 20 has a pair of circumferential grooves 27,28 bounded by lands, and is formed with a central axial bore 29 open at its opposite ends and communicating with a transverse diametral passage 30. The fixed sleeve 21 has two axially-spaced external circumferential grooves 31 and 32 near one end, groove 31 leading into radial ports 33 which extend through the sleeve wall into the bore of the sleeve, and groove 32 having passages 34; and the sleeve 21 has similar spaced grooves 36,35 with similar respective ports 38,37 near its other end. In its central position the sleeve 21 has a pair of external circumferential grooves 39,40 spaced at equal distances from its mid-point, the grooves 39 and 40 being interconnected by a part-circumferential recess 41. Groove 39 has radial ports 42 extending from its bottom through the wall thickness of the sleeve 21, and groove 40 has similar ports 43. Ports 34 lead into the spool groove 27, and ports 33 and 42 cooperate with opposite cut-of edges of the groove 27. Passages 37 lead into the other spool groove 28 and ports 43 and 38 cooperate with the opposite cut-off edges of the groove 28. As shown in Figures 1 and 4, with the spool 20 in its central closed position, ports 33,42,43 and 38 are all wholly closed by respective lands of the spool 20.

As seen best in Figures 2 and 5, the pressure inlet port 15 in the valve body 13 leads via a short passage 49 into a blind gallery 50 formed in the body 13, the open end of a gallery 50 being closed by a close-fitting plug 51. A branch passage 52 leads from the gallery 50 into the groove 31 of the fixed sleeve 21 as shown in Figure 10 and thus supplies pressure fluid from port 15 to ports 33. A similar branch passage (not shown) leads from the gallery 50 into the groove 36 at the other end of the sleeve and supplies pressure fluid to the ports 38. The return port 16 enters one end of a passage 55 (Figure 2) which leads directly into the recess 41 and thence to the ports 42 and 43.

Each of the operating ports, 17,18, leads via a short passage into a blind gallery, 58 or 59 respectively, shown in Figure 5, the galleries 58,59 being closed at their outer ends by plugs 60,61. Gallery 59 is connected by a branch passage 63 to the circumferential groove 32 in the sleeve and hence to its ports 34, as shown in Figure 11, while gallery 58 is similarly connected to the groove 35 and ports 37.

Thus when the valve spool 20 is moved from its closed position shown in Figure 1, in which the ports 33,42,43,38 are all closed by lands of the spool, in the leftwards direction as seen in Figure 1; the ports 33 and 43 progressively open into the respective spool grooves 27 and 28, while the ports 42 and 38 remain closed. This pressure fluid from the inlet port 15 is supplied via passage 49 gallery 50, passage 52, groove 31, ports 33, groove 27, ports 34, groove 32, passage 63, and gallery 59 to the operating port 18 and thence to the corresponding end of the jack cylinder to act on the jack piston; whilst the opposite end of the jack cylinder is connected to return via the operating port 17, gallery 58, groove 35, ports 37, groove 28, ports 43, groove 40, recess 41, passage 55, and return port 16. When the spool 20 is moved in the opposite direction, port 17 is pressurised and port 18 is connected to return, thus actuating the jack plunger in the opposite direction. The action of the servo valve 12 is a progressive one, the pressure and flow rate of fluid transmitted to the jack cylinder varying in accordance to the axial distance through which the spool is moved and uncovers the respective sleeve ports.

The spool 20 of the servo valve 12 is driven by means of the electric motors 11. These have stator assemblies 70 contained in housings 72,73 secured to opposite sides of a central body portion 75. A common motor shaft 77 carrying the rotors 78 of the two motors at its opposite ends is journalled in bearings 79 supported by fittings 80 bolted at 81 and elsewhere to the central body portion 75. Annular position pick-offs 82 are housed in the fittings 80 to surround the shaft 77. Each motor 11 is of a position-controlled type, which drives the shaft to rotate about its bearing axis to a selected angular position in a selected direction in response to an electrical input signal supplied to the motors as the command signal to the assembly. The motors 11 are d.c.-energised samarium-cobalt motors whose angular position is continuously monitored by the two rotary pick-offs 82 (RVDTS) providing continuous servo control. Both motors are normally in operation, being duplicated to ensure survival of operation in the event of one motor failing. The angular range of rotation of the motor shaft 77 is limited to $22\frac{1}{2}°$ on either side of its datum position, this limitation being effected as shown in Figures 1 and 2 by means of fixed stops 84 on the fittings 80 which are engaged by projections 85 on an enlarged central portion 86 of the shaft 77 in the limiting positions of the shaft.

The rotation of the motor shaft 77 is transmitted to the spool 20 of the valve 12 via a pivoted lever 90, whose resilient suspension embodies important features of the present invention. At one end, the upper end as seen in Figures 1,2 and 15-17, the lever 90 has an enlarged integral head 91 of part-spherical profile which is engaged as a sliding fit in a transverse bore 89 extending diametrally through the enlarged portion 86 of the motor shaft. The lever 90 is pivoted about a transverse axis 92 located at a distance of about two-thirds of the length of the lever from its end with the head 91. At its other end, which is about one third of its length away from its pivotal axis 92, the lever has a second enlarged integral head 93 of part-spherical profile. The lever extends upwardly - (in Figures 1,2) from its pivotal axis 92 through an aperture 95 formed in the central body portion 75, and extends downwardly from its pivotal axis through apertures in the valve body 13 and in the fixed valve sleeve 21 and its head 93 is engaged as a sliding fit in the transverse bore 30 in the valve spool 20. Thus when the motor shaft 77 rotates from its datum position of Figures 1 and 15 in either direction towards one or other of its limiting positions of Figures 16 and 17, this rotation will be transformed, by the sliding engagement of the lever head 91 in the transverse bore 89, at a level below the axis of the motor shaft 77, into a corresponding but smaller opposite rotation of the lever 90. This lever rotation is applied by its head 93 to the valve spool 20, to move the spool through a corresponding axial displacement. In a preferred practical construction in which the length dimensions of the lever are:

Length from axis 92 to centre of head 91 : 21.82 mm (0.505 inch)

Length from axis 92 to centre of head 93 : 7.11 mm (0.280 inch)

The rotation of the motor shaft 77 from its datum position through $22\frac{1}{2}°$ into either of its extreme positions will produce a corresponding axial displacement of the valve spool 20 of 0.5 mm (0.020 inch) from its closed position. The bore 89 in the motor shaft 77 has a frusto-conical portion 89A at one end to clear the lever 90 in the limiting positions. Each of the heads 91 and 93 of the lever 90 has a diameter of 4.76 mm (3/16th inch).

The detailed construction of the lever 90 and of its integral flexible suspension, which concept as indicated above is very important to the invention, is shown in Figures 12 to 14. The lever 90 is a rigid member having parallel opposite faces 100,101 perpendicular its pivotal axis 91, these faces being 3.05 mm (0.12 inch) apart. From each of these two faces 100,101 there projects at right angles a thin integral rectangular-section strip portion 105,106 terminating in a rectangular integral enlargement 107 formed with a countersunk screw hole 108. Each of the thin strips is disposed with its longitudinal axis coincident with the pivotal axis 92 of the lever 90, and with its width direction perpendicular to the length of the lever 90, as shown. Thus when the two enlargements 107 are screwed down on to a mounting face provided on the valve body 13, as shown in Figure 2, the thin integral strips 105,106 will act as torsion suspension springs, supporting the lever 90 in a manner permitting it to rotate about its axis 92 accompanied by the twisting of the strips 105,106 about their longitudinal axes, and moreover the strips 105,106 will impose a resilient centering bias on the lever 90 tending to restore it resiliently to its centralised position (of Figures 1 and 15) in which the valve 12 is closed.

The central body portion 75 which carries the two motors 11 is mounted on the valve body 13 by means of bolts 110 screwed into tapped holes in projecting portions 111 of the valve body, and when the central body portion and the two motors have been so mounted, with the opposite ends of the lever 90 engaged respectively with the motor shaft and with the valve spool, actuation of the motors will rotate the lever 90 against the bias of its flexible suspension strips to a corresponding extent to move the valve spool into the open position demanded by the input signal to the motors.

When a command signal to close the valve is given to the motors 11, these return the valve spool to its centralised position, aided by the resilient torque of the twisted suspension strips 105,106. This resilient centering action of the strips 105,106 thus augments the chip shear capability of the valve by producing a substantial additional return force at the valve spool, for example about 12lbs when the valve is fully open and the spring strips are fully deflected. If a particle of debris should become lodged in a valve port of the sleeve 21 protruding into the path of the spool 20 in operation, this additional spring shearing force plus the Bernoulli force plus the motor torque can provide a usefully augmented total chip shear capability at the valve amounting for example to about 70lb, to overcome the obstruction. The spring strips also serve to centralise the valve when the system is de-energised.

The use of the integral rectangular-section flexible strips 105,106 as the pivotal suspension for the driving lever 90 thus provides a frictionless bearing for the lever, as well as an inherent resilient centering torque.

It will be appreciated that with the valve and motor construction shown in the drawings, the integral flexible suspension 105,106 as well as the lever 90 itself are completely enclosed and sealed within a closed space defined between the central body portion 75, the two bearing fittings 80, and the valve body 13, and is thus completely protected from exposure to the deleterious effects of atmosphere or other contaminants.

The one-piece member shown in Figures 12 to 14 which forms the lever 90, its flexible suspension strips 105,106 and their mounting blocks 107 is preferably made from "Maraging" steel,

although many other high-strength alloy steels would be acceptable.

The preferred dimensions of the lever 90 have been given above, and to these can be added the following further preferred dimensions:

Length of parallel-sided portion of each thin strip 105,106: 4.44mm (0.175 inch)

to which end should be added fillets 115 of 0.51 mm (0.020 inch) radius at each end.

Width of each thin strip 105,106: 4.06 mm (0.160 inch)

Thickness of each thin strip 105,106: 0.51 mm - (0.020 inch)

Length of each mounting block 107: 4.70 mm - (0.185 inch)

Width of each mounting block 107: 5.08 mm (0.20 inch)

Thickness of each mounting block 197: 2.54 mm (0.10 inch)

The electrohydraulic servo valve described and illustrated may be designed to provide a maximum flow rate of from 9.1 litres/min. (2 gallons/min.) up to 36.4 litres/min. (8 gallons/min.) at 20,682 k Pa - (3000 p.s.i.) pressure differential, i.e. 10,341 KPa - (1500 p.s.i.) per land, depending on the choice of the exchangeable valve sleeve and porting, and to operate with a supply pressure of up to 55,152 kPa (8000 p.s.i.). It does not have a significant parasitic internal leakage as is common with conventional 2-stage electrohydraulic valves, for example Moog/ Abex valves, and is far less susceptible to contamination than conventional valves having no small first-stage orifices.

Figures 18 to 21 show a further pivotal driving lever/flexible mounting arrangement which will now be described.

The motor bearings of the arrangement described in relation to Figures 1 and 2 above are lubricated by the return system oil, that is to say by oil finding its way from the spool valve past the lever 90 up to the bearings 79. Immediately outboard of the bearings 79 there are annular seals through which the common motor shaft 77 passes, the annular seals serving to prevent passage of the return system oil to the rotor/stator assemblies.

There will be seen at Figure 18 a view similar to that of Figure 2. Marked on Figure 18 are on the valve spool 20 located substantially as previously in valve body 13. The valve body 13 has affixed to it at its upper end a lever plate 200. As an integral part of the lever plate 200 is a lever 190 which extends above and below the plane of the plate 200. At either end of the lever 190 are enlarged heads 191 and 193 which locate respectively with the motor shaft 77 and spool 20 in the manner of enlarged heads 91 and 93 of the arrangement shown in relation to Figures 1 and 2 and Figures 15 to 17.

Referring to Figure 19 the lever 190 is affixed, preferably integrally, substantially at right angles to the plate 200. On either side of the lever 190 there are areas or lines 210 of material removed from the plate 200. The removal of material from lines 210 leaves between them areas 205 and 206 of the material of the plate 200 corresponding to the thin integral strips 105 and 106 of the previously described embodiment. The areas 205 and 206 have length 4.44mm, width 2.04mm and thickness 1.02mm and will act as torsion suspension springs supporting the lever 190 in a manner permitting it to rotate by twisting of the areas 205 and 206 about that longitudinal axis that is to say about the axis marked at A on Figure 19. That rotation will of course be as a consequence of a movement of the motor and its effect transmitted to the lever via the enlarged head 191.

The pivot plate 200 is provided at its under side with an annular flange 215 which in use abuts the seat 216 on the upper surface of the valve body 13. The cylindrical volume 220 provided within the annular flange 215 is filled as will be seen in Figure 18 with a resilient e.g. rubbery material 221. The internal diameter of the cylinder 220 is such that the material 221 covers the whole of the underside of the areas or lines 210 thereby preventing the passage through the areas or lines 210 of fluid from the spool valve and its casing.

The material 221 may be formed in situ or may be provided by an equivalent shaped inset pressed into the cylinder 220.

By the use of a lever and lever plate arrangement as shown in relation to Figure 18 the spool valve fluid flow may be isolated entirely from the rotor/drive aspects of the valve.

The shape of the lines or areas 210 may be modified as required to provide areas 205 and 206 of the required dimensions having regard to the characteristics of the material of the assembly 200/190 and the response required.

For many applications it is preferred to use instead of the motor described with reference to Figures 1, 2 and 3, an improved design of motor described with reference to Figures 22 to 32 of the accompanying drawings.

As already described the function of the motor is to be able to turn the lever 90 about the axis 300 in response to an electrical command signal. The maximum required angular deflection of the lever from the null position shown in Figure 22 is 22½° in either sense.

The motor is duplicated on either side of the section line V-V in Figure 23 so that there can still be a drive in spite of possible failure of one motor. It will suffice here to describe the arrangement of one motor only since the two motors are identical and are mounted on opposite ends of the motor shaft 301.

Each motor comprises a rotor 302 with a construction as indicated in Figures 29 and 30 mounted at the end of the shaft 301 and rotating with the shaft in relation to a stator 303 whose construction is shown in Figures 26, 27 and 28.

The stator comprises a two-pole ferro-magnetic block 304 shown in Figure 28 with four windings 305 for magnetising it.

The block 304 is assembled from laminations parallel with the plane of Figure 28 and is in the form of a cylindrical ring 306 which can be mounted on a correspondingly shaped platform 307 formed in a stator housing 308 and secured in position by bolts in holes 309 in the block 304 and threaded holes 310 in the platform 307. Four poles 312 extend to either side from the ring 306 parallel with each other and equally spaced on either side of the centre line 313. The laminated block 304 is of constant thickness and of uniform shape so that the poles 312 are of rectangular shape as seen from either side that is in the direction of the axis 313.

It is also possible to splay the poles 312 out at an acute angle to axis 313 to obtain more favourable flux distribution. In this constitution it may be advantageous to close the flux path with an outer lamination assembly linking the ends of each pair of poles 312.

Each of the windings 305 is prewound on a former and assembled over one of the poles 312. The formers are of an irregular shape so as to fit in the available space between the ring and a pole while having an outer surface generally of cylindrical form. The windings 305 are connected to exciting terminals in such a way that when a direct exciting current is applied to them they will be magnetised as indicated by the letters N and S in Figure 28.

When the block 304 with its windings 305 is assembled in the housing 308 the stator will be as shown in Figures 31 and 32 with the outer ends of the poles 312 in contact with an upstanding part-cylindrical wall 315 formed as part of the housing 308 and providing a path for stator flux as indicated generally at 316 in Figure 31.

The rotor 302 is also of ferro-magnetic material with a central cylindrical body 331 having a central bore 332 for mounting it on the end of the shaft 301. As shown in Figure 29 the body 331 is generally of m-shape so that in the elevation of Figure 30 it is of substantial width but of restricted height. The body carries by means of an adhesive four samarium cobalt permanent magnets of which the inner magnets 333 are secured on either side of the body 331 while the outer magnets 334 are secured on the inner faces of outer limbs 335 of the body. Thus, the magnets 333 and 334 of each pair define between them a space 336 for the stator block 304.

The magnets are magnetised as indicated in Figures 29 and 30 so that each has a pole facing the space 336 and the space is defined between a north pole on one magnet and a south pole on another magnet.

The rotor and the stator can be easily assembled together as shown in Figures 31 and 32 by moving the rotor 302 towards the stator housing assembly along the direction of the axis 300 as shown by the arrowhead 337. It is secured on the shaft 301 which extends through the bore 332 and which also co-operates with a bore 338 in the stator housing.

An end cap 341 is fitted over the assembled motor stator as indicated best in Figures 23 and 25 and secured to the motor housing 349 by bolts 342 to which the stator housing is also secured by bolts 343 (Figure 23).

In the absence of any exciting current in the windings 305 the stator poles 312 are not magnetised and the rotor is centred in its null position by the spring biassing the lever 90 and described in connection with the valve mechanism. The rotor is thus in the position shown to the left of the vertical centre line in Figure 31.

If however, a control signal is applied to the windings 305 the four stator poles 312 all become magnetised as shown in Figure 31 and that establishes a magnetic field applying a torque to the rotor due to attraction between unlike stator and rotor poles and repulsion between like stator and rotor poles so that the rotor takes up the inclined position shown to the right of the centre line in Figure 31. The spring restoring force increases with deflection so that the rotor reaches a position of equilibrium before rotor poles become completely aligned with their corresponding stator poles. There is also a feedback signal provided by rotor voltage/displacement transducers 345 (Figures 23 and 25) having coils mounted on the stator co-operating with laminations mounted on the shaft to produce a signal proportional to angular shaft displacement. That signal is subtracted from the command signal and the final deflected position is established when the spring restoring force is balanced by the magnetic force due to stator pole excitation by a control signal amplified from the error equal to the command signal diminished by the feed-back signal, achieved by a separate electronic package. The system can be designed so that a command signal of a particular value results in an angular deflection of a particular value. As the command signal varies the deflection varies and so does the degree of opening of the valve, and when the command signal is removed the rotor returns to the null position of no deflection.

The motor has the following advantages.

By making the rotor with effectively two limbs each of which has two permanent magnets, torque can be generated more or less corresponding to that which would be generated by a four pole motor but the motor is of much more compact shape as shown in Figure 31 than would be the case if the four poles were equally angularly spaced around the axis 300. As shown in Figure 24 the dimension of the motor above the valve casing is less than the height of the valve casing so that the motor does not make the assembly so top heavy as with the motor described with reference to Figure 2. It is to be noted that the outer permanent magnets 334 act on a larger torque arm than the inner permanent magnets 333.

Another advantage is the ease of assembly by sliding the rotor and stator components together by movement towards each other along the axis 300. This is possible because of the formation of both the rotor and the stator as an open ended construction. The ends of the rotor and the stator away from the open ends provide flux paths respectively for stator and rotor flux but it is not believed that leakage flux will be excessive. The rotor may be manufactured more easily in solid form because a laminated construction with laminations parallel to the plane of Figure 32 would not have laminations all of the same shape, but if leakage flux perpendicular to the plane of Figure 32 was excessive a laminated construction may be adopted.

Another feature of the simplified construction and assembly is that the stator coils 305 can be wound separately on their formers with a conventional coil winding machine in a very simple operation and then simply assembled with the stator by sliding them over the poles, with it then only being necessary to connect the coils together and to the exciter terminals.

Another feature of the motor is the seal by means of which the conductors 347 are led into the motor housing.

A gland 348 (Figure 33) is threaded into the body 349 as shown in Figure 23 from the inside using external threads 351 on the gland and cooperating threads in the body 349. The central bore in the gland for a helical covering 352 around the conductors is then threaded into a correspondingly formed rolled type of thread 353 shown in Figure 34 which is a detail of Figure 33. That provides a very effective fluidtight seal between the interior of the body and the exterior.

Claims

1. A fluid valve (12) comprising a ported valve housing (13,21) a movable valve member (20), actuating means (11) for the valve, and a pivotally-supported lever (90) for transmitting movement from the actuating means directly to the valve member for causing movement of the valve member relative to the ported housing so as to alter the valve porting, in which the pivoting of the lever (90) is by distortion of its suspension or other support means (105. 106).

2. A hydraulic spool valve (12) comprising a ported valve housing (13,21) a valve spool (20) slidably movable in the housing to control the valve porting, actuating means (11) for the valve, and a pivotally-supported lever (90) which by pivoting about its support (105,106) transmits the drive of the actuating means directly to the valve spool to move the spool in the housing for valve operation, in which the pivoting of the lever is by distortion of its suspension or other support means (105, 106).

3. An electrohydraulic servo valve (10) comprising a ported valve housing (13,21) a movable valve spool (20) slidable in the housing to control the valve porting, electric motor actuating means (11) mounted on the valve housing, and a pivotally-supported lever (90) which by pivoting about its suspension or other support (105,106) transmits the drive of the output member (77) of the electric motor means directly to the valve spool to move the spool in the housing for valve operation, and in which the pivoting of the lever (77) is by distortion of its suspension or support means (105. 106).

4. A valve as claimed in any one of Claims 1 to 3, in which the lever (90) is pivotally supported by elongate torsion spring means (105,106) arranged to yield resiliently by twisting about its length as the lever pivots.

5. A valve as claimed in any one of Claims 1 to 3, in which the lever (90) is suspended by thin elongate strip spring means (105,106) extending transversely to the length of the lever and arranged to yield resiliently by twisting about its length as the lever pivots.

6. A valve as claimed in Claim 5 in which the lever (90) is suspended at an intermediate point of its length between adjacent ends of two aligned thin elongate spring strips (105,106) which are fixedly mounted (at 107) at their other ends and are arranged to yield resiliently by twisting in opposite directions about their respective lengths as the lever pivots.

7. A valve as claimed in Claim 6, in which the thin strips (105,106) in their untwisted and unloaded state are straight and are arranged with their

lengths and their widths extending at right angles to the length of the lever.

8. A valve as claimed in any one of Claims 5 to 7 in which the strip spring means (105,106) or each strip (105,106) is of rectangular cross-section.

9. A valve as claimed in any one of Claims 6 to 8, in which the thin spring strips are integral with the lever.

10. A valve as claimed in Claim 8 in which the lever (90) and its suspension strips (105,106) are made of alloy steel.

11. A valve as claimed in any one of Claims 5 to 8 in which at least the thin strip spring means - (105,106) is made of alloy steel.

12. A valve as claimed in any one of the preceding claims, in which the resiliently distortable suspension or support (105,106) for the lever (90) tends to restore the lever to a centralised angular position corresponding to the valve-closed position of the movable valve member (20).

13. An electrohydraulic servo valve as claimed in any one of the preceding claims, in which the actuating means (11) for the valve has a rotary ouput shaft (77) extending perpendicular to the direction of movement of the valve member (20) and shaft formed with a transverse bore (89) in which one end (91) of the lever (90) is trapped as a sliding fit, the pivotal axis of the lever (90) being parallel to the shaft axis, and in which the other end (93) of the lever (90) is trapped as a sliding fit in a a recess (30) in the movable valve member - (20), whereby rotation of the shaft (77) causes pivotal movement of the lever (90), which in turn causes movement of the movable valve member (20) to operate the valve (12).

14. A valve as claimed in any one of the preceding claims, which is a spool valve (12) having a linearly-movable spool (20).

15. A valve as claimed in any one of the preceding claims, in which the suspension or support means - (105,106) for the lever (90) is completely enclosed in a sealed compartment.

16. A valve as claimed in Claim 1 wherein said actuating means is an electric torque motor means.

17. A valve according to Claim 3 or 16 wherein said motor means comprises a motor and a stator, one of which has magnets while the other has coils for defining magnetic poles when electrically energized by a command signal which poles then react with the magnets to produce torque.

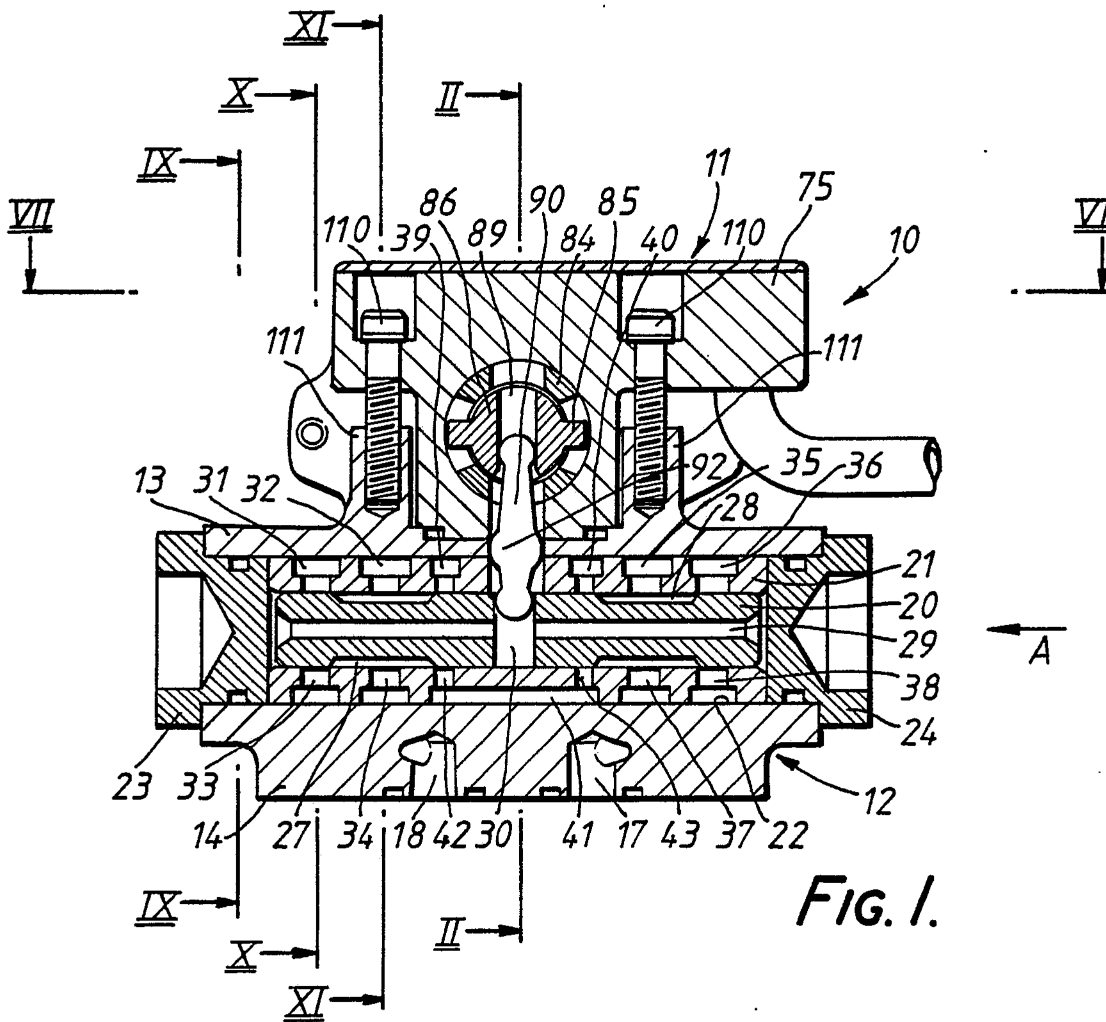
XI
X
II
IX
VII
11
75
10
86
90
85
110
39
89
84
40
110
111
111
92
35
36
13
31
32
28
21
20
29
A
38
24
23
33
12
14
27
34
18
42
30
41
17
43
37
22

FIG. 1.

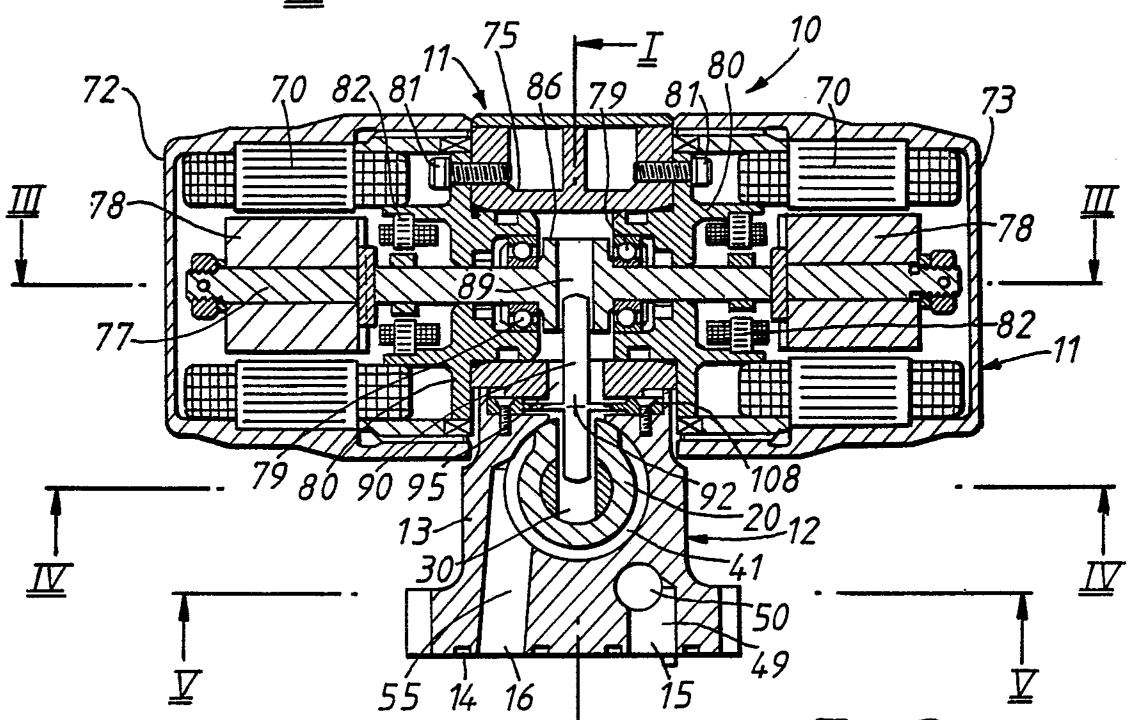
I
75
11
10
72
70
82
81
86
79
81
80
70
73
III
78
78
III
89
77
82
11
79
80
90
95
92
108
20
12
IV
13
30
41
IV
50
49
V
55
14
16
15
V

FIG. 2.

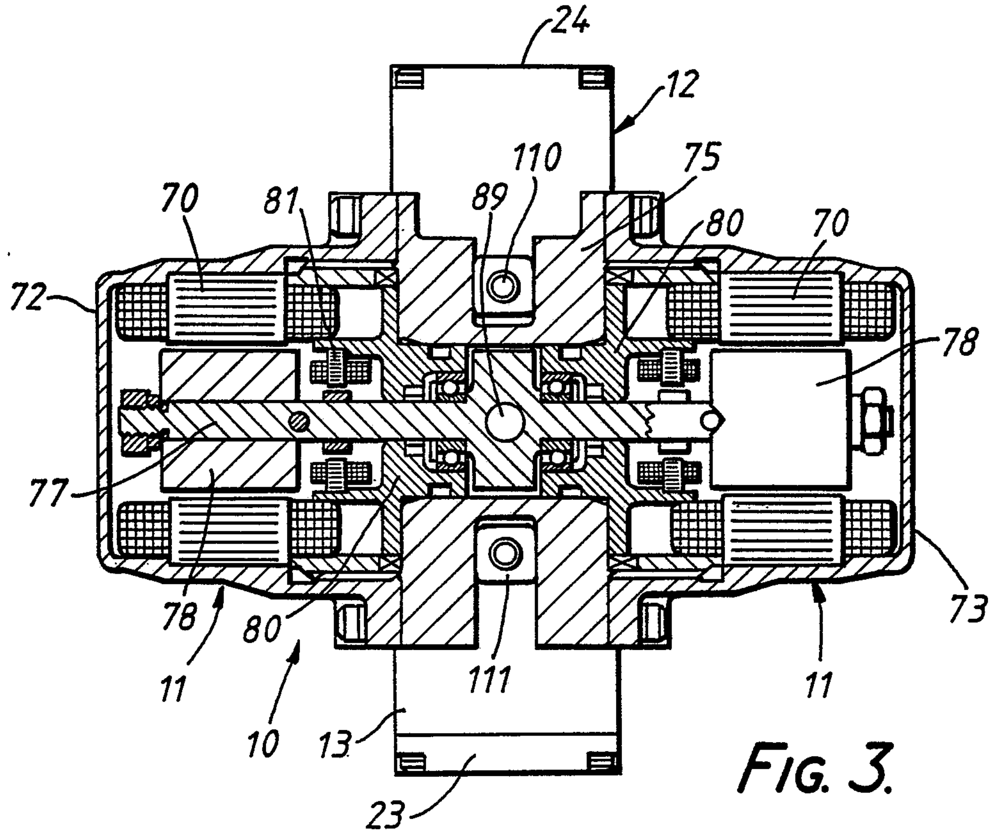
24
12
110
75
89
70
81
80
70
72
78
77
78
80
11
111
73
11
10
13
23

FIG. 3.

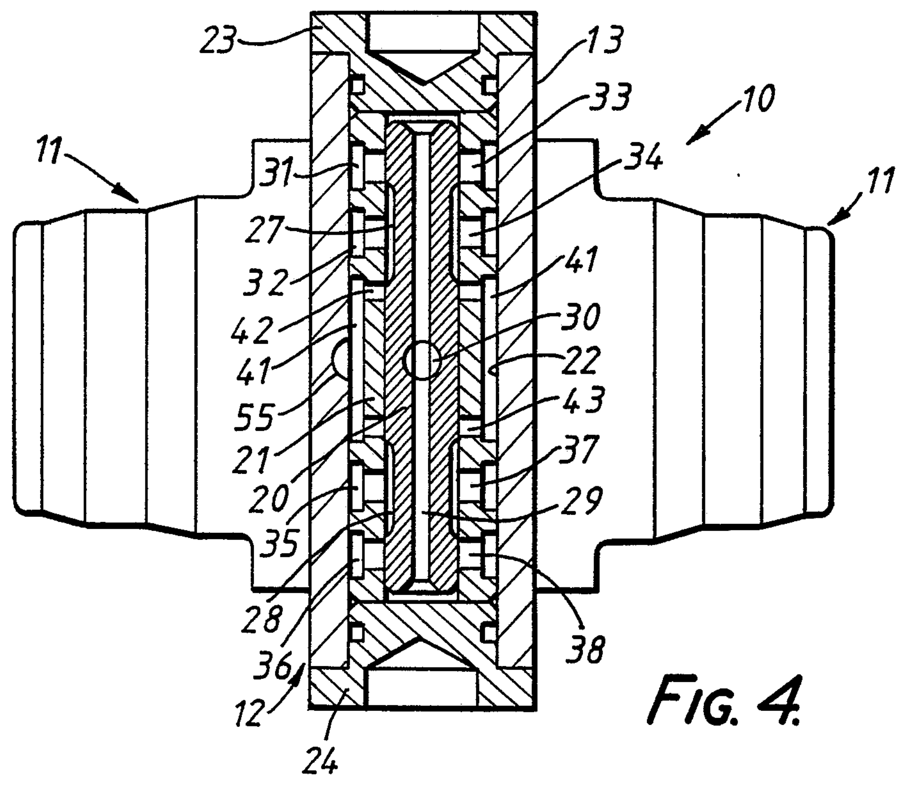
23
13
33
10
11
31
34
11
27
32
41
42
30
41
22
55
43
21
37
20
29
35
28
38
36
12
24

FIG. 4.

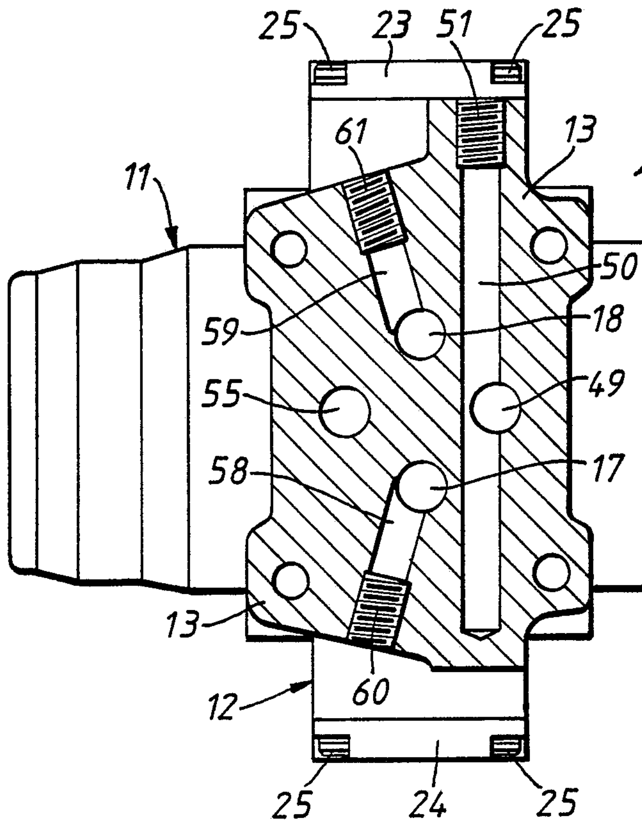
25
23
51
25
61
13
10
11
11
50
59
18
55
49
58
17
13
60
12
25
24
25

FIG. 5.

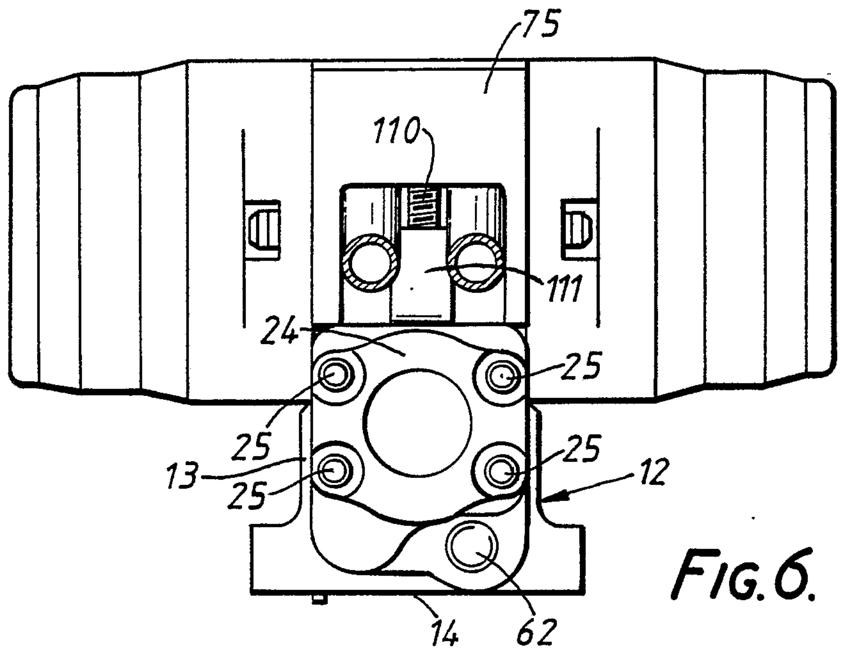
75
110
111
24
25
25
13
25
25
25
12
14
62

FIG. 6.

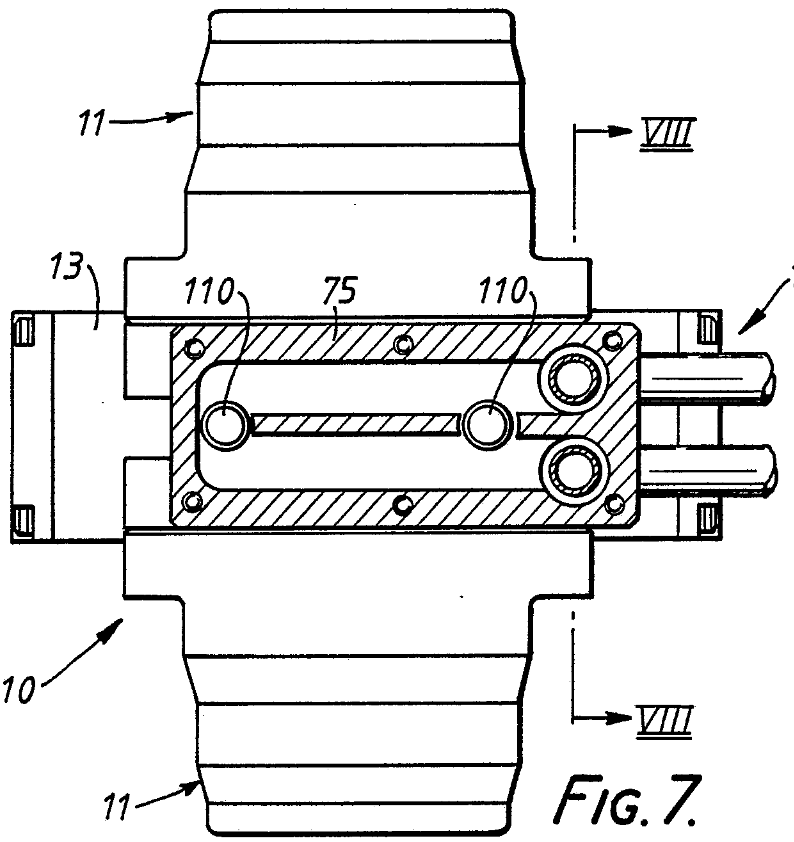

FIG. 7.

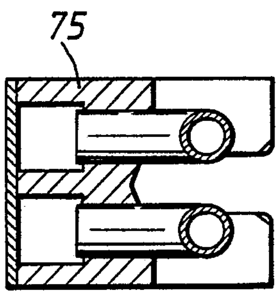

FIG. 8.

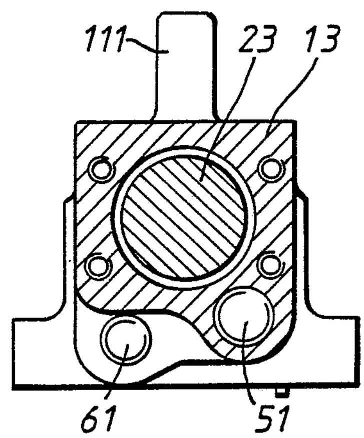

FIG. 9.

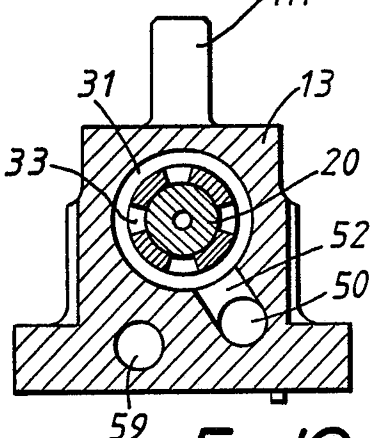

FIG. 10.

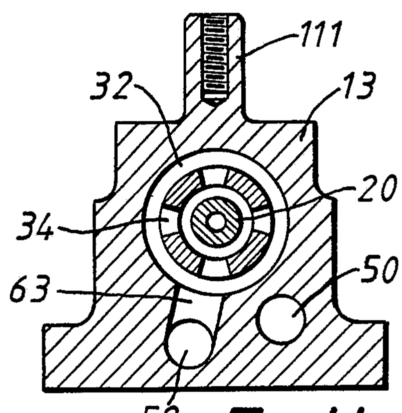

FIG. 11.

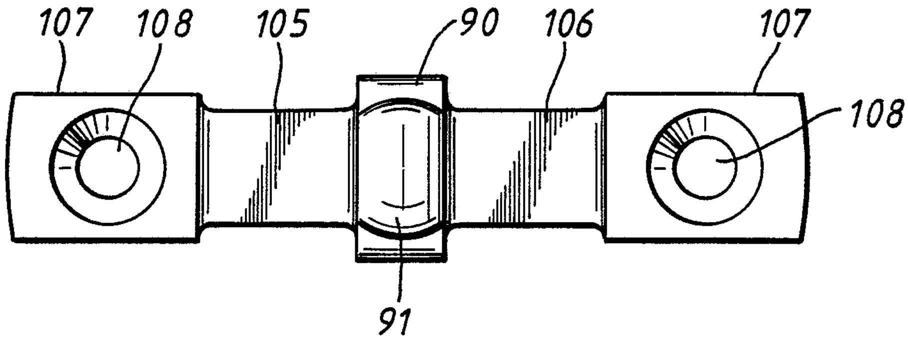

FIG. 12.

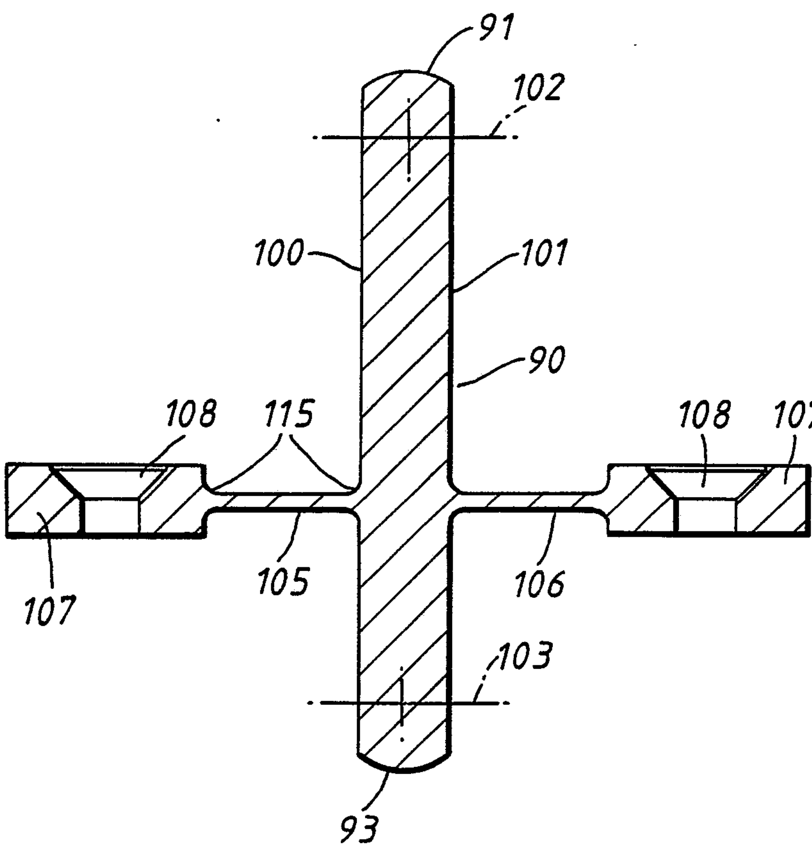

FIG. 13.

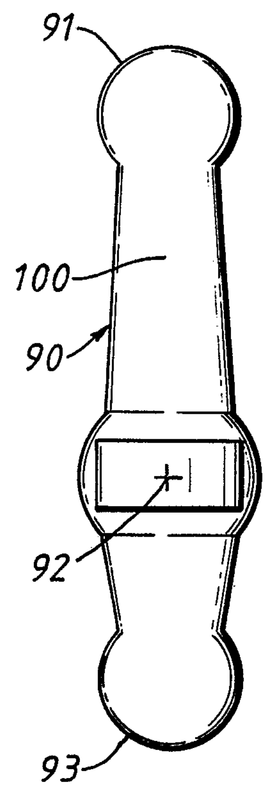

FIG. 14.

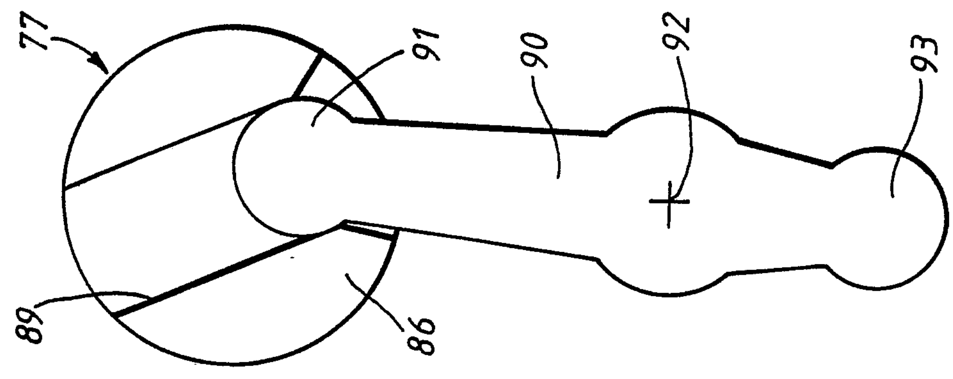

FIG. 17.

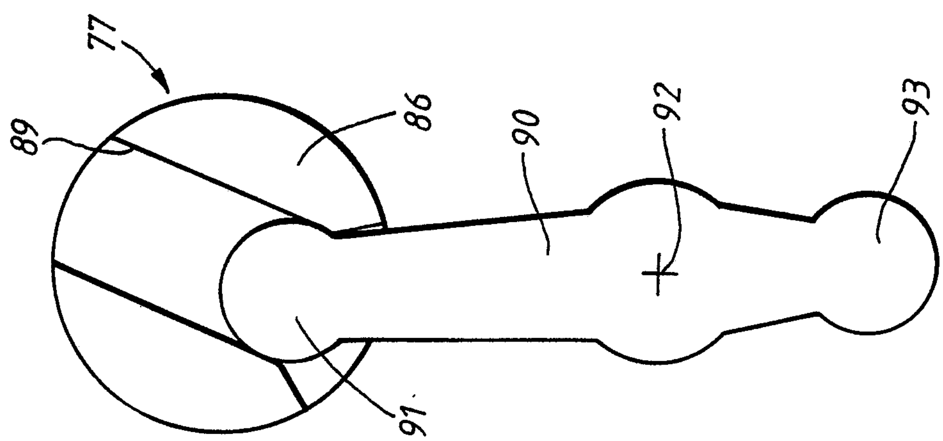

FIG. 16.

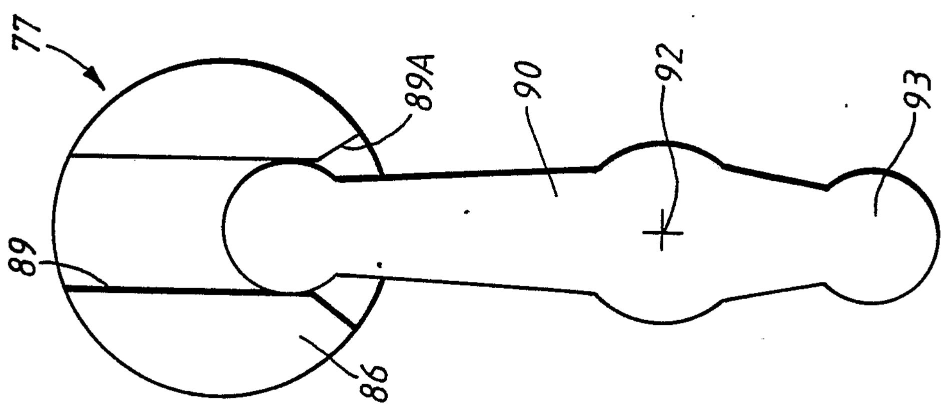

FIG. 15.

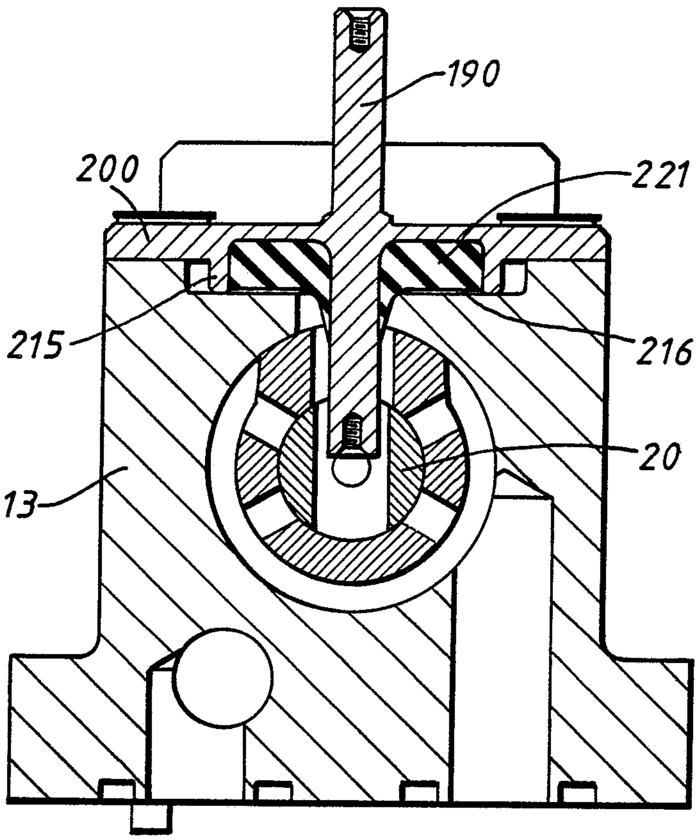

FIG. 18.

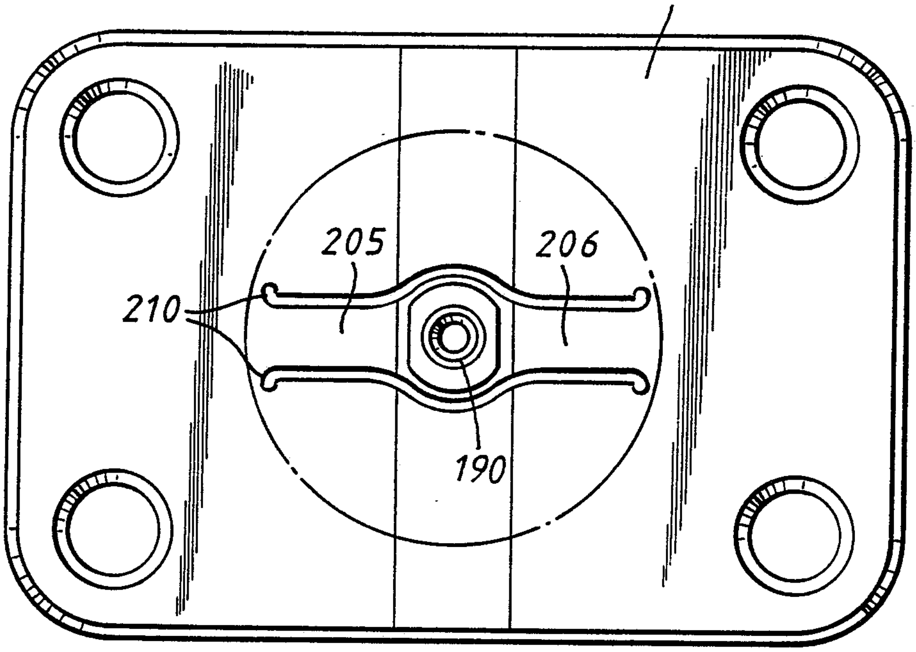

FIG. 19.

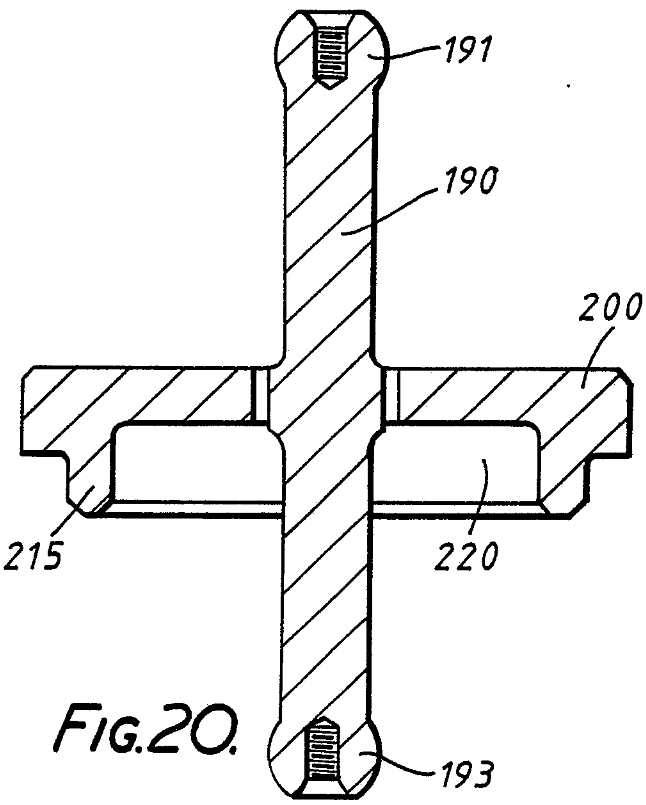

FIG.20.

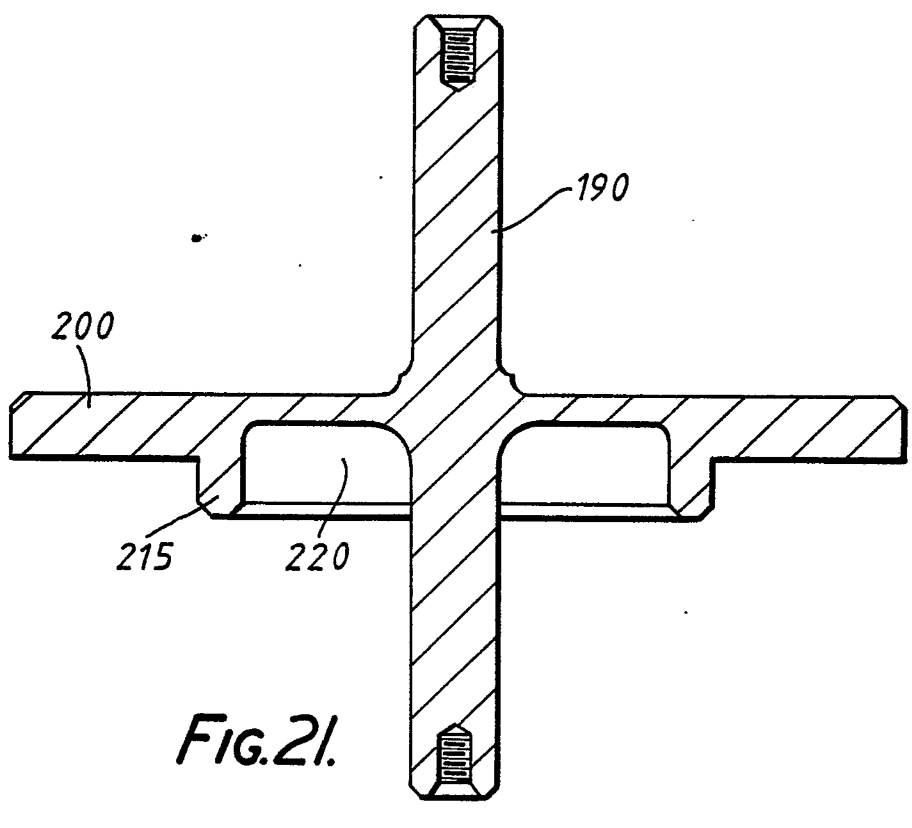

FIG.21.

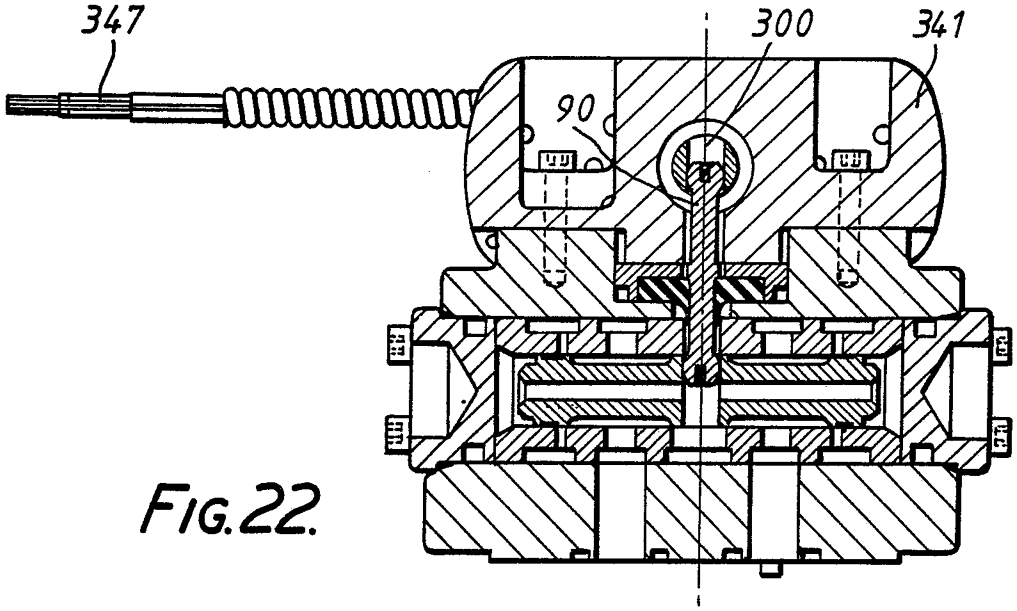
347
300
341
90

FIG. 22.

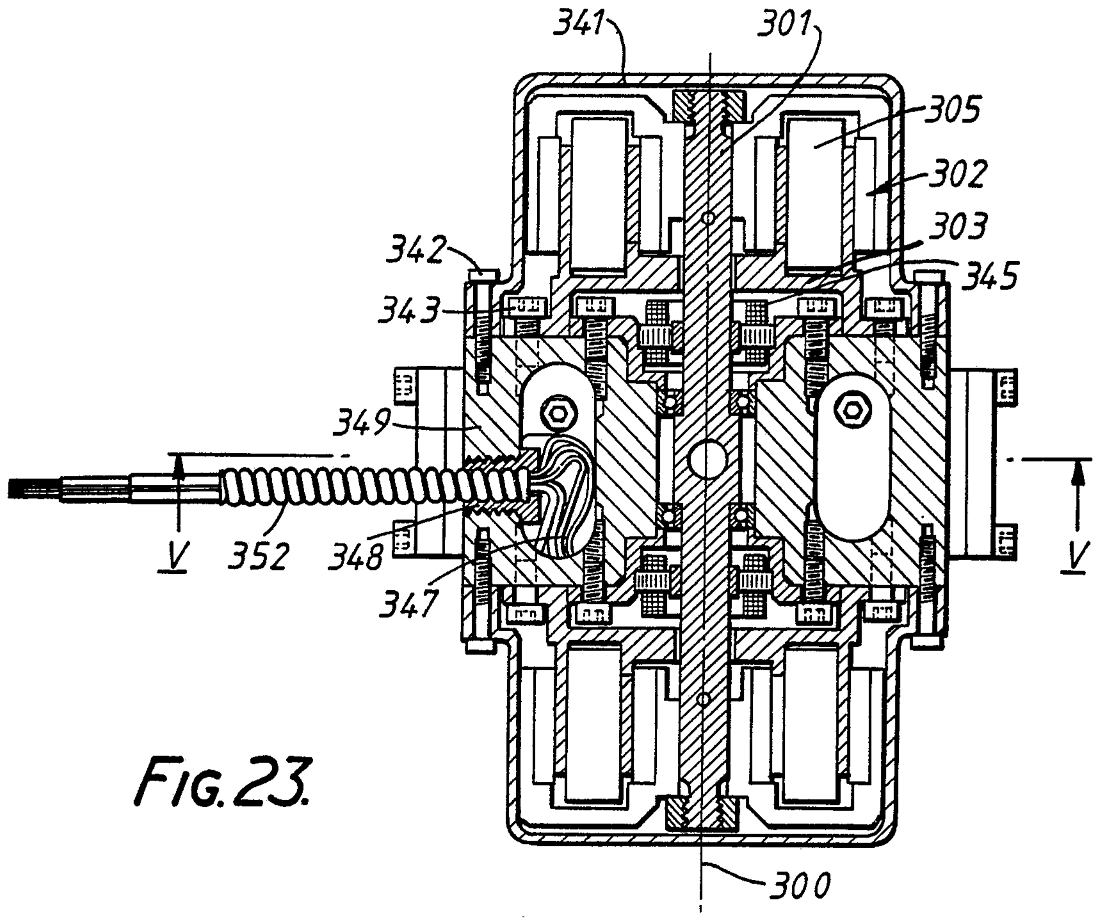
341
301
305
302
303
342
345
343
349
V
352
348
347
V
300

FIG. 23.

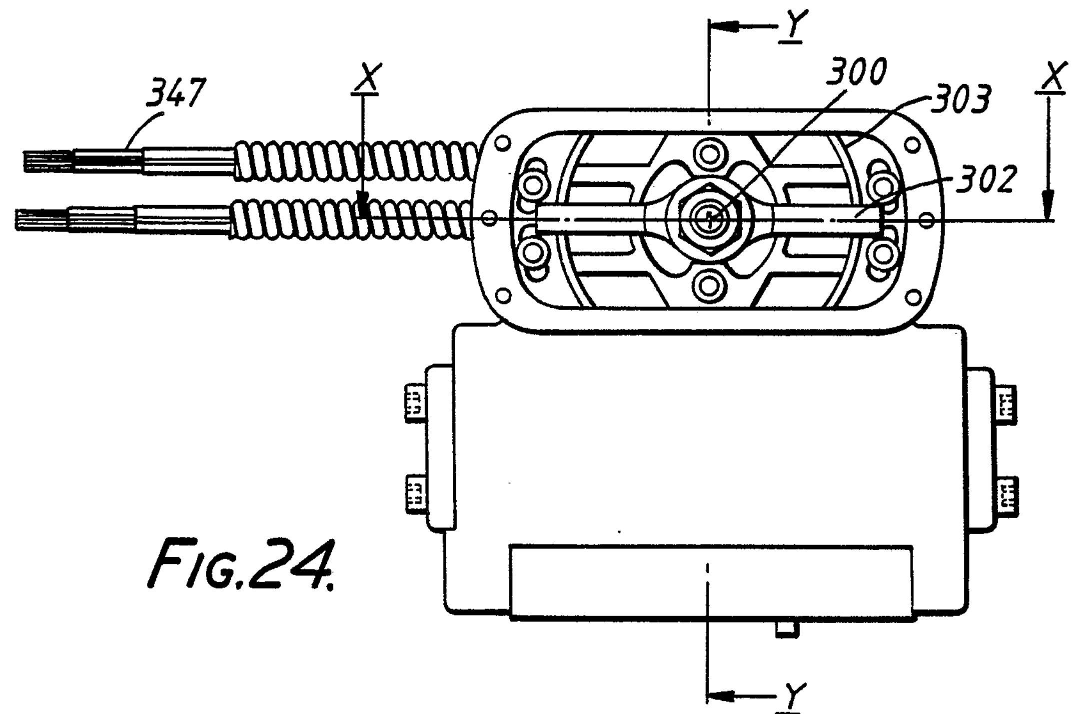

FIG. 24.

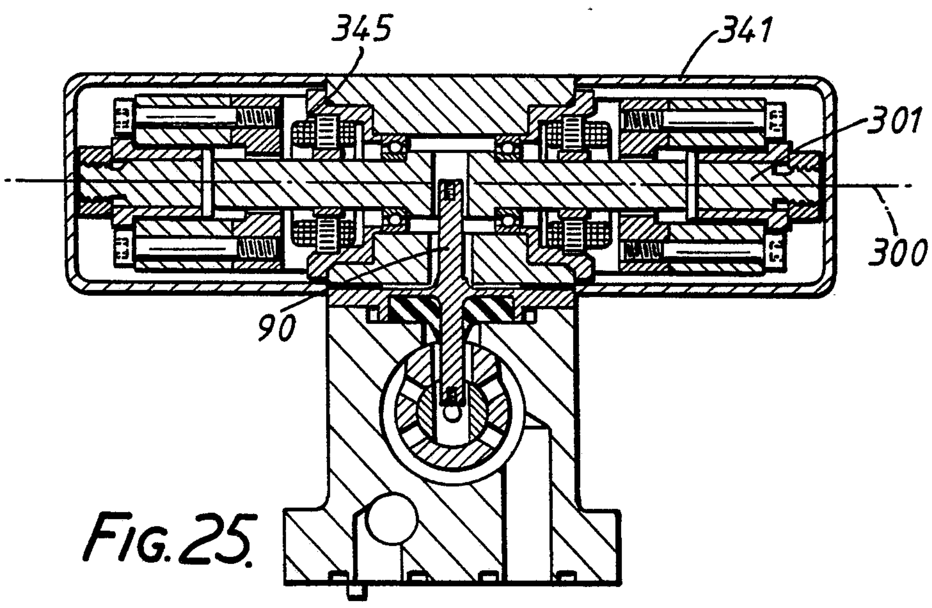

FIG. 25.

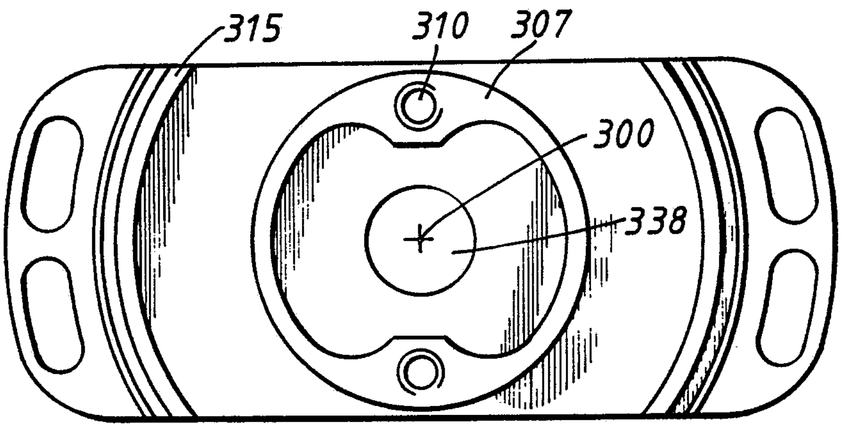

FIG. 26.

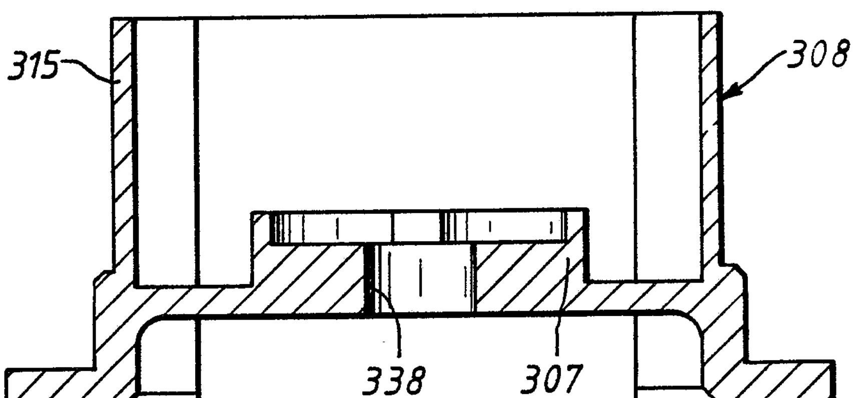

FIG. 27.

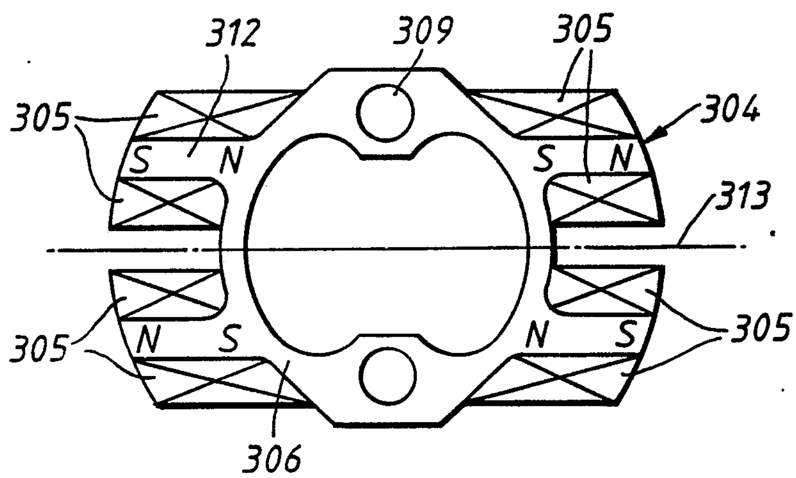

FIG. 28.

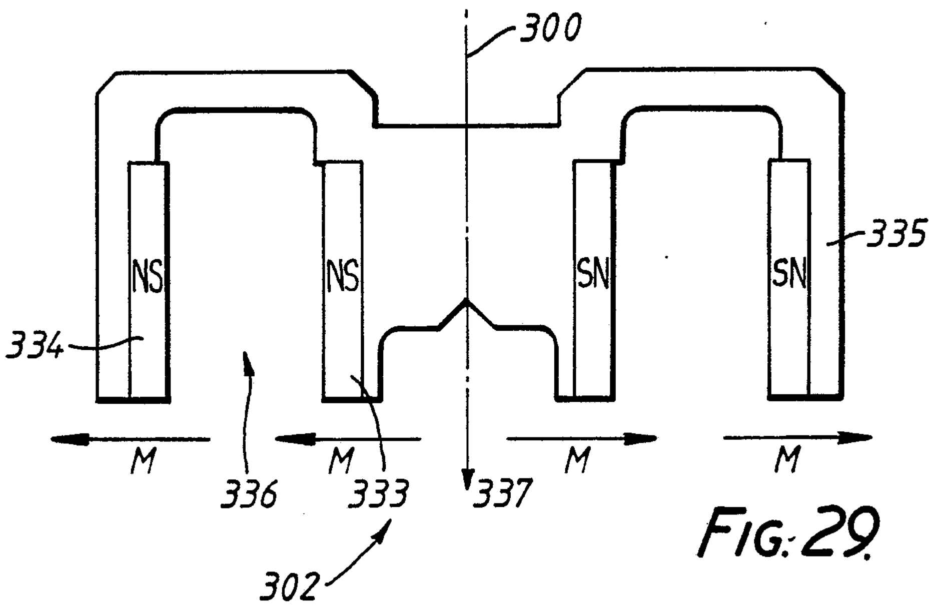

FIG. 29.

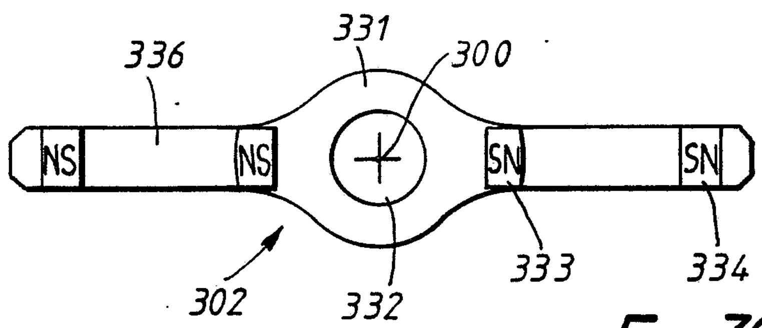

FIG. 30.

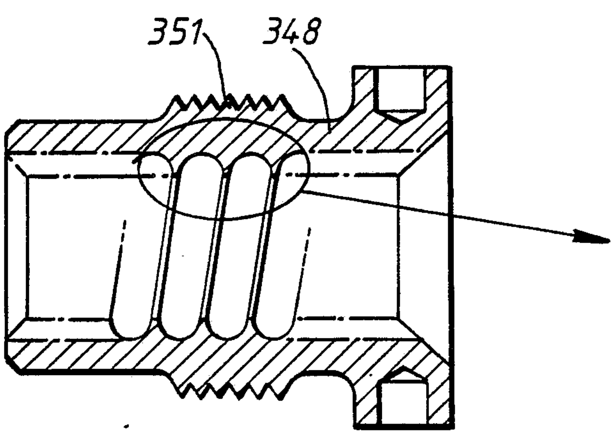

FIG. 33.

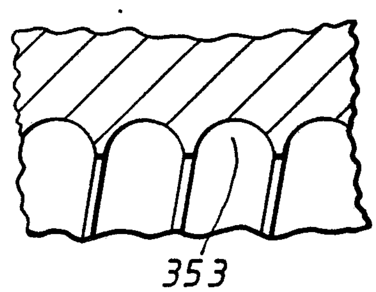

FIG. 34.

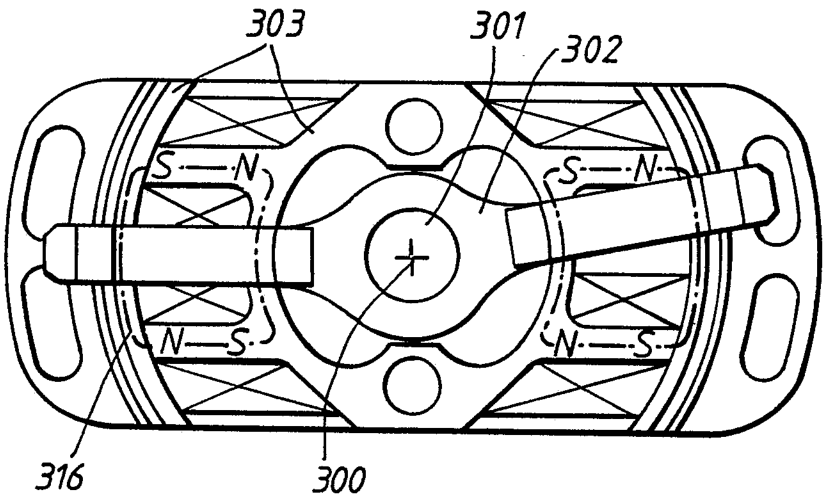

FIG. 31.

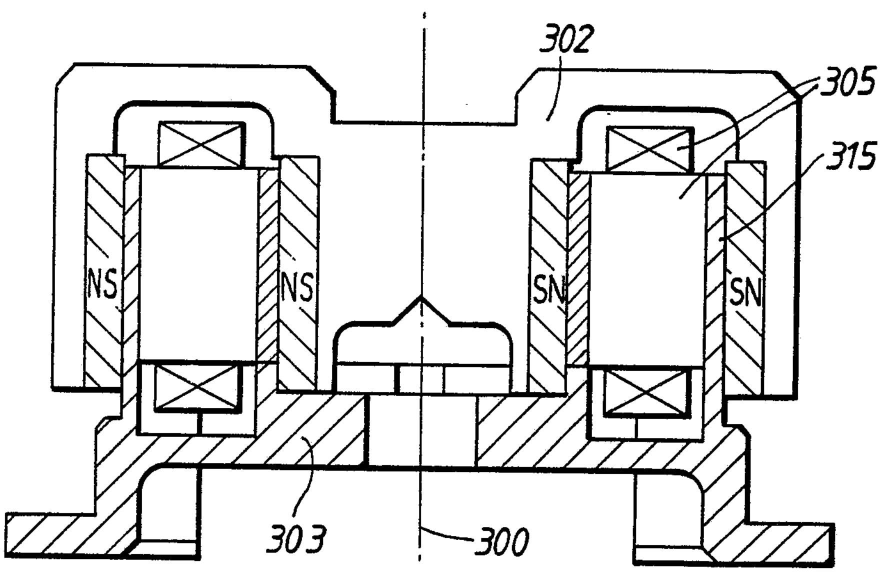

FIG. 32.