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

(11) Publication number: **0 202 011**
A2

(12) EUROPEAN PATENT APPLICATION

(21) Application number: **86302506.0**

(51) Int. Cl.[4]: **H01F 7/14**

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

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

(43) Date of publication of application:
20.11.86 Bulletin 86/47

(84) Designated Contracting States:
DE FR GB IT

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(54) Torque motors and valve assemblies.

(57) A torque motor is arranged at each end of a common shaft, e.g. for driving a servo valve.

The motor comprises a rotor and a stator. Preferably, the rotor carries at least one pair of samarium cobalt permanent magnets at radially spaced positions, the core material being disposed between the magnets. Such a motor can be relatively compact whilst producing a high torque.

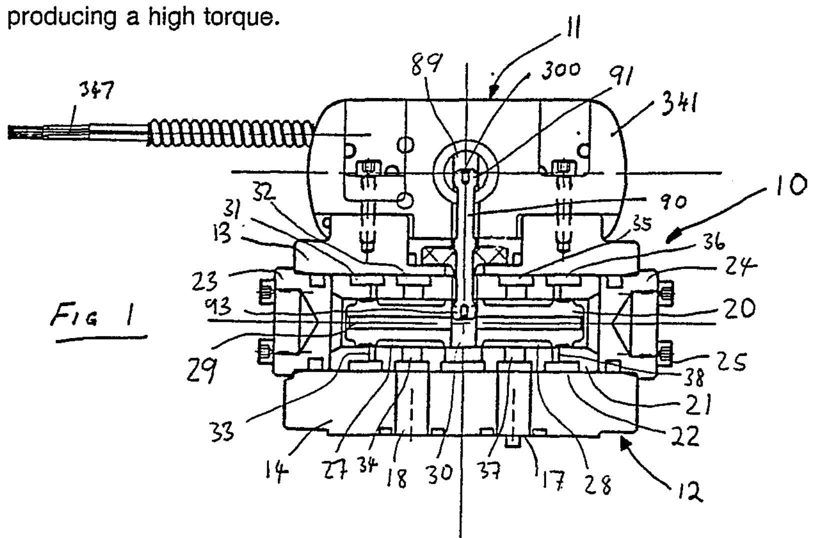


FIG 1

SECTION V-V

EP 0 202 011 A2

TORQUE MOTORS AND VALVE ASSEMBLIES

This invention relates to electric torque motors and to electrohydraulic servo valve assemblies, for example of the linearly-movable spool type, having such a motor.

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

However, known motors for this purpose are rather bulky and of disproportional size and weight as compared with the valve assembly. It is possible of course simply to reduce the size of the motor, but then problems arise in generating sufficient torque.

An object of the present invention is to provide an electric torque motor which can be both relatively compact and capable of generating a relatively large torque.

According to one aspect of the invention, there is provided an electric torque motor, whether for driving a fluid valve or for some other application, comprising 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 core material, e.g. iron, for the magnetic poles. Usually the material 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 arrangement 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 core material 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 circumferentially 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 where the magnetic poles 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 former 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.

From another aspect, the present invention comprises an electrohydraulic servo valve assembly including a ported valve housing, a movable valve spool slidable in the housing, electric motor actuating means according to said one aspect of the invention 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. Preferably, the pivoting of the lever is by distortion of its suspension or support.

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 the 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 strip strips shall be integral with the lever itself.

Where the electric motor 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, 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 vlave member to operate the valve.

In a further embodiment, 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 invention may be carried into practice in various ways, but one specific embodiment 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 V-V in Figure 2 in a plane through the longitudinal axis of the valve spool;

FIGURE 2 is a view in section on the line X-X in Figure 3;

Figure 3 is a view taken from the same direction as Figure 1 with an end cap of the motor removed;

Figure 4 is a section on the line Y-Y in Figure 3;

Figure 5 is a plan and Figure 6 is an elevation in section of the stator housing of the motor;

Figure 7 is a plan of the stator iron and windings for mounting in the housing of Figures 5 and 6 ;

Figures 8 and 9 are an elevation and plan of the rotor of the motor;

Figure 10 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 11 is a sectional elevation of the assembled rotor and stator; (Figures 10 and 11 are effectively enlarged views of parts of Figures 3 and 2);

Figure 12 is a sectional elevation of a sealing gland for leading the conductors into the motor housing;

Figures 13 is a detail of Figure 12.

Figures 14 shows a view in section of a valve casing and spool valve corresponding to that shown in Figure 4;

Figure 15 shows in plan view the driving lever support plate assembly of Figure 14;

Figures 16 and 17 show the support plate of Figure 15 in two sectional views at right angles to one another.

In the illustrated embodiment 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 duplicate 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 4) 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 35,36 with similar respective ports 37,38 near its other end.

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 301 carrying the rotors 302 of the two motors at its opposite ends is journalled in bearings 79 supported by fittings 80 bolted to the central body portion 75. Angular position pick-offs 345 are positioned to surround the shaft 301. 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 345 (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 301 is limited to $22\frac{1}{2}°$ on either side of its datum position. This limitation can be effected by means of fixed stops on end caps with which the spool abuts (not shown).

The rotation of the motor shaft 301 is transmitted to the spool 20 of the valve 12 via a pivoted lever 90, having a resilient suspension embodying important features of the assembly. At one end, the upper end as seen in figures 1 and 4, 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 diametrically through the enlarged portion 86 of the motor shaft. The lever 90 is pivoted about a transverse axis located at a distance of about half of the length of the lever from its end with the head 91. At its other end, the lever has a second enlarged integral head 93 of part-spherical profile. The lever extends upwardly from its pivotal axis 92 through an aperture formed in the central body portion 75, and extends downwardly from its pivotal axis through apertures in the valve body 13 and in th 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 301 rotates from its datum position of Figures 1 and 4 in either direction towards one or other of its limiting positions, this rotation will be transformed, by the sliding engagement of the lever head 91 in the transverse bore 89, at a lever below the axis of the motor shaft 301, 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 axis displacement. In a preferred practical construction, in which the length dimension of the lever is 25.65mm between the centres of head 91 and 93, rotation of the motor shaft 301 from its datum position through $22\frac{1}{2}°$ into either of its extreme positions will prdouce a corresponding axial displacement of the valve spool 29 of 0.5mm (0.020 inch) from its closed position. The bore 89 in the motor shaft 301 has a frustoconical portion 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 3.96mm.

As already described the function of the motor 11 is to be able to turn the lever 90 about its first axis in response to an electrical command signal. The maximum required angular deflection of the lever from the null position shown in Figure 1 is 2.27° in either sense.

The motor is duplicated on either side of the section line V-V in Figure 2 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 8 and 9 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 10 and 11.

The stator comprises a two-pole ferro-magnetic block 304 shown in Figure 7 with four windings 305 for magnetising it.

The block 304 is assembled from laminations parallel with the plane of Figure 7 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.

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 7.

When the block 304 with its windings 305 is assembled in the housing 308 the stator will be as shown in Figures 10 and 11 with the outer ends of the poles 312 in contact with an upstanding part-cylindrical wall 315 formed as a part of the housing 308 and providing a path for stator flux as indicated generally at 316 in Figure 10.

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 8 the body 331 is generally of m-shape so that in the elevation of Figure 9 it is of substantial width but of restricted height. The body carries, by means of an adhesive, four permanent samarium cobalt 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 are 334 of each pair define between them a space 336 for the stator block 304.

The magnets are magnetised as indicated in Figures 8 and 9 so that each has a pole facing the space 336 and the space is defined between the north pole on one magnet and a south pole on the other magnet.

The rotor and the stator can be easily assembled together as shown in Figures 10 and 11 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 2 and 4 and secured to the motor housing by bolts 342 to which the stator housing is also secured by bolts 343 (Figure 2).

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 10.

If however, a control signal is applied to the windings 305 the four stator poles 312 all become magnetised as shown in Figure 10 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 10. 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 2 and 4) 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 signal equal to the command signal diminished by the feed-back signal. 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 10 than would be the case if the four poles were equally angularly spaced around the axis 300. As shown in Figure 3 the dimension of the motor above the valve casing is less than that required with a conventional motor. 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 in solid form which is simpler than a laminated construction with laminations parallel to the plane of Figure 11, since the laminations are not all of the same shape, but if leakage flux perpendicular to the plane of Figure 11 is excessive a laminated construction can 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 neccessary 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 12) is threaded into the body 349 as shown in Figure 2 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 2 which is a detail of Figure 13. That provides a very effective fluid-tight seal between the interior of the body and the exterior.

The suspension of lever 19 will be described now with reference to Figures 14 to 17.

Referring first to Figure 14 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 the lever 90 which extends above and below the plane of the plate 200.

At either end of the lever 90 are the enlarged heads 91 and 93 locate respectively with the motor shaft 301 and spool 20.

Referring to Figures 15 to 17, the lever 90 is affixed, preferably integrally, substantially at right angles to the plate 200. On each side of the lever 90 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 thus forming thin integral strips. The areas 205 and 206 will act as torsion suspension springs supporting the lever 90 in a manner permitting it to rotate by twisting of the areas 205 and 206 about the longitudinal axis, that is to say about the axis marked at A on Figure 15. That rotation will of course be as a consequence of a movement of the motor 11 and its effect transmitted to the lever 90 via the enlarged head 91.

The plate 200 is provided at its under side with an annular flange 215 which in use abuts a corresponding seat 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 14 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 insert pressed into the cylinder 220.

By the use of a lever and lever plate arrangement as shown in relation to Figure 14 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 regards to the characteristics of the material of the assembly 200/90 and the the response required.

When a command signal to close the valve is given to the motors 11, these return the valve spool 20 to its centralised position, aided by the resilient torque of the twisted suspension strips 205,206. This resilient centering action of the strips 205,206 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 205,206 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 205,206 as well as the lever 90 itself are completely enclosed and sealed within a closed space defined between the plate 200 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 15 to 17 which forms the lever 90, its flexible suspension strips 205,206 and their mounting plate 200 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 205,206: 4.44mm (0.175 inch)

to which end should be added fillets of 0.51 mm

(0.020 inch) radius at each end.

Width of each thin strip 205,206: 2.03 mm (0.08 inch)

Thickness of each thin strip 205,206: 1.02 mm - (0.040 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.

The torque motor 11 may be used not only for driving the fluid vale defined in this the specification, but may be used for other applications where a compact body is required to produce a definite limited angular movement or torque in response to a command signal. Thus, the motor could be used as a torque motor for a gyroscope or perhaps for driving a potentiometer through a limited angle or for providing limited movement of a control device.

In Figure 7, the stator is illustrated in a version in which each pair of poles 312 extend in opposite directions parallel to axis 313. It is also possible however to splay each pair of poles apart at an acute angle to axis 313 and this may provide more favourable flux distribution leading to more uniform torque/angle characteristics. For further improvement, the flux path through each pole pair may be closed by respective outer arcuate lamination assemblies.

Claims

1. An electric torque motor comprising 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.

2. A motor according to Claim 1 wherein said magnets are permanent magnets.

3. A motor according to Claim 2 wherein said magnets are of samarium cobalt.

4. A motor according to Claim 1, 2 or 3 wherein said magnets are arranged in pairs which are radially spaced in relation to the torque axis to define between them a space for core material for the magnetic poles.

5. A motor according to Claim 4 wherein said core material is iron.

6. A motor according to Claim 4 or 5 wherein said core material is located in a space defined between a south pole on one magnet and a north pole on another magnet of a pair.

7. A motor according to Claim 4, 5 or 6 wherein there are provided two pairs of magnets on respec-

tive sides of the torque axis and on a common diameter, each pair defining a respective gap for a respective part of said core material.

8. A motor according to any one of Claims 4 to 7 wherein said core material is in the form of a figure of revolution having two parallel or inclined spaced cores on respective sides of the torque axis.

9. A motor according to Claim 8 wherein said cores are on respective sides of said magnets radially and/or circumferentially of the torque axis.

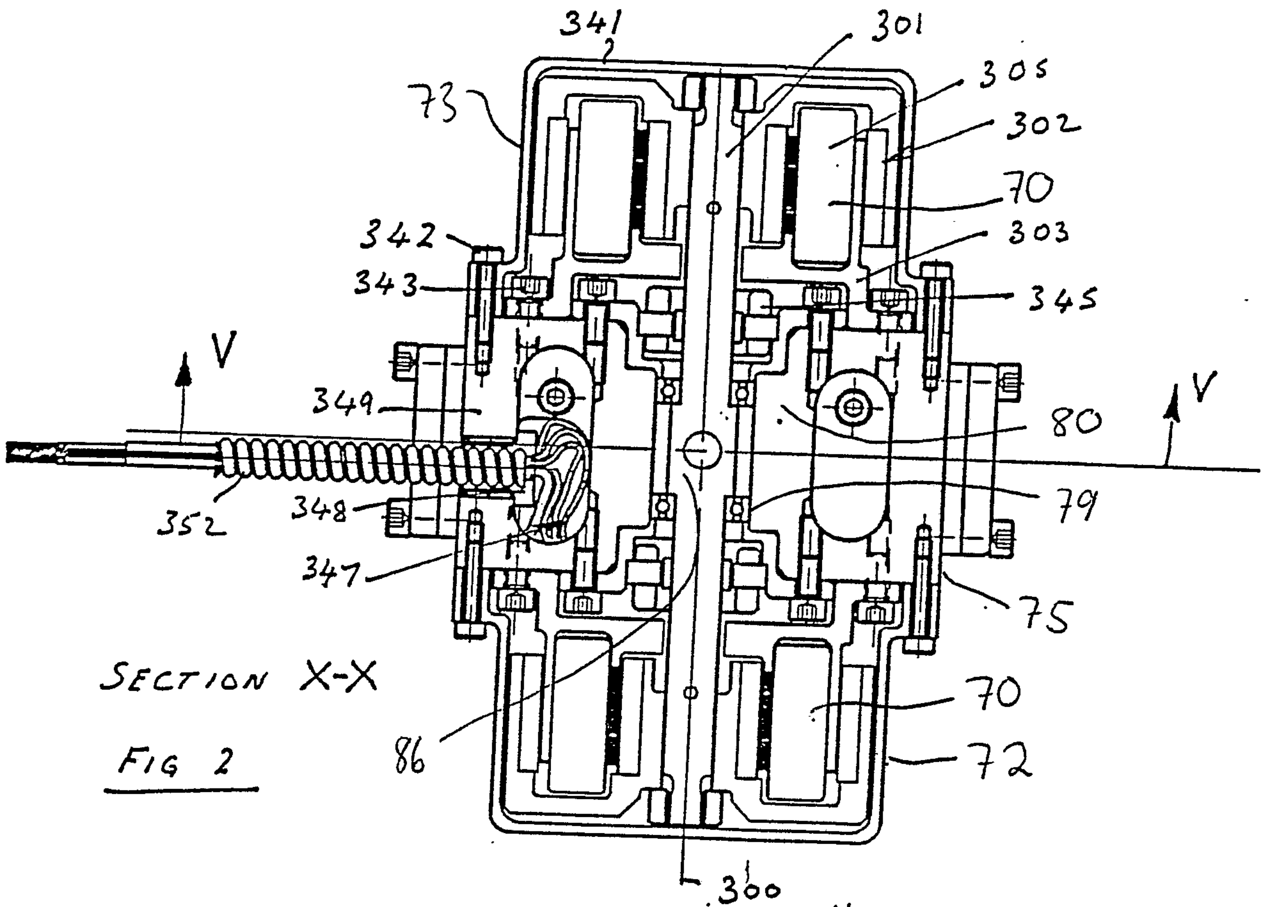
10. A motor according to any one of Claims 1 to 9 wherein the rotor and stator are each of multi-U form for assembly together by relative movement towards each other along the torque axis.

11. A valve assembly comprising a motor according to any one of the preceding claims and a hydraulic valve coupled to said motor to be driven thereby.

12. An assembly according to Claim 11 wherein said valve is coupled to said motor by way of a pivotably mounted lever.

13. An assembly according to Claim 12 wherein said lever is mounted for pivoting by distortion of its suspension or other support.

14. An electrohydraulic servo valve assembly including a ported valve housing, a movable valve spool slidable in said housing, an electric motor according to any one of Claims 1 to 10 mounted on the valve housing to serve as actuating means, and a pivotably supported lever which is arranged by pivoting about its suspension or other support to transmit drive from an output member of said motor directly to the valve spool to move the spool for valve operation.



SECTION X-X

FIG 2

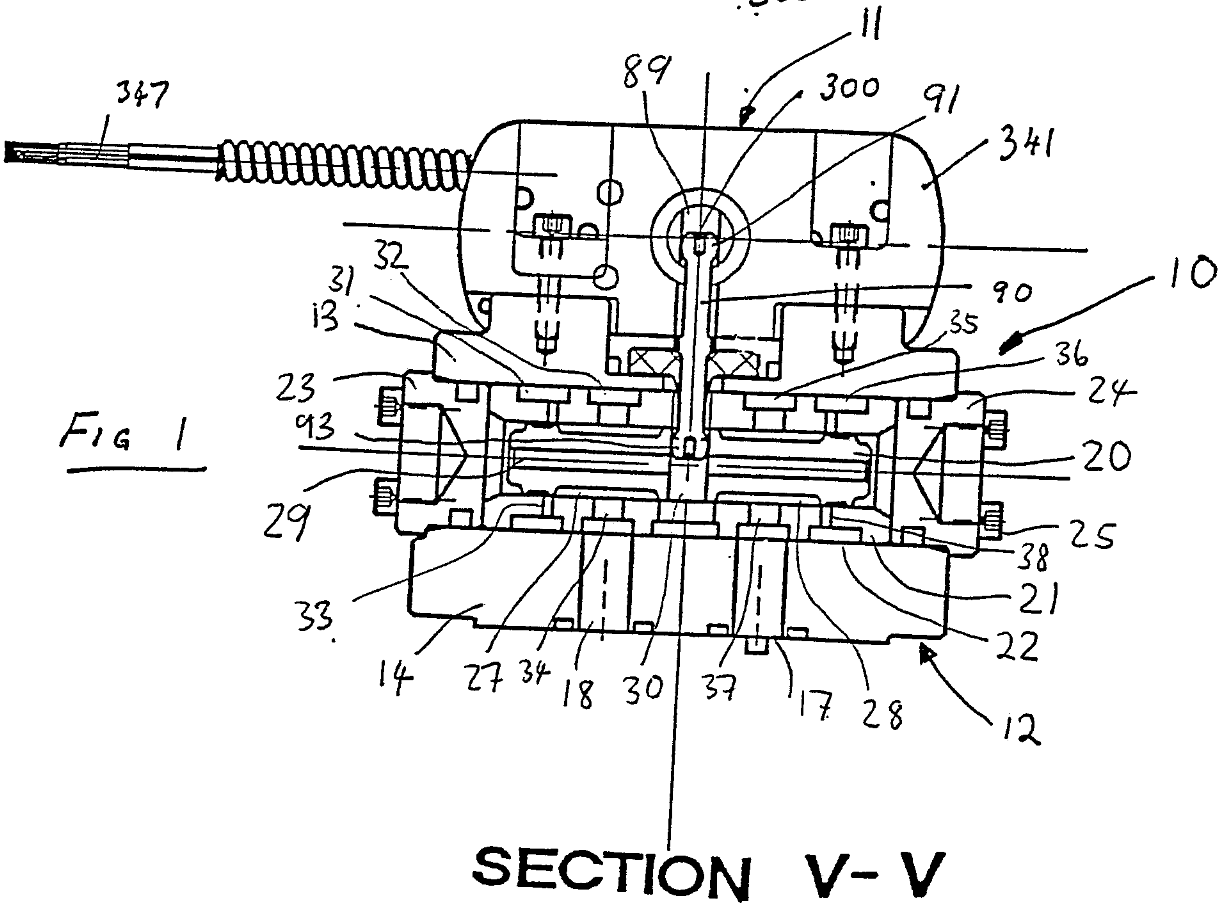


FIG 1

SECTION V-V

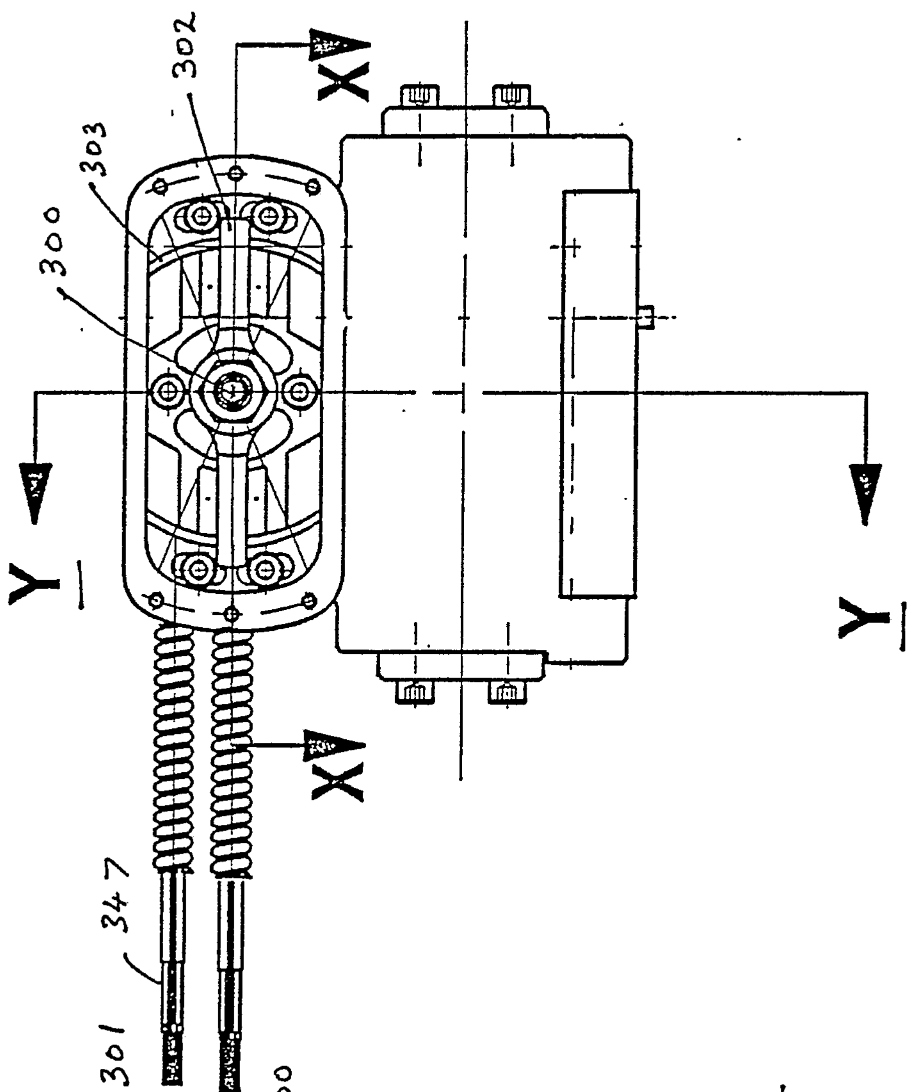


FIG 3

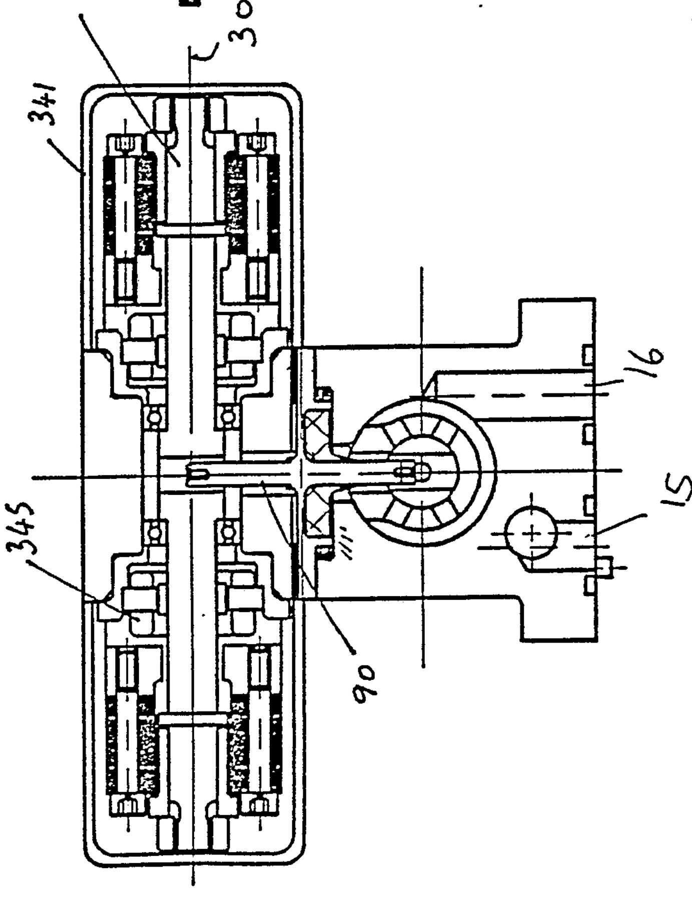


FIG 4

SECTION Y-Y

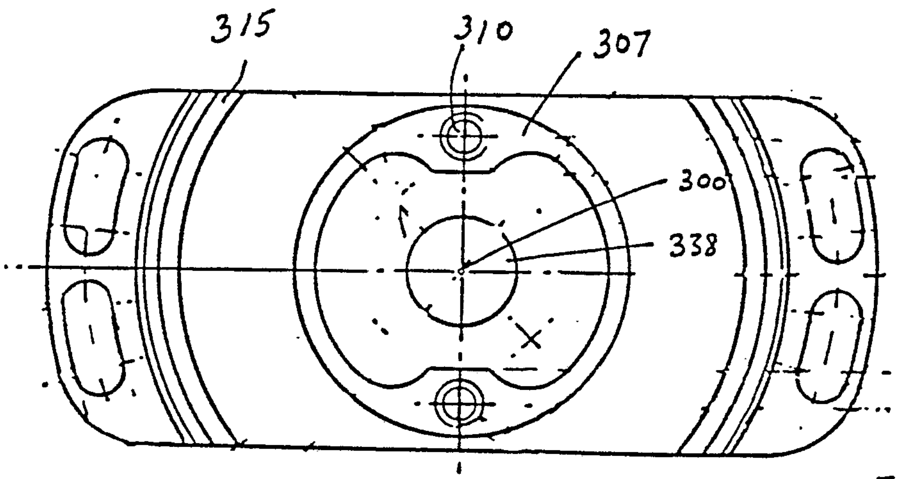


FIG 5

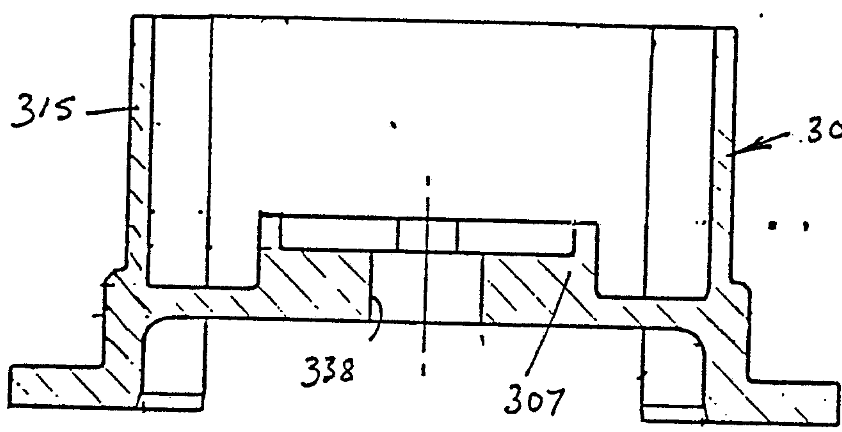


FIG. 6

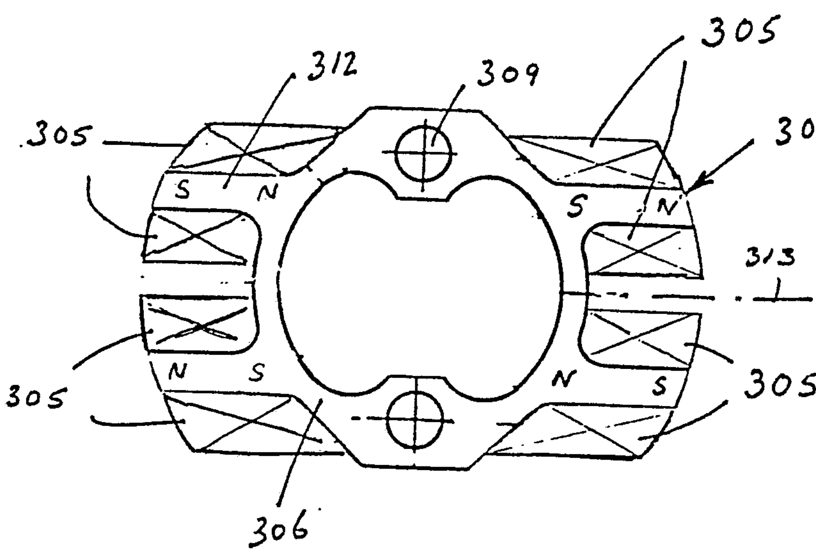


FIG 7

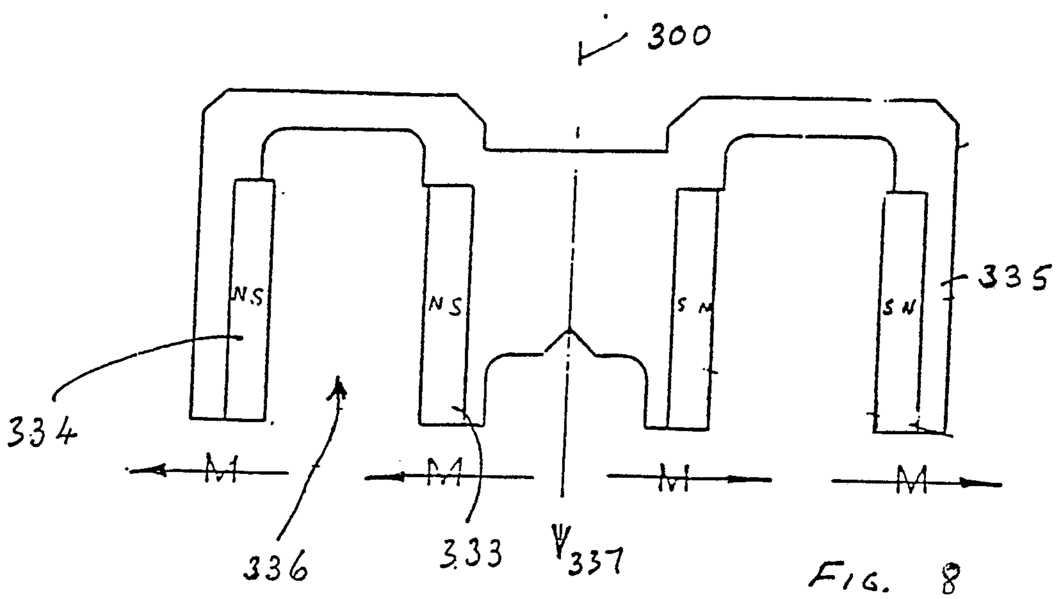


FIG. 8

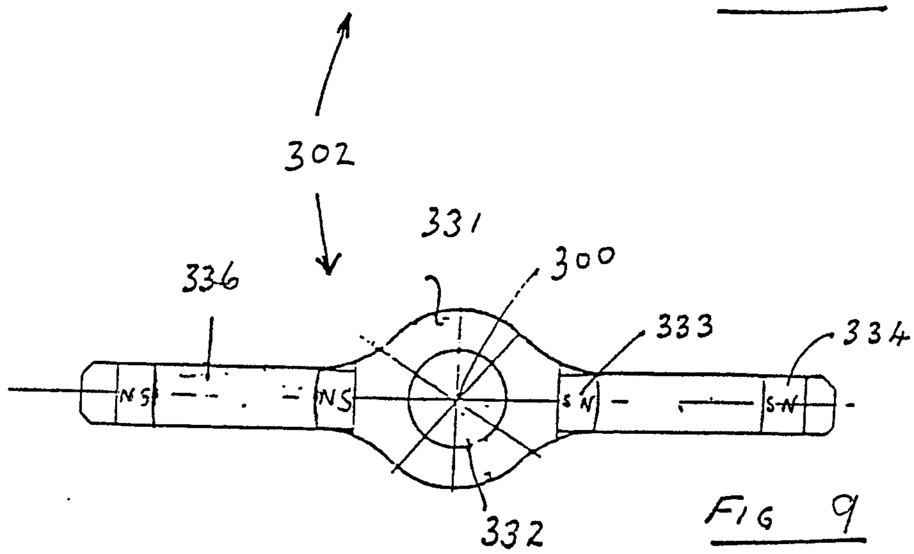


FIG 9

FIG 12

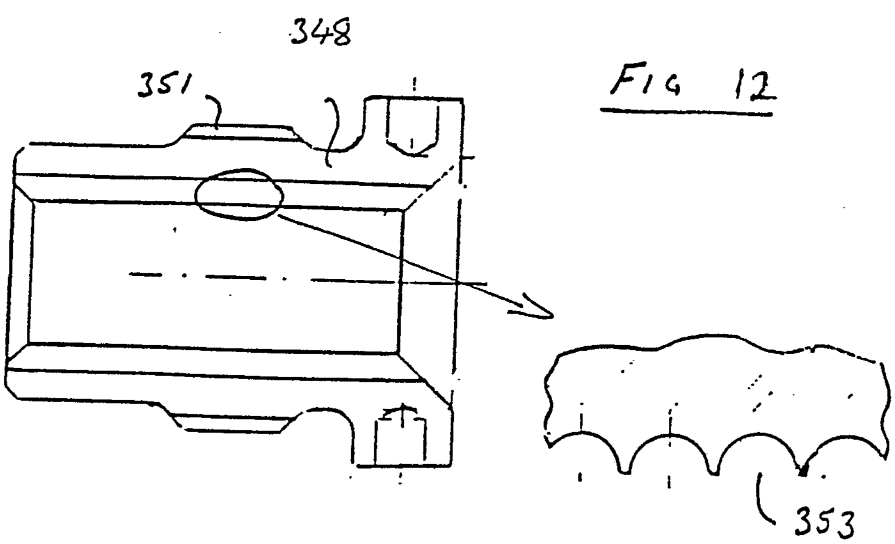


FIG 13

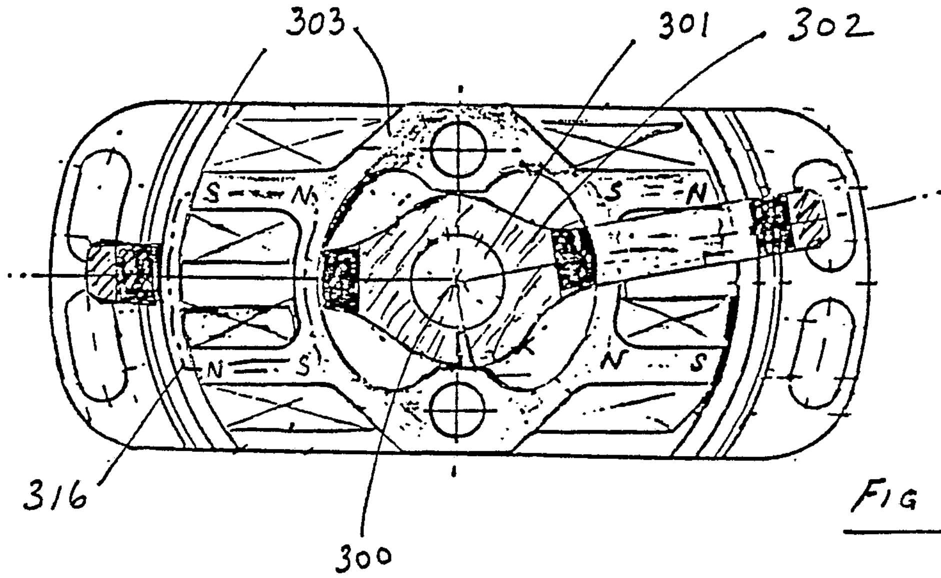


FIG 10

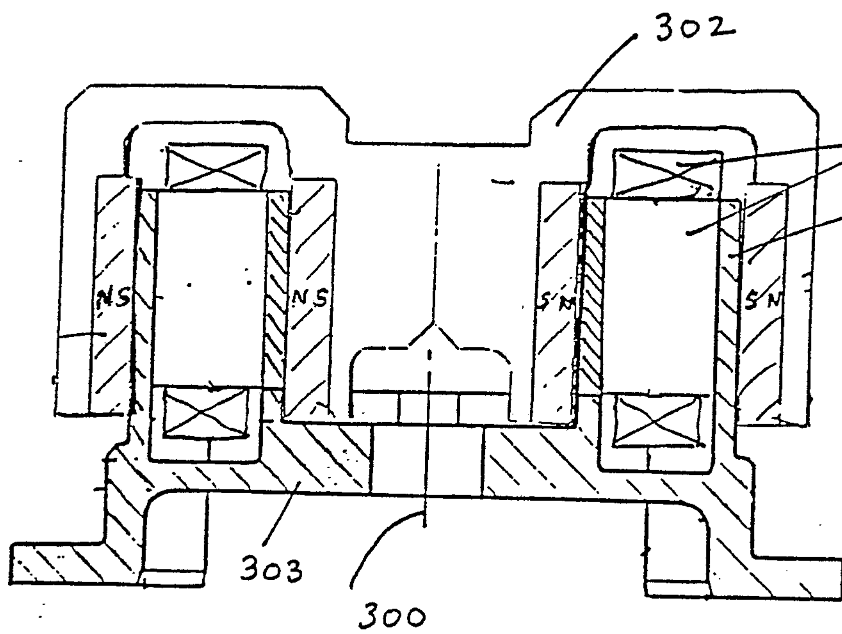


FIG. 11

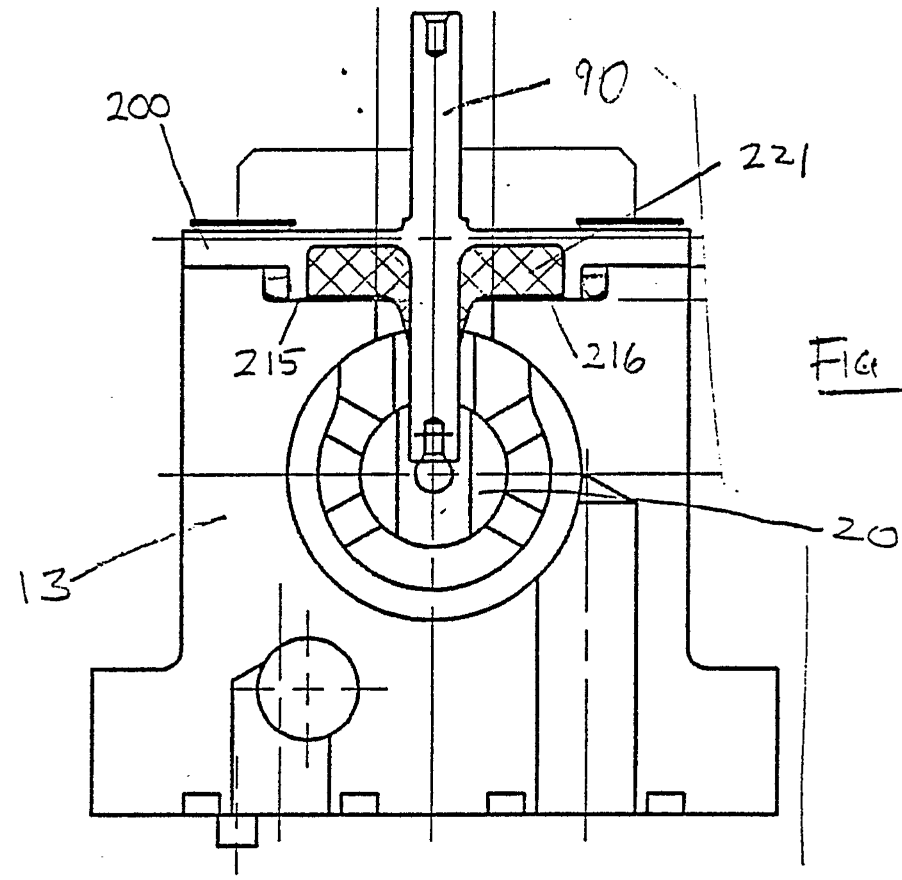


FIG. 14

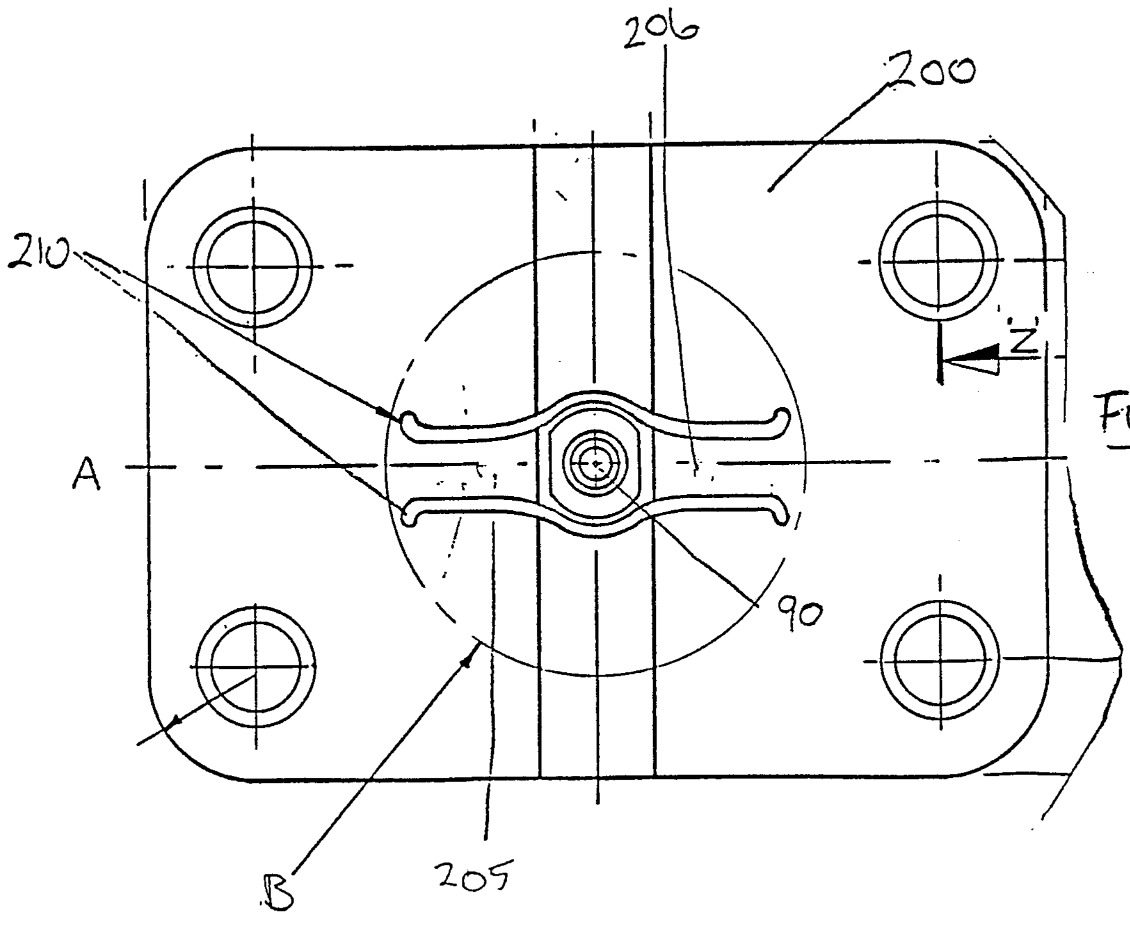


FIG 15.

FIG 16

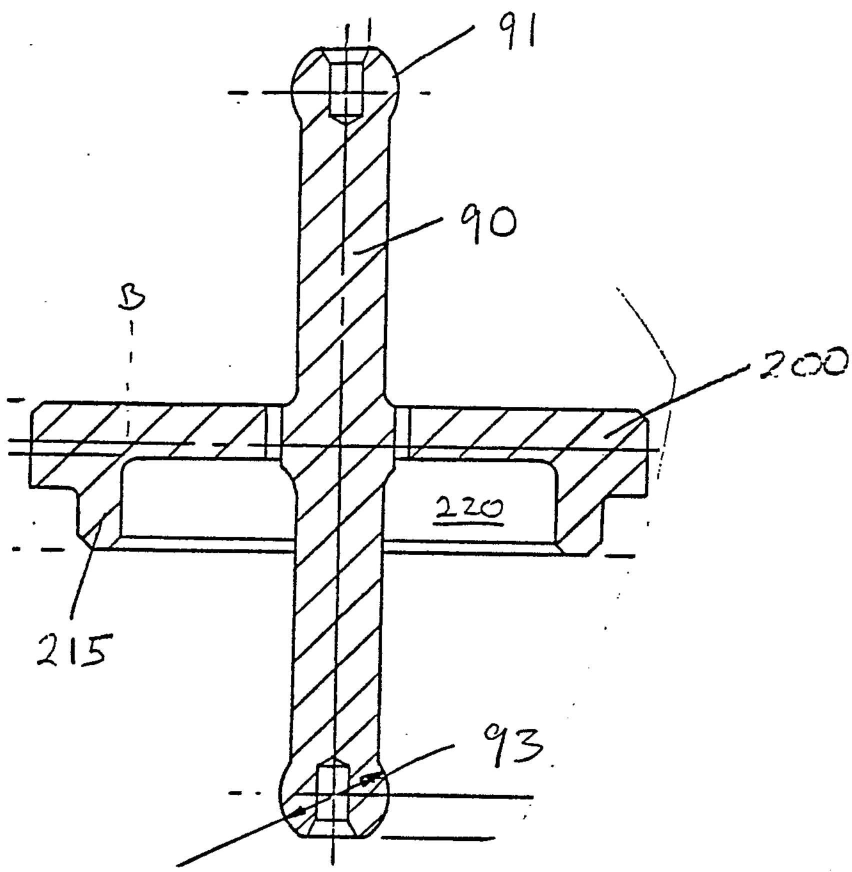


FIG.17