May 27, 1969 J. L. COAKLEY ET AL 3,447,111

SERVOVALVE CONSTRUCTION

Original Filed March 1, 1966

Sheet 1 of 3

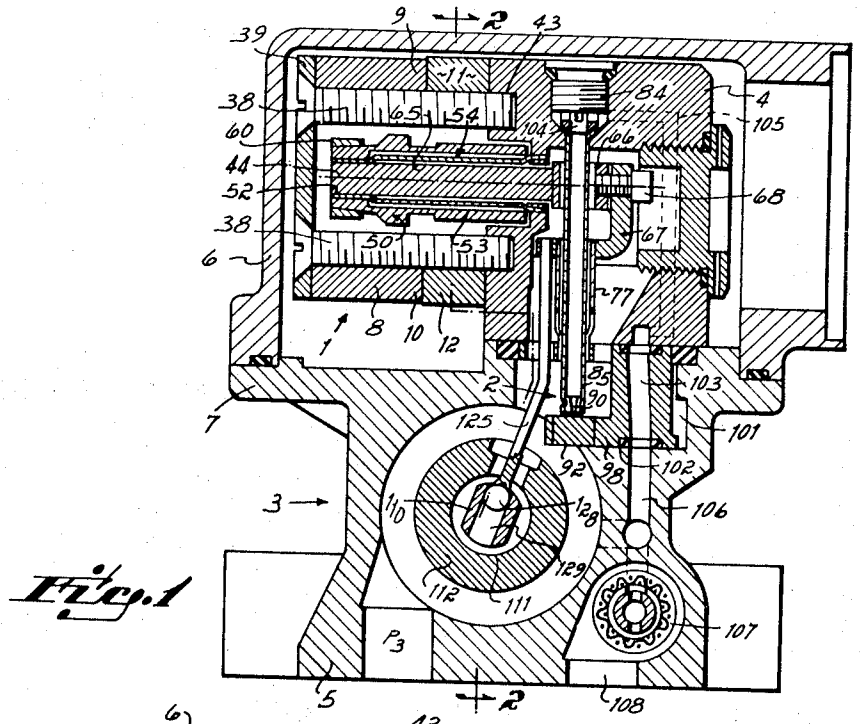


Fig. 1

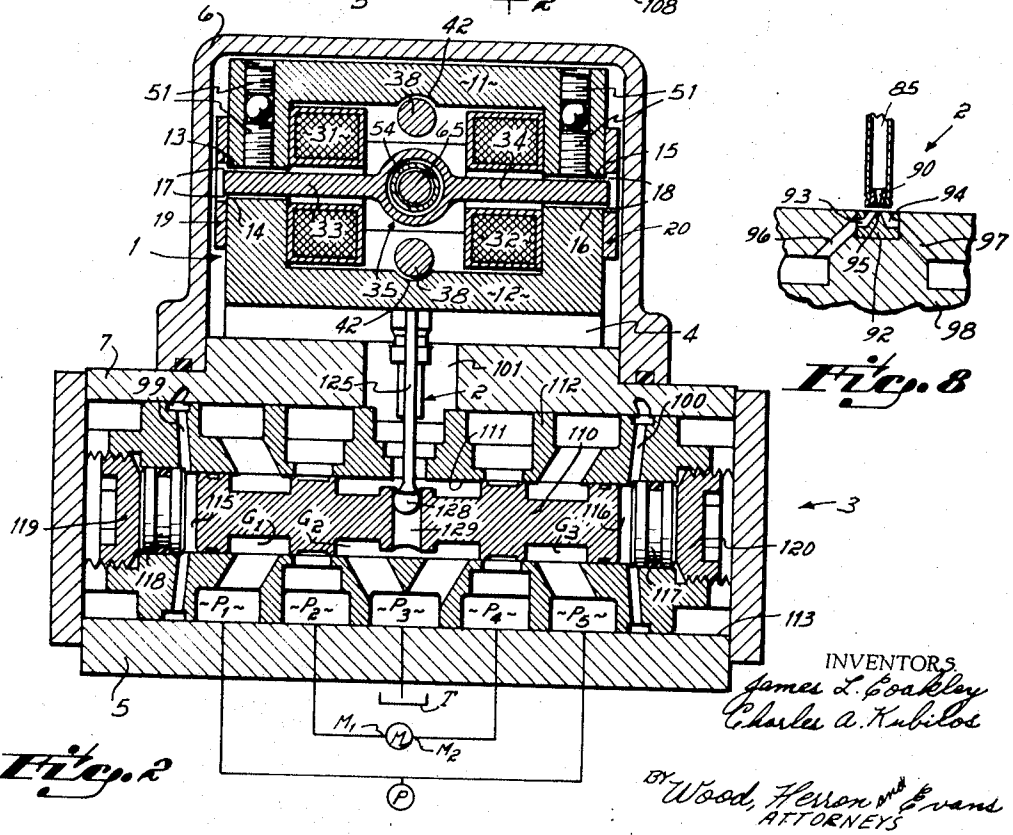


Fig. 2

Fig. 8

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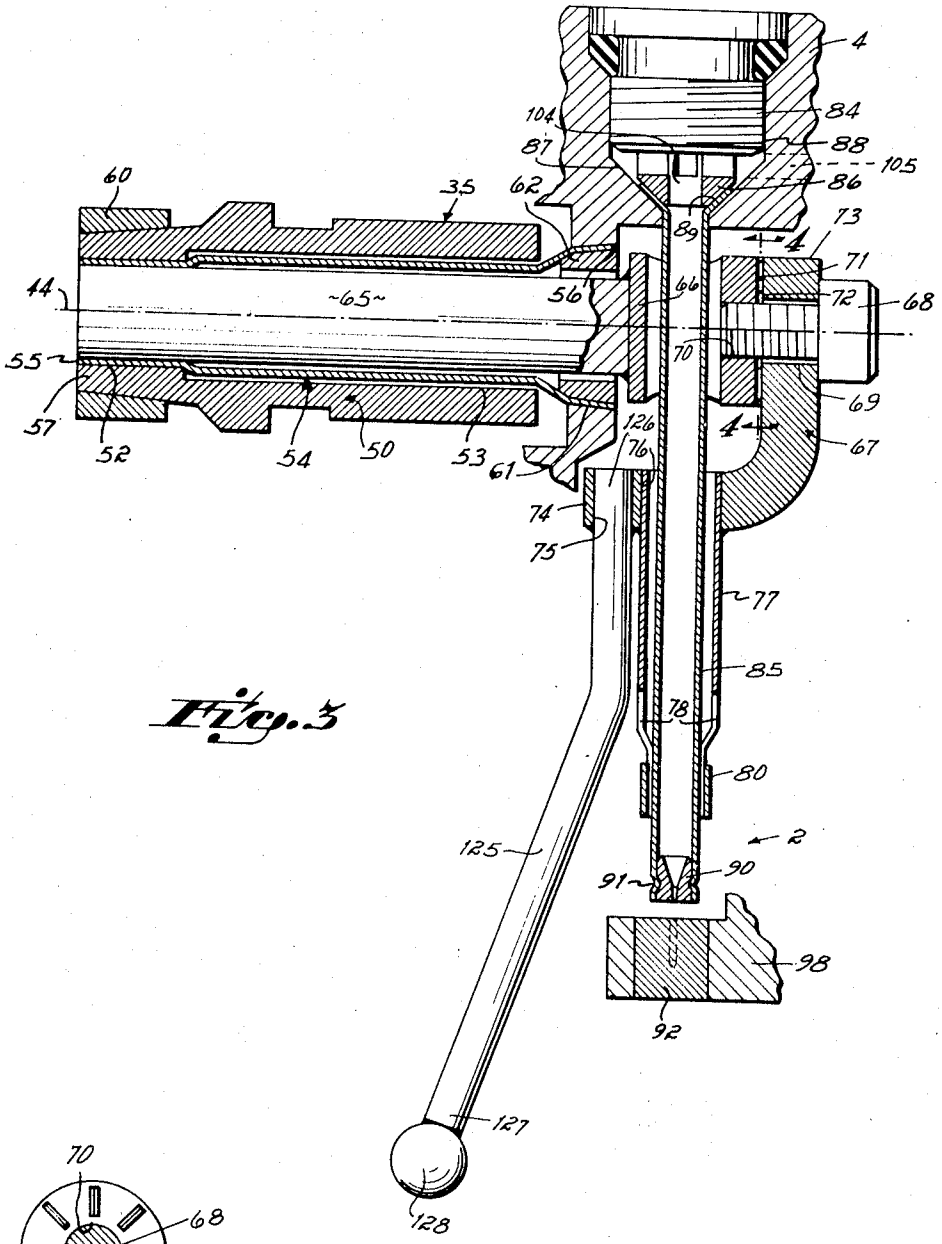


Fig. 3

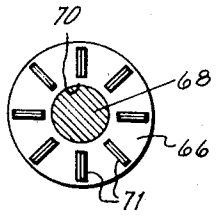


Fig. 4

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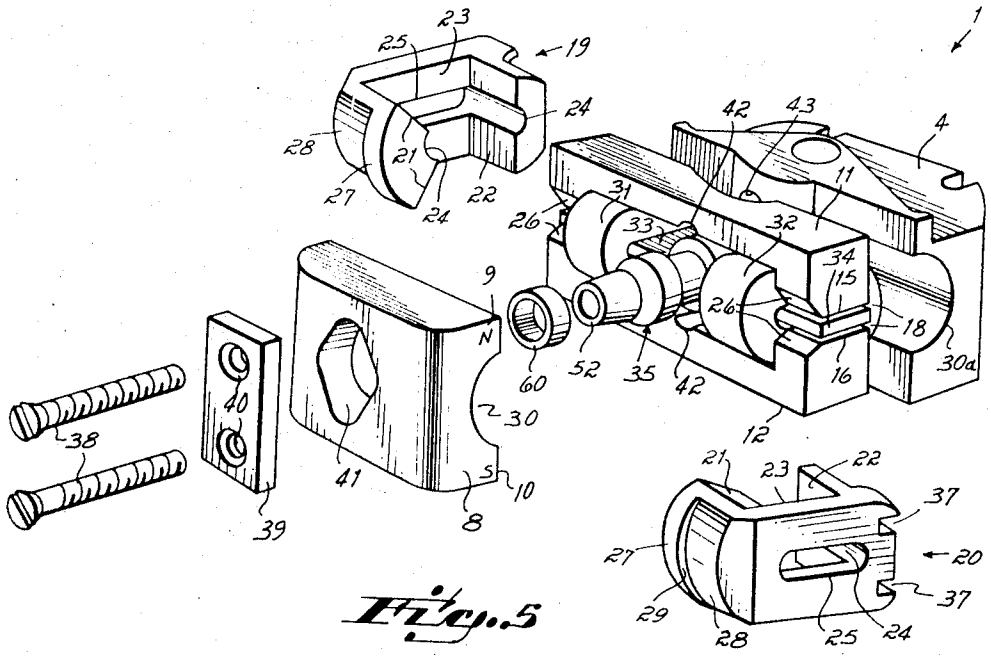


Fig. 5

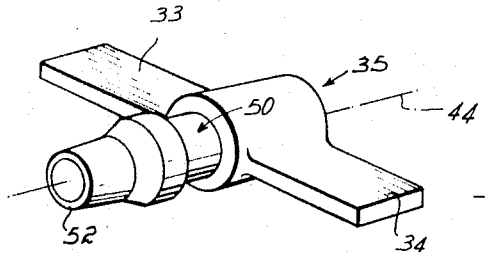


Fig. 6

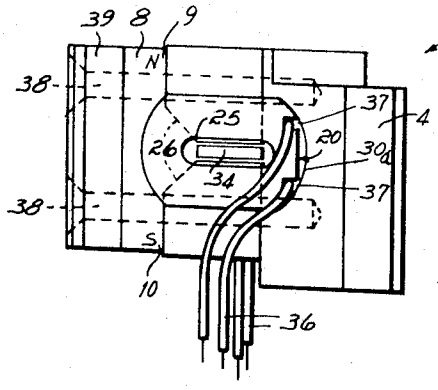


Fig. 7

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United States Patent Office 3,447,111
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3,447,111

SERVOVALVE CONSTRUCTION

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Original application Mar. 1, 1966, Ser. No. 530,916. Divided and this application Aug. 25, 1967, Ser. No. 671,906

Int. Cl. H01f 7/00, 7/08; H02k 33/00

U.S. Cl. 335—230

7 Claims

ABSTRACT OF THE DISCLOSURE

A torque motor having its armature mounted to a torsion member which is fixed to the armature at one point and fixed to a base at a second point. The torsion member is twisted axially by armature rotation. The armature operates a shaft or driver which is connected, at a position spaced from the connection of the armature to the torsion member, to transversely swingable output movement means. The output movement means are angularly disposed with respect to the shaft and are connected between the base and the shaft, and include a flexible portion between the connections to the base and the shaft.

This application is a division of my copending application Ser. No. 530,916, filed Mar. 1, 1966.

This invention relates to servomechanisms and more particularly to force feedback operated servovalves.

Servovalves of the general type to which this invention relates are operated by a torque motor and include two force amplification stages. Application of an electrical input control signal to an electromagnet coil in the torque motor causes an unbalanced flux distribution in the air gaps around the motor armature, causing a torque to act on the armature. The armature rotates in response to this torque, against spring means which bias the armature to its centered or null position. Movement of the armature shifts a jet of fluid issuing from a jet tube from a null position in which it is centered between two receiver ports, to a new position in which the jet impinges unequally on the two ports. This deflection of the jet establishes a differential pressure between the receiver ports which is proportioned to the input current. The fluid employed in conjunction with the jet tube may, of course, be either hydraulic or pneumatic fluid. In the description to follow, it is assumed that hydraulic fluid is utilized.

The pressures in the receiver ports are fed to the second stage of the servovalve, which is a spool valve hydraulic force amplifier. The differential pressure input from the first stage is reflected on opposed surfaces of a main spool or piston in the second stage, shifting the spool and establishing communication between various ports. Flow through these ports in the second stage varies with spool position. Spool movement in response to the differential pressure continues until a feedback spring member, through which the spool and jet tube are coupled, becomes sufficiently stressed that it returns the jet to the null position, thereby removing the pressure differential on the spool. When this has occurred the spool thereafter remains in that position, controlling flow through the second stage at a rate and direction corresponding to the magnitude and polarity of the electrical input signal to the torque motor.

From an economic standpoint as well as from a performance standpoint, the servovalves of the prior art have not been entirely satisfactory. The dissatisfaction can be traced to a number of structural features which, because of their design, have introduced complexities into the manufacture and assembly of the various component parts

constituting the valve. These complexities, in addition to increasing the costs of manufacture and assembly, have inherently limited the performance of the earlier valves.

For example, in one type of prior art servovalve the spring means used to bias the torque motor armature and jet tube to their balanced, central or null positions has included a tubular element which surrounds the jet tube and which functions in bending as a spring when the armature and jet tube are moved from their null positions.

In such valves, the spring means bends as the armature rotates in response to a signal. The extent to which the spring means bends is proportional to the total spring constant, which in turn is a function of spring shape and thickness. Since predictable and reliable operation requires close control of the spring constant, it has been found necessary in practice to machine these items with precision in order to accurately regulate their characteristic, and, hence, their spring rates. This need for precision machining has obviously added to the cost of such servovalves.

It has been an objective of this invention to provide an improved servovalve torque motor having an armature supporting and biasing spring which is more efficient of less critical manufacture, and which also is more economical than those which previous torque motors have used.

A further disadvantage of previous valves of the general type described is that they have not readily lent themselves to room temperature assembly procedures such as swaging, crimping, etc. Soldering or brazing has usually been required to make the critical connections, which invariably requires more skill, is costlier, and tends to produce warpage which may adversely affect valve operation unless compensated.

It has been a further object of this invention to provide a servovalve construction which eliminates the need for soldered or brazed connections at critical points, thereby eliminating warpage and misalignment which might otherwise be caused by heating of component parts during assembly.

Moreover, the prior art servovalves have often been difficult to assemble and align or adjust for maximum operating efficiency and performance. Once assembled, they have been difficult to disassemble for cleaning, repair, and inspection purposes.

It has been an additional object of this invention to provide a servovalve which can be assembled and disassembled relatively easily, and in which the first and second stages are separate subassemblies.

It has been another object of this invention to provide interlocking pole piece mounting means for a servovalve which permit accurate air gap dimensioning during assembly and protect against pole piece positional shifts while in use.

In a preferred embodiment of the invention, the torque motor armature has a pair of arms or wings on either side of a transversely extending hollow central body. An elongated armature restoring element in the form of a thin walled tube extends through the interior of the hollow central body of the armature. This tube is connected to and supports the armature only at a point forward of the wings, and is connected to a supporting base only at a point on the rear side of the wings. A shaft or driver also extends through the armature, internally of the armature restoring tube, and is connected to the armature and tube only at the front end thereof. Electromagnet coils are disposed on opposite sides of the armature and when energized are operative to turn the armature about the common axis of the shaft and tube, thereby rotating the shaft. The shaft or driver moves an elongated flexible jet tube which passes perpendicularly through an enlarged aperture in the rear portion of the

driver. The jet tube is secured at its fluid inlet end to the body above the driver and is connected to the driver through an elongated tube which surrounds the jet tube and which is clamped to the jet tube adjacent the fluid outlet end or nozzle thereof.

Use of the thin-walled tube described in this construction provides a number of advantages: a single length of precision tubing serves jointly as the support means for the armature, as a torsion spring biasing the armature to null position, and as an isolation element for preventing operating fluid within the hydraulic portion of the valve from reaching the inside of the electrical portion of the torque motor. In addition, the configuration of the hollow tube herein provided permits it to be connected to the armature and supporting base by swaging techniques, thus avoiding the usual disadvantages of machining and warping due to soldering or brazing during assembly.

In the torque motor, a pair of opposed, nonmagnetic members mechanically engage reference surfaces on the pole pieces of the electromagnetic coils and provide spacing means for establishing the proper air gap dimensions during assembly.

These and other objects and advantages of the present invention will be more readily apparent from a consideration of the following detailed description of the drawings illustrating a preferred embodiment of the invention.

In the drawings:

FIGURE 1 is a vertical section of a preferred embodiment of the servovalve of this invention, and is taken along the axis of the torque motor.

FIGURE 2 is a longitudinal section taken along line 2—2 of FIGURE 1, and also illustrates a typical hydraulic system including the servovalve.

FIGURE 3 is an enlarged vertical axial section of the first stage of the valve, showing the details of the torque tube, armature, hydraulic jet tube and receiver, and the force feedback spring assembly.

FIGURE 4 is a section taken along line 4—4 of FIGURE 3.

FIGURE 5 is a partially exploded perspective view of the torque motor assembly.

FIGURE 6 is an enlarged view in perspective of the armature.

FIGURE 7 is a side elevation of the assembled torque motor.

FIGURE 8 is an enlarged view in section of a portion of the jet tube and receiver.

The servovalve of this invention includes three principal sections, namely, a torque motor **1**, a first force amplifying stage **2**, and a second force amplifying stage **3**. As best shown in FIGURES 1 and 2, in a preferred embodiment, the torque motor **1** and first amplifying stage **2** are supported by a common base or frame member **4**. Base **4** is nonmagnetic, and is mounted on a body **5**, the body **5** also serving as a casing for the second section **3** of the servovalve. A housing **6** mounted on a horizontally extending flange **7** of the body **5** encloses motor **1** and amplifier **2**.

The torque motor **1**, as shown more particularly in FIGURES 5–7, includes a permanent magnet **8** having an upper north pole **9** and a lower south pole **10**. Magnet **8** may be an Alnico permanent magnet. Sandwiched between magnet **8** and base **4** are opposed ferromagnetic upper and lower C-shaped pole pieces **11** and **12**, respectively. The opposed planar end surfaces **13**, **14** and **15**, **16** of pole pieces **11** and **12**, respectively, are spaced, forming air gaps **17** and **18**, respectively (see FIGURE 2). The permanent magnet **8** functions to establish a unidirectional magnetic flux in each of the air gaps **17**, **18**.

Also sandwiched between magnet **8** and base **4** are a pair of nonmagnetic spacer members **19** and **20**. Since members **19** and **20** are similar, only the left member **19** will be described. Member **19** is C-shaped, as viewed from above, and includes opposed internal pole piece engaging surfaces **21**, **22** separated by pole piece end-engaging surface **23**. Surface **22** is generally planar for engaging the back surfaces (adjacent base **4**) of the pole pieces **11** and **12** to align them in its plane. Pole piece-end-engaging surface **23** is provided with a horizontal slot **25**, and from this slot horizontal grooves **24** extend across the inner side faces of the spacer to permit the assembly to be placed over the armature. The surface **23** abuts the ends of pole pieces **11** and **12**, establishing alignment in its plane. The angulated internal surfaces **21**, **21** (see FIGURE 5) engage the opposed beveled corner surfaces **26**, **26** of the pole pieces **11**, **12** and jointly function to locate and accurately space pole piece end surfaces **13**, **14**, thereby dimensioning air gap **17**. Thus, when spacer **19** is snugly fitted over the left ends of the pole pieces **11** and **12**, pole piece surfaces **13** and **14** are horizontally and vertically aligned by surfaces **22** and **23**, as well as spaced apart to form an air gap **17** by angulated surfaces **21**, **21**. Those skilled in the art will recognize the criticality of accurate air gap dimensioning.

A forwardly extending, vertical flange **27** is formed on the rounded external surface **28** of each spacing member. Flange **27** is provided with a flat shoulder surface **29**, best shown on the spacing member **20** in FIGURE 5, and engages and seats in the internal end surface **30** of the magnet **8**, thereby preventing movement of the spacing member relative to pole pieces **11**, **12** when the motor **1** is assembled.

The motor **1** also includes a pair of coils **31**, **32** through the open centers of which extend the flat wings **33**, **34**, respectively, of an armature **35** described in detail hereinafter. In the assembled torque motor **1**, the coils **31**, **32** are mounted by and between the opposed concave magnet surface **30** and concave base surface **30***a*, pole pieces **11**, **12**, and spacing members **19**, **20**. The coil leads **36** pass through slots **37** in the spacing members **19**, **20** for connection to a suitable electrical signal input means (not shown) which may be conventional.

The various parts of the torque motor assembly are held in operative relation by two screws **38** and a plate **39**. The screws **38** pass successively through plate apertures **40**, magnet aperture **41**, grooves **42** in pole pieces **11**, **12**, and thence into tapped holes **43** in base **4**. As screws **38** are tightened, magnet **8** and base **4** are drawn together, gripping the pole pieces **11**, **12** and holding the spacing members **19**, **20** between them. The spaces between members **19**, **20** and faces **30**, **30***a* are filled with an epoxy which provides a positive interlock in the torque motor.

The operation of the torque motor **1** follows principles which are well known and need not be discussed in detail. It is sufficient for the purposes of understanding the various features of this invention to appreciate merely that a differential current applied to coils **31**, **32** will result in a magnetic torque being applied to ferromagnetic armature **35**, rotating it about its axis **44**. Armature **35** rotates under the force of the applied torque to an angular position within air gaps **17**, **18** where the applied torque equals the armature restoring torque produced by means to be described. The direction and magnitude of the applied torque is dependent upon the level and polarity of the differential current flowing in the coils **31**, **32**. For a detailed discussion of the operation of torque motors, reference may be had to U.S. Patent 2,891,181, to Raymond D. Atchley, issued June 16, 1959, and entitled, "Torque Motor."

The armature **35** of motor **1** is generally T-shaped as viewed in plan, and includes a central tubular portion **50** provided with oppositely extending flat wings **33**, **34** of equal length (see FIGURE 6). The dimensioning of wings **33**, **34** is such that they extend into air gaps **17**, **18** respectively. Clearance is provided between the wings **33**, **34** and the pole piece end surfaces **13**, **14** and **15**, **16** respectively, permitting the armature **35** to rotate about its axis **44** in response to the application of an electrical signal to the windings **31**, **32**. The extent of armature rotation is

selectively limited by adjusting screws **51, 51** threaded into tapped holes in upper pole piece **11** (see FIGURE 2).

The forward extremity of central tubular portion **50** of armature **35** has a reduced internal diameter resulting in a stepped-diameter bore having a small diameter bore section **52** and a large diameter bore section **53** separated by an internal shoulder. Positioned within the bore sections **52, 53** is a non-magnetic stepped diameter armature-supporting torque and isolation tube **54**. The torque tube **54** is secured at its reduced diameter front end portion **55** to the end **57** of the armature tubular portion **50**, and at its other end **56** to the base **4**. The portion of tube **54** intermediate ends **55** and **56** is coextensive lengthwise with bore section **53** of central armature portion **50**, but is of reduced diameter and does not contact the armature.

The end **55** of torque tube **54** fits snugly within bore section **52** of the central armature portion **50** and is secured in place by an internally tapered swaging ferrule **60** which is pressed over the externally tapered armature end **57**. The complementary tapers of armature end **57** and ferrule **60** securely lock the armature **35** and torque tube **54** to the end of a coaxial driver **65**, providing a solderless connection therebetween.

The tube **54** at its inner end **56** is flared and fits snugly into a tapered bore **61** in base **4**. An externally tapered swaging ferrule **62** pressed within flared end **56** of torque tube **54** secures the torque tube to base **4**. The complementary tapers of swaging ferrule **62** and base bore **61** lock the flared end **56** of torque tube **54**, thereby providing a solderless connection between the base **4** and the torque tube **54**.

Thus, armature **35** is supported within motor **1**, with its wings **33, 34** centrally positoned within air gaps **17, 18** and biased against rotation about its axis **44** by torque tube **54**, the latter being connected at its outer end **55** to the front end of the armature and at its inner end, beyond the opposite end of the armature, to base **4** via ferrules **60** and **62**, respectively.

The relation of the torque tube **54** and armature **35**, as herein described, wherein the tube passes axially through the armature and is connected at its outer end to the armature enables a relatively long torque tube **54** to be employed as the spring element in the torque motor **1**. With a long torque tube **54** in contrast to a short one, there is less angular rotation of the tube per unit length for a given armature rotation.

To transmit the torque output of motor **1** to the first amplifying stage **2**, a deflection or coupling means is provided. The coupling means includes a non-magnetic driver **65** which passes axially through torque tube **54**. As previously mentioned, the outer end of driver **65** is secured to the armature **35** and torque tube **54** by swaging ferrule **60**. At its other or inner end driver **65** is secured through an element **66** having an opening extending therethrough at right angles to the driver, to an arm or yoke **67** for movement therewith. Arm **67** has a right angle bend intermediate its ends, thereby forming an L-shape, and its lower portion thus projects forwardly beneath element **66** and parallel to driver **65**. The connection between the vertical leg **73** of arm **67** and element **66** is by a screw **68** which passes through an oversized hole **69** in leg **73** and which is threaded into a tapped hole **70** in element **66**. Radial teeth **71** formed on the element face (see FIGURE 4) engage the forward surface **72** of vertical leg **73** to prevent relative angular movement between collar **66** and arm **67** when screw **68** is tightened.

The lower or forwardly extending leg **74** of arm **67** is provided with two holes **75** and **76**. A tube **77** is secured in hole **76** by suitable means. Soldering or brazing may be employed here since warpage is not critical at this point. The lower end of tube **77**, including the reduced-diameter lower end portion thereof, has circumferentially-spaced longitudinal slots **78** therein. The slots **78** enable the reduced-diameter portion of tube **77** to securely embrace the periphery of a vertically disposed flexible jet tube **85**. This tube extends through and is gripped by the lower end portion of tube **77** under the action of a press fitted ring **80** which clamps the slotted, reduced-diameter end portion of tube **77** to jet tube **85**.

In the first amplifying stage **2**, jet tube **85** extends through tube **77**, hole **76**, and element **66** and is secured at its upper end only to base **4** by a conical-ended retainer plug **86** and screw **84**. Plug **86** and screw **84** cooperate with the sloping walls **87** of a threaded hole **88** to securely lock the flared end **89** of jet tube **85** relative to base **4** when screw **84** is tightened. At its lower end, jet tube **85** is fitted internally with a projector jet **90** having an outlet nozzle and which is secured in place by a crimp **91**.

The first amplifying stage **2** also includes a receiver **92**. Receiver **92** is a plug having a pair of fluid passages **93, 94** (see FIGURE 8) which meet over a central knife edge **95**. Passages **93, 94** communicate with passages **96, 97**, respectively, formed in a receiver supporting member **98**. The passages **96, 97** in turn communicate with passages **99, 100** (see FIGURE 2) which constitute the inputs to the second amplifying stage **3**.

The receiver supporting member **98** is connected to base **4** by means not shown and, when the servovalve is assembled, is positioned within a cavity **101** in body **5**, seating and sealing on surface **102** thereof. A passage **103** is formed in member **98** which connects the upper end of jet tube **85** to a source of pressure fluid via passage **104** in plug **86**, passage **105** in base **4**, passage **106** in body **5**, filter **107**, and inlet port **108** in body **5**.

In operation, when an electrical signal is applied to the torque motor **1**, armature **25** initially rotates from a centered position to a point where the restoring force on the armature **35** equals the magnetic torque produced by the electrical input. These restoring forces arise from deflection of the torque tube **54**, jet tube **85** and a feedback spring to be described. The armature rotation is transmitted to the jet tube **85** via driver **65**, element **66**, arm **67**, and tube **77**, bending or deflecting jet tube **85** from a centered position directly over knife edge **95** of the receiver. As the jet tube **85** is deflected from the centered, null position shown in FIGURE 8, it directs a greater proportion of the fluid issuing from its nozzle **90** to one or the other of the receiver passages **93, 94**. The pressure in that receiver passage toward which the nozzle **90** is deflected will increase while the pressure in the other passage will decrease. Excess pilot flow from jet tube **85** which is not accepted by either receiver passage flows to a fluid reservoir. Thus a differential between the pressures in passages **93** and **94** is developed. This differential constitutes the input to the second amplifying stage. A slight rotation of armature **35** produces a relatively large displacement of jet tube **85** and a relatively large pressure differential develops between passages **93** and **94**. This pressure differential is capable of developing much larger forces than could be developed by the armature alone. Hence, force multiplication is produced by the first amplifying stage.

The second amplifying stage **3** includes a main spool valve having a spool or piston **110** slidable in a bore **111** of a sleeve **112** (see FIGURE 2). Spool **110** has a series of axially spaced peripheral grooves G_1, G_2, and G_3. Sleeve **112** is fitted into a bore **113** in the body **5** and it is provided with a plurality of port means P_1, P_2, P_3, P_4, and P_5 which communicate with bore **111** at axially spaced positions, and which cooperate with spool grooves G_1–G_3 to direct the flow of fluid through the main valve. Ports P_1–P_5 can be interconnected in various ways by the selective positioning of spool **110** relative to sleeve **112**. For example, if the spool valve is to control or meter the flow of fluid a variable speed reversible motor M, motor ports M_1 and M_2 may be connected to ports P_2 and P_4, respectively. The pump outlet port is connected to both ports P_1 and P_5, and port P_3 is connected to a tank T. In such a system, when spool **110** is moved to the right in sleeve

112, the motor M is driven in one direction by fluid from pump P which takes the following path: port P_1, groove G_1, port P_2, motor port M_1, motor M, motor port M_2, port P_4, groove G_2, port P_3, to tank T. If spool **110** is moved to the left, motor M is driven in the opposite direction by fluid from pump P taking the path through port P_5, groove G_3, port P_4, motor port M_2, motor M, motor port M_1, port P_2, groove G_2, port P_3, to tank T. The speed at which motor M is driven depends, of course, on the flow rate through motor M, which in turn depends on the extent to which spool **110** is displaced from the centered position wherein no flow occurs.

The port P_3 in sleeve **112** also communicates with the region surrounding projector jet **90**, thereby providing a path to tank T for excess jet stream fluid not entering either of the two receiver ports **93**, **94**.

The means for selectively moving spool **110** includes pressure chambers **115** and **116** in bore **111**, pressure in which acts upon the opposite end surfaces of spool **110**. Chambers **115** and **116** communicate with passages **99**, **96**, **93** and **100**, **97**, **94** respectively, and reflect the differential established by the first stage. Adjustable stops **117** and **118** are sealed to bore **111** and can be positioned axially therein to limit the movement of spool **110** by plugs **119** and **120** respectively which are threaded into body **5**.

In operation, the input to the second amplifier stage **3**, that is, the pressure differential between passages **93**, **94**, produces a differential or net axial force on spool **110**. The direction which this differential force moves spool **110** depends upon the polarity of the electrical signal input to the motor **1**. Thus, fluid flows to motor M, in the selected direction.

Since the electrical signal is supplied for as long as it is desired to drive motor M, which usually will be much longer than it takes spool **110** to shift an amount corresponding to the flow rate and motor speed desired, force feedback means are provided. This force feedback means includes a feedback spring **125** which is connected at its upper end **126** to horizontal leg **74** of arm **67**. The connection is effected by securing end **126** in hole **75**. The other end **127** of spring **125** has a ball **128** attached thereto. Ball **128** fits accurately and without play in a cross bore **129** in spool **110** forming a cam connection between the spool and the feedback spring.

Spool **110** will move in sleeve **112** as long as there is a pressure differential between chambers **115** and **116**. Since this pressure differential is caused by the unequal impingement of fluid on receivers **93**, **94** due to the deflection of jet tube **85**, the force on spool **110** will remain as long as the jet pipe **85** is deflected. However, spring **125** is responsive to the position of spool **110**, and supplies a feedback force to driver **65** which returns jet tube **85** to null position and thereby removes any net force on the spool **110** when the spool has been shifted an amount corresponding to the magnitude of the input signal.

By way of example, referring to FIGURE 2, a counterclockwise jet tube rotation will produce an unbalanced force in chamber **116** which shifts spool **110** to the left. As spool **110** moves to the left, it rotates the feedback spring **125** clockwise. This clockwise motion is transmitted to arm **67**, which in turn transmits it to the armature and tends to turn the jet tube clockwise to the null position. The spool position at which feedback spring **125** returns jet tube **85** to the null position corresponds to a unique and discrete input current level. Hence the servovalve will regulate the speed of motor M in accordance with the input signal. The spool **110** will remain in this position until the electrical signal is again varied.

It will be apparent from the symmetry of the valve that oppositely poled electrical input signals rotate the armature **35** and torque tube in the opposite direction, causing the spool to move toward the other side of its center or neutral position.

From the foregoing it will be apparent that the interrelation of the armature, torque tube, driver, arm, jet tube, and force feedback spring provides an assembly which is exceedingly compact in relation to the high gain which can be attained. The torsion spring length is relatively large in proportion to the small size of the assembly, as shown in FIGURE 3. Moreover, the arrangement of the first stage elements wherein the jet pipe projects through the driver and is engaged by the outer tube **77** only adjacent its lower end, provides a relatively long lever arm in compact form. Assembly of the valve is facilitated since the entire first stage subassembly forms an integral unit with torque motor **1** which can be fitted as a unit to the second stage **3**.

While we have described a preferred form of this invention, it will be understood that it is susceptible of various modifications and adaptations within the scope of the following claims.

What is claimed is:

1. A torque motor comprising:

a base,

magnet means mounted to said base, said magnet means having spaced poles defining an air gap between them,

coil means,

an armature having an axis of rotation, said armature including a portion extending into said air gap for magnetic interaction with flux in said gap,

a torsion member connected between said armature and said base at axially spaced positions for torsionally constraining the rotation of said armature about said axis, said armature being supported only by said torsion member to be rotated about the axis of said member in response to the application of an electric signal to said coil,

a shaft coupled to said armature for rotation therewith, said shaft providing a rotational movement correlated with the magnitude of said electric signal,

and transversely swingable output movement means angularly disposed with respect to said shaft, said output movement means being connected between said base and a position on said shaft spaced from the connection of said torsion member to said armature, said output movement means including a flexible portion between the connections to said base and said shaft.

2. The torque motor of claim **1** wherein said magnet means comprises a permanent magnet and two separate pole pieces in magnetic circuit relation therewith, said pole pieces presenting opposed reference surfaces, a reference surface being formed adjacent each air gap and extending angularly with respect thereto:

and a nonmagnetic member having angulated opposed spaced surface means extending between and engaging said reference surfaces of said pole pieces, said surface means disposed to oppositely align said pole pieces and to establish a predesigned minimum air gap width.

3. The torque motor of claim **2** wherein said motor includes an air gap on each side of said axis, said armature is symmetrical about said axis and includes opposed portions extending into said air gaps, there also being a pair of said nonmagnetic members:

said pole pieces and nonmagnetic members being clamped in sandwich relation between said permanent magnet and said base.

4. The torque motor of claim **1** wherein said armature includes a flat wing on each side of an axially disposed hollow central portion, the axial dimension of said central portion exceeding the axial dimension of said wings, and further wherein said torsion spring extends through said hollow portion of said armature and is connected to said armature only at one end of said central portion at a point spaced axially from said wings.

5. The torque motor of claim **1** wherein said output movement means projects freely through a diametrical

opening in said shaft and is connected to said shaft at a point thereon spaced axially from said opening.

6. The torque motor of claim 5 wherein said output movement means has a free outer end on one side of said diametrical opening and is connected to said shaft by an arm between said outer end and said point on said shaft.

7. A torque motor comprising:

a base having a bore therethrough,

a tube having one end positioned and sealed in said bore,

an armature disposed coaxially around said tube and rigidly connected to said tube at a second end thereof, said tube between its ends passing freely through an axial opening provided in said armature,

magnetic means for exerting rotational force on said armature, said means disposed to urge said armature to rotate about the axis of said tube, said tube torsionally resisting such rotation of said armature,

a shaft coupled to said armature for rotation therewith,

said shaft extending axially through the center of said tube and having a portion projecting beyond said tube through said bore,

and elongated flexible output movement means connected at one end to said base and extending angularly with respect to the axis of said shaft, said output movement means also being connected to the portion of said shaft which projects beyond said tube.

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GEORGE HARRIS, *Primary Examiner.*

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