Nov. 29, 1960 R. D. ATCHLEY 2,962,611

ELECTROMAGNETIC ACTUATOR

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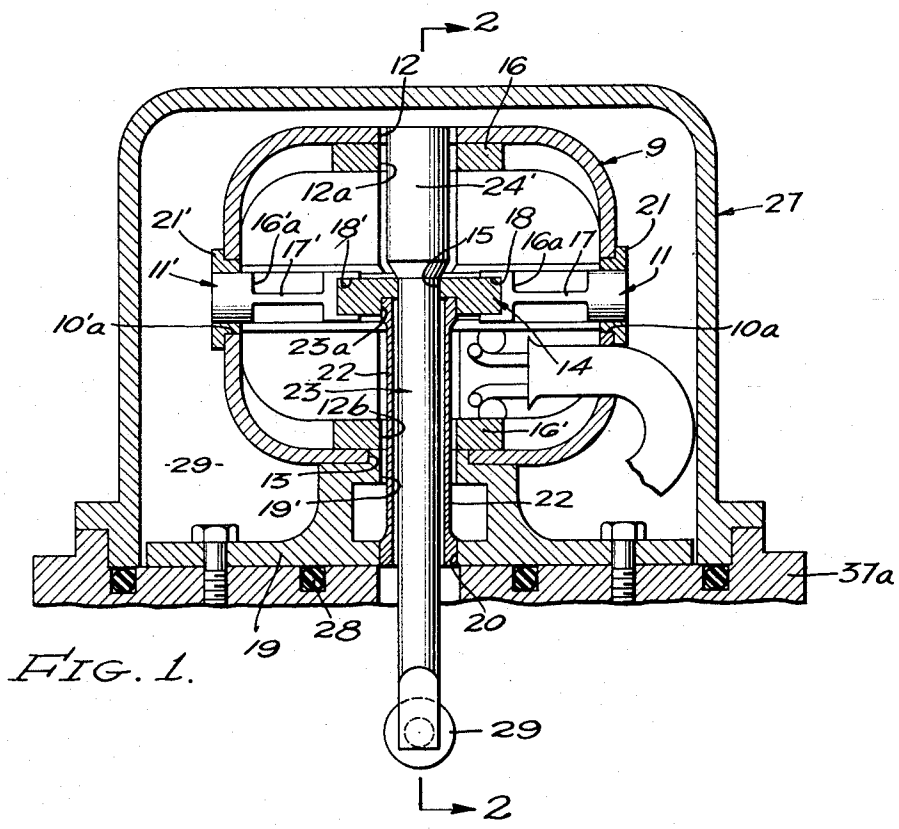
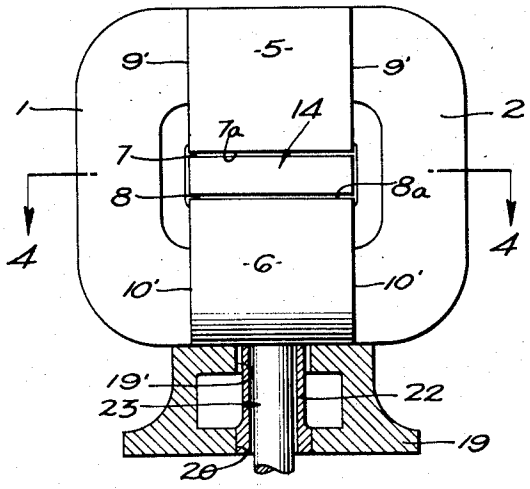



FIG. 1.

FIG. 3.




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ELECTROMAGNETIC ACTUATOR

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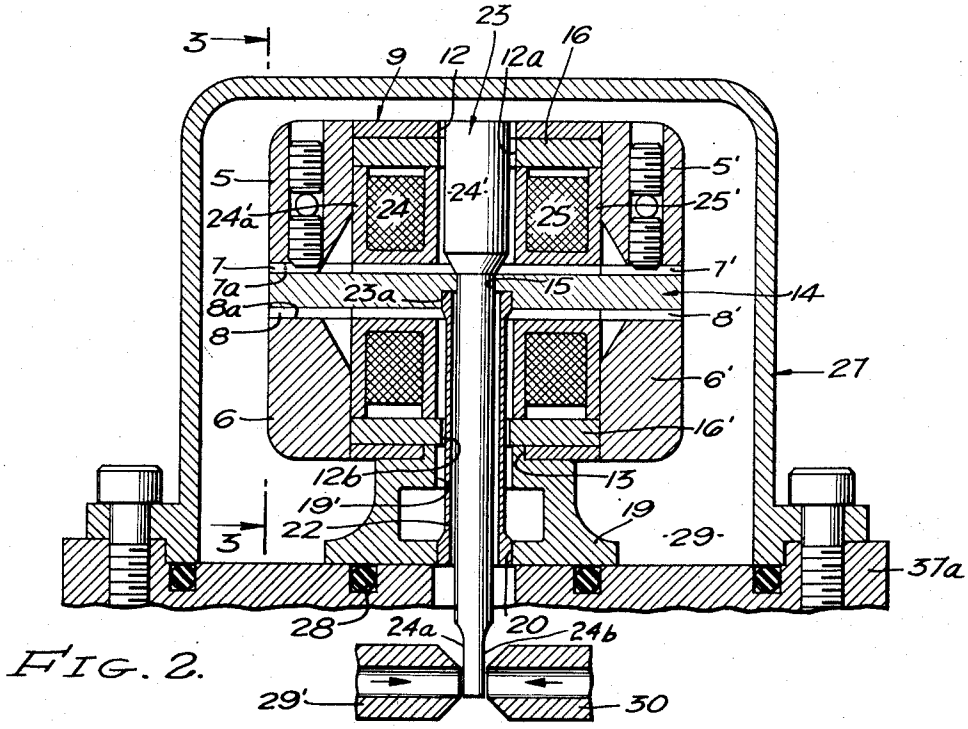



FIG. 2.

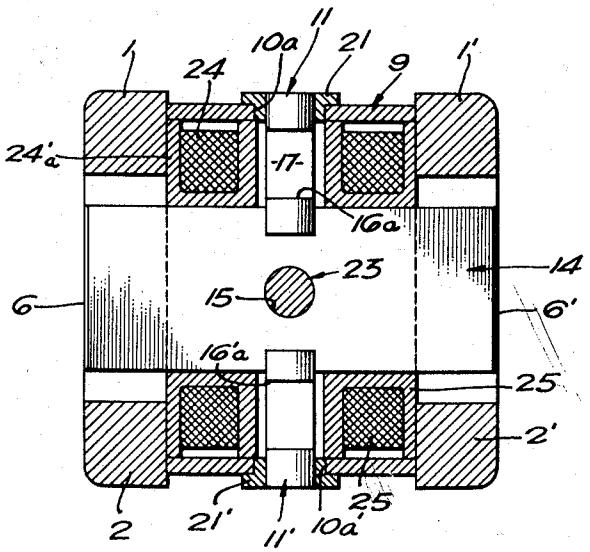



FIG. 4.

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FIG. 5.

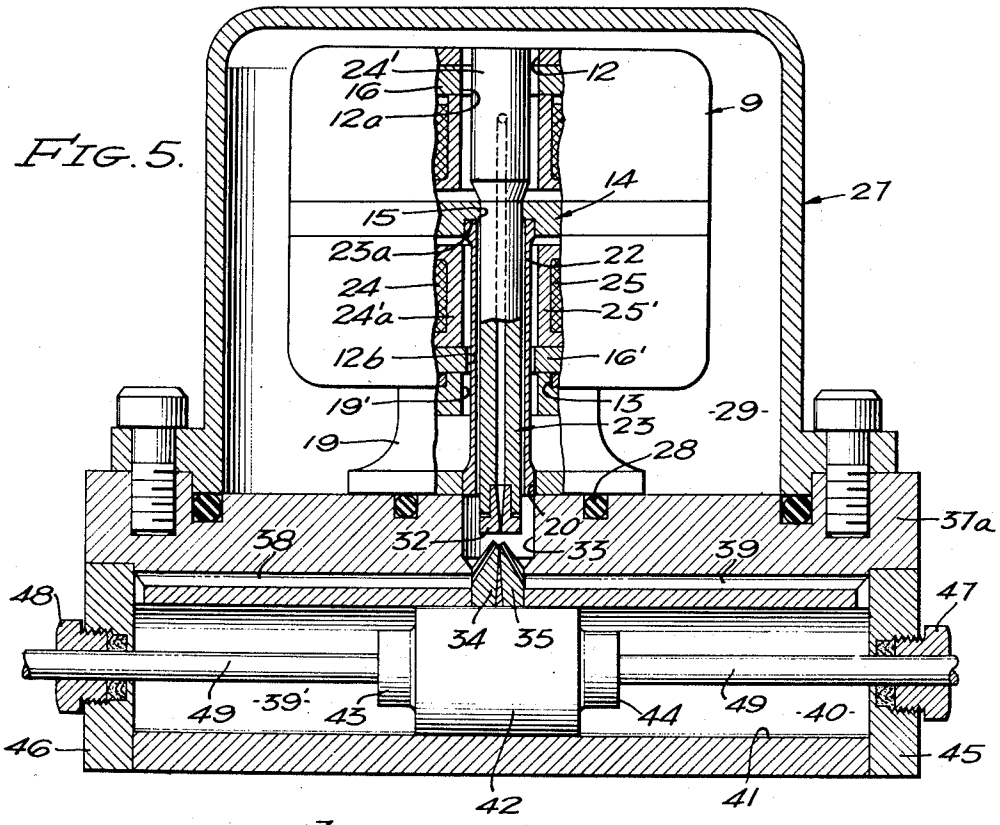



FIG. 6.

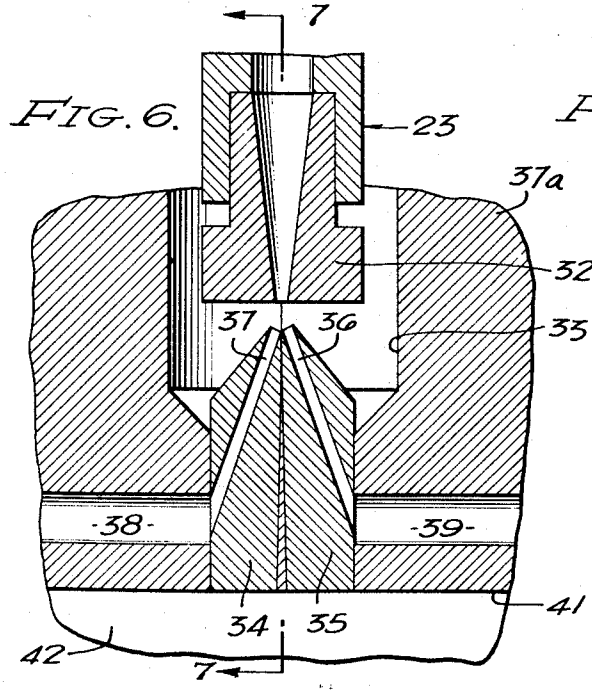
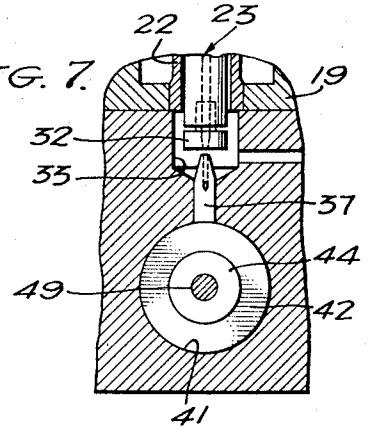



FIG. 7.




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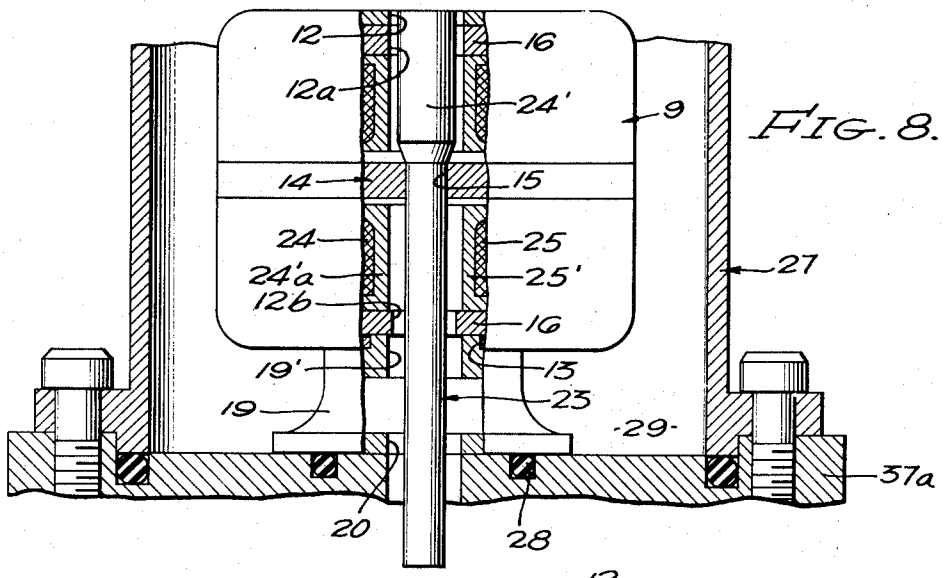



FIG. 8.

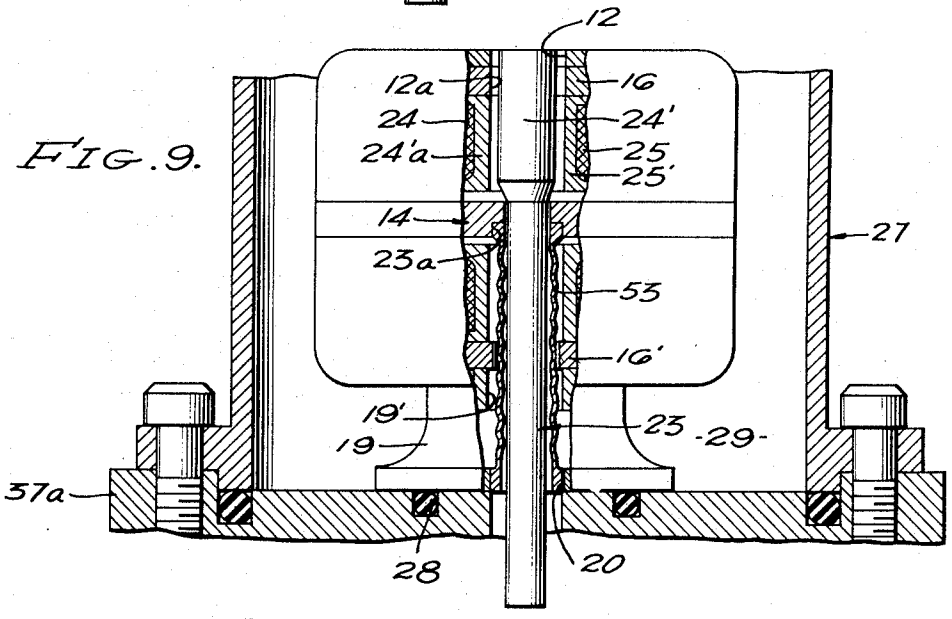



FIG. 9.

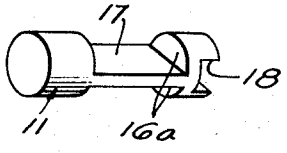



FIG. 10.

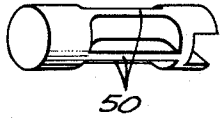



FIG. 11.

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United States Patent Office 2,962,611 Patented Nov. 29, 1960



2,962,611

# ELECTROMAGNETIC ACTUATOR

Raymond D. Atchley, Los Angeles, Calif., assignor to Raymond Atchley, Inc., Los Angeles, Calif., a corporation of California

Filed Aug. 18, 1958, Ser. No. 755,775

14 Claims. (Cl. 310—29)

This application is a continuation-in-part of application Serial No. 583,487, filed May 8, 1956, and of application Serial No. 681,310, filed August 30, 1957, which is a continuation-in-part of application Serial No. 586,778, filed May 23, 1956.

This invention relates to improvements in electromagnetic transducers which may be employed as actuators.

Electromagnetic transducers are well known in which an angularly displaceable armature is positioned in a pair of spaced gaps, between pole faces, in push-pull relationship and with one end of the armature in one of the gaps and the other end of the armature in the other of said gaps, wherein the flux in the gaps, termed the polarizing flux, is created by a permanent magnet, and the flux is modified by a flux induced in the armature by means of control coils, said modifying flux being termed the control flux, whereby the armature is displaced angularly against a flexible torsional constraint in amount which is a substantially linear function of the net current passing through the control flux. Usually the control coils are wound in pairs to buck each other and when an unequal potential is impressed on the coils, a differential current passes through the coils to generate the net current and the control flux. Such devices are quite old in the art and have been employed for many uses. In recent years, these devices have been used as an electromechanical transducer to produce a mechanical motion proportioned to an electrical current input, the displacement of the armature being used to actuate various mechanisms. Because the differential current causes a torque to be induced to rotate the armature, these devices have in more recent years been termed torque motors.

I have in application Serial No. 583,487 described an improvement in such torque motors and in application Serial No. 681,310 a further improvement in the means for connecting the armature of the torque motor for communication of the motion of the armature to the means to be moved by such armature. In said application I have described said means as a jet pipe of a jet valve assembly.

I have also described means whereby the case of the torque motor is sealed so that the atmosphere in the case may be isolated from the exterior environment and thus protected.

The said torque motor is useful as an actuator for purposes other than those described in said application Serial No. 681,310, filed August 30, 1957, which is a continuation-in-part of application Serial No. 586,778, filed May 23, 1956. Some such other uses are described in my copending application Serial No. 755,534, filed August 18, 1958. This application is a continuation-in-part of said application Serial No. 681,310 and of application Serial No. 586,778, filed May 23, 1956.

It is thus one purpose of the invention described in this application to connect the armature of my torque motor to a second flexure element comprising a flexure tube and to connect the armature at the center of rotation of said armature axially of said tubular flexure. A motion transmitting connection is provided in the form of a substantially rigid rod or tube connected to the armature and extending inside the flexible tube to an exterior point.



A base to support the torque motor may be provided to which the tube is connected and through which the rod or tube may protrude. As a result of this construction I am able to connect the armature to a flexure which is rigid in a direction perpendicular to the planar extent of the armature and by providing a case about the motor I may seal the tube and the case to the base through which the take-off rod protrudes and thus I may transmit the motion of the armature to the exterior of the sealed case.

These and other objects of my invention will be further described in connection with the drawings of which

Fig. 1 is a vertical section of the actuator of my invention;

Fig. 2 is a section on line 2—2 of Fig. 1;

Fig. 3 is an end view of my actuator with parts in section taken at line 3—3 of Fig. 2;

Fig. 4 is a section on line 4—4 of Fig. 3;

Fig. 5 shows a modification of my actuator for use in connection with jet projector and receptor jet valves;

Fig. 6 is an enlarged view of the jets of Fig. 5;

Fig. 7 is a section on line 7—7 of Fig. 6;

Fig. 8 is a modification of the actuator of Figs. 1–4;

Fig. 9 is a modification of the second flexure element of Figs. 1–4;

Fig. 10 is a perspective view of the torsional flexure of Fig. 1, and

Fig. 11 is a perspective view of the torsional flexure of Figs. 8 and 9.

In the above figures **1**, **2**, **1′** and **2′** are permanent magnets of magnetic material of high retentivity, such as, for example, Alnico, a permanent magnet material. They are connected to pole pieces **5** and **6**, and **5′** and **6′**. The pole pieces are formed as indicated of blocks of material having a width substantially equal to the width of the permanent magnets, and having a height sufficient to establish the gaps between the faces **7***a* and **8***a*. The abutting faces **9′** and **10′** of the magnets and the pole pieces are preferably ground flat and make flush fits for reasons to be more fully described hereinbelow.

The material of which the pole faces are made are those conventionally used for magnet pole faces, to wit: those having a high permeability and low retentivity.

I have found that by grinding the faces of the magnet and then electroplating them with a thin film of nickel, I may connect the pole pieces to the permanent magnets by brazing or soldering. Since I employ two such subassemblies in the torque motor designed, and each of them is of identical construction, they may each be formed from identical pieces and individually adjusted to produce subassemblies which I may stock to use at any time. One such assembly is made up of two C-shaped magnets **1** and **2** and two pole pieces **5** and **6** shown in Fig. 3 and a like assembly composed of the like shaped magnets **1′** and **2′** and two pole pieces of the same construction as **5** and **6** and similarly connected to the magnets **1′** and **2′** as **5** and **6** are connected to **1** and **2**.

The rectangular tube **9** acts as a frame to support the armature. It may be made by stretching a circular tube which is faced at its ends. It is bored at **10***a* and **10***a′* to a diameter greater than the diameter of the shaft **11** and **11′**, to be further described. The frame **9** is also bored at **12** and **13** (Fig. 2) for purposes to be further described. The armature **14** is in the form of a flat bar carrying a hole **15**. The shafts **11** and **11′** have a torsional flexure in the form of a flat spring section formed by milling slots **16***a* and **16***a′* to form a web **17** and **17′** (see Fig. 10). At one end of each shaft **11** and **11′**, a

slot is formed to form a fork 18 and 18' into which the armature is rigidly connected.

The magnetically permeable return flux path bars 16 and 16' are bored at 12*a* and 12*b* axially of the bores 12 and 13 are rigidly connected to the interior of the frame 9 and terminating at the outer ends of the frame 9. The frame 9 is rigidly connected to the base fitting 19 which is bored at 19' and 20 concentrically with the base 19, 12*a*, 15, 12*b* and 12.

The shafts 11 and 11' are rigidly mounted in the frame 9 by means of bushings 21 and 21' to which the shafts are brazed and which are brazed in the frame. Rigidly mounted in the base fitting 19 in bore 20 is the thin walled flexure tube 22 rigidly connected and sealed in the bore 20 and in the counterbore 23*a* in the armature 14. The rod 23 is rigidly positioned and sealed in the bore 15 whose center is on the central axis of shafts 11 and 11'. The enlarged portion 24' is positioned in bores 12*a* and 12 which are of larger diameter. The rod 23 may, if desired, be bored for lightness so that the mass of 24' above the armature 14 may balance the mass of the rod 23 and any connected structure.

The coils 24 and 25 are placed in the frame 9 about the armature 14 and the magnet and pole pieces rigidly connected to the frame so that the pole pieces 5 and 6 abut the flux return bars 16 and 16' at one end and the like pole pieces 5' and 6' about the bars 16 and 16' at the other end.

To assemble the structure the bars 16, 16' are placed in position in the frame 9 and the frame is positioned on the base fitting 19 and the parts brazed into a rigid structure. With the bushings 21 and 21' removed the armature and shafts which have been previously assembled and brazed are inserted into one end of the open frame 9 and the shaft 11 introduced into the bore 10*a* and then the shaft 11' is introduced into the bore 10*a*', the bushings are then inserted and the entire assembly brazed in position. The tube 22 is then inserted through the bores 20, 19' and 12*b* into the counterbore and brazed in position in the bore 20 and in the counterbore 23*a*. The rod 23, at that point not connected to any member, as shown, is inserted through the bores 12, 12*a*, 15 and the tube 22 and brazed to the armature 14.

The coils 24 and 25, which have been positioned on their coil forms 24*a*' and 25' are positioned in the frame 9 between the bars 16 and 16' and about the armature 14. The coil forms are so dimensioned that they abut against the faces of the pole pieces 5, 6, 5' and 6' and against each other with semi-cylindrical slots which form cylindrical openings for the passage of the tube 22, the rod enlargement 24' and the shafts 10 and 10' as shown in Figs. 2 and 4.

The magnet pole assemblies are separately assembled by electroplating the ground planar ends of the C magnets and the abutting faces of the pole pieces. The pole pieces and magnets may then be adjusted to give the desired separation and connected together by brazing or soldering. Two assemblies are thus formed. The assemblies are then magnetized so that they are oriented with the magnets 1 and 2 having their poles similarly oriented. The assemblies are then mounted on the ends of the frame 9 so as to provide equal gaps 7, 8 and 7' and 8' and with like poles on the same side of the armature. The pole pieces are in abutment to the ends of the frame 9 and the return bars 16 and 16'. The pole pieces are connected to the frame 9 by welding. Suitable connections to the coils 24 and 25 and terminals are provided, which, although not shown, will be understood by those skilled in the art. Similar connections are shown in application Serial No. 583,487.

Orientation of the poles is such that the two north poles are on one side of the magnet of the armature, and the two south poles are on the other side of the armature. The opposite ends of the bridge bar 16 in contact with the two pole pieces 5 and 5' are at equal magnetic potential, and the two ends of the bar 16' in contact with the pole faces 6 and 6' are at equal magnetic potential. Tube 22 being of material of very high reluctance, carries substantially no flux.

Referring now to the construction as previously described, it will be observed that the permanent C magnets are of uniform cross-section and contain no cores or bores, which reduces the cross-section. This is due to the fact that the assembly is made by brazing or soldering them to the pole pieces, and the pole pieces are connected to the framework 9 by welding. The polarizing flux passes from the magnets through the pole pieces, and through the armature gaps and the armature. All gaps are equal and the armature is centrally positioned.

The control flux which is generated by a differential current passing through the coils 24 and 25 generates a control flux. The control flux adds to or subtracts from the flux passing from the permanent magnets as will be clear to those skilled in the art, and circulates through the return path 16 and 16'. It will be observed that the control flux circuit is independent of the polarizing flux circuit except at the gaps.

It will be observed that with no signal voltage impressed on coils 24 and 25 or with equal signals in the like coils 24 and 25 no net control flux passes through the armature 14 and no torque is exerted on the shafts 11 and 11'. The armature is not displaced. If a differential signal is impressed on the coils so more current flows through one coil than through the other a net flux is generated in the armature 14 which passes through the gaps and returns through the return paths 16 and 16'. This modifies the equal fluxes from the permanent magnets and thus creates a net torque on the shaft 11 and 11'. The angular displacement of the armature is permitted by the flexible webs 17 and 17' and the flexible tube 22.

The base fitting 19 may be mounted so that a seal fit 28 is made between the base fitting 19 and any base or other member on which it is to be mounted. The assembly may be enclosed in a case 27 which may be made fluid tight.

It will be seen that as a result of the use of the tube 22, I may mount the actuator rod 23 so that it can be connected exteriorly of the case 27 and provide for a fluid-tight chamber 29 in which the torque motor is positioned. Thus where the atmosphere outside of the case is filled with liquid or gases the torque motor is sealed from exposure to the liquids or gases.

It will be observed that the tube 22 is rigid in an axial direction although flexible on imposition of any force transverse to the axis of the tube. However, because of the flat spring-like web 17 and 17', the armature structure is rigid in the plane of the web 17 or 17' but will permit rotation about a line perpendicular to the axis of the shaft 11 and 11'. In fact the web is made so thin so that it is not relied on to produce the restoring force on angular displacement of the armature. This is supplied by the flexible tube. For purposes of illustration and not as a limitation of my invention, I have found that a suitable proportion is about 5–10% of the total restoring force, the flexible tube supplying the remaining restoring force, except in the form of Fig. 5 as will be more fully described below. Such torsional flexures are referred to in this case as weak torsional flexures.

While I prefer to amount the rod rigidly in the frame as described above, it is possible to avoid the use of a torsional flexure in the shaft 11 by mounting it so that it is free to rotate in bushings 21 and 21'. This is possible since the torsional flexural properties of the armature mounting are not relied on for the restoring force. This is, I believe, much less desirable than the form employing the weak torsional flexure since, due to wear, the bushings may become enlarged permitting of the inaccurate location of the armature and an uncontrolled motion on re-

ceipt of a signal. The rod **23**, due to the mass of the upper end of rod **24**, is balanced so that acceleration in a line perpendicular to the plane of Fig. 4 will cause no substantial displacement of the tube **22** or rotation about the axis of the flexure **17** and **18'**. Consequently, no deflection of the armature resulting from acceleration, impact or other accidental forces will cause any movement of the rod **23**, except only due to the signal imposed by coils **24** and **25**, or due to an angular acceleration about an axis perpendicular to the axis of the tube **22** and passing centrally through the armature. However, because of the low mass of the armature and the permissible selection of flexibility of the tube **22**, the natural frequency of the structure can be controlled so that such accidental forces may be of no importance in the practical utility of the device. Additionally, it will be observed that because of the use of the tube **22** and the connection of the tube and the rod **23** at a substantially coincident point with the axis of rotation of the armature **14**, the angular displacement of the rod **23** may be made substantially equal to the angular displacement of the armature **14**, thus producing a system of high sensitivity.

The actuator of my invention may be employed for many purposes for which torque motors may be employed. It is particularly useful where it is desirable to obtain a sealed torque motor. It is also useful where the properties of the flexural element provided by the tube in addition to the torsional flexure of the armature mountings as described above may be employed advantageously. Such uses may occur with or without sealing the motor in a case.

In Figures 1 and 2 is illustrated one application to a flap controlled outlet of a jet controlled valve. As the rod **23** having flattened face portions **24***a* and **24***b* is moved from a position midway between the jets **29'** and **30** the pressure drop at the jet nozzles to the exterior environment is varied. Such flap controlled valves are employed in some forms of servo valves, for example, that illustrated in the Moog Patent 2,767,689, issued October 23, 1956.

Another use of the actuator of Figs. 1–4 is shown in Fig. 5 in which the rod **23** is formed with a central bore to which a flexible fluid feed pipe, not shown, is connected. The lower end of the tube **23** carries a nozzle **32** and projects into a bore **33** formed in the block **37**. Two cylindro conical jets **34** and **35** are positioned in bores provided in **37***a* and are provided with angularly disposed bores **36** and **37** so positioned that the angle of the nozzle **32** when in the neutral position bisects the angle between the center line of the jets. The bores **37** and **36** connect via bores **38** and **39** to the chambers **39'** and **40** in the cylindrical bore **41** in which is positioned piston **42** having bosses **43** and **44** positioned on opposite sides of the piston. The cylinder **41** is closed at both ends by the closures **45** and **46** through which, by means of suitably provided packing glands **47** and **48**, the piston rod **49** passes.

Responsive to the differential signal imposed on coils **24** and **25**, the rod **23** will be moved in the plane of Fig. 5 so that the ejector jet **32** passes more or less fluid into the jets **37** and **36** depending on which direction the rod **23** moves and thus a differential pressure will be exerted in chambers **39'** and **40** to cause the fluid motor to be displaced to one end of the cylinder and on removal of motion of the tube **23**, the motor may be reciprocated in the opposite direction. The function and operation of this jet valve fluid motor assembly is not a necessary part of the invention claimed in this application and is more fully described and claimed in my copending application Serial No. 681,310 and in application Serial No. 755,534.

In this form, the flexibility of the feed pipe is a factor in the stiffness which constitutes the restoring force. It may, however, be made flexible and of the same order as is the stiffness of the weak torsional flexure formed by web **17** or **17'**.

In the modification of Figs. 1–7, we have not relied in any material respect on the torsional stiffness of the torsional flexure on which the armature is mounted and have employed the tube **22** to give this restoring force and to also act as a seal.

Due to the fact that in order to obtain the desired degree of stiffness in the tube, the tube must be made of thin section and of small diameter, this form limits the angle through which the armature may be permitted to be deflected. As will be understood by those skilled in the art, the stiffness of a tube varies as the fourth power of the diameter. This factor thus imposes a limitation on the permissible travel of the end of the rod. Where the travel required is greater than the travel practically obtainable by the use of the tube **22**, I may solve this problem by sacrificing one or the other or both of the functions provided by the additional flexure tube **22**.

Thus I may remove the tube **22** entirely as shown in the form of Fig. 8 in which all parts are the same as in the form of Fig. 1, except that **22** has been removed and the counterbore **23***a* is no longer provided. In this case, I supply the rigidity in the direction of the axis of the rod as well as substantially the entire restoring force for the armature by employing a torsional flexure element in the shaft. This form of flexure is shown in Fig. 11 formed by milling the shaft to give four webs **50** spaced 90° apart on the shaft which is otherwise formed and mounted in the same fashion as **11**. It will be observed that the additional webs increase the torsional stiffness of the shaft and also the resistance to bending in the plane of each of the webs.

This form thus also does not have the function of the tube **22** to act as a seal for the torque motor.

An intermediate solution of the problem is shown in Fig. 9. In place of the tube **22**, I use the tube **53** which is formed with circular corrugations and may be generically defined as a bellows. This form of tube does not heave the stiffness of the tube **22** and will not withstand the fluid pressures of the tube **22** of like diameter and wall thickness. However, it may be made of greater diameter than tube **22** for like stiffness in bending. Depending on the diameter and its length, i.e., on the stiffness of the tube **53**, I may or may not employ the cruciform torsional flexure of Fig. 11 in place of the weak flexure of Fig. 10.

While I have described a particular embodiment of my invention for the purpose of illustration, it should be understood that various modifications and adaptations thereof may be made within the spirit of the invention as set forth in the appended claims.

I claim:

1. A torque motor comprising a pair of spaced polarizing magnet assemblies, each assembly composed of a pair of permanent magnets, said magnets being fastened at their north poles to a pole piece and at their south poles to a second pole piece, said pole pieces being spaced to form a gap completing a magnetic circuit through the pole pieces and each of said permanent magnets in each of said assemblies, an armature, said armature extending into the gap in each of said magnet assemblies, a mounting for said armature, said mounting comprising a support positioned between said magnet assemblies and fastened to each of said assemblies, and a flexure fixedly connected to said armature and said support for angular motion of said armature in said gaps above an axis through said flexure, a field coil positioned adjacent said armature in inductive relationship to said armature, a rod connected to said armature substantially at said axis and extending perpendicular to the said axis.

2. A torque motor comprising a pair of polarizing magnet assemblies, one at each end of said motor, each assembly composed of a pair of permanent magnets, said magnets being fastened at their north poles to a pole piece and at their south poles to a second pole piece, said pole pieces being spaced to form a gap completing a

magnetic circuit through the pole pieces and each of said permanent magnets in each assembly, an armature, said armature extending into the gap in each of said magnet assemblies, an open ended armature support frame connected to said assemblies, an armature positioned in said armature support frame and extending into the gap in each of said magnet assemblies, a shaft extending perpendicularly from said armature and fixedly connected to said armature support frame and said armature for angular displacement of said armature in said gaps, a torsional flexure in said shaft, and field coil positioned in said frame inductively coupled with said armature, a rod connected to said armature at the axis of said shaft and extending perpendicular to the axis of said shaft, and in combination with said torque motor a second flexural element comprising a flexible tube adjacent one end of said flexible tube to said armature concentrically with said shaft, a base for said torque motor, said flexible tube connected adjacent the other end of said flexible tube to said base.

3. A torque motor comprising a pair of spaced polarizing magnet assemblies, each assembly composed of a pair of permanent magnets, said magnets being fastened at their north poles to a pole piece and at their south poles to a second pole piece, said pole pieces being spaced to form a gap completing a magnetic circuit through the pole pieces and each of said permanent magnets in each assembly, an armature, said armature extending into the gap in each of said magnet assemblies, an open ended armature support frame, an armature positioned in said armature support frame and extending into the gap in each of said magnet assemblies, a shaft extending perpendicularly from said armature and fixedly connected to said armature and said armature support for angular displacement of said armature in said gaps, a flat flexure section in said shaft permitting torsional flexure, and field coils positioned in said frame inductively coupled with said armature, said frame connected to said assemblies by a weld joint between said frame and said pole pieces, a rod connected to said armature at said shaft and extending perpendicular to the axis of said shaft and said flexure, and in combination with said torque motor a second flexural element comprising a flexible tube connected to said armature adjacent one end of said flexible tube concentrically with said shaft, a support for said frame, said flexible tube connected adjacent the other end of said tube to said support.

4. A torque motor comprising a pair of spaced polarizing magnet assemblies, each assembly composed of a pair of permanent magnets, said magnets being fastened by soldering at their north poles to a pole piece and at their south poles to a second pole piece, said pole pieces being spaced to form a gap completing a magnetic circuit through the pole pieces and each of said permanent magnets in each assembly, an armature, said armature extending into the gap in each of said magnet assemblies, an open ended armature support frame, an armature positioned in said armature support frame and extending into the gap in each of said magnet assemblies, a shaft extending perpendicularly from said armature and fixedly connected to said armature and said armature support for angular displacement of said armature in said gaps, a cruciform section in said shaft forming torsional flexure, and field coils positioned in said frame inductively coupled with said armature, said frame connected to said assemblies, a rod connected to said armature at said shaft and extending perpendicular to the axis of said shaft, and in combination with said torque motor a second flexural element comprising a flexible tube connected adjacent one end of said flexible tube to said armature concentrically with said shaft, a support for said frame, said flexible tube connected to said support adjacent the other end of said tube.

5. A torque motor comprising a tubular frame, a shaft positioned in said frame, each end of said shaft fixedly connected to said tubular frame, an armature fixedly connected to said shaft, a torsional flexure in said shaft, a pair of polarizing magnet assemblies, one at each end of said tubular frame, said assemblies composed of permanent magnets, and each assembly containing a pair of spaced pole pieces, one of said pole pieces in each said assembly being connected to a south magnetic pole and the other of said pole pieces of each said assembly being connected to a north magnetic pole, said pole pieces in each assembly being spaced to form a gap in each assembly, said armature extending in said frame with one end of said armature in one of said gaps and the other end of the armature in the other of said gaps for angular deflection in said gaps about an axis through said flexure, a field coil in said frame in inductive relationship with said armature, and a rod connected to said armature substantially at said axis and extending perpendicular to the said axis.

6. A torque motor comprising a tubular frame, a shaft positioned in said frame, each end of said shaft fixedly connected to said tubular frame, an armature fixedly connected to said shaft, a torsional flexure in said shaft, a pair of polarizing magnet assemblies, one at each end of said tubular frame, said assemblies composed of a pair of permanent magnets and each assembly containing a pair of spaced pole pieces, one of said pole pieces in each said assembly being connected to a south magnetic pole of one of said magnets of said pair, and the other of said pole pieces of each said assembly being connected to a north magnetic pole of the other of said magnets of said pair, said pole pieces in each assembly being spaced to form a gap in each assembly, said armature extending in said frame with one end of said armature in one of said gaps and the other end of the armature in the other of said gaps for angular deflection in said gap about an axis through said flexure, a field coil in said frame in inductive relationship with said armature, a rod connected to said armature substantially at said axis and extending perpendicular to the said axis, and in combination with said torque motor a second flexure element comprising a flexible tube connected adjacent one end of said tube to said armature concentric with said rod, a support for said frame, said tube connected adjacent the other end of said tube to said support.

7. A torque motor comprising an open ended armature support frame, an armature in said frame, a shaft fixedly connected to said armature and to said frame, a torsional flexure in said shaft, permitting said armature to move angularly with respect to said shaft, a magnet assembly mounted one at each end of said armature frame, said assembly comprising permanent magnets and pole pieces, one of the pole pieces in each assembly being connected to a north magnetic pole, and another of the pole pieces in each assembly being connected to a south magnetic pole, said pole pieces in each assembly being spaced to form a gap, one end of said armature being positioned in one of said gaps, and the other end of said armature being positioned in the other of said gaps, a field coil in said frame inductively coupled with said armature, a rod connected to said armature at said shaft and extending perpendicular to the axis of said shaft, and in combination with said torque motor a second flexure comprising a flexible tube connected adjacent one end of said tube to said armature concentrically with said shaft, a support for said frame, said tube connected adjacent the other end of said tube to said support.

8. A torque motor comprising an open ended armature support frame, an armature in said frame, a shaft fixedly connected to said armature and to said frame, a torsional flexure in said shaft, permitting said armature to move angularly with respect to said shaft, a magnet assembly mounted one at each end of said armature frame, said assembly comprising a pair of permanent magnets and a pair of pole pieces, one of the pole pieces in each as-

sembly being connected to a north magnetic pole of each of said magnets of said pair, and another of the pole pieces in each assembly being connected to a south magnetic pole of each said magnet of said pair, said pole pieces in each assembly being spaced to form a gap, one end of said armature being positioned in one of said gaps, and the other end of said armature being positioned in the other of said gaps, a field coil in said frame inductively coupled with said armature, a rod connected to said armature at said shaft and extending perpendicular to the axis of said shaft, and in combination with said torque motor a second flexure element comprising a flexible tube connected adjacent one end of said tube to said armature concentrically with said shaft, a support for said frame, said tube connected adjacent the other end of said tube to said support.

9. A torque motor comprising four permanent magnets, each of said permanent magnets being magnetically connected at their north poles to pole members, and each at their south poles to pole members, said pole members being mounted and spaced from each other to form a pair of gaps, a frame, an armature having opposite faces and one end of said armature positioned in one of said gaps and the other end of said armature positioned in other of said gaps, means for mounting said armature in said frame and in said gaps for angular displacement of said armature in said gaps, said mounting including a torsional flexure constraint creating a positive angular restoring force on such angular displacement of said armature about an axis through said flexure, a field coil inductively coupled with said armature, a rod connected to said armature at said shaft and extending perpendicular to the axis of said shaft and said faces, and in combination with said torque motor a second flexure element comprising a flexible tube connected adjacent one end of said tube to said armature concentrically with said shaft, a base for said torque motor, said flexible tube connected adjacent its lower end to said base.

10. In the torque motor of claim 9, said frame having opposed ends, two of said magnets and the pole members connected thereto positioned adjacent one side of said frame, and the other two of said magnets and the pole member connected thereto positioned adjacent the other side of said frame.

11. In the torque motor of claim 9, the faces of said armature and said pole members forming four equal gaps.

12. In the torque motor of claim 10, the faces of said armature and said pole members forming four equal gaps.

13. A torque motor comprising a magnetic assembly including a pair of spaced pole pieces, one of said pole pieces connected to the north pole of a permanent magnet and the other of said pole pieces being connected to the south pole of said permanent magnet, said pole pieces being spaced to form a gap, a second pair of pole pieces, one of said pole pieces of said second pair connected to the north pole of a second permanent magnet and the other of said last named pole pieces of said second pair connected to the south pole of said permanent magnet, said last named pair of pole pieces being spaced to form a gap, an armature, one end of said armature being positioned in said first named gap and the other end of said armature being positioned in said last named gap, a field coil inductively coupled with said armature, a mounting for said armature for angular deflection of said armature in said gaps, about an axis positioned between the said ends of said armature, a rod connected at one end to said armature perpendicular to said armature and to said axis and positioned at said axis, a tubular flexure element connected adjacent one end of said tubular flexure element to said armature and concentric with said rod.

14. A torque motor comprising a magnetic assembly including a pair of spaced pole pieces, one of said pole pieces connected to the north pole of a permanent magnet and the other of said pole pieces being connected to the south pole of said permanent magnet, said pole pieces being spaced to form a gap, a second pair of pole pieces, one of said pole pieces of said second pair connected to the north pole of a second permanent magnet and the other of said last named pole pieces of said second pair connected to the south pole of said permanent magnet, said last named pair of pole pieces spaced to form a gap, an armature, one end of said armature being positioned in said last named gap, a field coil inductively coupled with said armature, a mounting for said armature for angular deflection of said armature in said gaps, about an axis positioned between the said ends of said armature, a rod connected at one end to said armature perpendicular to said armature and to said axis and positioned at said axis, a tubular flexure element connected adjacent one end of said tubular flexure element to said armature and concentric with said rod, a base for said torque motor, said tubular flexure connected to said base adjacent the other end of said tubular flexure element.

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