United States Patent

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[54] ELECTRO HYDRAULIC SERVOVALVE

8 Claims, 5 Drawing Figs.

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[50] Field of Search 137/625.65, 625.62, 625.4; 335/217, 236; 310/36, 29, (Inquired), 214, 216

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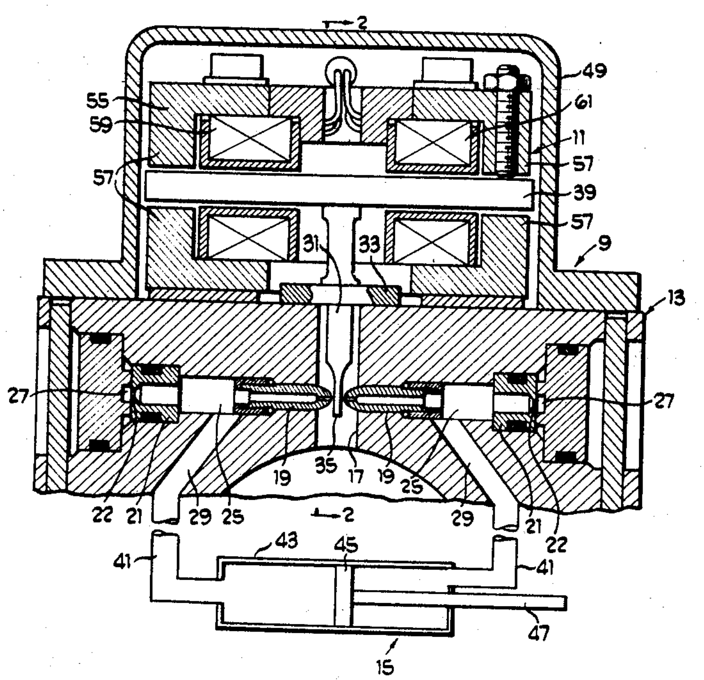
ABSTRACT: An electrohydraulic servovalve including a signal responsive torque motor having at least one high energy permanent magnet providing a magnetic flux field. A flux field shunt is affixed to the magnet to compensate for the effects of temperature on servovalve operating characteristics to ensure a consistent hydraulic output function in relation to a given input signal over a wide range of operating temperatures.



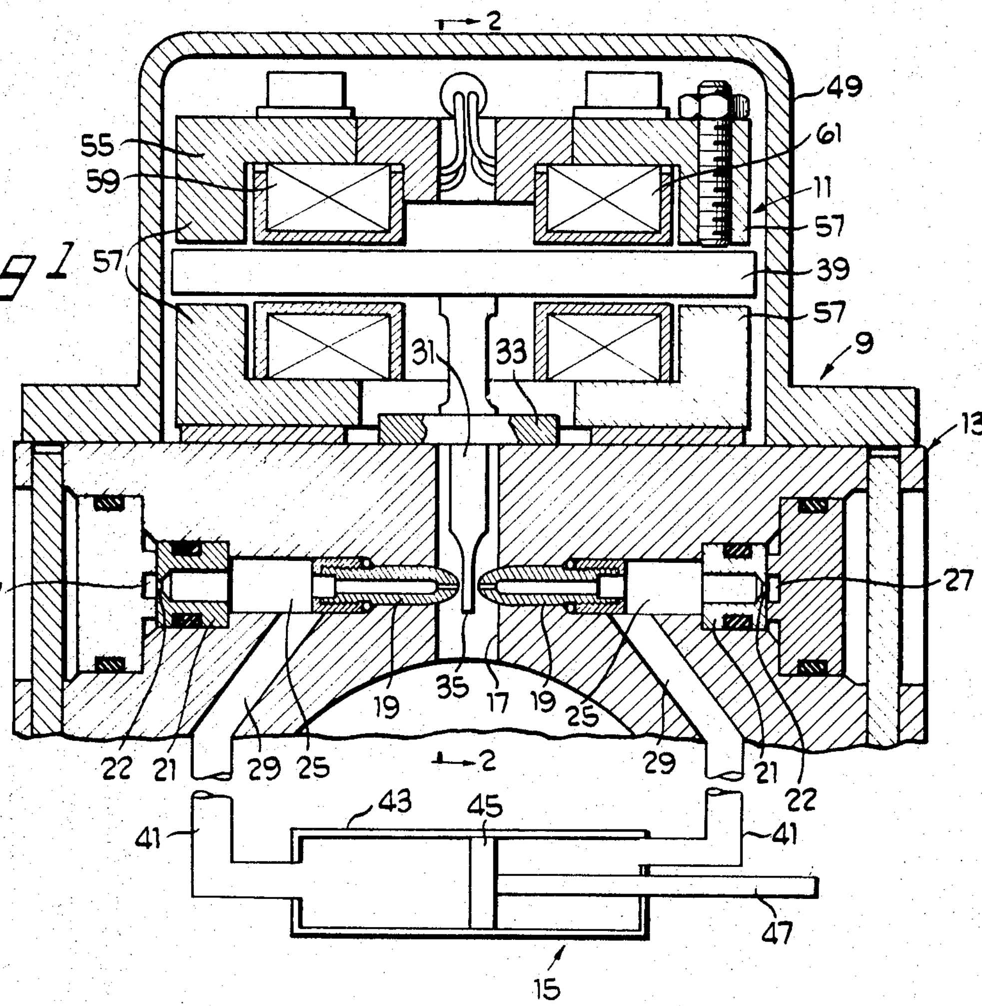


Fig 1

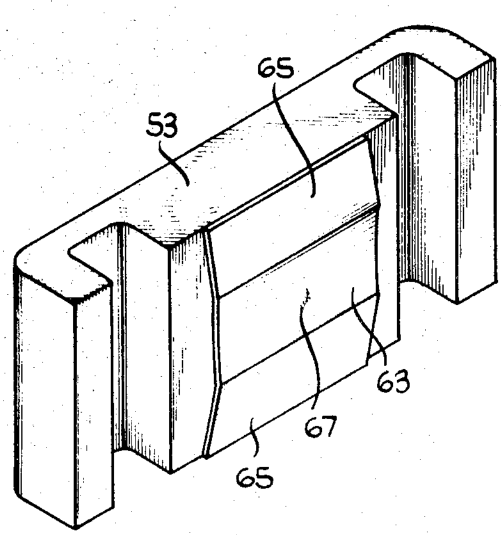


Fig 3

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Fig 2

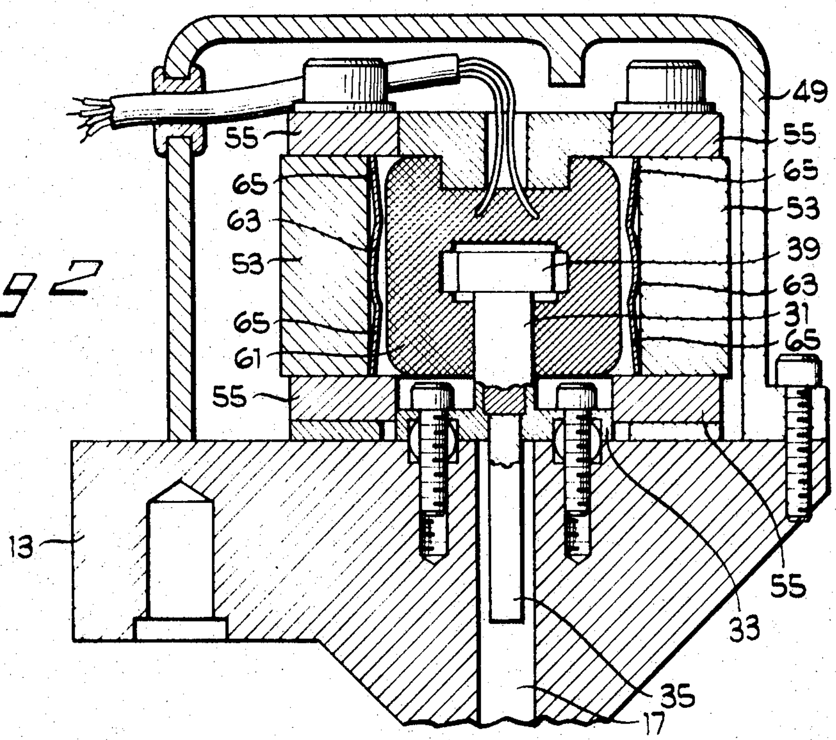


Fig 4

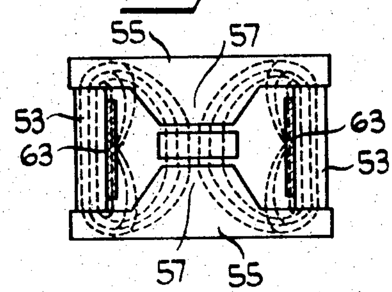
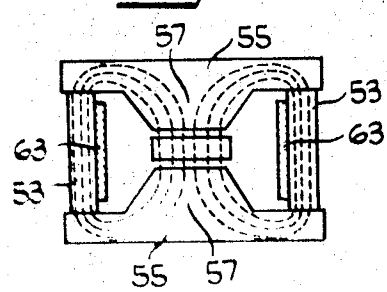


Fig 5



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ELECTRO HYDRAULIC SERVOVALVE

BACKGROUND OF THE INVENTION

The invention relates to electrohydraulic servovalves. More particularly, it relates to electrohydraulic servovalves having means to compensate for the effects of temperature on servovalve operating characteristics.

Electrohydraulic servovalves are used to translate a low energy electrical input to a high energy hydraulic output. Servovalves in many applications are exposed to a wide range of operating temperatures. Under such conditions, it is typical to experience a gradual degradation in servovalve output at any given electrical input as operating temperature increases. This phenomenon is attributed to a great extent to the thermal characteristics of the high energy permanent magnets commonly used in these devices.

The effect of temperature on the remanence of a permanent magnet manifests itself in two different ways:

1. The nonreversible effect; and
2. The reversible effect.

The former produces a loss in the remanent flux density, which when certain temperature extremes are encountered cannot be restored. This nonreversible effect can be eliminated by the simple expedient of cycling the magnet several times through the anticipated range before finally adjusting its operating flux density.

The reversible effect cannot be eliminated, however, and servovalve operating characteristics are affected by the degradation of the magnetic flux field as temperature increases.

In a servovalve, increased operating temperature not only affects the magnetic characteristics of the torque motor, but also produces significant changes in valve orifice and pumping characteristics due to mechanical thermal expansion.

It is essential to reliable servovalve performance to minimize the variations in output signal in relation to varying temperature conditions. It has been determined that compensation for the effects of temperature on the various operating characteristics may be provided by control of the flux density of the permanent magnets forming part of the servovalve torque motor. In this way, a single compensation means overcomes the undesirable variations in operating characteristics of the servovalve components.

Accordingly, it is the principal object of the present invention to provide an electrohydraulic servovalve which includes means for compensating for the effects of temperature upon all of the operating variables affected by changes in operating temperature to produce a consistent hydraulic output function in relation to given electrical input command.

SUMMARY OF THE INVENTION

Very generally, the electrohydraulic servovalve of the present invention includes a torque motor responsive to an electrical input signal to control an hydraulic output function. The hydraulic output function is variable in response to the input signal. The servovalve includes a torque motor having at least one permanent magnet to establish a flux field. A magnetic shunt is affixed to the permanent magnet which produces an inverse characteristic of gain in relation to increasing temperature to compensate for the effects of temperature upon the servovalve operating parameters including loss of magnetization, mechanical and thermal expansion, orifice characteristics, and pumping effects.

The compensator is affixed to the magnet in contact with the maximum potential portions of the magnet and is shaped to provide maximum contact with the magnet to provide optimum compensating efficiency. At low temperature, a portion of the magnetic flux field produced by the magnet is bypassed through the compensator. As temperature increases, the efficiency of the compensator, because of its inherent characteristic of inverse gain, is reduced. As temperature increases, an increased proportion of magnetic flux is released into the active magnetic circuit to compensate for the overall degradation of the available flux field as well as the other operating variables affected by the increased temperature.

More particular objects and advantages of the present invention will become apparent in connection with the following description having reference to the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a sectional elevational view in partial schematic of an electrohydraulic servovalve illustrative of principles of the present invention.

FIG. 2 is a side elevational sectional view of the apparatus of FIG. 1 taken generally along the line 2–2 of that FIG.

FIG. 3 is a perspective view of a portion of the apparatus of FIG. 1 illustrating a torque motor permanent magnet and attached compensator.

FIG. 4 is a diagrammatic view of a portion of the apparatus of FIG. 1 illustrating conditions existing at low temperature.

FIG. 5 is a diagrammatic view of a portion of the apparatus of FIG. 1 illustrating conditions existing at high temperature.

DETAILED DESCRIPTION

Referring specifically to the drawings, there is illustrated an electrohydraulic servovalve generally designated at **9**, illustrative of the principles of the present invention.

As illustrated, the electrohydraulic servovalve **9** includes an electromagnetic torque motor **11** and a valve body **13**, containing the hydraulic portion of the servovalve. The servovalve is connected to an actuator **15** which responds to servovalve operation to produce a mechanical output.

The valve body **13** includes a central opening **17** and is generally symmetrical with respect to that passage. Retained within the valve body, are a pair of nozzles **19** including discharge openings disposed within the vertical passage **17** in facing, spaced apart relation.

A pair of orifice elements **21** are disposed within the valve body and define fixed orifices **22** spaced outwardly of the nozzles in a direction away from the vertical passage **17**. Passages **25** provide fluid communication between the orifices **22** and the nozzles **19**.

Hydraulic fluid under pressure in the order of magnitude of 3,000 p.s.i. is applied to the servovalve by a hydraulic supply pump (not shown). This fluid enters the valve body and is divided into a pair of inlet or supply passages **27**. This fluid passes through the nozzles **22** into the passages **25**. Each passage **25** is in communication with an output passage **29**. These passages are, in turn, connected to the actuator **15** and fluid flow through the outlet passages accomplishes the desired movement of the actuator in response to the input signal. The passages **25** are additionally in communication with the sump of the supply pump through the nozzles **19** and the vertical passages **17**.

Disposed within the vertical passage **17** is a flapper **31**. The flapper includes a support ring **33** secured to the valve body **13** in fluid tight relation. This support ring is provided with a flexible diaphragm (not shown) which provides a flexible, fluid tight seal between the valve body **13** and the torque motor **11**.

The portion of the flapper **31** extending into the vertical passage includes a flattened end portion **35** disposed between the nozzles **19** in juxtaposed, spaced apart relation to the nozzle openings. The flapper further includes a portion **37** extending into the torque motor **11** which includes an integrally formed transverse armature **39** of magnetic material which forms the armature of the torque motor **11**.

The passages **29** communicate hydraulic output of the servovalve to the actuator **15** through passages or conduits **41**. The actuator **15** includes a hollow cylinder **43** within which is disposed a reciprocable piston **45**. The piston is secured to an output shaft **47** which extends outwardly of the cylinder and is connected to a mechanical linkage, and imparts movement to the linkage in response to the servovalve operation.

The conduits **41** are connected to the cylinder **43** on the opposite sides of the piston **45**. In this way, flow of hydraulic fluid through one portion of the divided flow path through one of the passages **29** and conduit **41** into the cylinder causes movement of the piston **45** and output shaft **47** in one direction. Conversely the flow of fluid through the other of the passages **29** and conduit **41** into the cylinder **43** causes movement of the piston **45** and output shaft **47** in the opposite direction. In this way, movement of the mechanical linkage may be readily accomplished in response to the hydraulic flow in the servovalve.

The torque motor **11** is secured to the main valve body **13** in overlying relation to the flapper **31**. A cover member **49** surrounds the torque motor.

The torque motor includes a pair of permanent magnets **53** supported in vertically disposed spaced apart relation between a pair of generally horizontal pole pieces **55**. The magnets are horizontally elongated and have poles or maximum potential portions in contact with the pole pieces.

As seen in FIG. **1** the pole pieces include upwardly and downwardly directed end portions **57** terminating in closely spaced relation defining working air gaps associated with opposite ends of the armature **39** of the flapper **31**. The pole pieces direct the flux field established by the permanent magnets across the gaps between the facing end portions and thereby establish a concentrated magnetic field associated with the flapper armature (see FIGS. **4** and **5**).

The torque motor **11** additionally includes a pair of electrical coils **59** and **61**. Each coil is disposed in surrounding relation to a portion of the armature **39** on opposite sides of the flapper. These coils are connected to a source of electrical input signal (not shown) which established an electromagnetic flux field.

Opposite ends of the armature **39** are each subjected to two magnetic flux fields, one established by the permanent magnets and concentrated upon the armature ends by the pole pieces **55** and one established by electrical coils **59** and **61**. By controlling the current flow to each coil, a differential flux is produced which will cause movement of the armature in either the clockwise or counterclockwise direction. This will in turn cause a corresponding movement of the flattened end portion **35** of the flapper toward one of the nozzles **19** and away from the other progressively inhibiting flow through one nozzle opening and progressively increasing flow through the other. Inhibiting flow through one nozzle causes a corresponding increase in the flow through the associated outlet passage **29** in conduit **41** into the actuator cylinder **43**. An increase in flow through the opposite nozzle causes flow from the cylinder **43** through the opposite conduit **41** in passage **29** into the passage **25** and through the nozzle opening to the sump. This action causes movement of the piston **45** and output shaft **47** in one direction or the other, depending upon the direction of movement of the flattened end portion **35**. Equalization of the current flow in the coils **59** and **61** returns the flapper flattened end portion **35** to the neutral position resulting in an equal flow through each nozzle opening. At that point movement of the piston **45** is terminated.

In accordance with the present invention and as best seen in FIG. **3**, compensating means are provided in the torque motor to ensure consistent hydraulic output in relation to a given input signal command. The compensating means includes a pair of shunts **63** secured to the permanent magnets **53** which provide the initial or constant flux field of the torque motor **11**.

The shunt **63** is essentially rectangular in shape and it includes opposite end portions **65** which are deformed slightly in a direction toward the magnet to which it is affixed to insure intimate contact with the end portions of the shunt with the areas of maximum potential of the magnet.

In the illustrated embodiment the shunts **63** are secured to the permanent magnets **53** by a spot weld **67** intermediate the poles of the magnet in the area of minimum potential. It must be appreciated that any suitable means for fastening the compensator may be utilized so long as intimate direct contact between the compensator and the magnet in the areas of maximum potential of the magnet is achieved.

The compensator is formed of any suitable permeable material such as, for example, nickel-iron alloy which has a high permeability and low temperature and suffers a loss of permeability as temperature increases, thus reducing its ability to divert magnetic flux.

FIGS. **4** and **5** illustrate the operation of the compensators **63**. While in the illustrated embodiment one such compensator **63** is attached to each one of the permanent magnets **53**, it must be appreciated that in certain applications only one compensator attached to one magnet need be used without in any way departing from the scope of the invention.

As illustrated, the compensators or shunts **63** attached to the magnets **53** present a high permeability path between the areas of maximum potential of the magnets at low operating temperatures. As a result the compensators bypass or divert a relatively large amount of magnetic flux from the pole pieces **55** and consequently from the working air gap between the pole piece end portions **57**. This arrangement establishes the maximum flux field provided by the permanent magnets to which the end portions of the armature **39** are subjected. As the temperature of the servovalve increases the magnetic field of the permanent magnets **53** inherently decreases. Simultaneously the permeability of the shunt or compensator **63** also decreases and is therefore less effective to bypass flux from the pole pieces **55** and working air gap between the end portions **57** of the pole pieces.

By selecting shunts of proper size and shape the flux across the working air gap may be maintained at a constant value and the servovalve can thus deliver a constant output regardless of the operating temperatures experienced. The shunt is sized to not only compensate for the degredation of the magnetic field of the permanent magnets **53** in relation to increasing temperature, but also is sized to compensate for the variation in other operating characteristics of the valve such as orifice characteristics, mechanical thermal expansion and pumping effects. Thus by utilizing a single compensating arrangement the effects of temperature upon all servovalve components is minimized and consistent output in response to the given input signal is assured throughout a wide range of operating temperatures.

In a specific example of an electrohydraulic servovalve of the type described a range of operating temperatures from between 20° F. to 320° F. was experienced. It was determined that the servovalve experienced an average gain, that is, change in hydraulic output function in relation to a given electrical input command in the order of −10 percent at 320° F. and+5 percent at 20° F. as referenced to the gain experienced at a temperature of 145° F. This gain was attributable to the variations in magnetic, hydraulic and mechanical characteristics of the servovalve in relation to variations in operating temperature. Since the compensator produces an inverse gain curve that is, it experiences a reduction in the ability to bypass magnetic flux as temperature increases, attachment of the magnet shunt to the permanent magnets result in the establishment of a constant hydraulic output function in response to a given electrical input signal over the entire operating range. A compensator of generally rectangular shape formed of Carpenter (Registered Trademark) 032 alloy of a metal thickness of .020 inch was determined to provide the necessary compensating capabilities. One such compensator was attached to each of the permanent magnets of the servovalve. The compensator was formed of rectangular shape to ensure that sufficient contact area between the compensator and the maximum potential portions of the magnet was provided. In this regard a contact area extending from the polarity extremes of the magnet to 25 percent of the distance to its neutral magnetic zone was provided.

As can be seen an electrohydraulic servovalve has been provided which produces a consistent hydraulic output function in relation to a given input signal over a wide range of operating temperatures. The compensator accommodates variations in magnetic, hydraulic and mechanical characteristics of the valve in relation to variations in temperature.

Various features of the invention have been particularly shown and described. However, it must be appreciated that various modifications may be made without departing from the scope of the invention.

I claim:

1. An electrohydraulic servovalve including a main valve body defining a divided fluid path, a pair of nozzles disposed in spaced apart facing relation, each one of said nozzles being in fluid communication with a separate portion of said fluid path, a flapper having an end portion positioned intermediate said nozzles and movable toward and away from each said nozzle to control the flow of fluid in each portion of said divided flow path, said flapper including an opposite end defining an armature, and a torque motor secured to said valve body to effect movement of said flapper, said torque motor including at least one permanent magnet to provide a permanent magnet flux field acting upon said armature, and at least one electric coil responsive to an electrical input signal to provide a variable flux field acting upon said armature to vary the position of said flapper, said torque motor including at least one compensating shunt made of permeable material affixed to said permanent magnet in contact therewith to bypass a portion of said permanent magnet flux field at low temperature and being responsive to temperature to reduce the amount of flux bypassed as temperature increases.

2. An electrohydraulic servovalve as claimed in claim 1 wherein said compensating shunt is in contact with said permanent magnet at the maximum potential portion of said magnet.

3. An electrohydraulic servovalve as claimed in claim 2 wherein said compensating shunt is generally rectangular and includes opposite end portions deformed slightly in a direction toward said magnet and wherein said shunt is affixed to said magnet with said deformed end portions thereof in contact with the maximum potential portions of said magnet.

4. An electrohydraulic servovalve as claimed in claim 1 wherein said torque motor includes a pair of permanent magnets disposed in spaced apart relation, a pair of pole pieces of magnetic material contacting said magnets at the maximum potential portions thereof, said pole pieces including opposite end portions disposed in facing spaced relation defining air gaps therebetween and a portion of said armature of said flapper is disposed in said air gap, said torque motor further including a pair of said electrical coils each one of said coils surrounding a portion of said armature adjacent said portions thereof disposed in one of said air gaps, and a pair of said compensating shunts, each one of which is affixed to one of said permanent magnets.

5. A torque motor for an electrohydraulic servovalve having a flapper movable to control the flow of fluid therethrough including an armature, said torque motor including at least one permanent magnet to provide a permanent magnet flux field acting upon the armature and at least one electric coil responsive to an electrical input signal to provide a variable flux field acting upon the armature, said torque motor including at least one compensating shunt made of permeable material affixed to said permanent magnet in contact therewith to bypass a portion of said permanent magnet flux field at low temperature and being responsive to temperature to reduce the amount of flux bypassed as temperature increases.

6. A torque motor as claimed in claim 5 wherein said compensating shunt is in contact with said permanent magnet at the maximum potential portions of said magnet.

7. A torque motor as claimed in claim 6 wherein said compensating shunt is generally rectangular and includes opposite end portions deformed slightly in a direction toward said magnet and wherein said shunt is affixed to said magnet with said deformed end portions thereof in contact with the maximum potential portions of said magnet.

8. A torque motor as claimed in claim 5 wherein said torque motor includes a pair of permanent magnets disposed in spaced apart relation, a pair of pole pieces of magnetic material contacting said magnets at the maximum potential portions thereof, said pole pieces including opposite end portions disposed in facing spaced relation defining air gaps therebetween and a portion of said armature of said flapper is disposed in each said air gap, said torque motor further including a pair of said electrical coils each one of said coils surrounding a portion of said armature adjacent said portions thereof disposed in one of said air gaps, and a pair of said compensating shunts, each one of which is affixed to one of said permanent magnets.