ABSTRACT

An electrical feedback signal for an electrohydraulic servovalve is provided by electrical strain gauge means influenced by the bending of a cantilever beam one end of which is constrained to move in a frictionless manner with the output stage valve member of the servovalve, said strain gauge means including a strain sensitive element having a resistance value varied by bending of said beam thereby to generate an electrical feedback signal proportional to the displacement of said valve member which is operatively associated with the electrical command signal for the servovalve.

11 Claims, 6 Drawing Figures
ELECTRICAL FEEDBACK SERVOVALVE

BACKGROUND OF THE INVENTION

Electrical feedback electrohydraulic servovalves are known but the prior art type employed linearly determined electrical position feedback of the output stage valve spool of the servovalve. Usually the electrical position feedback signal was generated by a linear variable differential transformer (hereinafter LVDT) having a fixed element and a movable element which was connected to the valve spool so as to move linearly therewith, relative movement between such elements generating the electrical position feedback signal which was algebraically summed with the electrical command signal to provide an error signal for the electrical force motor input stage of the servovalve. A LVDT is an inductive AC device requiring the provision of an oscillator and demodulator. This arrangement has the disadvantage of the frequency response of the LVDT being limited by the carrier frequency of the AC supply. A DC potentiometer, if employed instead of the LVDT to develop the electrical position feedback signal, has the disadvantage of requiring a mechanically sliding electrical connection.

SUMMARY OF THE INVENTION

The present invention relates to an improved electrical feedback electrohydraulic servovalve which avoids the aforementioned disadvantages of the prior art type of such servovalve.

More specifically, an object of the present invention is to provide an improved electrical feedback electrohydraulic servovalve which has a high frequency response, not limited by any carrier frequency as where a LVDT is used.

Another object is to provide such an unlimited frequency response servovalve which produces an electrical feedback signal in a substantially frictionless manner, without the requirement of mechanically sliding parts as in the case of a potentiometer.

Still another object is to provide such an improved electrical feedback servovalve which has a symmetrical mechanical and hydraulic configuration so as to minimize thermal shifts and provide a symmetrical hydraulic drive to the valve spool ends achieved by equal spool drive areas and equal chamber compliances.

Yet another object is to provide such an improved electrical feedback servovalve with a transducer assembly which is modular so as to be easily removed from and replaced on the main body of the valve, which when separate from the servovalve can be conveniently set up and tested as a subassembly, and which can be nulled when mounted on said main body by a simple shift of the mounting.

An advantage of said transducer assembly is that it has a pickoff element in the form of a cantilever beam which can be completely fluid immersed so as to avoid any need for a moving fluid seal.

Another advantage of said transducer assembly is that the movable end of said cantilever pickoff element can be connected to the valve spool in a substantially frictionless manner.

Other advantages of said transducer assembly are that it is compact, light in weight, rugged, reliable, possesses a long life, is low in cost, and is not likely to get out of order or require repairs.

Still other objects and advantages of the present invention will be apparent from the detailed description later herein of a preferred embodiment illustrated in the accompanying drawing.

In accordance with the present invention, there is provided a transducer assembly for an electrohydraulic servovalve having an input stage including an electrical force motor responsive to an electrical command signal, and an output stage including a body and a valve member movably arranged therein and operatively associated with said motor, said transducer assembly comprising a cantilever beam having a fixed end and a movable end, means mounting said fixed end on said body, means connecting said movable end in a substantially frictionless manner to said member for movement therewith, such movement resulting in bending of said beam, and electrical strain gauge means influenced by said bending for generating an electrical feedback signal operatively associated with said command signal.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of a servo loop including an electrical feedback servovalve embodying the present invention.

FIG. 2 is an enlarged fragmentary horizontal sectional view of the servovalve shown in FIG. 1, this view being taken through a modular transducer assembly shown as mounted on the main body of the servovalve and taken generally on line 2—2 of FIG. 3.

FIG. 3 is a fragmentary vertical sectional view thereof taken generally on line 3—3 of FIG. 2.

FIG. 4 is a still further enlarged top plan view of a cantilever beam constituting the pickoff element of the aforementioned transducer assembly and showing this beam at its opposite ends operatively associated with adjacent parts fragmentarily illustrated and intermediate its ends carrying electrical strain gauge means illustrated in section.

FIG. 5 is a side elevational view of the cantilever beam shown in FIG. 4 and illustrating the same in relation to the associated parts at its opposite ends and still further showing a portion of the encapsulation of the strain gauge means broken away so as to reveal two of the resistors thereof schematically illustrated.

FIG. 6 is a still further enlarged fragmentary view, partly in section, of the movable end portion of the cantilever beam shown in FIGS. 4 and 5.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The servo loop schematically illustrated in FIG. 1 includes an electrohydraulic servovalve 10 of any suitable construction having an input stage 11 and an output stage 12. Specifically, this servovalve may be one having a construction such as shown in U.S. Pat. No. 3,023,782 except that no feedback spring member is interposed between the output stage sliding spool and the flapper of the hydraulic amplifier controlled by the electrical force motor input stage.

Schematically, the input stage of the servovalve is shown in FIG. 1 as including a grounded coil 13 of the aforementioned electrical force motor, such as a torque motor, supplied by an electrical error signal through a conductor 14 leading from a summing amplifier 15. This amplifier is supplied with an electrical command signal via an input conductor 16. Also shown operatively associated with amplifier 15 is an electrical
feedback signal conductor 18. As is well known by those skilled in the art, amplifier 15 algebraically sums the command and feedback signals to provide an error signal transmitted by conductor 14 to motor coil 13.

The novelty of the present invention resides in the provision of a transducer assembly 19 operatively associated with servovalve 10 for generating an electrical feedback signal transmitted by conductor 18 which signal is responsive to the position of a movable valve member such as valve spool 20 slidably arranged in main body 21 of output stage 12. As is well known by those skilled in the art, valve spool 20 meters the flow of fluid with respect to a load such as a piston and cylinder type actuator (not shown).

Transducer assembly 19 is shown as a modular unit removably mounted on the main body 21 of servovalve 10. Referring to FIGS. 2 and 3, one side of servovalve body 21 is recessed to provide a flat surface 22 engaged by the flat end face 23 of a block-like body 24 of assembly 19. An annular seal 25 such as an O-ring is shown as interposed between surfaces 22 and 23. Body 24 is shown as provided with a horizontal central cylindrical through-bore 26 having an enlarged inner end portion 28 and a more greatly enlarged stepped outer end portion 29 having an outwardly facing annular shoulder 30. This construction leaves an annular wall body section 31 between bore portions 28 and 29. The outer end of bore portion 29 is shown as closed by the body 32 of an electrical connector 33 having outwardly projecting prongs 34 insulatingly and sealingly mounted on this body to extend therethrough. A stepped cylindrical plug section 35 on the inside of connector body 32 provides an annular shoulder 36 opposing and spaced from shoulder 30 and between which an annular seal 38 such as an O-ring is arranged. Connector body 32 is held to transducer body 24, in turn held to servovalve body 21, by a series of machine screws one of which is indicated at 39. The head of each such screw 39 is arranged in a counterbored hole 40 through body 32 and the screw Shank extends through a hole 41 in body 24 and its inner end screws into an internally threaded recess 42 provided in body 21, as shown in FIG. 2. Although any number of such screws 39 may be used, it is preferable to have one adjacent each of the four corners of assembly 19.

As shown in FIG. 2, valve spool 20 is slidably arranged in a cylindrical bore 43 of a bushing 44 suitably mounted in servovalve main body 21 and has a central cylindrical lobe 45 provided with an annular groove 46 formed by radially extending side walls 48 for a purpose hereinafter explained.

Transducer assembly 19 also includes a pickup element 49 comprising a movable end portion 50, a fixed end portion 51 and an intermediate cantilever beam 52. As shown in FIGS. 4-6, movable end portion 50 includes a cylindrical stem 53 projecting longitudinally and centrally from the one end of beam 52 as an integral extension thereof. The outer end of stem 53 is shown in FIG. 6 as having a conical recess 54 on the surface of which a spherical ball 55 is seated. This ball is secured to the stem in any suitable manner, preferably by being resistance welded thereto. This ball 55 projects into groove 46 and has a diameter very slightly less than the perpendicular spacing between the opposing parallel walls 48 of valve spool groove 46. In this manner the peripheral surface of this ball can have a rolling and hence substantially frictionless contact with one or the other of walls 48 during flexing or bending of beam 52.

Fixed end portion 51 is in the form of an enlarged cylindrical head formed integrally and symmetrically on the other end of beam 52, merging thereinto through an integral fillet transition section 56. Head 51 is press-fitted in bore 26 in transducer body 24.

Beam 52 is a flat-sided member, rectangular in cross-section and of uniform dimensions throughout its length, having a pair of opposing and parallel long sides 58, 58 and a pair of opposing and parallel short sides 59, 59. This beam is oriented relative to valve spool 20 so that its short sides 59 are parallel to the longitudinal axis of this valve spool and its long sides 58 are perpendicular to such axis, thereby rendering said beam flexible or bendable in the direction of displacement of this valve spool in either direction from its null position.

As shown in FIGS. 4 and 5, between its ends cantilever beam 52 carries electrical strain gauge means 60 which are influenced by bending of this beam resulting in electrical displacement means for generating an electrical feedback signal. As shown in FIG. 1, such electrical strain gauge means 60 comprises four strain sensitive resistors 61, 62, 63 and 64 arranged in a wheatstone bridge circuit having two branches. One branch includes resistors 61 and 64 connected in series, and the other branch includes resistors 62 and 63 connected in series. The two branches are connected together at 65 and this point via a conductor 66 is connected to the plus terminal of a suitable source of DC voltage (not shown). The other ends of the branches are connected together at 68 and via a conductor 69 are connected to the negative terminal of such DC source. Conductor 18 is connected at point 70 to one branch between resistors 61 and 64. The other branch is connected at point 71 between its resistors 62 and 63 to ground via a conductor 72.

Adverting to FIGS. 4 and 5, each of strain sensitive resistors 61-64 is shown in the form of a serpentine wire of suitable composition and configuration arranged in a common plane and suitably attached to a long side 58 of beam 52 about midway of its longitudinal extent. Two opposing resistors, such as resistors 61 and 63, are arranged on one side 58, and the other pair of opposing resistors 62 and 64 is arranged on the other side 58, symmetrically with respect to the first pair 61 and 63. For example, resistor 62 may be directly opposite resistor 61, and resistor 64 may be directly opposite resistor 63. The ends of these resistors have leads suitably electrically joined together to form the wheatstone bridge circuit shown in FIG. 1, such leads being suggested by the wires 73 shown in FIGS. 2 and 3 which pass successively through holes 74 in transducer body wall section 31 and are suitably electrically connected severally to the inner ends of connector prongs 34. Resistors 61-64 as attached to the sides 58 of beam 52 are shown encapsulated by a body 75 of suitable insulating material from which lead wires 73 extend. Prongs 34 are inserted in a receptacle (not shown) for an electrical conductor represented by line 18.

With the arrangement of pairs of strain sensitive resistors 61-64 on opposite sides of cantilever beam 52, it will be seen that when this beam is flexed or bent by displacement of valve spool 20 from null position shown in FIGS. 2-5, two opposing resistors in the bridge circuit will be put in tension and the other two in compression. Due to the characteristics of the mate-
rial of which these resistors are made and their orientation as a strain gauge on the cantilever beam, the resistance values of these resistors will vary to produce a DC voltage at point 70 of the bridge circuit which is proportional to the extent of bending of the beam and hence proportional to the displacement of valve spool 20, this voltage representing a feedback signal responsive to spool position and transmitted via conductor 18 to amplifier 15 where it is algebraically summed with the electrical command signal put in through conductor 16.

Accordingly, when a command signal is sent through conductor 14 and summed with position feedback signal returning through conductor 18, an error signal is transmitted via conductor 14 to motor coil 13. This coil will induce the movement of some part of a hydraulic amplifier (not shown) so as to produce a pressure differential proportional to the error signal which pressure differential is applied to the ends of valve spool 20 so as to induce longitudinal displacement thereof relative to servovalve body 21. Displacement of the valve spool causes beam 52 to bend since it is cantilever mounted. This bending of the beam will cause the strain sensitive resistors 61–64 of the wheatstone bridge circuit to be influenced, one pair increasing in resistance level and the other pair decreasing in resistance level, so as to generate an electrical feedback signal proportionate to the displacement of the valve spool. This signal is sent back via conductor 18 and summed with the command signal algebraically to provide the error signal servicing motor coil 13. When valve spool 20 attains the displaced position commanded, the feedback signal will cancel the command signal and the error signal will be zero.

While in the preferred embodiment illustrated, all four strain sensitive resistors 61–64 in the wheatstone bridge circuit are mounted on the bendable beam 52 so that each is influenced by the bending of this beam, it is within the concept of the present invention to provide only two active or variable resistors on the beam. These two strain sensitive resistors may be used with two other resistors having a fixed resistance value, or they may be used in a variety of other electrical circuits, known to those skilled in the art, which will produce an electrical feedback signal proportional to resistance variation.

In this alternate, two active arm arrangement, only two strain sensitive resistance elements, such as 61, 64 or 62, 63 are used. With the use of two strain sensitive resistance elements, one is mounted on each face 58 of the cantilever beam, preferably directly opposite each other. In this fashion the intermediate voltage (such as at 70 or 71) will not be subject to change with temperature of the cantilever beam which is immersed in the hydraulic fluid.

One advantage of this alternate, two active arm arrangement, is that the transducer assembly is simpler, hence lower in cost. However, the transducer electrical output signal is reduced as only two variable resistance arms are utilized.

Still another arrangement is with a single strain gauge element, being used as any one arm of the four arms of the wheatstone bridge circuit, or in an alternate electrical circuit wherein a signal proportional to gauge resistance is created. Generally a single strain gauge element is undesirable because its resistance will vary with temperature, hence give an erroneous indication of valve spool position.

The electrical schematic of FIG. 1, including the transducer wheatstone bridge, has been simplified for purpose of clarity. It is understood by those skilled in the art that various bridge compensation circuitry, such as nulling and sensitivity adjustments, are often utilized. Also the strain sensitive resistance elements may be of the metal foil, deposited metal, or semiconductor types rather than the metal-wire type elements illustrated.

It may be desirable to utilize the electrical spool position feedback arrangement shown, in conjunction with mechanical or hydraulic spool position feedback, to give a redundant feedback path as desirable in certain fail-safe control systems.

Another application for this electrical feedback spool position transducer is in conjunction with a three-stage servovalve wherein an intermediate stage of hydraulic amplification is imposed between the input stage and the sliding spool output stage.

What is claimed is:

1. In an electrical feedback servovalve having an input stage including an electrical force motor responsive to an electrical command signal, and an output stage including a body and a valve member arranged in said body to move relative to said body in response to the operation of said motor, the improvement which comprises a cantilever beam having a fixed end and a movable end, means mounting said fixed end on said body, means connecting said movable end in a substantially frictionless manner to said member for movement therewith, such movement bending said beam, and electrical strain gauge means for generating an electrical feedback signal responsive to said bending.

2. A servovalve according to claim 1 wherein said valve member is a slidable spool, and said movable end of said beam is connected by said connecting means to said spool symmetrically with respect to the length thereof.

3. A servovalve according to claim 1 wherein said electrical strain gauge means comprises electrical circuitry including a strain sensitive resistance element having a resistance value varied by said bending, said circuitry being arranged to produce said electrical feedback signal proportional to resistance variation.

4. A servovalve according to claim 3 wherein said circuitry includes at least two strain sensitive resistance elements mounted on said beam so that one is subjected to compression and the other to tension during such bending.

5. A servovalve according to claim 4 wherein said two strain sensitive resistance elements are mounted directly opposite each other on opposite sides of said beam.

6. A servovalve according to claim 5 wherein said circuitry is a wheatstone bridge circuit.

7. A servovalve according to claim 1 wherein said electrical strain gauge means comprises four strain sensitive resistance elements arranged in a wheatstone bridge circuit having two branches each including two of said elements mounted on said beam so that one of said elements from each of said branches is subjected to compression and the other of said elements from each of said branches is subjected to tension during said bending thereby to vary the resistance values of
said four elements and produce said electrical feedback signal proportional to resistance variation.

8. A servovalve according to claim 1 wherein said connecting means includes a spherical element on said movable end of said beam and received in a recess provided in said valve member and rollingly engaging a wall of said recess.

9. An electrical feedback servovalve according to claim 8 which further comprises means supporting said fixed end of said beam and removably mounted on said body and including an electrical connector for said strain gauge means.

10. An electrical feedback servovalve according to claim 9 wherein said supporting means, beam, spherical element, strain gauge means and connector constitute a modular transducer assembly removably mounted on said body.

11. A servovalve according to claim 10 wherein said valve member is a slidable spool and said recess therein is located symmetrically with respect to the length of said spool.

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