Aug. 8, 1967 P. G. BORTHWICK 3,334,642

ELECTRO-PNEUMATIC TRANSDUCER

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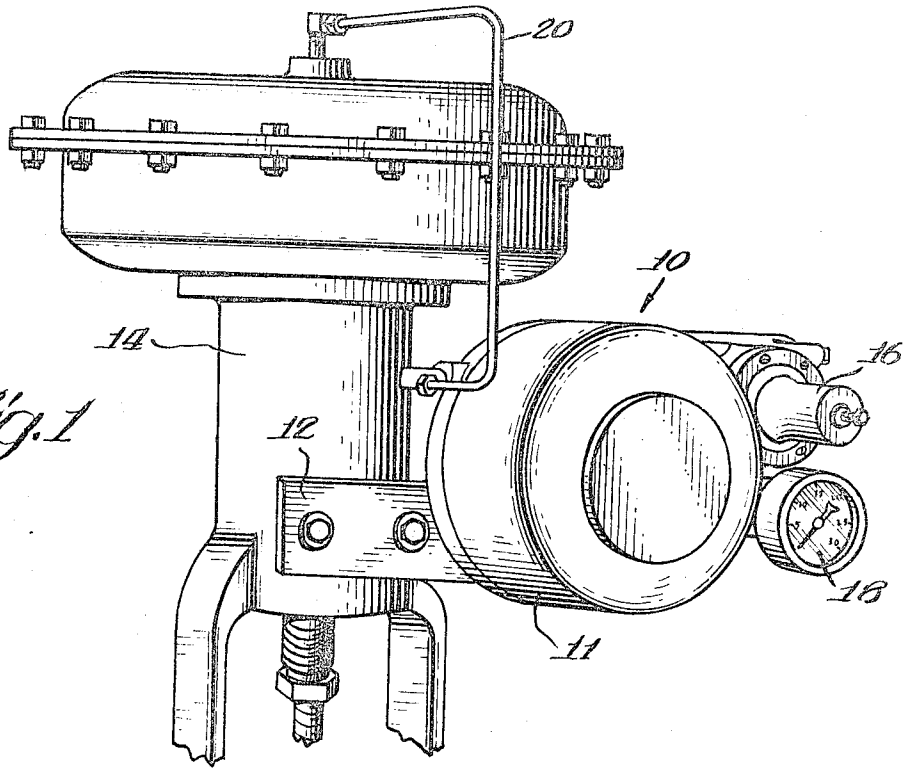


Fig. 1

Fig. 8

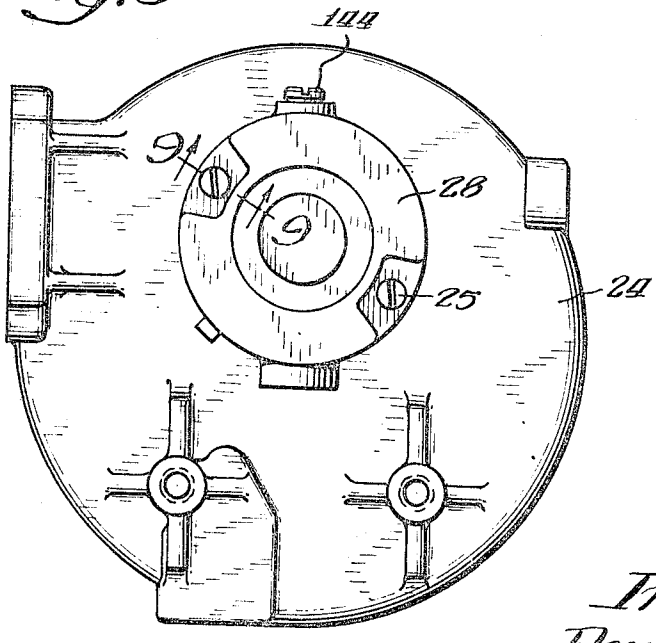
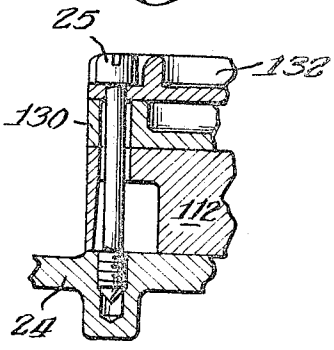


Fig. 9



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ELECTRO-PNEUMATIC TRANSDUCER

Filed Aug. 16, 1965 4 Sheets-Sheet 2

Fig. 2

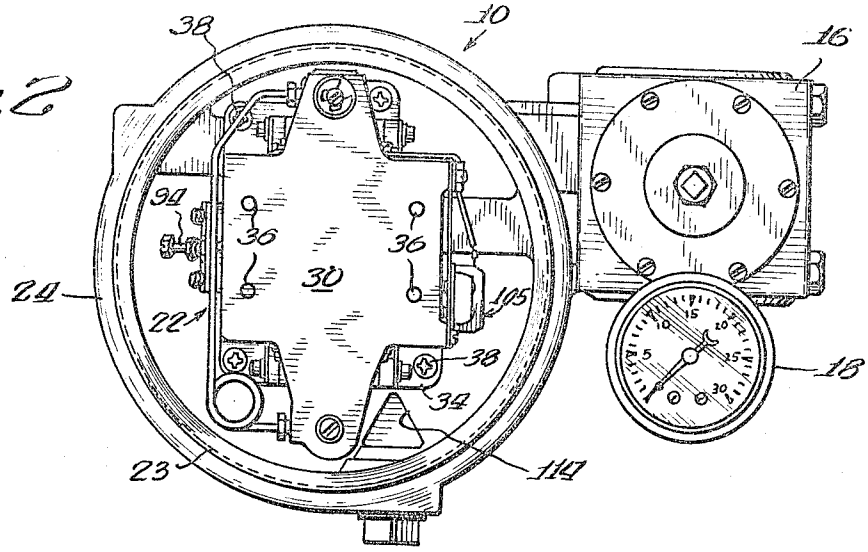
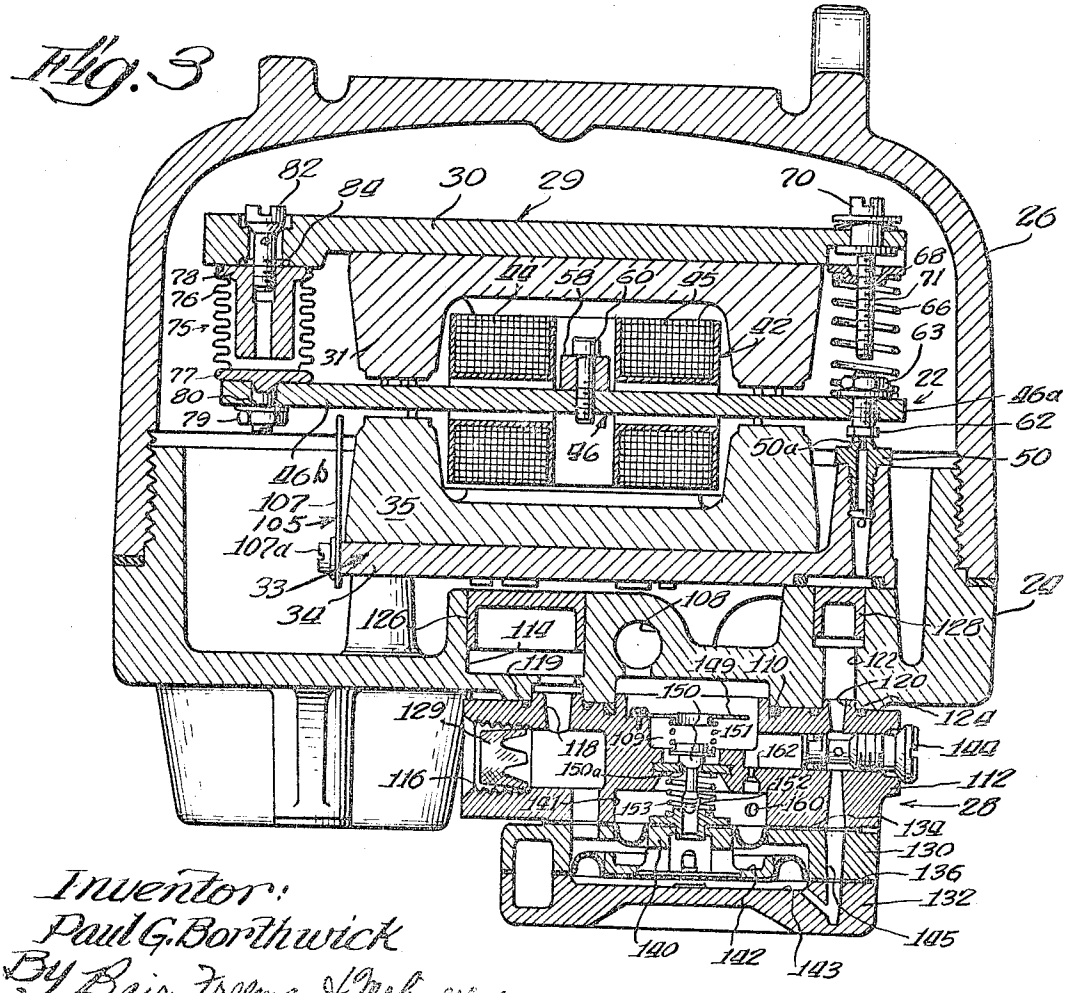


Fig. 3



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Aug. 8, 1967 P. G. BORTHWICK 3,334,642

ELECTRO-PNEUMATIC TRANSDUCER

Filed Aug. 16, 1965 4 Sheets-Sheet 3

Fig. 5

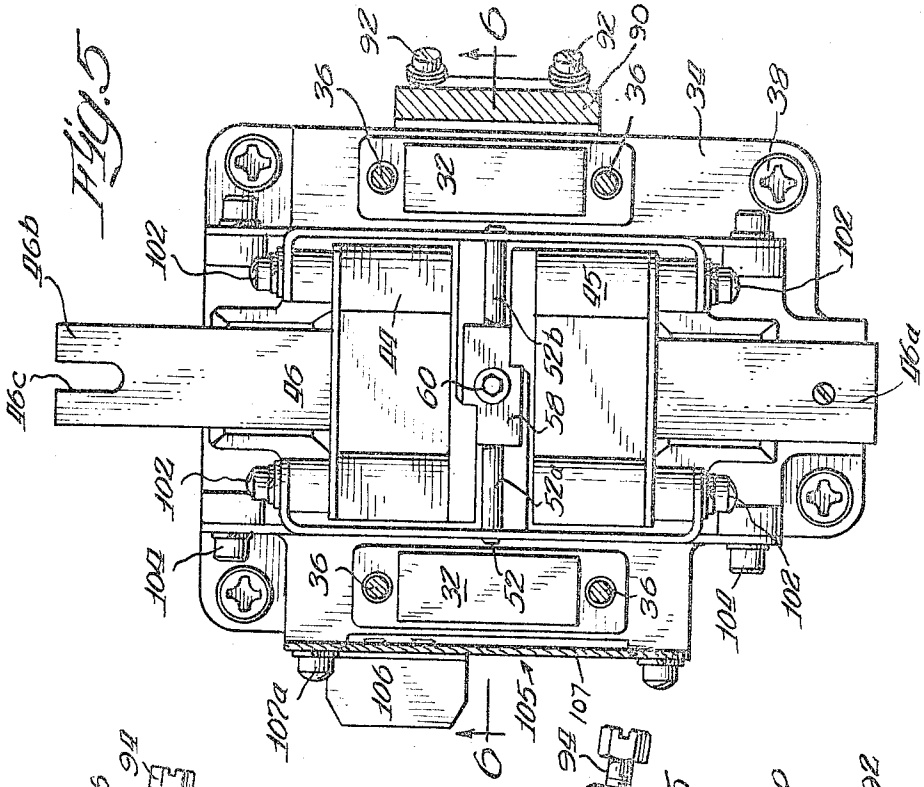


Fig. 4

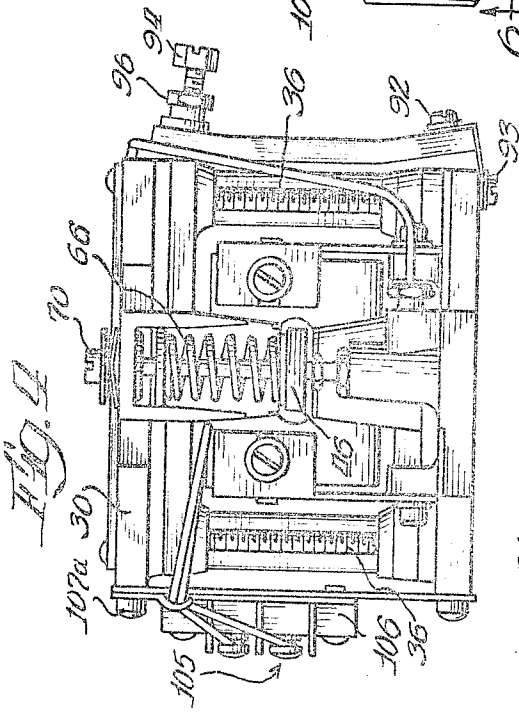
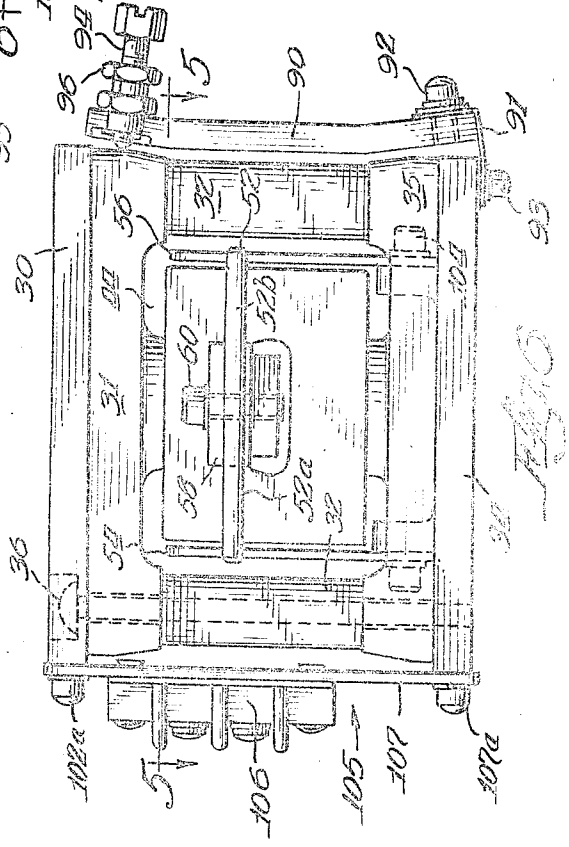


Fig. 6



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Aug. 8, 1967 P. G. BORTHWICK 3,334,642

ELECTRO-PNEUMATIC TRANSDUCER

Filed Aug. 16, 1965 4 Sheets-Sheet 4

Fig. 10

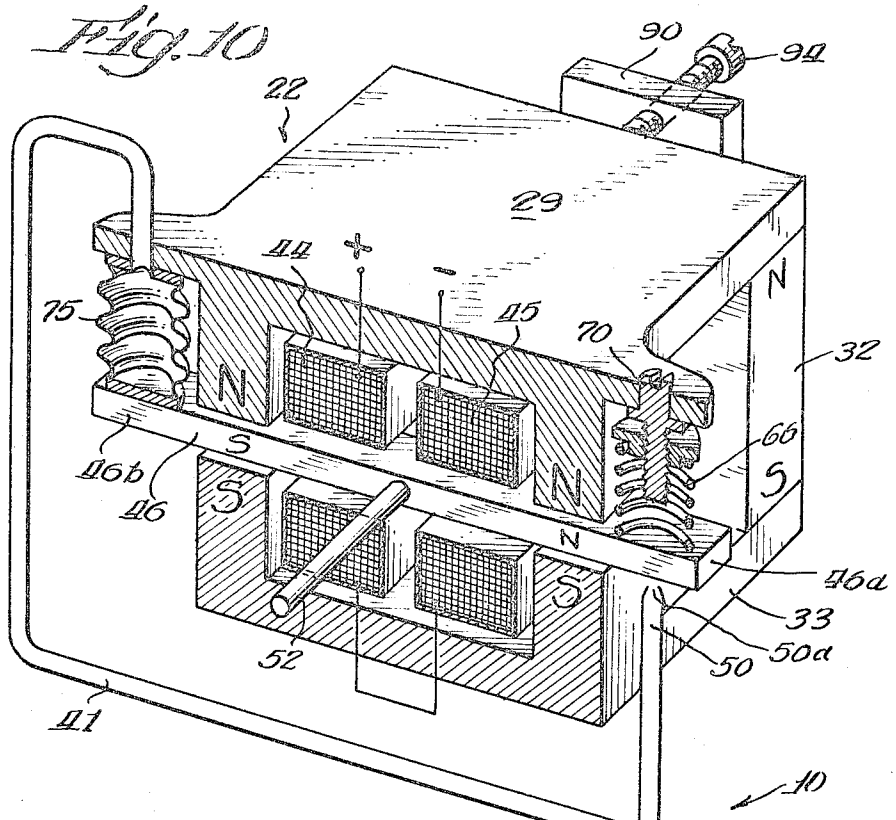
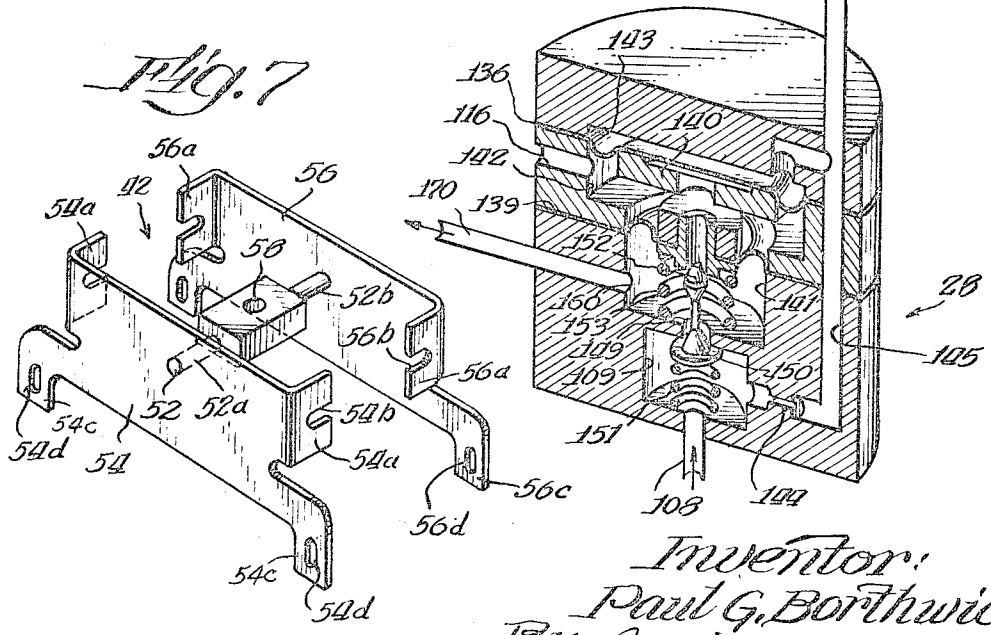


Fig. 7



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ELECTRO-PNEUMATIC TRANSDUCER

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Filed Aug. 16, 1965, Ser. No. 479,935
11 Claims. (Cl. 137—85)

This invention relates to an electro-pneumatic transducer and, more particularly, to an improved electro-pneumatic transducer for use in electrical control loops in which the final control element is pneumatically operated.

An object of the present invention is to provide an improved electro-pneumatic transducer that can be readily mounted on a control valve or like pneumatically-operated control element, such transducer receiving a direct current milliampere input signal and creating a pneumatic output pressure that is directly proportional to this input.

Another object of the present invention is to provide an improved electro-pneumatic transducer comprising a torque motor assembly and a relay assembly that attaches to a common case without tubing.

A further object of this invention is to provide a novel electro-pneumatic transducer having an improved torque motor that includes adjustable coil and armature means for facilitating adjustment of the armature.

Still another object of the present invention is to provide an improved electro-pneumatic transducer having a torque motor constructed and arranged so as to interchangeably receive a plurality of feedback bellows (one for every output range).

Yet another object of this invention is to provide an improved electro-pneumatic transducer, the torque motor of which includes a relatively simple temperature compensating means.

It is another object of this invention to provide an improved electro-pneumatic transducer having high loop gain, high torque output and torsion rod suspension that combine to result in high static performance for the transducer. These and other objects of the present invention will become more apparent hereinafter.

The specific details of a presently preferred form of the present invention and their mode of operation will be made most manifest and particularly pointed out in clear, concise and exact terms in conjunction with the accompanying drawings, wherein:

FIGURE 1 is a perspective view illustrating an electro-pneumatic transducer which embodies the principles of the present invention mounted on a control valve and showing an air set and pressure gauge for use therewith;

FIGURE 2 is a top view of the electro-pneumatic transducer with the cover of the housing removed to show the torque motor assembly;

FIGURE 3 is a sectional view of the electro-pneumatic transducer illustrating the torque motor and the relay;

FIGURE 4 is an end view of the torque motor assembly;

FIGURE 5 is a cross-sectional view of the torque motor assembly taken generally along the line 5—5 of FIGURE 6;

FIGURE 6 is a cross-sectional view of the torque motor assembly taken generally along the line 6—6 of FIGURE 5;

FIGURE 7 is a perspective view of the armature and coil support bracket;

FIGURE 8 is a rear view of the transducer housing and relay;

FIGURE 9 is a detail view taken along line 9—9 of FIGURE 8 illustrating the connection of the relay to the housing for the transducer; and

FIGURE 10 is a schematic illustration of the electro-pneumatic transducer of this invention.

Referring now to the drawing, there is illustrated in FIGURE 1 an electro-pneumatic transducer **10** embodying the principles of the present invention and having a casing or housing **11** which is mounted on a bracket **12** that is suitably affixed to the casing of a control valve **14** for controlling the operation of such control valve. It will be understood that the electro-pneumatic transducer **10** can also be mounted on a stand pipe with a U-bolt connection.

If desired, an air set **16** and a pressure gauge **18** may be mounted on the electro-pneumatic transducer **10**.

The pneumatic output from the transducer **10** is fed to the actuator of the control valve **14** or other device to be controlled pneumatically by means of a conduit **20**. The actuator of the control valve may be either a diaphragm or a piston.

Considering now FIGURES 2 and 3 of the drawing, it is seen that the transducer is comprised basically of a torque motor **22** enclosed within a housing **11** defined by a case **24** and a cover **26** threadedly connected to the case **24** and a relay **28** that is connected directly to the case **24** without the necessity for ancillary tubing. The transducer **10** is used in electrical control loops in which the final control element is pneumatically operated. It receives a direct current milliampere input signal and creates a pneumatic output pressure that is directly proportional to this input.

The torque motor **22** is the first stage in the conversion of an electrical input signal to a pneumatic output pressure. The second stage in the conversion from the electrical input to the pneumatic output takes place in the relay **28**.

The torque motor consists basically of a nozzle flapper signal amplifier and associated electro-mechanical elements. The torque motor **22**, as seen in FIGURES 2–6, includes top pole means comprising a top pole piece plate **30** and a top pole piece **31**, permanent magnet means **32** and bottom pole piece means comprising bottom pole piece plate **34** and bottom pole piece **35**. The assembly comprising the top pole piece plate **30**, the pole pieces **31**, **35**, permanent magnets **32** and bottom pole piece plate **34** are held together by suitable fastening means, as shown in the drawing by four round head screws **36**.

The bottom pole piece plate **34** is rigidly affixed to the case **24** by means of suitable machine screws **38** (FIG. 2) to mount the torque motor **22** within the case **24**.

The torque motor assembly **22** includes an armature and coil support assembly having bracket means **42** for carrying electrical coils **44** and **45** thereon and for supporting an armature **46** for pivotable movement within the housing means. The end **46***a* of the armature **46** cooperates with the opening **50***a* from nozzle **50** (that is threadedly connected to a tapped opening in the bottom pole piece plate **34** to cover or uncover the nozzle opening **50***a*) to control the flow of air therefrom.

The armature **46** pivots about a centrally located torsion bar means **52** that is fixed at its ends to the plate members **54** and **56** of the bracket means **42**. The torsion rod **52** comprises a pair of rod members **52***a* and **52***b* which are each rigidly affixed at one end to the block **58** and extend therefrom. The other ends of rod members **52***a* and **52***b*, respectively, are connected to plate members **54** and **56**, respectively. The armature **46** extends through the bracket means **42** between the coils **44** and **45** and is connected to the block **58** by means of suitable fastening means, as for example, machine screw **60**.

The armature **46** pivots about the axis of centrally located torsion bar **52** with a change in input signal to cover or uncover the nozzle **50**. The direction of current flow through the coils **44** and **45** determines the polarity of the armature **46**. Therefore, reversing the input leads to the coils will provide reverse action. The

armature and the pole pieces are preferably fabricated from magnetic materials which are chosen to reduce hysteresis and improve performance.

It is to be noted that a baffle 62 (FIG. 3) is provided on the end 46*a* of the armature 46 to serve as an adjustable extension of the armature to insure that the covering of the nozzle opening 50*a* (to obtain proper restriction of air flow) is accomplished with the armature 46 centered between the pole pieces. The exterior of the stud-like portion of baffle 62 is threaded for cooperation with a threaded opening in the end 46*a* of the armature. A lock nut 63 is provided to retain the baffle 62 in selected adjusted position.

Spring means are provided for biasing the armature end 46*a* toward nozzle covering position. The spring 66 acts between the armature 46 and the retainer member 68 which is threadedly engaged with an adjusting screw 70 to provide for selective adjustment of the spring bias force upon the armature. It is noted that the stem 71 of the adjusting screw 70, which is rotatably journaled in pole piece plate 30, has external threads thereon which engage with a threaded opening through the retaining member 68. The adjustment provided by the change of bias force on the spring 66 is referred to as the zero adjustment. The zero adjustment provides a means of setting the initial output pressure at the desired value of input signal.

Feedback means are provided for urging the armature 46 in a direction in opposition to the bias of the spring means 66. The feedback bellows assembly 75, which includes the feedback bellows 76 operatively connected at its ends to a base 77 and a cap 78, is removably affixed between the armature end 46*b* and the top pole piece plate 30 so as to permit ready replacement of the feedback bellows assembly 75. This is necessary for a different feedback bellows assembly is required for every selected output range.

The feedback bellows assembly 75 is readily removed by first loosening the lock nut 79 which engages with a stud portion 80 on the end of the base 77 that extends through an opening in the armature 46. Upon removal of lock screw 82, which extends through an opening in the top pole piece plate 30 into threaded engagement with the top cap 78, the feedback bellows assembly may be slid from position. It is noted from FIGURE 5 that the end 46*b* of armature 46 is provided with a slot 46*c* to permit the stud 80 to be easily slid outwardly from the armature. O-ring seal means 84 are provided between the top pole piece plate 30 and the top cap 78 to prevent loss of feedback air from within the feedback bellows assembly 75 during use.

Another important feature of this invention is the provision of a span adjustment for providing a means of obtaining a full change in output pressure for a full change in input signal. The span adjustment is accomplished by moving a piece of magnetic material 90 (FIGURES 5 and 6) toward or away from the permanent magnet 32 to shunt away or add to the magnetic flux in the armature air gap. The result is a change in the amount of torque produced.

The bar of magnetic material 90 is carried at one end on the pole piece plate 34 by means of an angle bracket 91 affixed to one end of bar 90 by screw means 92 and affixed at its other end to the pole piece plate 34 by screw means 93. The bracket 91 has resiliency and will normally function to bias the upper end of the bar 90 toward the permanent magnet 32. Adjustment screw 94, which is adapted to bear at its end against the pole piece 31, may be rotated to suitably adjust the position of the bar 90 with respect to the permanent magnet 32. Lock nut means 96 are provided to lock the adjustment screw in its selected adjusted position.

The support bracket 42 for the armature 46 and the coils 44 and 45, as seen in FIGURE 7, comprises a pair of plate members 54 and 56 joined together by the ends of torsion rod means 52. Each plate member includes inwardly extending arms 54*a* and 56*a*, respectively, having elongated recesses 54*b* and 56*b*, respectively, therein. In addition, downwardly depending legs 54*c* and 56*c*, respectively, are provided on the plate members 54 and 56. Within each of the legs 54*c* and 56*c*, respectively, is an elongated slot-like opening 54*d* and 56*d*, respectively. The slot-like openings 54*d* and 56*d* provide for adjustment of the bracket means 42 with respect to the bottom pole piece plate 34 to adjust the position of armature 46 between the pole pieces 31 and 35, as will be more clearly understood hereafter.

As best seen in FIGURES 4 and 5, the two identical coils 44 and 45 are mounted to the armature and coil support assembly 42 by screw means 102. The armature 46 is inserted through the two coils 44 and 45 and is fastened to the assembly 42 by the screw means 60, which preferably comprises a hexagonal socket head screw.

The coil and armature assembly 42 is adjustable by virtue of the slotted holes 54*d* and 56*d*, respectively, in the plate members 54 and 56. The assembly 42 is mounted on the bottom pole piece plate 34 by means of screw means 104, which may be hexagonal socket head screws. Before the four screws 104 are tightened, the armature 46 is centered between the two pole pieces 31 and 35. The four slotted mounting holes 54*d* and 56*d*, respectively, in the plate members 54 and 56 facilitate this adjustment.

Referring to FIGURES 4, 5 and 6, it is noted that the terminal mounting bracket assembly 105 is mounted directly on the torque motor. The terminal mounting bracket assembly comprises a terminal strip 106 and terminal strip mounting bracket 107 which is manufactured from a material whose magnetic permeability change with temperature change is the opposite from the permeability change of the pole pieces 31, 35 and the armature 46. Bracket 107 is affixed to the pole piece plates 30 and 34 by suitable fastening means 107*a*, for example, machine screws. The bracket 107 is positioned with respect to the permanent magnet 32 in such manner that part of the magnetic flux created from the permanent magnet is carried through the bracket. By virtue of this orientation of components, temperature compensation is provided for the bracket assembly 105.

Considering FIGURES 3, 8 and 9, it is seen that the relay 28 is connected directly to the case 24 by fastening means 25, such as elongated screws, without the necessity for ancillary tubing. The inlet opening 108 in the case 24, which is connected to a suitable source of air supply, communicates with a chamber 109 defined between the case 24 and the housing of the relay 28. The O-ring seal 110 is provided between the case 24 and the housing portion 112 of the relay 28 to seal the chamber 109.

Air may be exhausted from within the housing means 11 defined by cover 26 and case 24 through the exhaust opening 114 in the case 24 which communicates directly with the exhaust opening 116 in the relay 28 through the passage 118. An O-ring seal 119 is disposed about the passage 118 between the case 24 and the relay 28 to prevent escape of air from passage 118. Similarly, the opening 120 in the relay 28 communicates directly with the passage 122 in the case 24 that is connected with the nozzle 50. An O-ring 124 is provided about the opening 120 to prevent the undesired loss of pressure.

It is noted that porous stainless steel flame arresters 126 and 128 are provided in the air passages between the case 24 and the relay 28. The use of the flame arresters in cooperation with the housing means provides for an explosion-proof housing. Filter screen 129 is provided in vent opening 116 to prevent dirt from entering relay 28.

Considering now the construction of the relay 28, it is seen that the relay housing is comprised of separate members 112, 130 and 132 operatively connected to one another and joined to the case 24. Provided within the relay 28 are a pair of diaphragms 134 and 136 which are peripherally connected to the relay housing so as to per-

mit the central portions thereof to move longitudinally within the housing or casing of relay **28**. Spacer member **140** is operatively connected to the diaphragms **134** and **136** for movement therewith. The diaphragms cooperate with the relay housing to define compartments **141**, **142** and **143** therewithin.

Valve means comprising an inlet valve **150** and an exhaust valve **152** are interconnected for cooperation within the relay **28** to control the flow of air therethrough. Inlet valve **150** is biased toward closed position by spring **151**, which operates between the valve **150** and plate **149** fixed in chamber **109**. Spring **153** normally biases the spacer **140** away from exhaust valve **152** to exhaust air from chamber **141** through the exhaust passage through spacer **140** as will be more fully explained later.

Air from a suitable source of supply will flow through the passage **108** into the chamber **109** defined between the relay **28** and the case **24**. From the chamber **109**, air will flow through the fixed restriction **144** and through the passage **145** to the compartment or chamber **143** to exert a pressure on the spacer means in opposition to the pressure of spring **153**. A portion of the air will pass from the restriction **144** through the opening **120** and passageway **122** to the nozzle **50** for discharge therethrough.

When the nozzle opening is restricted by baffle **62** on armature **46**, the pressure will build up within compartment **143** until it is sufficient to overcome the spring bias and move the inlet valve **150** away from the opening **150***a* to permit the passage of air through opening **160** to the control valve or other pneumatically operated device. The outlet pressure flowing through the opening **160** will continue to increase until the relay diaphragm assembly comprising the spacer means **140** and diaphragms **134** and **136** is pushed back by the force of the pressure acting on the smaller diaphragm **134** to its original position and the inlet valve **150** is closed. When the force derived from the pressure within the chamber **141** acting on diaphragm **134** coupled with the force of spring **153** is sufficient to overcome the force derived from the pressure within the chamber **143** acting on diaphragm **136**, the spacer means **140** will move away from the exhaust valve **152** to permit the exhaust of air from the compartment **141**, through the exhaust passage in spacer **140**, compartment **142**, and the vent opening **116**. It is to be noted at this time that air may be exhausted from within the housing means **11** through passage **114** which communicates via passage **118** with the exhaust opening **116** in relay **28**.

Passage **162** permits a constant bleed of air from the compartment **109** through compartment **142** to the atmosphere. This allows a small clearance between the exhaust valve **152** and the exhaust valve seat (defined by the extension of spacer **140**) to prevent dead band.

The operation of the electro-pneumatic transducer of the present invention will best be understood by reference to FIGURE 10. The transducer **10** which comprises basically torque motor **22** and relay **28** is utilized in electrical control loops in which the final control element is pneumatically operated. The transducer receives a direct current milliampere input signal and creates a pneumatic output pressure that is directly proportional to this input. The torque motor **22** is the first stage in the conversion of the electrical input signal to a pneumatic output pressure. The second stage in the conversion from the electrical input to the pneumatic output takes place in the relay **28**.

Assuming that the transducer is direct-acting, an increase in the D-C milliampere signal to coils **44** and **45** increases magnetic field around the coils. This increase in magnetic field increases the magnetic strength in the armature **46** and the magnetic attraction across the air gap between the armature and the pole piece means **29** and **33**. The pole piece means are already polarized by the permanent magnet **32**. The armature polarity in this case will

be as shown in FIGURE 10, for example, with the top pole means **29** comprising a north pole and the bottom pole means **33** comprising a south pole. The magnetic attraction will, therefore, be downward at the nozzle end **46***a* of the armature **46** and upward at the feedback bellows end **46***b*, resulting in a torque that rotates the armature **46** about the fixed torsion rod **52** to cover the nozzle opening **50***a*.

The resulting restriction of the nozzle opening **50***a* of nozzle **50** produces an increased pressure in the nozzle, in the chamber **143** of the relay and in the feedback bellows **75**. The feedback bellows **75** communicates with nozzle **50** and passage **145** in relay **28** via line **41**. The relay **28** responds to the increase in nozzle pressure to increase the output pressure to the control valve. The increased pressure in the feedback bellows **75** creates a force that acts on the armature **46** to move it back to the equilibrium position. In this way, the new nozzle pressure is compared to the input current by the force balance principle.

The nozzle pressure acts on the relay diaphragm **136** to force the spacer means **140** (operatively mounted between the two diaphragms **134** and **136**) downward against the exhaust valve **152**, closing the exhaust port and opening the inlet port **150***a*. Supply air then flows through the inlet port **150***a* and the opening **160** from the chamber **141** through the conduit **170** to the control valve. The output pressure continues to increase until the relay diaphragm assembly is pushed back by the force of the pressure acting on the diaphragm **134** to its original position and the exhaust valve **152** is closed again.

When a decreasing D-C signal is received, the magnetic attraction across the air gap is reduced. The armature **46** rotates or pivots about the axis of torsion rod **52** to uncover the nozzle opening **50***a* and decrease the pressure in the nozzle **50**, relay **28** and feedback bellows **75**. The relay diaphragm assembly moves upwardly, as viewed in FIGURE 10, and the exhaust port in the spacer means **140** is opened to bleed the output pressure to the atmosphere through compartment **142** and exhaust opening **116**. The output decreases until the diaphragm assembly is forced back to its original position and the exhaust port is closed again. The reduced pressure in the feedback bellows **75** diminishes the force to return the armature **46** to the equilibrium position.

Reverse-acting transducers operate in a similar manner except that when the D-C input signal increases, the output pressure from the relay decreases. Conversely, a decreasing input signal increases the output pressure.

There has been provided by the present invention an improved electro-pneumatic transducer comprising a torque motor which is the first stage in the conversion of the electrical input signal to a pneumatic output pressure and a relay which is the second stage in the conversion from the electrical input to the pneumatic output. The two-stage design with each stage possessing its own feedback loop allows for uniformly high stability for any output load. An overall feedback loop was purposely avoided by the present invention in order to maintain stability that was completely independent of the output load. In a presently preferred form of the invention, the high capacity relay will amplify the torque motor nozzle pressure into the output pressure by a three to one ratio. Thus, for a nozzle pressure change of 4 p.s.i., the relay output pressure changes 12 p.s.i., the span for a standard 3 to 15 p.s.i. range.

The high loop gain, the high torque output, and the torsion rod suspension of the armature result in high static performance.

The back of the case or housing for the transducer is designed to mate with a plug-in relay so that the relay may be readily serviced without disturbing the electrical or pneumatic connections. The case and the cover thread together and are gasketed to form an explosion-proof housing which is preserved by the use of porous stainless

steel flame arresters in the air passages between the case and the relay.

While there has been shown and described a particular embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention. Therefore, it is intended in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

I claim:

1. In an electro-pneumatic transducer, the combination of housing means, a torque motor assembly removably mounted in said housing means, said torque motor assembly including permanent magnet means and pole pieces associated therewith, an armature and coil assembly including a support bracket carrying electrical coils and pivotally supporting an armature thereon, the armature being movable between the pole pieces in response to electrical energization of said coils, said permanent magnet means and said pole pieces being removable from the torque motor assembly separately from the armature and coil assembly, a bleed nozzle on said housing means operatively associated with said armature, said armature being biased toward the bleed nozzle for restricting the discharge of air from said nozzle, a feedback member operatively associated with said armature and acting on said armature to increase the discharge of air from said bleed nozzle, means for supplying a direct current input signal to said coils to energize said coils and produce a magnetic field having a strength that changes proportionately with the change in input signal, the magnetic attraction between the armature and pole pieces causing movement of the armature to vary the position of the armature with respect to the nozzle opening for controlling the discharge of air from said nozzle, the feedback member cooperating with the nozzle in a force balance relationship.

2. An electro-pneumatic transducer as in claim 1 wherein said feedback member comprises a bellows removably affixed to the armature so as to provide for interchangeability of bellows to accommodate a wide output range.

3. An electro-pneumatic transducer as in claim 1 wherein said armature is provided with adjustable baffle means for covering the nozzle to obtain proper restriction of air flow from the nozzle when the armature is centered between the pole pieces.

4. An electro-pneumatic transducer as in claim 1 wherein a terminal mounting bracket assembly is provided within said housing means for mounting on said torque motor assembly, said mounting bracket assembly including a mounting bracket disposed adjacent the permanent magnet means, the mounting bracket being made from a material whose magnetic permeability change with temperature change is the opposite from the magnetic permeability change of the pole pieces and armature so as to provide for temperature compensation.

5. An electro-pneumatic transducer as in claim 1 wherein a piece of magnetic material is adjustably positioned with respect to said permanent magnet to shunt away or add to the magnetic flux in the air gap between the armature and the pole pieces.

6. An electro-pneumatic transducer as in claim 1 wherein the support bracket is adjustably supported in the permanent magnet means for facilitating centering of the armature between the pole pieces.

7. In an electro-pneumatic transducer, the combination of housing means, a torque motor assembly removably mounted in said housing means, said torque motor assembly including permanent magnet means and pole pieces connected to form a subassembly, armature and coil means operatively associated with said pole pieces, said armature and coil means including a support frame fixed with respect to said pole pieces and carrying electrical coils thereon, an armature supported on said support frame for movement between the pole pieces about an axis transverse to the length of said armature, said permanent magnet means and said pole pieces being removable from the torque motor assembly separately from said armature and coil means, nozzle means in said housing means adjacent one end of said armature, said nozzle means being operatively connected to a pneumatic relay by conduit means, said one end of said armature being movable to regulate the discharge of air from said nozzle means, means for biasing the armature toward the nozzle means, a feedback member operative on the other end of said armature in opposition to said biasing means, said feedback bellows communicating with said conduit means, means for supplying a direct current input signal to said coil means to energize said coil means, the magnetic attraction between the armature and the pole pieces causing movement of said armature at its pivot axis to vary the position of said one end with respect to the nozzle means for controlling the discharge of air from said nozzle mean, the feedback member cooperating with the nozzle means in a force balance relationship.

8. An electro-pneumatic transducer as in claim 7 wherein said support frame includes a pair of generally parallel plate members having inwardly bent tabs thereon for supporting said coil means.

9. An electro-pneumatic transducer as in claim 7 wherein said support frame includes a pair of generally parallel plate members joined together by torsion rod means affixed at its ends to the plate members, said armature being fixedly connected intermediate the ends thereof to said torsion rod means.

10. An electro-pneumatic transducer as in claim 9 wherein said plate members are adjustably supported in said housing means to provide centering adjustment of said armature between said pole pieces.

11. An electro-pneumatic transducer as in claim 8 wherein said housing means has an exhaust opening, a supply air opening and a nozzle connecting opening in one wall thereof and said pneumatic relay includes a housing having an exhaust opening complementary to the housing means exhaust opening, a supply air inlet cooperating with said supply air opening in said housing means, and an outlet opening cooperating with said nozzle connecting opening, and O-ring seal means provided about the respective complementary and cooperating openings, and means for connecting the relay to the housing means, whereby the necessity for separate conduit between the housing means and the relay is obviated.

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ALAN COHAN, *Primary Examiner.*