Aug. 28, 1956 F. W. SIDE 2,760,509

ELECTROPNEUMATIC TRANSDUCER APPARATUS

Filed Oct. 31, 1952 2 Sheets-Sheet 1

FIG. 1

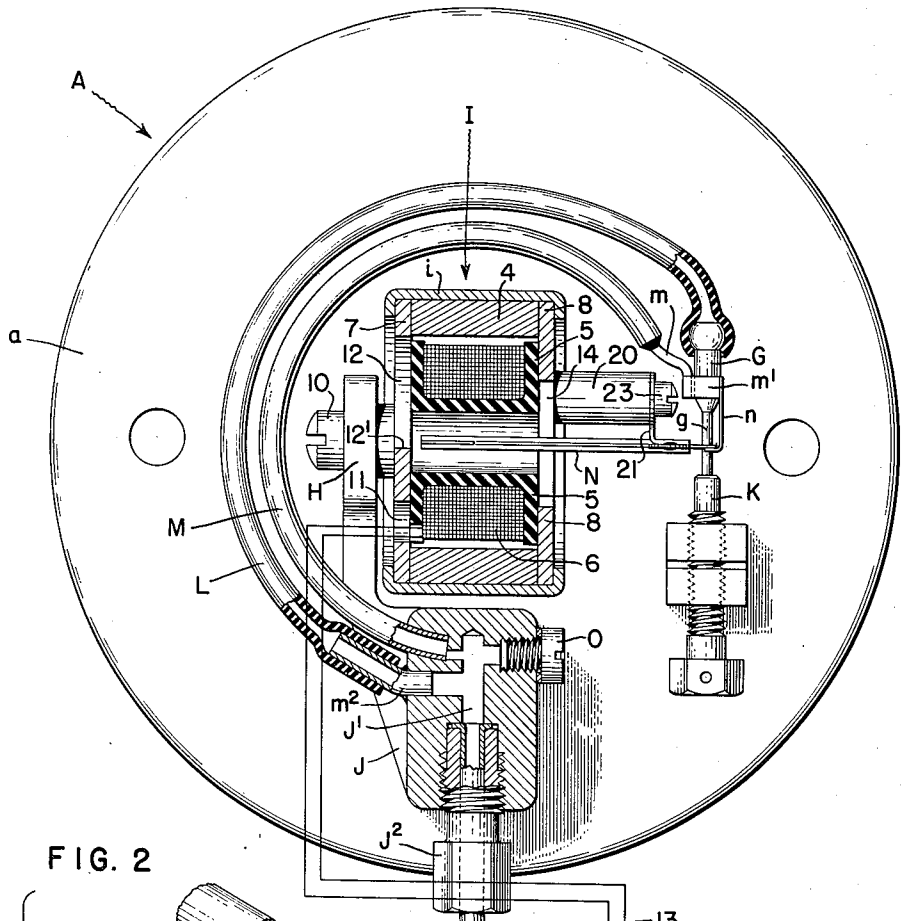


FIG. 2

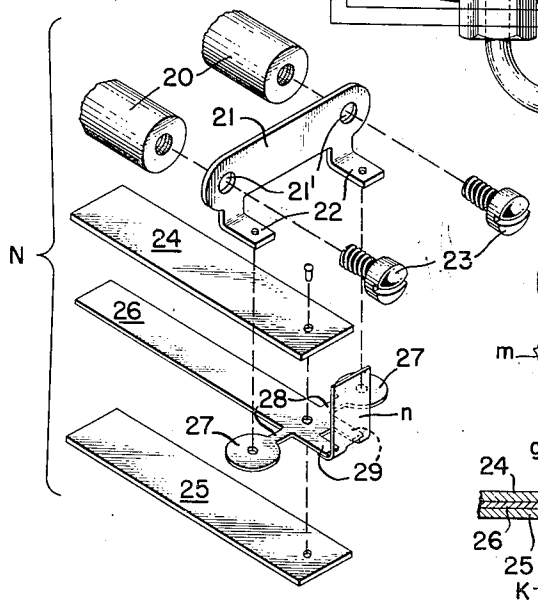
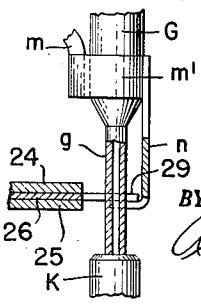


FIG. 5



INVENTOR.
FREDERICK W. SIDE
BY Arthur H. Swenson
ATTORNEY.

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ELECTROPNEUMATIC TRANSDUCER APPARATUS

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FIG. 3

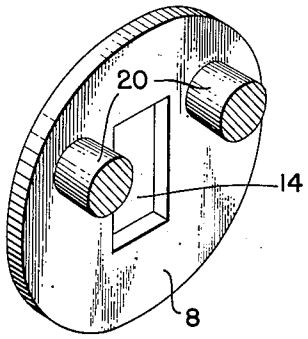


FIG. 4

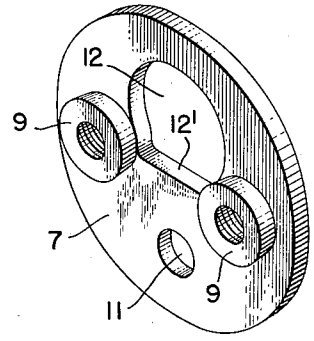
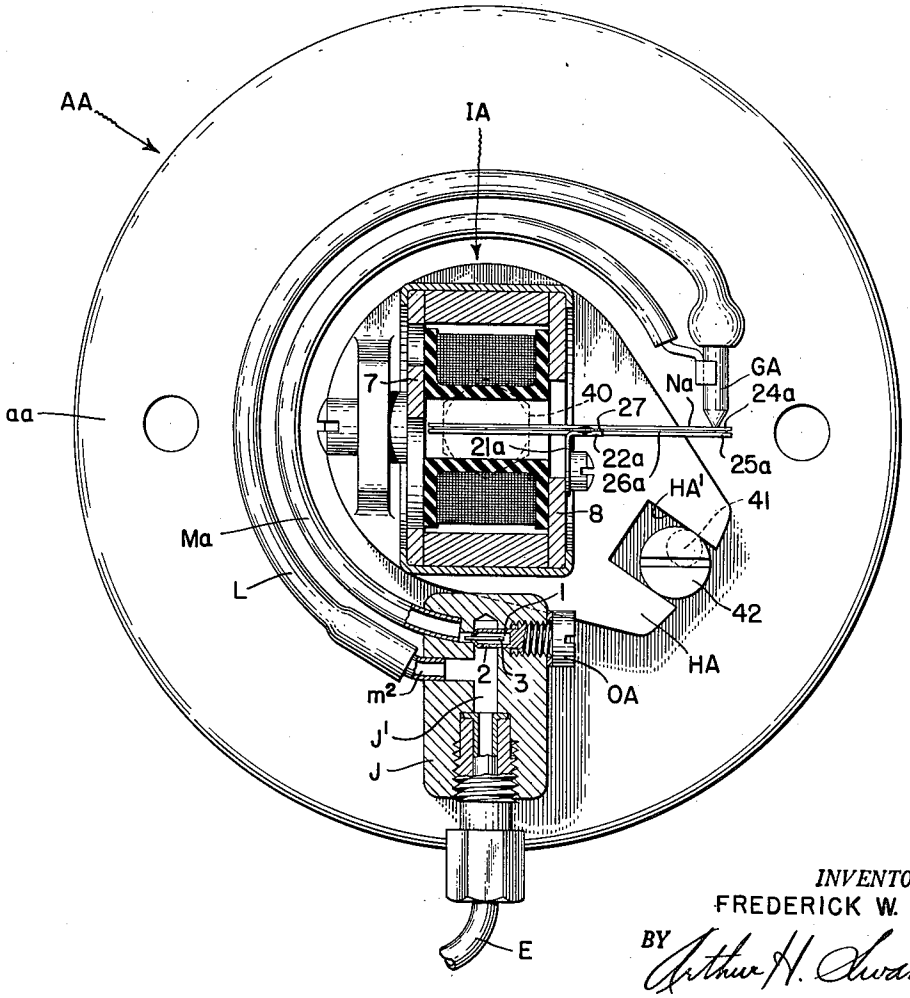


FIG. 6



INVENTOR.
FREDERICK W. SIDE
BY Arthur H. Swanson
ATTORNEY.

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2,760,509

ELECTROPNEUMATIC TRANSDUCER APPARATUS

Frederick W. Side, Philadelphia, Pa., assignor to Minneapolis-Honeywell Regulator Company, Minneapolis, Minn., a corporation of Delaware

Application October 31, 1952, Serial No. 317,908

10 Claims. (Cl. 137—85)

It is a general object of the present invention to provide a new and improved electric to pressure transducer. More specifically, it is an object to provide an electric to pressure transducer which is arranged to receive an electrical signal which is converted into a movement which causes a pneumatic nozzle back pressure to be varied.

In the field of automatic process control, it is frequently expedient to obtain the value of some variable by some electrical means and transmit the resultant electrical signal to some remote position where it may be converted to a pneumatic signal for control purposes. The electric to pneumatic transducing or converting apparatus must be arranged for ease of manufacture, ruggedness, and accuracy. Such apparatus must also have good linearity of response in transducing from an electric signal of relatively small amplitude to a pneumatic signal.

It is accordingly an object of the present invention to provide an improved electro-pneumatic valve actuating transducer characterized by its rugged construction and commercial stability.

A more specific object of the invention is to provide an electro-pneumatic valve actuator characterized by its capacity to respond instantaneously to small electric currents which may be transmitted to it over relatively long transmission lines.

A still more specific object of the invention is to provide an improved air controller of the known type including electromagnetic means for adjusting a flapper type valve regulating the discharge pressure in an air controller bleed nozzle.

A further object of the invention is to provide improved means for adjusting the relative positions of the bleed nozzle and associated flapper valve.

The invention is adapted for use in electro-pneumatic transducers of both force balance and space balance types, and major structural elements of the two types may be identical, and thus contribute to relatively low inherent production costs.

The various features of novelty which characterize my invention are pointed out with particularity in the claims annexed to and forming a part of this specification. For a better understanding of the invention, however, its advantages, and specific objects attained with its use, reference should be had to the accompanying drawings and descriptive matter in which I have illustrated and described preferred embodiments of the invention. Of the drawings:

Fig. 1 is an elevation partly in section of an electro-pneumatic transducer which is a valve actuator of the force balance type, and diagrammatically illustrates associated apparatus;

Fig. 2 is an exploded view of an armature and its supporting means shown in Fig. 1;

Figs. 3 and 4 are perspective views respectively illustrating the opposite end plates of a magnetic device shown in section in Fig. 1;

Fig. 5 is a section of the nozzle portion of Fig. 1; and

Fig. 6 is an elevation partly in section, of an electro-pneumatic valve actuator of the space balance type.

In Figs. 1–5 I have illustrated by way of example an electro-pneumatic transducer or valve actuator A of the force balance type embodying a desirable form of the present invention. The transducer A includes air controller means arranged to control the operation of a furnace B. As diagrammatically shown, the furnace B is heated by the combustion of fluid fuel supplied through a pipe C at a rate regulated by a control valve D. The valve D may be of conventional diaphragm motor type, and is directly controlled by air pressure transmitted to the valve D through a pipe *e*. As shown, the pipe *e* is a lateral branch of a conduit E arranged to receive air from a source F of air under substantially constant pressure through a restriction *f* connected to one end of the pipe E. The other end of the pipe E is connected to means for passing air to the tubular bleed nozzle element G of air controller means included in the transducer A. The nozzle G has its discharge end formed by a coaxial tubular extension *g* of reduced diameter.

In the form shown, the transducer A comprises a base plate *a* of disc form on which is mounted a bracket H. The latter supports a magnetic device or magnet structure I, a socket element J, and an anvil or abutment member K. The socket element J is formed with an inlet passage or chamber J′ connected to the conduit E by a threaded coupling element J^2. The chamber J′ has two lateral outlets. Through one of said outlets and a tube L, the chamber J′ is in free communication with the nozzle element G. Through its second lateral outlet, the chamber J′ is in restricted communication with the inlet end of a Bourdon tube M. The second end of the tube M is closed and is mechanically connected to the bleed nozzle G by a bent metallic rod or wire *m* and a yoke element *m′*. The tube M, nozzle G, and the connecting parts *m* and *m′* may be soldered together. The nozzle G is connected to one end of the elongated body of an armature N by a transverse armature part *n*.

The armature N is pivoted to the stationary magnet structure I to oscillate about an axis intermediate its ends. The armature N is actuated to move the part *n* in the direction of its length, and thereby toward and away from the anvil or abutment K, as the temperature of the furnace chamber B decreases and increases. The abutment K is a part of a threaded member and acts as a stationary flapper valve to variably throttle the outflow of air through the discharge tube *g*. As the throttling effect is decreased and increased, the air pressure in the tube L and pipe E respectively increases and decreases the rate at which fuel is passed into the chamber B.

The initial response to a change in the furnace temperature is directly due to an angular adjustment of the armature N effected by the device I. That angular adjustment results in a follow-up adjustment by the Bourdon tube. When the initial angular adjustment of the armature increases or decreases the bleed nozzle pressure, that pressure change causes the Bourdon tube M to move the nozzle G in the direction to eliminate a portion of the respective increase or decrease in bleed nozzle pressure produced by said adjustment of the armature N.

It is noted that the apparatus illustrated is described herein as though the apparatus A of Fig. 1 and AA of Fig. 6 were invariably vertical with its discharge end below its inlet end, merely as a matter of verbal convenience. In practice the operation of the controller A does not depend on the relative directions of the earth axis and the direction of any particular element of applicant's apparatus.

The element L connecting the chamber J′ to the bleed nozzle G is a tube of plastic or other yielding material of such length and flexibility that it offers no significant

opposition to the slight longitudinal movements given to the nozzle G by the armature N and Bourdon tube M. As shown, the tube L has its discharge end stretched to surround the globular outlet end of the nozzle G, and has its inlet end stretched to surround the outer end of a tubular metallic part m^2 extending into and soldered in the second lateral passage opening into the chamber.

As shown, air flows into the tube M from the chamber J' past a chamber closing element O having a threaded outer end portion screwed into an internally threaded opening in the wall of the chamber J'.

The magnetic device I comprises a permanent magnet in the form of an annulus or cylindrical body 4 of suitable metal. The latter may well be of the general nickel-aluminum-iron composition known as Alnico. The body 4 surrounds a spool or bobbin 5 on which wire is wound to form a coil 6. The bobbin 5 may be formed of plastic material such as Bakelite, and extends between a front pole plate 7 and a back plate 8. Each of said plates comprises a body portion in the form of a disc-shaped sheet of soft iron of high magnetic permeability. The outside diameters of the plates 7 and 8 are the same as the outside diameter of the annular member 4, and the peripheral edges of the plates 7 and 8 are flush with the outer surface of the member 4. The parts 4, 5, 7 and 8 of the magnetic structure I are firmly secured in their relative positions as shown in Fig. 1, by a brass cylinder *i* which surrounds and fits snugly about the annulus 4 and has its edges bent inward to form flanges bearing against the outer sides of the plates 7 and 8.

As shown in Fig. 4, the plate 7 is arranged with diametrically opposed bosses 9 at its outer side. Each of said bosses is formed with an axial socket into which the threaded end of a clamping screw 10 is screwed. Each clamping screw 10 extends through a portion of the bracket H which is alongside and parallel to the plate 7. One of the screws 10 is shown in Fig. 1. The pole plate 7 has a small aperture 11 in its lower portion and a larger aperture 12 in its upper portion shown best in Fig. 4. The terminal conductors 13 of the coil 6 pass through the aperture 11 and are connected to an appropriate direct circuit amplifier Q which has as an input a thermocouple P which is responsive to the temperature in the furnace chamber B. The aperture 12 is arranged so that the only magnetic lines affecting the armature N will originate from the edge 12'. This is accomplished by enlarging the aperture so that all the edges of the aperture are spaced away from edge 12' as is consistent with good mechanical design.

The back plate 8 is formed with an aperture 14 shown as rectangular and having half portions at opposite sides of a plane including the axis of the magnetic device I, shown best in Fig. 3. By disposing the armature N in the central portion of this rectangular aperture 14 with the elongated sides of the aperture being relatively close so that the flux lines are across the short gap of the aperture, there will be no adverse forces acting on the armature.

The previously mentioned armature N comprises a bar-like body portion extending through the aperture 14 and having one end adjacent the plate 7, and having its other end adjacent the lower end of the nozzle portion *g*. As shown in Fig. 1, the portion of the armature N between the plates 7 and 8 is centrally disposed in the space surrounded by the bobbin 5, and the underside of the armature is at approximately the same level as the straight bottom wall 12' of the aperture 12. In operation, the plate 7 constitutes the pole piece of the magnetic device I, and the disc 8 in conjunction with the armature N forms the return paths for two magnetic circuits, namely, the circuit for the permanent magnet flux produced by the permanent magnet body 4 and the circuit for the flux set up in the armature N by the current flowing in the coil 6.

As shown best in Fig. 2, the armature N is suspended from the ends of two side-by-side posts 20 parallel to the axis of the magnetic structure I and each rigidly connected at one end to the outer side of the back plate 8. The posts 20 are symmetrically disposed at opposite sides of the aperture 14 adjacent the upper end of the latter. As shown, the axis of each post 20 is between the upper end of the aperture 14 and the axis of the body I. The armature N is suspended from the posts 20 by means of a bracket member 21 formed of thin copper plate and having a bar-like body portion with apertures 21' in alignment with threaded openings in the ends of the posts 20 into which the threaded ends of screws 23 are screwed. The screws 23 clamp the apertured end portions of the bracket 21 against the ends of the posts 20. The bracket 21 has integral horizontal extensions 22 parallel to the posts 20 and beneath the level of the latter and at the opposite side of the body portion of the bracket 21 from said posts.

The armature parts 24 and 25 are shown as rectangular bars of Mu-metal having high magnetic permeability and low residual flux. In one form of the invention each of said bars was of a length, width, and thickness of the order of 1.25", 0.2", and 0.01", respectively. An element 26 is interposed between the parts 24 and 25 and is advantageously in the form of a bar-like strip of beryllium copper which had in one form a thickness of 0.004". The parts 27 are disc-like portions of integral lateral extensions of the part 26. The discs 27 are respectively beneath the bracket extensions 22 and have their apertures in alignment with apertures in the extensions 22. Each disc portion 27 is connected to the bracket extension 22 above it by solder. Each disc portion 27 is connected to the body portion of the bar or strip 26 by a narrow neck 28. The necks 28 form torsion spring elements through which the armature N is pivotally connected to the extensions 22 of the bracket 21.

The part 26 has its end adjacent the nozzle G bifurcated to form spaced apart extensions 29 arranged to straddle the lower end of the nozzle extension *g*. The extensions 29 overlap and are soldered to lateral projections from the lower end of the vertical plate *n*. The latter overlaps and is soldered or otherwise attached to the yoke member *m'*, as shown in Fig. 5. The lower end of the nozzle extension *g* is normally movable between a lower position in which it engages and has its bore substantially closed by the abutment K, and an upper position in which it is about 0.006" above the abutment K.

In Fig. 6 I have illustrated an electro-magnetic transducer or valve actuator AA of the space balance type, in which the maximum relative movement of the nozzle G and the flapper valve end of an armature N*a* in one form of the invention is of the order of 0.062", under operating conditions similar to those in which the maximum relative movement of the nozzle *g* and abutment K of Fig. 1 is 0.006". Notwithstanding the difference just noted and other operating differences hereinafter mentioned, the significant structural differences between the transducers A and AA are comparatively small.

The transducer AA comprises a disc-shaped base plate *aa* generally similar in form to the base plate *a* shown in Fig. 1 and supporting members J, L, and M*a* which individually considered do not differ significantly from the members J, L, and M of Fig. 1. Furthermore, the tubes L and M*a* are connected to a bleed nozzle GA which may be identical in structure with the bleed nozzle G of Fig. 1, except that, as shown, it includes no separate section like the section *g* of Fig. 1. The transducer AA in Fig. 6 includes a magnet device IA which may be identical in structure to the magnet device I of Fig. 1, except in respect to its mounting and the form and mounting of its armature N*a*. The magnet device IA is mounted on a supporting bracket HA which is pivotally connected to the base plate by means including a pivot 40. The bracket HA and thereby the magnet structure IA may be angularly adjusted about the axis of the pivot

40 to thereby adjust the free end of the magnet armature Na toward and away from the discharge end of the nozzle GA. As shown, the angular adjustment of the part HA is effected by rotating a shaft or pivot 41 journaled in the base plate and carrying an eccentric head 42 which is snugly received between the parallel side walls of a slot HA' formed in the member HA. The side walls of the slot HA' are at opposite sides of and parallel to a plane including the axis of the pivot 40.

The armature Na of Fig. 6 comprises outer parts 24a and 25a and an intermediate part 26a. The parts 24a and 25a need not differ significantly from the parts 24 and 25 respectively. The intermediate part 26a differs significantly from the part 26 in that it does not include anything analogous to the bifurcations 29 of the part 26, and in that its lateral extensions, which include discs 27, are approximately mid-way between the ends of the armature Na. The armature Na is supported by the back plate 8 of the electro-magnet IA through a bracket member 21a screw connected to said plate. As shown, the bracket 21a is a counterpart of the bracket 21 but is turned upside down with respect to the armature which it supports through its extensions 22a and the lateral extensions 27 of the armature. The end of the armature Na remote from the magnet device IA extends beneath the discharge end of the nozzle GA and moves toward and away from the latter as the temperature of a control element like the thermocouple P decreases and increases. Each up or down movement of the end of the armature adjacent the nozzle GA results in a down or up movement of the nozzle GA. That nozzle movement is the result of the follow up movement of the Bourdon tube Ma as the pressure in that tube is varied by the nozzle throttling effects of the up or down movement of the end of the armature adjacent the nozzle GA.

In the operation of the apparatus shown in Fig. 6, the movements given to the discharge end of the bleed nozzle GA are directly due to the air pressure in the Bourdon tube Ma. Those movements are dependent on the position of the armature Na only because the different positions of that armature subject the bleed nozzle outlet to different throttling effects and thereby modify the air pressure in the Bourdon tube. In the Fig. 6 arrangement, the angular adjustment of the armature Na has no direct mechanical effect on the position of the nozzle GA.

An inherent result of the difference between the controllers shown in Fig. 1 and in Fig. 6 is that the relative movement of the armature and nozzle for a given change in furnace temperature is much greater with the arrangement shown in Fig. 6 than with the arrangement shown in Fig. 1. Thus, in the use of the controllers A and AA with the normal control pressure span of 3 to 15 pounds per square inch, the movement of the discharge end of the nozzle G need be only approximately 0.006" in the case of the force balance instrument A shown in Fig. 1, while the movement of the discharge end of the Fig. 6 instrument AA may well be approximately 0.062". With the force balance instrument shown in Fig. 1, a shift of 0.002", in the relative positions of the nozzle part g and abutment K of the Fig. 1 instrument A can produce a pressure error of 5 pounds per inch, whereas the same shift of 0.002" would produce an error of only 1/30 of 5 pounds, or .17 pound per inch in the deflectional type instrument AA, shown in Fig. 6.

The armature N shown in Fig. 1 and the armature Na shown in Fig. 6 are each subjected to two magnetizing forces in normal operation. One of those forces is due to the magnetizing action of the permanent magnet 4 and associated end plates 7 and 8, and the second force is due to the current flow through the coil 6. The direction of the current flow through the winding 6 is such as to give the end of the armature adjacent the pole piece 7 the same polarity as the latter, thus producing a repelling force acting between the pole part 7 and the armature.

The first force attracts the armature end adjacent the pole piece 7 when the armature is not magnetized by the coil 6.

The force which attracts the unmagnetized armature to the pole piece 7, and the force which repels the armature when the latter is magnetized, are both square root functions in opposition to one another and working through the same air gap. They thus neutralize each other to an extent progressively increasing as the length of the air gap is varied. The air gap length variations result in substantially similar linear variations in the coil voltage and control air pressure. In practice, the current flow through the coil 6 may well be 5 milliamperes at 25 volts full span, or 125 milliwatts, and the coil resistance may be 5,000 ohms for D. C. operation. Due to the small current demand, the device is well suited to tube operation in electronic circuits. In order that the pressure change in Fig. 6 be in the same direction as pressure changes in Fig. 1, it is necessary to reverse the relative position of the plate 7 so that the armature will tend to move downwardly when the current in the coil increases.

The ideal position which the armature N or Na should normally assume in the permanent magnet field with a neutral suspension is that shown in Fig. 1 and in Fig. 6. However, that armature position is not overly critical and can be plus or minus 1/64". Moreover the position assumed under a given operating condition can be modified by bending the parts connecting the armature body to the magnet structure.

An inner end portion of a member OA is formed with a chamber 1, which is in communication with the chamber J' through a lateral port 2 in the chamber wall. The chamber 1 is in communication with the Bourdon tube Ma through a capillary tube 3 coaxial with the member OA and extending through the inner end wall of the chamber 1 and having its outer end opening into the adjacent end of the Bourdon tube bore. The tube 3 may have an internal diameter of the order of 0.006".

In operation, the armature Na of Fig. 6, deflecting in response to a change in current in the coil 6, tends to function as a sharp on-off controller, the action of which becomes more pronounced as the current departures become larger and more abrupt. This action is the result of the time delay in the response of the Bourdon tube Ma to the air flow through the restrictioned tube 3, which permits the end of the armature Na adjacent the momentary stationary nozzle GA to move away from the latter.

The follow-up action of the Bourdon tube Ma is a function of the bleed rate through the restrictioned portion of the part OA, and the damping characteristic of the valve actuator is determined by the bleed rate. For instance, if the bore of the tube 3 is undersized, the valve actuator when responding to a substantial current change will overshoot and then return to its destination. An oversize tube bore produces a drift-in effect, and a tube bore of the proper size results in a substantially critically damped performance. An increase in the reservoir or capacity tank effect of the member OA would further delay the response of the Bourdon tube.

Armature damping, with resulting stability, is provided by the locking-in action of the iron armature N or Na in the field provided by the Alnico-type magnet 4. Armature motion occurs when magnetic lines of force produced by current flow in the coil 6 are added to or removed from the lines emanating from the magnet body 4, all of which thread the armature and react in the air gap with the flux at the face of the pole piece 7, along the edge 12'.

From the sensitivity standpoint, the response of each of the two instruments shown is a characteristic derived from three co-ordinating functions; namely, the distance that the nozzle G moves relative to the associated flapper valve to produce a unit change in air pressure; the follow-

up rate of response of an air nozzle attached to and positioned by a Bourdon tube; and the capacity of the related air chambers.

With either construction, the energization of the coil **6** magnetizes the armature N or N*a* to a value or extent increasing with the current flowing through the coil, and the direction of current flow is such as to give the free end of the armature adjacent the pole piece **7** the same polarity as said pole piece, thus producing a repelling force between the stationary pole piece and the adjacent armature end. The magnetic flux created by the permanent magnet **4** tends of itself to give the end of the armature N or N*a* adjacent the pole piece **7** a polarity which is opposite to the polarity of the pole piece. Thus when the pole piece **7** is a north pole, the adjacent end of the armature N or N*a* becomes a south pole and is attracted to or repelled by the adjacent portion of the pole piece **7**, accordingly as the armature is not or is magnetized by the coil **6**. Thus, the effect on the end of the armature N of Fig. 1 adjacent the pole piece **7** is to move that armature end downward when there is no current flow through the coil **6** and to move the armature N upward when there is a substantial current flow through the coil **6**.

Under similar operating conditions, the sensitivity of response of the force balance transducer A is less than is obtainable with the space balance transducer AA, but is sufficient for all general applications.

The delay in the Bourdon tube response to a change in the pressure in the chamber J', created by the capillary restriction 3, momentarily leaves the bleed nozzle outlet of the transducer AA wide open or fully closed, with a resultant rapid change in the nozzle pressure. In certain applications of the device to a control problem, it may be desirable to have this rapid change.

While, in accordance with the provisions of the statutes, I have illustrated and described the best forms of embodiment of my invention now known to me, it will be apparent to those skilled in the art that changes may be made in the forms of the apparatus disclosed without departing from the spirit of my invention as set forth in the appended claims, and that in some cases certain features of my invention may be used to advantage without a corresponding use of other features.

Having now described my invention, what I claim as new and desire to secure by Letters Patent, is:

1. An electro-pneumatic valve actuator for varying a fluid pressure in accordance with changes in an electric current including in combination, a magnet structure comprising an annular permanent magnet, an apertured pole-plate at one end of said magnet, an apertured back plate at the opposite end of said magnet, a coil surrounded by said magnet and surrounding an axial space within said structure, an armature extending into said space through said back plate and pivoted to turn about an axis transverse to the axis of said device and having one end adjacent said pole-plate and uniting with said plates to form a closed path for magnetic fluxes created by said magnet and by electric current flow through said coil, means for passing an electric current, which varies in magnitude with changes in a controlling condition, through said coil with a flow direction so related to the polarity of said permanent magnet that said coil and magnet tend to deflect said armature in opposite directions, a Bourdon tube having one end adapted to deflect in one direction or in the opposite direction in response to an increase or decrease, respectively, in the fluid pressure within the tube, a bleed nozzle, means for passing fluid under pressure into said tube and into the inlet end of said bleed nozzle, and means jointly responsive to the deflection of said armature and to the pressure within said Bourdon tube for variably throttling said bleed nozzle and thereby regulating the pressure in said tube.

2. A valve actuator as specified in claim 1, including a supporting element and wherein the means for passing fluid into the Bourdon tube and the inlet end of the bleed nozzle includes a chambered element rigidly attached to said supporting element and wherein said magnet structure is mounted on said supporting element for adjustment of said armature relative to the discharge end of said bleed nozzle and thereby varying the throttling effect to which said bleed nozzle is subjected.

3. An electro-pneumatic transducer assembly comprising, an electromagnetic coil wound upon a hollow cylindrical bobbin, a permanent magnet in the form of a hollow cylinder surrounding said coil, a pair of apertured pole pieces on the ends of said magnet with the aperture of one of said pieces having an edge therein centered on the hole of said bobbin, a flat elongated armature projecting through a portion of said bobbin with one end adjacent said edge, a pivot bracket for said armature, means fastening said bracket to said other pole piece, a pneumatic nozzle whose nozzle back pressure is arranged to be changed by the movement of said armature, and a Bourdon tube attached to said nozzle, said Bourdon tube being responsive to nozzle back pressure and adjusting said nozzle in accordance with said back pressure.

4. An electro-pneumatic transducer comprising, a hollow circular cylindrical bobbin of insulating material, an electric coil wound thereon, a hollow circular cylindrical magnet positioned to surround said bobbin, a first pole piece having a rectangular aperture therein which is centered in said pole piece and attached to one end of said magnet, a second pole piece having an aperture therein within an edge of the aperture centered in the pole piece, and attached to the other end of said magnet, a pivoted armature extending through said rectangular aperture so that one end is adjacent said edge and the other is extending outside of said bobbin, a pneumatic nozzle assembly arranged to have the nozzle pressure changed by the movement of said armature, and a pneumatic follow-up element attached to said nozzle and adjusting said nozzle in accordance with nozzle back pressure.

5. Apparatus as set forth in claim 4 wherein the aperture in said second pole piece is arranged so that only the flux from said edge will affect said armature.

6. Apparatus as set forth in claim 4, wherein the aperture in said first pole piece has said armature passing therethrough in a plane where the magnetic flux across said aperture will not affect said armature.

7. An electro-pneumatic transducer comprising, a hollow circular cylindrical bobbin of insulating material, an electric coil wound thereon, a hollow circular cylindrical magnet positioned to surround said bobbin, a first pole piece having a rectangular aperture therein which is centered in said pole piece and attached to one end of said magnet, a second pole piece having an aperture therein with an edge of the aperture centered in the pole piece, and attached to the other end of said magnet, an armature extending through said rectangular aperture so that one end is adjacent said edge and the other is extending outside of said bobbin, a pivoting structure for said armature fastened to said second plate so that said armature is centered in said rectangular aperture, said structure comprising a flattened piece of resilient metal with reduced cross section, a pneumatic nozzle assembly arranged to have the nozzle pressure changed by the movement of said armature, and a pneumatic follow-up element attached to said nozzle and varying the position of said nozzle in accordance with change in nozzle back pressure.

8. An electro-pneumatic valve actuator means comprising in combination, an arcuate Bourdon tube having one end closed and adapted for movement at the closed end in accordance with the pressure applied to the Bourdon tube, means for connecting the other end of said tube to a rigid base and to a source of air under variable pressure, a bleed nozzle mechanically connected to and carried by the closed end of said Bourdon tube, means external to said tube for passing air from said source to the inlet end of said bleed nozzle, means including a resiliently mounted deflectable armature coop-

erating with said bleed nozzle to regulate the pressure at which air is discharged by said nozzle in accordance with the deflection of said armature, and electro-magnetic armature deflecting means mounted on said base and surrounded by said Bourdon tube, said deflecting means comprising a winding energized by electrical current varying in magnitude in accordance with variations in a control condition and acting directly on one end of said armature to deflect said armature in accordance with said variations to produce a pressure change on the inlet side of said bleed nozzle.

9. An electro-pneumatic actuator means comprising in combination, an arcuate Bourdon tube having one end closed and adapted for movement at the closed end in accordance with the pressure applied to the Bourdon tube, means for connecting the other end of said tube to a rigid base and to a source of air under variable pressure, a bleed nozzle mechanically connected to and carried by the closed end of said Bourdon tube, means external to said tube for passing air from said source to the inlet end of said bleed nozzle, means including a deflecting armature cooperating with said bleed nozzle to regulate the pressure at which air is discharged by said nozzle in accordance with the deflection of said armature, and electro-magnetic armature deflecting means mounted on said base by means of a supporting member relatively adjustable with respect to said base and being surrounded by said Bourdon tube, said deflecting means comprising a winding energized by electrical current varying in magnitude in accordance with variations in a control condition and deflecting said armature in accordance with said variations to produce a pressure change on the inlet side of said bleed nozzle.

10. An electro-pneumatic actuator means comprising in combination, an arcuate Bourdon tube having one end closed and adapted for movement at the closed end in

accordance with a pressure applied to the Bourdon tube, means for connecting the other end of said tube to a rigid base and to a source of air under variable pressure, a bleed nozzle mechanically connected to and carried by the closed end of said Bourdon tube, means external to said tube for passing air from said source to the inlet end of said bleed nozzle, means including a deflectable armature connected directly to said bleed nozzle to regulate the pressure at which the air is discharged by said nozzle in accordance with the deflection of said armature with respect to a fixed baffle plate mounted on said base, an electro-magnetic armature deflecting means mounted on said base and surrounded by said Bourdon tube, said deflecting means comprising a winding energized by electrical current varying in magnitude in accordance with variations in a control condition and deflecting said armature in accordance with said variations to produce a pressure change on the inlet side of said bleed nozzle, and means connecting the inlet nozzle pressure to the inlet of said Bourdon tube to produce a force in said Bourdon tube to balance the force from the armature deflecting means acting on said deflecting armature.

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