July 25, 1950 C. B. MOORE 2,516,333

PNEUMATIC CONTROL APPARATUS

Filed April 2, 1946

FIG. 1

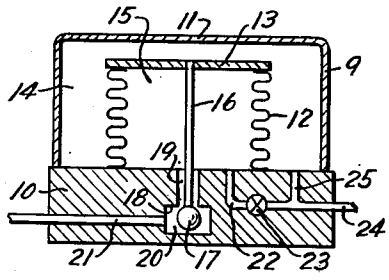


FIG. 2

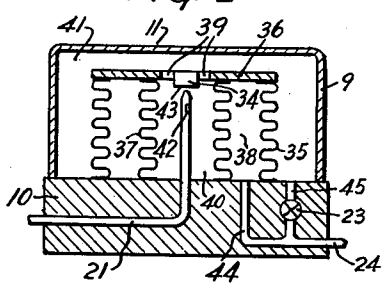


FIG. 3

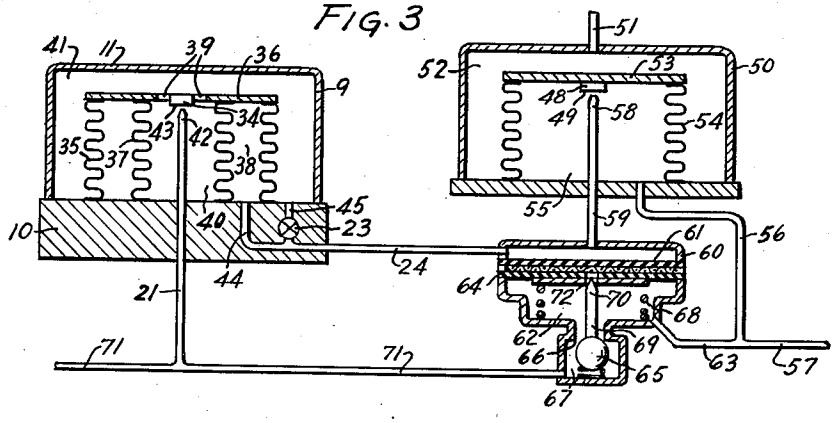


FIG. 4

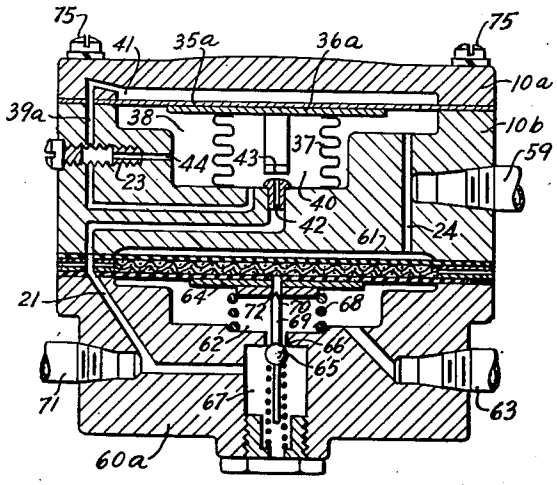
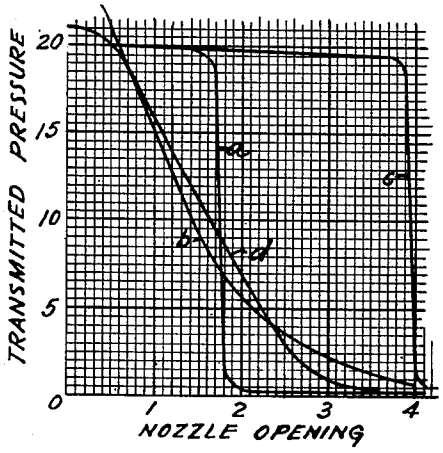


FIG. 5



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PNEUMATIC CONTROL APPARATUS

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9 Claims. (Cl. 137—153)

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This invention relates to pneumatic control apparatus and more particularly to improvements in pneumatic transmission circuits.

In certain types of pneumatic apparatus, and particularly in transmission systems difficulties have been encountered because of the compressibility of the transmitted fluid with increase in transmitted pressure. In certain types of transmitting systems, also, upon an increase in the transmitted pressure a decrease in flow occurs across a restriction employed therein. These conditions cause a departure from the optimum of linearity and stability desired.

In the pneumatic transmission system shown in my prior Letters Patent No. 2,359,236, a constant differential is maintained between the pressure on the upstream side of the detector nozzle and the transmitted pressure. For particular different values of transmitted pressure the clearance of the control surface with respect to the nozzle will also be different because of the decrease in flow across the fixed restriction and the compressibility of the transmitted air. These factors tend to be non-linear with respect to the transmitted pressure.

It is possible to eliminate the effect of change of flow across the restriction by substitution for the fixed restriction of a flow controller of the character shown in my prior application for Letters Patent, filed August 18, 1945, Serial No. 611,321, but this still does not obviate the effect of the compressibility of the transmitted air.

In accordance with the present invention pneumatic control apparatus is provided including an automatic restriction, which compensates both for the compressibility of the transmitted fluid by an increase in flow governed by the same physical laws and for the decrease in pressure drop across the supply restriction.

In accordance with the present invention also, a pneumatic control unit is provided having a restriction, in which the flow is proportional to the square root of the absolute pressure of the delivered fluid.

In accordance with the present invention also, a pneumatic control unit is provided which is particularly useful in transmission systems for providing linearity and stability.

In accordance with the present invention, also, a pneumatic control unit is provided which is free from likelihood of clogging of any restrictions therein and which, when employed with systems having a control nozzle, may have one to one transmission characteristics, and substantially reduces the necessity of squareness of the nozzle with respect to the cooperating control surface.

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Other advantageous features will be apparent from the specification and claims.

The nature and characteristic features of the invention will be more readily understood from the following description, taken in connection with the accompanying drawings forming part hereof, in which:

Figure 1 is a diagrammatic view of one form of the pneumatic control unit in accordance with the present invention;

Fig. 2 is a diagrammatic view of another form of pneumatic control unit in accordance with the present invention;

Fig. 3 is a diagrammatic view of a pneumatic circuit with the control unit of the present invention employed therewith;

Fig. 4 is a diagrammatic view of a booster pilot valve with a pneumatic control unit in accordance with the present invention embodied therein; and

Fig. 5 is a graph illustrating the characteristics obtained with the use of a pneumatic control unit in accordance with the present invention.

It should, of course, be understood that the description and drawings herein are illustrative merely, and that various modifications and changes may be made in the structure disclosed without departing from the spirit of the invention.

Referring more particularly to the drawings, the pneumatic control or automatic restriction unit 9, illustrated in Fig. 1, preferably includes a casing which is provided with a body portion 10 and a cover portion 11 secured to the body 10 in fluid-tight relationship. The casing has mounted therein, preferably within the cover 11 and secured to the body portion 10, in fluid-tight relationship, a flexible member which preferably comprises a flexible metallic bellows 12, closed, at the end remote from the body portion 10, by a closure plate 13. A fluid pressure chamber 14 is thus provided within the cover 11 and outside the bellows 12 and another fluid pressure chamber 15 is provided within the bellows 12.

The bellows 12 is shown partially expanded in its operating position. If the bellows 12 were in its free condition the same would be considerably shorter than as illustrated. By suitable selection of free length and spring rate of the bellows 12, the characteristics of the unit may be varied as desired.

The closure plate 13 has a stem 16 secured

thereto for movement thereby and the stem 16 is provided, on its terminal end, with a valve body portion 17 which is adapted to be positioned with respect to a valve seat 18 in accordance with the positioning of the bellows 12. The stem 16 extends through a passageway 19, of which the valve seat 18 forms a terminal, and the valve body 17 is located in a valve chamber 20. The valve chamber 20 has a fluid supply connection 21 connected thereto.

The fluid supply connection 21 is adapted to be connected to a suitable source of fluid under pressure, the pressure being regulated or not as desired, and the fluid may be air or other desired gaseous fluid.

A passageway 22 is provided, in communication with the chamber 15 in the interior of the bellows 12, and is connected through a fixed restriction 23 to a fluid delivery connection 24 for the delivery of pressure fluid as hereinafter explained. The size of opening or orifice in the fixed restriction 23 may be varied in order to change the flow characteristics. A passageway 25 is provided, connecting the fluid delivery connection 24 to the chamber 14.

In the form of the invention illustrated in Fig. 2, the body portion 10 of the pneumatic control or automatic restriction unit 9 is provided with a cover 11, as before. A flexible metallic bellows 35 is provided, connected at one end to the body portion 10, in fluid-tight relationship, and similarly connected at its other end to a bellows closure plate 36. Within the interior of the bellows 35, a smaller flexible metallic bellows 37 is provided, preferably concentric with respect to the bellows 35. The interior bellows 37 is connected at one end in fluid-tight relationship to the body portion 10 and is similarly connected at the other end to the bellows closure plate 36. A pressure chamber 38 is thus provided, between the bellows 35 and the bellows 37, and is closed at one end by the body 10 and at the other end by the closure plate 36.

The bellows 35 and 37 are shown partially contracted and in their normal operating position. If the bellows 35 and 37 were in their free condition the same would be considerably longer than illustrated. By suitable selection of free length and spring rate of the bellows 35 and 37 the characteristics of the unit may be varied as desired.

The bellows closure plate 36 is provided with openings or passageways 39 for free access of fluid from a chamber 40, within the interior of the bellows 37, to a chamber 41, in the interior of the casing and outside the bellows 35 and the closure plate 36.

A nozzle member 42 is provided, having a restriction or discharge opening of predetermined size therein, and is mounted in the chamber 40. A control surface 43 is provided, preferably formed as a face of a flat disc 34 mounted on the closure plate 36, for controlling the discharge of fluid through the nozzle 42 in accordance with the positioning of the control surface 43 with respect to the nozzle terminal as hereinafter explained.

The nozzle 42 has a fluid supply connection 21 in communication therewith, the fluid supply connection 21 being connected to a source of fluid under pressure of the same character as heretofore pointed out with respect to Fig. 1.

The chamber 38, between the bellows 35 and the bellows 37, is connected by a passageway 44 to the fluid delivery connection 24, and a passageway 45 extending between the passageway 44 and the chamber 41 is provided with a restriction 23, for purposes to be explained.

In Fig. 3 there is shown a pneumatic circuit in which the control unit in accordance with the present invention is applied in a pneumatic transmission system.

A detector pilot 50 is provided having a connection 51 for making a variable condition, which may be a variable fluid pressure, available in a chamber 52 and against a closure plate 53 of a bellows 54. A chamber 55, within the bellows 54, is connected by a conduit 56 to a fluid delivery connection 57. The bellows plate 53 is provided with a disc 48 having a flat control surface 49, which surface by its positioning by the plate 53 controls the flow through a nozzle 58, into the chamber 55. The nozzle 58 is connected by a pipe 59 to a chamber 61 of a booster pilot 60. The chamber 61 also has the fluid delivery connection 24 of the pneumatic control or automatic restriction unit 9 connected thereto.

The booster pilot 60 has a chamber 62 connected by a fluid connection 63 to the fluid delivery connection 57. The chambers 61 and 62 are separated by a diaphragm 64, which may be of the character shown in my prior application for Letters Patent filed December 22, 1945, Serial No. 637,057. The diaphragm 64 controls a valve member 65, movable with respect to a seat 66, in a valve chamber 67 for controlling the delivery of fluid from the chamber 67 to the chamber 62. A spring 68 may be provided, effective on the lower side of the diaphragm 64, for determining the differential across the nozzle 58.

The stem 69 on which the valve member 65 is carried may also be provided with a valve portion 70 for engagement with a valve seat 72 carried by the diaphragm 64 controlling the bleed through the diaphragm 64, although any other suitable bleed control could be employed if desired.

The chamber 67 is connected by a fluid supply connection 71 to a suitable source of fluid under pressure, the supply connection 21 also being connected to the connection 71.

In the form of the invention illustrated in Fig. 4, a booster pilot 60*a* is shown having the automatic restriction unit combined therewith. The booster pilot 60*a* has a chamber 61 and has a chamber 62 connected to a fluid delivery connection 63. The chambers 61 and 62 are separated by a diaphragm 64 of the character previously described. The diaphragm 64 controls a valve member 65 movable with respect to a seat 66 in a valve chamber 67 for controlling the delivery of fluid from the chamber 67 to the chamber 62. A spring 68 is provided, effective on the lower side of the diaphragm 64, for determining the differential across a detector nozzle (not shown). The stem 69, on which the valve member 65 is carried, is also provided with a valve portion 70 for engagement with a valve seat 72 carried by the diaphragm 64 for controlling the bleed through the diaphragm 64, although any other suitable bleed control could be employed if desired. The chamber 67 is connected by a fluid supply connection 71 to a suitable source of fluid under pressure.

The booster pilot 60*a* has body portions 10*a* and 10*b* secured in assembled relationship by screws 75 and the body portions 10*a* and 10*b* have a diaphragm 35*a* interposed therebetween which corresponds in function to the bellows 35. A chamber 41 is thus provided in the body por-

tion 10a, above the diaphragm 35a, and a chamber 38 is provided below the diaphragm 35a and in the body portion 10b. A flexible metallic bellows 37 is provided, is connected in fluid-tight relationship at its lower end in the body portion 10b and is closed at the other end by a closure plate 36a which corresponds to the closure plate 36. A chamber 40 is thus provided, as before, in the interior of the bellows 37 and is in free communication with the chamber 41 through a passageway 39a. The plate 36a carries thereon a control surface 43 for controlling the nozzle 42, the nozzle 42 being connected to a supply connection 21 which is connected to the supply connection 71. The chamber 38 is connected by a passageway 24 with the chamber 61. The chamber 38 is also in communication with the pipe 59, in this instance through the passageway 24. A fixed restriction 23 is mounted within the body portion 10b and is in communication with the chamber 38 through a passageway 44 on the downstream side.

Referring now to Fig. 1, fluid under pressure from the fluid supply connection 21 passes from the valve chamber 20 through the valve seat 18, to the chamber 15, then through the conduit 22, and the restriction 23 to the fluid delivery connection 24. The pressure of the fluid in the fluid delivery connection 24 is effective, through the fluid connection 25, in the chamber 14. The pressure drop across the restriction 23 produces a pressure differential on the bellows closure plate 13 urging the same upwardly, and tending to close the valve 17.

An equilibrium condition is reached when this differential in an upward direction is just sufficient to balance the spring action of the bellows 12 at a point at which the valve 17 is nearly, but not quite, closed.

The flow may tend to increase, due to an increase in the supply pressure effective at the fluid supply connection 21 or due to a decrease of the delivered pressure at the fluid delivery connection 24. If the flow tends to increase, this results in increasing the differential across the restriction 23, and an increase in the differential effective on the closure plate 13 moves the bellows 12 and the closure plate 13 thereof upwardly, further restricting the valve 17 and throttling the fluid from the fluid supply connection 21.

Similarly, if the flow tends to decrease, due to a decrease of supply pressure or an increase of the delivered pressure, this results in a decreased differential on the bellows plate 13 tends to move the bellows plate 13 downwardly, opening the valve 17 and decreasing the throttling of the fluid from the fluid supply connection 21.

Referring now to Fig. 2, the action is substantially the same as that described with respect to Fig. 1. Pressure fluid from the fluid delivery connection 21 passes through the nozzle 42 into the chamber 40, then into the chamber 41 through the openings 39, then through the conduit 45 and the restriction 23 to the delivery connection 24. The pressure of the fluid in the delivery connection 24 is effective, through the fluid connection 44 in the chamber 38. By reason of the openings 39, no differential will be effective between the chambers 40 and 41 but the differential is, however, effective between the chambers 38 and 41 on the closure plate 36. This differential forces the plate 36 downwardly from the free position, to a position with the nozzle 42 nearly but not quite closed by the control surface 43.

Any tendency of the flow to increase, effects an increase in the differential between the chambers 41 and 38 and this forces the bellows 35 and the bellows closure plate 36 downwardly so that the control surface 43 throttles the incoming fluid from the nozzle 42.

The flow of gaseous fluid across an orifice is proportional to the square root of the differential pressure across the orifice and is also proportional to the square root of the absolute pressure at the orifice. Since the differential across the restriction 23 is maintained substantially constant by the bellows 12 and the valve 17, or by the bellows 35 and 37 and the control surface 43, the flow will be proportional only to the square root of the absolute pressure at the restriction 23. The pressure at the restriction 23 is essentially the delivered pressure from this unit at the fluid delivery connection 24.

Referring now more particularly to Figs. 3 and 4, fluid from the fluid supply connection 71 passes through the supply connection 21 to and through the automatic restriction unit 9 in the manner heretofore explained, through the delivery connection 24 to the chamber 61, on the upper side of the diaphragm 64, and to the nozzle 58 in the transmitting unit 50. The fluid from the nozzle 58 flows into the chamber 55 and passes through the fluid connection 56 to the fluid delivery connection 57 and then to the instrumentality (not shown) to be controlled.

Fluid from the fluid supply connection 71 also flows into the valve chamber 67, from which it is admitted as required, by the valve 65, to the chamber 62 against the under side of the diaphragm 64, and passes through the fluid connection 63 and the fluid delivery connection 57 to the instrumentality to be controlled.

At any condition of equilibrium, the pressure in the chamber 52, the pressure in the chamber 55, and the spring effect of the bellows 54 will be balanced, and the control surface 53 will be very nearly but not quite in contact with the nozzle 58. The pressure in the chamber 61 will be sufficiently higher than that prevailing in the chamber 62 to compress the spring 68, so that valve 65 is seated and valve 70 exhausts the pressure fluid supplied through the connection 24 from the automatic restriction unit 9.

Any increase in pressure in the chamber 52 will momentarily depress the control surface 49 carried by the bellows plate 53 against the nozzle 58, and the flow of fluid through the delivery connection 24 will cause a building up of pressure in the chamber 61. This causes the diaphragm 64 to move the seat 72 to closed position with respect to the valve 70 and open the valve 65, allowing supply fluid from the fluid supply connection 71 to flow from the chamber 67, past the valve 65 and pass into the chamber 55 by way of the fluid connections 63 and 56 until the pressure in the chamber 55 is again in balance with the pressure in the chamber 52.

A decrease in pressure in the chamber 52 will move the bellows closure plate 53 and the control surface 49 carried thereby away from the nozzle 58, permitting the pressure in the chamber 61 to decrease, thus closing the valve 65 and opening the valve 70. Pressure fluid will then escape from the chamber 55 by way of the fluid connections 56 and 63, the valve 70 and through the diaphragm 64 to the atmosphere.

In transmission systems of the type herein referred to the pressure in the chamber 55 and the transmitted pressure effective at the delivery con-

nection 57 can have a one to one relationship to the pressure in the chamber 52 only if there is no change in the spring force exerted by the bellows 54. This condition cannot be obtained if the bellows 54 moves to a different position with respect to the nozzle 58 for each balanced pressure unless the bellows has a zero spring rate. No practical bellows of this character can be obtained, but the same result can be obtained if the motion of the bellows 54 is reduced to zero.

With a pilot nozzle system in which fluid is supplied through a fixed restriction to a rebalancing chamber having a control surface therein with the discharge to atmosphere from the chamber through a nozzle controlled by the positioning of the surface with respect thereto, to rebalance at a different pressure a relative motion between the control surface and the nozzle will be required, because of changes in the differential pressure across the nozzle, because of decrease in the rate of flow through the nozzle upon increase in the rebalancing pressure, and because of changes in the compressibility of the fluid at the nozzle.

In the pneumatic circuit shown in Fig. 3, the first of these factors is eliminated by the use of a constant differential between the chambers 61 and 62 which is brought about by the constant spring force of the spring 68. Even if the flow through the nozzle 58 were maintained constant, relative nozzle motion would still result due to the compressibility of the fluid. It is therefore necessary to increase the flow through the nozzle 58, for higher transmitted pressures, in such manner as to exactly compensate for the compressibility of the fluid. The amount of compensation required is proportional to the square root of the absolute pressure at the nozzle. It has been previously pointed out that the fluid supplied by the automatic restriction unit 9, through the delivery connection 24, varies in this manner provided the absolute pressures prevailing at the nozzle 58 and at the restriction 23 were identical. For practical purposes the effect of slight differences between these pressures is negligible. From the foregoing it will be seen that by reason of the compensating effect of the automatic restriction unit 9 only a negligible relative motion of the control surface 49 and the nozzle 58 will be required to effect a rebalance for different pressures applied in the chamber 52. Since there is only negligible relative motion of the control surface 49 with respect to the nozzle 58 the transmission is one to one or linear.

The significance of this can be seen in Fig. 5 in which values of relative nozzle motion are shown as abscissas and values of transmitted pressure are shown as ordinates. The curve at *a* is for the system just described. The curve *b* is for a pilot nozzle system exhausting to atmosphere. The curve at *d* shows the characteristics obtained with a transmission system shown in my prior Patent No. 2,359,236, in which a fixed restriction is employed in place of the automatic restriction 9 of the present invention.

It will be noted that in curve *a*, within the normal operating range of the system which may be assumed as values of transmitted pressure from three to eighteen units, there is a comparatively small relative motion of the control surface 49 and the nozzle 58, and that this relative nozzle motion is substantially linear.

It will be noted that curve *b*, within the operating range shows a considerable relative nozzle motion, which motion is very non-linear.

It will be noted that curve *d*, within the operating range shows a considerable relative nozzle motion, and that the motion is also non-linear. The effect of such relative nozzle motion is to reduce the change in the pressure in the chamber 55 for a corresponding change in the pressure in the chamber 52 and this reduction is not uniform throughout the operating range and is accordingly non-linear.

The curve shown at *c* is also taken with a system in accordance with the present invention but with the automatic restriction unit 9 set for a higher flow rate. It will be noted that the control surface 49 operates with greater clearance but maintains substantially the same small relative motion throughout the operating range.

The characteristic shown by curve *c* is of particular advantage in pneumatic transmission systems because of the relatively large nozzle clearance thereby made possible. With an increased nozzle clearance the parallelism between the nozzle and its cooperating control surface is rendered less significant.

In transmission systems as herein disclosed the variable pressure applied in the chamber 52 produces a relative motion between a control element, such as the control surface 49, and a nozzle, such as the nozzle 58, to bring about a change in the transmitted pressure and to rebalance or restore the control element and nozzle to their initial relative position. The stability of such a transmitting system is improved when the ratio of nozzle opening to nozzle diameter is increased. This is made possible, without detrimental effects, with the present invention as will be seen from curve *c* of Fig. 5. If the ratio of nozzle opening to nozzle diameter were increased to the same extent in the systems whose nozzle characteristics are shown by curves *b* or *d* (Fig. 5) the non-linearity and relative nozzle motion would be very greatly increased.

It will be noted that it is permissible to use a considerably larger restriction 23 by virtue of the small differential maintained thereacross as compared to the differential across a fixed restriction as shown in the transmission system of my prior Letters Patent No. 2,359,236. The major restrictive effect occurs at the valve 17 and seat 18 or at the nozzle 42 and control surface 43. These are both automatic in their action and open or close, as required, to maintain the differential across the restriction 23. This reduces the tendency to clogging.

I claim:

1. In pneumatic control apparatus, means responsive to changes in a condition including a member movable in response to changes in the condition, a pressure control member having an orifice controlled by the positioning of said movable member for controlling the discharge of fluid therefrom, a supply connection in communication with a source of pressure fluid, means for supplying pressure fluid to said control member through a restriction across which a substantially constant differential is maintained, and pressure transmitting means responsive to the pressure conditions on opposite sides of said orifice for controlling the pressure transmitted from said supply connection and for rebalancing said movable member substantially at its intial position.

2. In pneumatic control apparatus, a source of pressure fluid, detector pilot means having a portion movable in response to changes in a variable condition, booster pilot means controlled by said detector pilot means for transmitting fluid under

pressure from said source, and means for modifying the action of said booster pilot comprising means for compensating for the compressibility of the fluid supplied to said detector pilot means.

3. In pneumatic control apparatus, a source of pressure fluid, detector pilot means having a portion movable in response to changes in a variable condition, booster pilot means controlled by said detector pilot means for transmitting fluid under pressure from said source, and means for modifying the action of said booster pilot comprising means for supplying fluid to said detector pilot means proportional to the square root of the absolute pressure of the transmitted fluid.

4. In pneumatic control apparatus, a detector pilot comprising a control member and a pressure fluid supply nozzle mounted for relative motion in response to a variable condition, and compensated supply means for supplying pressure fluid to said nozzle for reducing the change of spacing of said control member with respect to said nozzle upon a change of said variable.

5. In pneumatic control apparatus, a detector pilot comprising a resilient member responsive to a change in a condition and a pressure fluid supply nozzle, compressibility compensated supply means for supplying pressure fluid to said nozzle, said nozzle having a discharge port controlled by the spacing of said resilient member with respect to said port.

6. In pneumatic control apparatus, a detector pilot comprising a member movable in response to a change in a variable condition and a pressure fluid supply nozzle controlled by said movable member, and fluid supply means for said nozzle for maintaining substantially constant spacing between said movable member and said nozzle.

7. In pneumatic control apparatus, a detector pilot comprising a bellows having a fixed closure wall and a movable end closure wall and a fixedly mounted pressure fluid supply nozzle extending through said fixed closure wall, compressibility compensated supply means for supplying pressure fluid to said nozzle, said nozzle having a discharge port controlled by the spacing of said movable wall with respect to said nozzle.

8. In pneumatic control apparatus, a supply connection in communication with a source of pressure fluid, a fluid delivery connection, a fluid discharge connection, compressibility compensated means for supplying pressure fluid to said discharge connection, a valve member interposed between the supply connection and the delivery connection, a movable pressure responsive member for controlling said valve member and against which the fluid from said valve member is effective in one direction, and fluid connections for applying the pressure effective at said discharge connection against said movable member in the other direction.

9. In pneumatic control apparatus, a supply connection in communication with a source of pressure fluid, a fluid delivery connection, a fluid discharge connection, means for controlling the flow of fluid to said discharge connection proportional to the square root of the absolute pressure at the discharge connection, a valve member interposed between said supply connection and said delivery connection, a movable pressure responsive member for controlling said valve member and against which the fluid from said valve member is effective in one direction, and fluid connections for applying the pressure effective at said discharge connection against said movable member in the other direction.

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