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# PNEUMATICALLY-OPERATED CONTROL INSTRUMENT WITH FOLLOW-UP

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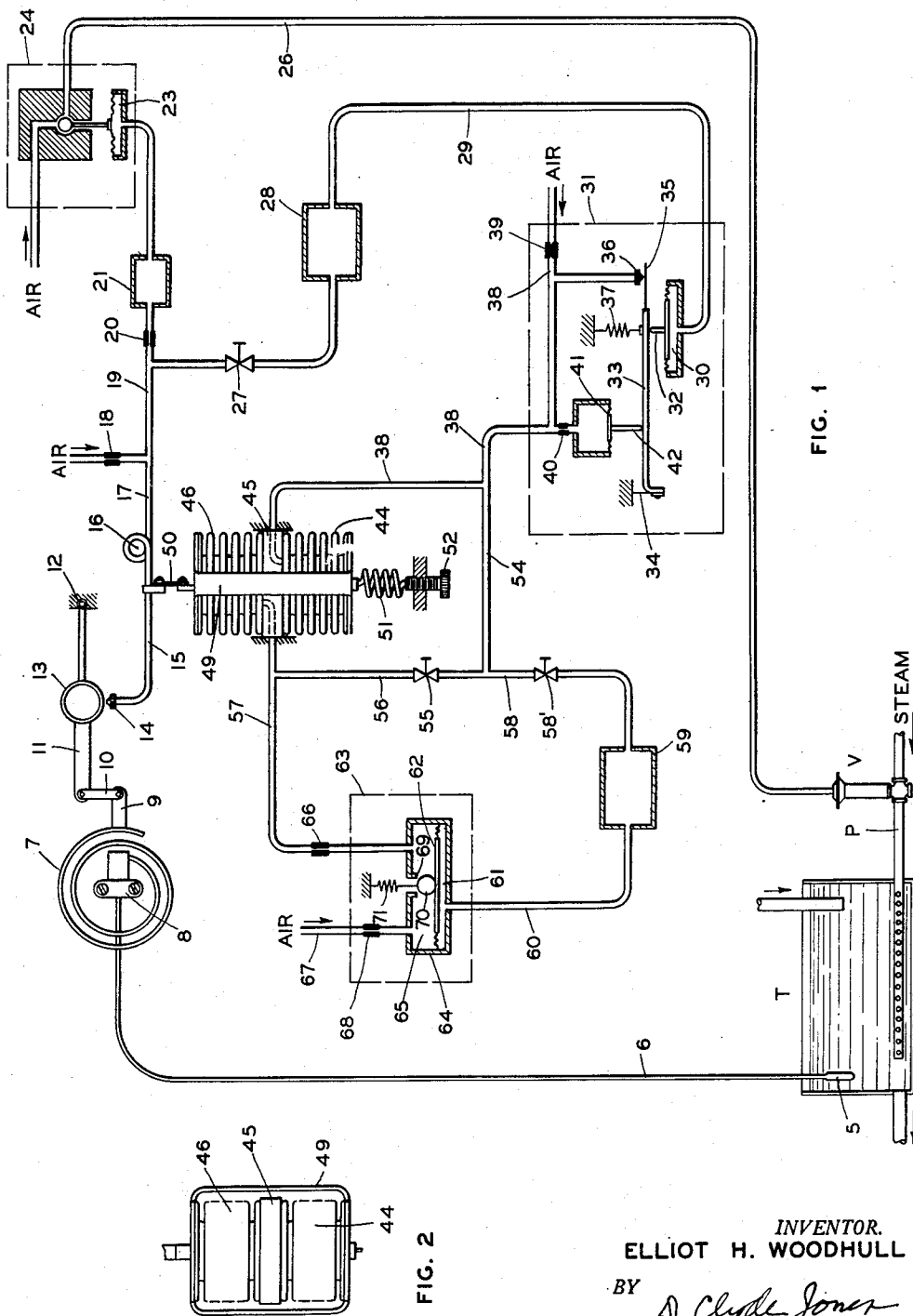


**FIG. 2**

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PNEUMATICALLY-OPERATED CONTROL  
INSTRUMENT WITH FOLLOW-UP

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10 Claims. (Cl. 121—41)

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This invention relates to a pneumatically-operated control instrument having proportional, derivative, and/or reset responses.

The present invention has for its purpose the provision of a controller of the mentioned type in which the sensitivity thereof can be adjusted over an especially wide range without the use of a system of mechanical levers; in which the follow-up mechanism is essentially free of friction; and in which the derivative response can be adjusted to a time constant as low as three seconds without the need of using an unusually large capacity in the controller output line.

The various features of the invention will appear from the detailed description and claims when taken with the drawings in which:

Fig. 1 diagrammatically illustrates the control instrument of the present invention incorporated in a temperature control system; and

Fig. 2 is a side view of the follow-up unit forming a part of the instrument.

In the control system illustrated in Fig. 1, there is provided a tank T containing material, the temperature of which is to be accurately maintained at a given value. A temperature regulating medium such as steam, is introduced into this tank through a pipe P, under the control of a diaphragm motor valve V. In order to sense variations in the temperature of the material in the tank, so that the valve V can be positioned to accurately govern the flow of the temperature correcting medium to the tank T, there is provided a thermosensitive tube system comprising a bulb 5 communicating through a capillary tube 6 with a hollow spiral Bourdon spring 7. The tube system, the bulb 5 of which projects into the material in the tank, is filled with a sensitive fluid.

The inner end of the Bourdon spring 7 is fixedly mounted at 8 while its outer or free end is provided with a take-off arm 9. This take-off arm is connected by a link 10 to one end of a baffle lever 11, the other end of which is pivotally mounted at 12 on a fixed support. The intermediate portion of the lever carries a baffle 13, herein illustrated as being cylindrical in form. A nozzle 14 carried on the free end of the nozzle pipe 15 wastes air to the atmosphere under the control of the baffle 13. The nozzle pipe is pivoted at 16 and at this region there are introduced several coils in the pipe to give it flexibility. The nozzle pipe communicates through the conduit 17 and a restriction 18 with a source of compressed air or the like. It will be understood that as the temperature changes at the bulb 5 of the tube

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system, the Bourdon spring 7 will move the baffle 13 toward or away from the nozzle 14 depending on the direction of the temperature change. This will vary the back pressure in the nozzle pipe 15 which communicates through conduit 19, restriction 20 and capacity 21, with the capsular chamber 23 of a power relay valve 24. A source of compressed air or the like is supplied to the valve 24 which under the control of the back pressure in the capsular chamber 23 effects an amplified pressure change at the output of relay valve 24 that is, for example, ten times greater than the back pressure change. The compressed air in the output of relay valve when controlled in the manner just described, is applied through conduit 26, to the diaphragm motor top of the valve V. It will be understood that the restriction 20 and capacity 21 serve to keep pneumatically stable, the follow-up mechanism to be described. These elements also serve to render the relay valve 24 less susceptible to mechanical vibration of the several parts of the control mechanism since the mentioned elements do not permit this valve to give a full amplitude response to baffle motions, having a frequency larger than, for example, one cycle per second.

If, for example, the temperature at the bulb 5 increases, the Bourdon spring 7 will raise the baffle a very slight distance away from the nozzle thereby reducing the back pressure in the nozzle pipe 15 and the capsular chamber 23 tending to open the inlet port of the relay valve 24, a slight amount. Compressed air at an increased pressure is supplied through this relay valve to the diaphragm motor of the valve V, tending to shut off the steam to the tank T. A drop in temperature at the bulb effects a similar operation but in the reverse sense.

The pipe 19 also communicates through the adjustable needle valve 27 and a capacity 28 as well as through a pipe 29 with the capsular diaphragm 30 of a force balance type of amplifying relay valve 31 which is herein indicated within the broken line rectangle. It should be mentioned that the needle valve 27 and capacity 28 tend to introduce an adjustable time delay in the follow-up action to be described, thereby providing what is known in the art as derivative action. For those applications where derivative action is not required pipe 19 may communicate directly through a pipe with capsular diaphragm 30. The diaphragm 30 is provided with an upwardly extending stud 32 in a position to engage the under side of the movable end of a baffle lever 33. This baffle lever is pivotally supported at its left end,

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on a leaf hinge 34. The right end of this lever carries a baffle 35 in operative relation to a nozzle 36. A spring 37 having one end engaging a fixed part of the frame and its other end engaging the top of the baffle lever tends to hold this lever 33 in contact with the stud 32. The nozzle 36 communicates through a pipe 38 and the restriction 39, with a source of compressed air or the like. Pipe 38 also communicates through a restriction 40 with a capsular diaphragm 41. This diaphragm is provided with a downwardly directed stud 42 positioned to engage the upper side of the baffle lever 33. By this construction the two capsular chambers since they tend to move the baffle lever in opposite directions, will be effective to position the baffle 35 with respect to the nozzle until the change in pressure on capsular diaphragm 41 tends to produce a moment in baffle lever 33 which opposes any moment produced by changes in pressure on diaphragm 30. The several parts may be so designed that the amplification between input pressure and output pressure is, for example, ten. It should also be pointed out that the restriction 40 and the capacity of the capsular diaphragm chamber 41 serve to keep pneumatically stable the followup mechanism to be described. As built, these elements do not permit diaphragm 41 to give a full amplitude response to pressures in 38 having a frequency larger than about 1 cycle per second.

The pipe 38 communicates with a bellows 44 of a followup and reset bellows unit, the construction of which is illustrated in Fig. 2. This bellows unit comprises a fixed support 45 to the lower surface of which there is sealed the open end of the bellows 44. A second bellows 46 has its open end sealed to the upper end of the support so that the free end of this bellows projects upward. A rectangular yoke 49 engages the free ends of the bellows 44 and the bellows 46 to be moved thereby. Thus when the pressure in bellows 46 is less than that in bellows 44, the yoke 49 will move downward and since this yoke is connected by a leaf hinge 50 to the nozzle pipe 15, this pipe will also move downward to separate the nozzle 14 from the baffle 13 a slight amount. In a similar manner when the pressure in bellows 46 is greater than that in bellows 44, the several parts will operate in the reverse sense to make the nozzle 14 approach the baffle 13. It should be mentioned that the spring 51 attached to yoke 49 can have its tension adjusted by the knurled adjusting knob 52 so that one or the other of the bellows 44 and 46 can be stretched and the other compressed until their effective areas are equal. It was found experimentally that a standard bellows changes its effective area with position such that as the bellows is extended from its free length the effective area decreases and as it is compressed its effective area increases. This effective area is not changed by the magnitude of pressure in the bellows and depends upon position alone. By means of biasing spring, such as 51, it is possible to take two bellows which are of the same nominal area and extend one and simultaneously compress the other until the areas are exactly matched.

A branch pipe connection 54, which communicates with pipe 38, also communicates through the sensitivity adjusting needle valve 55 and through pipes 56 and 57 to the interior of bellows 46. This last mentioned connection together with a connection including restriction 66 and pipe 57, to be described, supply pressure fluid to bellows 46 which tends to oppose the

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followup action of bellows 44 by an adjustable amount to provide adjustable sensitivity where adjustable sensitivity is defined as the amount of opening or closing of valve V in response to a given movement of baffle 13. The preferred locations of restrictions 55 and 66 are as shown in Fig. 1, although, they may be interchanged. The branch pipe 54 also communicates through pipe 57, reset time adjusting needle valve 59, capacity 59 and pipe 60, to the diaphragm chamber 61 of the one to one relay valve 63. By the use of such a relay valve, the output pressure thereof to restriction 66 is equal to the input pressure in pipe 60 leading thereto. Thus this relay functions to apply the pressure of line 60 to restriction 66 without permitting direct flow between 60 and 66. Any one-to-one relay will be suitable for this purpose.

The relay herein disclosed comprises the input or diaphragm chamber 61 defined by the diaphragm 62 and the lower part of the shallow cylindrical casing 64. The upper part of the casing together with the diaphragm 62 defined the output chamber 65 of the relay, which communicates through the restriction 66 with the pipe 57'. A source of pressure fluid such as compressed air is supplied through pipe 67 and restriction 68 to the output chamber. The top of the casing is also provided with an opening which functions as nozzle 69, while a ball valve 70 actuated by the diaphragm 62, acts as a baffle to govern the waste of compressed air from the output chamber to the atmosphere until the pressures in the output and input chambers are substantially equal. The effective area of the top surface of the diaphragm is reduced by the area of the nozzle 69. This tends to make the gain of the relay greater than unity, since a greater change in pressure in the upper chamber than in the lower chamber is required to bring about an equilibrium condition in these chambers. However, by properly selecting the spring rate of spring 71 the gain can be made almost exactly unity. The initial compression in spring 71 must be greater than supply pressure times port area 69 so that the ball 70 will never fail to make contact with plate 61.

The arrangement of the power relay 24 in the pneumatic circuits of the present controller, makes it possible to operate from the output pressure of this power relay, a valve V with a diaphragm motor of any desired volume without in any way changing the proportional, reset and derivative responses which are all effected directly from the back pressure in the nozzle pipe.

It has been pointed out above how an increase in temperature at the bulb 5 operates the Bourdon spring 7 to raise the baffle 13 a very slight distance away from the nozzle, thereby reducing the back pressure in the nozzle pipe 15, and also that this reduction in back pressure actuates the relay valve 24 which supplies compressed air at increased pressure to the diaphragm motor of the valve V, tending to shut off the steam to the tank T. At the same time the reduction in back pressure in nozzle pipe 15 is supplied through the needle valve 27, the capacity 28, and pipe 29 to the capsular chamber 30. This results in a slight withdrawal of the baffle 35 from the nozzle 36 thereby modifying the pressure of the air supplied through the restriction 39, pipe 38, to the capsular diaphragm 41. The pressure of the air thus supplied is reduced until the pressure in the capsular diaphragm 41 is equal to that in the capsular diaphragm 30. The reduction in pressure in pipe

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38 is communicated to the bellows 44 which tends to contract, thereby moving the nozzle pipe 15 and its nozzle toward the baffle 30 at the same time, but at a delayed rate the reduced pressure in the pipe 34 is communicated through pipe 60 and the one-to-one relay valve 63 and pipe 57', leading to the bellows 46. Bellows 46 tends to cancel out the follow-up action of the bellows 44, thereby tending to restore the initial baffle nozzle separation. A drop in pressure at the bulb 5 assures a similar operation of the controller but in the reverse sense.

It should be noted that the sensitivity adjustment in the present controller, is effected by simply turning the knob of the needle valve 55, the operation of which is such that its reference scale can have uniformly spaced graduations throughout. This construction obviates the need of levers and pivots necessary in conventional sensitivity reducing arrangements.

As compared with prior controllers of this type, the present controller has a follow-up unit in which the number of pivots has been so reduced that friction has been greatly minimized with the resultant increase in accuracy of operation.

What I claim is:

1. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for relatively moving said baffle and nozzle whereby the back pressure in the nozzle is changed in amounts corresponding to changes in the variable, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a follow-up unit tending to reduce any given relative movement of said elements without moving said mechanism, said follow-up unit including two pressure chambers and means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers a pressure corresponding to said back pressure, and governing means for supplying fluid under modifying pressure to said other chamber, said governing means comprising two restrictions each of which communicates with said other chamber, one of which restrictions is supplied with fluid under a given pressure, the other of the restrictions being supplied with fluid under a pressure proportional to said back pressure.

2. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for relatively moving said baffle and nozzle in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said

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chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween without substantially interfering with the free deflection of said mechanism, means for applying to one of said chambers a pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying a fixed pressure to one end of said divider circuit, means for supplying a pressure corresponding to said back pressure to the other end of said pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

3. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle which nozzle wastes fluid to the atmosphere, means including said mechanism for relatively moving said baffle and nozzle in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers a pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying a fixed pressure to one end of said divider circuit, means for supplying a pressure corresponding to said back pressure to the other end of said pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

4. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for moving one of said elements relative to the other in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween while applying substantially no force to said mechanism, means for applying to one of said chambers an actuating pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for

supplying said actuating pressure to one end of the pressure divider circuit, means which include a restriction and a capacity for supplying a modified actuating pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

5. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle which nozzle wastes fluid to the atmosphere, means including said mechanism for relatively moving said baffle and nozzle in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers an actuating pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying said actuating pressure to one end of the pressure divider circuit, means which include another variable restriction and a capacity for supplying a modified actuating pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

6. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for moving one of said elements relative to the other in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween without substantially interfering with the free deflection of said mechanism, means for applying to one of said chambers an actuating pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying said actuating pressure to one end of the pressure divider circuit, means which include another variable restriction, capacity, and relay valve for supplying a modified actuating pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed

and variable restrictions of said pressure divider to said other pressure chamber.

7. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle which nozzle wastes fluid to the atmosphere, means including said mechanism for relatively moving said baffle and nozzle in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to said device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers an actuating pressure corresponding to said back pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying said actuating pressure to one end of the pressure divider circuit, means which include another variable restriction, capacity, and relay valve for supplying a modified actuating pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

8. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for relatively moving said baffle and nozzle in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween without moving said mechanism, means for applying to one of said chambers a pressure corresponding to said throttled pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying a fixed pressure to one end of said divider circuit, means for supplying a pressure corresponding to said throttled pressure to the other end of said pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

9. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied

to said nozzle, means including said mechanism for moving one of said elements relative to the other in response to changes in said variable whereby the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, means for producing an actuating pressure which means includes a resistance, capacity and relay valve to which said back pressure is applied, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers said actuating pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying said actuating pressure to one end of the pressure divider circuit, means which include another variable restriction, capacity, and relay valve for supplying a modified actuating pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

10. In a controller, mechanism for sensing changes in a variable condition, a source of elastic fluid under pressure, a pneumatic couple comprising a nozzle element and a baffle element relatively movable with respect to each other, a restriction through which said fluid is supplied to said nozzle, means including said mechanism for moving one of said elements relative to the other in response to changes in said variable whereby

the back pressure in the nozzle is changed in amounts corresponding to said changes, a pneumatically operated control device, means responsive in correspondence with said back pressure for supplying throttled pressure fluid to such device, means for producing an actuating pressure which means includes a restriction, capacity and relay valve to which said back pressure is applied, a followup unit tending to reduce any given relative movement of said elements, said followup unit including two pressure chambers, means responsive to the difference in pressure in said chambers for moving the one of said elements in a direction tending to reduce any relative movement therebetween, means for applying to one of said chambers said actuating pressure, a pressure divider circuit consisting of a fixed restriction and a variable restriction in series, means for supplying said actuating pressure to one end of the pressure divider circuit, means for supplying a given pressure to the other end of the pressure divider circuit, and means for supplying the resultant pressure occurring between the fixed and variable restrictions of said pressure divider to said other pressure chamber.

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