

July 27, 1943.

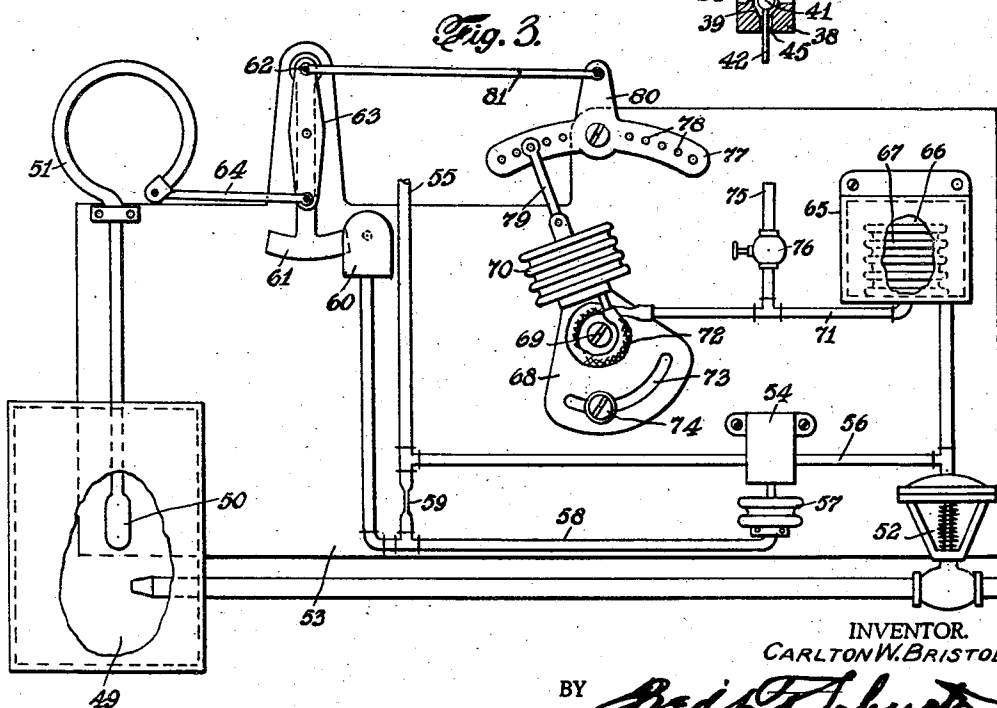
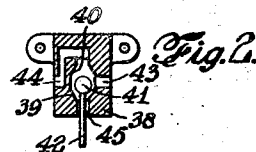
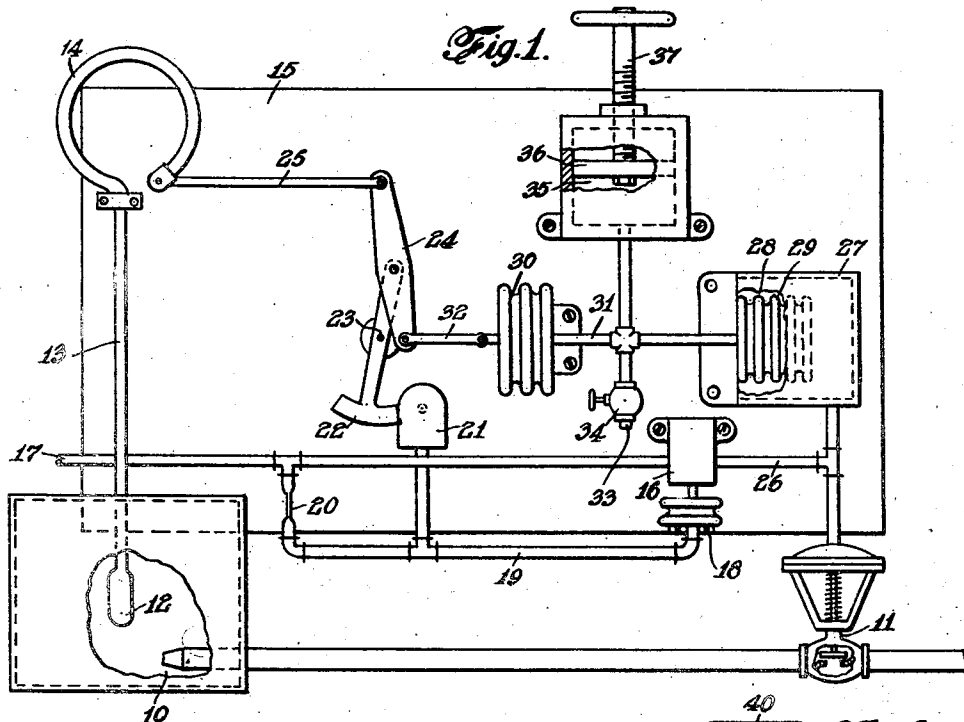
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2,325,103

FLUID-PRESSURE-ACTUATED REGULATING SYSTEM

Filed Nov. 15, 1937

3 Sheets-Sheet 1



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FLUID-PRESSURE-ACTUATED REGULATING SYSTEM

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3 Sheets-Sheet 2

Fig. 4.

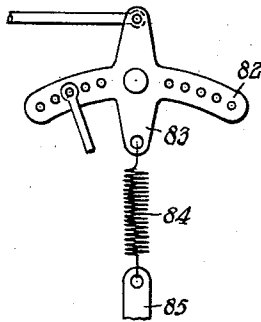


Fig. 5.

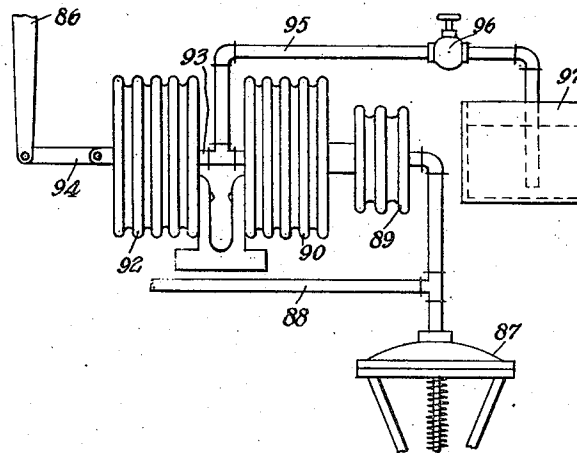


Fig. 6.

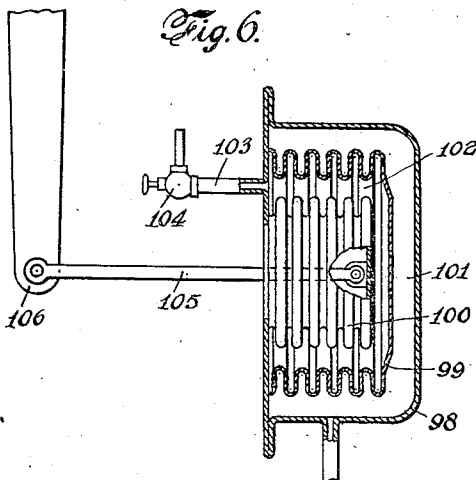
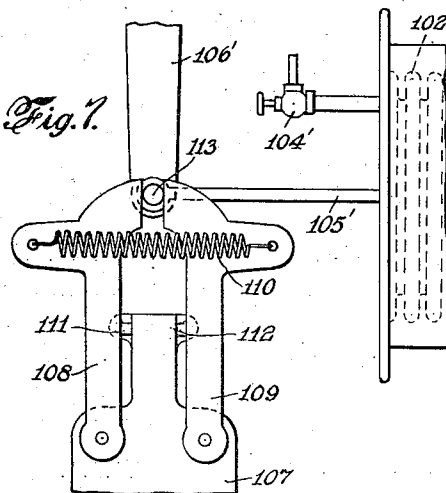


Fig. 7.



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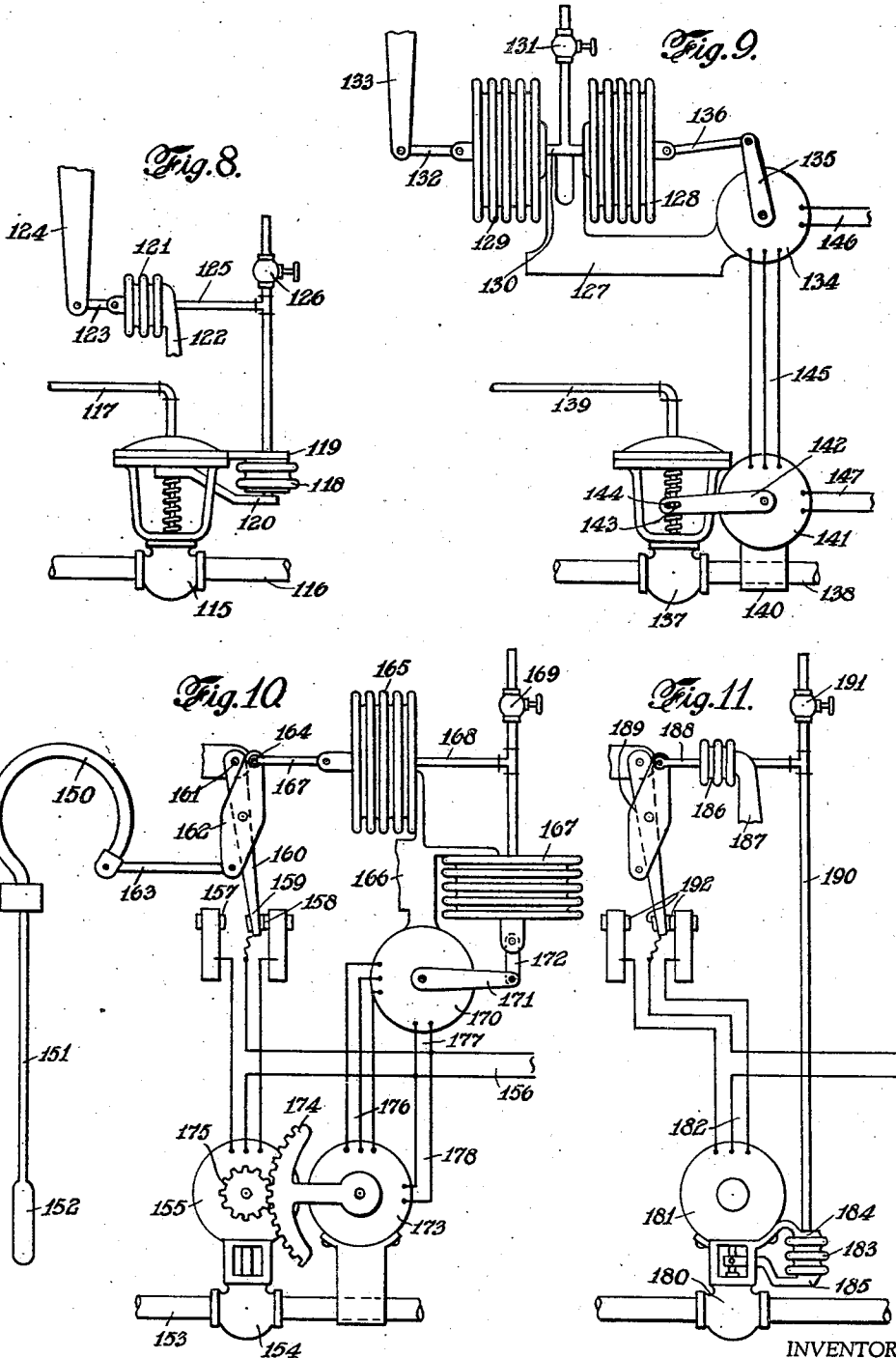
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FLUID-PRESSURE-ACTUATED REGULATING SYSTEM

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3 Sheets-Sheet 3



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2,325,103

FLUID-PRESSURE-ACTUATED REGULATING SYSTEM

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Application November 15, 1937, Serial No. 174,609

5 Claims. (Cl. 236—82)

This invention relates to automatic regulating systems, and more particularly to fluid-pressure systems in which there is superimposed on a basic control directly responsive to variations in a magnitude under regulation, an auxiliary control, the intensity of whose action is related to the rate at which variations take place in the regulated magnitude or in a fluid pressure subject thereto.

In regulating systems of this nature it has been found advantageous that the auxiliary control be first applied substantially simultaneously with the basic control and subsequently be gradually withdrawn, until, under steady-state conditions, the basic control alone is effective. A control of this nature is well exemplified in U. S. Letters Patent No. 2,005,773, issued June 25, 1935, to Luis de Florez. Herein, the basic control is effected by means of a principal bellows member, and the auxiliary control by means of a pair of mechanically opposed bellows members, one of which responds simultaneously with the principal bellows, and the other is subject to a time delay, as determined by a constriction in a conduit supplying fluid pressure thereto. A regulating valve is made subject to the joint influence of these two elements of the control system by means of a floating lever.

In constructions of this nature, where the opposed motor members are in communication with the pressure fluid by which control is effected, the pressure must usually be above atmospheric, with the result that any leak which may develop in the system will result in the escape of pressure fluid and a consequent disturbance of the control function. In other forms, in which the opposed motor members are tightly sealed, it is necessary to provide special compensating means to eliminate the effects of changes in temperature of the sealed-in fluid.

In any case wherein bellows members are utilized in direct opposition the arrangement does not make for flexibility in design nor for ready adjustment; and the stresses set up under operating conditions necessitate the use of stiff and heavy parts quite incompatible with the required delicacy of performance.

It is an object of this invention to provide for regulators of the class under consideration, an auxiliary control utilizing fluid-pressure-responsive time-delay means of a nature whose normal function will not be adversely affected by slow leaks or by extreme temperature changes.

A further object of the invention lies in the adaptation of a principle which lends itself

readily to the utilization of either an elastic fluid or an incompressible fluid in the auxiliary control means.

A still further object lies in the provision of auxiliary control means of this class, which shall be readily adaptable to electrical, as well as to pneumatic, basic control.

The invention has for another object to facilitate flexibility in the design and operation of regulating systems of this class.

Still another object lies in the provision of a design which shall be at once simple, light in weight, and inexpensive to construct and adjust, and which shall be readily adaptable to quantity production methods.

In the proposed control system, the time-delay element makes use of a fluid normally at atmospheric pressure. This may be atmospheric air, or it may be an incompressible fluid in communication with the atmosphere. Actual operation of the auxiliary control is effected by a single bellows member which first responds simultaneously with the basic control action, and then gradually withdraws its effect at a rate depending upon the extent of the initial response. The internal system, being in communication with the atmosphere, is not subject to adverse effects due to slow leaks or by temperature changes which might affect a completely sealed system. The operation of the bellows members at or near atmospheric pressure (a condition not possible in those systems in which the auxiliary control is operated from the control pressure fluid) renders it possible to make use of bellows members of extremely light material, thus eliminating the undesirable effects of stiffness and inertia inseparable from bellows members having relatively thick metal walls.

The nature of the invention, however, will best be understood when described in connection with the accompanying drawings, in which:

Fig. 1 is a diagrammatic representation of a pneumatic control system embodying the invention, and particularly adapted to the regulation of temperature in an enclosed space by the control of the flow of a heating agent, such as steam, thereto.

Fig. 2 shows to an enlarged scale a section of a three-way valve adapted to use in such a system.

Fig. 3 is a diagrammatic view of an alternative form of pneumatic control system embodying the invention.

Fig. 4 is a detail view of an element of mechanism adaptable to use in such a system.

Fig. 5 is a view of a portion of a control system embodying the invention, the system being particularly adapted to the use of a non-elastic fluid in certain elements of the mechanism.

Fig. 6 is a detail sectional view of a part of an alternative mechanism incorporating the invention.

Fig. 7 is a view of an element of mechanism particularly adapted to use in conjunction with the embodiment shown in Fig. 6.

Fig. 8 illustrates a simplified form of the invention.

Fig. 9 illustrates the adaptation of electrical motion-transmitting means to a pneumatic control embodying the invention.

Fig. 10 shows diagrammatically an electrical temperature-regulating system incorporating the invention.

Fig. 11 shows a simplified form of the electrical embodiment of the invention.

Referring to Fig. 1 of the drawings, 10 designates a closed vessel or chamber in which it is desired to maintain by the admission of a suitable heating agent, such as steam, through a pneumatically-operated direct-acting regulating valve 11, a predetermined constant temperature, as determined by a sensitive bulb 12. The latter contains an expansible or volatile fluid and forms a part of a closed system including a capillary tube 13 and a Bourdon spring 14 carried by a mounting plate 15. The regulating system of which the above-mentioned elements comprise coacting units may be of the class set forth in U. S. Letters Patent No. 1,880,247, granted October 4, 1932, and is subject to certain modifications hereinafter to be set forth.

A three-way valve 16 of the supply-and-waste type, fixed to the base or mounting plate 15, is adapted to receive fluid under pressure, such as air, from a constant pressure source 17, and to control the outgoing pressure of the same. To this end, the valve 16 is arranged to be operatively actuated by a bellows member 18, also affixed to the base 15, in such a sense that increase of fluid pressure within said bellows member will cause the valve to lower the pressure of air delivered by the same, and vice versa. Bellows member 18 is placed in communication with the constant pressure source 17 by a conduit 19 having therein a constricted portion 20.

Connected to the conduit 19 is a stationary orifice member 21, having double-opposed jets, substantially as set forth in the above-mentioned Letters Patent No. 1,880,247. A vane member 22 is adapted to swing through a limited angle about a stationary axis or spindle 23, and to pass freely between the jets of the orifice member 21 in a sense more or less to obstruct the escape of pressure fluid therefrom, and thereby govern the back-pressure in the conduit 19 and in the bellows member 18. Pivotal attachment to an extension of the vane member 22 is the mid-point of a floating lever 24; and the upper extremity of this lever, as shown in the diagram, is attached by a link 25 to the Bourdon spring 14.

Communicating with the outlet side of the three-way valve 16 is a conduit 26, providing direct connection to the diaphragm top of the pneumatically actuated valve 11. This valve, being of the direct-acting class, will tend to close with increase of pressure in the conduit 26, and vice versa.

Fixed to the base 15 is a bellows assembly 27 consisting of a closed chamber 28 having therein

a resilient collapsible bellows member 29, the space within the chamber and exterior to the bellows being directly in communication with the conduit 26. A resilient bellows member 30 fixed at one end to the base-plate 15 has its interior space in free communication with the interior space of the bellows member 29 by means of a conduit 31. The free end of bellows member 30 is attached by means of a link 32 to the lower end of the floating lever 24, the relative disposition of these parts being such that the line of action of the link 32 passes through the axis 23, and with the bellows member 30 in a state of repose, the point of attachment of the link 32 to the floating lever 24 will lie upon said axis. Tapped off the conduit 31 is a bleeder or vent 33 to the atmosphere, the same having interposed therein a constricted portion, which may take the form of a throttling valve 34. There may also be connected to the conduit 31 a stationary chamber 35 having its internal volume adjustable, as by a piston 36 adapted to be positioned by a manually operable screw member 37.

The internal arrangement of the three-way valve 16 is shown diagrammatically in Fig. 2. A body member 38 has internally located therein two opposed conical seating surfaces 39 and 40, either of which may be engaged by a ball member 41 carried on the upper extremity of a stem 42, thus serving to place an outlet port 43 in communication with an inlet port 44 or with a vent port 45, according to, whether the ball is in its low or its high position. This form of valve provides a delicate control of air pressure in any conduit or associated apparatus connected to the outlet port, and, being well known in the art of pneumatic control, here demands no further elucidation.

Operation of the control system as shown in Fig. 1 may be described as follows: Assume there first to exist a steady-state condition, in which the supply of heating agent through the valve 11 is exactly equal to the demand in order to maintain the temperature at the predetermined value. The Bourdon spring 14 will serve to position the upper end of the lever 24 in accordance with this value. The system being in equilibrium, the pressure in conduit 26 will be steady, and the interiors of bellows members 29 and 30 will assume the pressure of the atmosphere, with which they are in communication through the conduit 31 and the vent 33. Bellows member 29 will assume a position of repose as determined by its resiliency, and, through the link 32, will position the lower end of the lever 24, so that the point of attachment of the link 32 to the lever 24 will lie on the axis 23 about which swings the vane member 22. The vane 22 will thus be given in relation to the orifice 21 a definite optimum position corresponding to a steady-state condition in the control system.

Consider now a condition in which the temperature under regulation manifests a tendency to rise. This will be reflected in an increase in fluid pressure within the bulb 12 and the Bourdon spring 14, and a consequent deflection of the upper end of the floating lever 24 toward the right, whereby the vane 22 will be deflected away from the orifice member 21, permitting an increased escape of air from the same and causing the pressure of air in the conduit 19, as limited by flow through the constriction 20, to be lowered, with a corresponding axial shortening of the bellows member 18 and a movement of the valve 16 in a sense to increase air pressure in

the conduit 26 and all members communicating therewith. The immediate result of the increased pressure in conduit 26 is to cause the valve 11 to close and decrease the flow of heating agent to the space within the chamber 10, thus tending to compensate for the original tendency toward rising temperature. During this part of the cycle, the lever 24 may be considered as swinging about the point of attachment to the link 32 as a fulcrum; and, this point of attachment lying in the axis 23, the deflection of said vane member will be exactly proportional to that of the Bourdon spring 14.

A further result of the increase of pressure in the conduit 26, and therefore in the chamber 28, is an immediate compression of the bellows member 29, and a consequent expulsion of air therefrom, which air tends to pass freely through the conduit 31 to the bellows member 30, expanding the same and moving the fulcrum of the floating lever 24 toward the left, which action tends to annul the original control effect. The conduit 31 being in communication with the atmosphere through the constricted valve 34 and the vent 33, and the pressure therein having been increased by the inherent resiliency of the bellows member 30 acting in opposition to the flow of air thereinto from the bellows member 29, there will be a tendency for air to flow slowly out through the vent until the interior space is again at atmospheric pressure, the bellows member 30 restored to its normal position of repose, and the vane to its original deflected position subject solely to the Bourdon spring 14.

Similarly, it will be seen that upon a decrease in temperature in the chamber 10, the vane 22 will be deflected by the Bourdon spring 14 toward the right, which action will be followed by a momentary deflection toward the left as the bellows member 30 temporarily contracts, after which the equalization of interior and exterior pressures in the bellows member 30 will cause the vane to move gradually toward the right until the bellows member 30 resumes its normal position of repose. This action of momentarily opposing the control effect, and subsequently and gradually withdrawing the opposition, has been found under many types of operating conditions to minimize any tendency toward "hunting" and to produce a stable control.

Adjustment of the rate of response of the bellows member 30 to movement of bellows member 29, and of its subsequent return to normal dimensions, may be effected both by varying the amount of opening of the valve 34, and by adjusting the internal volume of the chamber 35 by positioning the piston 36 through manipulation of the screw 37. Compensation may thus be made for different thermal inertia characteristics as manifested in different types of apparatus to be made subject to automatic temperature regulation.

In Fig. 3 is shown a control system embodying the principles of the invention in an alternative form, the basic control being effected in a manner identical with that above set forth. A closed vessel 49 in which it is desired to maintain a predetermined constant temperature, as measured by a temperature sensitive bulb 50 communicating with a Bourdon spring 51, is arranged to have steam or other suitable heating agent admitted to its interior space through a fluid-pressure-actuated flow-regulating valve 52. Mounted on a suitable supporting base 53 is a three-way valve 54 of the form shown in Fig. 2,

and adapted to control the pressure of air from a constant-pressure source 55, as exerted through a conduit 56 on the operating element of the regulating valve 52. The three-way valve 54 is operably associated with a bellows member 57, receiving air from the source 55 through a conduit 58, having therein a constricted portion 59, and subject to regulation of its internal pressure by the rate of escape of air through a double-opposed orifice member 60 having juxtaposed thereto a vane member 61 rotatable through a small angle about a pivotal support or axis 62 on the base 53. A floating lever 63, pivoted at its mid-point upon the structure of the vane member 61, has one of its extremities operatively attached by a link 64 to the free end of the Bourdon spring 51.

Mounted on the base 53 is a bellows assembly 65 consisting of a closed chamber 66 having therein a resilient collapsible bellows member 67, the annular space within said chamber and exterior to the bellows being directly in communication with the conduit 56. Mounted upon a plate 68, angularly adjustable about an axis 69 and carried by the base 53 is a resilient bellows member 70, having its interior space directly in communication with that of bellows member 67 through a conduit 71 having a portion 72 flexible to permit angular adjustment of the plate 68 and the bellows member 70 carried thereby. Formed in the plate 68 is an arcuate slot 73, whereby the adjusted position of the plate may be definitely fixed by means of a screw 74 threadedly engaging the base plate. Tapped off the conduit 71 is a bleeder or vent 75, having interposed therein a constricted portion, which may take the form of a throttling valve 76.

Pivoted to the plate 53 is a bell-crank lever member 77 having opposed extensions carrying a plurality of tapped holes or the like, arcuately disposed, and, in the neutral position of the elements, as shown in the drawings and corresponding to equal internal and external pressures on bellows member 70, concentric with the axis 69. The holes 78 serve as points of selective attachment for a pivotal connection with a link or extension 79 carried by the free end of the bellows member 70, whereby the latter may be caused to move angularly the member 77 in a direction depending upon which of its opposed extremities is selected for attachment of the link 79, and to an extent governed by the radial distance of the selected hole from the center of rotation. A lever arm 80 forming a part of the bell-crank member 77 is operatively attached to the free extremity of the floating lever 63 by means of a link 81, whereby such motion as the bell-crank member may receive from the resilient bellows member 70 will be imparted to the said floating lever, and will thereby be combined with the movements of the Bourdon spring 51 in positioning the vane member 61. The proportioning and location of the floating lever 63 are made such that the pivot point of attachment of the link 81 to the floating lever may in its travel pass through the axis 62, and the length of the link 81 is made such that when the bell-crank member 77 lies with the arc upon which are located the holes 78 concentric with the axis 69, the said pivot point will coincide with the axis 62.

The operation of the primary control elements of the embodiment shown in Fig. 3 is identical with that set forth in connection with the form shown in Fig. 1, the valve 52 tending to be automatically positioned by the control mechanism

to admit to the chamber 49 a flow of heating agent sufficient to maintain or restore thermal equilibrium at the predetermined temperature value. Variations in the control pressure in the conduit 56 will be transmitted to the interior of the chamber 65, tending to affect the dimensions of the bellows member 67, and thereby to deflect the bellows member 70, thus acting through the bell-crank member 77 and the link 81 to superimpose a stabilizing movement on the floating lever 63 and modify the positioning of the vane 61 in a sense to damp out oscillations otherwise inherent to the system of control. The intensity of the secondary action may be adjusted to existing conditions by a suitable selection among the pivot locations 78, the bellows member 70 being subjected to a corresponding angular displacement by setting of the plate 68.

Connecting the link 79 to the member 77 alternatively on one side or the other of the latter's axis of rotation effects a reversal of the secondary control action, and makes possible the selection between two methods, each of which is especially applicable in particular cases. The proportioning and adjustment of parts is such that with the elements of the control mechanism brought to the neutral position, as shown in Fig. 3, where the center of the arc of location of the holes 78 coincides with the axis 69, the plate 68 carrying the bellows 70 may be set in any desired position in its range of adjustment without disturbing other adjustments of the mechanism.

In the event of there being desired a higher degree of resiliency to restore the bellows member 70 to its normal position of repose, resort may be had to means such as set forth in Fig. 4. A bell-crank member 82, corresponding to the bell-crank 77 in Fig. 3, is provided with a radial projection 83, from which a tension spring 84 is connected to an abutment 85 affixed to the frame of the mechanism. The tendency of this spring will be to maintain the bell-crank 82 in a position where the point of pivoting of the same will lie on a straight line with the points of attachment of the spring 84 to the projection 83 and the abutment 85, which position may be made to correspond to the neutral point or position of repose of the bellows member 70.

In Fig. 5 is shown an alternative form of the invention, particularly suited to the utilization of a non-elastic fluid in the auxiliary control. The function and arrangement of the floating lever 86 and the main regulating valve 87 shown in this figure are identical with those of the lever 24 and the valve 11 shown in Fig. 1; and the general method of basic control is in all respects identical with that hereinabove set forth. A conduit 88, serving to convey pressure fluid to the valve 87 for the purpose of controlling the same in a manner identical with that above set forth, communicates also with a bellows member 89, making the same responsive in all its movements to the pressure of the fluid in the conduit 88, and tending at all times to take up a position corresponding to that of the valve 87. Mechanically attached to the bellows member 89, but having no interior communication therewith is a bellows member 90 fixed to the frame of the instrument. Also fixed to the frame of the instrument is a bellows member 92, communicating freely with bellows member 90 through a conduit 93 and operatively connected by means of a link 94 to the extremity of floating lever 86 in a manner similar to the attachment of link 32 to lever 24 in Fig. 1. Communicating with conduit 93 is a conduit 95

having therein a constricted portion, as, for example, a throttling valve 96, and entering a tank or open reservoir 97. The system comprising bellows members 90 and 92 and conduits 93 and 95 is normally filled with an inelastic fluid, such as thin oil, the reservoir 97 also containing sufficient of the same fluid that under no conditions may air obtain entry to the conduit 95 or any other part of the auxiliary control system.

Operation of the invention as shown in Fig. 5 is similar to that of the elastic-fluid-filled types shown in Figs. 1 and 3; but the incompressibility of the liquid content of the bellows members 90 and 92 will render definite and positive the response of the latter to movements of the former, except as the combined resiliencies of the said members may cause liquid to pass through the conduit 95 and the constriction 96 into or out of the tank 97, thus providing the time element of ultimate response which characterizes the performance of the invention.

A further alternative form is shown in Fig. 6, wherein the several elements of the mechanism are "nested" in a manner to effect compactness of construction. A hollow cylindrical shell 98 has concentrically positioned within it an outer and an inner resilient bellows member 99 and 100, respectively, the interior of the inner member 100 being open and in free communication with the atmosphere. One of the two annular chambers, for example the outer chamber 101, is connected in a manner similar to chamber 28 in Fig. 1 to the three-way valve and pressure-actuated regulating valve of a basic control system of the type hereinabove set forth. The other (inner) chamber 102 is vented to the atmosphere through a conduit 103 having a constricted portion, as a throttling valve 104. The interior of bellows member 100 is operatively attached by means of a link 105 to an extremity of a floating lever 106 in a manner exactly similar to, and with the same function in view, as the connection between link 32 and lever 24 in Fig. 1.

The performance of the combination will be such that a change in fluid pressure, as communicated from the control system to the chamber 101, will act on the exterior of bellows member 99 to compress the same, which action will at first immediately be communicated through the air contained within the annular chamber 102 to the bellows member 100, producing motion of the link 105 and of the extremity of the floating lever 106, effecting a compensating action similar to that set forth in connection with the previously described embodiments of the invention. Subsequently and gradually, as permitted by the equalization of fluid pressure through the constriction 104 to or from the atmosphere, the resiliency of the bellows member 99 will cause it to assume its normal position of repose with its exterior surface at atmospheric pressure, thus restoring the lower extremity of the lever 106 to its original position, and effecting the secondary and delayed action of the auxiliary control.

In the event of its being desired to augment the normal resiliency of bellows member 100, resort may be had to a spring combination similar to that shown in Fig. 7. As shown, there are pivotally mounted on a base plate 107 two opposed lever arms 108 and 109 normally maintained by a tension spring 110 in engagement with stops 111 and 112, forming parts of the plate 107. A pin 113, carried by the lower end of the floating lever 106, rests in the space between the lever arms in such a manner as to be maintained thereby in the neutral or normal position of

repose. Upon deflection of the lever 106' in either direction by action of the link 105', one or other of the lever arms will yield in opposition to the tension of the spring 119, which will act to restore the moving parts associated therewith to their normal position of repose, as the pressure of the fluid within the chamber 102' becomes equalized with atmospheric pressure due to delayed flow through the constriction 104'.

In Fig. 8 is shown a form of the invention in which the auxiliary control having a time-delay characteristic is derived directly from motion of the main regulating valve, rather than from changes in air pressure governing said valve. A regulating valve 115 in a pipe line 116 is adapted to be operatively controlled by pressure of the fluid in a conduit 117 leading from a three-way valve (not shown and similar in construction and arrangement to those hereinabove fully set forth and described). A bellows member 118 carried by a bracket 119 fixed to the body of the valve 115 is adapted to have its length, and therefore its internal volume, varied in response to movements of the valve 115 by means of an arm 120 carried by the stem of said valve. A second bellows member 121, carried on a stationary support 122 is attached by a link 123 to a floating lever 124, adapted to function as an element of a control mechanism in a manner identical with the several similar floating levers hereinabove set forth. A conduit 125 provides free communication between the interior spaces of bellows members 118 and 121, and also communicates with the atmosphere through the throttling valve 126.

The operation of the embodiment shown in Fig. 8 is similar to those hereinabove set forth, the action of the auxiliary control system being derived from motion of the bellows member 118, as derived from movement of the valve 115 through the arm 120. Upon a change in position of this valve, the corresponding change in dimension of the bellows 118 will cause a change in pressure of the air in conduit 125 and bellows member 121, whereby the lower extremity of the floating lever 124 will be moved, and the control modified as in the embodiments hereinabove set forth. As the pressure within the conduit 125 becomes equalized with that of the ambient atmosphere by seepage through the constricted valve 126, the bellows member 121 will be restored to its normal dimension, and the lower extremity of the floating lever to its position of repose, thus retracting the original auxiliary control action.

In Fig. 9 is shown a form of the invention, in which the movement of the auxiliary control elements is derived from that of the regulating valve through the medium of an electrical telemetering system of the instantaneous type. Mounted upon a common support 127 are two resilient bellows members 128 and 129, communicating freely with each other by means of a conduit 130 and restrictedly with the atmosphere through a throttling valve 131. Bellows member 128 is attached by means of a link 132 to the lower extremity of a floating lever 133 whose function in control is identical with that of the floating levers hereinabove set forth. Carried by the support 127 is a position motor 134 (such as the well-known "Selsyn" type), having its moving element connected through a crank-arm 135 and a link 136, to the bellows member 128, whereby movement of the moving element of said position motor will be communicated to the said bellows member, effecting a change in its internal volume. A regulating valve 137 in a pipe line 138

carrying a heating agent or the like to be regulated, is adapted to have its degree of opening controlled by a pressure fluid in a conduit 139 connecting the operating element of valve 137 with a three-way valve (not shown and identical in connection and function with those hereinabove set forth).

Carried on a stationary support 140 is a position motor 141 similar to motor 134 and having its moving element operatively associated with the stem of valve 137, as by a crank-arm 142 attached to the moving element of the motor and having therein a slot 143 engaging a pin 144 carried by the valve stem. The internal windings of the position motors 134 and 141 are connected together by a three-conductor circuit 145, and to synchronous sources of alternating current 146 and 147, respectively, whereupon, in accordance with principles well known in the art of automatic control, the moving elements of the two motors will tend to assume corresponding positions in space.

In operation, any movement of the stem of the valve 137 subject to pressure variation in conduit 139 will be communicated to the rotating element of the position motor 141 and immediately reproduced by position motor 134, causing the bellows member 128 to change its internal volume and produce in bellows member 129 an immediate response and a corresponding movement of the lower extremity of floating lever 133, with an auxiliary effect on the elements governing the pressure applied to the main regulating valve as hereinabove set forth. As the pressure within the conduit 130 becomes equalized with that of the ambient atmosphere by seepage through the constricted valve 131, the resilient bellows member 129 will be restored to its normal dimension, and the lower extremity of the floating lever 133 to its position of repose, thus retracting the auxiliary control action.

Fig. 10 shows an embodiment of the invention in which the primary or basic control, instead of being pneumatic, as hereinabove set forth, is electrical, the only utilization of fluid pressure in the control system being in the bellows members, communicating freely with each other and restrictedly with the atmosphere, in which feature lies the essence of the invention. A Bourdon spring 150 connected by a capillary tube 151 to a bulb 152 containing an expansive or volatile fluid, forms an element responsive to changes in temperature to which the bulb may be exposed. The bulb 152 is located in a chamber or enclosed space (not shown in the drawings, but similar in all respects to chamber 10 in Fig. 1) whose temperature is to be regulated to a constant and predetermined value by the control of a heating agent, such as steam, admitted to said chamber through a pipe 153 having therein a regulating valve 154, adapted for operation in either direction by a reversible electric motor 155. Operation of the motor 155 is effected by means of an electric circuit including a source of supply 156, stationary contacts 157 and 158, with either of which may coact a movable contact 159, together with such interconnecting conductors that when contact 159 engages contact 158 the motor will be operated in a direction to close the valve 154, and when contact 159 engages contact 157, the motor will be operated in a sense to open the valve, this system of control being standard practice and well known in the practice of automatic regulation of temperatures and the like.

The contact 159 is carried by an arm 160, swing-

able through a small angle about a stationary axis 161, and bearing a pivot upon which is mounted at its intermediate point a floating lever 162. One extremity of the floating lever 162 is connected by a link 163 to the Bourdon spring 150. The remote extremity of the floating lever 162 is provided with a pivot point 164, which may be brought into alignment with the axis 161. A resilient bellows member 165 mounted on a stationary support 166 is operatively connected by means of a link 167 to the pivot point 164 on the lever 162, so that the position taken by the intermediate fulcrum of said lever, and hence of the contact 159, will be subject to the joint influence of the Bourdon spring 150 and the bellows member 165. Also mounted on support 166 is a resilient bellows member 167. The interior spaces of said bellows members communicate freely with each other by means of a conduit 168 and restrictedly with the atmosphere through a throttling valve 169.

A position motor 170 is carried by the support 166, and has its movable member operatively connected by means of an arm 171 and a link 172 to the bellows member 167. A position motor 173, adapted for electrical coaction with motor 170, is fixed in relation to the body of the regulating valve 154, and has its moving element adapted for positioning in correspondence with the valve 154, as by a gear sector 174 mounted on the moving element of the position motor and meshing with a pinion 175 forming a part of the motor 155 and definitely associated with movements of the valve 154. The internal windings of the position motors 170 and 173 are connected together by a three-conductor circuit 176, and to synchronous sources of alternating current (which may be embodied in the common source 156 as shown) by two two-conductor circuits 177 and 178, whereupon, in accordance with principles well known in the art of automatic electrical control, the moving elements of the two position motors will tend to take up corresponding positions in space.

For the purpose of explaining the operation of this apparatus, conditions may first be considered in which the pivot 164 lies on the axis 161, which corresponds to the normal position of repose of the system. Basic or primary regulation of the valve 154 in response to variations of temperature at the bulb 152 will then be effected as hereinbefore set forth, with a resulting tendency to maintain the said temperature at a definite and predetermined value. Any movement of the motor 155 in a sense to change the setting of the valve 154 will at the same time be communicated through the pinion 175 and the sector 174 to the position motor 173, and thence to the position motor 170 and bellows member 167, changing its internal volume and thereby varying the pressure of the contained air, with a resultant immediate response of bellows member 165 and a movement of the upper extremity of the floating lever 162 away from its position of repose, giving a resultant secondary movement of the contact 159. The secondary movement of the contact 159 may be in a sense to increase the original movement due to deflection of the Bourdon spring or to decrease said movement, according to the requirements of the system to be regulated, selection between these two relative actions being dependent upon the relative directional action of the position motors 173 and 170, and this, in turn, depending upon the electrical connections. As the pressure within the conduit

168 becomes equalized with that of the ambient atmosphere by seepage through the constricted valve 169, the resilient bellows member 165 will be restored to its normal dimension, and the pivot point 164 on the floating lever 162 will resume its normal position of repose lying on the axis 161, thus retracting the secondary control action introduced by the auxiliary mechanism, including the position motors and the bellows members.

In Fig. 11 is shown a form of the invention in which an electric-motor-operated valve is caused to actuate directly the auxiliary control having a time-delay characteristic, without the interposition of a telemetering system or its equivalent. In this embodiment a regulating valve 180 is adapted for operation in either direction by a reversible electric motor 181, actuated through a three-conductor circuit 182 in a manner identical with the motor 155 shown in Fig. 10. A bellows member 183 carried by a bracket 184 fixed to the body of the valve is adapted to have its length, and therefore its internal volume, varied in response to movements of the valve 180 by means of an arm 185 carried by the stem of said valve.

A second bellows member 186 carried on a stationary support 187, is attached by a link 188 to a floating lever 189 adapted to function as an element of an electrical control mechanism in a manner identical with the floating lever 162 in Fig. 10. A conduit 190 provides free communication between the interior spaces of bellows members 183 and 186, and also communicates with the atmosphere through the throttling valve 191.

Operation of the embodiment shown in Fig. 11 is similar to those hereinabove set forth, the electrical control being identical with that explained in connection with the embodiment shown in Fig. 10, and the auxiliary time-delay control identical with that explained in connection with the embodiment shown in Fig. 8, so that upon the motor 181 moving in response to the action of electrical contacts 192, the resulting motion of the stem of valve 180, acting through the arm 185, will change the dimensions of bellows member 183, thus causing the pressure within the conduit 190 and the bellows member 186 to be varied, with a corresponding movement of one extremity of the floating lever 189. The reaction upon the electrical contacts 192 is identical in manner with the performance of the embodiment shown in Fig. 10; after which, as the pressure in the bellows member 186 becomes equalized with that of the ambient atmosphere by seepage of air through the constricted valve 191, the bellows member 186 will be restored to its normal dimension and the secondary control action gradually withdrawn.

While the several embodiments of the invention as hereinabove disclosed and illustrated have been shown as directed to the control of a valve for regulating the passage of a flowing fluid, it will be obvious to those versed in the art that the principles are equally applicable to the positioning of an electrical contactor or a rheostat, or other type of regulator for controlling the flow of electric current to a heating device or other means for affecting the magnitude of a condition to be controlled, such, for example, as disclosed in U. S. Letters Patent No. 1,685,995 issued October 2, 1928.

I claim:

1. In a system for automatically regulating a variable condition to a predetermined value, including power-operated means for controlling the flow of an agent to affect said condition, a mem-

ber sensitive to changes in the value of said condition, relay means for governing the application of power to said power-operated means, and means rotatable through a limited angle about an axis for commanding the application of power through said relay means to said regulating means for operating the same; a resilient fluid-pressure-responsive member subjected only to a substantially constant external pressure and having an inside closed space adapted to receive fluid under pressure in immediate correspondence with and in exact proportion to changes in said regulating means, and means for gradually equalizing inside and outside fluid pressures on said member, a floating lever intermediately pivoted on said commanding means and having pivot means on its respective extremities operatively and respectively connected to said sensitive member and to said resilient member, whereby the said commanding means may partake of the resultant motion of both said members.

2. In a system for automatically regulating a variable condition to a predetermined value, including power-operated means for controlling the flow of an agent to affect said condition, a member sensitive to changes in the value of said condition, relay means for governing the application of power to said power-operated means, and means rotatable through a limited angle about an axis for commanding the application of power through said relay means to said regulating means for operating the same: a resilient fluid-pressure-responsive member exteriorly subjected only to a substantially constant fluid pressure, and having an inside closed space adapted to receive fluid under pressure in immediate correspondence with and in exact proportion to changes in said regulating means, and means for gradually equalizing inside and outside fluid pressures on said member, a floating lever intermediately pivoted on said commanding means and having pivot means on its respective extremities operatively and respectively connected to said sensitive member and to said resilient member, whereby the said commanding means may partake of the resultant motion of both said members, the pivoted connection of said resilient member to said floating lever being adapted at a point

in its excursion to coincide with the axis of rotation of said commanding element, said point corresponding to a condition of equality of inside and outside pressures on said resilient member.

3. In an automatic control system: a fluid-pressure-actuated valve device for controlling a condition, mechanism responsive to changes in the condition for regulating the same, and adjustment means for the responsive mechanism, comprising a bellows affected by the valve device in accordance with the condition under control, movable fluid-pressure-actuated means connected with the said bellows and with the responsive mechanism, and having restricted communication with an external atmosphere.

4. In an automatic control system: valve means responsive to a variable force for regulating a flow of energy, a first resilient member having an internal space of variable volume and adapted to be actuated to vary said volume simultaneously and in direct proportion to movement of said valve means, a second resilient member having an internal space of variable volume in free communication with that of said first member and subjected only to the difference between the fluid pressure therein and atmospheric pressure, and a constricted bleeder vent permitting a gradual equalization of pressures internal and external to said second resilient member, the said second member affecting the variable force to which the responsive means is subjected.

5. In a control system having a fluid-pressure-actuated regulating member and a device for commanding the action of said member through control of the pressure applied thereto: variable-volume means communicating directly with the regulating member to have its internal volume varied in immediate correspondence with and in exact proportion to the action of the fluid pressure exerted upon said member, fluid-pressure-responsive means adapted to affect said commanding device, in free communication with said variable-volume means and in restricted communication with the atmosphere, said fluid-pressure-responsive means responding only to the difference in pressure within the variable-volume means and atmospheric pressure.

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