April 12, 1949. L. M. PUSTER 2,466,865

TEMPERATURE CONTROL

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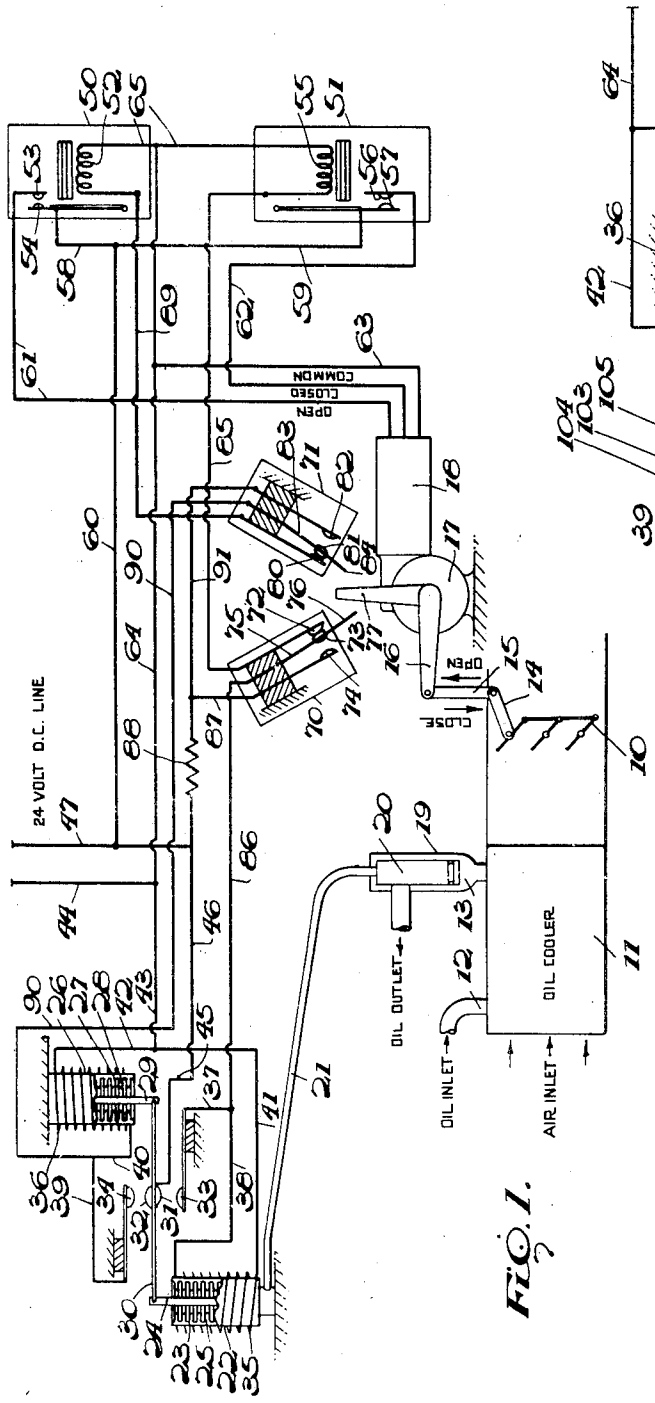


FIG. 1.

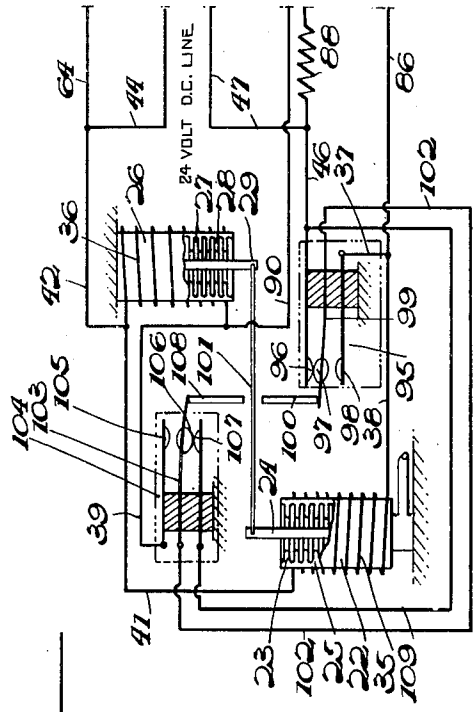


FIG. 2.

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TEMPERATURE CONTROL

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17 Claims. (Cl. 236—68)

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This invention relates to temperature controls, and more particularly to electrically operated temperature controls.

The invention is applicable to a wide variety of systems employing reversible motors, as reversible electric motors, oppositely acting heat motors or motors acting on the hot chamber principle, which will be generically referred to as reversible motive means, to operate dampers, valves, shutters, etc., which will be generically referred to as means to be controlled, although for purposes of exemplification the invention will be illustrated and described as applied to shutters operated by a reversible electrical motor, but with the express understanding that the invention is not restricted thereto.

It is an object of this invention to provide an improved temperature control of the type characterized whereby the means to be controlled may be moved incrementally by desired amounts in either direction.

Another object of this invention is to provide an improved device of the type characterized wherein the direction of the movement of the means to be controlled may be reversed without going to a limit position.

Another object of this invention is to provide an improved device of the type characterized which minimizes hunting or cycling of the means to be controlled.

Another object of this invention is to provide an improved device of the type characterized wherein closer modulation may be obtained than heretofore secured in motor operated systems.

Another object of this invention is to provide an improved device of the type characterized which is at all times fully compensated against changes of temperature in the ambient.

Another object of this invention is to provide an improved device of the type characterized wherein upon occurrence of a predetermined temperature change the means to be controlled is moved in the direction required by the change in temperature and then given a pause to determine if it has sufficiently anticipated the changing needs of the system.

Another object of this invention is to provide an improved device of the type characterized which includes limit switches and means whereby, when a limit switch has come into operation, the system is conditioned automatically, notwithstanding the opening of the circuit by the limit switch, to respond promptly and sensitively to a change in temperature requiring movement in the opposite direction of the means to be controlled.

Another object of this invention is to provide an improved device of the type last referred to wherein an anticipating movement of the means to be controlled is provided for at its limit positions to anticipate need for movement in the opposite direction and thereby prevent overshooting or undershooting.

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Another object of this invention is to provide an improved device of the type characterized whereby, particularly in the neighborhood of limit positions where the change in temperature is likely to be at a maximum rate, rapid temperature changes at the temperature responsive element are largely balanced out so as to maintain the desired anticipating effect.

Another object of this invention is to provide an improved device of the type characterized whereby desired modulating effects may be obtained by incremental movement of the means to be controlled, in amounts and at rates of movement conditioned by the temperature to be controlled, to the end that nice and sensitive adjustment of the means to be controlled to changes in temperature may be effected in order to maintain a closer temperature regulation than heretofore obtained by comparable systems.

Another object of this invention is to provide an improved device of the type characterized which is certain in operation, highly efficient, and readily adapted to a wide variety of conditions.

Other objects will appear as the description of the invention proceeds.

The invention is capable of receiving a variety of expressions, two of which are illustrated diagrammatically on the accompanying drawing, but it is to be expressly understood that the drawing is for purposes of illustration only and is not to be construed as a definition of the limits of the invention, reference being had to the appended claims for that purpose.

Referring in detail to the accompanying drawing, wherein the same reference characters are employed to designate corresponding parts in the two figures,

Fig. 1 is a diagrammatic view of an embodiment of the present invention, and

Fig. 2 is a diagrammatic part view to illustrate interlocking switches in the embodiment of Fig. 1.

As illustrated, the invention is applied to the control of any suitable shutters **10** associated with an oil cooler **11** having an inlet **12** and an outlet **13** for the oil circulation. The shutters **10** are operated in any suitable way, as by arm **14** and link **15**, from a rotatable arm **16** driven by a suitable reduction gear diagrammatically indicated at **17** that in turn is driven by any suitable reversible motive means, as a reversible electric motor, designated by the rectangle **18**. Rotation of the arm **16** in a clockwise direction effects opening of the shutters and rotation of said arm **16** in an anticlockwise direction effects closure of the shutters as indicated by the arrows in Fig. 1.

Mounted in an enlargement **19** of the oil outlet **13** is the bulb **20** of any suitable thermostat,

preferably of the liquid expansion type, said bulb being in communication through conduit 21 with an expansible and collapsible chamber, here shown as composed of an exterior generally cylindrical vessel 22 within which is hermetically sealed an expansible and collapsible corrugated tubular metal wall 23 having a post 24 secured to its movable end wall. The space 25 between walls 22 and 23 constitutes the expansible and collapsible chamber referred to and has means, here shown as the bulb 20 and conduit 19, for subjecting the thermostatic charge in said chamber and means to the temperature to be controlled.

Mounted adjacent to and in opposition to but out of alignment with said expansible and collapsible chamber 25 is a thermostat including a similarly charged and like expansible and collapsible chamber mounted in any suitable way and shown as composed of an exterior generally cylindrical tubular vessel 26 within which is hermetically sealed an expansible and collapsible corrugated tubular metal wall 27 forming an expansible and collapsible chamber 28 therebetween, this thermostat being shown as of the type wherein the thermostatic charge in said chamber is subjected directly to the ambient or other suitable but different temperature from that to which bulb 20 is subjected. The movable end wall of corrugated wall 27 also carries a post 29, and attached to the two posts 24 and 29 is a floating switch element 30 provided with contacts 31 and 32 midway of its length. Suitably mounted on the stationary structure of the apparatus and in position for cooperation with said contacts 31 and 32 respectively, are stationary contact elements 33 and 34.

Surrounding the tubular wall 22 but insulated therefrom is a heating coil 35, and similarly surrounding the tubular wall 26 but insulated therefrom is a heating coil 36. Contact 33 is connected to the coil 35 by leads 37 and 38 and contact 34 is connected to the heating coil 36 by leads 39 and 40. Leads 41 and 42 from said respective coils are connected by lead 43 to trunk line 44. Contacts 31 and 32 are connected by lead 45 to lead 46 which is connected to the opposite trunk line 47.

The parts as so far described constitute the thermostatic switch assembly.

Particularly when used with D. C. current, the thermostatic switch assembly as so far described is designed to operate either one or the other of a pair of relays for predetermining the direction in which the motor 18 moves the shutters 10. The two relays as here illustrated are generally designated 50 and 51. Relay 50 includes a coil 52 for operating a pair of contacts 53 and 54. Relay 51 similarly includes a coil 55 for operating a pair of contacts 56 and 57. Contacts 54, 57 are connected in parallel by leads 58 and 59 with lead 60 connected to trunk line 47. Contact 53 is connected through lead 61 with the motor 18 and contact 56 is similarly connected through lead 62 with motor 18. A common return line 63 from the motor 18 is connected through lead 64 with the main trunk line 44. The two coils 52 and 55 are also connected by leads 65 with lead 64 and said trunk line 44, and the opposite terminals of said coils 52 and 55 are connected through leads 89 and 85 to limit switches next to be described.

Disposed adjacent the motor 18 are a pair of limit switches respectively designated 70 and 71. Limit switch 70 includes three contacts 72, 73 and 74, the contact 73 being mounted on a contact arm 75 which normally biases the contact 73 into engagement with the contact 72. Arm 75 also has an extension 76 for engagement by an arm 77 actuated by the reducing gear 17 and adapted to disengage contacts 72 and 73 and engage contacts 73 and 74 as hereinafter explained. Limit switch 71 also includes three contacts 80, 81 and 82, contact 81 being mounted on a contact arm 83 which normally biases contact 81 into engagement with contact 80. Contact arm 83 also has an extension 84 for engagement by the arm 77 to disengage contacts 80 and 81 and engage contacts 81 and 82.

Contact 72 is connected through lead 85 with relay coil 55. Contact 73 is connected through contact arm 75 and lead 86 to leads 37 and 38. Contact 74 is connected through lead 87 and a resistance coil 88, for a purpose to be explained, to the main trunk line 47. Contact 80 is connected through lead 89 with the relay coil 52. Contact 81 is connected through contact arm 83 and lead 90 with leads 39 and 40. Contact 82 is connected through lead 91 and resistance coil 88 to trunk line 47.

Preliminarily to describing the operation of the system and the function of its component parts, the compensating characteristics of the thermostatic switch assembly will first be pointed out. Inasmuch as the contact carrier 30 is floatingly mounted on the posts 24 and 29, while the corrugated walls 23 and 27 are of the same size and the volumes of the thermostatic chamber 25 and compensating vessel 28 are equated and said thermostat and compensating vessel act in opposition on the floating contact carrier 30, any change in the ambient temperature will equally affect the thermostat and compensating vessel and produce equal and opposite effects on the floating contact carrier 30. Since the contacts 31 and 32 are located at the center of the contact carrier 30 such equal and opposite movements transmitted to the contact carrier through posts 24 and 29 will have no effect upon the location of the contacts 31 and 32. Accordingly, the effect of changes in temperature of the ambient is completely balanced out by the aforesaid action. On the other hand, if the ambient temperature remains constant, post 29 has no movement while the contact carrier 30 may pivot about the fulcrum provided therefor at the end of the post 29. Hence the expansion and contraction of chamber 25 produced by changes of temperature at the bulb 20 will be transmitted by the post 24 to the contact carrier 30 whereby the latter will pivot on the post 29 and the contacts 32 and 31 respectively, will be advanced toward their coacting contacts 34 and 33, respectively.

For the purpose of exemplifying the operation of the system and the functioning of its component parts, assume that the system is started in operation with all parts relatively cold. Thermostatic bulb 20 being subjected to a relatively cold temperature, the expansible and collapsible vessel 25 is in its relatively contracted position and contact 31 is held in engagement with contact 33. Assuming all other parts to be in the relative position shown in the drawings, current may now flow from line 47 through leads 46, 45 to contacts 31 and 33, and thence through leads 37 and 86 to the engaged contacts 73 and 72. From contact 72 current may flow through relay coil 55 and back to line 44 through leads 65 and 64. Energization of coil 55 engages contacts 56 and 57 and current may flow from line 47

through leads 60 and 59, contacts 57 and 56, and lead 62 to motor 18, returning through leads 63 and 64 to line 44. Motor 18 will then drive arms 77 and 16 in an anticlockwise direction, to close the shutters 10, open the contacts 72 and 73 and engage contacts 73 and 74. From the position of the shutters as shown, they would be closed in either one step or a plurality of steps depending on the amount of the departure of the temperature of the bulb 20 below the temperature to be maintained, as hereinafter explained, but the point here to be noted is that the motor 18 would be operated to close the shutters and operate the limit switch.

The opening of contacts 72 and 73 interrupts the current through the coil 55 which effects opening of the contacts 56 and 57 in the motor circuit, stopping the motor at its limit position with the shutters 10 in fully closed position. Hence the motor can not be further driven in an anticlockwise direction to injure the device. At the same time current may also flow from the line 47 through leads 46 and 45, contacts 31 and 33, leads 37 and 38, heating coil 35, and leads 41 and 43, to line 44. Heating coil 35 will thus heat and cause expansion of chamber 25 causing the contacts 31 and 33 to separate and open the circuit through the heating coil. When the limit switch 70 has been operated to close contacts 73 and 74, current may also flow from line 47 through resistance coil 88 and lead 87 to contacts 74 and 73, and thence through leads 86 and 38 and heating coil 35 back to the line 44 through leads 41 and 43. As long as contacts 31, 33 are in engagement the circuit through contacts 31, 33 is the line of least resistance, and the full heating current is applied to the heating coil 35. When the heating coil 35 has effected the opening of the contacts 31 and 33, however, current may still flow through the heating coil 35 but only to such an amount as determined by the characteristics of resistance coil 88.

The value of resistor 88 is made such that the heat input into the expansible and collapsible chamber 25 is only such as can produce an expansion of said chamber equivalent to some small predetermined temperature change at the bulb 20, say a change of 5° or 10° F. It will thus be apparent that if the bulb 20 is at a temperature whose departure below the temperature to be maintained is greater than the operative range of the coil 35 when under the control of resistor 88, chamber 25 will not respond to the heating action of coil 35 sufficiently to cause separation of contacts 31 and 33, whereas if the departure is less than the operating range of coil 35 when under the control of resistor 88, chamber 25 will expand to move the contact 32 toward contact 34. Thus the heating coil 35 under the action of the resistor 88 conditions the thermostatic switch assembly, when the limit switch 70 has its contacts 73 and 74 in engagement, so that any departure of the temperature at the bulb 20 below the predetermined temperature to be maintained by an amount less than that fixed by the range of the coil 35 when under the control of the resistor 88 is effective to immediately start the movement of the switch 32, 34 in the opposite direction toward the position to initiate opening of the shutters in order to restore the temperature to that which is to be maintained. This may be called an anticipating movement. Thereby even though the limit switch be thrown by the motor 18 to its limit position, the system is sensitively responsive to any change in temperature requiring an opening of the shutters, because any

change in temperature at the bulb 20 that produces an effect on the chamber 25 that, when superimposed on the control maintained by the coil 35 when under the action of resistor 88, is sufficient to engage contacts 32 with 34, initiates the operation of the shutter opening movements next to be explained. By predetermining the effect of coil 35 when under the control of the resistor 88, this response can be made as narrow as desired.

Assuming now that the temperature at bulb 20 is increased as aforesaid so as to engage contact 32 with contact 34, current may now flow from line 47 through leads 46 and 45, contacts 32 and 34, leads 39 and 90, through contacts 81, 80, through lead 89, to relay coil 52, returning through leads 65 and 64 to line 44. Actuation of coil 52 closes contacts 53 and 54 so that current may flow from line 47 through leads 60 and 58 to contacts 54 and 53 and lead 61 to motor 18, causing the motor to rotate in a clockwise direction to open the shutters, the current returning from the motor through leads 63 and 64 to line 44. At the same time current may flow from lead 39 through lead 40 and heating coil 36 back through leads 42 and 43 to line 44. Heating of coil 36 expands chamber 28 to move contact carrier 30 in a direction to withdraw contact 32 from contact 34, thereby interrupting the current through the heating coil 36 and relay coil 52 and introducing an anticipating pause. Rotation of the motor 18 to initiate opening of the shutters also moves arm 77 in a clockwise direction, disengaging contacts 73 and 74 and reestablishing the circuit at contacts 72 and 73. Thereby the parallel circuit through the resistor 88 is open, but the circuit is reestablished at contacts 72 and 73 in preparation for the next engagement of contacts 31 and 33.

The amount that the shutters are opened during the cycle just described is a function of the heat input into the compensating expansible and collapsible chamber 28 and the speed of operation of the motor 18. In general, the speed of operation of the motor is fixed by the character of the installation, while the heat input is so adjusted that the expansible and collapsible chamber 28 will be operated to open the contacts 32 and 34 after the motor 18 has moved the shutters 10 through a predetermined fraction of their total range of movement, say from one sixth to one tenth thereof. In most cases it is not necessary that the shutters operate rapidly, although this will vary with the character of the installation. It has been found that if the motor moves the shutters from open to closed position, or vice versa, in a period from thirty to sixty seconds when applied to aircraft oil cooler applications satisfactory control is obtained. On the other hand, in air conditioning systems, for example, the time for full movement from open to closed position, or vice versa, may be on the order of several minutes.

Assuming that the cycle of operation in the opening direction as just described has effected an opening of the shutters by one-tenth of their full amount, it will be observed that this shutter operation with its ensuing pause is by way of anticipating the needs of the oil cooler illustrated. At the end of the opening movement described the motor 18 goes out of operation and there is a pause in the operation of the system to determine whether or not the increase in air flow is adequate to restore the temperature to that which it is desired to maintain. If so, the system remains

in the condition to which the parts have been moved.

Assuming that the temperature at the bulb continues to rise, chamber 25 will again expand to reengage contacts 32 and 34, again actuating relay 50 to reestablish the circuit through the motor, producing the next installment of opening movement, current being simultaneously supplied to the heating coil 36 to again open the circuit through the contacts 32 and 34 after the predetermined incremental movement of the shutters 10. If, on the other hand, the temperature of bulb 20 does not continue to increase but is still at a temperature above that which it is desired to maintain, cooling of chamber 28 will cause its contraction, which will reestablish the circuit through contacts 32 and 34 and initiate the next installment of movement toward the open position in order to restore the desired temperature.

It will be observed that throughout the operation as so far described, expansible and collapsible chamber 28 is functioning as a compensating chamber for the expansible and collapsible chamber 25, both of them expanding and contracting at the same rate under the influence of the temperature of the ambient, and it is only a differential temperature that has any effect on the position of contacts 31 and 32. Furthermore, because chambers 28 and 25 are acting in opposition and by way of compensation, a definite temperature rise at either is required to effect such movement of the contacts 31 or 32 as to open the circuits to the relays, whereby the amount of anticipation, or the running time before the pause, is definitely predetermined by the heating characteristics of the respective heating coils. Since the wattage or power input is always the same for the heater coils, the rate of heating or rate of temperature rise will always be the same, and it will be independent of ambient temperature. This fact makes the operation not only entirely independent of the ambient temperature but the extent of movement effected during each interval of operation is entirely predictable.

If the rate of temperature rise of the bulb 20 causes a more rapid increase in the volume of the chamber 25 than the rate of increase in the volume of the chamber 28 due to the effect of the heating coil 36, the shutters 10 will be driven to the fully open position in one step. If on the other hand, the rate of temperature rise of the bulb 20 causes a less rapid increase in the volume of the chamber 25 than the rate of increase in the volume of chamber 28 due to the effect of the heating coil 36, the shutters will be moved to the open position in a plurality of stages. If the demands of the means to be controlled are such as to cause the motor to move said means to its limit position, arm 77 will eventually engage the extension 84 on contact arm 83, opening the contacts 80, 81 and closing the contacts 81, 82. Opening of the contacts 80 and 81 interrupts the circuit through the relay coil 52, causing contacts 53 and 54 to become separated, and thus stopping movement of the motor in the opening direction. Closing of the contacts 81 and 82, however, has reestablished the circuit through the resistor 88, as current can now flow from line 47 through resistor 88, contacts 82 and 81, leads 90 and 40, heating coil 36, and leads 42 and 43 to line 44. Thereby heating coil 36 is energized under the control of the resistor 88 to function as heretofore explained, so that any departure of the temperature at the bulb 20 above the predetermined temperature to be maintained, by an amount less than that fixed by the range of the coil 36 when under the control of the resistor 88, will initiate movement of the switch 31, 33 in the closing direction.

Now assume a lowering of the temperature at the bulb 20 sufficient to engage contacts 31 and 33. Current may now flow from line 47 through leads 46 and 45, contacts 31 and 33, leads 37 and 86, contacts 73 and 72, and relay coil 55 back through leads 65 and 64 to line 44. Coil 55 closes contacts 56 and 57 so that current may flow from line 47 through leads 60 and 59, contacts 57 and 56, and lead 62 to motor 18 initiating movement of the motor in the direction to close the shutters, the current returning from the motor through leads 63 and 64 to line 44. Simultaneously, current flows from line 47 through leads 46 and 45, contacts 31 and 33, leads 37 and 38, heating coil 35, and leads 41 and 43 to line 44. Heating of the coil 35 expands the chamber 25 to separate contacts 31 and 33, thereby interrupting the circuit through the relay coil 55 and causing the contacts 56 and 57 to open and the motor to stop. This movement of the arm 77 in an anticlockwise direction permits the contacts 80 and 81 to become reengaged, separating contacts 81 and 82 to interrupt the circuit through the resistor 88. Closure of the contacts 80 and 81 reestablishes the circuit for the relay coil 52 in preparation for the next engagement of the contacts 32 and 34. If the partial closure of the shutters is not sufficient to reestablish and maintain the desired operating temperature at the oil cooler, further cooling at thermostat 20 causes further contraction at the chamber 25 and reestablishment of the circuit through contacts 31 and 33, with actuation of the relay 51 to initiate the next closing movement of the shutters. If on the other hand, the temperature of bulb 20 does not continue to decrease but is still below that which it is desired to maintain, cooling of chamber 25 will cause its contraction, which will reestablish the circuit through contacts 31 and 33 and initiate the next installment of movement towards the closed position in order to restore the desired temperature. Thus the shutters may be moved in step by step movement through as many increments of movement as required for the appropriate shutter opening to maintain the desired temperature.

Therefore, whenever the temperature at the bulb 20 departs in either direction from the temperature to be maintained, the shutters are moved in the proper direction for restoring the desired temperature, and then an anticipating pause is introduced to determine whether or not the desired temperature is reestablished before initiating the next increment of movement.

When the shutters are in wide open position and movement in the direction of closing the shutters is initiated, it will be observed that, during the first increment of movement from the limit position, cooling of bulb 20 is causing a contraction of chamber 25 and likewise, since contacts 81 and 82 are separated at the outset of this movement, chamber 28 is also cooling and consequently contracting in the direction to offset the movement of contacts 31 and 32 caused by contraction of chamber 25. At the same time, coil 35 is energized by the closure of contacts 31 and 33 causing a superimposed expansion of chamber 25 which results in the separation of contacts 31 and 33. The separation of contacts 31 and 33 causes the motor operation to cease. A like con-

dition exists when the shutters are in the fully closed condition and an opening movement is initiated, because here the cooling of chamber 25 is at least in part balanced out by the expansion at the bulb 20 because the temperature is likely to be rising rapidly inasmuch as the shutters are in nearly closed position. Thus at the two limits of movement, if the rate of temperature change at the bulb 20 is relatively large, it tends to cancel out the anticipating effect introduced by the operation of the then active heating coil. This balancing action is required only at the limits of travel, since normally the rate of temperature change at the bulb is large only in these positions. The effect of this balancing action is to hold the rate of anticipation consistent with normal operating anticipation. Without the balancing action the effect of the heating or cooling of the bulb might go far toward interfering with the anticipation feature, even to the extent of causing the system to go out of control and cause cycling from one extremity to the other of the range of operation of the system.

The first stage or increment of movement of the motor in each direction from its extreme position is in effect advanced, as is desirable, at the limits of movement of the shutters where the temperature is likely to be changing rapidly because they are at wide open or fully closed positions. The coils under the action of the resistor 88, as heretofore explained, function at the limits of movement to bias the system in its direction for taking the first step or increment of movement initiated in the opening or closing direction, as the case may be, which anticipates the need of the system for a change in the means to be controlled, and thereby minimizes danger of undershooting or overshooting.

While in describing the operation it has been assumed that the shutters move to their extreme positions of wide open or fully closed, in practice such may rarely occur. Once the system is in operation the shutters are moved to an intermediate position at which the temperature is maintained at substantially the desired degree, and as the temperature at the bulb fluctuates above or below said temperature the floating contact carrier is moved in one direction or the other to engage its contacts 31 and 32 with contact 33 or 34, as the case may be, and produce the incremental movement of the means to be controlled in one or the other direction as required, the system operating as heretofore described to move the means to be controlled incrementally in proper direction until the desired temperature is approximately restored, the means to be controlled being given a pause after each incremental movement to determine if the change effected is sufficient to reestablish the desired operating or control temperature.

For best operation it is desirable that the limit switches 70 and 71 be double throw, single pole switches wherein the movable contact element, 75 or 83, is biased toward one extreme position, to engage contacts 73, 72 and 81, 80, but yieldable under the action of arm 77 for movement to its opposite extreme position. Better contact life and the elimination of relay chatter can also be insured by the use of two single pole, single throw, short travel, snap switches in place of the switches 31, 33 and 32, 34, as will be explained in conjunction with Fig. 2. As to be explained in conjunction with Fig. 2, it is also desirable to supply interlocks in the system so that both relays cannot be closed at the same time to injure the motor. While interlocking relays may be employed, interlocking switches may take the place of switches 31, 33 and 32, 34, as next to be described. Although it is to be understood that mechanical interlocks may be used in place of electrical interlocks, the latter at any suitable part of the system is preferred.

Referring to Fig. 2, the system except for the details shown are to be assumed as the same as in Fig. 1, corresponding elements in Figs. 1 and 2 receiving the same reference characters. As illustrated in Fig. 2, the switch 31, 33 is replaced by switch 95 having three contacts 96, 97, 98. The movable contact arm 99 carrying contact 97 is provided with a suitable extension 100 operated by the floating link 101 which takes the place of the floating contact carrier 30, the construction of the floating link with its associated expansible and collapsible vessels for operating the same being otherwise the same as in Fig. 1. Contact 96 is connected to the lead 46 and contact 98 is connected to the lead 37. The movable intermediate contact 97 is connected through its movable arm 99 with lead 102 connected to the movable contact arm 103 of a second switch 104 taking the place of switch 32, 34 of Fig. 1. Switch 104 includes three contacts 105, 106, 107, contact 106 being on the movable contact arm 103 which is provided with an extension 108 operated by the floating link 101. Contact 105 is connected to lead 39 and contact 107 is connected by lead 109 with lead 46. The switches generally designated by the reference characters 95 and 104 are thus short travel, single pole, double throw, snap acting switches, and by reason of their construction it is impossible for contact 106 to be in engagement with both contacts 105 and 107 and for contact 97 to be in contact with both contacts 96 and 98.

Since the primary function of the thermostatic switch is to connect line 47 through lead 46 to the circuit, either through the lead 86 or the lead 90 to actuate the corresponding relays, it may be assumed that if lines 86 and 90 cannot both be energized at the same time regardless of the position of switches 95 and 104, a satisfactory electrical interlock is established. Assuming all possible positions of the switches 95 and 104, in the neutral position shown neither lead 86 nor lead 90 is in the circuit because contacts 97 and 98 are out of engagement and contacts 105 and 106 are out of engagement. If contacts 105 and 106 are closed, while contacts 96 and 97 are engaged, contacts 106 and 107 must be open due to the nature of the switch. Lead 90 will then be in circuit because contacts 105 and 106 are engaged, current flowing from line 47 to lead 46, contacts 96 and 97, lead 102, contacts 106 and 105 and lead 39 to lead 90. Similarly, if contacts 97 and 98 are engaged while contacts 106 and 107 are in engagement, lead 86 is in the circuit, current flowing from line 47 through leads 46 and 109, contacts 107 and 106, lead 102, contacts 97 and 98 and lead 37 to lead 86. The foregoing are the two normal operating conditions.

If it be assumed that contacts 97 and 98 become fused together and contacts 105 and 106 are closed by thermostatic action, current cannot flow between contacts 96 and 97 because, by the assumption, these contacts are held out of engagement. If the circuit is traced from line 47 it will be observed that the circuit is open at contacts 106 and 107 as well as at 96, 97 by the assumption and hence the motor is dead. A like analysis of the circuit if contacts 105 and 106 are assumed to be

fused and contacts 97 and 98 are closed by thermostatic action will show that the circuit is open so that the motor is dead. Hence the use of single pole, double throw, snap acting switches as illustrated will provide an electrical interlock that insures against injury to the motor in the event of electric fault, such as fusing of the contacts together.

It will therefore be perceived that by the present invention an electrically operated thermostatic control has been provided which will maintain substantially the desired temperature by incremental adjustment of the means to be controlled in either direction from any intermediate position. Thereby the need of going through a limit position if the demand for succeeding movement is in the opposite direction to that of the preceding movement is avoided. Hence very close temperature control can be maintained and at the same time full modulation can be effected through adjustment of the means to be controlled. The hunting or cycling that has heretofore characterized attempts to closely control operating differentials has been entirely avoided, the anticipating feature causing the means to be controlled to pause after moving in the desired direction indicated by the temperature trend to enable the need for further adjustment to be determined. At the limit of adjustment of the means to be controlled, the system is biased for movement in the proper direction such that at a predetermined temperature above or below the temperature to be maintained, as the case may be, the first increment of movement is initiated to compensate for the tendency of the temperature to change rapidly when the means to be controlled is in either of its extreme positions. In addition, the system operates automatically so as to balance out the effect of rapid temperature changes at the bulb when the means to be controlled is in either of its extreme positions, in order that the anticipation under these conditions be maintained consistent with normal operating anticipation.

Furthermore, the control is entirely independent of changes in the ambient temperature, because the effect of the ambient temperature is exactly compensated whether the thermostat is in course of expanding or contracting due to temperature change at the bulb 20 or whether it is neutral so far as the bulb 20 is concerned. By predetermining the characteristics of the heating coils, and also resistor 88 insofar as predetermining the operation of said coils at the limit positions, the stroke of the means to be controlled may be subdivided into as many steps or increments as desired and thereby the anticipating feature may be nicely predetermined while at the same time the control may be made highly sensitive to fluctuations of temperature and also capable of responding promptly, and in either direction, to effect the necessary adjustment in order to bring the temperature substantially to the desired temperature to be maintained. The control of the present invention is therefore entirely predictable in operation as well as certain in its functioning and efficient in its sensitive control of temperature.

While the embodiments of the invention illustrated on the drawings have been described with considerable particularity, it is to be expressly understood that the invention is not restricted thereto as the same is capable of receiving a variety of expressions as will now be apparent to those skilled in the art while changes may be made in the form and details of construction of the component elements, circuit arrangements, etc., and in the character of the reversible motive means, and means to be controlled, without departing from the principles of the present invention. Reference is therefore to be had to the appended claims for a definition of the invention.

What is claimed is:

1. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers mounted to expand in opposite directions and having laterally spaced axes, each of said chambers having a movable end wall, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to and solely carried by said movable end walls to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating means associated with said chambers and energized when said contacts are closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by said contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other.

2. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers mounted to expand in opposite directions and having laterally spaced axes, each of said chambers having a movable end wall, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to and solely carried by said movable end walls to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating means associated with said chambers and energized when said contacts are closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by said contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other, said chambers being constructed to be equally responsive to changes in temperature of the ambient to balance out the effect of changes of temperature in the ambient on the actuation of said floating contact-operating member by said chambers.

3. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers mounted to expand in oppo-

site directions and having laterally spaced axes, each of said chambers having a movable end wall, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to and solely carried by said movable end walls to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating means associated with said chambers and energized when said contacts are closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by said contacts, said connections including relay mechanism operative to effect movement of said motive means in one direction or the other and selectively operated by the closure of contacts by said member moving in one direction or the other.

4. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers mounted to expand in opposite directions and having laterally spaced axes, each of said chambers having a movable end wall, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to and solely carried by said movable end walls to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating coils associated with said chambers, electrical connections to said coils completed by said contacts for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, and electrical connections to said motive means completed by said contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other.

5. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers mounted to expand in opposite directions and having laterally spaced axes, each of said chambers having a movable end wall, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to and solely carried by said movable end walls to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating coils associated with said chambers, electrical connections to said coils completed by said contacts for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each said switch including normally closed contacts in circuit with one of said coils and one of said first named contacts, and electrical connections to said motive means completed by said first named contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other.

6. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to said chambers to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating coils associated with said chambers, electrical connections to said coils completed by said contacts for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each said switch including normally closed contacts in circuit with one of said coils and one of said first named contacts, and electrical connections to said motive means completed by said first named contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said limit switches each including additional contacts closed by the opening of the normally closed contacts and in circuit with that one of said coils which when energized tends to actuate its associated chamber and said member in a direction to initiate movement of the motive means away from its limit position.

7. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to said chambers to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating coils associated with said chambers, electrical connections to said coils completed by said contacts for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each said switch including normally closed contacts in cir-

cuit with one of said coils and one of said first named contacts, electrical connections to said motive means completed by said first named contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said limit switches each including additional contacts closed by the opening of the normally closed contacts and in circuit with that one of said coils which when energized tends to actuate its associated chamber and said member in a direction to initiate movement of the motive means away from its limit position, and electrical means in circuit with said coils and said contacts closed by the operation of said limit switches for predeterminately producing a continuous minimum heating effect of the associated coil.

8. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, a thermostatically operated switch device including two expansible and collapsible chambers, one of said chambers containing a thermostatic charge and having means subjecting said charge to the temperature to be controlled and the other of said chambers containing a thermostatic charge and subjecting the same to a different temperature, a floating contact-operating member operatively connected to said chambers to be moved in opposite directions thereby, contacts closed by said member when moved at least predominantly by one or the other of said chambers, heating coils associated with said chambers, electrical connections to said coils completed by said contacts for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each said switch including normally closed contacts in circuit with one of said coils and one of said first named contacts, and electrical connections to said motive means completed by said first named contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said chambers and coils cooperating to partly cancel out the effect of the then active heating coil when the temperature under control is changing rapidly.

9. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, means for temporarily opening the closed contacts to introduce a circuit interruption including heating means associated with said chambers and energized when a set of contacts is closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by one or the other of said sets of contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other.

10. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, means for temporarily opening the closed contacts to introduce a circuit interruption including heating means associated with said chambers and energized when a set of contacts is closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections of said motive means completed by one or the other of said sets of contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other, said expansible and collapsible chambers being constructed to be equally responsive to changes in the temperature of the ambient to balance out the effect of changes of temperature in the ambient on the actuation of said floating contact-operating member by said chambers.

11. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said

set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, means for temporarily opening the closed contacts to introduce a circuit interruption including heating means associated with said chambers and energized when a set of contacts is closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by one or the other of said sets of contacts, said connections including relay mechanism operative to effect movement of said motive means in one direction or the other and selectively operated by the closure of one or the other of said sets of contacts by said member moving in one direction or the other.

12. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, heating coils associated with said chambers, electrical connections to said coils completed by said sets of contacts respectively for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, and electrical connections to said motive means completed by one or the other of said sets of contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other.

13. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, means for temporarily opening the closed contacts to introduce a circuit interruption including heating means associated with said chambers and energized when a set of contacts is closed to effect expansion of that chamber which will reverse the direction of movement of said member and open the closed contacts, and electrical connections to said motive means completed by one or the other of said sets of contacts upon movement of said member in one direction or the other to energize said motive means for movement in one direction or the other, said sets of contacts having electrical connections between contacts of the respective sets such that two sets of contacts operable to energize said motive means for movement in opposite directions cannot be closed at the same time.

14. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to and under the sole control of the movable walls of said two chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, heating coils associated with said chambers, electrical connections to said coils completed by said sets of contacts respectively for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each of said switches including normally closed contacts in circuit with one of said coils and one of said sets of first named contacts, and electrical connections to said motive means completed by one or the other of said first named sets of contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other.

15. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to the movable walls of said chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is

moved at least predominantly by one or the other of said chambers in one direction or the other, heating coils associated with said chambers, electrical connections to said coils completed by said sets of contacts respectively for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each of said switches including normally closed contacts in circuit with one of said coils and one of said sets of first named contacts, and electrical connections to said motive means completed by one or the other of said first named sets of contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said limit switches each including additional contacts closed by the opening of the normally closed contacts and in circuit with that one of said coils which when energized tends to actuate its associated chamber and said member in a direction to initiate movement of the motive means away from its limit position.

16. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in oppoiste directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to the movable walls of said chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, heating coils associated with said chambers, electrical connections to said coils completed by said sets of contacts respectively for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each of said switches including normally closed contacts in circuit with one of said coils and one of said sets of first named contacts, and electrical connections to said motive means completed by one or the other of said first named sets of contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said limit switches each including additional contacts closed by the opening of the normally closed contacts and in circuit with that one of said coils which when energized tends to actuate its associated chamber and said member in a direction to initiate movement of the motive means away from its limit position, and electrical means in circuit with said coils and said contacts closed by the operation of said limit switches for predeterminately producing a continuous minimum heating effect of the associated coil.

17. In an electrically operated temperature control system, in combination with means to be controlled and reversible motive means for operating the same, means for energizing said motive means to move said means to be controlled incrementally in opposite directions and operable in opposite directions from intermediate positions including a thermostat having an expansible and collapsible chamber having a thermostatic charge and means for subjecting said charge to the temperature to be controlled, a second expansible and collapsible chamber having a thermostatic charge and subjected to a different temperature, a floating contact-operating member operatively connected to the movable walls of said chambers to be moved in opposite directions thereby, two sets of contacts, one contact of each set being operatively connected to said member and engageable with the other contact of said set when said member is moved at least predominantly by one or the other of said chambers in one direction or the other, heating coils associated with said chambers, electrical connections to said coils completed by said sets of contacts respectively for energizing that coil which will actuate its associated chamber to move said member in the direction to open the closed contacts, a pair of limit switches operated by said motive means at the limit of its movement in each direction, each of said switches including normally closed contacts in circuit with one of said coils and one of said sets of first named contacts, and electrical connections to said motive means completed by one or the other of said first named sets of contacts through said limit switches when closed to energize said motive means for movement in one direction or the other depending on the movement of said member in one direction or the other, said chambers and coils cooperating to partly cancel out the effect of the then active heating coil when the temperature under control is changing rapidly.

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