July 16, 1946. C. I. HALL 2,404,227

ELECTROMAGNETIC CONTROL APPARATUS

Filed Jan. 8, 1943

Fig. 1.

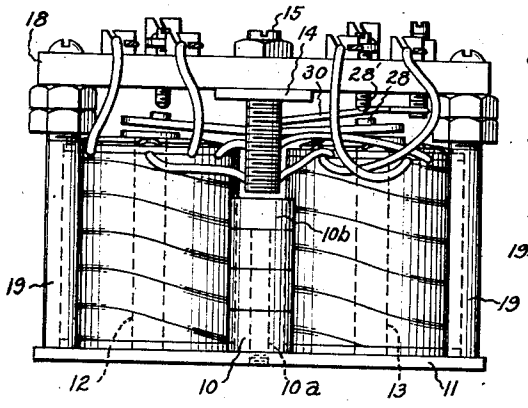


Fig. 2.

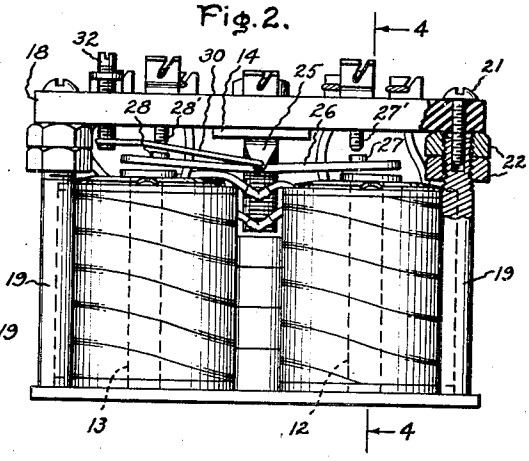


Fig. 3.

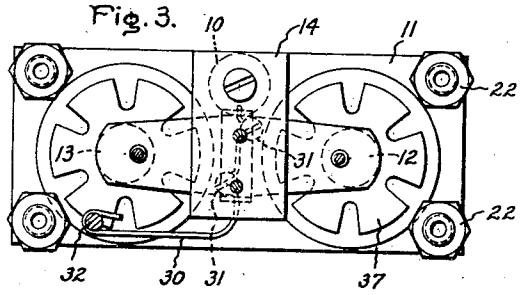


Fig. 4.

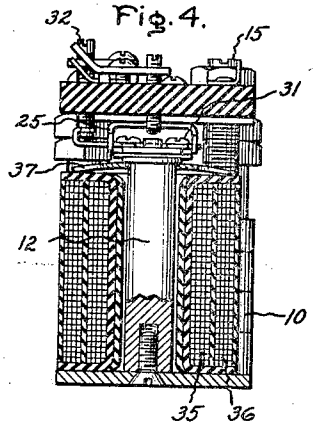


Fig. 5.

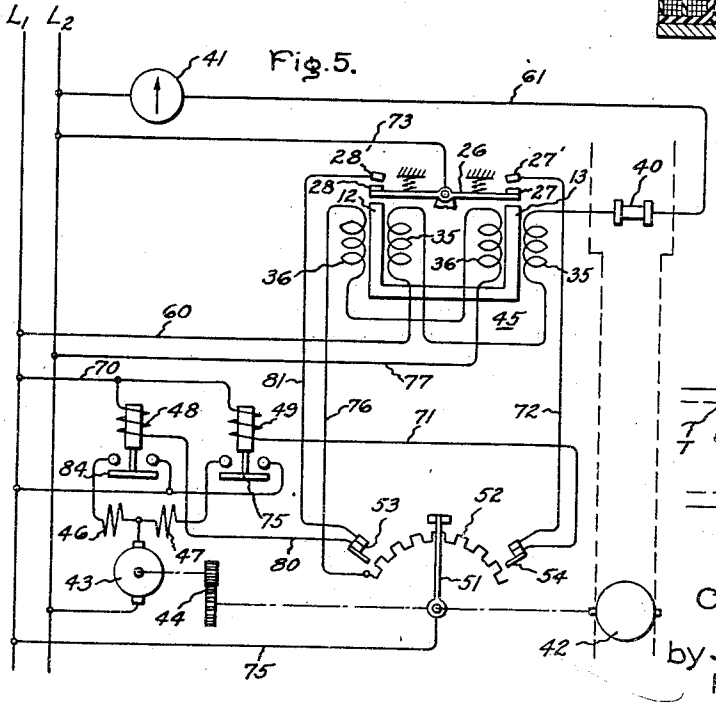


Fig. 6.

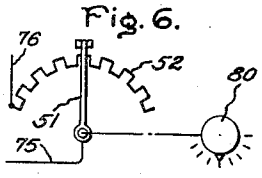
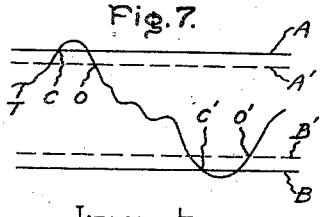


Fig. 7.



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Patented July 16, 1946

2,404,227

UNITED STATES PATENT OFFICE

2,404,227

ELECTROMAGNETIC CONTROL APPARATUS

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Application January 8, 1943, Serial No. 471,739

18 Claims. (Cl. 236—78)

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The invention relates to electromagnetic control apparatus, particularly electromagnetically controlled directive relay systems, and provides an improved sensitive polarized selective circuit controlling relay having an improved differential polarization control system particularly adapted for automatic temperature regulating or other condition modulating or directive reversing control service.

The principal object is to provide an improved form of sensitive circuit controlling relay having a polarized triple pole magnetic structure with differential polarization control windings for controlling a centrally pivoted reversely tilting magnetic operating member so as to produce an improved polarized flux shifting power amplifying action for sensitizing the relay electromagnetic energization control. In this way a very sensitive trigger controlled reversible magnetic biasing action may be obtained to effect snap action opening and closing of the relay circuit controlling contacts and also provide adequate circuit closing contact pressure even with a relatively feeble electromagnetic polarization control power.

A further object is to provide an improved polarized relay magnetic structure having improved sensitizing calibrating means capable of selectively adjusting the relative magnetic reluctances of a polarized flux shifting forked path and a differentially interlinked electromagnetic polarization control flux path with both paths extending through a three-position flux responsive tilting member that can thereby be selectively biased to any one of three control positions. This improved differentially controlled polarized magnetic structure enables selective relay calibrating and biasing adjustments to be made to meet widely varying control conditions and requirements in temperature regulating or other control service.

A still further object is to provide an improved differential electromagnetic polarization control system for the three-pole polarized relay so as to further improve the sensitivity, accuracy, speed of response, and ability to meet widely varying control conditions and requirements. In this way the control power losses and other regulating difficulties and limitations encountered in the usual Wheatstone bridge or other conventional types of directive relay systems can be materially reduced.

A more specific object is to improve the three-pole polarized relay and the electromagnetic polarization control system therefor so as to enable direct control by a very sensitive but very

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low power temperature responsive control resistor having a marked negative temperature coefficient of resistance such, for example, as disclosed in my Patent 2,271,975. In this way no auxiliary thermionic or other control power amplifying means are required due to the control power magnetic amplifying action provided directly by the sensitized directive relay and the differential electromagnetic polarization control system therefor. In addition, the improved temperature responsive system is substantially freed from the usual frictional control inaccuracies; false operations due to contact vibration when subject to shock; control element space and temperature limitations; and various other difficulties encountered in the usual forms of temperature responsive directive relay systems. Also, an electrical "preheat" control stabilizing action is automatically obtained that tends to increase the sensitivity of response and thus prevent overshooting and undershooting of the desired temperature.

Further objects and advantages of the present invention are set forth in the following description of the preferred embodiment thereof illustrated in the accompanying drawing in which Fig. 1 is a front view of the improved polarized directive relay structure; Fig. 2 is a back view of the relay; Fig. 3 is a top view of the relay with certain parts omitted for the sake of clarity; Fig. 4 is a sectional view along the line 4—4 of Fig. 2 to show more clearly the details of the relay construction; Fig. 5 is a circuit diagram showing schematically the improved relay electromagnetic differential polarization control system adapted for automatic polarization equalizing or rebalancing operation in temperature modulating service under the control of a negative temperature coefficient resistor; Fig. 6 shows a manually adjusted polarization equalizing modification of the control system of Fig. 5; and Fig. 7 is a chart showing the improved temperature band type of control that may be obtained with the temperature responsive control system modified as shown in Fig. 6.

In Fig. 1 of the drawing, the permanent magnet 10 for polarizing the relay is shown as formed of a series of permanently magnetized bodies, preferably of the sintered high reluctance type providing a strong polarizing magnetic power. The permanent magnet 10 is mounted by means of a screw 10a and the magnetic head 10b upon the base plate 11 of magnetic material from which the two magnetic pole pieces 12 and 13 extend in parallel alignment so as to constitute a polarized

magnetic structure having a pair of magnetically balanced like poles.

A cooperating magnetic structure comprising the opposite pole piece 14 and the air gap adjusting screw 15 is centrally offset between the two aligned poles 12 and 13 and oppositely polarized by the permanent magnet 10 with the reluctance of the polarizing flux path variable in accordance with the adjustment of the screw 15 towards or away from the magnetic head 10b. The opposite pole piece 14 is suitably mounted upon a relay terminal connection panel 18, preferably formed of molded insulating material and supported in adjustable spaced apart relation with the mounting base plate 11 by the four corner supporting posts 19. The adjusting screws 21 and nuts 22 permit the position of the panel 18 together with the opposite pole piece 14 carried thereby to be varied while maintaining the opposite pole 14 in symmetrical offset relation between the pair of magnetically balanced poles 12 and 13 so as to establish an acute fork in the polarized flux path therebetween.

The opposite pole piece 14 carries a mounting yoke 25 of non-magnetic material for centrally pivoting the statically balanced reversely tilting magnetic directive member or armature 26 with its axis located at the acute fork in the polarized magnetic flux path between the three poles 12, 13, and 14. Thus the three poles of the polarized magnetic structure straddle the axis of the tilting magnetic directive member 26 and this enables a slight tilting of magnetic member 26 either way from its mid-position to shift a substantial and progressively increasing amount of polarized flux between the two like poles 12 and 13 without substantially changing the total reluctance of the polarized forked flux path. The improved magnetic structure also provides a local control flux path extending through the magnetic plate 11, the two parallel pole pieces 12 and 13, and the tilting magnetic member 26, and differentially interlinked with the forked polarized flux shifting path. This differential interlinking of the two flux paths enables a relatively weak electromagnetic energization of the local control flux path to shift a substantial amount of polarized flux from one fork to the other and thereby initiate a slight tilting of magnetic member 26 from the mid-position. Such initial tilting automatically amplifies the polarized flux shift to produce a further tilting and a further shifting of the polarized flux at a progressively increasing rate.

As shown, the magnetic member 26 operates the reversing control switch contacts 27 and 28 that cooperate with corresponding adjustable contact screws 27' and 28' carried by panel 18 so as to open both circuits controlled thereby when the magnetic directive member 26 is in the mid-position and selectively to close one or the other of the contacts 27, 27' or 28, 28' when the member 26 is tilted sufficiently from the mid control position. The adjustable contact screws 27' and 28' also serve as adjustable stops to limit the tilting movement of member 26 to an amount dependent upon the adjustment thereof. Thus the adjustment of these stops will vary the control flux values at which the tilting magnetic member 26 will be returned to its mid-position.

The magnetic member 26 may be selectively biased to its mid-position in which it is shown, or to either of its contact closing positions, by means of the resilient biasing spring 30. Preferably, the biasing spring 30 is bent at one end

so as to extend through suitable pivot bearing openings formed in the supporting yoke 25 and thus form the central supporting pivots for the magnetic member 26. The pivot end of spring 30 preferably is formed so as to be secured centrally to the member 26 by the screws 31, as shown more clearly in Fig. 3, and thereby provide the central axis for the member 26 that is symmetrically located in the space between the poles 12, 13, and 14. The other end of the biasing spring 30 preferably is looped as shown so as to engage with a groove in the spring bias adjusting screw 32.

Due to the symmetrically forked form of the polarized three-pole magnetic relay structure, the centrally pivoted tilting magnetic member 26 is in a state of magnetic equilibrium only when it is in the mid-position to which it may be biased, as shown in Figs. 1 and 2, by the spring 30. Consequently, upon any tilting of the member 26 from its mid-position, the magnetic equilibrium becomes disturbed and the opposing magnetic pulls exerted upon the opposite ends of the member 26 by the two like poles 12 and 13 become unbalanced at a progressively increasing rate. Thus by an adjustment of the air gap reluctance screw 15 in the polarizing magnetic flux path to increase the polarizing flux to a maximum, the unbalanced magnetic biasing force provided by the polarizing electromagnet may, if desired, be made strong enough when the magnetic member 26 reaches a critical position within the limits of its tilting range to predominate over the opposing resilient bias of the spring 30 so as thereby to effect a continued tilting movement of the member 26 with a snap action to one or the other of the control positions in which contacts 27, 27' or 28, 28' are closed. However, such a strong snap action polarizing flux shift adjustment ordinarily is not desirable since the member 26 is then likely to be accidentally tilted to the critical position by extraneous vibrations or shocks. Hence to insure against such accidental operation, the amount of polarizing flux shift may be limited to such a value as will enable the biasing force gradient of spring 30 to remain predominant over the unbalanced magnetic pull throughout the tilting and the polarized flux shifting range of member 26 as determined by the adjustments of both the polarizing flux air gap reluctance screw 15 and the tilting range limiting stops 27' and 28'.

In order to obtain a sensitive electromagnetic differential polarization control of the differentially interlinked local flux path so as to effect selective tilting of the polarized magnetic member 26 from its mid-position, the two like poles 12 and 13 are provided with double opposing differential polarization control windings, preferably but not necessarily of the improved type shown in Fig. 4. As shown, each of the poles 12 and 13 is provided with an inner magnetizing winding 35 and an outer opposing magnetizing winding 36, each suitably insulated from the other and from the magnetic structure. The two inner windings 35 are electrically interconnected so as differentially to vary the polarizing flux of the two like poles 12 and 13 and the opposing outer windings 36 are similarly interconnected.

Thus the magnetizing effect of the two inner windings 35 is cumulative in tending to produce flux in one direction in the local control flux path that is differentially interlinked with the forked polarized flux path through the tilting member 26 and the two like poles 12 and 13 while the mag-

netizing effect of the two outer opposing windings 36 is cumulative in tending to produce flux in the opposite direction in the local control flux path. Hence, these two opposing local magnetizing effects may effectively neutralize or nullify each other or either one may predominate over the other in accordance with the relative energization of the opposing differential selective polarization control windings 35 and 36. This enables the magnetic member 26 to be maintained in magnetic equilibrium in its mid-position or to be selectively biased for magnetic snap action tilting in each direction therefrom in response to a relatively small increase or decrease in the energization of only one of the differential windings 35 or 36. The other differential winding serves as a calibrating or nullifying winding since member 26 is responsive to the relative energization of the two differential selective polarity control windings.

To enable the directive action of the magnetic member 26 to be controlled by a sensitive negative temperature coefficient resistor or other control device having relatively feeble control power, the inner magnetizing windings 35 preferably are energized under the control thereof and are formed with a relatively large number of turns of relatively low current carrying capacity while the outer opposing calibrating magnetizing windings 36 may comprise a fewer number of turns of larger current carrying capacity. Both of these windings may be held firmly in place by a resilient mounting spring washer 37, with their terminals connected to suitable terminal posts carried on the panel 18.

In the improved temperature modulating system shown in the schematic circuit diagram of Fig. 5, the differential selective polarization control windings 35 of the directive relay 45 are connected by conductors 60 and 61 to be energized from the power supply lines L1, L2 under the control of the sensitive temperature responsive resistor 40 having a marked negative temperature coefficient. Thus the control resistor 40 is connected directly in series circuit with the windings 35 so as differentially to vary the polarizing flux in the like poles 12 and 13 as an inverse function of the temperature variations to which the control resistor 40 is subjected. A control current measuring instrument 41 may, if desired, be connected in the series circuit controlled by the resistor 40 so as to serve as a heat regulating damper position indicating device.

In the temperature regulating system of Fig. 5, the directive relay 45 is employed to control the operation of a reversible motor operated damper 42 that may be assumed as regulating the supply of a heating medium to control the temperature to which the negative temperature coefficient control resistor 40 is subjected. As shown schematically in Fig. 5, the damper 42 is operated by the reversible positioning motor 43 through suitable speed reducing gearing 44. The motor 43 is reversed by means of the reversing field windings 46 and 47 which are energized by the electromagnetic reversing switches 48 and 49 under the selective control of the directive relay 45 to regulate the positioning of the damper 42. The reversible motor 43 also drives the sliding contact arm 51 of the control rebalancing resistor 52 which is connected by conductors 75, 76 and 77 in series circuit with the opposing differential calibrating windings 36 of the directive relay 45. The motor reversing switches 48 and 49 have selective energizing circuits controlled by the directive relay contacts 27, 27' and 28, 28', preferably with the limit switches 53 and 54 connected in their respective circuits.

Operation

With the biasing spring 30 adjusted to bias the movable magnetic directive member of the relay 45 to its mid-position and with the relative reluctance of the polarizing and control flux paths suitably proportioned for the desired sensitive equilibrium conditions by adjusting the air gap control screw 15 and also the air gap adjusting screws 21 and 22, and with the tilting range limiting stop screws 27' and 28' adjusted for suitably limiting the polarized flux shifting from the desired sensitive equilibrium condition, the operation of the control system shown in Fig. 5 is as follows. With the magnetic directive member 26 maintained in equilibrium in its mid-position as shown, the motor 43 is deenergized and the damper 42 will be maintained in a fixed position as long as the temperature to which resistor 40 is subjected remains in substantial equilibrium. Under these equilibrium conditions the polarizing effect provided by the differential magnetizing windings 35 is substantially neutralized by the opposing polarizing effect provided by the differential magnetizing windings 36. Thus there is no resultant polarization predominance of either winding over the other. To produce such equibrium conditions, the rebalancing resistor 52 must regulate the current through the windings 36 to a value with respect to the current through the windings 35, as determined by the temperature responsive resistor 40 substantially in the inverse ratio of the number of turns of these windings. Thus under such equilibrium conditions, the opposing magnetic pulls exerted by the like poles 12 and 13 upon the magnetic member 26 are balanced due to the symmetrically forked form of the three-pole magnetic structure that straddles the axis of member 26 and is polarized by the permanent magnet 10. With the proper adjustments, the magnetic pull exerted by the opposite pole 14 on the statically balanced tilting member 26 may be made substantially to neutralize the combined opposing magnetic pulls exerted by the like poles 12 and 13 so that the tilting magnetic member 26 remains practically floating in a very sensitive state of magnetic suspension with relatively little, if any, frictional pressure exerted upon the supporting or guiding pivots of the tilting member 26. To produce such a sensitive floating magnetic suspension, the screws 21 and 22 may be adjusted so as to vary the air gaps and therefore the pulls exerted upon the magnetic member 26 in its mid-position by the like poles 12 and 13 relative to the opposing pull exerted thereon by the opposite pole 14.

If the temperature to which the control resistor 40 is subjected should rise from the desired equilibrium value, then the resistance of the negative coefficient resistor 40 will decrease as an inverse function of the temperature rise, while if the temperature should decrease, the resistance of resistor 40 will increase accordingly. In each case, the energizing current passing through the differential polarized flux shifting windings 35 will correspondingly increase or decrease and thereby reverse the polarization predominance thereof to provide an initial selective shifting of the polarizing flux between the poles 12 and 13 to unbalance the relative polarization thereof, and consequently the magnetic pulls exerted thereby upon the magnetic member 26. Hence,

upon even a slight unbalance in the magnetic pulls exerted thereon, the member 26 will readily start to move selectively one way or the other from its mid-position thereby setting up an opposing strain in the biasing spring 30 that tends to return the member 26 to the mid-position. But as indicated above, the improved magnetic structure is such that the tilting movement of magnetic member 26 from the mid-position will automatically produce a further shifting of the polarizing flux between the poles 12 and 13 at a progressively increasing rate while relatively little, if any, variation in the total reluctance of the total polarizing flux path is produced. This latter is also true of the local flux path acted upon by the differential control windings 35 and 36 and extending through the magnetic plate 11, the poles 12 and 13, and the tilting magnetic member 26. Consequently, a predetermined critical tilting of the magnetic member 26 from its mid-position is readily obtained upon a relatively small change in the relative energization of winding 35 and 36 producing a reversible polarization predominance of either one over the other whereupon the cumulative unbalanced magnetic biasing force acting on the magnetic member 26 will rapidly predominate over the opposing force gradient of the resilient biasing spring 30 so as to effect a snap action operation of the magnetic biasing member 26 to its control position in which either contacts 27, 27' are closed or contacts 28, 28' are closed. In this way the improved polarized relay construction of the present invention provides an improved cumulative power amplifying magnetic biasing action to produce a selective snap action operation of the magnetic member 26 even though the initiating reversible polarization predominance resulting from a slight variation in the energization of the differential polarization control windings 35 is relatively weak.

Under the assumed conditions, if the temperature of resistor 40 rises, the current will increase in the energizing circuit for the differential reversible polarization control windings 35 extending from supply line L1 through conductor 60, windings 35, resistor 40, conductor 61, and the damper position indicating ammeter 41 to supply line L2. When the energizing current of winding 35 increases a predetermined amount as determined by the adjustments of the relay, the directive relay 45 will close its contacts 27, 27' to energize the motor reversing switch 49 through a circuit extending from the supply line L1 through conductor 70, the operating winding of the reversing switch 49, conductor 71, limit switch 54, conductor 72, relay contacts 27, 27', and conductor 73 to the other supply line L2. The resulting closure of the reversing switch contact 75 will energize the motor 43 to rotate the damper 42 through the gearing 44 so as to reduce the amount of heating medium supplied and thereby lower the temperature to which the resistor 40 is responsive. As the damper rotates, the sliding relay rebalancing contact 51 is moved progressively in a direction to decrease the current in the energization circuit of the relay polarization rebalancing windings 36 extending from supply line L1 through conductor 75, sliding contact 51, resistor 52, conductor 76, differential windings 36, and conductor 77 to supply line L2, and thereby rebalance the polarization of the poles 12 and 13 at a modulated equilibrium temperature of resistor 40. When the motor 43 has thus operated the rebalancing resistor slider 51 to effect the required rebalancing of the polarization of the poles 12 and 13, as determined by the adjustment of limit stop 27', so that the unbalanced magnetic biasing force no longer predominates over the spring biasing force, then the force of the biasing spring 30 becomes effective to return the magnetic member 26 with a snap action to its mid-position to deenergize the reversing switch 49 and thereby deenergize the motor 43. As the magnetic member 26 returns to its mid-position, the relative reluctances of the forked paths for the polarizing flux through poles 12 and 13 progressively become rebalanced so that magnetic equilibrium of member 26 is rapidly reestablished.

During the entire operation of the damper to decrease the equilibrium temperature as just described, the current passing through the control resistor 40 was increased due to the assumed rise in the temperature to which the resistor 40 was subjected. Consequently, the heating effect of the increased current passing through the control resistor 40 also increases. This provides, in effect, an automatic electroresponsive amplifying control action since the increased heating effect will cause the resistor 40 to be heated somewhat above the variable ambient temperature to which it is subjected and thereby gradually decrease its resistance independently of the ambient temperature changes. As a result, a control sensitizing action is automatically obtained that tends to increase the sensitivity by accelerating the unbalancing of the magnetic bias forces and thereby prevent undershooting of the modulated equilibrium temperature.

In case the temperature of the control resistor 40 should decrease from the modulated equilibrium value, then the energizing current of the differential windings 35 will decrease due to the increased resistance of the negative temperature coefficient resistor 40. In this case, the resulting unbalanced magnetomotive force due to polarizing predominance of winding 36 and acting differentially to shift the polarizing flux between the poles 12 and 13 is in the opposite direction from that previousiy described and therefore tends to oppositely unbalance the polarization of the poles 12 and 13 so as to move magnetic member 26 from its mid-position to engage contacts 28, 28' with a snap action after a predetermined initial critical movement of the magnetic member 26 from its mid-position. Exactly the same magnetic amplification of the initiating control power occurs due to the polarizing flux shifting from pole 13 to pole 12 at a progressively increasing rate as the movement of the magnetic member 26 from its mid-position progresses to the critical snap action position.

The closure of relay contacts 28, 28' establishes an energizing circuit for the motor reversing switch 48 extending from the supply line L1 through conductor 70, the operating winding of reversing switch 48, conductor 80, limit switch 53, conductor 81, relay contacts 28, 28' and conductor 73 to the other supply line L2. When the contact 84 of the motor reversing switch 48 closes, the motor 43 is energized through its reversing field winding 46 to effect a positioning operation of the damper 42 and the resistor slide contact 51 in the opposite direction. Consequently, the supply of heating medium affecting resistor 40 will be increased while the energizing current of the calibrating magnetizing windings 36 will increase thereby again tending to rebalance the polarization of the poles 12 and 13 at a reversely modulated temperature of resistor 40.

When a sufficient rebalancing is obtained, as determined by the adjustment of limit stop 28', the force of the resilient biasing spring 30 will predominate over the unbalanced magnetic biasing force to effect a snap action return of the magnetic member 26 to its mid-position.

During the entire temperature increasing damper operation just described, the decreased current passing through the control resistor 40 provides an automatic sensitizing control effect that tends to lower the temperature of the control resistor relative to the ambient and thereby accelerate the unbalancing of the magnetic biasing forces so as to avoid overshooting of the modulated equilibrium temperature.

The several calibrating adjustments embodied in the improved electromagnetic directive relay structure enable the cumulative flux shifting magnetic biasing forces to be adjusted relative to the biasing force gradient of the spring 30 either to produce the maximum sensitivity, the maximum snap action, or the maximum stability of the magnetic member 26 in its mid-position as desired. The latter is of importance where the directive relay may be subject to excessive vibration or shock. Some special condition of service may require adjustment of the screw 32 so as to spring bias the movable magnetic member to a predetermined one of its contact making positions rather than the mid-position as, for example, to provide a desired fail-safe protection. In such case, the resulting force gradient of spring 30 will be displaced with respect to the automatically amplified magnetic flux shifting biasing action but the relay will continue to operate with a snap action to each of its three control positions. However, under such a special condition the relative energization of the opposing differential windings 35 and 36 necessarily will be proportioned so that when the member 26 is in the mid-position a magnetic force is available for balancing the displaced biasing force of the biasing spring 30. Also, in some special case it may be desirable to eliminate the resilient biasing spring 30 entirely thereby providing for snap action operation of member 26 between only the two extreme control positions. In all cases the sensitivity of the relay may be enhanced by the reduction of bearing friction on the movable magnetic member 26 obtained by substantially equalizing the magnetic pulls exerted on the member by the opposite pole 14, and the two like poles 12 and 13.

The automatic rebalancing temperature control system shown in Fig. 5 operates to modulate the equilibrium temperature to which the negative temperature coefficient resistor 40 is responsive. In such a temperature modulating system the directive relay 45 is balanced in its mid-position at each of a series of different equilibrium temperature values so that the damper 42 is held in different positions intermediate the open and closed positions as the temperature to which the resistor 40 is responsive varies in steps over a considerable range. In such a system the movement of the rebalancing resistor sliding contact 51 along with the damper serves to recalibrate in steps the equilibrium temperature values of resistor 40 at which the directive relay 45 is balanced in its mid-position.

In the modification of the temperature control system of Fig. 5 shown in Fig. 6, the sliding contact 51 of resistor 52 is entirely disconnected from the damper so as either to remain fixed or to be manually adjusted by the knob 80. With this

change the temperature responsive control system of Fig. 5 then will provide a fixed or adjustable band type of temperature control such as indicated diagrammatically in Fig. 7. The two horizontal straight lines A and B shown in Fig. 7 represent the upper and lower limits of the temperature control band. The upper limit A is the temperature value of resistor 40 at which the directive relay 45 will close its contacts 27, 27' to energize the motor reversing switch 49 through the circuit previously described to effect operation of the motor 43 to move the damper 42 to decrease the supply of heating medium. The lower limit B is the temperature value of resistor 40 at which the directive control relay 45 closes its contacts 28, 28' to energize the motor reversing switch 48 through the circuit previously described so as to operate the damper 42 to increase the supply of heating medium. The two horizontal dotted lines A', B' represent the temperature values of the resistor 40 between which the directive relay 45 will return to its mid-position, the line A' indicating the temperature value following the closing of the relay contacts 27, 27', and the line B' indicating the temperature value following the closing of the relay contacts 28, 28'.

In operation the irregular line T represents a hypothetic variation of the control temperature to which the negative temperature coefficient control resistor 40 may be subjected. Thus, as shown, the initial control temperature T lies between the two temperature band limits A' and B' and the directive relay 45 is therefore in its mid-position so that the damper 42 is being maintained in some fixed position. If, due to external causes, the control temperature T should rapidly rise, as shown, then at the point C the directive relay 45 will close its contacts 28, 28' and thereby operates the motor 43 to reposition the damper 42 so as to decrease the supply of heating medium. This causes first the levelling off of the control temperature T and then a reduction in the control temperature T until, at the point 0, the directive relay 45 returns to its mid-position thereby stopping operation of the motor 43. The control temperature T then may continue to fall within the limits of the band A'B' until point C' is reached. Thereupon the directive relay 45 closes its contacts 27, 27' thus operating the motor 43 to reposition the damper 42 so as to increase the supply of heating medium and thereby effect an increase in the control temperature T. When the control temperature T reaches the point 0', the directive relay 45 returns to its mid-position so as to stop operation of the motor 43 and maintain the damper 42 in a fixed position. The modified control system will continue to vary the position of the damper 42 in accordance with further variations in the control temperature T within the temperature band limits in the manner just described.

In the band type of temperature control system just described, manual or other adjustment of the position of the sliding contact 51 of the control resistor 52 will shift the limits AB and A'B', these limits being raised when the sliding contact 51 is moved in a counterclockwise direction so as to increase the energization of the opposing differential windings 36 of the relay and decreased when contact 51 is moved in the opposite direction. In this way movement of the sliding contact 51 serves to calibrate or adjust the operating temperature band limits of the system.

In the band type of temperature control it is desirable that the time lag of the temperature sensitive control element 40 and of the temperature changing means be relatively small so that overshooting and undershooting are reduced to a minimum, preferably being less than the time lag of the heating medium supply. These conditions are met when there is always available an adequate supply of heating medium to be controlled by the damper 42, and where the movement of the damper is effected gradually by the speed reducing gearing 44 so that there is an opportunity for the control resistor 40 to respond before the damper has been moved too far.

It will be understood that either the modulating or the band type of temperature control systems described above may be adapted for cooling control service simply by reversing the field connections or the reversing control connections of motor 43.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electromagnetic reversing control apparatus including a reversely tilting magnetic member having reversing control means operated thereby and having an off position between two reversing control positions, resilient means for biasing said member each way to said off position, a polarized magnetic structure having three poles straddling the axis of said magnetic member and having opposing differential windings for shifting the polarizing flux thereof to magnetically bias said member selectively to said reversing control positions upon corresponding variation in the relative energization of said windings, condition responsive means for controlling the energization of one of said windings, and means including a reversible motor operated under the control of said reversing control means for controlling the energization of the other of said windings.

2. An electromagnetic reversing control apparatus including a reversely tilting magnetic member having a mid-control position between two reversing control positions, resilient means for biasing said member each way to said mid-position, a polarized magnetic structure having three poles straddling said magnetic member and having opposing differential windings for shifting the flux thereof to magnetically bias said member selectively to said reversing control positions upon corresponding variation in the relative energization of said windings, a temperature responsive resistor connected in series circuit with one of said windings for directly regulating the energization thereof, an adjustable resistor connected in series circuit with the other of said windings for directly regulating the energization thereof, and reversible temperature regulating means operated under the control of said member.

3. An electromagnetic selective polarization control apparatus having in combination a centrally pivoted reversely tilting magnetic member having a mid control position between two other control positions, resilient means biasing said member to said mid control position, a magnetic structure having polarizing means for providing three poles disposed one adjacent each end of said members and one adjacent the axis of said member and having opposing differential polarization control windings, each upon polarizing preponderance thereof selectively varying the relative polarization of said poles to magnetically

bias said member for snap action movement to a corresponding one of said other control positions, a condition responsive variable resistor energized in series with one of said windings for reversely varying said polarizing preponderance of said one winding, and electrical control means for varying the energization of the other of said windings to independently vary said polarizing predominance of said one winding.

4. An electromagnetic selective biasing control apparatus having in combination a centrally pivoted reversely tilting magnetic member having an intermediate control position, resilient means for biasing said member to said intermediate position, magnetic structure having polarizing means for providing a pair of poles each disposed adjacent a corresponding end of said member and a third pole disposed adjacent the axis of said member and having opposed differential polarization control windings for varying the polarization of said poles to magnetically bias said member for snap action movement reversely from said intermediate position, means for reversely varying the energization of one of said windings selectively to reverse said magnetic bias of said member, and means for varying the energization of the other of said windings to neutralize said magnetic bias of said member.

5. In combination, a magnetic structure having polarizing means for providing a pair of magnetically balanced poles in alinement and a third pole therebetween, a reversely tilting magnetic member centrally pivoted adjacent said third pole for balancing said member in magnetic equilibrium only in a position in symmetrical alinement with said balanced poles, resilient means for biasing said member to said position, opposed differential polarization control windings for varying the polarization of said poles to magnetically unbalance said member for snap action movement each way from said position, means for reversely varying the energization of one of said windings to reverse said magnetic unbalancing of said member, and means for varying the energization of the other of said windings to magnetically balance said member.

6. An electromagnetic control apparatus including a magnetic structure having a pair of magnetically balanced poles in alignment, a cooperating magnetic structure having a single pole symmetrically offset between said pair of poles, a permanent magnet for oppositely polarizing said magnetic structures and having means for providing an adjustable air gap to regulate the magnetic field between said poles, a centrally pivoted reversely tilting magnetic directive control member having a mid control position between two other control positions and having an axis in the magnetic field between said poles for equalizing the polarized magnetic pulls thereon only with said member in said mid control position, adjustable resilient means for biasing said member to a selected one of said three control positions, and differential selective polarization control windings for said pair of poles, each having an independently variable energization control means for varying the relative energization of said windings to selectively vary said polarized magnetic pulls and thereby magnetically bias said directive control member for snap action movement to and from each of the other of said control positions.

7. An electromagnetic selective polarization control device having in combination a magnetic structure having polarizing means for providing

one pole between two spaced apart poles and having a reversely tilting magnetic member centrally pivoted adjacent said one pole for equalizing the attraction of the other of said poles only in an intermediate position of said member, resilient means biasing said member to return to said position upon tilting each way therefrom, and a pair of differential polarization control windings, each oppositely interlinking said other poles for oppositely varying the polarization of said other poles and having a relative energization for nullifying each other to return said member to said intermediate position and each of said windings having an independently variable energization control means to magnetically bias said member for snap action tilting movement each way from said position upon a corresponding increase and decrease in the relative energization of said winding.

8. A three-position selective control apparatus including a three-pole magnetic structure having polarizing means for providing a pair of magnetically balanced poles in spaced apart alinement and a central pole therebetween, a reversely tilting magnetic three-position selective control member having a central axis adjacent said central pole and provided with resilient biasing means for opposing the normal polarized attraction of said pair of poles to centrally position said member thereagainst, a pair of differential selective polarization control windings for varying the polarization of each of said pair of poles into predominance over said resilient biasing means to tilt said member with a snap action from said central position, and independently variable resistors each connected in series circuit with a corresponding one of said windings for increasing and decreasing the energization thereof to separately and reversely control the tilting of said directive control member to and from said central position.

9. An electromagnetic control apparatus including a magnetic structure having a pair of magnetically balanced poles in alignment, a cooperating magnetic structure having a single pole centrally offset from said pair of poles, a permanent magnet for oppositely polarizing said magnetic structures and having means including an adjustable air gap for adjusting the polarization thereof, a statically balanced tilting armature having an axis between said poles for balancing the polarized magnetic pulls of said like poles on said armature only in a predetermined position thereof, adjustable resilient means for biasing said armature to said position, adjustable stop means for limiting the tilting of said armature, and a pair of counteracting electromagnetic polarizing means, each differentially polarizing said pair of like poles to control the tilting of said armature selectively each way from said balanced position thereof upon opposite variation in the polarizing predominance of said means.

10. An electromagnetic control apparatus including a polarized three-pole magnetic structure having a pair of magnetically balanced like poles in alignment and a single opposite pole in central offset relation therewith, a statically balanced tilting magnetic member having control means operated thereby and having an axis between said poles for balancing the polarized magnetic pulls of said like poles on said member only in a predetermined position thereof, adjustable stop means for limiting the tilting of said member, and a pair of counteracting separately variable electromagnetic polarizing means, each differentially magnetizing said pair of like poles to control the tilting of said member.

11. An electromagnetic control apparatus including a magnetic structure having polarizing means for providing a pair of magnetically balanced like poles in parallel alignment and a single opposite pole offset centrally therefrom, a centrally pivoted reversely tilting magnetic member having directive control means operated thereby and having an axis centric in the space between said poles for balancing the magnetic pulls of said pair of like poles on said member only upon a predetermined alignment thereof with said pair of like poles, double opposing differential magnetizing windings for said pair of like poles, and independently variable means for controlling the relative energization of each of said windings to magnetically unbalance and balance said member.

12. An electromagnetic control apparatus including a centrally pivoted reversely tilting magnetic member having a mid control position between two other control positions, a resilient biasing element for biasing said member each way to said mid-position, and a polarized three-pole variable magnetic biasing structure having opposing differential magnetizing windings, each oppositely varying the polarization of a pair of poles thereof for selectively opposing said resilient biasing element to effect snap action operation of said member to each of said other control positions upon a corresponding increase and decrease in the relative energization of said winding.

13. In combination, a centrally pivoted reversely tilting magnetic member having an off position between two reversing control positions, resilient means for biasing said member to return to said off position upon tilting each way therefrom, snap action magnetic biasing means for reversely opposing said resilient biasing means including a three-pole magnetic structure having polarizing means for providing a pair of magnetically balanced poles each substantially equally adjacent a corresponding end of said member in said off position and an intermediate pole adjacent the center of said member for magnetically biasing said member for snap action movement to each of said other control positions upon a predetermined unbalancing of said magnetically balanced poles and having opposing polarization control windings for differentially unbalancing said pair of magnetically balanced poles, condition responsive electric control means for reversely varying the energization of one of said windings to effect snap action movement of said member to each of said reversing control positions, and means including a reversible motor operated under the control of said magnetic member for controlling the relative energization of the other of said windings to rebalance said magnetically balanced poles and thereby effect the return of said member to said off position.

14. An electromagnetic control apparatus including a polarized magnetic structure having a pair of magnetically balanced like poles and an opposite pole in symmetrically offset relation, a tilting magnetic member having an axis symmetrical in the space between said poles for oppositely shifting the polarizing flux between said like poles at a progressively variable rate upon opposite tilting of said member from a predetermined mid-position, and a pair of counteracting separately variable electromagnetic polarizing means, each for selectively shifting the polarizing

flux between said pair of like poles to effect said tilting of said member upon opposite variation of the polarizing predominance thereof.

15. An electromagnetic control apparatus including a polarized magnetic structure having a pair of magnetically balanced like poles and an opposite offset pole for providing an acute fork in the polarized flux path therebetween, a tilting magnetic member having a central axis at said acute fork for oppositely shifting the polarizing flux between said like poles at a progressively variable rate upon opposite tilting of said member from a predetermined position, and a pair of counteracting separately variable electromagnetic polarizing means, each for selectively shifting the polarizing flux between said pair of like poles to effect said tilting of said member upon opposite variation of the polarizing predominance thereof.

16. In combination, a centrally pivoted reversely tilting magnetic control member having three control positions, resilient means for biasing said member to an intermediate one of said positions, a three-pole magnetic biasing means having polarizing means for providing a pole adjacent each end of said magnetic member and an intermediate pole adjacent the center of said member and having differential windings for differentially magnetizing said poles to magnetically bias said member for snap action tilting movement each way from said intermediate position, a temperature responsive variable resistor connected in series with one of said windings and jointly responsive to variations of a predetermined temperature condition and variations in the heating effect of the energizing current of said one winding for controlling said magnetic biasing of said member, and means controlling the energization of the other of said windings for independently varying said magnetic biasing of said member.

17. In combination, a centrally pivoted reversely tilting magnetic control member having resilient means biasing said member to a mid position, a magnetic biasing means having polarizing means for providing three poles disposed respectively one adjacent each end of said member and one adjacent the center thereof and having differential windings for differentially magnetizing said poles to magnetically bias said member for snap action tilting each way from said mid position, a negative temperature coefficient resistor connected in series circuit with one of said windings for regulating the energization thereof to control said tilting of said member jointly in response to variations in a predetermined temperature condition and to variations in the heating effect of the energizing current of said winding, a separate adjustable resistor connected in series circuit with the other of said windings for regulating the relative energization thereof to separately control said tilting of said member, and means operated under the control of said member for adjusting said resistor.

18. In combination, a three-pole magnetic structure having polarizing means for providing a centrally pivoted reversely tilting magnetic member biased to a mid position and having flux shifting differential windings for reversely tilting said member with a snap action to and from said position, a temperature responsive resistor having a negative coefficient of resistance connected in series circuit with one of said windings for varying the relative energization thereof to control said tilting of said member responsively to variations in the resistance of said resistor between the limits of a predetermined range, and means including an adjustable energization controlling resistor connected in series circuit with the other of said windings to shift said range.

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