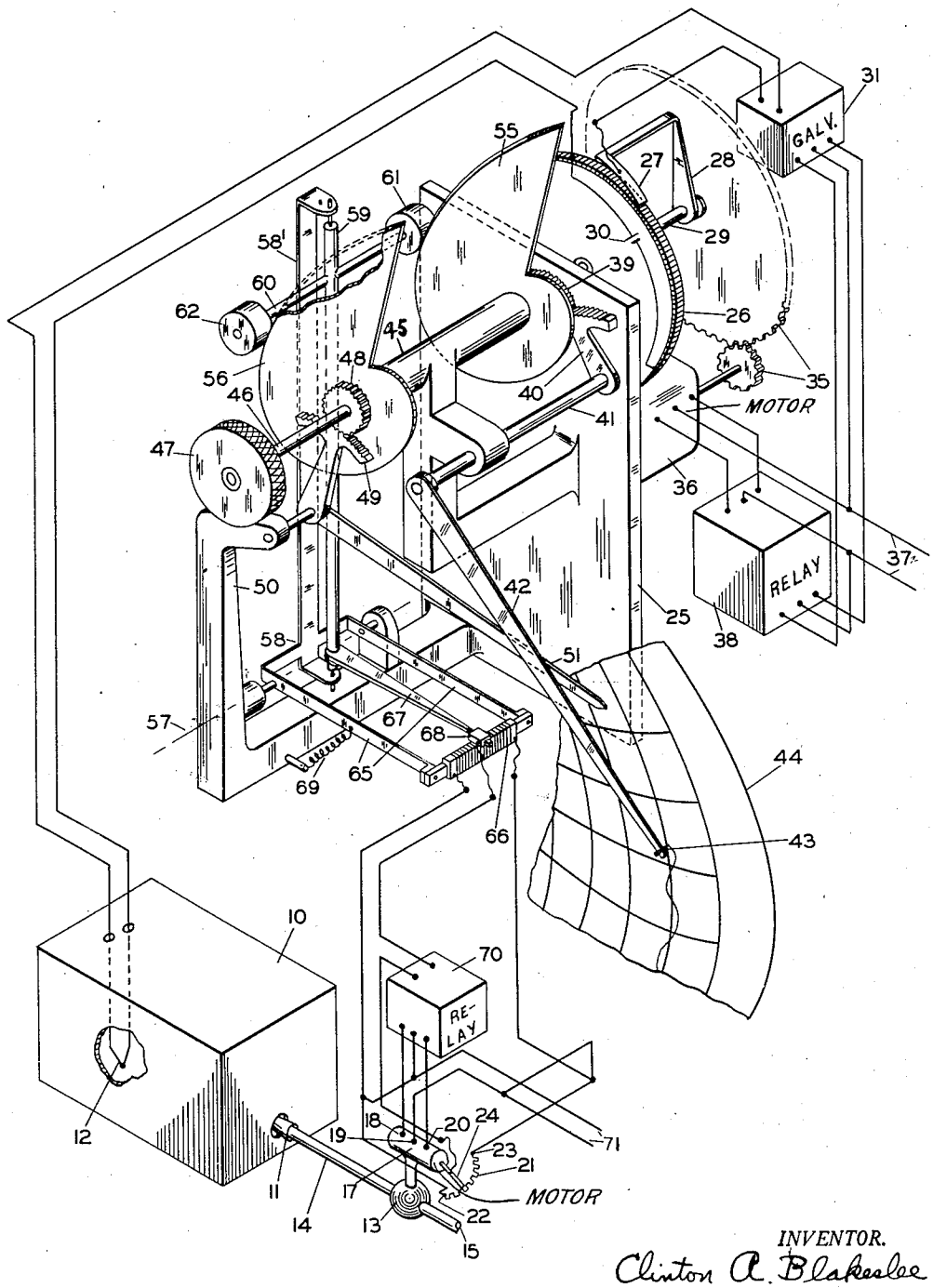
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CONTROL APPARATUS

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## CONTROL APPARATUS

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1

This invention relates to automatic control mechanisms, and more especially to a device wherein the control point of a regulating mechanism operated by a measuring instrument of the self-balancing potentiometer class may readily be adjusted through a wide range and use of a high degree of precision. In U. S. Letters Patent No. 2,326,238, granted to A. R. Mabey, August 10, 1943, there is disclosed a method whereby a pneumatic control device may effectively be rendered subject to a recording instrument of the potentiometer class having a chart with rectangular coordinates. The present invention involves the application of a differential principle to the actuation of a control device from a self-balancing instrument having circular coordinates; and while it is applicable to other forms of control, is especially adapted for use in a control system wherein modulation is effected by varying the condition of an electrical circuit.

It is an object of this invention to provide a differential control mechanism readily adaptable to coordination with a self-balancing measuring instrument.

It is a further object to provide such a mechanism in a form which shall be inherently free of backlash between the control and actuated elements.

It is a further object to provide such a mechanism in a form especially adaptable to modulated regulation of the electrical type.

It is a further object to provide such a mechanism in a form which shall be readily adjustable to any desired control point, and which shall show a consistent performance at all settings.

In carrying out the purposes of the invention it is proposed to provide a measuring and controlling instrument having two identical cam members movable by the measuring element and the setting mechanism respectively, said cam members being mutually disposed in a manner to act jointly upon a differential mechanism which is simultaneously in engagement with their respective peripheral surfaces. The degree of activity of the controlling mechanism is made responsive to the displacement of said differential mechanism as produced by the relative positioning of said cam members. The element of the control mechanism which is directly in engagement with the differential mechanism preferably takes the form of a slide-wire rheostat forming a part of a bridge circuit; and to this circuit may be applied various compensating and anticipatory devices which, while not forming parts of the present invention, are sometimes desirable in con-

2

junction with control systems to which this invention is especially applicable.

The single figure of the drawing represents an embodiment of the invention whereby an electrically-operated valve may be operatively associated with a temperature-measuring instrument of the potentiometer class.

Referring now to the drawing:

The numeral 10 designates a furnace, oven, or other enclosed space adapted to be heated by the combustion of fluid fuel admitted thereto through a burner 11, and in which it is desired to maintain a predetermined constant temperature as measured by a thermocouple 12 located within the furnace, the regulation of said temperature being effected by control of the position of a valve 13 connected in a conduit 14 through which said fuel is supplied to the burner from a source 15. The valve 13 is actuated by a reversible electric motor 17 having three terminals 18, 19, and 20. The internal connections of the motor are made such that when voltage from a suitable source is applied to the terminals 18 and 19 the motor will rotate in a sense to close the valve 13, and when said voltage is applied to the terminals 20 and 19 the motor will operate in a sense to open said valve. A slide-wire rheostat 21, having terminals 22 and 23 is operatively engaged by a sliding contact 24 attached to the mechanism of the valve 13 and moved therewith by the motor 17 in a sense that as said valve is moved toward a closed position the contact approaches the terminal 22 and as said valve is opened the contact approaches the terminal 23.

Mounted upon a base-plate 25 is a circular slide wire structure 26, electrically engaged by a movable contact or slider 27, carried by an arm 28, which in turn is attached to a rotatable shaft 29 passing centrally through the slide-wire structure 26 and journaled in the base-plate 25, whereby, with rotation of the shaft 29 the contact 27 may traverse the length of the slide wire. For purposes of clarity in the drawing, the active length of the slide-wire is shown as occupying a comparatively small portion of the periphery of the structure; but it will be understood that its active length may be increased as desired in practice. The slide wire 26 forms a part of a conventional potentiometer circuit, including a battery 30 adapted to apply a constant potential to the slide-wire terminals, and a contact-making galvanometer 31. The thermocouple 12 is connected between a terminal of slide wire 26 and the galvanometer 31; and the electrical ar-

rangement of the network is made such that by moving the slider 27 with respect to the slide-wire 26 there may be obtained a condition of balance as detected by the galvanometer 31, wherein the position of the slider with respect to the slide-wire becomes a measure of the potential existing between the terminals of the thermocouple 12, and therefore of the temperature to which it is exposed.

Rotation of the shaft 29 is effected through suitable gearing 35 by means of a reversible electric motor 36 receiving power from a source 37 and controlled by relay means 38 directly subject to the deflection of the galvanometer 31. The mechanism and means for balancing the potentiometer network through rotation of the shaft 29 in response to the detection of an unbalanced condition by the galvanometer 31 may, for example, be of the form fully set forth and described in U. S. Letters Patent No. 2,320,066 issued to F. B. Bristol, May 25, 1943; and since this and other forms of electrical self-balancing mechanisms are well known in the art, no further explanation of that element of the device need here be given.

Fixed to the shaft 29 is a pinion 39 meshing with a gear sector 40 integral with a shaft 41 journaled in the base plate 25. Attached to the shaft 41, and deflectable with the rotation thereof through a limited angle, is an extended arm 42 carrying a pen or stylus 43 adapted to transverse the face of a graduated record chart 44, and to inscribe thereon a trace of its movements. The chart 44 is driven at a constant velocity by means of a conventional timing mechanism not shown in the drawing, whereby the trace made by the pen or stylus 43 becomes a graphic record of positions assumed by said pen or stylus, and therefore of the temperatures existing within the furnace or oven 10 over a period of time.

Journaled in a bracket member 45 integral with the base-plate 25 (which bracket member may also form auxiliary bearings for the shafts 29 and 41) is a shaft 46 coaxial with the shaft 29 and adapted for angular adjustment about its axis by means of a knob 47. Fixed to the shaft 46 is a pinion 48 meshing with a gear sector 49 journaled upon a bracket 50 integral with the base-plate 25, and rotatable through a limited angle about an axis parallel to but displaced from the axis of the shaft 41. Attached to the gear sector 49 is an extended arm 51 terminating in an index or pointer adapted to traverse the graduated surface of the chart 44, and to follow a time graduation upon said surface, but, by virtue of the displacement of the axis of the shaft 46 from that of the shaft 41, not in any position intersecting the path of the pen or stylus 43.

Fixed to the shafts 29 and 46 respectively are cams 55 and 56, angularly rotatable with said shafts in parallel planes and having their peripheries conformed to identical spiral contours whereby the length of any selected radius will be proportional to its angular displacement from a selected reference radius.

Journaled upon the bracket 50 and rotatable through a limited angle about an axis 57 parallel to, but displaced from, the common axis of the shafts 29 and 46, is a rocker-arm structure 58 having a projecting portion 58' extended beyond said common axis and carrying a pivotally mounted shaft or spindle 59 rotatable through a limited angle about an axis intersecting the axis 57 and movable with said rocker arm structure about said last-named axis. Fixed to, and extending



traversely from, the shaft 59 is a cross-arm 60, carrying on its extremities cam-followers or rollers 61 and 62 engaging the peripheries of the cams 55 and 56 respectively.

Extending from the rocker arm structure 58 in a sense substantially perpendicular to the projection 58' is a bracket 65 carrying on its extremity a slide-wire resistance 66. Fixed to the shaft or spindle 59, and deflectable therewith, is an extended arm 67 bearing an insulated contact 68 adapted to traverse said slide-wire and to assume with respect to the extended length thereof a position dependent upon the angular deflection of said shaft about its axis of rotation. A tension spring 69, extended between the bracket 65 and a fixed abutment on the base-plate 25 maintains the followers 61 and 62 in definite engagement with cams 56 and 55 respectively, and effectively eliminates backlash from the mechanism.

Connected to the motor 17 of the valve 13 is a relay member 70 having a sensitive winding and circuit-controlling elements (not shown in the drawing) whereby said circuit-controlling elements will be actuated in a sense dependent upon the direction of current flowing in said winding. The relay member 70 is interconnected with the slide-wire resistors 21 and 66 and a source of electrical energy 71 to form a bridge circuit; and the circuit controlling elements of the relay are connected to said source of energy and to the motor 20 in such a manner that unbalance of the bridge circuit due to motion of the sliding contact 68 along the slide-wire 66, will cause the relay member 70 to respond and actuate the motor 20 in a sense to cause the contact arm 24 by its movement with respect to the slide wire 21 to reestablish balance in the bridge network. This is a conventional and well-known form of control, and is found in many devices for distant regulation of motors. An early example of such a control is disclosed in U. S. Letters Patent No. 599,903 granted to M. Pfatischer, May 12, 1896, where the principle is shown in its application to the steering of ships. For this element of the control system forming a part of the present invention no novelty is claimed; and it need not here be further described.

The operation of the apparatus embodying the principle of the invention may be described as follows:

Assuming first that there exists a condition of equilibrium, with the valve 13 set at such a position as to admit to the burner 11 sufficient fuel to maintain the space within chamber 10 at a predetermined constant temperature as detected by the thermocouple 12 and measured by the position of the sliding contact 27 with respect to the slide-wire 26, the shaft 29 and the cam 55 will be maintained in position representative of said temperature, and the arm 42, actuated through the shaft 41 from the co-acting gear members 39 and 40, will position the pen or stylus 43 upon the graduated surface of the chart 44 to provide a measure of said temperature value. By previous adjustment the angular position of the cam 55 about the common axis of the shafts 29 and 46 will be the same as that of the cam 56, so that the cam followers 61 and 62 resting upon the cams 55 and 56 respectively will be at a common radial distance from said axis, and the shaft 59 subject to the joint influence of said cam followers will cause the arm 67 to occupy an intermediate position, whereby the contact 68 carried thereby will rest upon the slide wire 66 in a location to maintain a balanced condition in the

bridge circuit which includes the slide wire 21; and the valve motor 17 will remain at rest.

It may now be assumed that there has developed a condition tending to lower the temperature within chamber 10. The E. M. F. developed by the thermocouple 12 will be correspondingly lowered with a resultant disturbance of the potentiometer balance, whereby current will flow through the sliding contact 27 and the galvanometer 31. The response of the galvanometer will be such as to actuate the relay 38, according to principles hereinbefore set forth, in a sense to cause the motor 36, acting through the gear train 35 to rotate the shaft 29 in a counter-clockwise sense as seen in the drawing, and to shift the sliding contact 27 to a position of lower potential along the slide-wire 26, whereby electrical balance of the potentiometer network will be restored. The shaft 41 will have been correspondingly rotated and the pointer arm 43 moved to a position where the pen or stylus 43 will provide on the chart 44 a measure of the newly attained temperature value.

The cam 56 will have been correspondingly rotated in a counter-clockwise sense, so as to cause the follower 61 to engage a portion of its periphery having an increased radius. The movement of the follower 61, acting through the cross arm 60, will cause said arm to swing about the point of enegagement of the follower 62 with the periphery of the cam 56 as a fulcrum, whereby the shaft 59 and the rocker-arm structure 58, will be given bodily rotation about the axis 57, carrying the bracket 65 and the slide wire 66 through a corresponding limited angle about said axis. As said rotary motion is derived from a change in position of one end only of the cross arm 60, the consequent angular rotation of the shaft 59 with respect to the rocker-arm structure 58 will cause the arm 67 to be similarly rotated, whereby the contact 68 will assume a new position with respect to the slide wire 66, the change in position being toward the right as seen in the drawing.

The change in position of the contact 68 with respect to the slide wire 66 will disturb the balance of the bridge circuit comprising said slide wire 66 and the slide wire 21, whereby the relay 70 will be energized in a sense to actuate the valve motor 17 and open the valve 13, causing an increased supply of fuel to be admitted from the source 15 through the conduit 14 to the burner 11, with a corresponding tendency to restore the temperature within the chamber 10 to its former predetermined value. At the same time, the contact arm 24 will have been shifted along the slide wire 21 in a sense to restore the balance of the bridge circuit and render the relay 70 inactive, so that the valve motor 17 will be brought to rest with the valve 13 in a new position corresponding to the increased demand for fuel.

In a similar manner, should the temperature within the chamber 10 rise above the predetermined value, the resultant increased potential developed by the thermocouple 12, acting upon the galvanometer 31 through sliding contact 27 of the potentiometer circuit, will cause the relay 37 to respond and to actuate the motor 36 in a sense to restore the potentiometer balance by rotating the shaft 29 in a clockwise sense as seen in the drawing and shifting the sliding contact 27 toward the right on the slide wire 26, which change will be indicated by pen or stylus 43 assuming a new position on the chart 44. At the same time, the cam 55, being rotated in a clockwise sense, will present a decreased radius to the follower 61 whereby the cross arm 60 will be rotated about the point of engagement of the follower 62 with the cam 48 as a fulcrum, causing the rocker-arm structure 58 to be rotated in a clockwise sense about the axis 57, and the shaft 59 at the same time to be rotated with respect to said rocker-arm structure in a sense to move the arm 67 and the contact 68 carried thereby, toward the left-hand end of the slide wire 66. This action will cause the bridge network comprising said slide wire 66 and slide wire 21 to become unbalanced, whereupon the relay 70 will act to operate the motor 17 in a direction to close the valve 13, and incidentally to restore the bridge balance by movement of the contact arm 24 with respect to the slide wire 21.

It will thus be seen there has been provided a mechanism which will continually tend to regulate the conditions within the chamber 10 to a constant temperature. It will further be apparent that the temperature toward which regulation is effected may be established at any desired predetermined value by manual adjustment of the angular position of the cam 56 by means of the knob 47. The pointer 51, angularly movable with the gear sector 49, will be subject to displacement with any change in the setting of the cam 56, so that it may be caused to provide on the graduated surface of the chart 44 an indication of the control point established by the setting of the cam 56.

The terms and expressions which I have employed are used as terms of description and not of limitation, and I have no intention, in the use of such terms and expressions, of excluding any equivalents of the features shown and described or portions thereof, but recognize that various modifications are possible within the scope of the invention claimed.

I claim:

1. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means cooperating with said cams and operable thereby into positions corresponding to differences between the settings of said cams, and means controlled by said differential means for affecting the magnitude of said variable.

2. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam having a working surface substantially identical with that of the first mentioned cam, means for positioning said second cam in accordance with a desired magnitude, differential means cooperating with said cams and operable thereby into positions corresponding to differences between the settings of said cams, and means controlled by said differential means for affecting the magnitude of said variable.

3. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam having a working surface substantially identical with that of the first mentioned cam and movable in a plane substantially parallel to that of said first mentioned cam, means for posi-

tioning said second cam in accordance with a desired magnitude, differential means cooperating with said cams and operable thereby into positions corresponding to differences between the settings of said cams, and means controlled by said differential means for affecting the magnitude of said variable.

4. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means cooperating simultaneously with said cams and rockable thereby about an axis into positions corresponding to differences between the settings of said cams, and means controlled by said differential means for affecting the magnitude of said variable.

5. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means comprising a rockable shaft having extensions engaging said cams and rockable thereby into positions corresponding to differences between the settings of said cams, and means controlled by said differential means for affecting the magnitude of said variable.

6. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means cooperating simultaneously with said cams and movable thereby into positions corresponding to differences between the settings of said cams, a frame carrying said differential means and movable by said cams, control means movable with said differential means and said frame respectively, and means controlled by said control means for affecting the magnitude of said variable.

7. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means comprising a rockable shaft having extensions engaging said cams and rockable thereby into positions corresponding to differences between the settings of said cams, a frame carrying said differential means and rockable by said cams about an axis different from that of said rockable shaft, control means movable with said differential means and said frame respectively, and means controlled by said control means for affecting the magnitude of said variable.

8. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a cam, means controlled by said instrument for positioning said cam in accordance with said magnitude, a second cam, means for positioning said second cam in accordance with a desired magnitude, differential means cooperating with said cams and operable thereby into positions corresponding to differences between the settings of said cams, reversible electric motor means for affecting the magnitude of said variable, and electric circuit means controlled by said differential means for controlling the operation of said motor.

9. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a first cam member movable under control of said instrument, a second cam member having a working surface substantially identical with that of said first cam member and adjustable in a plane parallel to that of said first cam member, a rocker element rotatable through a limited angle about an axis perpendicular to the planes of said cam members, said rocker element having pivoted thereon an extended differential member with its extremities simultaneously engaging the respective cam members, first control means carried by said rocker element, second control means movable with respect to said first control means in response to variations in the angular position of said differential member about its axis, and means controlled by said first and second control means to affect the magnitude of said variable.

10. In apparatus for controlling the magnitudeof a variable, a measuring instrument having a movable element adapted to assume a position representative of the magnitude of a condition to be controlled, a first cam member movable with said element, a second cam member movable in a plane parallel to that of said first cam member, a rocker-arm rotatable through a limited angle about an axis perpendicular to the planes of said cam members, said rocker arm having pivoted about an axis thereon an extended differential member with its extremities engaging said cam members, and means carried by said rocker arm and adapted to affect the magnitude of said variable according to the deflection of said differential member about its pivotal axis.

11. In a device for controlling the magnitude of a variable, a measuring instrument sensitive to changes in said variable, a first cam member movable under control of said instrument, a second cam member having a working surface substantially identical with that of said first cam member and adjustable in a plane parallel to that of said first cam member, a rocker element rotatable through a limited angle about an axis perpendicular to the planes of said cam members, said rocker element having pivoted thereon an extended differential member with its extremities simultaneously engaging the respective cam members, first control means carried by said rocker element, second control means movable with respect to said first control means in response to variations in the angular position of said differential member about its axis, and means controlled by said first and second control means to affect the magnitude of said variable, separate indicating means associated respectively with said cam members, and movable to provide indications of the measured magnitude of said variable and the setting of said second cam member respectively.

12. In an instrument for measuring and controlling the magnitude of a variable condition, means sensitive to changes in said magnitude, a graduated surface, a first deflecting member juxtaposed to said surface and adapted to provide thereon a measure of said magnitude, a first ro-

tatable element controlled by said sensitive means for positioning said member with respect to the graduations on said surface, a second deflecting member juxtaposed to said surface and adapted to provide in conjunction with the graduations thereon measures corresponding to desired magnitudes of said condition, a second rotatable element operable concurrently with the positioning of said second deflecting member, differential mechanism comprising two similar cam members and a follower jointly positioned by the same, one of the said cam members being connected to the first rotatable element for movement thereby, and the other of the said cam members being connected to the second rotatable element for movement thereby, and means actuated by said follower for controlling said variable condition.

13. In apparatus for controlling the magnitude of a variable, a measuring instrument having a movable element adapted to assume a position representative of the magnitude of a condition to be controlled, a first cam member movable with said element in a plane, a second cam member movable in a plane parallel to that of said first cam member, a rocker-arm rotatable through a limited angle about an axis perpendicular to the planes of said cam members, a variable resistance unit carried by said rocker arm, an electrical network including said resistance unit and means for controlling said magnitude, whereby changes in said resistance unit will affect the performance of said controlling means, and means movably carried upon said rocker arm and positioned relatively thereto under the joint influence of said cam elements to vary said resistance and thereby to command the operation of said controlling means.

14. In a device for controlling the magnitude of a variable, an electric motor adapted to control said magnitude, a control circuit for said motor, including a resistance element variable by said motor and a directional relay adapted to command the operation of said motor, a measuring instrument having a movable element adapted to assume a position representative of said magnitude, a first cam member movable with said element, a second cam member movable in a plane parallel to that of said first cam element, a rocker-arm rotatable through a limited angle about an axis perpendicular to the planes of said cam members, said rocker-arm having pivotally mounted thereon a differential member adapted to be angularly positioned by the joint influence of said first and second cam members, and resistance means variable in accordance with the angular position of said differential member and connected in said control circuit to form with said first resistance element a bridge network with said relay directionally responsive to unbalance conditions to command the operation of said motor in a sense to restore the balance of said network.

15. In a device for controlling the magnitude of a variable, an electric motor adapted to control said magnitude, a control circuit for said motor including a resistance variable by said motor and a directional relay adapted to command the operation of said motor, a measuring instrument having a movable element adapted to assume a position representative of said magnitude, means settable into a position representative of a desired magnitude, differential means positioned under the joint control of said movable element and said settable means, and resistance means variable in accordance with the position of said differential means and connected in said control circuit to form with said first resistance a bridge network with said relay directionally responsive to unbalance conditions to command the operation of said motor in a sense to restore the balance of said network.

16. In a control system for limiting the departure of the magnitude of a condition from a predetermined value, the combination of two cam members having similar contours and displaceable in parallel planes, one of said cam members being positionable at will in accordance with said predetermined value, and the other having means for positioning it in accordance with said magnitude, an element rotatable through limited angles about two axes, one of said axes lying in a plane parallel to said planes, and the other being angularly disposed thereto, said rotatable element having parts engaging both said cams, whereby to be deflected about the first of said axes in response to differences in the displacements of said cams, and to be deflected about the other of said axes to an extent proportional to the mean of the effective heights of said cams, and means operatively connected to said element for controlling said condition.

17. In a control system for limiting the departure of the magnitude of a condition from a predetermined value, the combination of two cam members having similar contours and angularly displaceable in different planes about a common axis intersecting said planes, one of said cams being positionable about said axis at will in accordance with said predetermined value, and the other having means for positioning it in accordance with said magnitude, an element rotatable through a limited angle about two axes, one of said axes lying in a plane parallel to said planes, and the other being angularly disposed thereto, said rotatable element having parts engaging both said cams whereby to be deflected about the first of said two axes in response to differences in the displacements of said cams, and to be deflected about the other of said two axes to an extent proportional to the mean of the effective radii of said cams, and means operatively connected to said element for controlling said condition.

18. In a control system for limiting the departure of the magnitude of a condition from a predetermined value, the combination of two cam members having similar contours and displaceable in parallel planes, one of said cam members being positionable at will in accordance with said predetermined value, and the other having means for positioning it in accordance with said magnitude, an element rotatable through limited angles about two axes, one of said axes lying in a plane parallel to said planes, and the other being angularly disposed thereto, said rotatable element having parts engaging both said cams, whereby to be deflected about the first of said axes in response to differences in the displacements of said cams, and to be deflected about the other of said axes to an extent proportional to the means of the effective heights of said cams, and means operatively connected to said element for controlling said condition in response to deflection of said element about said first axis.

19. In a control system for limiting the departure of the magnitude of a condition from a predetermined value, the combination of two cam members having similar contours and angularly displaceable in different planes about a common axis intersecting said planes, one of said cams being positionable about said axis at will in ac-

cordance with said predetermined value, and the other having means for positioning it in accordance with said magnitude, an element rotatable through a limited angle about two axes, one of said axes lying in a plane parallel to said planes, and the other being angularly disposed thereto, said rotatable element having parts engaging both said cams whereby to be deflected about the first of said two axes in response to differences in the displacements of said cams, and to be deflected about the other of said two axes to an extent proportional to the mean of the effective radii of said cams, and means operatively connected to said element for controlling said condition in response to deflection of said element about said first axis.



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