July 18, 1939. L. K. DAVIS 2,166,239

MOVEMENT-PRODUCING DEVICE

Filed May 5, 1936 2 Sheets-Sheet 1

Fig. 4

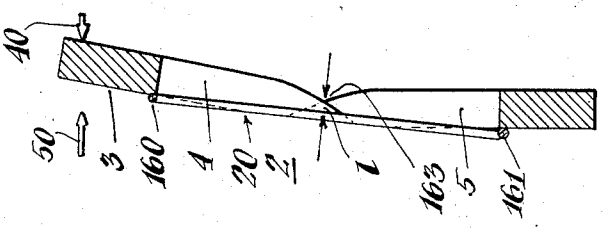


Fig. 3

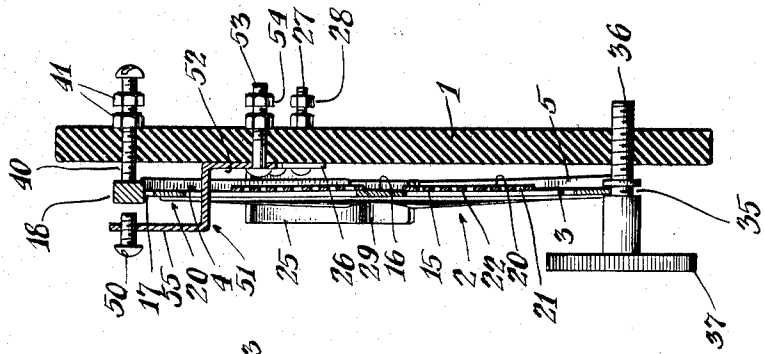


Fig. 2

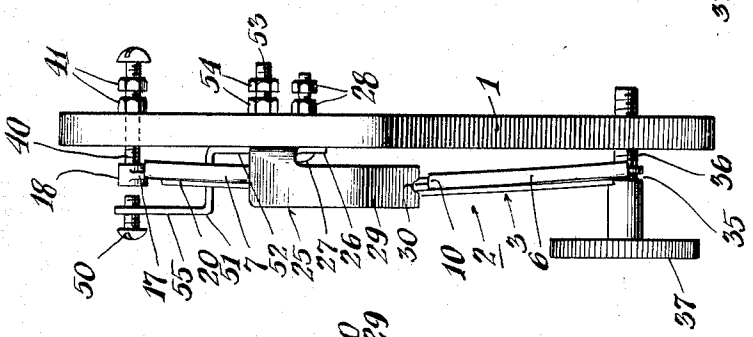
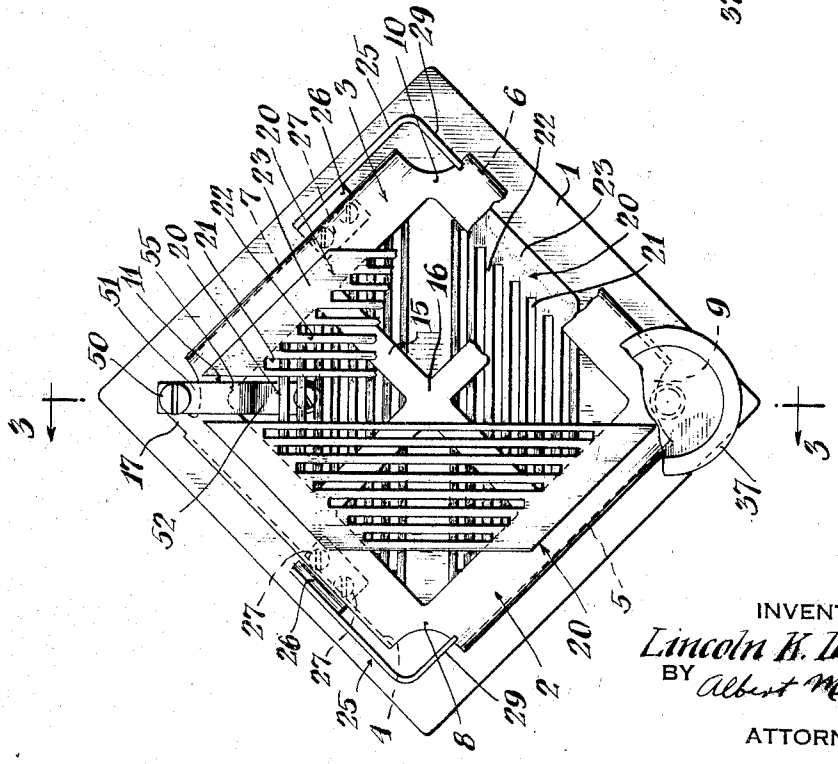


Fig. 1



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Fig. 5

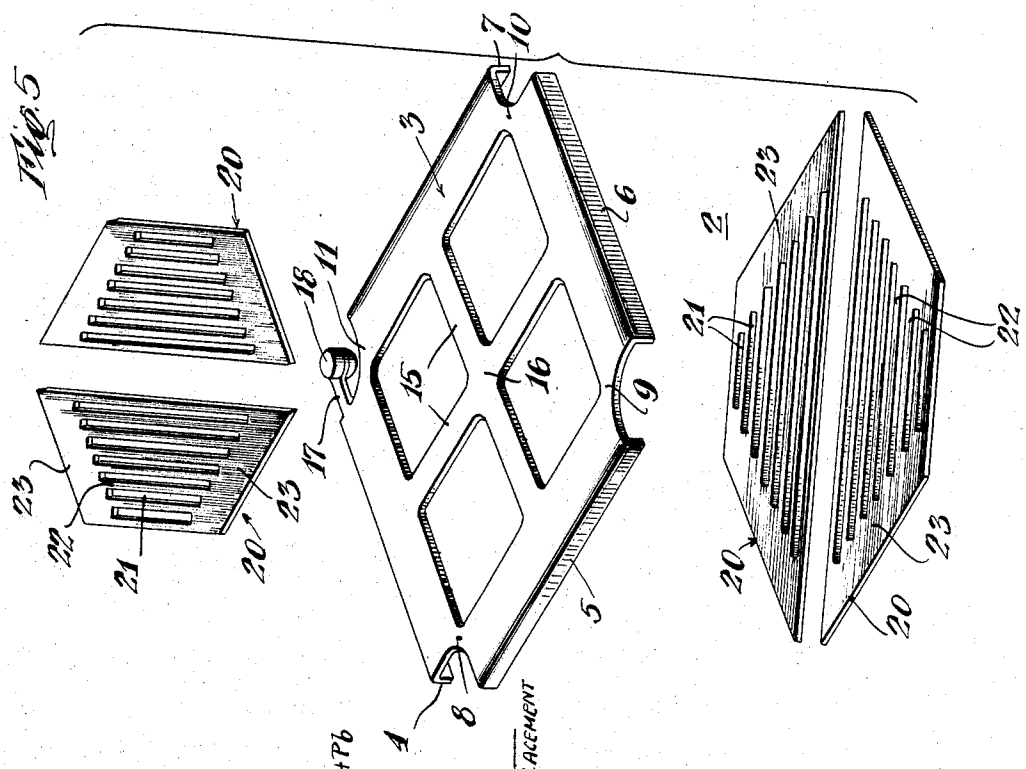
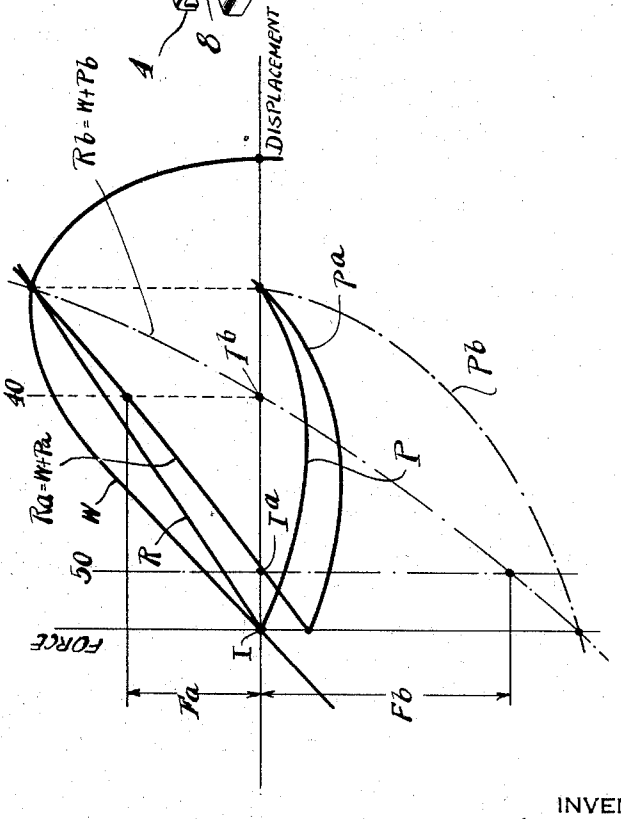


Fig. 6



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2,166,239

UNITED STATES PATENT OFFICE

2,166,239

MOVEMENT-PRODUCING DEVICE

Lincoln K. Davis, Brockton, Mass.

Application May 5, 1936, Serial No. 77,941

12 Claims. (Cl. 74—97)

This invention relates to movement-producing devices, and particularly to self-acting devices adapted to operate upon a predetermined change in dimension of the component parts produced by an external stimulus.

According to the invention, there is provided a member having relatively movable portions associated with resilient means adapted to be stressed when the movable portions are moved to predetermined positions, which tends to return the movable portions to a predetermined position or positions, and a second member is attached between spaced points on the movable portions of the first member in such a way that, upon a predetermined change in the effective relative dimensions of the connected members, a predetermined movement of the movable portions of the first member is produced.

In an illustrative embodiment of the invention, one member is formed as a frame having relatively rigid side portions connected by a flexible resilient portion, and the frame is initially stressed to cause the rigid portions to lie in a warped surface. Stresses are set up in the resilient portion when the rigid portions are moved from the warped surface, and tend to return the rigid portions to their original position. A second member is connected between spaced points on at least two of the rigid portions, and the frame and second member are adapted to undergo a relative change in their effective dimensions, upon a predetermined physical stimulus such as a change in temperature, to effect a predetermined relative movement of the rigid portions. Preferably, one or more of the rigid portions is adapted to be moved through a position of unstable equilibrium by the action of the connected member, whereby the device moves between two positions with a "snap-action".

The invention provides a device which is well adapted for use as a thermostat for indicating a change in temperature, or for actuating associated devices, which thermostat may be made extremely sensitive, quick-acting and readily adjustable.

The invention also provides a device of the class described, which is simple and inexpensive to manufacture and assemble, which may be made extremely sensitive and effective, and which is positive and efficient in operation.

Various other features and advantages of the invention will be apparent from the following particular description and from an inspection of the accompanying drawings.

This application is in part a continuation of my copending application Serial No. 15,033, filed April 6, 1935.

Although the novel features which are believed to be characteristic of this invention will be particularly pointed out in the claims appended hereto, the invention itself, as to its objects and advantages, and the manner in which it may be carried out, may be better understood by referring to the following description taken in connection with the accompanying drawings forming a part thereof, in which:

Fig. 1 is a top plan view of a thermostat constructed in accordance with the invention;

Fig. 2 is a side elevational view of the thermostat;

Fig. 3 is a transverse sectional view taken along the line 3—3 of Fig. 1;

Fig. 4 is a diagrammatic sectional view of a thermostatic unit operating similarly to that shown in Figs. 1 to 3;

Fig. 5 is an exploded perspective view showing the thermostatic unit of the thermostat shown in Fig. 1; and

Fig. 6 is a qualitative graph illustrating force-displacement characteristics of the thermostat.

In the following description and in the claims, various details will be identified by specific names for convenience, but they are intended to be as generic in their application as the art will permit.

Like reference characters denote like parts in the several figures of the drawings.

In the drawings accompanying and forming part of this specification, certain specific disclosure of the invention is made for purposes of explanation, but it will be understood that the details may be modified in various respects without departure from the broad aspect of the invention.

Referring particularly to Figs. 1, 2 and 3, there is shown a thermostat comprising a base 1, formed of suitable material such as synthetic resin or other rigid and preferably non-warping material, on which is suitably mounted a thermostatic unit 2, comprising a frame 3 and grids 20 attached thereto. The frame 3 may be square and may be formed from a thin metal sheet, the edge portions 4, 5, 6 and 7 being stiffened by bending down the edges of the sheet. The stiffened edge portions 4, 5, 6 and 7 may terminate short of each corner of the frame, and the corners may be cut to provide relatively flexible portions 8, 9, 10 and 11 connecting the stiffened side portions 4 to 7.

The side portions 4, 5, 6 and 7 may be con-

nected by a cruciform strap portion 15 integral with or suitably attached to the side portions 4, 5, 6 and 7, and stressed, preferably by peening the flexible portions 8, 9, 10 and 11, to lengthen the periphery, thus placing the strap portion 15 under tension whereby it tends to draw the opposite sides of the frame 3 toward each other. This causes the frame 2 to be warped out of flatness, and to be curved oppositely about its principal diagonals, whereby it lies in either one of two hyperbolic paraboloidal surfaces of opposite curvature. Where the "curvature" of the frame is referred to herein, it will be understood to mean the curvature of the surface in which the frame lies, rather than any curvature of the frame itself, unless otherwise expressly noted.

If desired, the warping stresses may be introduced by compressing the strap, or by indenting it, or by stretching the sides without altering the length of the strap 15. Also, the strap 15 may take the form of a single strap extending between two opposite sides of the frame; however, it is generally desirable to form it as a cross in order to prevent unsymmetrical warping of the frame.

The frame may be provided at one corner with an extension 17 having integral therewith or attached thereto a contact button 18, the function of which will appear hereinafter.

A grid 20 may be attached to adjacent side portions of the frame, and is adapted to exert a force thereon to effect movement thereof upon a predetermined change in the relative effective dimensions of the frame and grid, such as produced by a change in temperature. Preferably, a plurality of grids 20 are employed, there being a pair of grids 20 attached to each face of the frame 3, the grids on one face being on opposite sides of one principal diagonal of the frame, and the grids on the other face being on opposite sides of the other diagonal so as to extend perpendicularly to the grids on the first face. Although a single grid may be used, it is usually preferable to employ a plurality of grids, as shown, in order to prevent undesired distortion of the frame 3.

Each grid 20 may be formed from a thin sheet of metal or other suitable material, and preferably takes the shape of a trapezium having a plurality of elongated perforations 21 extending parallel to the parallel sides, to provide a plurality of elongated parallel straps 22 extending between inclined end portions 23. Each grid 20 may be attached to a frame 3 by securing the end portions 23 in a suitable manner, such as by welding, to the side portions of adjacent sides of the frame 3. The grids 20 may be attached under suitable tension so that they exert predetermined stresses on the frame at the predetermined temperatures at which the device is designated to operate. Preferably, the effective length of each strap 22, or like longitudinal portion of the grid 20, is proportional to the effective distance between the points of attachment, whereby, upon a thermally-induced change in length of the grid or frame or both, all of the straps of the grid are stressed equally and the grid is not distorted. It will be obvious as the description proceeds that the grids need not be attached so as to exert a force on the frame parallel to the diagonals, but may be inclined thereto.

The thermostatic unit 2, constituted by the frame 3 and attached grids 20, preferably is mounted on the base 1 by a pair of oppositely disposed mounting blades 25, each of which has a foot 26 secured to the base by screws 27 on which are threaded nuts 28. The blade 25 also has an arm 29 extending from the foot 26, and spaced from the base 1, and having a notch 30 in its free end adapted to receive the end edge of the adjacent side portion. Two mounting blades 25 are provided, and are adapted to engage the non-adjacent ends of the side portions 5 and 6, and to exert a force against these portions, respectively, in the direction of their point of intersection.

The corner portion 9 is adapted to seat in a circumferential groove 35 in the shank portion of an adjusting screw 36 threaded into the base 1, and having a knurled adjusting head 37. The adjusting screw 36 and the mounting blades 25 together provide means for mounting the thermostatic unit 2 on the base 1, and also for rocking the thermostatic unit 2 about the ends of the mounting blades 25, whereby the position of the contact button 18 relative to the base 1 may be adjusted.

Threaded into the base 1 in position to be engaged by the contact button 18 is a contact screw or stop 40 provided with one or more nuts 41. The stop 40 may be adjusted relative to the base 1, and thus establishes the right-hand limiting position of the thermostatic unit 2.

The left-hand limiting position of the thermostatic unit 2 is established by a contact screw or stop 50 threaded into the end of a mounting blade 51 having a foot portion 52 secured to the base by screws 53 carrying nuts 54, and an arm portion 55 spaced from the base 1. The screw 50 is adjustable in the arm 55 for adjusting the left-hand limiting position of the thermostatic unit 2.

Referring now to Fig. 4, there is shown a figure representing very diagrammatically, and with certain dimensions exaggerated, a cross-section through the thermostatic unit 2, the relatively movable portions 4 and 5 being represented as rigid bars, and one of the grids 20 is represented as a single strap attached to the portions 4, 5 at points 160, 161, respectively. The portion 5 is assumed as rigidly supported, and the portion 4 pivots about an axis 163. The grid 20 exerts a force on the portion 4 at a distance l from the axis 163. Where movement of the "frame" is referred to, it will be understood, in the present example, to mean the portion 4.

When the frame 3 is formed and the strap 15 is tensioned as described, internal stresses are set up which force the frame to assume either of two positions of opposite curvature. Both of these are stable positions wherein the bending resistance of the corner and strap portions of the frame balance the internal stresses set up by the warping operation. The frame will return toward flatness when an external force is applied; however, this causes the internal stresses to predominate, and they are released when the external force is removed and cause the frame to be returned to the position of stability with a snap movement. If the frame is symmetrically warped, the position of flatness will be one of unstable equilibrium, and the frame will be moved therefrom to either of two positions of stability when the external force is removed. If the warping is sufficiently unsymmetrical, the frame will have but one position of stability, but will have a position of unstable equilibrium.

The force-displacement characteristic of the frame is represented qualitatively by curve W of

Fig. 6, to which reference now is made. The abscissae represent the displacement from flat position of any predetermined point in the portion **4** of the frame, and the ordinates represent the corresponding force exerted by the frame at any position of curvature. The frame is assumed to be symmetrically stressed, and curve W is symmetrical in opposite quadrants; hence only one-half of the curve is shown.

If the frame is flattened and a grid is attached under no stress, and the frame is then released, the frame will tend to move out of flat position and will stress the grid, and the latter will exert a force-moment on the frame opposing the internal stresses of the frame. The force-moment exerted by the grid is the product of its tensional stress and its distance *l* from the axis **163** of moment of the frame, and this is represented by curve P of Fig. 6. The total stress exerted by the unit constituted by the frame and grid is represented by the resultant curve R, which is the algebraic sum of the curves W and P, the positive force values of which represent the force developed by the unit which urges the frame to the right and the negative values of which represent the force urging the frame to the left. The intersection I of the curve R with the displacement axis represents the position of unstable equilibrium of the frame.

Let it be assumed that the stops **50** and **40** are set at positions corresponding to I*a* and I*b*, respectively, that the frame bears initially against stop **40**, and that the temperature of the unit is decreased by T*a*. Assuming the grid to have the greater coefficient of thermal expansibility, the length of the grid between points of attachment **160** and **161**, or the "effective" length, will decrease relatively more than the corresponding effective length of the frame. Thus, the moment exerted by the grid will change to P*a* and a new resultant R*a* will be produced. It will be seen that the position of unstable equilibrium shifts to the point I*a*, and the frame bears against the stop **40** with a force F*a* toward the right.

If the temperature decreases again to the value T*b*, a further shortening of the grid relative to the frame occurs, and resultant R*b* is produced, the position of unstable equilibrium moving to I*b*. If now the temperature decreases to a value infinitesimally less than T*b*, the position of unstable equilibrium shifts to a point just to the right of I*b*, so that the resultant force on the frame reverses its direction and acts toward the left, and the frame is moved away from the right stop **40**, and moves into abutment with the left stop **50** with a snap action, and bears against this stop with a force F*b* to the left. Conversely, if the frame is at the temperature T*b*, and abutting the left stop **50**, upon an increase in temperature to a value infinitesimally more than T*a*, the position of unstable equilibrium shifts to a point just to the left of I*a*, and the frame is snapped to the right into abutment with stop **40**.

From the foregoing, it will be seen that the range of movement and the range of actuating temperature of the thermostatic unit may be adjusted throughout a considerable extent by suitably positioning the stops relative to each other and to the position of flatness of the frame. A result similar to moving the stop relative to the frame may be accomplished by tilting the frame bodily relative to the stops. This adjustment may be accomplished by means of the adjusting screw **36**, or other suitable mechanisms.

The foregoing discussion has been based upon the assumption that the grid could be considered as attached to the frame by a frictionless, pivotal connection. If the grid is connected rigidly to the frame so that the grid is caused to bend as the frame is warped, the bending stresses set up in the grid exert a leaf-spring action which opposes the warping of the frame with a force varying linearly as the displacement from flat position. Thus, the grids, when acting in this manner, cause the first derivative of the curve R to be decreased; and, hence, a greater movement of the frame is produced by a given force than where this effect is not present.

While the actuating forces result from the differential change in effective length of the frame and the attached grid, the thermostat may be made to operate even though both the frame and the grid have the same coefficients of expansion. Since the grid is attached to the frame at spaced points only, there is little opportunity for heat transference. The grid may be made to have a greater ratio of area-to-mass than the frame, whereby a sudden change in temperature will cause it to absorb heat more quickly than the frame, and thus effect operation of the thermostat. However, a slow change in temperature will allow both the frame and grid to respond equally, so that no operation will take place. It is obvious that the material or materials used in constructing this form of device must have an appreciable coefficient of thermal expansion.

Operation of the thermostat may be effected by subjecting only one element, for example, the grid, to a change in temperature whether or not both frame and grid are of the same materials. If the elements are of different composition or properties, it is evident that the element which is subjected to a temperature change must have a substantial expansion coefficient. If they are of the same material, then this material must be of a thermally-expansible type, as pointed out above. In the latter case, the thermostat as a whole will not be responsive to slow changes in temperature of the surrounding medium, but will operate only when one element undergoes a change in temperature as intended, so that ambient changes will be compensated.

In the preferred form of the device, wherein the frame and grid elements have different coefficients of thermal expansion, the frame may have a low or negligible expansiveness, while the grid may have a relatively high coefficient of expansion. Furthermore, if the grid is of less mass than the frame, has a large ratio of area to mass, is so formed—for example, by perforating—as to increase its flexibility in respect to warping and also to increase its ratio of exposed surface to mass, and is so attached to the frame that there is a minimum opportunity for heat transference between it and the other element, the thermostat will not only have a high sensitivity, but will respond very rapidly to temperature changes. Only a small quantity of heat will be required to cause operation, since but one element, which, in this example, is the grid, will have to be affected, and it is not necessary that the entire mass of both elements be brought to the same temperature at once.

While the frame may have the higher expansiveness, it is preferable that the element normally having the lesser mass have the higher coefficient, this being the grid in the preferred embodiment of the device, unless it is desired that the response be slow. It is also possible to make

the frame, or grid, or both, imperforate, in which case the speed of response may be made less and the sensitivity also diminished, if for any reason this is desired.

The frame and grids may be formed of various combinations of materials including steel, brass, nickel, aluminum, various alloys such as "invar", and others. In order to obtain maximum sensitivity, it is generally preferable to form the two elements of materials having as greatly different thermal expansibilities as possible. By way of example, in one instance, the frame was formed of "invar" and the grids of brass. However, the selection of materials will generally depend upon various factors such as, the prospective operating conditions, strength desired, cost of manufacture, ease of connecting the grid or grids to the frame, and so forth.

Various modifications may be made in the structure shown. For example, the grids may be replaced by other elements such as bars, wires, strips, plates, or other suitable members, such as suggested in my copending application referred to above. The grids or other elements may be made sufficiently rigid so as to be capable of exerting a push as well as a pull upon the frame, in which case the frame may operate either between two positions on one side of flatness, as shown, or between positions on either side of flatness.

The device also may be constructed of elements which undergo a change in length, due to stimuli other than temperature changes; for example, hygroscopic members may be substituted for the grids. The device also is capable of being employed to actuate associated apparatus such as switches, indicators and others in response to a change in the stimulus to which it is responsive, the movement of the frame being utilized for this purpose.

The thermostat shown may be readily adapted to serve as a switch, and may be used in the form shown by connecting suitable conductors (not shown) to the screw **27** and to the contact screw **40** or both screw **40** and screw **50**. The frame, or frame and grids together, may then form a portion of the circuit, which circuit is opened or closed in accordance with the position of the frame, as determined by the temperature of the thermostatic unit.

From the foregoing it will be seen that the present invention provides a movement-producing device of simple construction which can be easily formed and assembled from memebrs which can be given their final shape and properties prior to assembly. The device can be made very sensitive and is capable of simple and easy adjustment and is effective and certain in operation.

What is claimed is:

1. A movement-producing device comprising a frame having a resilient portion and relatively rigid portions relatively movable through a position of unstable equilibrium, and a flexible sheet connected between movable portions of said frame, the width of said sheet corresponding to the lengths of the movable portions to which it is connected, said frame and sheet being active upon a predetermined change in their relative dimensions to produce movement of said frame through the position of unstable equilibrium.

2. A snap-acting device comprising a frame having a resilient portion and relatively rigid portions movable through a position of unstable equilibrium, and a plurality of sheets connected between movable portions of said frame, said frame and sheets being adapted upon a predetermined change in their relative dimensions to effect movement of said frame through the position of unstable equilibrium, said sheets being disposed in at least one pair, of which the sheets lie on opposite sides of an axis of movement of said portions, to thereby produce substantially symmetrical forces on said frame with respect to said axis.

3. A movement-producing device comprising a frame element having a resilient portion and relatively rigid portions relatively movable through a position of unstable equilibrium, and a second element connected between movable portions of said frame, said second element comprising a sheet having a plurality of openings therein, providing a grid-like structure of relatively small heat capacity and relatively high flexibility.

4. A movement-producing device comprising a snap-acting frame having relatively movable portions, and a grid connected between said portions, said grid comprising a sheet having a series of slots forming a plurality of spaced elongate portions extending in the same general direction between said movable portions, said frame and grid being active upon a predetermined change in their relative dimensions to produce a snap-acting movement of said frame.

5. A movement-producing device comprising a first element having relatively rigid, elongated portions, means connecting said portions to form a generally rectangular frame and permitting relative angular movement of said portions, and means connecting at least certain of said rigid portions and adapted to be stressed in accordance with the relative positions of said rigid portions, and a second element including a flexible sheet-like member connected diagonally between at least certain of said relatively rigid portions and adapted to effect relative movement of said rigid portions upon a differential change in effective length of said elements.

6. In a device responsive to change in condition, a set of members having different response characteristics, one of said members being of relatively large extent in two dimensions and of comparatively small extent in the third dimension, said member defining a surface having intersecting diagonals, said diagonals following gradual curves throughout their lengths, one of said curves being concave and the other being convex with respect to any one face of the member, the ends of said diagonals constituting reference points, a mounting supporting any three reference points in a fixed plane, and a second member attached to said first member in such manner that change in condition causes relative movement between said mounting on the one hand and the fourth reference point on the other hand.

7. In a device responsive to change in condition, a set of first and second members having different response characteristics, said first member being of relatively large extent in two dimensions and of comparatively small extent in the third dimension, said member defining a surface having intersecting first and second reference lines, said reference lines following gradual curves throughout their lengths, one of said reference lines being concave and the other reference line being convex with respect to any one face of the member, said second member being attached to said first member in such manner that change in condition causes relative movement between parts of said device, a base, means for mounting said first member on said base at

both ends of said first reference line and at one end of the second reference line, leaving the other end of the second reference line free to move with respect to said base.

8. In a device responsive to change in external condition, a supporting member of relatively large area and relatively small thickness, a first set of parallel elongate members secured to and acting across one face of said supporting member, and a second set of parallel elongate members secured to and acting across the other face of said supporting member, said sets extending at an angle to each other, both said supporting member and said sets being of comparatively open construction to permit free access of the surrounding medium.

9. In a device responsive to change in external condition, a supporting member of relatively large area and relatively small thickness, a first set of substantially parallel elongate members secured to and acting across one face of said supporting member, and a second set of substantially parallel elongate members secured to and acting across the other face of said supporting member, said sets extending at an angle to each other, said supporting member on the one hand and said sets on the other hand constituting the essential actuating elements whose difference in response characteristics causes said device to respond to change of condition.

10. In a device responsive to change in external condition, a first element comprising a frame-like member having four, relatively movable, comparatively stiff sides, junctions between said sides, a second element comprising sets of elongate members, one set disposed on each face of said frame-like member, the elongate members of each set having their lines of action transversely disposed with respect to those of the other set, one set acting to change the distance between non-adjoining junctions on one face of said frame-like member, the other set acting to change the distance between non-adjoining junctions on the other face of said frame-like member, said elements constituting the essential actuating elements whose difference in response characteristics causes said device to respond to change of condition.

11. In a device responsive to change in external condition, a frame-like element comprising a frame having four, relatively stiff, side portions and junctions between said side portions permitting relative angular movement of said side portions, a cooperating element comprising two sets of parallel elongate members, the elongate members of one set connecting adjoining side portions of said frame on opposite sides of a pair of diagonally opposed junctions, the elongate members of the other set crossing the first elongate members and connecting adjoining side portions on opposite sides of the other pair of diagonally opposed junctions, said frame-like element and said cooperating element constituting the essential actuating elements whose difference in response characteristics causes movement of said device.

12. In a device responsive to change in external condition, a set of members having different response characteristics, each member being of substantially flat homogeneous sheet metal, one of said members comprising relatively stiff parts having a flexible joint therebetween, said parts having toggle relationship to each other, said sheet metal members having limited areas of their flat faces in direct contact and being rigidly attached together at said areas, said areas being on opposite sides of said joint, said members being unattached between said areas, whereby said members may be moved relatively toward and away from each other.

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