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Griffith et al.

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[54] **PRESSURE AND TEMPERATURE ACTUATED SWITCHES UTILIZING BELLEVILLE SPRINGS**

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[51] **Int. Cl.** **H01h 15/18**; H01h 35/34

[58] **Field of Search** .... 200/67 D, 67 DA, 67 DB, 200/76, 83 S, 83 P, 83 W, 16 D, 153 SC, 241, 243, 250, 288, 290

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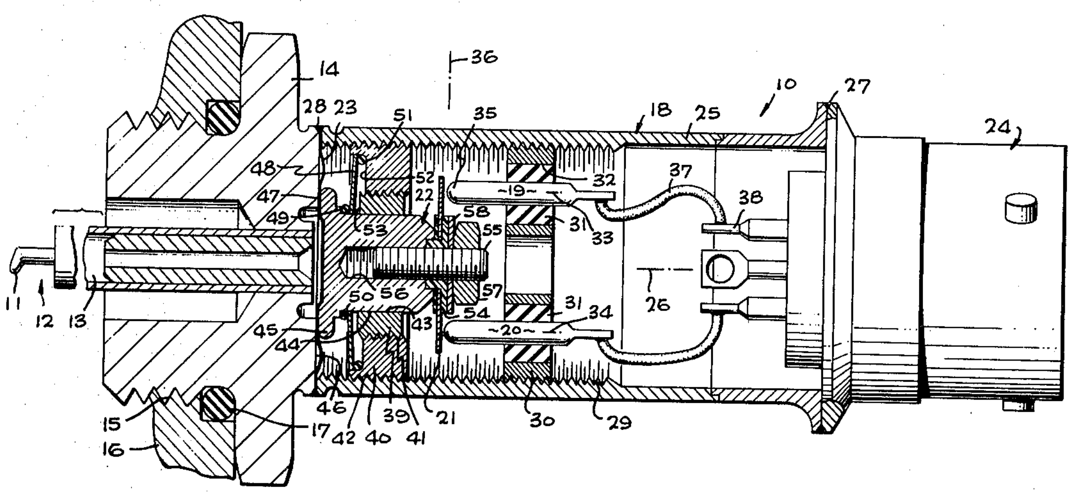
[57] **ABSTRACT**

Temperature or pressure responsive electrical switches in which movement of one contact relative to another is resisted by a belleville spring or springs having a negative spring rate giving the switch a snap action, with at least one of the contacts being mounted resiliently to deflect slightly after initial engagement of the contacts, and with the resilience of that contact having a spring rate which is positive, but of a low enough positive value to give it and the belleville spring a combined spring rate which is negative during at least an initial portion of the overtravel flexure of the contact mounting after initial engagement of the contacts, in a relation causing continuance of the snap action beyond that point of initial engagement to assure positive closure of the contacts.

23 Claims, 10 Drawing Figures



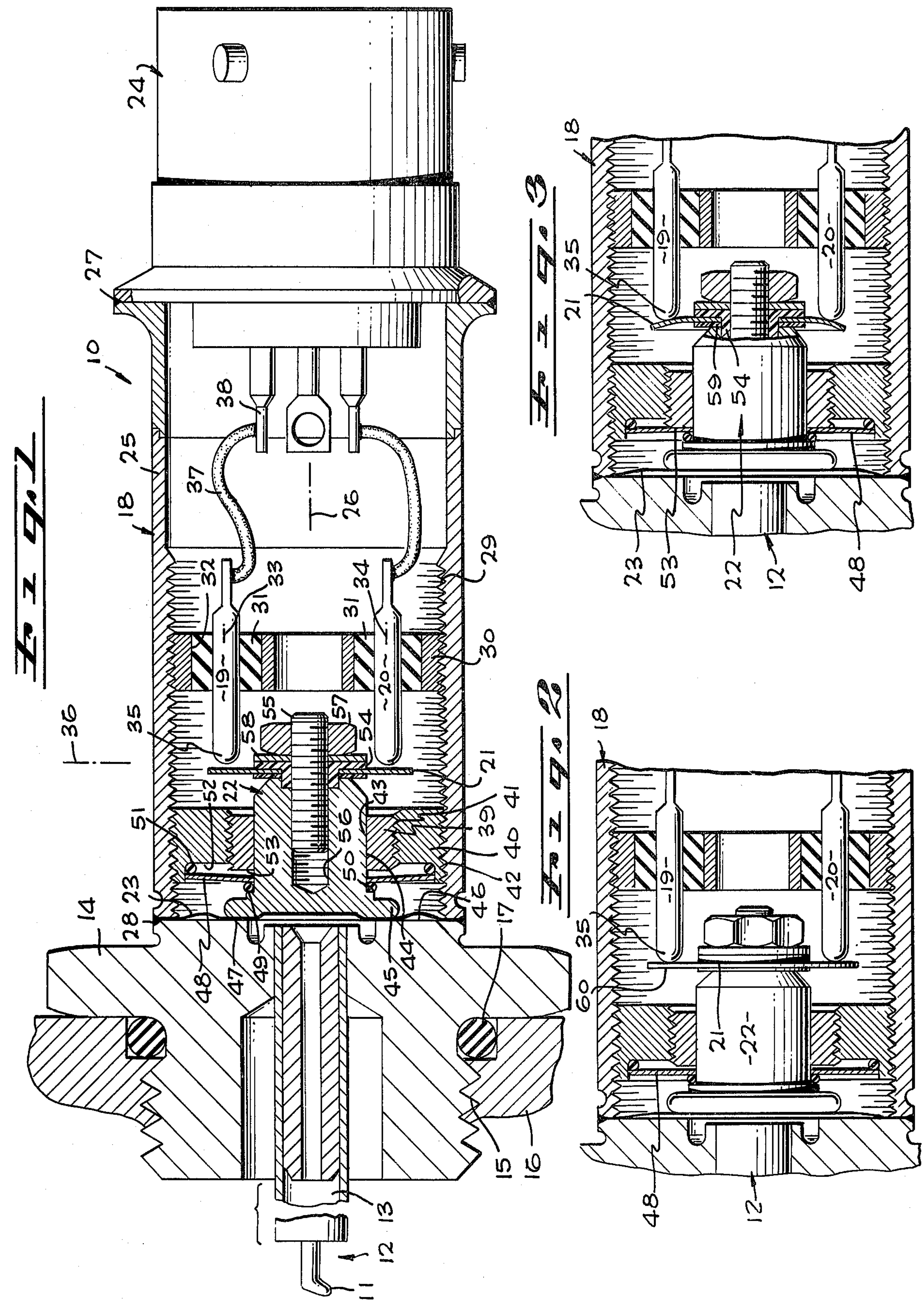


Fig. 1

Fig. 2

Fig. 3

Fig. 4

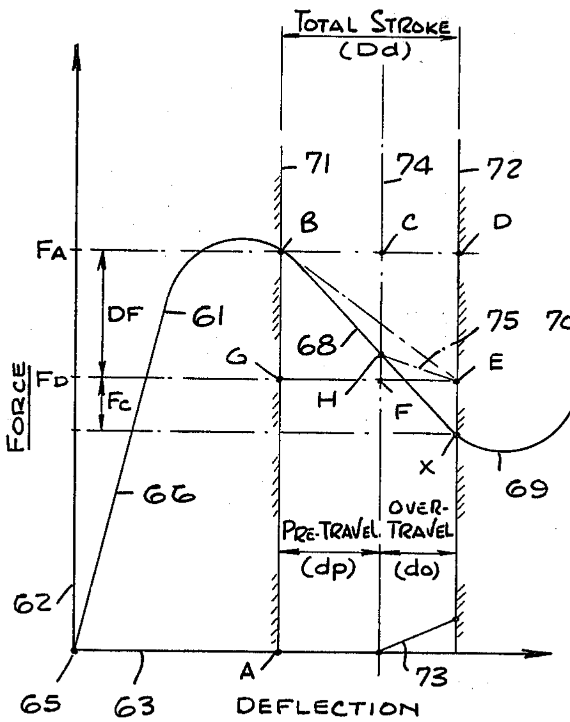


Fig. 7

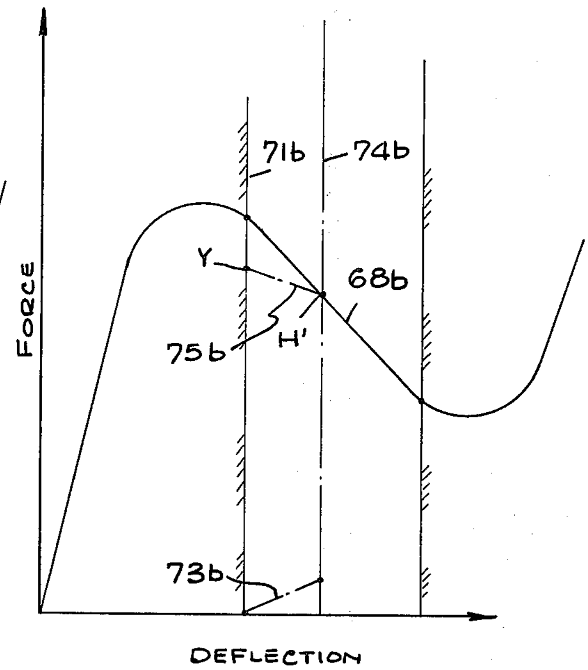


Fig. 6

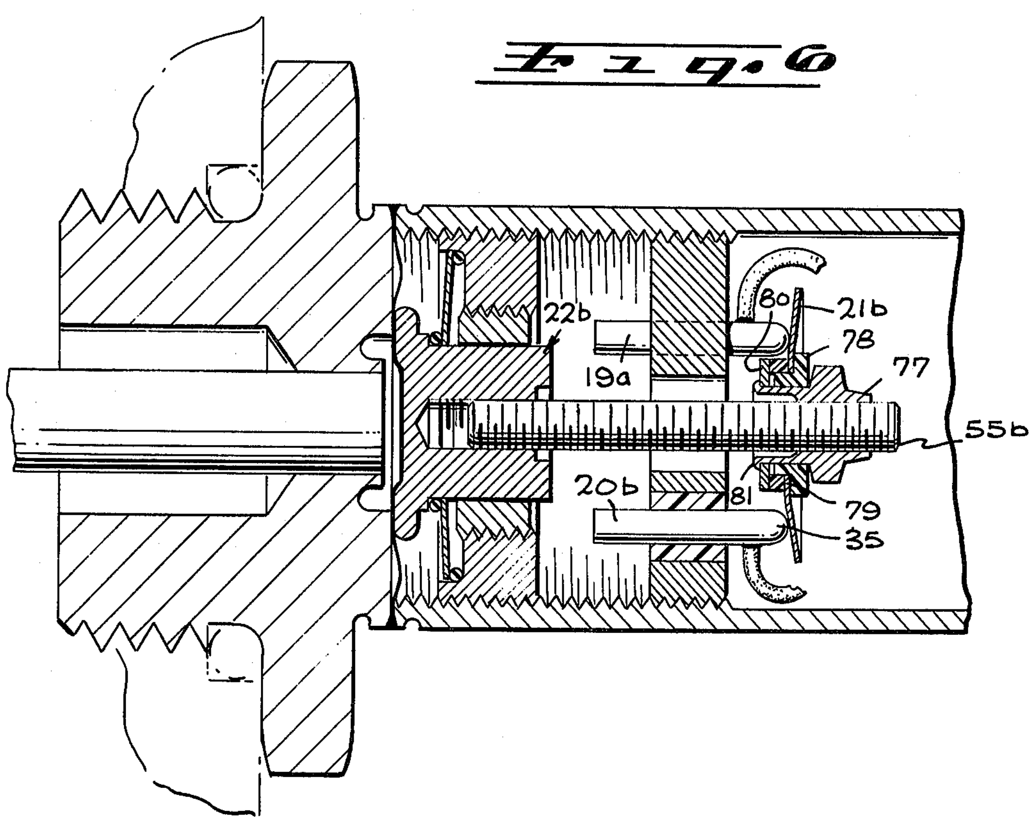


Fig. 8

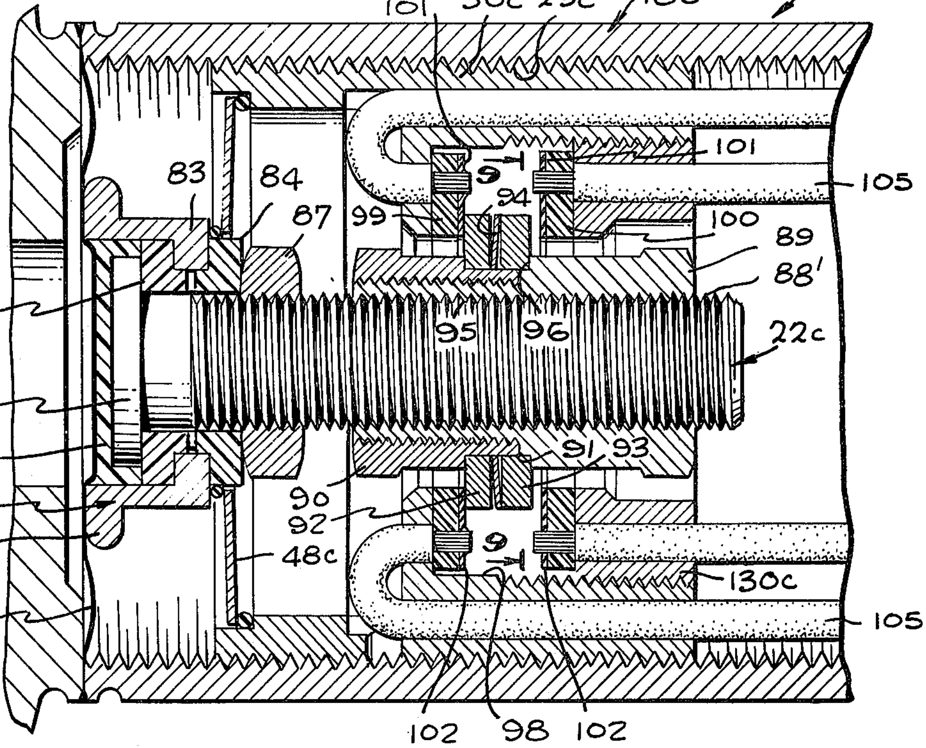


Fig. 9

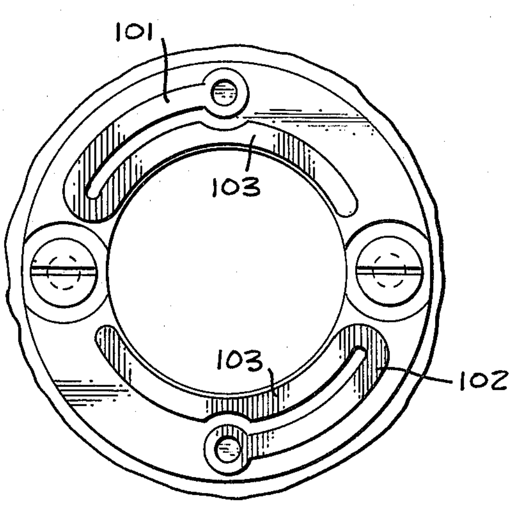
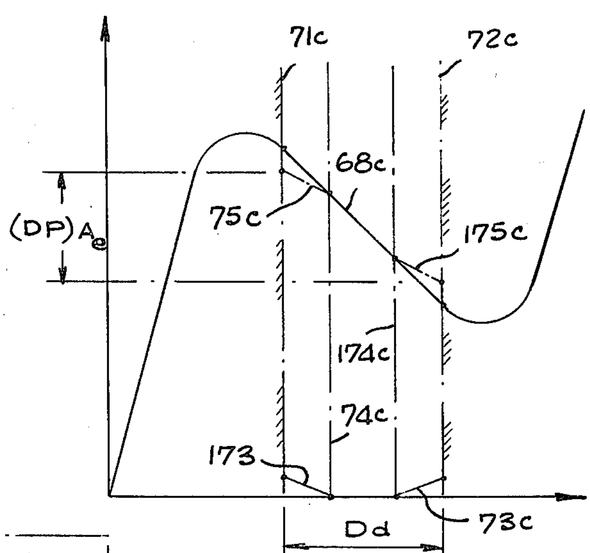


Fig. 10



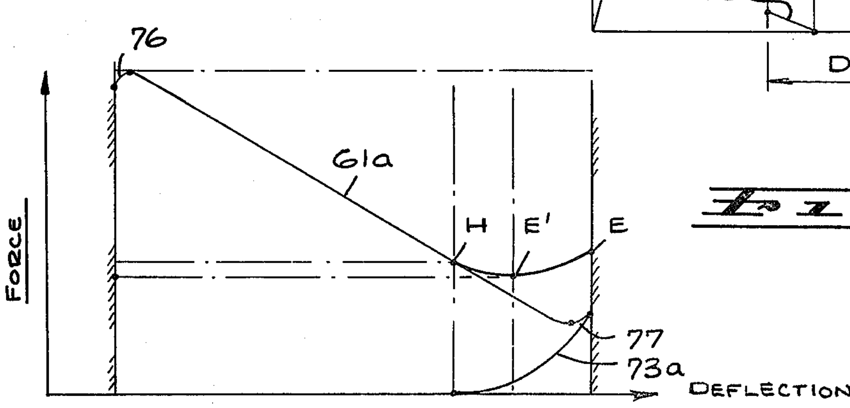


Fig. 5

PRESSURE AND TEMPERATURE ACTUATED SWITCHES UTILIZING BELLEVILLE SPRINGS

BACKGROUND OF THE INVENTION

This invention relates to improved electrical switches of a type having a snap action, and adapted to be actuated between open and closed conditions in response to a very small amount of movement of an actuating element.

There have in the past been devised temperature or pressure actuated electrical switches utilizing a "belleville" type spring for resisting the actuation of the switch to give it a snap action. Such belleville springs take the form of conically tapered rings of sheet metal or the like, which may be shaped to have a negative spring rate, so that upon application of a predetermined critical force, the spring will quickly deflect through a substantial range of movement to rapidly open or close a set of contacts. For example, a switch mechanism of this type is shown in U.S. Pat. No. 3,824,919 issued to A.V.C. Davis on Feb. 25, 1958. In the apparatus of that patent, the snap action produced by the belleville spring is utilized to actuate a microswitch, through an actuating linkage. However, in the prior belleville actuated switches of this type with which we are familiar, the force applied by the mechanism to the contacts to hold them in closed condition has not been heavy enough to assure an effective engagement of the contacts, and as a result there has been a tendency for sparking between the contacts, and resultant burning of the contacts and other damage thereto in a manner needlessly reducing the length of life over which the switches are useable. Further, the contacts have had a tendency to chatter when the actuating force nears the critical snap action value, and the switch has been generally less reliable in operation than would be desired.

SUMMARY OF THE INVENTION

The switches embodying the present invention employ the above discussed type of belleville spring actuation, but embody improvements on the prior belleville arrangements resulting in a much more effective and positive engagement of the contacts upon closure of the switch, and a much more reliable and predictable actuation of the contacts into and out of engagement. In particular, there is no condition in the present switches in which the force holding a pair of contacts closed is light enough to permit indecisive action of the switch and chattering of the contacts relative to one another. Instead, once the condition is reached at which the contacts move into engagement, the movement of the contacts continues to a point at which one contact is urged against another with a very substantial force, sufficient to assure positive and reliable maintenance of an electrical connection therebetween and prevent sparking or burning of the contact surfaces. The same is true during a switch opening operation, in which the contacts commence movement from a condition of reliable and full contact and make a very clean break from one another without possibility of hesitation or indecisiveness at the instant of separation.

Structurally, these results are achieved largely by provision of an arrangement in which one or more of the switch contacts are mounted for resilient deflection relative to a carrier structure, in a particular unique relationship with respect to a belleville spring or springs

of the above discussed type. This relationship is such that, during a closing movement of a pair of contacts, two structures carrying those contacts first move relative to one another to a position in which the contacts engage and close a circuit therethrough, and then have further 'overtravel' relative movement which deflects one of the contacts relative to the structure by which it is carried and against the resilience of the mounting of that contact, to assure full and positive interengagement of the contacts in a reliably conductive relation. In order to hold the contacts in tight engagement during this overtravel, the parts are so designed that the spring rate of the belleville spring or springs is more negative than the spring rate of the resilient mounting of the contacts during the overtravel movement. Further, in order to assure continuance of the rapid snap action motion of the contacts past the point of initial engagement of the contacts and into the overtravel region, the spring rates are given values such that the combined or resultant spring rate of the belleville and the resilient contact mounting together will be negative during a substantial portion of the travel into the overcenter range and beyond the point of initial engagement of the contacts. Desirably, this overall combined spring rate of the two elements remains negative through at least about one-fourth of the overtravel range of movement, and optimally through that entire range, up to a point of limitation of the overtravel movement by engagement with associated stop means.

The resilient mounting of the contact is in one case attained by forming the contact itself as a resilient member, desirably a disc, having a first portion which engages another contact and a second portion which flexes to allow axial deflection of the first portion. In another arrangement, the resilient mounting may take the form of a second belleville spring. In one form of the invention, a double throw switch is provided having a pair of contact elements whose resilient mounting is attained by provision of a spring element axially between the two contacts.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other features and objects of the invention will be better understood from the following detailed description of the typical embodiments illustrated in the accompanying drawings in which:

FIG. **1** is an axial section view through a first form of temperature or pressure actuated switch constructed in accordance with the invention;

FIG. **2** is a fragmentary representation of a portion of the FIG. **1** switch, showing the contacts and the actuating mechanism as they appear at precisely the point of initial engagement of the contacts;

FIG. **3** is a view similar to FIG. **2,** but showing the mechanism at the end of its overtravel movement;

FIG. **4** is a graph or diagram representing in somewhat idealized form the theory of operation of the switch of FIGS. **1** to **3**;

FIG. **5** is a graph similar to FIG. **4,** but representing the functioning of the device as it may be affected by frictional forces and other forces encountered in an actual operating mechanism;

FIG. **6** is a fragmentary axial section through a variational form of the invention;

FIG. **7** is a graph representing the operation of the FIG. **6** switch;

FIG. 8 is an axial section through another variational arrangement;

FIG. 9 is a section taken on line 9—9 of FIG. 8; and

FIG. 10 is a graph representing the operation of the device of FIGS. 8 and 9.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1, I have shown a switch 10 which may be adapted for response to variations in either temperature or pressure conditions; and which is typically illustrated as responding to the pressure of a confined body of liquid and vapor within an inner sealed chamber 13 in a temperature probe 12. The right end of the probe in FIG. 1 is connected to a mounting element 14, which may be threadedly connected into an opening 15 in a support structure 16, being sealed by an O-ring 17 or the like.

The switch assembly 10 includes a hollow rigid housing or body part 18 carrying a plurality of stationary contacts 19 and 20 which are engageable with a movable contact 21 mounted to a part 22 which is actuated by the pressure of vapor within the probe through a diaphragm 23. In the FIG. 1 form of the invention, there are illustrated for simplicity and clarity two of the contacts at diametrically opposite locations, though in most instances it is preferred that three or more contacts be employed, spaced evenly about axis 26 of the switch. At its right end, the body 18 may carry a suitable electrical connector 24, such as a conventional plug or receptacle, to which a mating connector may be attached for providing external electrical connections to the stationary contacts 19 and 20. The purpose of the switch is to make and break an electrical circuit between contacts 19 and 20 through movable contact 21 in response to changes in the pressure within probe 12 (or within any line or chamber which may be connected to the switch in substitution for the probe).

The body 18 of the device has an essentially cylindrical wall 25 centered about axis 26 and suitably secured at one end to the mounting part 14, as by an annular weld 27, and similarly secured at its opposite end to connector 24 as by a weld 28. Internally, the side wall 25 of body 18 has a series of threads 29 toward its left end as viewed in FIG. 1, into which an annular rigid part 30 may be threadedly connected, with the engagement of the thread being sufficiently tight to frictionally retain part 30 in any set position while at the same time permitting adjustment of that part axially by forced rotation relative to threads 29. Part 30 carries the previously mentioned rigid contacts 19 and 20, which may be carried by insulators 31 located within openings 32 in part 30. The contacts 19 and 20 may be identical, and take the form of externally cylindrical pins extending along and centered about a pair of axes 33 and 34 parallel to and spaced equal distances in opposite directions from axis 26. At their left ends, pins 19 and 20 may be convexly and preferably hemispherically rounded at 35, to present leftward extremities lying in a common plane 36 disposed transversely of axis 26. At their right ends, contacts 19 and 20 may be electrically connected by short leads 37 to a pair of terminals 38 respectively of the electrical connector 24.

The movable part 22 which carries contact 21 may be guided for movement along axis 26 by reception within a guide ring 39 which is mounted for adjustment relative to an outer ring 40 by threads 41 having sufficient friction to retain ring 39 in any desired set position relative to ring 40. Externally, the ring 40 has threads 42 which engage and are adjustable relative to internal threads 29, and are frictionally retained in any set position relative thereto. Internally, the inner ring 39 has a cylindrical inner surface 43 slidably engaging a cylindrical external surface 44 to guide part 22 for the desired axial movement. At its left end, part 22 has an annular flange 45 engaging diaphragm 23 and adapted to press that diaphragm against a transverse surface 46 of element 14 at 47 in a relation limiting the leftward movement of part 22 in the FIG. 1 position. The diaphragm 23 is of course fluid tight, and is peripherally secured to part 14 in any appropriate manner, as by the weld 27, and may extend entirely across the left face of part 22.

At the right side of flange 45 of part 22, there is provided about surface 44 a belleville spring 48. This spring is formed of sheet metal or other similar sheet material extending generally transversely of axis 26 and forming a ring centered about that axis. The belleville spring is given a conically tapering configuration, as seen clearly in FIG. 1, to advance gradually in a rightward direction as it advances radially outwardly. The inner annular edge portion of belleville spring 48 engages leftwardly against a rigid ring 49 typically formed of an appropriate metal and having the circular cross section illustrated in FIG. 1, with this ring 49 in turn bearing leftwardly against an annular shoulder 50 formed on part 22. The outer peripheral edge of belleville spring 48 bears rightwardly against a rigid ring 51 typically of circular cross section as shown, which in turn bears rightwardly against a transverse shoulder 52 on part 40. The pressure within probe 12 acts to displace part 22 rightwardly against the yielding resistance offered by belleville spring 48, with the rightward movement of part 22 being limited by engagement of the inner portion of belleville spring 48 with a transverse annular end surface 53 formed on part 41 (see FIG. 3).

The flexible contact disc 21 is mounted to the right end of part 22 by reception about an annular insulator 54 received about a screw 55 connected into a threaded bore 56 in part 22. A nut 57 and washer 58 tighten the insulator 54 and contact 21 against part 22, with an insulator 59 preventing engagement between contact 21 and the right end of part 22. Contact 21 is preferably a flat annular disc of an appropriate resiliently deformable metal, such as copper, whose inner peripheral edge is clamped to part 22 as discussed, and which projects outwardly from that peripheral edge to provide an annular free portion 60 of conact 21 lying in a plane disposed transversely of axis 26 and engageable simultaneously with pin contacts 19 and 20 upon rightward movement of contact 21 (see FIG. 2).

To describe a cycle of operation of the FIG. 1 device, assume that the switch is initially in the open condition of FIG. 1, in which part 22 and contact 21 are moved leftwardly to the leftward limit of their range of movement, as determined by engagement of flange 45 with diaphragm 23 and engagement of diaphragm 23 with surface 46. The parts are urged leftwardly against stop surface 46 by the resilience of belleville spring 48 in the FIG. 1 setting. As the temperature at 11 then increases, the corresponding increase in pressure of the liquid contained within probe 12 ultimately reaches a point at which it overcomes the force of belleville spring 48, and actuates part 22 and contact 21 rightwardly from the FIG. 1 position to the FIG. 3 position in which the motion is limited by engagement of the belleville spring with stop surface 53 of part 39. Since the belleville washer is to constructed and adjusted as to have a negative spring rate through this entire permitted range of travel between the FIG. 1 and FIG. 3 extreme positions, the rightward movement of parts 22 and 21 will be instantaneous and of the snap action type.

In this connection, attention is directed to FIG. 4 which represents graphically at 61 the force-deflection curve of belleville spring 48, with force being measured along the vertical coordinate 62 and deflection being represented along the horizontal coordinate 63. As force and deflection increase from the origin 65 of this curve, the curve has an initial portion 66 with a positive spring rate, that is, in which the resistance offered or force exerted by the spring increases as the deflection of the spring increases. At the location 67, this curve gradually changes direction to form a portion 68 of the curve in which element 48 has a negative spring rate, that is, the resistance offered or force exerted by the spring decreases as deflection increases. Ultimately, the curve 61 reaches a point 69 at which it curves back upwardly to have a final positive spring rate portion 70. The stops are so located that the entire range of permitted travel of parts 22 and 21 is within the negative spring rate portion 68 of curve 61, between a point B and a point X in FIG. 4. This limitation of movement is illustrated in FIG. 4 by the vertical line 71 which represents the position of the left stop surface 46 in FIG. 1, and by the vertical line 72 which represents the position of the right stop surface 53 in FIG. 1.

At an intermediate position between the extreme positions of FIGS. 1 and 3, contact 21 moves into initial engagement with contacts 19 and 20 as seen in FIG. 2. The movement of parts 22 and 21 from the FIG. 1 position to the FIG. 2 position may be referred to as a 'pre-travel' range of movement, while the movement of part 22 from the FIG. 2 position to the FIG. 3 position may be referred to as an 'over travel' range of movement. During this over travel interval, the contact disc 21 is deflected against its own resilience from the FIG. 2 position to the FIG. 3 position, and therefore adds its spring force tending to resist movement of part 22 from the FIG. 2 position to the FIG. 3 position. Contact 21 is preferably so designed that its spring rate is positive, as distinguished from the negative effective rate of the belleville element, within the over travel range. Stated somewhat more broadly, it is desirable that the spring rate of belleville element 48 be more negative than that of contact 21 within the over travel range. The preferred positive spring rate of contact 21 is represented at 73 in FIG. 4, and is in effect added to the negative spring rate of the belleville 48 to produce beyond the vertical line 74 of FIG. 4 representing the point of initial engagement of the contacts a composite spring rate 75 consisting of the sum of the spring rates of elements 48 and 21. To assure a proper snap action in accordance with the present invention, the spring rate of element 21, though preferably positive, is of a sufficiently low positive value to assure that the combined spring rate 75 as it advances rightwardly beyond the point H of FIG. 4 will still be negative, that is, sloped downwardly, for a substantial distance beyond the point H and into the overtravel range d_o, desirably at least about one-fourth of that range. In the optimum arrangement represented in FIG. 4, this negative rate continues through the entire overtravel range, from the point H to the point E at which rightward movement of part 22 is halted positively by stop surface 53. Because the combined spring rate 75 is thus kept negative into the overtravel range and beyond the point H of FIG. 4, the snap action induced by the negative value of the spring rate between points B and H continues beyond the point H to rapidly move contact 21 all of the way from its FIG. 1 position to its FIG. 3 position. Thus, there is no hesitation in the FIG. 2 initial contact setting, but rather there is full movement of the contacts into the completely engaged condition of FIG. 3 in which the resilience of contact 21 acts to hold it in tight engagement with contacts 19 and 20, and prevent chattering or the like in the FIG. 2 setting. Similarly, upon opening movement of the contacts, part 22 moves rapidly leftwardly from the FIG. 3 setting to the FIG. 1 setting, without hesitation at or near the FIG. 2 setting, by virtue of the fact that the effective spring rate of the system throughout this entire range of movement is negative.

To recapitulate the functioning of the switch of FIGS. 1 to 3 in a somewhat different fashion, and with reference primarily to the graph of FIG. 4, as the pressure tending to move part 22 rightwardly in FIG. 1 increases from the point A of FIG. 4 to the point B, there is no contact movement until the actuation force F_A is attained, at which time the mechanism becomes unstable and 'snaps' from point B to point D, through deflection Dd. After accelerating through the pre-travel range d_p, the contacts engage at point C, initiating electrical contact. As the 'snap' deflection continues, contact loading increases by deflecting the shunt disc by the amount of the over travel d_o.

At the end of the snap deflection, the mechanism impacts against the decreasing pressure stop surface 53, and returns instantaneously to a stable condition maintained by a differential force DF. Contact load is maintained at F_c, which is determined by deflection d_o and the disc characteristics. Upon a decreases in pressure, the force applied to the belleville mechanism decreases from point D to the deactuation load F_D at point E in FIG. 4, at which time the mechanism again becomes unstable and snaps from point E to point G through deflection Dd. The shunt disc 21 maintains electrical contact until point F, where the mechanism is accelerating to move rapidly through point F and break the contact cleanly and completely without hesitation, by virtue of the discussed negative spring rate in both the pre-travel and over travel regions. On contact with the leftward stop surface 46, the mechanism returns instantaneously to a stable condition maintained by a differential force DF.

The arrangement of FIGS. 1 to 3 allows sufficient adjustability to assure maintenance of the above discussed full snap action of the switch. For example, the force levels F_A and F_D at which the switch snaps from open to closed position and vice versa may be adjusted by moving elements 39 and 40 of FIG. 1 relative to one another and relative to surface 46. The total stroke of the system can be similarly adjusted by varying the positions of parts 39 and 40 relative to one another. Contact gap, pre-travel, over travel, and contact load are altered by moving element 30 and its carried contacts 19 and 20 relative to the contact 21.

The switch structure of FIG. 1 has numerous advantages over and above the primary advantage discussed above relating to continuance of the snap action beyond the point of initial engagement of the contacts, and the resultant opening and closing of the contacts during acceleration of the mechanism. Specifically, the flexible contact disc **21** has the advantage of having an extremely low mass and high resonant frequency, a very large heat dissipation area, and no friction or pivot points or points of relative motion in the contact structure. Further, the contact loads attained by this mechanism can be measured in pounds rather than grams, to eliminate teasing, deadbreak, etc., and the contact load, gap, and other characteristics can be easily adjusted as discussed.

In FIG. **4**, the spring rates of the belleville spring and contact **21** are both assumed to be linear within the range of movement of the parts. In an actual installation, this may not be for practical reasons be completely true. Consequently, FIG. **5** shows a similar graph of a variational arrangement in which it is assumed that the belleville spring force-deflection characteristic is not a linear function, and the slight resilience of the end stops and effects of friction tend to further produce nonlinear force-deflection characteristics. In FIG. **5**, the primarily negative rate portion of curve **61***a* of the belleville spring may have short positive rate portions **76** and **77** at its opposite ends, and the spring rate **73***a* of the contact **21** may also have a similar upward curve, so that the resultant curve beyond the point H of initial contact may first advance downwardly from H to E′, and then curve upwardly from E′ to E. The combined curve therefore has a negative portion of substantial extent from H to E′, beyond the point of initial engagement of the contacts and into the overtravel region, but may have a final portion of positive spring rate. While this is not as optimum a relationship as that shown in FIG. **4**, the primary advantage of FIG. **4** is still attained since the negative spring rate from point H to E′ assures continuance of the snap action rightwardly beyond the point of initial engagement of the contacts, so that the apparatus does not stop at that point of initial engagement but develops a substantial contact load preventing chattering, burning of the contacts, etc.

FIG. **6** shows another form of the invention which may be considered as identical with that of FIGS. **1** to **3**, except that the stationary contacts **19***b* and **20***b* are reversed, to have their rounded extremities **35** at their right ends, with the contact disc **21***b* being engageable with those right ends of the contacts in the leftward rather than rightward position of part **22***b*. The FIG. **6** arrangement is also typically illustrated as one in which there are three of the stationary contacts, located at evenly circularly spaced positions for engagement with disc **21***a* at correspondingly spaced points.

To mount contact **21***b*, the screw **55***b* has been lengthened as compared with the corresponding screw **55** of FIG. **1**, and threadedly and adjustably mounts a carrier part **77**, to which disc **21***b* is secured by two insulative clamping rings **78** and **79** tightened against the contact **21***b* by a washer **80** retained by an annular turned flange **81** of part **77**.

In FIG. **6** leftmost position of contact **21***b*, that contact is deflected against its resilience to maintain a contact load with respect to elements **19***b*, **20***b*, etc. As the contact **21***b* moves rightwardly, this load is progressively decreased to the point of initial engagement of the contacts, beyond which contact **21***b* moves out of engagement with the stationary contacts to a fully opened position. The belleville spring of the FIG. **6** arrangement has a negative spring rate through substantially its entire permitted range of movement, as represented at **68***b* in FIG. **7**, while the spring contact **21***b* preferably has a positive rate as represented at **73***b* in FIG. **7**, but of a low enough value that the combined spring rate **75***b* is still negative, so that the part **22***b* will have a snap action through substantially its entire range of movement, including at least a substantial portion of the distance from point H′ to point Y, and into the overtravel range between the vertical line **74***b* and **71***b*. More particularly, the snap action continues through the line **74***b* of initial contact and into the overtravel region, to prevent hesitation at the point of initial engagement of the contacts, as discussed previously.

FIGS. **8** and **9** show another form of the invention, consisting of a switch **10***c* having a double pole, double throw action. In FIG. **8**, part **22***c* is actuated rightwardly under the influence of temperature induced pressure at the left side of diaphragm **23***c* and flange **45***c* of a part **82** having a flange **83** which is clamped with two insulator rings **84** and **85** against an end flange **86** of part **22***c* by a nut **87**. An insulative cup shaped head cover **88** may be provided about flange **86** and suitably secured thereto. The reduced diameter externally threaded portion **88′** of part **22***c* carries at a threadedly adjustable location an outer sleeve **89** carrying a ring **90** forming with part **89** an annular peripheral groove **91** within which two contact rings **92** and **93** are received. A belleville spring **94** may be received axially between the two rings **92** and **93**, to urge them yieldingly apart and against two annular end shoulders **95** and **96** defining the ends of groove **94**, whose inner wall **97** may be cylindrical.

A main belleville spring **48***c* serves the function of spring **48** of FIG. **1**, in yieldingly urging part **22***c* and the connected parts leftwardly relative to the outer body **18***c* of the switch. Body **18***c* has inner threads **29***c* within which a tubular member **30***c* is retained in a position which is fixed by friction but forceably adjustable. Part **30***c* and a connected part **130***c* form together an annular radially inwardly facing recess or groove **98**, at the opposite ends of which are mounted two insulative rings **99** and **100**, each rigidly carrying in fixed position at its axially inner side two circularly spaced approximately semicircular contacts **101** and **102** (see FIG. **9**), whose inner arcuate portions **103** are located axially opposite and adapted to engage the outer transverse faces **104** of the contact rings **92** and **93**. The contacts **101** and **102** carried by each ring **99** or **100** are connected to appropriate leads **105** so that ring **92** can form a shunt connection between the contacts **101** and **102** of ring **99**, and the ring **93** can form a shunt connection across the contacts **101** and **102** of ring **100**.

When the part **22***c* of FIG. **8** is in its leftmost position (slightly to the left of the position illustrated in FIG. **8**), contact **92** is in engagement with contacts **101** and **102** of ring **99**, but contact **93** is out of engagement with the corresponding contacts of ring **100**, as shown. Also, the leftward force exerted by main belleville spring **48***c* acts through shoulder **96** to urge ring **93** leftwardly in a manner compressing belleville spring **94** against its resilience, to thereby yieldingly urge contact **92** against contacts **101** and **102** on ring **99** with a substantial contact load maintaining effective electrical connection at this point.

When the rightward force on part **22**c increases to a point at which it can overcome the force of belleville spring **48**c, part **22**c snaps from its leftmost position to a rightward position in which ring **93** moves into engagement with the contacts on ring **101,** and ring **92** moves out of engagement with its contacts. That overall range of travel of the part **22**c includes three successive subranges, during a first of which shoulder **96** allows rightward movement of contact ring **93** and shoulder **95** moves into engagement with ring **92,** following which there is an intermediate range of travel in which elements **92, 93** and **94** move rightwardly together with part **22**c, with both of the contacts **92** and **93** out of engagement with the respective elements **101** and **102,** until part **93** reaches a point of initial contact with contacts **101** and **102** on ring **100,** following which there is a third range of movement in which shoulder **95** causes ring **92** to compress spring **94** and put a load on the contacts. In consistency with the other forms of the invention, the springs of FIG. **8** are so designed as to maintain an overall effective spring rate which is negative through most of the range of travel of part **22**c, and preferably that entire range of travel, or at the very least through the center range and portions of both of the end ranges (the overtravel ranges) beyond the points of initial engagement of the contacts. This relationship is brought out by the FIG. **10** graph, in which the portion **68**c of the spriing rate curve with the range of movement Dd of part **22**c, between the stop locations **71**c and **72**c determined by the positions of full compression of spring **94,** has a negative spring rate. The points of initial contact of rings **92** and **93** with the engaged stationary contacts are represented at **74**c and **174**c, in FIG. **10.** Between these two lines **74**c and **174**c, the switch is open, while within each of the overtravel regions beyond these lines one of the switches is closed. In FIG. **10,** it is assumed that element **94** has a positive spring rate, as represented at **73**c and **173**c, which positive rate is added to the negative spring rate **68**c of belleville spring **48**c at opposite ends of the travel to form combined spring rates **75**c and **175**c. It is contemplated more broadly, however, that element **94** may if desired in some instances have a slightly negative spring rate, so long as it is kept less negative than that of main spring **48**c within the overtravel regions.

The combined spring rate **75**c in FIG. **10** is negative for a substantial distance leftwardly of the line of initial contact **74**c, and preferably for substantially the entire distance from line **74**c to line **71**c, while the combined spring rate **175**c is negative for a substantial distance rightwardly of line **174**c, and preferably for the entire distance from that line to line **72**c. Thus, upon movement in both directions, the combined negative rates assure snap action through both of the initial contact regions defined by lines **74**c and **174**c in FIG. **10,** to attain the advantages of positive and rapid making and breaking of the electrical connections discussed above in connection with the other forms of the invention. The positive stop locations represented at **74**c and **174**c are determined by arrival of spring **94** at predetermined conditions of maximum compression, beyond which it cannot be compressed further by main belleville spring **48**c. Preferably, these positive stop conditions occur when the normally conical belleville spring **94** reaches a completely flattened condition, in which it is clamped tightly between rings **92** and **93** and transmits forces directly therethrough without possibility of further deflection. This flattened condition occurs when part **22**c is slightly to the left of the position illustrated in FIG. **8.**

It will of course be understood that the smewhat idealized curves of FIGS. **4, 7** and **10** can be varied to account for variations in the spring rates or other factors at the ends of the travel of the parts in the manner represented in FIG. **5,** and the advantages of the invention will be attained so long as a combined negative spring rate is maintained beyond each point of initial engagement of a pair of contacts, and for a substantial distance into the associated overtravel range of movement.

Theoretical Analysis of Certain Spring Rate and Load Considerations:

To further clarify the present disclosure, it may be helpful to set forth a brief mathematical analysis of certain aspects of one of the preferred embodiments of the invention. Accordingly, the following discussion is given of the system whose actuation curve is represented in FIG. **4,** in which the springs have the optimum characteristic of a combined negative spring rate continuing throughout the entire range of movement of part **22.** In this discussion, it will be assumed for simplicity that all spring rates are linear, and that any spring rate of the sensor (diaphragm **23**) is negligible with respect to the spring rates of belleville **48** and contact **21.**

In commencing the discussion of FIG. **4,** the "system spring rate" (R_{sys}) may be defined as the algebraic summation of the spring rates of all elements comprising the system. R_{sys} is determined by the desired deadband (DP), system stroke (Dd), and sense area (A_e) chosen, i.e., for a negative rate system:

$$R_{sys} = (DP.A_e/Dd)$$

where "deadband" is defined as the difference between actuating and reset pressures, i.e., increasing and decreasing pressure settings (typically in pounds per square inch); and "sense area" is the theoretical equivalent surface area (typically in square inches) that would produce the same force per unit pressure differential as the diaphragm sensor being used.

Since it is assumed that the sensor spring rate is negligible:

$$R_{sys} = \epsilon R = R_{bv} + R_d'$$

Because the shunt disc **21** is deflected only during a portion of the system stroke, its effective or apparent spring rate (R_d') is lower than its actual spring rate (R_d). The effective disc rate is:

$$R_d' = (F_c/Dd) = (R_d\ d_o/Dd)$$

Then

$$R_{sys} = (-DP{\cdot}A_e/Dd) = R_{bv} + (F_c/Dd) - DP{\cdot}A_e/Dd = R_{bv} + (F_c/Dd)$$

Or

$$DP = -\ (R_{bv} \cdot Dd + F_c/A_e)$$

In order to prevent creep (graduating motion associated with force changes on a positive spring rate) prior to "snap" action, Point E should optimally always remain below Point H (in terms of force level), i.e., the line HE should have a negative slope.

From the plot:

$$F(E) = F_d$$

and:

$$F(H) = F_d - F_c - d_o R_{br}$$

For line HE to have negative slope:

$$F(E) - F(H) \leq 0$$

Or:

$$F_d - F_d + F_c + d_p R_{br} \leq 0$$

$$F_c + d_p R_{br} \leq 0$$

$$R_d\, d_o + d_p\, R_{br} \leq 0$$

$$d_o\,(R_{br} + R_d) \leq 0$$

The limiting case is:

$$R_{d_{max}} d_o + d_o R_{br} = 0$$

$$R_{d_{max}} = -R_{br}$$

In which case the maximum contact load is:

$$F_c = d_o R_d$$

$$F_{c_{max}} = d_o\, R_{d_{max}} = -\, d_o R_{br}$$

$$F_{c_{max}} = -\, d_o\, R_{br}$$

While certain specific embodiments of the present invention have been disclosed as typical, the invention is of course not limited to these particular forms, but rather is applicable broadly to all such variations as fall within the scope of the appended claims.

We claim:

1. A switch comprising a first structure, a second structure mounted for movement along an axis relative to said first structure, belleville spring means resisting movement of said second structure axially relative to the first and having a negative spring rate, a pair of first contacts carried by one of said structures at axially spaced locations and facing axially toward one another, a pair of second contacts carried by the other structure and received axially between the contacts of said first pair and engageable therewith respectively upon axial movement of said second structure in opposite directions relative to said first structure, said second contacts being free for limited axial movement relative to one another and relative to said other structure, and spring means axially between said second contacts and yieldingly urging them relatively apart.

2. A switch as recited in claim **1,** in which said spring means comprise second belleville spring means.

3. A switch comprising a hollow body, a part mounted for movement within said body along a predetermined axis, a belleville spring having a radially inner portion acting against said part and a radially outer portion acting against said hollow body and yieldingly resisting axial movement of said part, said belleville spring having a negative spring rate, two contact rings extending about said part and having radially inner portions received within a peripheral groove in said part and free for limited axial movement therein relative to one another and relative to said part, an additional spring interposed axially between said contact rings and urging them relatively axially apart, and first and second contacts carried by said body at locations radially outwardly of said part and at opposite axial sides of said rings and engageable with said rings respectively upon movement of said part in opposite axial directions.

4. A switch as recited in claim **3,** in which there are two of said first contacts simultaneously engageable with a first of said rings to close a circuit therethrough upon movement of said part in one axial direction, there being two of said second contacts engageable with the other ring upon movement of said part in the opposite axial direction.

5. A switch as recited in claim **3,** in which said additional spring and said belleville spring have together a combined spring rate which is negative through at least a portion of the travel of said part at each end of its travel after initial engagement of said rings with said first and second contacts.

6. A switch comprising:

a housing structure;

a belleville spring carried by said housing structure centered about a predetermined axis and having a portion movable along said axis relative to the housing structure;

a carrier structure movable along said axis with said portion of the belleville spring;

two stops limiting said axial movement of the carrier structure at two spaced locations and at opposite ends respectively of a range of movement;

said belleville spring having a negative spring rate through the major portion of said range of movement;

first contact means including a thin resilient movable contact carried by and movable with said carrier structure and disposed generally transversely of said axis, said movable contact having a radially inner portion connected to said carrier structure and a resiliently distortable radially outer portion with an outer free edge; and

second contact means including a plurality of stationary contacts carried by said housing structure and positioned to engage and progressively resiliently distort said outer portion of said thin movable contact at different locations about said axis as said carrier structure moves within a first portion of said range of movement near a first end of said range;

said stationary contacts being so positioned that said movable contact is out of engagement therewith through a second portion of said range of movement at the opposite end of said range, and moves into and out of engagement at an intermediate point in said range;

said movable contact having a spring rate which is positive at said intermediate point and for a substantial distance therebeyond within said first portion of said range of movement;

all spring forces acting on said carrier structure, including those of said belleville spring and said movable contact, having a combined effective spring rate which is negative at said intermediate point and for a substantial distance in both directions from said point.

7. A switch as recited in claim **6,** in which said stationary contacts are a plurality of contact pins extending generally axially at different locations spaced apart circularly about said axis and having rounded ends engageable with said thin movable contact.

8. A switch as recited in claim **6**, in which said movable contact is an essentially circular flat disc disposed transversely of said axis.

9. A switch as recited in claim **6**, in which said belleville spring yieldingly urges said movable contact in a direction away from said stationary contacts.

10. A switch as recited in claim **6**, in which said belleville spring yieldingly urges said movable contact in a direction toward said stationary contacts.

11. A switch as recited in claim **6**, including electrical insulator means mounting said movable contact to said carrier structure in electrically insulated relation.

12. A switch as recited in claim **6**, including a locating structure mounted within said housing structure and containing an opening slidably receiving said carrier structure and guiding it for movement along said axis.

13. A switch as recited in claim **6**, including a locating part disposed about said carrier structure and containing an opening closely receiving and guiding said carrier structure for axial movement, one of said stops comprising a shoulder formed on said locating part.

14. A switch as recited in claim **6**, including a locating part containing an opening slidably receiving said carrier structure and guiding it for said axial movement, one of said stops being a shoulder formed at an end of said locating part and engageable with an inner portion of said belleville spring at one side thereof to limit movement thereof, said carrier structure having a shoulder at the oyposite side of said belleville spring exerting force thereagainst in a direction toward said locating part.

15. A switch as recited in claim **6**, including a mounting part having external threads adjustably engaging internal threads within said housing structure and taking force in a first axial direction from a radially outer portion of said belleville spring, and a locating part having external threads adjustably engaging internal threads within said mounting part and containing an opening slidably receiving and locating said carrier structure and guiding it for axial movement, one of said stops being a shoulder formed at an end of said locating part and engageable with an inner portion of said belleville spring at one side thereof, said carrier structure having a shoulder at the opposite side of said belleville spring applying force against the inner portion of the belleville spring in a direction toward said locating part.

16. A switch as recited in claim **6**, including means mounting said movable contact to said carrier structure for relative adjusting movement.

17. A switch as recited in claim **6**, in which said carrier structure includes a first carrier part movable axially with said portion of the belleville spring, and an externally threaded screw projecting axially from said carrier part, there being a contact holding structure carrying said movable contact and threadedly engaging said screw in a relation enabling adjustment of said contact carrying structure and said movable contact axially relative to said carrier part.

18. A switch as recited in claim **17**, including a part mounted to said housing and carrying said stationary contacts and located axially between said carrier part and said movable contact and containing an opening through which said screw extends.

19. A switch as recited in claim **6**, including means mounting one of said first and second contact means to a corresponding one of said structures for relative adjusting movement along said axis to enable adjustment of the amount of distortion of said movable contact at one end of its range of movement.

20. A switch as recited in claim **6**, including a mounting part carrying said stationary contacts and connected to said housing structure for adjusting movement with the stationary contacts along said axis to adjust the amount of distortion of the movable contact at one end of its range of travel.

21. A switch as recited in claim **20**, in which said mounting part has external threads engageable with internal threads in said housing structure to effect said axial adjustment thereof, there being insulators connecting said stationary contacts to said mounting part in electrically insulated relation.

22. A switch as recited in claim **21**, in which said stationary contacts are axially extending pins having rounded ends, said movable contact being a flat circular disc disposed directly transversely of said axis, there being an insulator structure mounting an inner edge of said disc to said carrier structure in electrically insulated relation, a second mounting part having external threads adjustably engaging internal threads within said housing structure and taking forces exerted by a radially outer edge of said belleville spring, a locating part having external threads engaging internal threads within said second mounting part and having an inner axially extending passage slidably receiving and guiding said carrier structure for axial movement, one of said stops being an end shoulder formed on said locating part and engageable with an inner edge portion of said belleville spring to limit its movement in one direction, said carrier structure having a shoulder exerting force toward said locating part and against said inner edge portion of said belleville spring.

23. A switch as recited in claim **22**, including a part projecting from said carrier structure and through an opening in said first mounting part and carrying said movable contact for threaded adjusting movement relative to said carrier structure with said movable contact and carrier structure at opposite axial sides of said first mounting part.

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