PRESSURE ACTUATED SNAP ACTION ELECTRIC SWITCH
UTILIZING AN IMPROVED BELLEVILLE SPRING
Filed Dec. 1, 1966

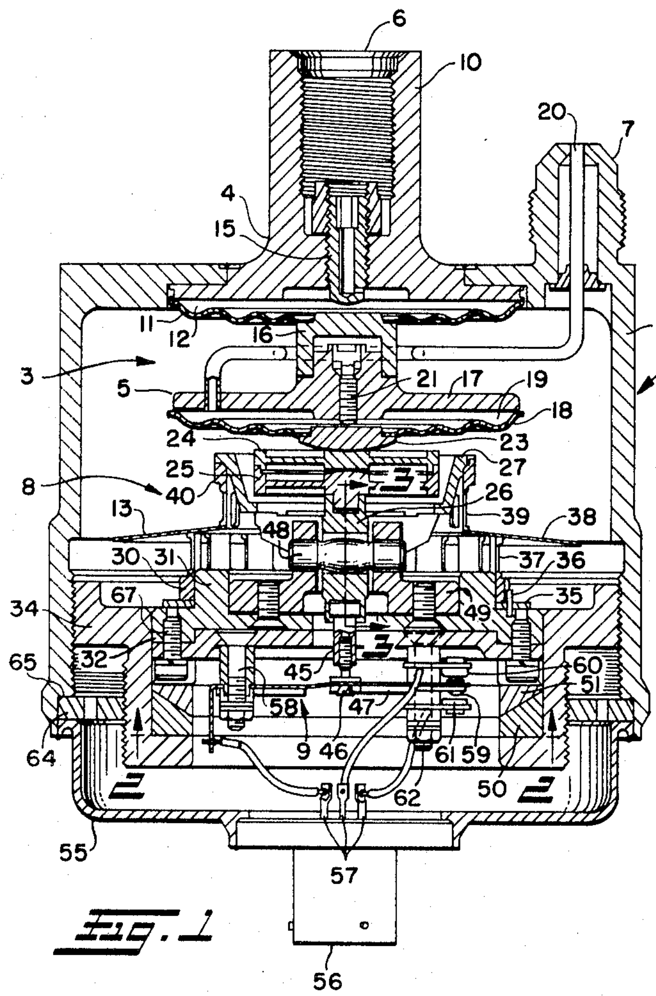


Fig. 1

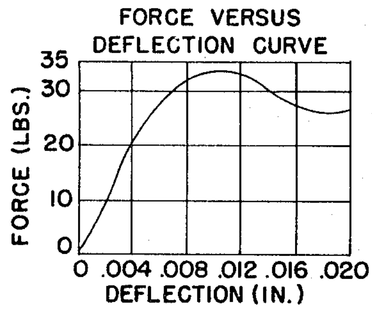


Fig. 5

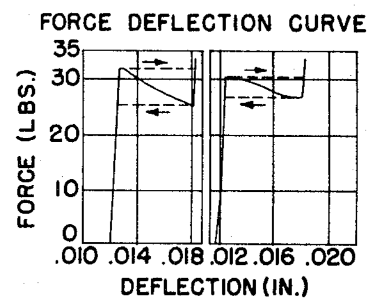


Fig. 6

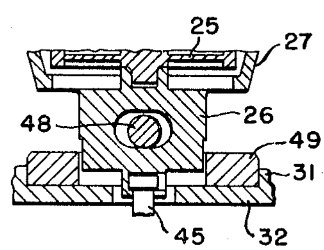


Fig. 3

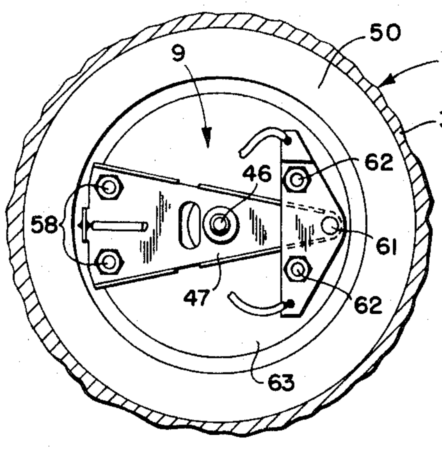


Fig. 2

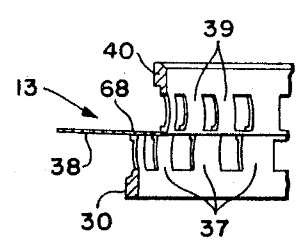


Fig. 4

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# PRESSURE ACTUATED SNAP ACTION ELECTRIC SWITCH UTILIZING AN IMPROVED BELLEVILLE SPRING

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U.S. Cl. 200—83 28 Claims

## ABSTRACT OF THE DISCLOSURE

A fluid pressure actuated switch including a movable contact which is actuated upon deflection of a snap action Belleville spring by a flexible diaphragm.

The present invention relates generally as indicated to a pressure operated electric switch and more particularly to a snap action switch which employs a Belleville spring operating in the negative spring rate portion of its force-stroke curve whereat the deflection increases as the load decreases.

It is a principal object of this invention to provide a pressure operated electric switch of the type aforesaid, which maintains a high degree of accuracy even during vibration and throughout a broad range of temperature change, for example, from +300° F. to −423° F.

It is another object of this invention to provide in a snap action switch a novel form of flexure pivoted Belleville spring which virtually eliminates friction and which provides for mass balancing thus to achieve true snap action with high vibration resistance and to achieve exceptional accuracy and repeatability with predictable performance and without first cycle stick.

It is another object of this invention to provide a pressure operated electric switch having calibration and system capsules arranged in series and equalized so that the switch will be actuated by predetermined pressure whether introduced in the calibration capsule or in the system capsule whereby operation of the switch may be checked by pressure in the calibration capsule from any convenient source without requiring operation of the fluid system.

It is another object to provide a negative rate spring assembly for effecting snap action of the switch element wherein the spring rate of the assembly may be accurately adjusted with the use of parts that do not require high dimensional accuracy. This is accomplished by arranging one or more high positive rate springs (herein called a complier) in series with a low negative rate spring so that relatively large variations in the rate of the complier due to relatively wide dimensional tolerances will result in only small changes in the negative rate of the spring assembly.

It is another object of this invention to provide a pressure operated electric switch which as aforesaid is temperature compensated to accurately maintain its set point over a wide range of temperatures.

It is another object of this invention to provide a pressure operated electric switch in which the entire assembly of moving parts is mass balanced to minimize response to acceleration and environmental vibration.

It is another object of this invention to provide a pressure operated electric switch having novel means for adjusting the preload and deflection of the Belleville spring.

It is another object of this invention to provide a pressure operated electric switch which has only a minute on-off differential which is on the order of 2% of the maximum pressure setting and in which the repeatability is on the order of 0.1% for any given environmental condition.

Other objects and advantages of the present invention



will become apparent as the following description proceeds.

To the accomplishment of the foregoing and related ends, the invention, then, comprises the features hereinafter fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail a certain illustrative embodiment of the invention, this being indicative, however, of but one of the various ways in which the principle of the invention may be employed.

In said annexed drawings:

FIG. 1 is a cross section view of a pressure operated electric switch embodying the present invention;

FIG. 2 is a bottom plan view as viewed upwardly along the line 2—2, FIG. 1;

FIG. 3 is a fragmenetary cross section view taken substantially along the line 3—3, FIG. 1;

FIG. 4 is an enlarged fragmentary cross section view of a novel form of Belleville spring employed in the present switch showing the same in its deflected switch actuating condition;

FIG. 5 is a typical force-stroke diagram of the Belleville spring herein; and

FIG. 6 is a graph illustrating the snap action of the switch herein.

Referring now in detail to the drawings, the pressure operated switch **1** herein comprises a housing **2** having therein: (1) a fluid pressure sensing assembly **3** including calibration and sensing capsules **4** and **5** in series providing respective calibration and system pressure sensing ports **6** and **7**; (2) a spring assembly **8**; and (3) a switch assembly **9**.

### Fluid pressure sensing assembly 3

As best shown in FIG. 1, the calibration capsule **4** comprises a body **10** secured as by welding to the housing **2**, and a corrugated metal diaphragm **11** peripherally secured as by welding to the flange of said body **10** and defining therewith a chamber **12** into which fluid under pressure is adapted to be introduced through the calibration port **6** and adjustable stop screw **15**; the stop screw **15** being abuttingly engaged by the fitting **16** fixed to the center of said diaphragm **11** when the switch **1** is actuated by pressure in the system capsule **5**.

The fitting **16** has a telescopic fit and abutting engagement with the body **17** of the system capsule **5** for centering the capsules **4** and **5** with respect to each other and for moving the body **17** when fluid under pressure of magnitude sufficient to deflect the diaphragm **11** is introduced into the chamber **12**. The body **17** has a corrugated metal diaphragm **18** peripherally secured thereto as by welding to define a chamber **19** which is communicated with the system port **7** of the housing **2** through a tube **20** which has a spring rate so small in comparison with the spring rate of the diaphragm as to have negligible effect on the spring rate of the diaphragm **18**. The body **17** also has a stop screw **21** which cooperates with the fitting **23** at the center of the diphragm, said fitting being engaged with complier plates **24–25** which, in turn, are engaged with the bridge portion **26** of a force and motion transmitting ring **27**, the latter being engaged with a Belleville spring **13** and being coupled to the switch assembly **9**.

The diaphragms **11** and **18** of the calibration and sensing capsules **4** and **5** are preferably of equal diameter, thickness, and material so as to have equal spring rates whereby if there is a gap between the stop screw **21** and the fitting **23** of the sensing capsule **5** there should also be a like gap between the stop screw **15** and fitting **16** of the calibration capsule **4** and thus when fluid under pressure is introduced into the calibration chamber **12**, the deformation of the calibration diaphragm **11** will move the body **17** of the sensing capsule **5** downwardly to engage the stop screw **21** with the fitting **23**, whereafter the sensing capsule **5** will move downwardly in unison to apply downward force and motion on the complier plates **24–25**. Similarly, when the calibraton chamber **12** is vented and fluid pressure is admitted into the system sensing chamber **19**, the body **17** of the sensing capsule **5** and the fitting **16** of the calibration capsule **4** will move upwardly until the fitting **16** abuts the adjusting screw **15** whereupon the fitting **23** of the sensing capsule **5** will apply downward force and motion on the complier plates **24–25**.

When the pressure switch **1** is connected, for example, to a large tank, it is often impractical, time-consuming, and expensive to pressurize the entire tank merely to test the pressure switch **1** to be sure that it is operating properly and, therefore, in the present case, the pressure switch **1** is provided with a calibration port **6** which actuates the diaphragm **11** which has the same characteristics as the system diaphragm **18**. Thus, when predetermined pressure is introduced into the chamber **12** behind the calibration diaphragm **11** its central fitting **16** is forced downwardly to actuate the system capsule **5** downwardly with the same force as through desired system pressure were in the system chamber **19**. In this way, the operating characteristics of the pressure switch **1** may be checked without having to pressurize the tank or other unit to which the system port **7** is connected for normal operation of the pressure switch **1**.

If both capsules **4** and **5** have identical preloads and effective areas, then that would obviously produce equal actuation pressures. In addition, if they had equal spring rates, then the on-off differentials would be the same. Of course, manufacturing variations inevitably cause the preloads, and effective areas to be unequal. As previously pointed out, there are positive stops **15** and **21** in the respective capsules **4** and **5** which provide means for adjusting these variations. These positive stops **15** and **21** may, but do not have to be, in contact with respective center fittings **16** and **23** when the pressure switch **1** is in the unpressurized state. It is only necessary when the system port **7** is pressurized that the calibration capsule **4** bottoms against its stop **15** before the pressure switch **1** actuates. Similarly, when the calibration port **6** is pressurized it is necessary that the system capsule **5** bottoms against its stop **21** before the actuation pressure is reached. With equal spring rates, equal preloads require equal deflections of the capsules **4** and **5** from their free position. This deflection consists of two components, i.e., the deflection of the capsule **4** or **5** in the installed and unpressurized state and the additional deflection thereof when pressurized to actuation pressure. Because the capsules **4** and **5** are in series they will exert equal axial forces assuming that neither internal stop **15** nor **21** is bottomed. Each capsule **4** and **5** must, therefore, experience additional deflection when it alone is pressurized in order that the preload force of the system capsule **5** will be the same when it actuates the pressure switch **1** as the preload force of the calibration capsule **4** when it actuates the pressure switch **1**. This means that in the installed unpressurized state, each capsule **4** and **5** will have an equal gap at its internal stop **15** and **21**.

In practice, the positive stop **21** of the system capsule **5** is preset so that it will bottom out at a small percentage of the actuation pressure. The positive stop **15** of the calibration capsule **4** is adjusted to make the system and calibration actuation pressures identical. Then, the entire spring assembly **8** hereinafter described will be adjusted to deflect both capsules **4** and **5** simultaneously a distance sufficient to give the exact preloads that produce desired actuation pressure. As a practical matter, the manufacturing variations in the diaphragms **11** and **18** are not of sufficient significance as to make necessary any adjustment for unequal spring rates thereof. The variations in preload and effective area are taken care of as described above.



## Spring assembly 8

The spring assembly **8** includes a negative rate Belleville spring **13** and positive rate complier spring plates **24**, **25** arranged in series. Spring **13** is fabricated from a single piece of spring metal which has a rigid circular base **30** located coaxially within the housing **2** by reason of its close fit over the upstanding annular boss **31** of a ring **32** disposed in an adjustable carrier **34**. Between the circuit base **30** and the ring **32** there may be a spacer shim **35** for adjusting the initial deflection and hence the preload of Belleville spring **13** and both the shim **35** and the Belleville spring **13** are keyed against rotation with respect to the ring **32** as by means of the dowell pin **36**. Extending vertically from the base **30** are a circular series of flexible columns **37** which may be radially thickened, as shown, where they join the circular base **30** and the Belleville spring portion **38**, the latter being in the form of a coned or dished washer. Extending upwardly from the Belleville spring portion **38** at a diameter smaller than the juncture of the lower columns **37** are another circular series of flexible columns **39** which may also be radially thickened as shown, when joined to the Belleville spring portion **38** and to the upper rigid ring portion **40**.

Telescoped within and abutting the upper ring portion **40** is the force and motion transmitting ring **27** to the bridge **26** of which force and motion is transmitted from the system capsule **5** or from the calibration capsule **4** as previously mentioned through the intervening complier plates **24–25**. The ring **27** and Belleville spring **13** are keyed together as shown to prevent relative rotation. The lower end of said bridge has secured therein a motion transmitting rod **45** which is adjustably connected to the stud **46** of the movable contactor **47**. The bridge **26** has an opening therethrough which is vertically larger than the center barrel-shaped portion of the pin **48** which extends across the upper bifurcated end of the stop member **49**, the ends of said pin being anchored in the stop member **49**.

Between the ring **27** and the system capsule **5** are the so-called complier plates **24–25** through which movement of the system capsule **5**, either by pressure in the calibration chamber **12** or in the system chamber **19**, is transmitted to the ring **27** to the upper ring portion **40** of the Belleville spring **13**.

In the present case the Belleville spring **13** is of negative rate and is used to provide a negative spring rate for spring assembly **8** to cause snap-action operation of the switch element. Of course, the magnitude of the negative spring rate of spring assembly **8** will determine the on-off differential of the pressure switch **1**. The purpose of the complier **24–25** is to provide a precise, convenient, and practical method of adjusting the negative rate of the spring assembly **8** so that the pressure switch **1** will have the desired on-off differential. Adjustment is necessary because Belleville spring **13** cannot be manufactured to spring-rate tolerances so close as to preclude the necessity for individual adjustment or selection of springs where, for example, the on-off differential is to be held to tolerances as close as plus or minus 1% of actuation pressure.

Because complier **24–25** is a positive rate spring in series with the negative rate Belleville spring **13**, decreasing the rate of the complier **24–25** increases (makes more negative) the negative rate of the assembly. However, the complier **24–25** is quite stiff, that is, of high rate, as compared to the Belleville spring **13** and because of this, large changes in complier **24–25** spring rate cause only small changes in spring rate of the assembly. It is therefore easy to establish the desired negative rate of the assembly within close limits by pairing an appropriate set of complier plates **24**, **25** with a given Belleville spring **13**. As shown, the complier **24–25** is simply a pair of flat metal plates **24** and **25** nested one within the other, the spring rate of which is varied by varying the plate thickness.

With any given Belleville spring **13**, complier plates **24**, **25** from a relatively wide thickness range may be used and still have the negative rate of the assembly fall within the desired close range and thus the compliers need not be manufactured to close tolerances. Where the complier **24–25** contacts other pressure switch parts or contacts other compliers as shown, a thickened rim or hub is provided as shown to prevent deflections at the points of contact which could introduce friction forces detrimental to the accuracy of the pressure switch **1**.

With reference to temperature compensation, in order to cancel out the change in setting caused by temperature, a compensating change in setting is introduced by changing the deflection of the sensing capsule **5** with temperature. Because the sensing capsule **5** has a high positive constant spring rate, small changes in sensing capsule **5** deflection will cause the required compensatory pressure setting change. This is done by repositioning according to temperature, the entire spring **8**-positive stop **48–49** assembly which is, in effect, a self-contained module which rests on a device which may be called a thermal compensator comprising an Invar ring **50** mated with a steel or aluminum ring **51** and the wedge-shaped cross section of the rings **50** and **51** together with the difference in coefficients of thermal expansion thereof causes the height or thickness of the said compensator to vary with temperature in a controlled manner.

A snap action pressure switch **1** which actuates at a certain pressure as pressure is increased, will deactuate or snap back to the original state at a pressure level which is always lower than that required to cause actuation. This difference between actuation pressure and deactuation pressure is necessary in order to store energy to power the snap action switching. This difference is the on-off differential and the magnitude thereof depends on the net negative spring rate of the pressure switch mechanism and, therefore, depends on the negative spring rate of the spring assembly **8**. Because the force-deflection curve of spring assembly **8** is not a straight line (see FIG. 5), the effective spring rate depends on the location of the positive stops **48–49** for spring assembly **8** between which it operates the pressure switch. If changes in temperature were permitted to change the location of the positive stops **48–49** relative to the spring assembly **8**, this would change the effective negative spring rate of the spring assembly **8** and would, in turn, result in a change in on-off differential. The typical force deflection curve shown in FIGS. 5 and 6 shows how rapidly the spring rate can change for even a few thousandths inch change in positive stop position. The positive stops **48–49** for the spring assembly **8** therefore are located in the close proximity to the spring assembly **8** and the entire spring **8**-positive stop **48–49** assembly is designed as a self-contained module constructed from materials having substantially identical coefficients of thermal expansion. Despite temperature changes, this keeps the positive stops **48–49** at the same relative location on the spring assembly **8** force-deflection curve. This feature substantially simplifies the task of insuring that pressure switch performance does not vary with temperature. In FIG. 6 the dotted lines show the snap action motion of the flexure pivoted spring assembly **8** installed between positive stops (left curve without electrical contactor forces and right curve with electrical contactor forces.)

Accordingly, one of the novel features of the present pressure switch temperature compensation arrangement is the use of the wedge type compensator rings **50** and **51** to provide the compensating movement and embodying such compensating movement of the entire spring **8**-positive stop **48–49** assembly so as to leave the spring assembly **8** centered in the snap action region while obtaining the compensation from the change in sensing capsule **5** preload.

### Switch assembly 9

Secured as by welding in the lower end of the housing **2** is a cap **55** to which is welded an electrical receptacle **56** having contact pins **57** to which switch leads are connected as shown. As best shown in FIGS. 1 and 2, the movable contactor **47** is mounted at one end on posts **58** between insulating sleeves for flexing in the manner of a cantilever beam and having weakened flexible sections adjacent the intermediate actuator stud **46**. The free end of the flexible contactor **47** is provided with contacts **59** which alternately engage the normally closed and normally open contacts **60** and **61**, respectively, said contacts **60** and **61** being mounted on screw posts **62** between insulating sleeves. As hereinafter described, the flexible contactor **47** is preferably preloaded when in the FIG. 1 position, and when the pressure switch **1** is actuated, the normally open contact **61** is similarly engaged by contact **59** with load on the contactor **47**. In this way, the switch contacts **59** and **60** or **59** and **61** will remain in engagement despite environmental vibration of the pressure switch **1** and moreover, the spring contactor **47** has a high natural frequency and is mass balanced further to resist contact chatter under conditions of vibration.



The switch plate **63** which carries the spring contactor **47** and the fixed contacts **60** and **61** is bolted to the ring **32** which has the upstanding annular boss **31** around which the Belleville spring **13** is coaxially disposed and within which is seated the stop member **49**.

Between the switch plate **63** and the inturned flange of the carrier **34** are the previously referred to temperature compensating rings **50** and **51**. As can be seen, the stop pin **48** and stop member **49** and base **30** of the Belleville spring **13** may be adjusted toward or away from the system capsule **5** by rotary adjustment of the carrier **34**, the latter being locked in adjusted position as by means of the lock nut **64** which has threaded engagement with said carrier **34** and which is seated against a shoulder **65** in the housing **2**. Furthermore, when the cap **55** is welded in place, it further engages the lock nut **64**.

Adjustment of the contacts **59** so as to exert contact load on contact **60** and on contact **61** may be effected as by removing the screws **67** and rotating the switch plate **63** in angular increments corresponding to screw hole spacing which causes the stud **46** to be screwed into, or unscrewed from, the motion transmitting rod **45**.

### Operation

In normal operation of the pressure operated electric switch **1** herein the system pressure enters the chamber **19** through the system port **7** and the tube **20** and applies a downward force on the system diaphragm **18** and an upward reaction force on the body **17** to deflect the calibration diaphragm **11** until the fitting **16** engages the positive stop screw **15**. The downward force is transmitted by complier **24**, **25** to the Belleville spring **13** through the ring **27** which bears downwardly on the upper ring portion **40** of said Belleville spring **13**. When the system pressure equals the switch actuation pressure, the downward force deflects the Belleville spring **13** and compliers **24**, **25**. Because the net spring rate of the spring assembly is negative, the downward accelerating force increases as the system capsule **5** expands downwardly. As a result, the motion is a snap action to the FIG. 4 condition of the Belleville spring **13** whereat the bridge **26** opening engages the upper surface of the stop pin **48**. At that stop position the rod **45** will have flexed the movable contactor **47** to engage the contact **59** with normally open contact **61** with a desired contact load.

When the pressure switch **1** is used in its normal manner wherein the system capsule **5** senses system pressure in port **7**, the calibration port **6** is vented to ambient pressure. The system pressure in the chamber **19** exerts a substantial holding force on the calibration diaphragm **11** by engagement of the fitting **16** thereof with the stop screw **15**. Because neither system pressure nor acceleration forces due, for example, to vibration, can pull the calibration diaphragm **11** away from its stop **15**, such pressure or vibration cannot influence normal switch operation.

When it is desired to check the operation of the pressure switch **1** without having the system in operation, switch actuation pressure is applied in the calibration chamber **12** whereupon the calibration diaphragm **11** deflects downwardly with consequent engagement of stop screw **21** with fitting **23**. Downward force on the compliers **24–25** and on the ring **27** again, as above-described, deflects the Belleville spring **13** to effect switch actuation.

## Summary

The Belleville spring portion **38** herein is supported by flexure columns **37** and **39** which, as aforesaid, are preferably machined integral with the Belleville spring portion **38**, said flexure columns **37** and **39** having the advantage of providing a flexure supported Belleville spring with elimination of mechanical friction. Another advantage of the integral one-piece unit constituting the Belleville spring **13** is that testing thereof is possible on its supports **32** and **27** prior to assembly with the sensing assembly **3** and the switch assembly **9**. The flexure columns **37** and **39** are spaced to provide a flexure support and are dimensioned to impart minimum end moments to the Belleville spring portion **38** during flexure of the latter. By arranging the flexure columns **37** and **39** circularly, as shown, there is provided an inherently rigid construction that resists transverse loading in all directions by placing the long width of approximately one-third of the columns in almost pure shear. As best shown in FIG. 4, the flexure columns **37** and **39** are placed to operate the Belleville spring portion **38** in the manner of a lever having a fulcrum at **68** so that the moving masses on each side of said fulcrum **68** counterbalance each other. The lever ratio is selected depending on the desired pressure setting.

Another consideration is that mechanical friction and hysteresis are sources of error in devices of this type. In the present case, mechanical friction is nil and internal hysteresis in the stressed members is minimized by keeping the stresses in critical members low. In known Belleville spring support systems using conventional pivots, the friction is about 1½%, whereas mechanical friction is eliminated in the present switch **1**. The importance of this is revealed by the fact that in numerous consecutive cycles the repeatability is within 0.1%, because there are no sliding or rolling contacts and instead only the elastic flexure of the thin strips of the flexure columns **37** and **39** which preferably have a low spring constant in the desired direction of flexure and a very high spring constant for movement in other directions.

Another undesirable characteristic of known pressure switches is often referred to as "first cycle stick" which, as the term implies, requires application of increased switch actuation force the first time that the switch is actuated. With the present switch **1** first cycle stick is eliminated by the frictionless flexure pivoted Belleville spring **13**. Even in tests wherein the pressure switch **1** herein was cooled to −320° F. there was complete absence of first cycle stick.

By way of illustrative example, a pressure switch **1** in accordance with this invention may employ a Belleville spring **13** in which there are sixteen flexure columns **37** and **39** of about 0.0007" radial thickness and of about 0.130" in length in each of the lower and upper sections of the Belleville spring **13**.

Other modes of applying the principle of the invention may be employed, change being made as regards the details described, provided the features stated in any of the following claims, or the equivalent of such, be employed.

We therefore particularly point out and distinctly claim as our invention:

**1.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring between the inner and outer periphery thereof; said spring having radially spaced apart axial projection on opposite sides; support means engaging the projections on one side of said spring; and fluid pressure actuated means for applying axial force to the projections on the other side of said spring to deflect said spring, said projections being radially spaced from one of said peripheries whereby said spring is thus deflected by lever action.



**2.** The switch of claim **1** wherein said fluid pressure actuated means comprises a pressure capsule and means for introducing fluid under pressure thereinto; said capsule comprising a flexible diaphragm which exerts axial force on said spring upon introduction of fluid pressure into said capsule.

**3.** The switch of claim **25** wherein said capsules have respective first and second axially adjustable stops means engaged by the respective diaphragms and backed up respectively by said housing and by said first capsule whereby when said first diaphragm is axially deformed as aforesaid it applies axial force on said spring through engagement of said second stop means with said second diaphragm and when said second diaphragm is axially deformed as aforesaid it applies axial force on said spring while said second capsule is backed up by engagement of said first stop means with said first diaphragm.

**4.** The switch of claim **26** wherein said portions are a fixed part of said spring.

**5.** The switch of claim **26** wherein said portions are disposed in concentric circles.

**6.** The switch of claim **5** wherein said portions are a fixed part of said spring and comprise circumferentially spaced apart columns.

**7.** The switch of claim **6** wherein said columns are relatively thin radially so as to flex to arched form as said spring is deflected.

**8.** The switch of claim **7** wherein said columns are integral with said spring; said columns being integrally joined at their ends axially remote from said spring to continuous rings; one of said rings being engaged with said support means and the other of said rings having such axial force applied thereto.

**9.** The switch of claim **27** wherein said temperature compensating means comprises a pair of juxtaposed rings having mating frusto-conical surfaces, one ring having a substantially smaller coefficient of thermal expansion than the other ring whereby radial expansion or contraction of the latter due to temperature change is reflected as a change in the composite axial thickness of said rings according to the apex angle of such frusto-conical surfaces.

**10.** The switch of claim **1** wherein said Belleville spring has a force vs. deflection curve of which a portion is of negative slope to effect snap-action actuation of said switch means.

**11.** The switch of claim **28** wherein said complier comprises at least one plate of which the center portion deflects relative to the peripheral portion under switch actuating load.

**12.** A Belleville spring adapted for use in a fluid pressure operated switch and the like comprising a frusto-conical ring portion, and radially spaced apart axial projections on opposite sides of said ring portion through which opposite axial forces are adapted to be applied to said ring portion to deflect it to a greater apex angle and to a shorter axial distance between the inner and outer peripheries thereof, said projections being radially spaced from one of said peripheries whereby said spring is thus deflected by lever action.

**13.** The Belleville spring of claim **12** wherein said projections lie on concentric circles which are coaxial with said ring portion.

**14.** The Belleville spring of claim **12** wherein said projections are a fixed part of said ring portion.

**15.** The Belleville spring of claim **12** wherein said projections comprises circumferentially spaced columns on opposite sides of said ring portion.

**16.** The Belleville spring of claim **15** wherein said columns are joined with continuous ring means at their ends axially remote from said ring portion whereby axial forces are applied on said ring portion through said means.

**17.** The Belleville spring of claim **16** wherein said columns are integral with said ring portion and with said ring means and are of relatively small radial thickness so as to flex to arched form as such axial forces are applied to said ring portion.

**18.** The Belleville spring of claim **17** wherein said columns are radially thickened where joined to said ring portion and to said ring means.

**19.** Snap-action mechanism for a fluid pressure actuated electric switch and the like comprising a Belleville spring adapted when deflected by axial force thereon to actuate such switch; support means engaging one side of said spring; said spring having a force vs. deflection curve which is characterized by having a portion of negative slope; stop means on said support effective to pre-load said spring to an extent near the transition of said curve from positive slope to negative slope and to restrict further deflection so as to be in the negative slope portion of said curve; and fluid pressure actuated means applying axial force on the other side of said spring at a zone radially spaced from said support means; said axial force, when of magnitude exceeding such pre-load on said spring, producing snap-action deflection of said spring with corresponding snap-action actuation of a switch and the like adapted for actuation by said spring.

**20.** The snap-action mechanism of claim **19** wherein said spring has integral circular series of radially thin columns which project axially in opposite directions and which are integrally joined to continuous ring portions at their ends axially remote from said spring; said columns being flexed to arch form when said spring is pre-loaded and subsequently deflected thus to provide a flexure pivoted spring that eliminates mechanical friction.

**21.** The snap-action mechanism of claim **19** wherein a complier is interposed between said Belleville spring and said fluid pressure actuated means; said complier being a positive rate spring having a substantially greater rate than said Belleville spring whereby the combined rate of said complier and Belleville spring is different from the rate of the latter.

**22.** The snap-action mechanism of claim **21** wherein said complier comprises at least one plate of which the center portion deflects relative to the peripheral portion under switch actuating load.

**23.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring; support means engaging one side of said spring; and fluid pressure actuated means applying axial force on the other side of said spring at a zone radially spaced from said support means to deflect said spring by lever action; the moving parts of said spring and said fluid pressure actuated means defining a substantially mass-balanced assembly thus to minimize response of said switch to vibration.

**24.** The switch of claim **23** wherein said movable contact is mass balanced and has a relatively high natural frequency further to resist chatter under conditions of vibration of said switch.

**25.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable



contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring; and fluid pressure actuated means for applying axial force to deflect said spring; said fluid pressure actuated means comprising first and second axially adjacent pressure capsules and first and second means for introducing fluid under pressure into the respective capsules; said capsules comprising respective first and second flexible diaphragms which, in the case of said first diaphragm, exerts axial force on said spring through said second capsule upon introduction of fluid pressure into said first capsule and which, in the case of said second diaphragm, exerts axial force directly on said spring upon introduction of fluid pressure into said second second capsule.

**26.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring; support means engaging one side of said spring; and fluid pressure actuated means applying axial force on the other side of said spring at a zone radially spaced from said support means to deflect said spring by lever action; said spring having opposite axially extending portions constituting said support means and axial force transmission means through which such axial force is applied on said spring.

**27.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring; support means engaging one side of said spring; and fluid presure actuated means applying axial force on the other side of said spring at a zone radially spaced from said support means to deflect said spring by lever action; and temperature compensating means interposed between said support means and said housing to maintain a predetermined relation between said spring and said fluid pressure actuated means over a wide range of ambient temperatures.

**28.** A fluid pressure operated electric switch comprising a housing having therein: switch means with a movable contact; a Belleville spring operatively engaging said contact to actuate said switch means upon deflection of said spring; fluid pressure actuated means for applying axial force to deflect said springs; said Belleville spring having a force vs. deflection curve of which a portion is of negative slope to effect snap-action actuation of said switch means; and a complier interposed between said Belleville spring and said fluid pressure actuated means; said complier being a positive rate spring having a substantially greater rate than said Belleville spring whereby the combined rate of said complier and Belleville spring is different from the rate of the latter.


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