United States Patent

Willson et al.

[15] **3,652,969**

[45] **Mar. 28, 1972**

[54] METHOD AND APPARATUS FOR STABILIZING AND EMPLOYING TEMPERATURE SENSITIVE MATERIALS EXHIBITING MARTENSITIC TRANSITIONS

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[22] Filed: **May 27, 1969**

[21] Appl. No.: **828,243**

[52] **U.S. Cl.** **337/140,** 148/11.5, 337/393
[51] **Int. Cl.** **C21d**, H01h 37/50, H01h 71/18
[58] **Field of Search** 337/123, 140, 382, 393; 148/11.5, 131

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[57] **ABSTRACT**

A method and apparatus for stabilizing and employing temperature sensitive material exhibiting martensitic transitions for use in control and work performing devices. The method includes subjecting the martensitic-transition material to a greater unit stress than the material would be required to work against in its application to thereby stretch the material beyond its expected deflection, and subsequently completing a number of temperature cycles while the material is in such overstressed condition, through which it is heated to a point above its transition temperature and cooled back to its annealed temperature. After treatment the material operates through complete work cycles with no loss of dimension stability. In one embodiment, the apparatus defines a temperature sensitive switch including a load to apply an increased stress to the material during the initial stabilization temperature-cycling period and a reduced work-load stress during periods of in-service operation.

10 Claims, 5 Drawing Figures

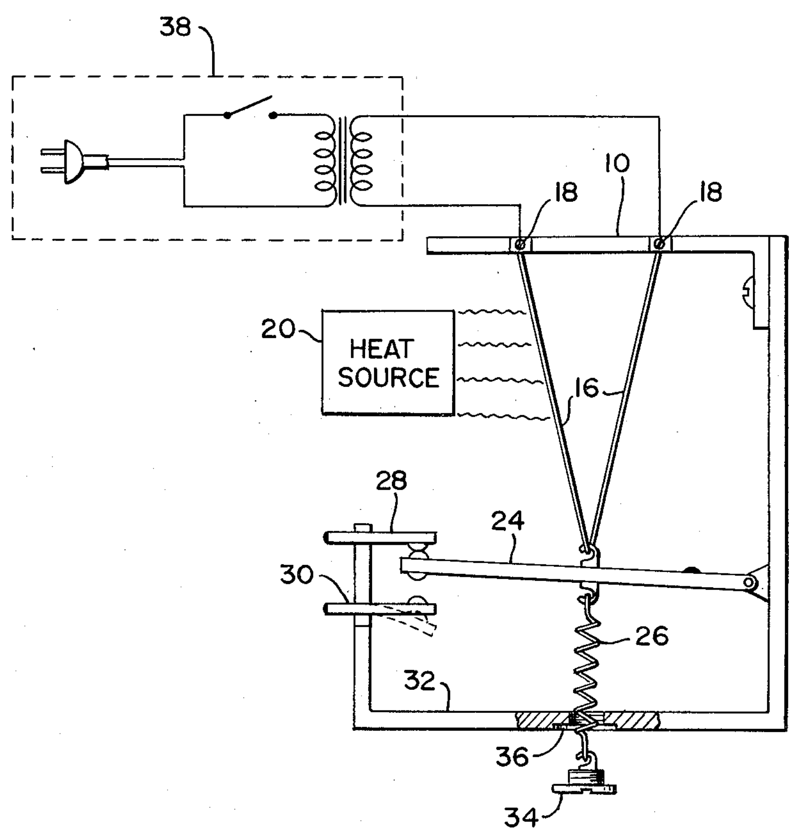

FIG. 1

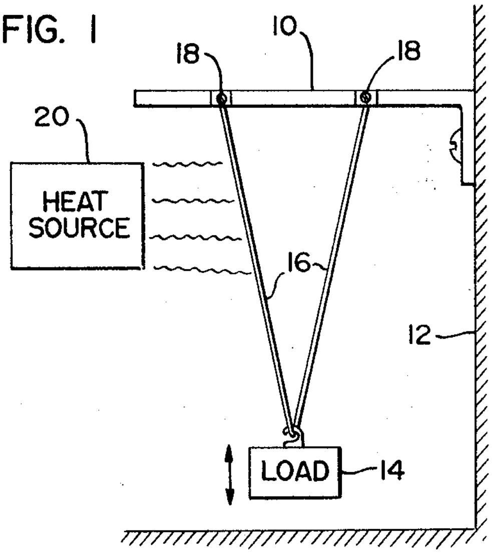

FIG. 2

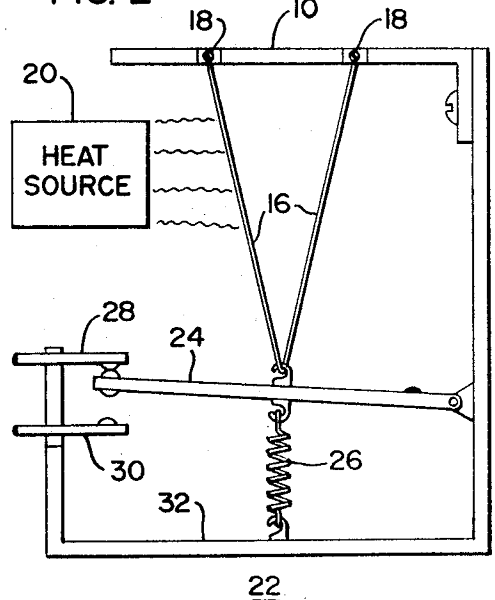

FIG. 3

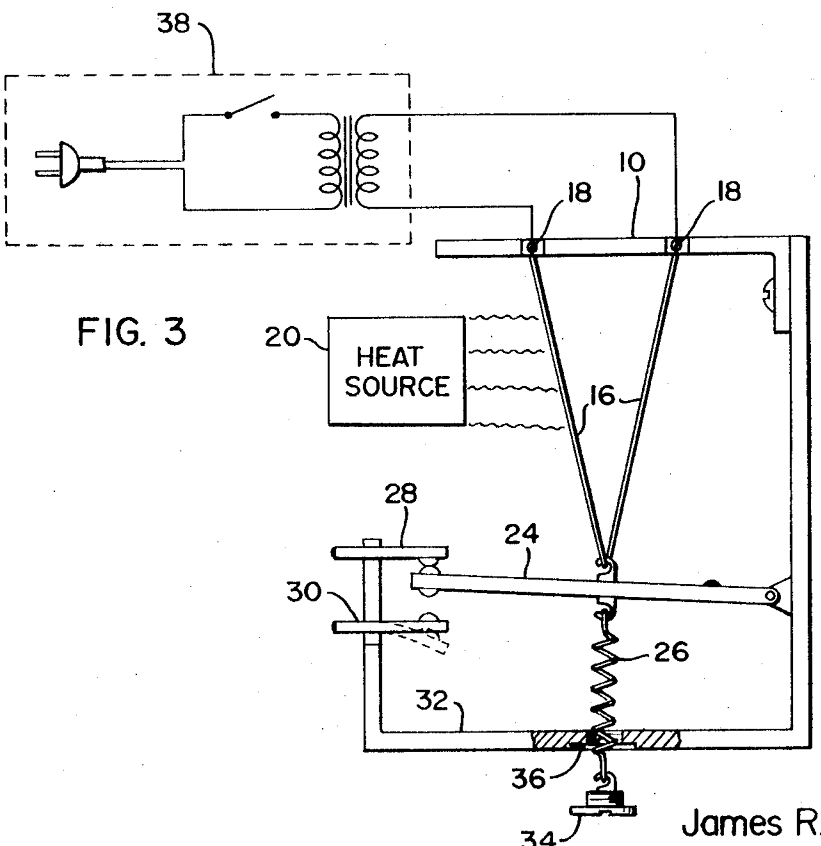

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FIG. 4

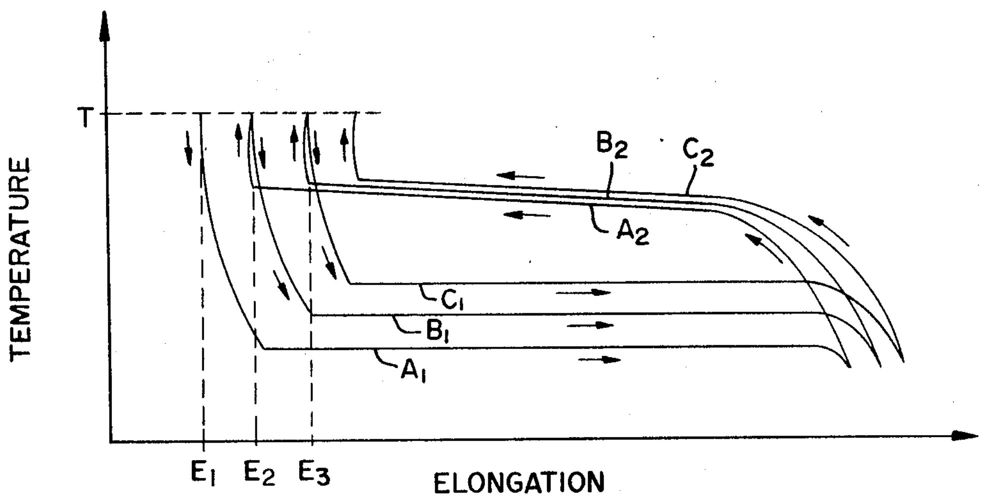
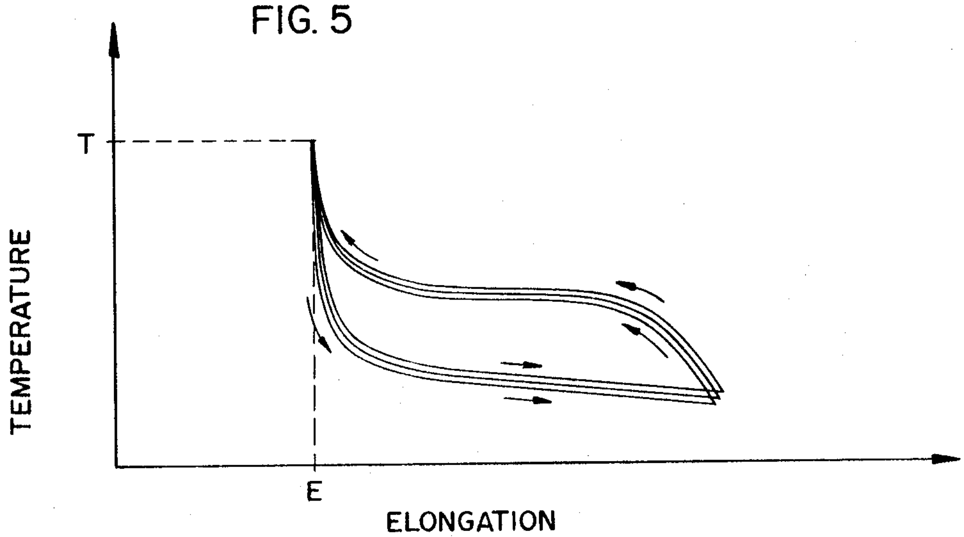


FIG. 5



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METHOD AND APPARATUS FOR STABILIZING AND EMPLOYING TEMPERATURE SENSITIVE MATERIALS EXHIBITING MARTENSITIC TRANSITIONS

BACKGROUND OF THE INVENTION

The present invention relates generally to the stabilization of temperature sensitive materials and, more particularly, to a method and apparatus for stabilizing temperature sensitive materials exhibiting martensitic transitions for use in control and work performing devices.

Many diversified applications in the systems control art, to mention but one, require a simple, yet efficient heat sensitive element for converting thermal energy into mechanical energy. One of the most obvious applications for such an element is the conventional thermostat used extensively in the control of home and office heating and cooling systems as well as a number of small home appliances. Heretofore, what was considered to be the most effective element for the direct conversion of heat into mechanical energy was the bimetallic couple wherein two metals having dissimilar degrees of thermal expansion are bonded together. While such devices have generally served the purpose, they have not proven entirely satisfactory under all conditions of operation. Some of the more obvious reasons for these limitations are the limited mechanical deflection per degree temperature change, the inefficient thermo-mechanical energy conversion, and the difficulty of manufacture and standardization.

With recent developments in metallurgy, specifically in the study of thermally sensitive materials which exhibit martensitic transitions, research efforts have been directed toward seeking a better thermo-mechanical conversion element. At this point, while a detailed theoretical explanation of martensitic transition type materials is unnecessary for the purpose of disclosing the present invention, a brief discussion thereof will be described for the sake of clarity. Certain nickel-titanium alloys, for example, containing approximately 53.5–56.5 percent nickel with the remainder being essentially titanium, have been found to undergo a temperature dependent martensitic transition at a particular critical temperature, this temperature being a function of the alloy composition. This transition is produced by applying a load to the material which is sufficiently great to produce a greater deflection below its critical temperature than would normally be expected. The structural deformation this produced causes a molecular change which is accompanied by the liberation of heat. Graphically it has been found that such a structural transition follows a curve of decreasing modulus of elasticity as well as a curve of decreasing modulus of torsion as the temperature decreases. If the material under stress is now heated to a point above its critical temperature, it will move in a direction opposite to the direction in which it has been deformed with the capability to perform useful work. It is important to note, however, that the curves of increasing modulus of elasticity and torsion with increasing temperature are different than the curves observed during the decreasing temperature transition; and, more importantly, the cyclic transition produces certain changes in the physical properties of the material which cause it to take a set after each cycle preventing it from returning precisely to its original position. This periodically increasing offset has, heretofore, proven to be a major inhibiting factor in the development of an acceptable commercial device using a thermo-mechanical element of the type discussed above in the place of the conventional bimetallic element.

OBJECTS OF THE INVENTION

It is, therefore, an object of the present invention to provide a method and apparatus for stabilizing temperature sensitive materials exhibiting martensitic transitions for use in control devices.

Another object of this invention is to provide a stabilized thermo-mechanical conversion element having a closed temperature-deflection loop.

This invention has the further object in the provision of a control device having improved operational characteristics.

An additional object of the present invention is the provision of a work performing device having stabilization means integrally incorporated therein.

An advantage of the invention is the provision of a simple and efficient temperature sensing control device.

An additional advantage of the present invention is the provision of a stabilizing process and apparatus permitting the use of materials heretofore impractical for performing control and work functions where closed-loop temperature-deflection cycles are contemplated.

SUMMARY OF THE INVENTION

The present invention is summarized in that a method for stabilizing a temperature sensitive material exhibiting a martensitic transition at a critical temperature to perform work upon a load having a particular value includes the steps of applying a force to the material having a value greater than the particular value of the load, and temperature-cycling the material through the critical temperature in a positive and then a negative direction repetitively in succession to complete a plurality of complete cycles.

In addition, the present invention includes apparatus for stabilizing and utilizing such a temperature sensitive material as a control or work performing device.

The inventive concept as well as other objects and advantages of the present invention will become more fully apparent from the following detailed description of the preferred embodiments of the invention when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a stabilizing apparatus for stabilizing a temperature sensitive material for subsequent use in a control device;

FIG. **2** shows a temperature sensing control device utilizing a pre-stabilized thermal sensor;

FIG. **3** shows a temperature sensing control device including an integral stabilizing means;

FIG. **4** shows a stabilization temperature-elongation curve for the material to be used in the apparatus of FIGS. **1**, **2** and **3**; and

FIG. **5** shows the closed-loop temperature-elongation curves produced after stabilization by the method and apparatus of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. **1**, there is shown a simplified apparatus operating according to the method of the present invention to pre-stabilize a thermally sensitive material exhibiting a martensitic transition at a critical temperature for subsequent cyclic use in control devices. The structure consists of a cantilevered beam **10** mounted to wall **12** so as to support a load **14** for vertical movement, as shown by the arrow. The load is hung from the beam **10** by a single drawn piece of martensitic transition type wire **16** firmly attached by connectors **18**. A radiant heat source **20**, the temperature of which can be manually adjusted, is located adjacent the wire **16** within heating proximity thereto.

Before going into the details of operation of the device, it is important to note first that other suitable heat sources may be employed such as direct internal heating by a current flowing therethrough, or the like; and second, the thermal sensor **16** may be shaped and mounted in any number of various ways, for example, as a cantilevered beam or a coiled spring, depending upon the operational characteristics desired and the contemplated application of the heat sensing material.

In describing the operation of the device of FIG. **1**, reference will be made to the curves illustrated in FIGS. **4** and **5**. It is further pointed out that the description, below, of the operation of the device of FIG. **1** will serve also to outline the method of the present invention.

FIG. 4 shows a curve illustrating the elongation characteristics of a nickel-titanium wire cycled through its critical temperature a number of times. The apparatus of FIG. 1 can be utilized to produce the above-mentioned curves, and, in one experiment, a load of 40,000 pounds per square inch was employed. At temperature T, the load applied to the nickel-titanium wire produces an elongation, measured vertically, of value E_1. As the temperature produced by source 20 is decreased, the material follows segment A_1 of the curve which illustrates the rapid increase of elongation produced by the load when the material passes through its critical temperature. As the temperature is then increased through the critical temperature in a positive going direction, the material follows segment A_2 which shows how the alloy tends to return to its original position. This characteristic shape-memory action exhibited by materials such as nickel-titanium is primarily due to the aforementioned martensitic transitions which take place at the critical temperature. As explained above, due to certain molecular changes which take place in the structure of the material when temperature-cycled under load, the material does not return precisely to its original elongation E_1 but decreases only to point E_2. As the material is temperature-cycled again through its critical temperature, segments B_1 and B_2 of the curve are followed showing a further offset since elongation point E_3 is the shortest length the material will then reach. Additional cycle C_1–C_2 produces similar results, as expected.

Thus, with a load of 40,000 pounds per square inch, the nickel-titanium alloy wire when utilized in the apparatus of FIG. 1 will exhibit martensitic transitions during temperature-cycling through its critical temperature but at the end of each cycle will not return precisely to its starting point. If, according to the present invention, the wire, which was temperature-stabilized at 40,000 pounds per square inch, is temperature-cycled with a reduced load of 20,000 pounds per square inch, for example, the curves illustrated in FIG. 5 will be produced. As can be seen, the curves form closed-loops since the elongation of the wire at the end of each cycle is precisely the same as at the beginning thereof. Thus, by temperature-cycling a temperature sensitive alloy of the type referred to above at a load greater than the load to be utilized in the contemplated control device, the material becomes cyclically stabilized and exhibits closed-loop operation required in most heat sensing electrical and mechanical control units.

Referring now to FIG. 2, wherein similar numerals are used to refer to similar components utilized in FIG. 1, there is illustrated an electrical single-pole double-throw temperature sensitive switch 22. The device employs a temperature sensitive element 16 which has been previously temperature stabilized by cycling at an increased load in apparatus of the type shown in FIG. 1. The mid-point of the wire is coupled to the moveable bar 24, which forms the switchable contact of the electrical switch. The bar 24 is in turn connected to a spring load 26 which is less than the load 14 utilized during the pre-stabilizing temperature-cycling process performed by the apparatus of FIG. 1. This assures accurate closed-loop operation as explained with reference to FIG. 5. The two fixed contacts 28 and 30 of the switch 22 are shown affixed to a base or frame member 32.

One typical application of the apparatus shown in FIG. 2 is a conventional thermostat for a home or office heating system. In this application, radiant heat source 20 schematically illustrates the radiant ambient heat produced by the room or area in which the thermostat is mounted and for which the thermostat is designed to monitor. As the temperature of the room decreases below the critical temperature of the wire sensor 16, thereby indicating a need for heat, the wire is allowed to be stretched by load spring 26 which then moves bar 24 away from contact 28 toward contact 30 completing an electrical current path from contact 30 to the contact on bar 24 to thereby initiate operation of the heating unit used (not shown). Furthermore, as the temperature of the room subsequently increases, the temperature sensing wire 16 returns to its initial position, due to its inherent shape-memory, against the force produced by spring 26 to thereby move bar 24 away from contact 30 back to its original position in physical contact with contact point 28. As the temperature of the room fluctuates, the device will continue to cycle indefinitely in the same manner, the wire sensing material 16 remaining in its stabilized condition having once been pre-stabilized according to the principles of the present invention.

In FIG. 3, there is shown a more refined switching apparatus combining the desired operational characteristics of the alloy under present discussion with the stabilization process of the present invention. With this apparatus, an unstabilized nickel-titanium wire, or the like, can be immediately installed in place as element 16 without requiring pre-cycling in a separate unit. The switch shown in FIG. 3 is basically similar to the unit in FIG. 2 with the exception of a threadably engageable load 34 attached to the lower end of spring 26. In operation an unstabilized sensor wire 16 is placed in the switch as shown and the load 34 is threadably removed from its mounting bore 36 in frame 32, as illustrated. In addition, since the additional load will cause a greater than normal elongation, contact 30 is bent slightly to the dotted position shown in FIG. 3 during this stabilization period. Since load 34 is now applying an additional force to the wire 16 over that applied by spring 26 above, the device is ready for pre-cycling to stabilize the wire sensor for subsequent closed-loop operation without the additional load 34. To accomplish the pre-cycling heating of element 16, a controllable electrical power source 38 is shown coupled to the wire whereupon heat will be internally generated therein at the desired times. The unit is then temperature-cycled through a number of complete cycles, as typified by the curves of FIG. 4. After this is completed, load 34 is threadably mounted to frame 32 and the contact end of contact 30 is bent back to its operative position, whereupon a decreased force will be applied to the element 16 which then will provide closed-loop operation as exemplified by the curves of FIG. 5. It is noted that radiant heat source 20 and electrical power supply 38 are both provided to apply heat to the temperature sensitive nickel-titanium element 16; however, other diverse heat sources can be utilized depending upon the particular installation.

In summary, there is shown and described a method and apparatus for stabilizing and employing temperature sensitive materials exhibiting martensitic-transitions at various critical temperatures, such as nickel-titanium, or the like, for use in control and work performing devices where accurate temperature-elongation closed-loop operation is required. Thus, control devices utilizing nickel-titanium, for example, as the temperature sensing element having new, improved, and desired characteristics are made feasible for many diverse and commercially important applications.

Inasmuch as the present invention is subject to many variations, modifications and changes in detail, it is intended that all matter contained in the foregoing description or shown in the accompanying drawing shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An accurate temperature responsive control device comprising:

means for sensing temperature;

moveable control means coupled to said temperature sensing means for performing a control function in response to actuation by said temperature sensing means; and

means coupled to said temperature sensing means for applying a load thereto having a particular value;

said temperature sensing means being a temperature sensitive material exhibiting a martensitic transition at a critical temperature, which has been deformed by a force greater than the particular value of said load means and subsequently temperature-cycled through said critical temperature in a positive and then a negative direction repetitively in succession to complete a plurality of complete cycles, heating of said material above its critical temperature thereafter moving said temperature sensitive means from its rest position resulting in movement of said control means to effectuate said control function, and cooling of said material below its critical temperature thereafter allowing said temperature sensitive means to return precisely to its rest position under the influence of said load means.

2. The invention as recited in claim **1** wherein said plurality of complete cycles is at least three.

3. The invention as recited in claim **2** wherein said temperature sensitive material comprises an alloy comprising 53.5–56.5 percent nickel by weight, the remainder being essentially titanium.

4. The invention as recited in claim **2** wherein said temperature sensitive material comprises an alloy comprising 55 percent nickel by weight, the remainder being essentially titanium.

5. The invention as recited in claim **4**, wherein said control function comprises electrical switching.

6. An accurate temperature responsive control device, comprising:

means for sensing temperature comprising a temperature sensitive material exhibiting a martensitic transition at a critical temperature;

moveable control means coupled to said temperature sensing means for performing a control function in response to actuation by said temperature sensing means;

means coupled to said temperature sensing means for applying a load thereto;

stabilizer means coupled to said temperature sensing means and said load means for selectively applying an additional stabilization load to said temperature sensing means; and

means coupled to said temperature sensing means for temperature-cycling said temperature sensitive material through said critical temperature in a positive and then a negative direction repetitively in succession to complete a plurality of complete cycles after said additional stabilization load has been applied thereto by said stabilizer means to thereby temperature stabilize said material for subsequent operation without said additional stabilization load;

heating of said material above its critical temperature thereafter moving said temperature sensing means from its rest position resulting in movement of said control means to effectuate said control function, and cooling of said material below its critical temperature thereafter allowing said temperature sensing means to return precisely to its rest position under the influence of said load means.

7. The invention as recited in claim **6**, wherein said plurality of complete cycles is at least three.

8. The invention as recited in claim **7** wherein said temperature sensitive material comprises an alloy comprising 53.5–56.5 percent nickel by weight, the remainder being essentially titanium.

9. The invention as recited in claim **7** wherein said temperature sensitive material comprises an alloy comprising 55 percent nickel by weight, the remainder being essentially titanium.

10. The invention as recited in claim **9** wherein said control function comprises electrical switching.

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