Dec. 27, 1966 K. M. BOWYER ET AL 3,295,081

THERMO-MAGNETICALLY OPERATED SWITCHES

Filed July 21, 1964

FIG. 1

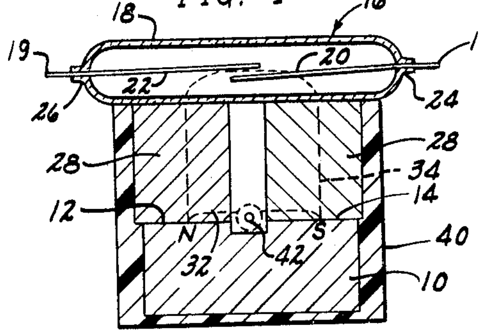


FIG. 3

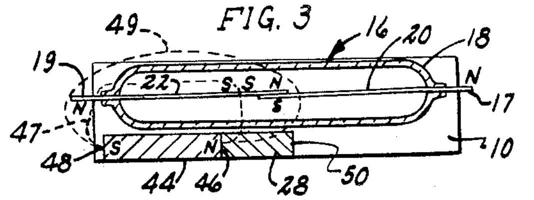


FIG. 4

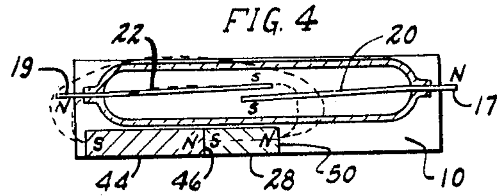


FIG. 2

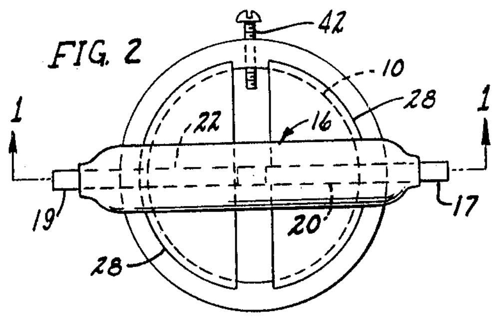


FIG. 6

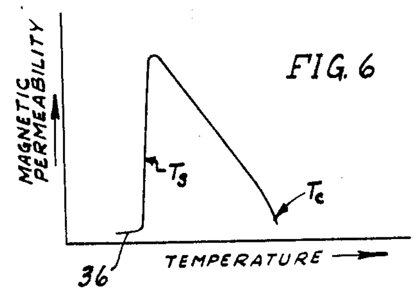
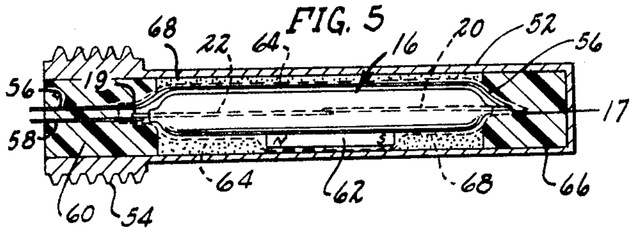


FIG. 5



INVENTORS
KERN M. BOWYER
RICHARD L. CAMPBELL
BY
JOHN E. MC RAE

United States Patent Office

3,295,081
Patented Dec. 27, 1966

3,295,081

THERMO-MAGNETICALLY OPERATED SWITCHES

Kern M. Bowyer, Wilmington, Del., and Richard Lyons Campbell, Birmingham, Mich., assignors, by direct and mesne assignments, to American Radiator & Standard Sanitary Corporation, New York, N.Y., a corporation of Delaware

Filed July 21, 1964, Ser. No. 384,193
3 Claims. (Cl. 335—208)

This invention relates to temperature-operated electric switches.

One object of the invention is to provide a temperature-operated switch wherein the switch elements are hermetically sealed within an enclosure to thus provide long switch life.

A further object is to provide a temperature-operated switch which operates with snap action, whereby to cause opening and closing of the switch contacts at the same temperature during each opening-closing cycle.

A still further object of the invention is to provide a temperature-operated switch wherein contact pressure is maintained until the switch-actuating temperature is reached, to thus preclude switch blade flutter or loss of contact pressure in the presence of vibrational disturbances.

An additional object is to provide a temperature-operated switch which can be utilized in any position, for example vertically, horizontally, rightside up, or upside down.

An additional object is to provide a temperature-operated switch which is capable of manufacture as a relatively small size device, whereby to permit use thereof in restricted spaces.

Other objects of this invention will appear from the following description, accompanying drawings and appended claims.

In the drawings:

FIGURE 1 is a sectional view taken on line 1—1 of FIG. 2 and illustrating one embodiment of the invention;

FIG. 2 is a top plan view of the FIG. 1 embodiment;

FIG. 3 is a sectional view taken through a second embodiment of the invention illustrating its operation when exposed to a particular temperature;

FIG. 4 is a sectional view in the direction of FIG. 3, but taken with the embodiment exposed to a different temperature;

FIG. 5 is a sectional view taken through a third embodiment of the invention; and

FIG. 6 is a graph depicting the performance of preferred magnetic exchange inversion materials employed in the practice of the invention.

Before explaining the present invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and arrangement of parts illustrated in the accompanying drawings, since the invention is capable of other embodiments and of being practiced or carried out in various ways. Also, it is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

As shown in FIG. 1 the invention comprises a permanent magnet 10 having pole faces 12 and 14 spaced from a reed switch 16. As shown in FIG. 2 the permanent magnet is circular in outline, although other configurations could be employed.

Reed switch 16 comprises an elongated glass enclosure 18 and two overlapping ferromagnetic reeds 20 and 22 having hermetic seals at 24 and 26, whereby to provide exposed terminal ends 17 and 19 for connection with lead wiring (not shown).

Disposed between pole faces 12 and 14, and reed switch 16 are two block-like members 28 formed of magnetic exchange inversion material. When members 28 are in one temperature range they are anti-ferromagnetic, such that a major part of the flux of magnet 10 follows the path denoted by numeral 32; under these conditions the reed switch is maintained in open position. When members 28 are in a different temperature range they become ferrimagnetic or ferromagnetic such that a major part of the magnetic flux follows the path designated by numeral 34. The induced magnetism in reeds 20 and 22 causes them to snap together to close an electric circuit therethrough.

Exchange inversion materials that are useful in the device of this invention can be defined as materials that undergo a sharp and reversible change in magnetization properties, e.g., a sharp and reversible increase in saturation induction, with rise in temperature, at a temperature below the Curie point of the material. The temperature at which this increase occurs is referred to as the lower ferromagnetic transition temperature to distinguish from the upper transition temperature or Curie point. The unusual dependence of magnetization on temperature at the lower transition temperature is believed to result from a transition from antiferromagnetic to a ferrimagnetic state. Thus, at the transition temperature, the total quantum mechanical exchange between adjacent sublattices is believed to change sign and it is this exchange inversion which is presumed to be at the basis of the observed change in magnetic properties. The transition is a first-order solid-phase-to-solid-phase transition with maintenance of crystal symmetry and any magnetic material having such a transition is useful according to this invention.

A first-order transition, also known as a transition of the first kind, is one in which a discontinuity occurs in the first derivatives of the Gibbs free energy. For example, there are discontinuities in the first derivative with respect to temperature, i.e., entropy, with respect to pressure, i.e., in volume, and for a magnetic material with respect to magnetic field, i.e., in magnetization.

A second-order transition is one in which the second derivative of the free energy is discontinuous but the first derivative is continuous. In other words, at a second-order transition energy, volume, and in a magnetic substance magnetization change continuously but the temperature derivatives of these quantities have singularities. The Curie point in a magnetic material is an example of a second-order transition.

Further discussion of first- and second-order transistions is found in Swalin, "Thermodynamics of Solids," John Wiley & Sons, Inc., New York, 1962, pp. 72–73, and in "Phase Transformations in Solids" (Symposium at Cornell University, August 23–28, 1948), John Wiley & Sons, Inc., New York, 1951, Chap. I, by L. Tisza, pp. 1–2.

Various materials may be employed for the magnetic exchange inversion material used for members 28. For example, we can employ the materials disclosed in U.S. Patent 3,126,345 and 3,126,347 issued to T. J. Swoboda, and U.S. Patent 3,126,346 issued to T. A. Bither.

Iron-rhodium alloys (FeRh) and iron-rhodium alloys containing up to 20 atom percent of at least one other element (FeRh–M) are also useful as magnetic exchange inversion materials. Suitable Fe–Rh alloys include those described by Fallot, "Revue Scientifique," 77, 498 (1939); Kouvel et al., "General Electric Research Report No. 61–RL–2870M." Suitable Fe–Rh–M alloys are described in copending U.S. applications Serial Nos. 177,229 and 177,230, now Patent Nos. 3,140,941 and 3,140,942 filed March 5, 1962, by P. H. L. Walter; application Serial No. 192,060, now Patent No. 3,144,325 filed May 3, 1962, by P. H. L. Walter; and application Serial No. 192,059, now Patent No. 3,144,324 filed May 3, 1962, by T. A. Bither.

Other useful compositions are represented by the formula $Mn_{2-x-y}T'_xT''_ySb_zIn_a$, where T' is chromium and/or vanadium, T'' is one or more of iron, cobalt, nickel and copper, x is 0.003 to 0.25, y is 0.003 to 0.25, z is 0.50 to 1.00, and a is 0 to 0.50. These compositions are more fully described in application Serial No. 261,784, now Patent No. 3,241,952 of W. W. Gilbert and T. J. Swoboda, filed February 28, 1963.

Processes for preparing compositions useful as the magnetic exchange inversion material of this invention are described in the foregoing applications and in application Serial No. 120,679, now Patent No. 3,196,055, of W. W. Gilbert, filed June 29, 1961.

The performance of preferred materials follows the general curve shown in FIG. 6. At relatively low temperatures the material is anti-ferromagnetic as denoted by numeral 36. In the relatively narrow transition temperature range T_s the material becomes ferrimagnetic or ferromagnetic. At extremely high temperatures the material gradually loses its magnetic qualities as it approaches the Curie temperature T_c.

Previously it has been proposed to provide temperature-operated switches using the Curie temperature of nickel-copper or nickel-iron alloys as the controlling characteristic. We prefer to use the transition temperature T_s of the above-mentioned magnetic exchange inversion materials as the controlling characteristic because the slope of the curve at T_s is much steeper, and the switch-actuating temperature is therefore much sharper and susceptible to greater repeatability. As disclosed in certain of the aforementioned patent applications and patents, the slope of the transition temperature range T_s can be varied by suitable treatments as described in aforementioned application Serial No. 120,679, now Patent No. 3,196,055. The present invention is not concerned with the particular magnetic exchange inversion materials, but rather with their use in association with a magnet and ferromagnetic switch reeds to form a temperature-operated switch.

When exchange inversion materials having an easy axis of magnetization are employed it is desirable to position such materials in the switches so that their axis of easy magnetization is parallel to the lines of magnetic flux. With the chromium manganese antimonides this easy axis is the C axis, or tetragonal axis, in the temperature range −30° C. to +80° C.

As shown in FIG. 1, the magnet 10, magnetic exchange inversion members 28, and reed switch 16 can be encapsulated within an encapsulating material 40. Preferably at least the upper faces of members 28 are exposed for improved temperature sensing. To regulate the force of the magnetic flux through path 34 there may advantageously be provided an adjustable magnetic shunt which in the FIG. 1 embodiment takes the form of a ferromagnetic screw 42. By turning the screw into the encapsulation 40 the screw diverts progressively larger amounts of the flux from members 28, and thus adjusts the maximum operating flux applied to reeds 20 and 22.

A switch constructed according to FIGS. 1 and 2 uses a permanent magnet made of the alloy known commercially as Alnico-2 of cylindrical shape with a diameter of ⅜" and a height of 3⁄16", having a slot ⅛" wide and 5⁄64" deep across the top of the cylinder separating the two poles of the magnet.

A cylindrical block of chromium-modified manganese antimonide, $Mn_{1.903}Cr_{0.097}Sb_{0.95}In_{0.05}$, having a diameter of 7⁄16" and a length of 11⁄64" is prepared by quenching an antimonide melt of the indicated composition into a water-cooled copper mold of the specified shape, and finally annealing the antimonide ingot at 850° C. for one hour and cooling it at 30° C. per hour to room temperature. This antimonide undergoes magnetic exchange inversion with 10% inversion at 28.5° C., 50% inversion at 30.0° C., and 90% inversion at 32.2° C. This cylindrical block is cut in half lengthwise and the two semi-cylindrical pieces are placed on top of the permanent magnet with an air space of ⅛" between them and with this air space parallel to the slot in the top of the magnet. A glass enclosed reed switch of a type commercially available having gold-plated, ferrous metal reeds about ¼" long is placed on top of the antimonide blocks with the flat surfaces of the reeds and placed parallel to the top surfaces of the antimonide blocks and with the contact ends of the reeds directly over the air space between the antimonide blocks. The entire assembly of magnet, antimonide blocks and reed switch is placed in a quick setting plastic composition which sets up to form a protective coating around the device. An adjustable No. 4 steel machine screw, approximately ¼" long is threaded into the plastic case between the pole pieces of the permanent magnet to provide a means for adjusting the effective strength of the magnet by shunting part of its field.

As shown in FIGS. 3 and 4 the invention comprises a permanent bar magnet 44 located alongside a reed switch 16 with its pole faces 46 and 48 spaced from reed 22. Engaged with pole face 46 is a block member 28 formed of magnetic exchange inversion material. Preferably pole face 46 is located short of the overlapped areas of reeds 20 and 22, and face 50 of block member 28 is located just to the right of the overlapped areas.

As shown in FIG. 3, member 28 is in a low temperature range below its transition temperature T_s, such that the magnetic flux from magnet 44 follows paths designated by numerals 47 and 49. The flux passes through the lefthand portion of reed 22, setting up two south poles in said reed near the north pole of the bar magnet 44; north poles are set up at both ends of reed 22. Nearly all of the magnetic lines of flux intercepting the right hand reed 20 set up a south pole at the contact end of this reed and a north pole at the terminal end 17; the overlapped contact ends of the reeds, being of opposite polarity, are snapped together, maintaining a closed electric circuit through the reeds.

When block 28 is warmed through its transition temperature T_s it becomes ferromagnetic or ferrimagnetic, whereupon the magnetic lines of flux are redirected through member 28 as shown in FIG. 4. The overlapped contact ends of the reeds have south poles induced in them, and the terminal ends 17 and 19 have north poles induced in them. The contacts are thus repelled from one another to open the electric circuit with snap action.

A switch constructed according to FIGS. 3 and 4 uses a permanent bar magnet 1⅛" long and 3⁄16" square. Against one end of this magnet is placed a block of exchange inversion material having the same cross-sectional area as the bar magnet and 3⁄16" long. This exchange inversion material is composed of a chromium-modified manganese antimonide of the composition

$$Mn_{1.9}CR_{0.1}Sb_{0.90}In_{0.10}Al_{0.0057}$$

and is c-axis oriented. This antimonide exhibits 10% inversion at 15.2° C., 50% inversion at 33.4° C., and 90% inversion at 41.6° C. A glass enclosed reed switch of a type available commercially is placed above the magnet and the antimonide block as shown in FIGS. 3 and 4. The reeds in this switch are made of gold-plated ferromagnetic material and are 0.12" wide, 0.02" thick, and 0.75" long. The entire assembly of magnet, antimonide and reed switch is enclosed in a non-magnetic case made of "Quick-Set" plastic potting compound. The terminals are connected to the electric circuit that is to be controlled. While the transition range of the antimonide block is 26.4° C., the on-off operating range of the switch is only 5° C.

The embodiment shown in FIG. 5 comprises a tubular temperature sensing probe 52 having a threaded portion 54 for enabling it to be mounted in a threaded opening in a liquid tank, liquid line, engine block, or other location in which it is desired to utilize the switch. It will be understood that the tubular portion to the right of threaded area **54** is exposed to the temperature which is being sensed by the switch.

The particular switch shown in FIG. 5 includes a normally open reed switch **16** having lead wires **56** and **58** connected with the aforementioned exposed terminals **17** and **19**; these wires extend outwardly through a plastic encapsulating material **60**. Disposed alongside reed switch **16** is a permanent magnet **62**, preferably located with its pole faces located alongside respective ones of reeds **20** and **22**. To facilitate an accurate location of magnet **62** and switch **16** the switch and magnet may be encapsulated within the shrunk-on envelope denoted in dotted lines by numeral **64**. A preferred envelope material is the tetrafluoroethylene polymer sold by the E. I. du Pont de Nemours and Company under its trademark "Teflon." Retention of the envelope and contents may be facilitated by inserting same partly within an epoxy encapsulation material **66**. When the envelope and contents are thus positioned a quantity of magnetic exchange inversion powder **68** may be poured around the envelope, after which the encapsulation **60** may be applied.

When the tubular probe **52** is located within an environment having a temperature below the transition temperature T_s of material **68** the switch reeds **20** and **22** are located within the field of magnet **62**, and their contacts are closed to complete a circuit across the lead wires **56** and **58**. When the temperature is raised to the transition temperature T_s material **68** becomes ferrimagnetic or ferromagnetic to shunt the magnetic flux away from switch reeds **20** and **22**, whereby to permit the reeds to open the circuit across the switch contacts.

Temperature-operated switches constructed as shown in FIGS. 1, 3 and 5 are characterized by snap action at predetermined temperatures. The use of magnetic forces causes the contact pressure to be maintained substantially at its normal value until the instant of switch actuation; the switches are therefore susceptible to use in enviroments subject to vibrational forces which would otherwise have an adverse effect on the switch action. Since the switches are hermetically sealed in glass envelopes they are susceptible to relatively long life.

A further characteristic of the illustrated switches is the ability of the switch to be manufactured in relatively small sizes. For example the switch of FIGS. 3 and 4 has been built using a bar magnet only about one inch in length. It is believed that the invention can be incorporated in smaller dimensions.

The illustrated switches utilize permanent magnets. However it is possible to build switches using electromagnets, provided that heat generated by the electromagnet is taken into consideration in selecting the magnetic exchange inversion material. In some instances the electromagnet could be used to remotely vary the actuation temperature of the switch. For example, by varying the current to the electromagnet we can vary the magnetic field, and in turn vary the point on the steeply sloped portion of the curve at which the magnetic exchange inversion material is able to actuate the switch.

What is claimed:

1. In combination: an elongated hollow temperature sensing probe; ferromagnetic switch means disposed in said probe; a magnet disposed in said probe adjacent said switch means; and a mass of magnetic exchange inversion powder disposed in the probe for redirecting the normal field of the magnet to operate the switch means from its normal position.

2. In combination: an elongated tubular temperature sensing probe; an elongated reed switch disposed within said probe, comprising an enclosure, and a pair of ferromagnetic reeds hermetically sealed therein with adjacent ends thereof overlapped for opening and closing movements relative to one another; a magnet disposed within the tubular sensing probe alongside the reed switch; and a mass of magnetic exchange inversion powder associated with the magnet within the probe, whereby temperatures below the transition temperature of the powder cause the ferromagnetic reeds to be within the field of the magnet, and temperatures above the transition temperature cause the powder to shunt the field around the reeds.

3. In combination: a reed switch comprising a pair of generally parallel, oppositely extending flexible reeds of ferromagnetic material, said reeds have their remote ends fixedly mounted and their adjacent ends overlapping one another for opening and closing movements relative to one another; an elongated bar magnet disposed alongside and parallel to one of the reeds, said bar having one of its pole faces disposed adjacent the mounted end of said one reed and the other of its pole faces disposed just short of the overlapped contact ends; and a magnetic exchange inversion member engaged with said other pole face and extending to the vicinity of the overlapped contact ends; said bar magnet being positioned sufficiently close to said one reed so that said magnet and one reed form a complete magnetic circuit in the magnetic absence of the inversion member; said other pole face of the bar magnet being located adjacent a flexible portion of said one reed for drawing said flexible portion toward said other pole face when said inversion member is magnetically absent; said exchange inversion member being ferrimagnetic or ferromagnetic in one temperature range and anti-ferromagnetic in another temperature range; whereby temperatures wherein the magnetic exchange inversion member is anti-ferromagnetic cause the bar magnet to induce opposite polarities in the overlapped ends of the reeds, thereby causing said overlapped ends to be attracted toward one another, and temperatures wherein the inversion member is ferrimagnetic or ferromagnetic cause the bar magnet to induce similar polarities in the overlapped ends of the reeds, thereby causing said overlapped ends to be repelled from one another.

References Cited by the Examiner

UNITED STATES PATENTS

2,232,501	2/1941	Wittmann	200—88
2,973,419	2/1961	Bolesky et al.	200—138
3,008,019	11/1961	Scheidig	200—87 X

BERNARD A. GILHEANY, *Primary Examiner.*

J. J. BAKER, *Assistant Examiner.*