

Feb. 3, 1942.

C. I. HALL

2,271,975

TEMPERATURE RESPONSIVE DEVICE

Filed April 4, 1940

3 Sheets-Sheet 1

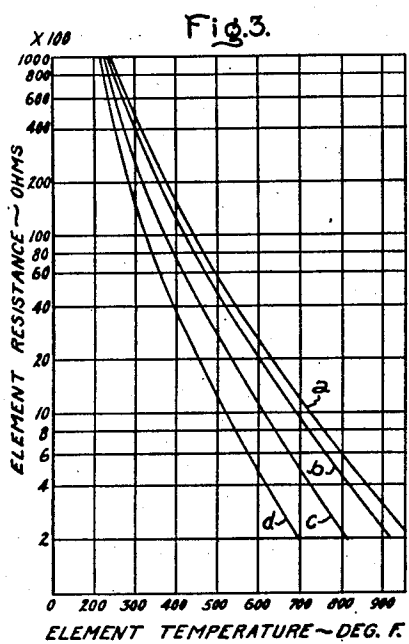
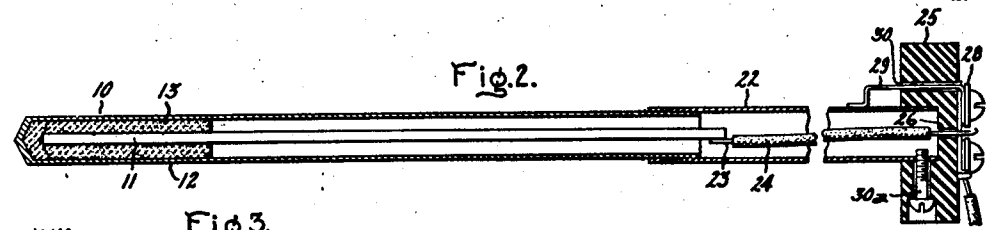
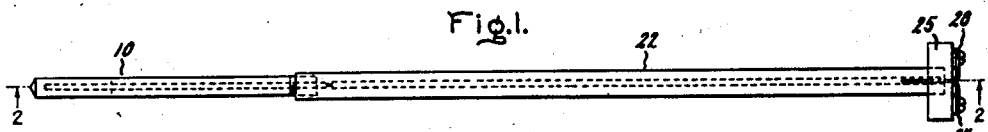


Fig. 4.

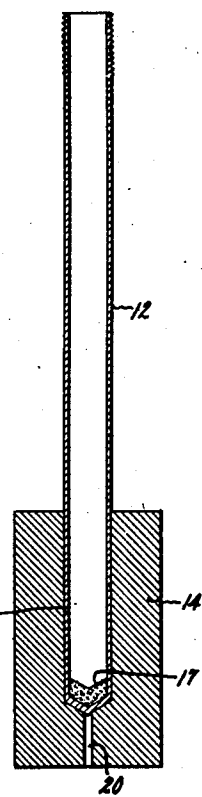


Fig. 5.

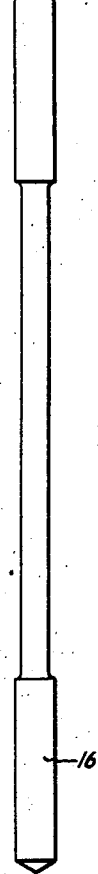
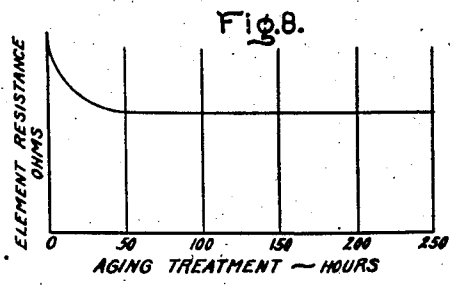
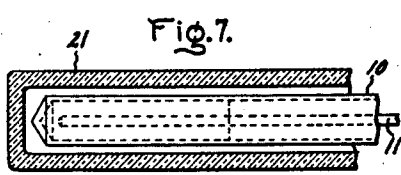
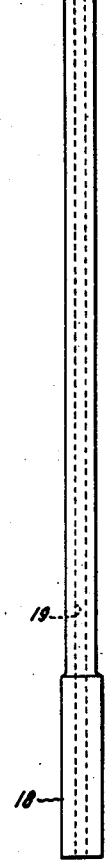


Fig. 6.



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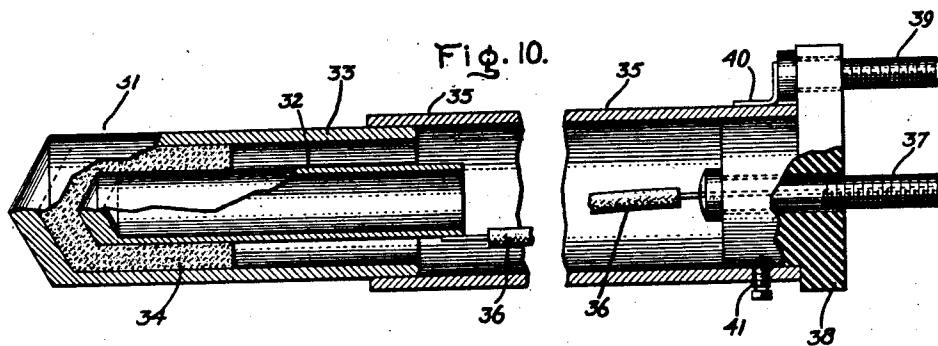
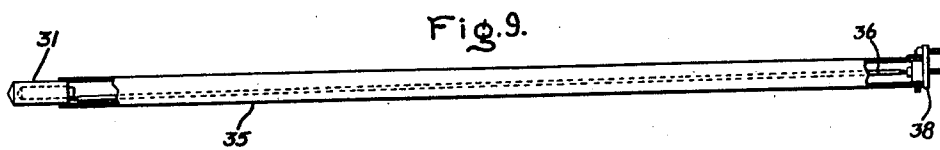
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3 Sheets-Sheet 2

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TEMPERATURE RESPONSIVE DEVICE

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Fig. 11.

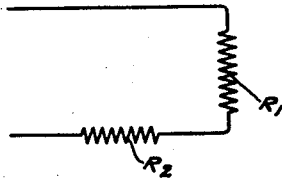


Fig. 12.

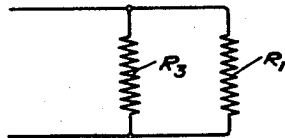
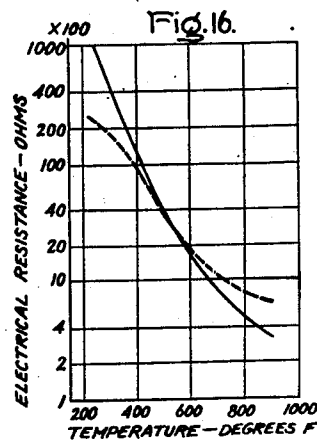
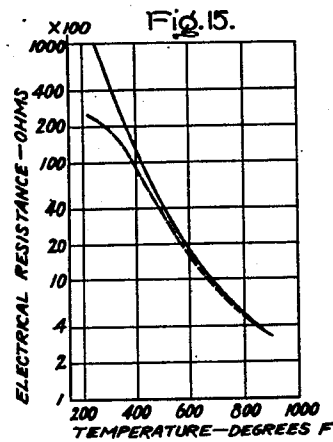
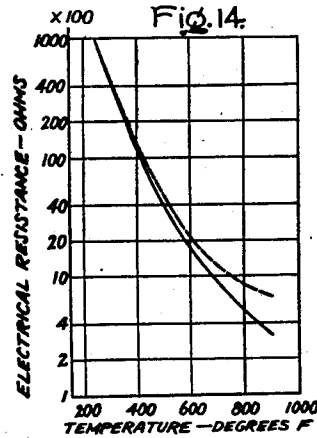
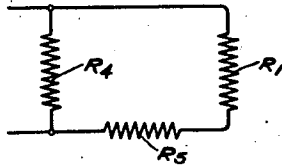


Fig. 13.



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UNITED STATES PATENT OFFICE

2,271,975

TEMPERATURE RESPONSIVE DEVICE

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Application April 4, 1940, Serial No. 327,901

12 Claims. (Cl. 201-76) 63

This invention relates to temperature responsive devices, and it has for its object the provision of an improved device of this character and method of making it.

This application is a continuation-in-part of my copending application, Serial No. 281,856, filed June 29, 1939, which is assigned to the same assignee as this application.

More specifically, this invention contemplates the provision of a temperature responsive device which may be used, for example, to control an electric circuit in accordance with temperature, the responsive device being provided with an element the resistance of which varies with temperature, that is, one having, for example, a high initial resistance that is reduced as the temperature of the element increases. And this invention contemplates the provision of an improved temperature responsive device of this character which is extremely sensitive to temperature changes; which may be operated through a very wide temperature range, and at very high temperatures; one which will provide extremely large variations in resistance with small temperature changes; one that will give constant resistance values and characteristics when manufactured and also after long continued service, that is, a control device which is reliable and stable in its operation; and one which is simple, rugged, and mechanically strong; and it further contemplates an improved method of making the control device that insures a reliable and uniform product, and which may be manufactured cheaply with comparatively simple manufacturing methods.

In accordance with this invention, a suitable temperature sensitive resistance material is highly compacted, and is intimately bonded with its electrodes that are suitably prepared in accordance with this invention to insure the intimate relationship between the highly compacted resistance material and their surfaces that contact the material. One of the electrodes may be in the form of a casing housing the insulating material, and preferably will be arranged so that it may be placed directly in contact with the medium or body to whose temperature the device is responsive. In this manner, the time required for the transfer of heat from the body or medium to the temperature sensitive material is greatly reduced.

The resistance material in granular form is highly compressed, preferably in relatively short sections, and while in contact with the electrodes. It is suitably heat-treated to sinter it into a

compact, coherent mass having uniform density throughout and having considerable mechanical strength. This mass is bonded to the electrodes so as to be in intimate thermal and electrical contact with them. For this purpose, the electrodes before the sintering operation will have been provided with coatings of a flux and an oxide of the electrodes. During the sintering operation, these coatings coalesce with the resistance material so that in effect the resistance material is sintered into a coherent mass with the electrodes.

The temperature sensitive device forming the subject matter of this application may be employed either as an element of a pyrometer or thermostat, that is either as a device to record temperature or to control temperature. Any suitable means may be used to determine the resistance of the device and hence inferentially the temperature to which it is subjected. By way of example, if the device is connected in series circuit with a source of potential, the current flow in the circuit will vary in functional relation to the resistance. Hence, a current measuring device connected in the circuit may be graduated to read directly in temperature.

Likewise, the device may be used in conjunction with control devices to regulate automatically the temperature to which it is exposed or to control an agent or medium in accordance with that temperature. Such control devices may be actuated directly or in conjunction with the measuring devices previously referred to.

For a more complete understanding of this invention, reference should be had to the accompanying drawings in which Fig. 1 is an elevation of a temperature responsive device arranged in accordance with this invention; Fig. 2 is an enlarged fragmentary sectional view of the device of Fig. 1; Fig. 3 is a diagrammatic view illustrating the resistance-temperature relationships for various resistance materials used as the temperature sensitive element; Figs. 4, 5 and 6 are elevations illustrating certain devices used in making the control device of Figs. 1 and 2, the elevation in Fig. 4 being in section; Fig. 7 illustrates diagrammatically a heating member used to heat-treat the temperature sensitive element in accordance with this invention; Fig. 8 is a diagrammatic representation showing the relationship between the resistance of the control device and time that is effected in one of the heat-treating steps used in making the control device; Fig. 9 is a view similar to Fig. 1, but showing a modified form of this invention, and having parts in

section; Fig. 10 is an enlarged sectional view of the modified form of the invention shown in Fig. 9; Figs. 11, 12 and 13 are diagrammatic views illustrating certain means for modifying the fundamental relationship between temperature and resistance of the control device of this invention; and Figs. 14, 15 and 16 are curves showing the changes in the fundamental resistance characteristics of the control device effected by the controlling elements shown in Figs. 11, 12 and 13 respectively.

Referring to Figs. 1 and 2, this invention has been shown in one form in connection with a temperature control device for controlling the circuit of an electric furnace (not shown). As shown, the control device comprises a cartridge 10 which is provided with a pair of electrodes 11 and 12 spaced from each other. The inner electrode 11 is in the form of a core, while the outer electrode 12 is in the form of a cylinder, closed at one end, as shown. Interposed between the electrodes and embedding the inner end of the electrode 11 is a mass 13 formed of resistance material having a negative temperature coefficient.

The material of which the inner and outer electrodes 11 and 12 is made may vary widely, the maximum temperature at which the control device is to operate being one of the chief factors to be considered in selecting the material that will be used; for example, for temperatures ranging between zero and 800° F. a metal known as "Monel" may be used, while if the temperature range should vary between 100 and 1000° F. it is preferable to use nickel.

The material 13 will be chosen in accordance with the characteristic temperature-resistance curve desired, and also so as to provide an insulating mass having substantially the same thermal coefficient of expansion as have the electrodes that will be used. For a particular desired temperature-resistance curve and where nickel electrodes are used, a mixture of magnesium oxide, sodium silicate and copper oxide (CuO₂) will be used having a ratio by weight of .25 of copper oxide to 2.52 of magnesium oxide and 1.47 of sodium silicate. The sodium silicate is made up of silicon oxide and sodium oxide, and it is preferable that these materials shall be in the ratio of approximately 1:3.22, although this ratio may be varied to give different desirable physical characteristics.

Different temperature-resistance characteristics and coefficients of thermal expansion may be obtained by varying the proportions of the ingredients used. Generally it is preferable to vary the percentage of the copper oxide in the mixture. Fig. 3 illustrates how the resistance characteristics will vary with temperature with different ratios of copper oxide. Curve a corresponds to the above example where the resistance has a ratio by weight of .25 of copper oxide, to 2.52 of magnesium oxide and 1.47 of sodium silicate; curve b is the curve of a resistance where the ratio by weight of copper oxide is changed to 1; c where it is changed to 3; and d where it is changed to 6. When the ratio of copper oxide is varied to control the resistance characteristics, the ratio of magnesium oxide to sodium silicate should be substantially constant for the various resistances.

However, the percentages of magnesium oxide, sodium silicate and copper oxide all may be varied to obtain different temperature-resistance characteristics, and to provide different coefficients of

expansion. Mixtures of magnesium oxide and sodium silicate alone, without any copper oxide, may be used in different proportions to obtain different desired characteristic curves and coefficients of expansion; and still other variations may be had by substituting zirconium oxide, aluminum oxide and the like for the magnesium oxide, and using zinc oxide, nickel oxide, chromium oxide and the like in place of the copper oxide. A wide range of temperature-resistance characteristic curves, and coefficients of expansion may be obtained by selecting different ones of these materials and using them in different proportions.

The resistance 13 is highly compacted and the various ingredients of the resistance are sintered to each other and are also intimately bonded to the outer surfaces of the inner electrode 11 and to the inner surfaces of the outer electrode 12.

The control device thus far described is made as follows. The inner surface of the outer electrode 12 and the outer surface of the inner electrode 11 are covered with an oxide layer. This may be and preferably is accomplished by heating these surfaces with a flame in air. And then while these surfaces are heated a quantity of a suitable flux, such as sodium silicate, is dusted on these surfaces in the form of a powder. This powder will dissolve and combine with the oxide to form coatings of a mixture of the oxide and silicate on the surfaces of the electrodes.

The outer electrode 12 is then mounted in a form 14 (Fig. 4) having great mechanical strength. This form 14, as shown, is provided with a hole or recess 15 which will have such a diameter that the outer electrode 12 will have a sliding fit with it. A measured quantity of the resistance material 13 in granular form is then poured into the outer electrode 12.

It is to be understood that it is desirable that the material 13 be in the form of fine granules that will pass through a 200 mesh screen. Moreover, the granular ingredients which make up the material 13 must be thoroughly mixed. Furthermore, it is desirable that these materials be chemically pure and anhydrous. Before the granular mixture be used, it is preferable that it be heated for about 3 hours at around 400° F. in order to drive off any moisture that may have been absorbed by the mixture while it is being handled, and preferably it will be introduced into the electrode 12 while still hot.

After the measured quantity of the mixture has been placed with in the outer electrode 12, it is subjected to a great pressure by means of a suitable plunger, such as the plunger 16 shown in Fig. 5. Preferably, the mixture will be compressed at about ten tons per square inch. This forms a small tablet 17 in the inner end of the electrode 12, as shown in Fig. 4 and as indicated in dotted lines in Fig. 2. It will be observed that the lower end of the plunger 16 which contacts the resistance granules is conical so that the tablet 17 will be provided with an upper conical surface, as shown.

The inner electrode 11 is then placed in the outer electrode 12 while the latter is still in the form 14. The conical upper surface of the tablet 17 functions to center the lower end of the inner electrode 11.

Then the remainder of the resistance material 13 will be highly compacted into the spaces between the electrodes 11 and 12. Preferably the entire quantity will not be introduced at one time, but only small quantities, that is, short sec-

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tions, will be supplied at a time, and each small quantity after being introduced will be compressed before any more is added. This insures an adequate pressure throughout all of the powder and eliminates any tendency for the powder at the lower part of the assembly to remain porous. Each amount of the resistance material that is put in the electrode 12 is subjected to a pressure of around ten tons per square inch. In compressing these measured amounts of the resistance material a plunger 18, such as that shown in Fig. 6, will be used. As shown, this plunger is provided with a passageway 19 throughout its length; this passageway receives the inner electrode 11 while the plunger is used to compress the resistance powder, and it functions to center the inner electrode 11 during the compressing steps.

The assembly of the two electrodes 11 and 12 and the compressed resistance material 13 is then removed from the form 14. Generally a considerable force is required to remove the assembly and the form 14 is provided with an aperture 20 through which a suitable instrument (not shown) may be inserted to drive the assembly from the form.

The assembly of the two electrodes 11 and 12 and the compressed resistance material 13 is then placed in a suitable furnace, such as an electric furnace, where it is heated for about one hour at a temperature of around 950° F. It is brought up to this temperature from room temperature relatively slowly so that any moisture or water which might be contained in the powder will not generate steam which might blow out or disturb portions of the powder. Preferably, it should require about one hour to bring the unit up to this temperature of 950° F. This heating operation drives out any moisture which may have been picked up by the resistance material, or which may not have been driven out by the previous drying out step referred to above.

The assembly of the electrodes and resistance powder may be heated in this manner in a tube 21 as shown in Fig. 7. This tube has one end closed and the other end open, and is sufficiently long to receive the entire cartridge unit 10. Preferably, the walls will be made of a suitable high temperature porcelain material. The tube and cartridge assembly preferably will be heated in a high temperature electric furnace.

After the assembly has been heated for one hour at 950° F. the energy rate to the furnace is increased so that in a period of about two hours a high sintering temperature will be reached. This temperature while high should be well below the melting temperatures of the materials. For the above specific example having a ratio by weight of .25 of copper oxide to 2.52 of magnesium oxide and 1.47 of sodium silicate a sintering temperature of around 1975° F. will be used. The assembly is held at this temperature for about ten minutes and then is permitted to cool down slowly to a temperature of about 1100° F. where it is held for about 16 hours, after which it is permitted to cool.

One end of the furnace 21 is left open during the above-described heating steps so as to expose the resistance material 13 within the outer electrode 12 to a normal air atmosphere, while the outer surfaces of the electrode 12 are in an atmosphere substantially free from oxygen. It is important that the contents of the electrode 12 be thus exposed to air, particularly where one of the ingredients is copper oxide, because in

heating it is found that the copper oxide in the form CuO_2 has a tendency to reduce to copper oxide in the form CuO . The latter form has a higher resistance than the former and is not stable in an air atmosphere at high temperatures. Thus, in the air atmosphere it has a tendency to go back to the first form CuO_2 .

The sintering operation causes the particles of the granular mixture 13 to intimately coalesce with each other and with the coatings that were provided on the inner surface of the outer electrode 12 and the outer surface of the inner electrode 11 so as to form a coherent mass of resistance material which is intimately bonded with the surfaces of the electrodes 11 and 12. During the switching operation, the coatings provided in the electrodes actually sinter with the particles of the granular mixture so that in effect the resistance material 13 is formed into a coherent mass with the electrodes.

The assembly then is allowed to "age" at a medium high temperature and for a relatively long period of time, and in "aging" it is desirable that the interior of the assembly be exposed to an air atmosphere. The same furnace 21 may be used for "aging." With the resistance material mixture of the above example, the assembly is aged at a temperature of around 1000 to 1100° F. and for a period of about 40 to 50 hours. The aging temperature is selected so as to be somewhat higher than the ultimate temperature at which the element is to be operated. While the unit is "aging" an electrical current of about twenty milliamperes is caused to pass through the resistance material between the electrodes. The amount of current may be varied somewhat, but at present I prefer to use around twenty milliamperes. The aging process causes all of the copper oxide in the form of CuO , which has not reverted to CuO_2 , to go back to this stable form. This stabilizes the resistance. The effect of this "aging" treatment is shown graphically in Fig. 8. Here the resistance at the end of the firing is likely to be higher than the stabilized resistance, as shown by the curve, but after about 40 to 50 hours of aging it will drop down and will become stable due to the conversion of the copper oxide from the form CuO to CuO_2 . Moreover, I have found that the aging process greatly improves the joint or bond between the electrodes and the resistance mass.

The assembly after "aging" is then assembled with an extension tube 22 which is used to support the cartridge 10 in assembled relation with the medium whose temperature is to be controlled, and which tube may be formed of any suitable material, such as steel. For example, if the control device is to be used to control the temperature of an electric furnace, the tube 22 will be passed through the furnace wall so as to hold the cartridge 10 in position to be immersed in the furnace atmosphere. The length of the supporting tube 22 will depend, of course, upon the particular application of the control element 10. Preferably, the tube 22 will be threaded on the electrode 12, as shown, the electrode and tube having relatively fine interfitting threads. The threaded joint between the electrode and tube will be sealed by a suitable high temperature cement which is placed on the threads before they are threaded together.

A suitable lead 23, which preferably will be formed of nickel, is brazed to the inner electrode 12 and extends outwardly through the tube 22. This lead is provided with a covering 24 of a suit-

able electrically insulating material, such as asbestos.

The outer end of the tube 22, that is its right-hand end as viewed in Figs. 1 and 2 is closed by means of an electrically insulating terminal block 25 which, as shown, is fitted over this end like a cap. The block 25 is made of any suitable material, such as a suitable asbestos board. This terminal block is provided with an aperture 26 through which the lead 23 is passed and it carries a terminal 27 (Fig. 1) to which the lead is brazed. The terminal block 25 also carries a terminal 28 to which the lead 29 is electrically connected. This lead 29 is directed through an aperture 30 provided for it in the terminal block and it is welded, as shown, to the outer surface of the tube 22, the tube 22, of course, constituting a continuation of the outer electrode 12.

The terminal block is secured by means of a set screw 30a; and the joint between the block 25 and the outer surface of the tube 22 and between the inner walls of the channel 26 and the lead 23 are covered with a suitable electrically insulating sealing cement, such as a suitable alkyd resin.

In the form of the invention shown in Figs. 9 and 10, the cartridge 31 is provided with inner and outer electrodes 32 and 33 which are both in the form of cylinders closed at one end, as shown. Here the two electrodes are separated by a mass 34 formed of the resistance material having a negative temperature coefficient and which material will be the same as the material 13 of the first form.

The cartridge 31 is made in substantially the same way as the cartridge 10. Thus, the inner walls of the outer electrode and the outer walls of the inner are provided with coatings comprising the oxides of the electrode walls and a suitable flux, such as sodium silicate; the resistance material 34 is prepared in the same way as the material 13; the electrode 31 is placed in a form and a tablet of the resistance material, similar to the tablet 17, is formed in its inner end; the inner electrode is inserted with its tapered end fitted in the tablet; and the rest of the resistance material 34 is then compressed into place. The assembly is then given the treatments described in connection with the first form, whereby a coherent mass of sintered resistance material 34 is provided embedding the inner end of the electrode 32 and integrally united with the surfaces of the electrodes which it contacts. Here, a supporting steel tube 35 is secured to the outer end of the electrode 33. In this case the tube 35 is welded to the electrode. An insulated lead 36 has its inner conducting end welded to the inner electrode 32 while its outer end is passed through a conducting bolt 37 which has a central passageway, as shown, for receiving the lead. This outer end of the lead is soldered to the outer end of the stud 37. This stud 37 passes through an insulating terminal block or head 38 formed of any suitable electrically insulating material, such as asbestos board. As shown, this member 38 has a centrally arranged aperture through which the stud 37 passes.

A second terminal stud 39 passes through an aperture provided for it in the head 38, as shown and the head of this stud is welded to the outer wall of the tube 35 through the medium of a conducting strip 40 which is welded both to the head and to the side wall of the tube. The head is secured by means of a set screw 41, and preferably will be sealed to the inner walls of the tube

35 and to the stud 37 by means of a suitable electrically insulating cement, such as alkyd resin.

It will be understood that for my given temperature responsive cartridge having a particular temperature sensitive resistance the cartridge will have a fundamental temperature-resistance relationship. That is, the resistance of the element will drop rapidly with temperature increase, along a fixed curve, which is incapable of modification after the cartridge has once been produced since the slope of the curve and the actual values of the coordinates are dependent entirely upon the quality and kind of resistance material used and the process through which it has been carried. For example, with a specific cartridge, the resistance of the element will vary with temperature as shown by the solid curve in Fig. 14. At times, it is desirable to modify the shape of this curve and this may be accomplished by suitable controlling resistances inserted in the controlled circuit in which the controlling cartridge is placed. Referring to Fig. 11, the resistance of the cartridge is indicated R_1 . If a series resistance R_2 be placed in the controlled circuit, as shown diagrammatically in Fig. 11, the high temperature end of the curve alone is affected, as indicated in dotted lines in Fig. 14. This is because a fixed series resistance becomes proportionately a lower ratio of the total resistance as the temperature is reduced.

On the other hand, a parallel resistance will affect only the cold end of the curve since its ratio of effectiveness is entirely negligible when the control element resistance R_1 is low. Fig. 12 shows a resistance R_3 connected in parallel with the resistance R_1 , and Fig. 15 shows in dotted lines the effect of the addition of this resistance on the fundamental temperature-resistance curve.

In Fig. 13 both a series resistance R_3 and a parallel resistance R_4 are used. In this case one resistance is effective at one end of the curve and the other at the other end so as to modify the slope of the curve throughout, as shown in Fig. 16.

It will be understood, of course, that the effectiveness of the controlling resistances may be varied as desired by any suitable adjusting means so that the slope of the fundamental characteristic curve for any particular cartridge element may be varied.

It will be observed that I have provided a temperature control element which is extremely sensitive to temperature changes. The sensitive resistance is in intimate thermal relation with its outer electrode which functions as a casing to bring it into contact directly with the medium whose temperature is to be controlled; the particles forming the resistance sensitive element are compacted under a tremendous pressure and are sintered so as to form a compact, coherent mass. This coherent compacted body is bonded and substantially integrally united with the surfaces of the outer electrode which is immersed in the medium whose temperature is to be controlled which insures a minimum time lag in the response of the control device to temperature changes. Moreover, the resistance mass is bonded with the outer electrode and also with the inner electrode to effect a very good electrical connection between these members. In addition, the unit is mechanically strong and will withstand considerable abuse before it will be damaged, far more abuse than will be encountered

in its controlling applications; it is stable and durable; and is physically small so that its range of application is materially extended. It will also be observed in view of the foregoing description of the method of making this unit that relatively simple manufacturing steps are used. In addition to this, the construction of the element in its various parts and the method whereby these parts are assembled insure a uniform product. It has been found that the elements made in accordance with this invention are duplicates of each other and that they have the same resistance and other characteristics; the controlling elements made in accordance with this invention not only are the duplicates of each other at the time of manufacture, but retain substantially the same operating characteristics after a very long life.

While I have shown particular embodiments of my invention, it will be understood, of course, that I do not wish to be limited thereto since many modifications may be made, and I, therefore, contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. A temperature responsive device comprising a tubular metallic electrode closed at one end, a second metallic electrode inserted in said tubular electrode and spaced from its walls, and a temperature sensitive resistance material within said tubular electrode embedding the inner end of said second electrode formed of a preselected mixture of granular magnesium oxide, sodium silicate and copper oxide, the granular particles of said mixture being highly compressed and sintered into a coherent mass and bonded intimately with the surfaces of said two electrodes.

2. A temperature sensitive device comprising spaced metallic electrodes, a sintered mass of temperature sensitive granular resistance material between surfaces of said electrodes, said surfaces being provided with fluxed coatings intimately bonded with said surfaces and also sintered into a coherent mass with said sintered granular resistance material.

3. A temperature responsive device comprising a tubular metallic electrode closed at one end, a second metallic electrode inserted in said tubular electrode and spaced from its walls, granular resistance material within said tubular electrode embedding the inner end portion of said second electrode sintered into a coherent mass that is bonded intimately with surfaces of said electrodes, a tubular supporting extension supporting said outer electrode, a lead connected to said inner electrode extending through said tubular extension, a lead connected to said tubular extension, an insulating member closing said tubular extension and having apertures through which said leads pass, and means for sealing the joints between said electrode and said extension, and between said extension and said closing member, and also for sealing said closing member to said lead that extends from said inner electrode.

4. The method of making a temperature responsive device which comprises inserting a metallic electrode into a tubular metallic electrode that has one end closed so that the first-named electrode is in spaced relation with the walls of the latter, inserting granular temperature sensitive resistance material into said tubular electrode in relatively small quantities at

a time and highly compressing each quantity of the material after it has been added and before the next quantity has been added, and then firing at a high temperature to sinter said granular resistance material.

5. The method of making a temperature responsive device having a pair of spaced electrodes joined by a temperature sensitive resistance material formed of magnesium oxide, sodium silicate, and copper oxide which comprises mixing granules of said materials together, placing them between said electrodes, compressing said granules to highly compact them while in contact with said electrodes, heating said compacted granules slowly until a temperature of around 950° F. is reached in about one hour, holding said temperature for about one hour, increasing said temperature in about two hours to around 1975° F. and holding said temperature for around ten minutes, and then permitting said resistance material to cool.

6. The method of making a temperature responsive element having a pair of spaced electrodes joined by a temperature sensitive resistance material formed of magnesium oxide, sodium silicate, and copper oxide which comprises mixing granules of said materials together, heating said granules at a temperature of around 400° F. for about three hours, placing said granules while heated between said electrodes, compressing said granules to highly compact them while in contact with said electrodes, then gradually raising the temperature of said compacted granules in about one hour to a temperature of about 950° F. and holding said temperature for about one hour, increasing the temperature of said compacted granules so that in about two hours it reaches a sintering temperature of around 1975° F. and holding said temperature for around ten minutes, and then permitting said insulating material to cool to a temperature of around 1100° F. and holding said temperature for about sixteen hours.

7. The method of making a temperature responsive device having spaced metallic electrodes and a temperature responsive element formed of a sintered granular temperature sensitive resistance material between them comprising forming on the surfaces of said electrodes that shall contact said resistance material coatings consisting of a mixture of a metallic oxide and a flux that are capable of being sintered to said granular resistance material, compressing granules of said resistance material into a dense mass in contact with said coatings, and then sintering said granules to cause them to coalesce with each other and with said coatings.

8. The method of making a temperature responsive device having spaced metallic electrodes and a temperature responsive element formed of a temperature sensitive resistance material between them comprising heating surfaces of said electrodes so as to form an oxidized layer on said surfaces, applying a quantity of fluxing material in powdered form to said oxidized layers while heated to cause said material to unite with said layers, and form coatings capable of being sintered, compressing granules of said resistance material into a dense mass in contact with said coatings, and then highly heating the assembly of electrodes and said dense mass to sinter the granules into a coalescent mass with said coatings.

9. The method of making a temperature responsive device having spaced electrodes and a

temperature sensitive resistance element joining said electrode which comprises forming a tubular electrode, and also a second electrode adapted to be inserted in said first electrode in spaced relation with its walls, inserting a quantity of said resistance material in said first electrode, highly compressing said material to form a relatively small capsule in the bottom of said electrode and so that it has a centrally positioned depression, placing said second electrode with one end received in said depression, highly compacting the remainder of said resistance material in a series of pressure steps between said electrodes, and then highly heating the assembly of electrodes and resistance material so as to form a substantially coherent mass of said resistance material.

10. The method of making a temperature responsive device having spaced electrodes and a temperature sensitive resistance element joining said electrodes which comprises forming a tubular electrode and a second electrode adapted to be inserted in said first electrode in spaced relation with its walls, inserting a quantity of a mixture of magnesium oxide, sodium silicate and copper oxide granules in predetermined proportions in said first electrode and highly compacting said granules in the spaces between said electrodes, and highly heating the assembly of electrodes and granules to sinter the granules into a coherent mass while maintaining a non-oxidizing atmosphere outside of said assembly and an oxidizing atmosphere within said first electrode.

11. The method of making a temperature re-

sponsive device having a pair of spaced electrodes joined by a temperature sensitive resistance material formed of magnesium oxide, sodium silicate, and copper oxide which comprises mixing granules of said materials together, placing them between said electrodes, compressing said granules to highly compact them while in contact with said electrodes, heating said compacted granules slowly until a temperature of around 950° F. is reached in about one hour, holding said temperature for about one hour, increasing said temperature in about two hours to around 1975° F. and holding said temperature for around ten minutes, and then permitting said granules to cool down to a temperature of around 1100° F. and holding it at this temperature for around sixteen hours, and then "aging" said resistance material from around forty to fifty hours at a temperature of around 1000 to 1100° F.

12. The method of making a temperature responsive device having a pair of spaced electrodes joined by a temperature sensitive resistance material formed of magnesium oxide, sodium silicate, and copper oxide which comprises mixing granules of said materials together, placing them between said electrodes, compressing said granules to highly compact them while in contact with said electrodes, heating said compacted granules to sinter them into a coherent mass, and "aging" said mass at a temperature of around 1000 to 1100° F. for about forty to fifty hours.

CHESTER I. HALL.

CERTIFICATE OF CORRECTION.

Patent No. 2,271,975.

February 3, 1942.

CHESTER I. HALL.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 53-54, for "characteristic" read --characteristics--; page 4, second column, line 4, for "my" read --any--; page 6, first column, line 2, claim 9, for "electrode" read --electrodes--; and that the said Letters Patent should be read with this correction that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 24th day of March, A. D. 1942.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.

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