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M. L. BARFIELD ET AL

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TEMPERATURE-STABLE MOLDED RESISTOR

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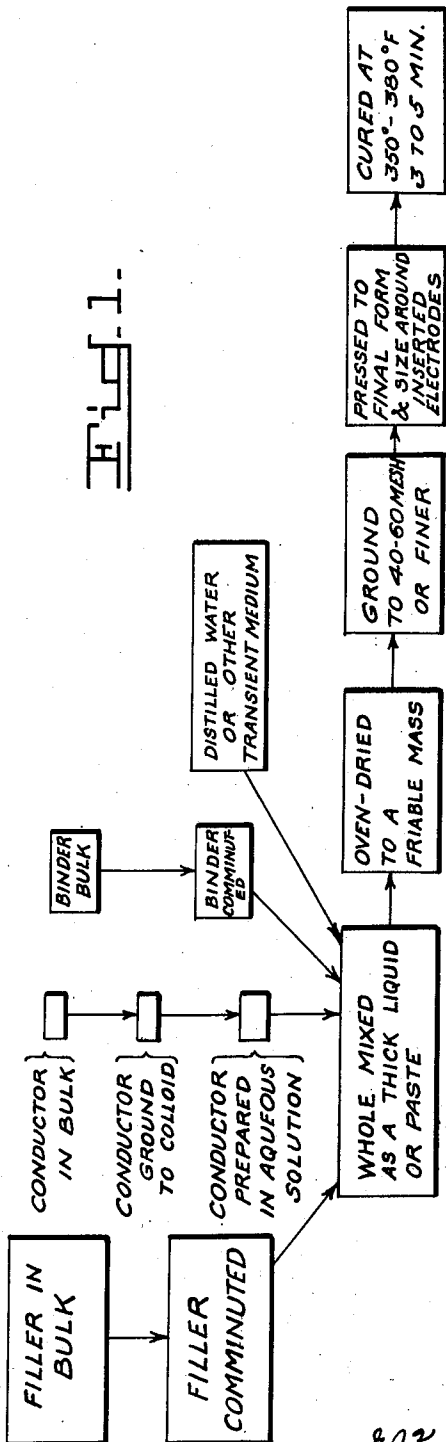


Fig. 2-

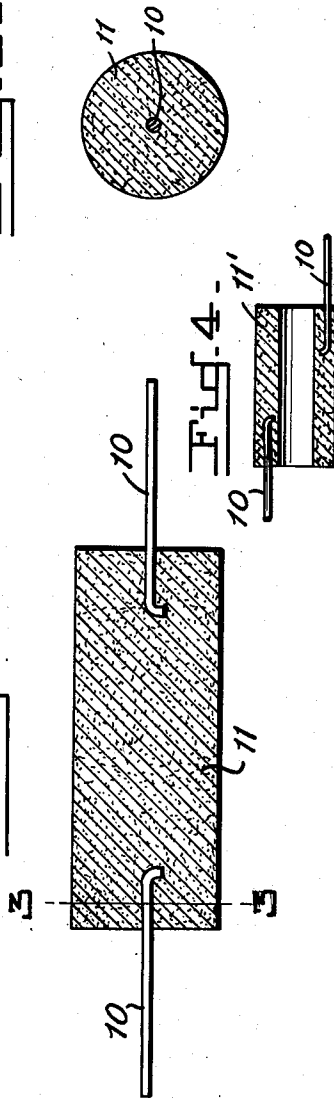
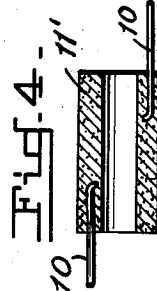
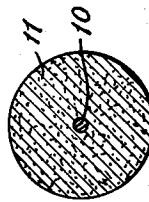


Fig. 3-



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TEMPERATURE-STABLE MOLDED RESISTOR

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3 Claims. (Cl. 201—76)

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The invention described in the foregoing specification and claims may be manufactured and used by or for the Government for governmental purposes without the payment to us of any royalty thereon.

The invention relates to resistors used in electrical and electronic circuits, and particularly the latter.

The object of our invention is the production of electrical resistance elements, commonly termed resistors, the electrical resistance of which is held to close tolerances even when the temperature of the element is widely varied.

It is also an aim to present a resistor of such composition that it will have great stability under the influence of water vapor, and which will be thoroughly water-proof.

Another purpose is to produce a strong resistor body of a simple nature.

In electrical and electronic circuits, it is highly desirable that the electrical values of the various circuit components remain constant within close limits, despite wide changes in such operating conditions as the temperature and humidity which the device may encounter in use. It is a normal characteristic of most existing resistance elements that their resistance value increases appreciably when their temperature rises. Such change in resistance may cause malfunction of the circuit in which the elements are used; for example, variation of resistance in an electrical oscillator circuit will cause variation in the frequency at which the circuit oscillates.

In our invention, one embodiment of which is hereinafter described, resistance varies less than $\pm 1\%$ when temperature varies between -65 degrees centigrade and $+70$ degrees centigrade, which involves negligible effects on circuits of the nature above mentioned.

Commercially available resistors have fallen far short of this and have varied as much as 40% in value within the temperature range stated.

The method of mixing the material composing our resistor is greatly at variance with the methods ordinarily used in the resistor manufacture industry, and affords a more homogeneous and stable end product than do other methods. In addition, the use of a heat polymerizable resin such as melamine-formaldehyde type of plastic instead of the commonly used resins of the Bakelite type is a novel feature of our resistor, which enables it to exhibit the desired characteristic of maintaining resistance at a constant (within $\pm 1\%$) value despite large changes in temperature.

Various objects, advantages and features of in-

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vention other than those specifically stated, reside in the combination of ingredients and the treatments and order of steps in the production of the article as disclosed herein, and will be apparent or understood from the following description and accompanying drawing, wherein

Figure 1 is a chart of the materials and steps of their treatment, combination and processing to produce the article having the advantages, qualities, properties and characteristics sought;

Figures 2 and 3 are longitudinal and cross-sections of a resistor;

Figure 4, shows a modification.

Our resistor is composed of three basic materials which are processed and affixed to suitable electrodes. The three materials are a binder, a filler, and a conductor.

The binder may be selected phenolic condensate, especially a selected thermosetting resin; examples are certain plastics, including melamine-formaldehyde plastics, and resorcinol-formaldehyde plastics. We prefer to use plastics of the melamine-formaldehyde type because they afford greater stability at extreme temperatures and are least affected by moisture. Certain phenaldehyde resins having inherent stability as a dielectric may be used as hereinafter described to produce a resistor having high stability under thermal variations of its condition.

The filler may be any fine-grain mineral fiber, such as asbestos or mineralite. We prefer to use asbestos because its characteristics afford more uniform flow of the material during molding.

The conductive material may be any finely-divided conductive mineral, such as graphite, lampblack, or such combinations of graphite and lampblack as hydrograf, aquadag, etc., or powdered metals such as silver, copper, and the like. We prefer graphite, lampblack, or a combination of the two, because these materials are readily suspended in an aqueous medium, and because in the emulsion formed, they readily coat the resin particles.

In manufacture, the binder and filler are reduced to a degree of fineness between grades commercially known as 40-mesh and 60-mesh or finer, through the use of a ball mill or other suitable equipment. The conducting material is also greatly reduced, and is preferably obtained as a colloidal solution before mixing. The binder and filler are made into a paste using water of extreme purity, preferably distilled water. The conducting material is introduced thereto followed by the other ingredients, and the whole mixture thoroughly agitated and blended, the proportions

of the materials being described hereinafter. A wetting agent or dispersing agent may be added, with benefit to homogeneity. The paste-like mix is then oven-dried to a hard cake at temperatures lying, preferably, between 60 degrees and 80 degrees centigrade, to remove the moisture. After drying, the material is friable, being a cake having a crushing strength approximately like that of sun-dried clay brick.

This cake is broken and again ground to the original fineness (i. e., from 40 to 60 mesh or finer). The powder thus produced is introduced into molds in which electrodes 10 are set so as to be embedded in the body 11 of the article. The material is then compressed in the molds under high pressure of from 3000 pounds to 6000 pounds per square inch; and while maintained under such pressure is cured at 350 to 380 degrees Fahrenheit for periods ranging between three and five minutes, the time and temperature not being critical within these limits. With a given formula in the initial mixture the lesser pressure will result in a higher resistance, and the higher pressure a lower resistance. The higher named pressure 15 is preferred, and gives greater assurance of stability. Greater pressure is not harmful, but no corresponding improvement in stability is gained with the components stated. Instead of water; aliphatics, and aromatics, of selected forms may be used as the medium in which the mixture and stirring may be carried out for producing the cake referred to and if desired, the colloidal suspension of the conductor for introduction into the mix may be in some congruous liquid other than water.

Among the aliphatics we have used alcohols, acetone, and ketones; and among the aromatics available are hydrogenated naphthalene, benzene, and toluene. Carbon tetrachloride has been found undesirable on account of the impurities present in the article available on the market.

The material may be baked at lower or moderately higher temperatures with corresponding lengthening or shortening of the time, the lower limit of baking being determined by the effective temperatures required for the proper setting of the plastic, and the upper limits being fixed by the liability of charring or of impairing the hardness and strength or resistivity of the binder. Excessive periods of baking within the preferred range of temperatures may also similarly affect the properties of the resistor. Shorter baking may result in imperfect thermosetting.

The proportions of binder, filler, and conductive material may be varied over a wide range for the purpose of producing (a) resistors of the same size and same inter-electrode spacing, but with differing resistance values; (b) resistors of differing size, but with the same inter-electrode spacing and the same resistance values; (c) resistors of the same size, but with differing inter-electrode spacing and the same resistance values; (d) resistors of differing sizes and inter-electrode spacing, but with the same resistance values; (e) resistors of shape or form differing from those shown in the drawings, and of desired resistance value; (f) other desirable resistors.

We have produced, by use of the composition and method herein described, resistors ranging in value from 20,000 ohms to 100,000,000,000 ohms, but these values by no means indicate the limits of values obtainable, which may be carried to values of ten to the 12th, using melamine. Higher values may be possible according to the binder and filler and the formula. By varying the form,

dimensions, proportions of materials, and electrode spacing, values from a small fraction of 1 ohm to many billions of ohms may be obtained through the use of our composition and method, and the close resistance tolerance of $\pm 1\%$ will be retained.

In practical production, variation in the proportions of the ingredients, form and dimensions of the resistor, and form, dimensions and spacing of the electrodes are used, singly or in combination, to control the resistance value of the resistors. The following examples illustrate this effect:

Resistance Value, Ohms	Diameter of Res.	Elec.	Electrode Spacing ¹	Binder Parts	Filler Parts	Conductor Parts
	Inches		Inches			
1,000,000	$\frac{3}{4}$	#18	$\frac{3}{16}$	23	69	8
1,000,000	$\frac{3}{4}$	#18	$\frac{5}{16}$	24	73	3
1,000,000	$\frac{3}{4}$	#18	$\frac{5}{16}$	18	82	3
20,000	$\frac{3}{4}$	#18	$\frac{5}{16}$	26	74	16

Parts are designated by weights.

¹ No. 18 tinned copper wire.

² The resistors are $1\frac{1}{4}$ inches long, irrespective of electrode spacing.

While we have used tinned wire to good advantage, it will be appreciated that other conductors may be used, or copper with silver or other coating employed.

In manufacturing the resistors, the electrodes 10 are put into the mold prior to the introduction of the mix, and their spacing is accurately controlled by means of stops which may be set to provide the required inter-electrode spacing.

The accompanying drawings illustrate an end view and an axial cross section of a resistor having a body 11 of the low conductance material $\frac{1}{4}$ inch in diameter and $1\frac{1}{8}$ inches long, more or less, which is one of the many forms and sizes which can be produced by our method. As an example of another size, the resistor might be $\frac{1}{2}$ inch in diameter and 4 inches long; as an example of another shape, the resistor body 11' might be tubular, as shown in Figure 4.

It will be understood that in the initial drying of the caked mixture at the temperature indicated, after the evaporation of the water, the plastic will become closely bonded with the filler, but because the drying temperature is below that required for the necessary alteration of the plastic to result in its final setting, the resulting cake remains a friable body, the hardness and strength of which may be compared to that of pressed clay brick not fired, but air dried, my mixture at this stage being somewhat stronger in fact. This results in a very homogeneous mixture produced by the crushing and grinding of the cake rather than being entirely dependent on stirring and blending, and the bond between the resin and filler and conductor is also believed to improve the homogeneity of the mixture. The stirring of the paste is likewise important.

In the final baking at high temperature, the plastic becomes highly liquefied, and completely permeates the filler and conductor mass, so that there is finally produced a completely homogeneous and greatly strengthened and hardened body. The plastic becomes permanently set, and highly resistant to fire, if not fireproof, in addition to being moisture resistant and stable in resistivity. The specific mixture disclosed makes a water repellant resistor.

Comparative tests of resistors heretofore made using phenolic resins and fillers as heretofore known and practiced show our article to have ex-

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ceptional thermal stability and moisture resistance. We attribute the exceptional thermal stability and moisture resistant quality and stability of our resistor largely to the intermediate steps of mixture of the well ground components in a water diluted mass, its drying into a friable cake, the grinding of that cake to produce the final fine moldable material, and its high compression and baking at thermo-setting temperature thereafter. These intermediate steps produce a structural relation of the components in the final product which involves a greater intimacy of the mixture and high homogeneity with a consequent material effect in achieving the higher stability of resistance in our resistor as compared to prior available products. In addition the use of the melamine-formaldehyde we believe has contributed at least in part, to this achievement.

I claim:

1. The method of producing a resistor body comprising comminuting an unpolymerized thermoplastic base, comminuting a filler material of low cohesive quality and high electrical resistance, reducing a conductive material to a colloid, mixing all the ingredients in a transient liquid medium, to produce a viscid mass, baking the mass at low temperature to produce a completely dry relatively weak friable mass, comminuting said mass to at least the fineness of the original said comminution of binder and filler, pressing the last

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comminuted material in a mold with high pressure, and curing the same at a high temperature.

2. The invention recited in claim 1 wherein said unpolymerized thermoplastic base and said filler material are comminuted to pass at least a 40-mesh screen.

3. The invention recited in claim 2 wherein the molding pressure is in the range of 3,000-6,000 pounds and the molding temperature ranges from 350-380° F.

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