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LOW VOLTAGE NON-LINEAR ELECTRICAL RESISTANCE ELEMENTS
AND METHOD OF MANUFACTURE THEREOF

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Fig. 1.

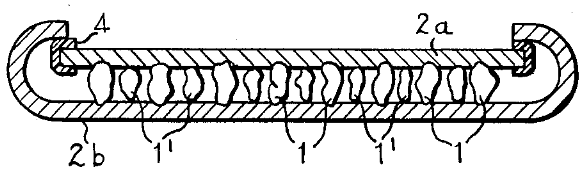


Fig. 2.

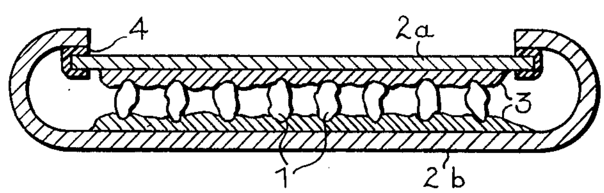
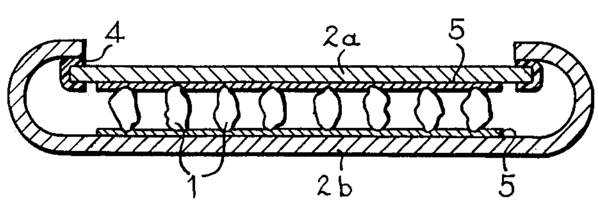


Fig. 3.



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LOW VOLTAGE NON-LINEAR ELECTRICAL RESISTANCE ELEMENTS AND METHOD OF MANUFACTURE THEREOF

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12 Claims. (Cl. 338—20)

This invention relates to non-linear electrical resistance elements, that is, resistance elements which have a non-linear voltage-current characteristic.

Such resistance elements for use with voltages greater than, say, 25 volts are kell known and usually consist of a quantity of discrete particles of a resistance material such as silicon carbide the electrical resistance of which varies with variation in applied voltage, in combination with a ceramic binder. One well known type is known under the registered trade mark "Metrosil" and its electrical characteristic may be expressed in the form:

$$V=KI\beta$$

I and V are the current through and voltage across the resistance element respectively, the index β is characteristic of the material from which the resistance element is made, and the constant K depends upon the shape and size of the resistance element as well as on the material. In practice, the voltage at any current density is proportional to the thickness of the resistance element and the current at any voltage gradient is proportional to the area of the resistance element. The most common form of this type of resistance element is a disc and the lower the voltage, the thinner the disc is required to be.

Resistance elements of this type are usually manufactured by pressing a mixture of granules of silicon carbide or other such material and a ceramic material into the form of a disc which is then sintered. However such resistance elements designed for low voltage applications are rather fragile. For example, for use at 25 volts the disc may be only 0.02" thick. For very low voltage applications the disc will comprise a single layer of a finite number of the granules and this precludes the use of a ceramic binder on the grounds of extreme fragility.

Various solutions of this problem have been proposed which employ bonding agents such as epoxy resins (which are electrical insulating materials) in place of ceramic material. This has the disadvantage that some of the granules may be encapsulated in the insulating material, thereby introducing an uncertainty into the manufacturing process and leading to uncontrolled variation in the electrical properties of the resistance element.

It is an object of the present invention to provide a non-linear resistance element which is suitable for use with low voltages (e.g. voltages of the order of ¼ to 5 volts) and which is robust and has electrical properties that can be accurately controlled and reproduced during manufacture.

According to the invention a non-linear resistance element is manufactured by arranging between two electrically conductive surfaces a relatively hard single layer of granules of a resistance material the electrical resistance of which varies with variation in applied voltage, applying pressure to cause at least one of said surfaces to undergo plastic flow sufficient to cause the granules to penetrate into it, and securing said surfaces against separation.

Also, according to the invention, there is provided such a non-linear resistance element in which a single layer

of granules of a resistance material whose electrical resistance varies with variation in applied voltage, is constrained between two electrically conductive surfaces at least one of which has the ability to undergo plastic flow or application of pressure and has the granules penetrating into it.

In carrying out the invention the interstices between the granules may be filled with other granules of smaller particle size to give mechanical stability to the resistance element.

In order that the invention may be more fully understood reference will now be made to the accompanying drawing in which, on an enlarged scale:

FIGS. 1–3 are sectional views of respective exemplary constructions of a non-linear resistance element conforming to the invention.

Referring to FIG. 1, the resistance element there shown comprises a finite number of granules **1** of silicon carbide or other resistance material the electrical resistance of which varies with variation in applied voltage, which are arranged as a single layer and have been constrained under pressure between two facing electrical conducting surfaces presented by a pair of juxtaposed metal discs **2***a*, **2***b*. Each of these discs **2***a*, **2***b* is composed of soft conductive material such as aluminium or soft copper with the result that the applied pressure has caused the granules **1** to penetrate into them. The edges of the lower disc **2***b* are bent over to enclose the granules **1** and to maintain the metal discs **2***a*, **2***b* in position; the top disc **2***a* and the rim of the lower disc **2***b* are electrically insulated from each other by an annular insulating washer **4**. Electrical contact with the resistance element thus formed can be made by conventional means such as spring contacts, tags, etc. (not shown).

To enhance the mechanical stability of the complete resistance element, the interstices between the granules **1** may, as shown, be filled with other granules **1'**, of smaller particle size, of either an electrically inert material such as sand or molochite or possibly of a non-linear resistance material which may or may not be the same as that from which the principle granules **1** are constituted: in the latter case it is contemplated that the smaller granules would affect the electrical properties to only a small extent, contributing mainly to mechanical stability.

The resistance element shown in FIG. 2 also comprises a finite number of granules **1** of silicon carbide or other such resistance material which are constrained as a single layer between two facing electrical conducting surfaces presented by a pair juxtaposed metal discs **2***a*, **2***b*. However, in this construction the discs **2***a*, **2***b* are of rigid metal and each has its conducting surface coated with a layer of soft solder **3** into which the granules **1** have been pressed as a result of applied pressure.

A detailed manufacturing procedure for the resistance element of FIG. 2 is as follows:

One surface of each of two metal discs is coated with a layer of soft solder, the thickness of this layer being preferably less than half the size of the granules which have been selected because of their electrical properties. To facilitate the attainment of a single layer of granules, one solder surface is smeared with a thin film of grease, preferably a silicone grease. The requisite number of granules are sprinkled on to this prepared surface and are temporarily retained thereon by the grease film. The other solder surface is then placed in contact with these granules and the two discs pressed together, thereby causing the surface coatings of solder to undergo plastic flow at the points in contact with the granules so that the granules penetrate into and are held by the solder. The depth of penetration can be controlled by either regulating the pressure applied to the discs or by restricting the thickness of the solder layer. For instance there may be employed a thick solder layer with high pressure, a thick solder layer with low pressure, or a thin solder layer with high pressure. The extent of penetration governs the area of contact between the granules and the solder and serves as an additional control over the electrical properties of the resistance element, i.e. the greater the area of contact, the greater the current and heat capacity and the less the β value at low currents. While maintaining the pressure between the two discs, the rim of one of them (which has a greater diameter than the other) is bent over to retain the two discs in position upon subsequent removal of the pressure. As in the case of the resistance element of FIG. 1, electrical insulation between the two discs is achieved by means of an annular U-shaped washer of insulating material interposed between their rims, while electrical contact with the resistance element can be made by conventional means such as spring contacts, tags, etc.

In the resistance element of FIG. 3, foil or other deformable conductive material **5** is used instead of solder as the surface coatings: the resistance elements of FIGS. 2 and 3 and the method of making them are in all other respects the same. In both FIGS. 2 and 3 the interstices between the granules **1** may be filled with other granules of small particle size (not shown) as described previously with reference to FIG. 1.

In each of the resistance elements described above, instead of bending over the rim of one of the discs to hold the latter in position, nut and bolt, spring clips, or other clamping means may equally well be provided for this purpose. Also, the discs of the resistance element need not necessarily be flat, being for instance of arcuate shape instead.

The term "single layer of granules" has been used throughout the specification because the characteristics of a non-linear resistance element according to the invention are determined by those granules which contact both conducting surfaces. However, there may be some granules which overlie others and the above term is therefore to be construed as including this possibility.

What I claim is:

1. In a method of manufacturing a non-linear resistance element, the steps of providing for a single layer of discrete granules of a resistance material, the electrical resistance of which varies with the variation in applied voltage, arranging between two electrically conductive surfaces, said layer of discrete granules so that said electrically conductive surfaces engage oppositely facing surfaces of at least a substantial number of said discrete granules in said layer, applying pressure to cause at least one of said electrically conductive surfaces to undergo plastic flow sufficient to cause the granules to be held by penetration into said one of said electrically conductive surfaces, and thereafter securing said surfaces against separation.

2. In a method of manufacturing a resistance element, the steps of coating one surface of each of two metal members with a conductive material susceptible to plastic flow under pressure, providing for a layer of discrete granules of a resistance material, the electrical resistance of which varies with variation in applied voltage, applying said layer of discrete granules to the coated surface of one member, so placing the coated surface of the other member in contact with the granules that the coatings on said metal members engage oppositely facing surface portions of at least a substantiial number of said granules in said layer, pressing the two members together with sufficient force to cause the surface coatings to undergo plastic flow at the points of contact with the granules so that the granules penetrate into and are held by the material of said coatings, and thereafter securing said members together in such manner that they are mutually insulated other than through the granules.

3. The method defined in claim **2** using soft solder for the coatings of conductive material.

4. The method defined in claim **2** using metal foil for the coatings of conductive material.

5. The method according to claim **1**, including step of filling the interstices between the granules with other granules of smaller particle size.

6. The method defined in claim **5** wherein said granules of smaller particle size are of electrically inert material.

7. A non-linear resistance element comprising a single layer of discrete granules of a resistance material whose electrical resistance varies with variation in applied voltage said granules being constrained between two electrically conductive surfaces at least one of which has the ability to undergo plastic flow on application of pressure and has the granules penetrating into it, said electrically conductive surfaces being so disposed as to engage oppositely facing surfaces of at least a substantial number of said granules in said layer.

8. The resistance element defined in claim **7** wherein the interstices between the granules of said resistance material are filled with other granules of smaller particle size to improve mechanical stability.

9. The resistance element defined in claim **8** wherein the granules of smaller particle size are of electrically inert material.

10. In a method of manufacturing a non-linear resistance element particularly suitable for use with relatively low voltages, the steps of providing for a single layer of discrete granules of a relatively hard resistance material whose electrical resistance varies with variations in applied voltage, so confining said layer of said discrete granules between two members having coextensive electrically conductive surfaces that said members contact oppositely facing surface portions of at least a substantial number of said granules in said layers, exerting sufficient pressure urging said members together to cause at least one of said surfaces to undergo plastic flow sufficient to enable said granules to penetrate into said one of said surfaces to be held by one of said members, and thereafter securing said members against separation.

11. A non-linear resistance element comprising two members having coextensive electrically conductive surfaces holding between them under pressure a single layer of discrete granules of an electrical resistance material whose electrical resistance varies with variation in applied voltage, said granules being harder than at least one of said surfaces and said pressure being sufficient to cause penetration of said granules into said one surface, said granules in said layer being so disposed that oppositely facing surfaces of a substantial number of said granules in said layer engage said electrically conductive surfaces.

12. The resistance element defined in claim **11**, wherein said granules are silicon carbide.

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