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(54) CURRENT LIMITING DEVICE

(71) We, MITSUBISHI DENKI KABUSHIKI KAISHA, of No. 12, Marunouchi 2-chome, Chiyoda-ku, Tokyo, Japan, a Body Corporated, organized and existing under the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to a current limiting device, and more particularly a current limiting fuse of self-restoring type including sodium, potassium or a solid solution thereof as a current limiting material.

The self-restoring current limiting devices called "permanent fuses" are capable of repeated current limiting operations and include, as current limiting material, metal in the form of a liquid or a solid solution readily liquefiable at room temperature; flow of shortcircuit current through the current limiting material vaporizes the material owing to the generation of Joule heat therein, whereby a plasma with very high vapour pressure is formed. The evaporated material and the plasma present to the current a specific resistance much higher than the shortcircuit impedance of the associated circuit and thereby limit the shortcircuit current below a predetermined magnitude. After the completion of the current limiting operation, the material is rapidly cooled or agitated by turbulence and is restored to its original, good electrically conductive state.

The current-limiting material is commonly sodium (Na), potassium (K), or an alloy thereof (NaK). In any event, the current limiting material must be such as greatly to increase in vapour pressure in response to flow of shortcircuit current therethrough. The enclosure containing the current limiting material undergoes a very high internal pressure and must have a mechanical strength sufficient to withstand such pressure.

The invention resides in a current limiting device comprising a body of current limiting material responsive to a flow of current therethrough above a predetermined magnitude to be evaporated thereby to perform a current limiting operation and restored to the original state after the completion of the current limiting operation, and a pressure proof enclosure for surrounding the body of current limiting material to be subject to a pressure upon evaporating the material, characterized in that the pressure proof enclosure includes a pair of metallic members in the form of hollow cylinders, one of the cylindrical members having one end portion of reduced diameter loosely inserted into the other cylindrical member to form a gap therebetween, and a solid material fills the gap and the interior of the cylindrical members except for the body of current limiting material to unite the cylindrical members into a unitary structure, the last-mentioned solid material being selected from the group consisting of electrically insulating materials and electrically resisting materials.

Preferably the said one end portion of the one cylindrical member gradually increases in outside diameter toward the extremity thereof while the adjacent end portion of the other cylindrical member is substantially complementary in shape to the said one end portion of the one cylindrical member.

Advantageously, the solid material is an electrically resisting material, and a pair of electrodes are electrically connected to the remote ends of the united cylindrical members to electrically connect the electrically resisting material in parallel circuit relationship with the body of current limiting material through the pair of electrodes connected to the body of current limiting material.

The invention will be further described by way of example in conjunction with the accompanying drawing in which:—

Figure 1 is a fragmental longitudinal sec-

tional view of a current limiting device constructed in accordance with the invention;

Figure 2 is a longitudinal sectional view of the device being prepared;

Figure 3 is a fragmental longitudinal sectional view of a second embodiment of the invention; and

Figure 5 is a longitudinal sectional view of a further embodiment of the invention.

Throughout the Figures like reference numerals designate the corresponding components.

Figure 1 illustrates a current limiting device, which comprises a pair of reinforcing tubular members 10 and 12 of substantially equal outside and inside diameters, disposed end-to-end. One of the tubular members, for example the member 10 has one end portion 14 of decreased outside diameter to form a spigot and loosely inserted into the adjacent end portion 16 of the other tubular member 12, which is of enlarged internal diameter to form a socket; a gap 18 is left between the spigot and socket. The tubular members may be formed of any suitable metallic material having a mechanical strength which need be sufficient only to withstand a moulding pressure at a predetermined moulding temperature upon moulding of the device as described hereinafter. The coefficient of thermal expansion of the material is not critical. The material need only have adequate mechanical strength at room temperature. Suitable materials are iron, and stainless steels.

As shown in Figure 1, a corrosion resisting, electrically insulating material 20 fills the gap 18 and an internal cylindrical space defined by the internal surfaces of the tubular members 10 and 12, except for a central bore 22 which will be subsequently filled with a current limiting material such as previously described.

A moulding device as shown in Figure 2 may be conveniently used to prepare the arrangement described in conjunction with Figure 1. The moulding device comprises a moulding box 24 and a three part mould 26 snugly fitted into the box 24. With the lower end (as viewed in Figure 2) of the mould 26 closed by a support block 28, the tubular members 10 and 12 are fitted one above the other into the mould 26 until the adjacent ends of the members are somewhat spaced apart as shown in solid lines in Figure 2. Then the electrically insulating material 20 in the form of a powder is charged to fill the rest of the cavity of the mould 26. Thereafter the upper end of the mould is closed by a push block 30.

The assembly thus produced is heated at a predetermined temperature at which the insulating material is liquid or plastic. Then the assembly is placed in any suitable press. While the predetermined temperature is maintained, the assembly is pressed until the tubular member 10 is brought into its predetermined position as shown in dotted lines in Figure 2 and the insulating material has been moulded.

Thereafter the pressed assembly along with the moulding device is allowed to cool under the pressure. Then the moulding device is dismantled and the resulting moulding is removed from the mould. The moulding is machined to form the central bore 22 extending therethrough. Thus a pressure proof sleeve is formed. It has been found that the insulating material 20, solidified and bonded to the adjacent end portions and the internal peripheral surfaces of the tubular members 10 and 12, has high pressure resistance and ensures that the tubular metallic members 10 and 12 are electrically insulated from each other while being united into a unitary structure.

A current limiting element (not shown in Figure 1) complementary in shape to the bore 22 is threaded through the bore 22. The current limiting element is composed of sodium, potassium or a solid solution thereof.

Figure 3 shows a modification wherein the spigot portion 14 is flared towards its tip, and the recess in the adjacent end portion 16 of the other tubular member 12 is substantially complementary in shape to the end portion 14. In other words the arrangement is identical to that shown in Figure 1, but is better able to withstand axial tensile stress.

Figure 4 shows another modification wherein the metallic tubular members 10 and 12 also serve as electrodes for a fuse device. The arrangement is identical to that illustrated in Figure 3 except for a pair of electrode terminals 32 and 34 rigidly secured to the free ends of the tubular members 10 and 12 respectively, e.g., by bolting or brazing. If desired, either of the terminals 32 and 34 may have incorporated therein buffer means for decreasing the pressure within the tubular members upon evaporation of the current limiting material, and a valve through which the current limiting material is charged into the members.

The corrosion resisting, electrically insulating material 20 is preferably produced starting with either an inorganic mixture in the form of a powder consisting of natural or synthetic mica, a low melting-point glass and graphite, or an organic mixture in the form of a powder consisting of a thermosettable resinous material and graphite.

If it is desired to produce a corrosion resisting, electrically insulating material of the inorganic type, then a mixture of powdered mica, low melting-point glass and graphite is charged into a suitable moulding machine and heated at 500°C in an electric furnace for 30 minutes after which it is moulded under a pressure of 1,500 kg/cm² while it is

maintained at the specified temperature. The moulded material is then finely pulverized ready for use.

The type and composition of the starting material greatly affects the corrosion resistance of the resulting material which will be subsequently described.

It has been previous practice to use a powder of mica having a relatively large particle size, for example 60 to 140 mesh for the purpose of providing mica moulding including a low melting point glass as a binder and high in mechanical strength and also to use in many cases lead borate glass excellent in mechanical characteristics. If such a mica moulding as produced is used as a pressure proof inner wall (or cylinder) it will be corroded to a considerable extent for various reasons. Among them the most serious reason is the presence of lead oxide in the glass. It is well known that any glass containing lead oxide is strongly attacked by alkali metals such as sodium and potassium.

To increase the alkali resistance of a particular glass requires the inclusions of an oxide(s) of an alkali metal(s) or alkaline earth metal(s) in the glass as the essential basic component. However it is to be noted that among the alkaline earth metals, only barium and strontium are suitable because the remaining alkaline earth metals such as calcium and magnesium are of high melting point and apt to be devitrified. The acidic component of the glass must be essentially boric acid, the content of silicic acid being maintained as low as possible. In addition to meeting these requirements for the glass composition, the glass should have a viscosity permitting it to flow at 500°C while at the same time preventing devitrification thereof during cooling from 500°C down to room temperature. A particular glass meeting the last-mentioned requirements may react by itself with moisture or carbon dioxide gas in the air and thereby suddenly decrease in surface resistance. It has been determined that this phenomenon occurs substantially negligibly with mouldings of such glass because it can contact the air with an extremely decreased contact area. It has also been found that the phenomenon is largely governed by the particle size of the powdered mica used and that the smaller the particle size of the powdered mica the less the occurrence of the phenomenon will be. Thus it is preferable to use mica powder having a particle size equal to or less than 140 mesh. Such powdered mica may comprise 70 to 30% by volume, the content of glass ranging from 20 to 50% by volume.

It has been found that with proper selection of the glass composition, the particle size of the powdered mica and/or the proportion of glass to mica, a mixture consisting only of the glass and mica can provide a sleeve of satisfactory pressure resistance. However such a sleeve is not of satisfactory corrosion resistance. The addition of powdered graphite to the mixture greatly increases the corrosion resistance of the resulting material. It has been found that the use of powdered graphite having a particle size of from 60 to 140 mesh and a content of approximately 20% on the basis of the total volume of the mixture is very advantageous in that it decreases corrosion loss by a factor of two without varying the moulding ability, mechanical strength etc. The powdered graphite may constitute up to 40% by volume with satisfactory results. The resulting material decreases in electric resistance as the graphite content increases. Since the addition of graphite in a content of 30% by volume provides an electric volume resistivity of the order of 10^9 Ω-cm, a material including graphite in a content up to 30% by volume may be regarded as being an electrically insulating material. The addition of graphite in a content of from 30 to 40% by volume causes a further decrease in electric resistance and provides a so-called electrically resisting material. It has been found that if the content of graphite exceeds 40% by volume the resulting material has insufficient mechanical strength to be of practical use.

The organic type of corrosion resisting, electrically insulating material may be prepared from thermosetting resinous materials and graphite. A mixture consisting of a selected thermosetting resin in the form of a powder and graphite powder is charged into a suitable moulding machine and heated at 500°C in an electric furnace for 30 minutes after which it is moulded under a pressure of 500 kg/cm² while it is maintained at that temperature. The moulded material is then finely pulverized for use.

Like the inorganic corrosion resisting electrically insulating materials, the organic type materials have corrosion resistances which are greatly affected by the type and composition of their starting materials. First it is essential that the thermosetting resin materials themselves have excellent resistance to both sodium and potassium. As is well known, thermosetting resins of good resistance to sodium and potassium generally comprise aromatic compounds. For example it has been found that the use of polymethylene diphenyloxide gives very satisfactory result.

Graphite is mixed with the thermosetting resin for the same reasons as above described in terms of the inorganic type materials. It has been found however that the use of fibrous graphite results in great improvements in mouldability and mechanical strength. The proportion of graphite to resin has a close bearing upon the mouldability and corrosion resistance of the resulting material. It has been determined that a higher proportion of

graphite to resin increases the corrosion resistance but adversely affects the mouldability of the resulting material. In other words, the content of graphite governs the uniformity of density distribution of the moulding. It has been found that as in the inorganic type materials described above graphite content may be up to approximately 40% on the basis of the volume of the starting mixture although the content of graphite must not be extremely high.

The results of experiments indicated that corrosion resisting, electrically insulating material, whether it is of the inorganic or organic type, produced in the manner described above is much improved in static load characteristics such as the bending strength and in impact load characteristics, compared with the porcelain materials previously used. This is because the effect of the graphite used as filling material is to increase the elastic coefficient of the resulting material. The corrosion resisting, electrically insulating materials are not subject to damage due to thermal shock. In addition, as the pair of tubular metallic members united together as previously described accommodate the vapour pressure developed therein due to the evaporation of the current limiting material, damage to the insulating material can be completely prevented by properly determining the dimensions of the tubular metallic members.

Further the present insulating materials are far superior in corrosion resistance to the conventional porcelain materials which include a large amount of silicate which is of poor alkali resistance, because the present materials include graphite which completely resists both sodium and potassium.

The inorganic type materials can be advantageously used in small-sized devices to decrease the manufacturing costs whereas the use of the organic type materials in large-sized devices is advantageous in that the problem of dielectric strength can readily be solved. Thus whether the inorganic type or the organic type is used is determined by the particular application.

The corrosion resisting, electrically insulating material may be resistive rather than truly insulating if the graphite content is suitably selected as to amount and particle size as previously described. That is graphite can be used in a content of from 30 to 40% by volume. The electrically resistive material thus prepared constitutes an electrical resistance connected between the metallic members in parallel with the body of current limiting material by the terminal electrodes e.g., as shown at 32 and 34 in Figure 4. This arrangement suppresses over voltages developed between the electrodes upon limiting of shortcircuit current.

WHAT WE CLAIM IS:—

1. A current limiting device comprising a pressure-resisting enclosure containing a body of current-limiting material responsive to a flow of current there-through above a predetermined magnitude to be evaporated and thereby to perform a current limiting operation and being restored to its original state after the completion of the current limiting operation, the enclosure including a pair of metallic members in the form of hollow cylinders, one of said cylindrical members having at one end a spigot portion of reduced diameter disposed in the adjacent end portion of the other cylindrical member with a gap therebetween, and a solid electrically insulating or resistive material filling said gap and disposed on the interior surfaces of said cylindrical members and uniting said cylindrical members into a unitary structure.

2. A current limiting device as claimed in claim 1, in which the said adjacent end portion has a socket receiving the said spigot portion.

3. A current limiting device as claimed in claim 1 or 2, wherein said spigot portion gradually increases in outside diameter toward the extremity thereof and said adjacent end portion of the other cylindrical member is substantially complementary in shape to said spigot portion.

4. A current limiting device as claimed in claim 1, 2 or 3, wherein metallic electrodes are electrically connected to respective remote ends of said cylindrical members and to the current limiting material.

5. A current limiting device as claimed in claim 4, in which the said solid material is electrically resistive and the electrodes electrically connect said electrically resistive material in parallel with said body of current limiting material.

6. A current limiting device as claimed in any of claims 1 to 4, wherein said solid material includes mica having a particle size equal to at most 140 mesh, a low melting point glass enriched in borate and including barium oxide and/or strontium oxide, and graphite having a particle size of from 60 to 140 mesh, said graphite being included in an amount of approximately 20% of the volume of said solid material.

7. A current limiting device as claimed in any of claims 1 to 5, wherein said solid material includes a thermosetting resin consisting essentially of an aromatic compound having high resistance to both sodium and potassium, and fibrous graphite whose content is approximately 40% of the volume of said solid material.

8. A current limiting device as claimed in any of claims 1 to 4, in which the said solid material comprises particles or fibrous graphite in a binder resistant to the current-limiting material, the graphite constituting

graphite to resin increases the corrosion resistance but adversely affects the mouldability of the resulting material. In other words, the content of graphite governs the uniformity of density distribution of the moulding. It has been found that as in the inorganic type materials described above graphite content may be up to approximately 40% on the basis of the volume of the starting mixture although the content of graphite must not be extremely high.

The results of experiments indicated that corrosion resisting, electrically insulating material, whether it is of the inorganic or organic type, produced in the manner described above is much improved in static load characteristics such as the bending strength and in impact load characteristics, compared with the porcelain materials previously used. This is because the effect of the graphite used as filling material is to increase the elastic coefficient of the resulting material. The corrosion resisting, electrically insulating materials are not subject to damage due to thermal shock. In addition, as the pair of tubular metallic members united together as previously described accommodate the vapour pressure developed therein due to the evaporation of the current limiting material, damage to the insulating material can be completely prevented by properly determining the dimensions of the tubular metallic members.

Further the present insulating materials are far superior in corrosion resistance to the conventional porcelain materials which include a large amount of silicate which is of poor alkali resistance, because the present materials include graphite which completely resists both sodium and potassium.

The inorganic type materials can be advantageously used in small-sized devices to decrease the manufacturing costs whereas the use of the organic type materials in large-sized devices is advantageous in that the problem of dielectric strength can readily be solved. Thus whether the inorganic type or the organic type is used is determined by the particular application.

The corrosion resisting, electrically insulating material may be resistive rather than truly insulating if the graphite content is suitably selected as to amount and particle size as previously described. That is graphite can be used in a content of from 30 to 40% by volume. The electrically resistive material thus prepared constitutes an electrical resistance connected between the metallic members in parallel with the body of current limiting material by the terminal electrodes e.g., as shown at 32 and 34 in Figure 4. This arrangement suppresses over voltages developed between the electrodes upon limiting of shortcircuit current.

WHAT WE CLAIM IS:—

1. A current limiting device comprising a pressure-resisting enclosure containing a body of current-limiting material responsive to a flow of current there-through above a predetermined magnitude to be evaporated and thereby to perform a current limiting operation and being restored to its original state after the completion of the current limiting operation, the enclosure including a pair of metallic members in the form of hollow cylinders, one of said cylindrical members having at one end a spigot portion of reduced diameter disposed in the adjacent end portion of the other cylindrical member with a gap therebetween, and a solid electrically insulating or resistive material filling said gap and disposed on the interior surfaces of said cylindrical members and uniting said cylindrical members into a unitary structure.

2. A current limiting device as claimed in claim 1, in which the said adjacent end portion has a socket receiving the said spigot portion.

3. A current limiting device as claimed in claim 1 or 2, wherein said spigot portion gradually increases in outside diameter toward the extremity thereof and said adjacent end portion of the other cylindrical member is substantially complementary in shape to said spigot portion.

4. A current limiting device as claimed in claim 1, 2 or 3, wherein metallic electrodes are electrically connected to respective remote ends of said cylindrical members and to the current limiting material.

5. A current limiting device as claimed in claim 4, in which the said solid material is electrically resistive and the electrodes electrically connect said electrically resistive material in parallel with said body of current limiting material.

6. A current limiting device as claimed in any of claims 1 to 4, wherein said solid material includes mica having a particle size equal to at most 140 mesh, a low melting point glass enriched in borate and including barium oxide and/or strontium oxide, and graphite having a particle size of from 60 to 140 mesh, said graphite being included in an amount of approximately 20% of the volume of said solid material.

7. A current limiting device as claimed in any of claims 1 to 5, wherein said solid material includes a thermosetting resin consisting essentially of an aromatic compound having high resistance to both sodium and potassium, and fibrous graphite whose content is approximately 40% of the volume of said solid material.

8. A current limiting device as claimed in any of claims 1 to 4, in which the said solid material comprises particles or fibrous graphite in a binder resistant to the current-limiting material, the graphite constituting

20% to 40% by volume of the said solid material.

9. A current limiting device as claimed in claim 6, in which the said solid material is electrically resistive and the graphite content is 20% to 30% by volume.

10. A current limiting device as claimed in any of claims 1 to 5, in which the said solid material is electrically resistive and comprises particulate or fibrous graphite in a binder resistant to the current limiting material, the graphite constituting 30% to 40% by volume of the said solid material.

11. A current limiting device as claimed in any of claims 8 to 10, in which the binder is a thermosetting resin.

12. A current limiting device as claimed in claim 10, in which the resin is an aromatic compound, the current limiting material being sodium, potassium, or a solid solution thereof.

13. A current limiting device as claimed in claim 7 or 10 in which the resin is polymethylene diphenyloxide.

14. A current limiting device as claimed in any of claims 8 to 10, in which the binder is a borate glass of low melting point comprising an oxide of an alkali metal or an alkaline earth metal, and the said solid material further comprises particulate mica dispersed in the binder.

15. A current limiting device as claimed in any of claims 1 to 14, having the said solid material moulded in situ with the cylindrical members.

16. A current limiting device as claimed in any of claims 1 to 15 in which the current limiting material is sodium, potassium, or a solid solution thereof.

17. A current limiting device substantially as herein described and shown in the accompanying drawings.

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