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PTC CIRCUIT PROTECTION DEVICE

This invention relates to circuit protection devices comprising PTC conductive polymer elements.

Conductive polymer compositions, and devices comprising them, are known or are described in our copending patent applications. Reference may be made for example to U.S. Patents Nos. 2,952,761, 2,978,665, 3,243,753, 3,351,882, 3,571,777, 3,757,086, 3,793,716, 3,823,217, 3,861,029, 4,017,715, 4,072,848, 4,085,286, 4,117,312, 4,177,376, 4,177,446, 4,188,276, 4,237,441, 4,238,812, 4,242,573, 4,246,468, 4,250,400, 4,255,698, 4,272,471, 4,276,466, 4,314,230, 4,315,237, 4,317,027, 4,318,881, 4,334,351, 4,352,083 and 4,361,799; U.K. Patent No. 1,534,715; J. Applied Polymer Science 19, 813-815 (1975), Klason and Kubat; Polymer Engineering and Science 18, 649-653 (1978) Narkis et al; German OLS Nos. 2,634,999, 2,755,077, 2,746,602, 2,755,076, 2,821,799, 2,949,173 and 3,030,799; and European Published Patent Applications Nos. 0,026,571, 0,028,142, 0,030,479, 0,038,713, 0,038,714, 0,038,715, 0,038,716, 0,038,717, 0,038,718, 0,063,440, 0,067,679, 0,067,681 and 0,068,688. The disclosure of each of the patents, publications and applications referred to above is incorporated herein by reference.

Particularly useful devices comprising PTC conductive polymers are circuit protection devices. Such devices have a relatively low resistance under the normal operating conditions of the circuit, but are "tripped", i.e. converted into a high resistance state, when a fault condition, e.g. excessive current or temperature, occurs. Such devices are described for example in U.S. Patents Nos. 4,237,441, 4,238,812, 4,255,698, 4,315,237, 4,317,027, and 4,352,083 and European Published Patent Applications Nos. 0,038,715 and 0,063,440. It is usually necessary for such devices to include an enclosure around the conductive polymer element in order to electrically insulate and/or physically protect the element. The enclosure is preferably spaced apart from the element, and can also serve as an oxygen barrier.

The essential and the desired characteristics of a circuit protection device vary widely from one application to another, depending, for example, on the peak voltage, i.e. the voltage which is dropped across the device in its tripped condition, and the number of times which the device is expected to function. European Published Patent Application No. 0,038,715 (U.S. Serial No. 141,987) discusses problems which can arise when PTC conductive polymer devices are used to protect circuits against very rapid increases in current, and in particular the increasing difficulty of providing effective protection as the peak current and/or the peak voltage increase. The application points out that such problems appear to result from arc formation within the conductive polymer and that as the PTC element is repeatedly tripped, it becomes eroded in the vicinity of the hot zone so that it can ultimately be divided in half half by the erosion. The application recommends the use of

PTC compositions containing an arc-controlling additive e.g. alumina trihydrate, which reduces the susceptibility of the PTC composition to form carbonaceous conductive paths, and the use of an oxygen barrier around the PTC element which is composed of a material which does not entrap any decomposition products of the PTC material resulting from arcing and which is not itself decomposed or damaged by arcing of the PTC element.

One characteristic which is always desired in a circuit protection device is that the device should "fail-safe", i.e. that when the device does fail, it fails in a high resistance state (including opening the circuit entirely). In tests carried out with the best of the prior art devices comprising a PTC conductive polymer element and a spaced-apart enclosure, we found that, when a batch of identically manufactured devices was tested at a peak voltage of about 240 volts or higher, the proportion which did not fail-safe (i.e. which failed in a low resistance state) was dependent on the peak voltage. Thus a significant proportion of the devices did not fail-safe at a peak voltage of 240 volts, and a much higher proportion did not fail-safe at a peak voltage of 600 volts DC. Our investigations have shown that when a PTC conductive polymer element is tripped, carbonaceous dust is ejected from the PTC element and that this dust can form a permanent low resistance conductive path which results in failure of the device at low resistance. The present invention relates to means for reducing the likelihood that permanent low resistance paths will be formed by carbonaceous dust ejected from a PTC conductive polymer element when it is tripped. Such means include:-

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- (1) Correlation of the size of the PTC element and the area of the surfaces within an enclosure surrounding the element (including the interior surface of the enclosure itself) in order to minimize the thickness of the layer of carbonaceous dust on surfaces which could form part of an electrical short within the device.
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- (2) Selection of suitable materials for at least part of the interior surface of an enclosure surrounding the PTC element and/or for other surfaces which, when coated with carbon dust, could form part of an electrical short within the device.
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- (3) Means for ensuring an adequate distance (along surfaces which can become coated with carbonaceous dust) between non-insulated parts of the device which, if electrically connected, would cause shorting around the PTC element.
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- Such means include the use of enclosures having exit ports for the leads which are relatively widely spaced from each other, e.g. at opposite ends of the enclosure, and the use of insulated leads.
- 25
- (4) Selection of a suitable shape for the PTC element.
- (5) Selection of the thermal transfer characteristics of those parts of the device which can become coated with carbon dust and which lie between

5 Through use of the present invention, it is possible to prepare circuit protection devices which fail-safe even at peak voltages of 600 volts or higher.

10 (1) a PTC element composed of a conductive polymer
composition which exhibits PTC behavior
and which comprises a polymeric component
and, dispersed in the polymeric component, a
15 particulate conductive filler comprising
carbon black;

(2) two electrodes which are electrically connected
to the PTC element; and

(3) an enclosure

20 (a) which encloses and is spaced apart from
at least the potential erosion zone of the
PTC element, and which preferably encloses
and is spaced apart from, the whole of the
PTC element; and

(b) which is substantially impervious to
25 carbon dust;

the device comprising means for reducing the likelihood that permanent low resistance paths will be formed by carbonaceous dust ejected from the PTC element when the device is converted into the high resistance state.

The "potential "erosion zone "of a PTC element is, in general terms, the part of a PTC element which is subject to erosion when the device is tripped, and is defined herein as that part of the PTC element which has the hot zone at its center and whose volume is three times the volume of the hot zone, the hot zone being defined as that part of the PTC element which, when the device has been tripped by passing a fault current through it, has been converted into a zone of high temperature and high resistance such that 90% of the peak voltage (i.e. the total voltage dropped over the device as a whole) is dropped over that zone.

In one preferred embodiment, at least a part of the interior surface of the enclosure and any additional non-conducting surfaces within the enclosure is composed of an insulating material which passes the carbon burn-off test at a test voltage of 440 volts DC, and preferably at a test voltage of 600 volts DC. The Carbon burn-off test is defined in detail later in the specification. Suitable insulating materials of this kind include ceramics, polytetrafluoroethylene and other high melting fluoropolymers including copolymers of tetrafluoroethylene.

In another preferred embodiment, the physical dimensions of the device are such that the ratio V_1/A_1 is less than 0.0064 cm (0.0025 inch), preferably less than 0.005 cm (0.002 inch), particularly less than 0.0025 cm (0.001 inch), where V_1 is the volume in cubic centimeters (cubic inches) of the potential erosion zone of the PTC element and A_1 is the area in square centimeters (square inches) of the surfaces within the enclosure which do not carry current during normal operation of the device (i.e. the area of the internal surface of the enclosure, plus the surface area of any additional surfaces). The ratio of the exposed

surface area of the potential erosion zone of the PTC element to the area A_1 is preferably less than 0.08, especially less than 0.04.

In another preferred embodiment, the physical dimensions of the device are such that the ratio V_2/A_1 is less than 0.02 cm (0.008 inch) preferably less than 0.018 cm (0.007 inch) especially less than 0.015 cm (0.006 inch), particularly less than 0.0075 cm (0.003 inch), where V_2 is the volume in cubic centimeters (cubic inches) of the PTC element and A_1 is the area in square centimeters (square inches) of the surfaces within the enclosure which do not carry current during normal operation of the device. Preferably the ratio of the exposed surface area of the PTC element to the area A_1 is less than 0.2, more preferably less than 0.16, particularly less than 0.10.

In the two embodiments of the invention just described, the ratios V_1/A_1 and V_2/A_1 are a measure of the thickness of the layer of carbonaceous dust deposited on the interior surfaces of the device.

We also prefer that V_2/A_2 is less than 0.02 cm (0.008 inch), particularly less than 0.018 cm (0.007 inch), where A_2 is the area in square cm (square inches) of the internal surface of the enclosure.

More preferably, the device of the invention further comprises two leads, one connected to each electrode; wherein the enclosure (a) is electrically insulated from the PTC element, the electrodes and the leads, and (b) comprises exit ports through which the leads pass; wherein the interior surface of said enclosure, in an area which lies in the shortest geometrical path between the exit ports, is composed of an insulating material which passes the carbon

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burn-off test using a test voltage of 600 volts DC; and wherein said ratio V_2/A_1 is from 0.0025 to 0.007 inch (0.006 to 0.018 cm).

In the known circuit protection devices comprising PTC conductive polymers, connection of the electrodes to the electrical leads are not insulated and the leads and the exit ports in the enclosure; the power supply is achieved by means of electrical leads which pass through insulated exit ports are relatively close to each other, because the voltages employed are not such as to permit arcing between the leads. However, once we had realized that failure could occur because carbonaceous dust ejected from the PTC element had formed a low resistance path, e.g. between the leads, we also realized that the likelihood of such failure could be reduced by keeping the leads and exit ports widely separated or by insulating one (and preferably both) of

the leads over at least a substantial proportion (and preferably all) of its length. Preferred embodiments of the invention make use of one or both of these expedients.

In looking for ways in which to keep the leads widely separated, we also found that it was possible to make use of electrode shapes and relative positions which had not been used in the past. Thus the PTC element may be (a) composed of a PTC conductive polymer composition which has a resistivity at 23°C of less than 100 ohm cm and which comprises a polymeric component and, dispersed in the polymeric component, a particulate conductive filler comprising carbon black; and (b) in the form of a strip, preferably a strip of cylindrical cross-section whose length is greater than the largest cross-sectional dimension of the strip.

Preferably, the enclosure is spaced apart from the whole of the PTC element and is in the shape of a tube with closed ends, the axis of the tube and the axis of the PTC element being substantially the same, and the closed ends comprising exit ports through which pass electrical leads which are connected to the electrodes.

In one preferred embodiment, each of the electrodes is in the form of a cap having (i) a substantially planar end which contacts and has substantially the same cross-section as one end of the PTC element and (ii) a side wall which contacts the side of the PTC element. In another preferred embodiment, each of the electrodes is embedded in an end portion of the PTC element.

The devices of the present invention are particularly useful for protecting circuits which are powered by power sources having relatively high voltages, e.g. at least 240 volts, at least 360 volts or at least 440 volts, and circuits which are powered by sources of voltage less than 240 volts, e.g. 50-140 volts DC, but which are subject to faults which result in a relatively high peak voltage.

Accordingly, in another aspect, the invention provides an electrical circuit which comprises

- (a) a power source having a voltage V which is at least 440 volts (DC or RMS value of an AC source);
- (b) an electrical load; and

(c) a circuit protection device which comprises

- 5 (1) a PTC element composed of a conductive polymer composition which exhibits PTC behavior and which comprises a polymeric component and, dispersed in the polymeric component, a particulate conductive filler comprising carbon black;
- 10 (2) two electrodes which are electrically connected to the PTC element and which are connectable to a source of electrical power to cause current to pass through the PTC element; and
- 15 (3) an enclosure
 - (a) which encloses and is spaced apart from at least the potential erosion zone of the PTC element;
 - (b) which is substantially impervious to carbon dust; and
 - 20 (c) at least a part of whose interior surface is composed of an insulating material which passes the carbon burn-off test at a test voltage of V volts.

25 The devices of the invention generally comprise an enclosure which encloses and is spaced-apart from the potential erosion zone of the PTC element, and it is usually convenient for the enclosure to enclose and be spaced apart from the whole of the PTC element. The enclosure must not of course provide a current path between the two electrodes, and generally therefore, 30 consists at least in part of insulating material.

Often it is convenient for the device to include electrical leads connected to (or integrally formed with) the electrodes, with the leads passing through exit ports in the enclosure, so that the enclosure encloses and is spaced apart from the electrodes and the PTC element. Under these circumstances, it is preferred that at least one of the parts of the enclosure defining an exit port is composed of insulating material and/or that one or both of the leads should be insulated.

It is also possible for one or both of the electrodes to form part of the enclosure. Under these circumstances, it is preferred that each part of the enclosure contiguous with an electrode is made of insulating material.

As noted above, we have found that the nature of the interior surfaces of the device can play an important part in determining the likelihood that a device will fail in the low resistance state. In particular we have found that at least a part of the surfaces which can become coated with carbon dust from the PTC element, and can thus provide a path for a short circuit, are preferably composed of a material which will pass the "Carbon Burn-off Test" described below. Thus it is preferred that at least part of the interior surface of the enclosure should be composed of such a material, especially, of course, those parts which provide the shortest distance along the surface) between parts of the device which are at a different potential during operation of the device. It is also preferred that, when the device comprises one or two leads within the enclosure, at least one lead should be insulated with a material which

passes the carbon burn-off test and/or at least one of the exit ports in the enclosure should be defined by a part of the enclosure which is composed of such a material.

The Carbon Burn-Off Test

5 There is prepared a self-supporting rectangular plaque of the material, having a thickness of at least 0.1 cm (0.04 inch) and a planar upper surface 0.64 cm (0.25 inch) wide and at least 1.27 cm (0.5 inch) long. Two holes are drilled through the plaque at right angles to the planar
10 upper surface, the centers of the holes being 0.64 cm (0.25 inch) apart and 0.32 cm (0.125 inch) or more from each edge of the plaque, and the diameter of each hole being just large enough to accommodate a 20 gauge wire (diameter 0.09 cm). A solid copper wire of 20 gauge is pushed through
15 each hole so that it protrudes 0.64 cm (0.25 inch) above the planar surface. A typical test sample prepared in this way is shown in Figure 3 and comprises plaque 61 having wires 62 and 63 pushed therethrough. A circuit as shown in Figure 4
20 is then made, with the copper wires 62 and 63 connected in series with a fixed resistor 65, an ammeter 66 and a variable voltage power supply 67. With the planar surface horizontal, carbon black is dusted onto the surface until no more will stay on, as shown by 64 in Figure 4. The voltage is then
25 increased from zero to the test voltage at a rate of about 10 volts per second. Sometimes, as the voltage is increased, an arc is struck between the wires above the planar surface, blowing off some of the carbon black; if that happens, the voltage is reduced to zero and carbon black is again powdered onto the surface before repeating the test. After the voltage
30 has been increased to the test voltage, it is maintained at that level until a stable condition is reached, before being reduced to zero to complete the test.

Plaques made of preferred materials will not burn, melt or distort when subjected to the carbon burn-off test, and such materials are described in this specification as "materials which will pass the carbon burn-off test". It is particularly preferred to use materials which, when subjected to the carbon burn-off test, not only pass the test but also result in a current in the test circuit which is below 0.005 amp at the end of the test.

The ability of a particular material to pass the carbon burn-off test at voltages above 240 volts is dependent on the test voltage employed in the test, to a lesser extent on whether the power source is a DC or AC power source (voltages given in this specification are RMS values for AC power sources). In tests using a 600 volt DC test voltage, we have found that polytetrafluoroethylene ("Teflon", Trade Mark sold by E.I. du Pont de Nemours) and various ceramics pass the carbon burn-off test, whereas poly (methyl methacrylate) ("Plexiglas", Trade Mark), polycarbonates ("Lexan", Trade Mark), acetal resins ("Delrin", Trade Mark), commercial glass, borosilicate glass, epoxy resins, and phenolic-resin-impregnated paper do not pass the test. Insulating materials which have previously been used to provide at least a part of the interior surface of an enclosure for a PTC conductive polymer element in a circuit protection device are epoxy resins (E.G. Hysol, Trade Mark, epoxy resin EE 0149) and conventional glass; these materials fail the carbon burn-off test at a voltage of 440 volts DC.

In order to ensure that the device will fail in the high resistance state, the test voltage used in the carbon burn-off test should be at least as high as the voltage dropped over the device in the fault condition. We have carried out the test using Raven 8000 as the carbon black, but we believe that the results are not dependent on the carbon black used.

The enclosures used in the present invention preferably insulate and physically protect the PTC element; in addition they also prevent carbonaceous dust evolved from the PTC element from being deposited on adjacent articles (especially electrically active articles which might be undesirably changed by such deposition). When carbonaceous dust is evolved from the PTC element, gaseous decomposition products are generally evolved at the same time. If not released, such gases can create undesirably high pressures within the enclosure; accordingly it is preferred that the enclosure is pervious to gases which are generated within it.

While the thermal transfer characteristics of the device are not generally as important as the nature of the internal surfaces and their areas, their effect on the likelihood of low resistance failure can be significant. We have found that by heat sinking a part of the device which is coated with carbon dust, the likelihood of a short being formed through that carbon dust can be increased. Conversely, if the part is very well insulated, the likelihood of a short is reduced.

The circuit protection devices of the invention usually have a resistance of less than 1000 ohms, often less than 100 ohms, particularly less than 50 ohms.

5 The PTC elements of the invention are preferably composed of a conductive polymer composition which has a resistivity at 23°C of less than 100 ohm.cm, particularly less than 50 ohm.cm, especially less than 10 ohm.cm. Suitable compositions are disclosed in the documents incorporated by reference herein; preferably they
10 comprise an arc-controlling additive, e.g. a hydrated metal oxide.

The PTC element can be in the form of a strip whose length is greater than its largest cross-sectional dimension, the element can be formed in any convenient way,
15 for example by molding, especially by molding around the electrodes, or by cutting a short length from a melt-extruded strip. When using such an element, the electrodes are preferably electrically connected to opposite ends of the strip. The electrodes generally contact the PTC
20 element directly but can be electrically connected to it through another element, e.g. a ZTC conductive polymer element. The PTC element can be of generally cylindrical shape, but strips of non-circular cross-section can also be used. Preferably the PTC element includes means
25 for inducing the formation of the hot zone away from the electrodes, as disclosed in the documents incorporated by reference herein.

The electrodes used in this invention can be of any suitable configuration, including the novel configurations previously noted as well as the known planar and columnar electrodes; planar electrodes can cover all or
5 part of the cross-section of the PTC element.

In the circuits of the invention, the supply voltage is at least 240 volts, e.g. at least 360 volts or at least 440 volts. The invention also includes circuits in which the supply voltage is less than 240 volts,
10 e.g. 50-140 volts DC, but the expected fault condition will result in a peak voltage across the device of at least 240 volts.

Referring now to Figure 1 of the drawing, this illustrates in cross-section a circuit protection
15 device of the invention which comprises a cylindrical PTC element 1 having a hole 11 drilled through it to induce formation of the hot zone in the center of the element. Fitted to the ends of PTC element 1 are cap electrodes 2 having leads 3 secured thereto. Insulating
20 discs 41 are fitted over the leads 3 and are themselves fitted within a cylindrical metal tube 42 having an external covering of insulating tape 43.

Referring now to Figure 2, this shows a circuit of the invention comprising a power source 101, a
25 circuit protection device 102 and an electrical load 103 in series therewith.

The invention is illustrated by the following Example.

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EXAMPLE

A circuit protection device as illustrated in Figure 1 was prepared as follows.

A granulated conductive polymer composition was prepared by the procedure given in the Example of European Published Application No. 0.038,715 (U.S. Serial No. 141,987). It contained, by volume, about 54.7% of high density polyethylene, about 26.9% of carbon black (Furnex N765, Trade Mark), about 16.5% of alumina trihydrate and about 1.9% of antioxidant. The granulated composition was melt-extruded as a rod of diameter 0.33 cm (0.128 inch). The rod was cut into PTC elements 0.88 cm (0.345 inch) long and a hole 0.064 cm (0.025 inch) in diameter was drilled radially through the center of each element. Each element was irradiated to about 40 mrad and then annealed. The electrode caps, having 22 AWG (diameter 0.07 cm) leads secured thereto and being 0.32 cm (0.125 inch) in internal diameter and 0.25 cm (0.1 inch) deep, were press-fitted and crimped over the ends of the PTC element.

The PTC element and the electrodes were placed within a cylindrical shell comprising a metal cylinder (0.64 cm, 0.25 inch, inner diameter and 1.9 cm, 0.75 inch, long) and polyester/acrylic adhesive tape wrapped around the metal cylinder. Polytetrafluoroethylene end caps, with central 22 AWG holes in them and having an outer diameter of 0.64 cm, 0.25 inch, were fitted over the leads and press-fitted into the cylindrical shell, which was then crimped around them.

The device as described above was found to fail safe when tested at a peak voltage of 600 volts AC.



Claims

1. A circuit protection device which comprises

- (1) a PTC element composed of a conductive polymer composition which exhibits PTC behavior and which comprises a polymeric component and, dispersed in the polymeric component, a particulate conductive filler comprising carbon black;
- (2) two electrodes which are electrically connected to the PTC element and which are connectable to a source of electrical power to cause current to pass through the PTC element; and
- (3) an enclosure
 - (a) which encloses and is spaced apart from at least the potential erosion zone of the PTC element; and
 - (b) which is substantially impervious to carbon dust;

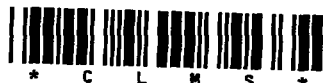
the device comprising means for reducing the likelihood that permanent low resistance paths will be formed by carbonaceous dust ejected from the PTC element when the device is converted into the high resistance state.

2. A circuit protection device comprising a PTC conductive polymer element from which carbonaceous dust is emitted on tripping and an enclosure surrounding and spaced apart from at least a potential erosion zone of the element, the material for at least part of the interior surface of the enclosure and/or for other surfaces which, when coated with carbon dust, could form part of an electrical short within the device, being an insulating material which passes the carbon burn-off test at a test voltage of 440 volts DC, thereby reducing the likelihood that permanent low resistance paths will be formed by said dust.



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3. A device according to claim 2 wherein said insulating material passes the carbon burn-off test at a test voltage of 600 volts DC.
4. A device according to claim 2 or 3 wherein said insulating material is polytetrafluoroethylene.
5. A device according to claim 2 or 3 wherein said insulating material is a ceramic or a fluoropolymer.
6. A circuit protection device comprising a PTC conductive polymer element from which carbonaceous dust is emitted on tripping and an enclosure surrounding and spaced apart from at least a potential erosion zone of the element, the size of the PTC element and the area of surfaces within the enclosure being correlated such that the ratio V_1/A_1 is less than 0.0025 inch (0.0064 cm) where V_1 is the volume in cubic inches (cubic cms) of a potential erosion zone of the PTC element and A_1 is the area in square inches (square cms) of the surfaces within the enclosure which do not carry current during normal operation of the device, said correlation reducing the likelihood that permanent low resistance paths will be formed by said dust.
7. A device according to claim 6 wherein said ratio is less than 0.002 inch (.005 cm).
8. A device according to claim 7 wherein said ratio is less than 0.001 inch (.0025 cm).
9. A device according to any one of claims 6 to 8 wherein the ratio of the exposed surface area of the potential erosion zone of the PTC element to the area A_1 is less than 0.08.
10. A device according to claim 9 wherein said area ratio is less than 0.04.
11. A circuit protection device comprising a PTC conductive polymer element from which carbonaceous dust is emitted on



(13) tripping and an enclosure surrounding the element and spaced apart from whole of the element, the size of the PTC element and the area of surfaces within the enclosure being correlated such that the ratio V_2/A_1 is less than 0.008 inch (0.02 cm) where V_2 is the volume in cubic inches (cubic cms) of the PTC element and A_1 is the area in square inches (square cms) of the surfaces within the enclosure which do not carry current during normal operation of the device, said correlation reducing the likelihood that permanent low resistance paths will be formed by said dust.

12. A device according to claim 11 wherein the ratio V_2/A_1 is less than 0.003 inch (0.008 cm).

13. A device according to claim 11 or 12 wherein the ratio V_2/A_2 is less than 0.008 inch (0.02cm) where A_2 is the area in square inches (square cms) of the internal surface of the enclosure.

14. A device according to claim 13 wherein A_2 is equal to A_1 and the ratio V_2/A_2 is less than 0.007 inch (0.018 cm).

15. A device according to any one of claims 11 to 14 which further comprises two leads, one connected to each electrode; wherein the enclosure (a) is electrically insulated from the PTC element, the electrodes and the leads, and (b) comprises exit ports through which the leads pass; wherein the interior surface of said enclosure, in an area which lies in the shortest geometrical path between the exit ports, is composed of an insulating material which passes the carbon burn-off test using a test voltage of 600 volts DC; and wherein said ratio V_2/A_1 is from 0.0025 to 0.007 inch (0.006 to 0.018 cm).

16. A device according to any one of claims 11 to 15 wherein the ratio of the exposed surface area of the PTC element to the area A_1 is less than 0.2.

17. A device according to claim 16 wherein said area ratio is less than 0.16.



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18. A device according to claim 16, wherein said area ratio is less than 0.10.

19. A circuit protection device comprising a PTC conductive polymer circuit protection element from which carbonaceous dust is emitted on tripping and an enclosure surrounding and spaced apart from at least a potential erosion zone of the element, the shape of the PTC element being such that it is in the form of a strip with substantially planar parallel end portions, the length of the strip being greater than the largest cross-sectional dimension of the strip; and electrodes of the device being in electrical contact with the end portions of the element, thereby reducing the likelihood that permanent low resistance paths will be formed by said dust.

20. A device according to claim 19 wherein each of the electrodes is in the form of a cap having (i) a substantially planar end which contacts and has substantially the same cross-section as one end of the PTC element and (ii) a side wall which contacts the side of the PTC element.

21. A device according to claim 19 wherein the electrodes are embedded in the end portions of the PTC element.

22. A device according to any one of claims 19 to 21 wherein the element is cylindrical in shape.

23. A device according to any one of claims 19 to 22 wherein the enclosure encloses and is spaced apart from the whole of the PTC element and is in the shape of a tube with closed ends, the axis of the tube and the axis of the PTC element being substantially the same.

24. A circuit protection device comprising a PTC conductive polymer circuit protection element from which carbonaceous dust is emitted on tripping and an enclosure surrounding the element and spaced apart from the whole of the element, the device also comprising electrical leads and electrodes to which the leads are connected, the leads passing through



exit ports in the enclosure, at least one of the leads being electrically insulated over at least a substantial portion of its length from the exit port through which it passes towards the electrode to which it is connected, said exit ports and leads being so positioned as to ensure an adequate distance, along surfaces which can become coated with carbonaceous dust, between non-insulated parts of the device which if electrically connected would cause shorting around the PTC element, thereby reducing the likelihood that permanent low resistance paths will be formed by said dust.

25. A device according to claim 24 wherein at least one of the electrical leads is insulated over substantially the whole of its length between the exit port through which it passes and the electrode to which it is connected.

26. A circuit protection device comprising a PTC conductive polymer circuit protection element from which carbonaceous dust is emitted on tripping and an enclosure surrounding and spaced apart from at least a potential erosion zone of the element, the thermal transfer characteristics of those parts of the device which can become coated with carbonaceous dust and which lie between non-insulated parts of the device which, if electrically connected, would cause shorting around the PTC element, being such that the likelihood is reduced of permanent low resistance paths being formed by said dust.

27. A circuit protection device according to claim 1 and to any of claims 2-26.

28. A device according to claim 1 substantially as hereinbefore described with reference to and as illustrated in Figure 1 of the accompanying drawings;

29. an electrical circuit which comprises

- (a) a power source having a voltage V which is at least 440 volts
- (b) an electrical load; and



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- (c) a circuit protection device which comprises (1) a PTC element composed of a conductive polymer composition which exhibits PTC behavior and which comprises a polymeric component and, dispersed in the polymeric component, a particulate conductive filler comprising carbon black;
- (2) two electrodes which are electrically connected to the PTC element and which are connectable to the source of electrical power to cause current to pass through the PTC element; and
- (3) an enclosure
- (a) which encloses and is spaced apart from at least the potential erosion zone of the PTC element;
 - (b) which is substantially impervious to carbon dust; and
 - (c) at least a part of whose interior surface is composed of an insulating material which passes the carbon burn-off test at a test voltage of V volts.
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