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(54) **Current limiting device**

(57) A current limiting device (1) utilizes an electrically conductive composite material (5) and an inhomogeneous distribution of resistance (7). The structure comprises a conducting filler, where a substantial fraction of the electrical current is carried by a low pyrolysis temperature material, such as an organic conductor. The inhomogeneous distribution is typically chosen so that at least one selected thin layer of the current limiting device has much higher resistance than the rest of the current limiting device. In the device, pressure (P) is typically exerted on the composite material in a direction normal to the selected thin layer.

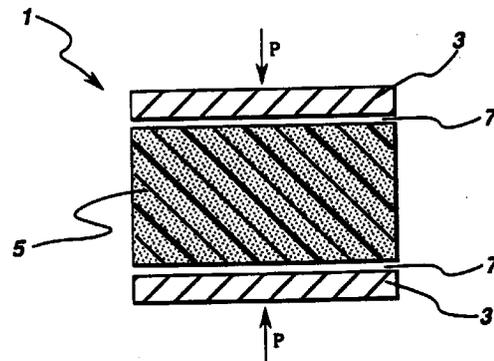


FIG. 1

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## Description

### Background of the Invention

This invention relates generally to devices for general circuit protection including electrical distribution and motor control applications. In particular, the invention relates to a current limiting device comprising an inhomogeneous resistance structure and an electrically conducting material, where a substantial fraction of the current is carried by a conductor with a low pyrolysis or thermal ablation temperature. The conductor may be an organic conductor.

There are numerous devices that are capable of limiting the current in a circuit when a short-circuit occurs. One known limiting device includes a filled polymer material which exhibits what is commonly referred to as a PTCR (positive-temperature coefficient of resistance) or PTC effect. The unique attribute of the PTCR or PTC effect is that at a certain switch temperature the PTCR material undergoes a transformation from a more conducting material to a more resistive material. In some of these prior current limiting devices, the PTCR material (typically polyethylene loaded with carbon black) is placed between pressure contact electrodes.

Current limiting devices are used in many applications to protect sensitive components in an electrical circuit from high fault currents. Applications for current limiting devices include applications to protect sensitive components in an electrical circuit from high fault currents. Applications range from low voltage/current electrical circuits to high voltage/current electrical distribution systems. A important retirement for many applications is a fast current limiting response in order to minimize the peak fault current that develops.

In operation, current limiting devices are placed in a circuit to be protected. Under normal circuit conditions, the current limiting device is in a highly conducting state. When a short-circuit occurs, the PTCR material heats up through resistive heating until the temperature is above the switch temperature. At this point, the PTCR material resistance changes to a high resistance state and the short-circuit current is limited. When the short-circuit is cleared, the current limiting device cools down over a time period that may be long to below the switch temperature and returns to the highly conducting state. In the highly conducting state, the current limiting device is again capable of switching to the high resistance state in response to future short-circuit events.

U. S. Patent 5,382,938 describes a PTC element comprising a body of an electrically conductive polymer composition having a resistivity with a positive temperature coefficient, the body defining two parallel end surfaces and two electrodes arranged in contact with the end surfaces for carrying current through the body. The polymer composition of the body includes a polymer material and an electrically conductive powdered material distributed in the polymer material. The term PTC

element is the accepted term for an element which exhibits a positive temperature coefficient of resistance with a switch temperature as shown in Fig. 1 of U. S. Patent 5,382,938. At least one of the parallel surfaces on the body is in free contact with an electrode or with a parallel surface on another body of electrically conductive polymer composition. A pressure device inserts a pressure directed perpendicularly to the parallel surfaces on the body, or the bodies, on the electrodes. The pressure device is preferably provided with a pressure-exerting device with the ability to be resilient. After changing from a low resistance to a high resistance state, the PTC element returns to the initial resistance and is reusable after having been subjected to short-circuit currents. The parallel surfaces on the body, or the bodies, of polymer composition may be concentric. PTC elements are used in electric circuits as overcurrent protection.

U. S. Patent 5,313,184 describes an electric resistor having a resistor body arranged between two contact terminals. The resistor core includes an element with PTC behavior, which, below a material-specific temperature, forms an electrically conducting path running between the two contact terminals. The resistor can be simple and inexpensive, but still having high rate current-carrying capacity protected against local and overall overvoltages. This is achieved by the resistor core additionally containing a material having varistor behavior. The varistor material is connected in parallel with at least one subsection of the electrically conducting path, forming at least one varistor, and is brought into intimate electrical contact with the part of the PTC material forming the at least one subsection. The parallel connection of the element with PTC behavior and the varistor can be realized both by a microscopic construction and by a macroscopic arrangement.

European Patent 0,640,995 A1 describes an electrical resistance element containing a resistive material that has PTC characteristics and is arranged between two plane-parallel electrodes that are subjected to pressure, whereby the resistive material consists of a polymer matrix and two filler components that consist of electrically conducting particles, wherein the two filler components are embedded in the polymer matrix. In the event of a short-circuit current, the resistivity of the resistive material changes, in a step-like manner above a limiting temperature value, in a surface layer that lies on the electrodes and that contain at least the first of the two filler components. The second of the two filler components is selected in such a way that a composite material that contains at least a polymer matrix and the second filler component exhibits PTC characteristics with a step characteristic that is higher by at least one order of magnitude, relative to the surface layer. At the same time, this composite material has a resistivity that is lower, by at least one order of magnitude, than a composite material that is formed from the polymer matrix and the first filler component.

European Patent Appln. 0,762,439 discloses a current limiting device. This current limiting device relied on a composite material and an inhomogeneous distribution of resistance structure.

Known current limiting devices utilize a composite material comprising a low pyrolysis or vaporization temperature binder and an electrically conducting filler combined with an inhomogeneous distribution of resistance structure. The switching action of these devices occurs when joule heating of the electrically conducting filler in the relatively higher resistance part of the composite material causes sufficient heating to cause pyrolysis or vaporization of the binder material. However, the switching time is limited by time required for heat to diffuse from the conducting filler to the surrounding binder material. Thus, rapid switching is not readily available with known current limiting devices.

Despite the efforts described above to provide simpler, more durable current limiting devices, a need still exists for a simpler, quicker, more durable, reusable potentially low cost current limiting device for general circuit protection in electrical distribution and motor control applications that can be tailored to a plurality of applications. Moreover, the switching action should be relatively quick to avoid disadvantageous effects to the circuitry from the time delay.

Current limiting devices are used in many applications to protect sensitive components in an electrical circuit from high fault currents. Applications range from low voltage/current electrical circuits to high voltage/current electrical distribution systems. The present invention provides a relatively quick, simple, reusable, potentially low cost current limiting device that can be tailored to a plurality of applications.

Accordingly, it is an object of the invention to provide a quick, simple, reusable, potentially low cost current limiting device, where the current limiting device overcomes the above noted and other disadvantages of the related art.

It is a further object of the invention to provide a current limiting device, where a conducting filler is chosen so that a substantial fraction of the electrical current is carried by a low pyrolysis temperature material, such as an organic conductor. Therefore, switching during short circuit conditions occurs faster than in known current limiter devices because the switching is instigated by pyrolysis of the organic conductor. Thus, a time delay to heat diffusion from the conductor to the surrounding low pyrolysis temperature binding material can be avoided.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a current limiting device in accordance with the invention; and

Fig. 2 is a schematic representation of a current limiting device with separate conductive composite

materials, in accordance with the invention.

In accordance with one example of the invention, a current limiting device is constructed using an electrically conductive composite material so that there is an inhomogeneous distribution of resistance throughout the device, where a conducting filler is chosen so that a substantial fraction of the electrical current is carried by a low pyrolysis temperature material such as an organic conductor.

To be a reusable current limiting device, the inhomogeneous resistance distribution is arranged so at least one thin layer of the current limiting device is positioned perpendicular to the direction of current flow and has a much higher resistance than the average resistance for an average layer of the same size and orientation in the device. In addition, the current limiting device is under compressive pressure in a direction perpendicular to the selected thin high resistance layer. The compressive pressure may be inherent in the current limiting device or exerted by a resilient structure, assembly or device, such as but not limited to a spring.

One example current limiting device, in accordance with the invention, comprises a highly conducting composite material with low pyrolysis temperature binder and conducting filler that is pressure contacted to electrodes so that there is a significant contact resistance between the material and one or both electrodes, where the conducting filler(s) is (are) chosen so that a substantial fraction of the electrical current is carried by a low pyrolysis temperature material such as an organic conductor.

In operation, the device is placed in the electrical circuit to be protected. During normal operation, the resistance of the limiting device is low, i.e., in this example the resistance of the current limiting device would be equal to the resistance of the highly conducting composite material plus the resistance of the electrodes plus the contact resistance. When a short-circuit occurs, a high current density starts to flow through the device. In initial stages of the short-circuit, the resistive heating of the device is believed to be adiabatic. Thus, it is believed that the selected thin, more resistive layer of the current limiting device heats up much faster than the rest of the current limiting device. With a properly designed thin layer, it is believed that the thin layer heats up so quickly that thermal expansion of and/or gas evolution from the thin layer cause a separation within the current limiting device at the thin layer.

The invention, in accordance with the invention comprises a fast-acting current limiting device 1. As illustrated in Fig. 1, the current limiting device 1 comprises electrodes 3 and a composite material 5, which comprises a low pyrolysis or vaporization temperature binder and an electrically conducting filler combined with inhomogeneous distributions 7 of resistance structure under compressive pressure P. However, the scope of the invention includes any suitable construction

where a higher resistance is anywhere between the electrodes. For example, the higher resistance may be between two Composite materials 55, as illustrated in Fig. 2. However, this is merely exemplary and is not meant to limit the invention in any way.

The binder should be chosen such that significant gas evolution occurs at a low (about approximately <800°C) temperature. The inhomogeneous distribution structure is typically chosen so that at least one selected thin layer of the current limiting device has much higher resistance than the rest of the current limiting device.

The conducting filler is selected so that a substantial fraction of the electrical current is carried by a low pyrolysis temperature material, such as for example an organic conductor. With such a construction, switching during short circuit conditions occurs faster than previous current limiting devices because the switching can be instigated by pyrolysis of the organic conductor itself. Thus, any time delay due to heat diffusion from the conductor to the surrounding low pyrolysis temperature binding material is eliminated.

The inhomogeneous distribution of resistance is arranged so that at least one thin layer positioned perpendicular to the direction of current flow has a predetermined resistance, which is at least about ten percent (10%) greater than an average resistance for an average layer of the same size and orientation. Further, it is positioned proximate to at least one electrode electrically conductive composite material interface.

It is believed that the advantageous results of the invention are obtained because, during a short-circuit, adiabatic resistive heating of the thin layer followed by rapid thermal expansion and gas evolution from the binding material, which leads to a partial or complete physical separation of the current limiting device at the selected thin layer, and produces a higher over-all device resistance to electric current flow. Therefore, the current limiting device limits the flow of current through the short-circuited current path. When the short-circuit is cleared externally, it is believed that the current limiting device regains its low resistance state due to the compressive pressure built into the current limiting device allowing thereby electrical current to flow normally. The current limiting in accordance with the invention is reusable for many such short circuit conditions, depending upon such factors, among others, as the severity and duration of each short circuit.

Examples of low pyrolysis temperature conducting filler materials, in accordance with the invention, comprise conductive polymers, such as but not limited to, polythiophene, polypyrrole, polyaniline, and also organic conductive materials, such as but not limited to, tetrathiafulvalene-tetracyanoquinodimethane. These compositions can be used as a sole electrically conducting element in the composite material. Alternatively, they can be used together with metal or ceramic conducting fillers.

In a current limiting device in accordance with the invention, it is believed that the vaporization and/or ablation of the composite material causes a partial or complete physical separation at the area of high resistance, for example the electrode/material interface. In this separated state, it is believed that ablation of the composite material occurs and arcing between the separated layers of the current limiting device can occur. However, the overall resistance in the separated state is much higher than in the nonseparated state. This high arc resistance is believed due to the high pressure generated at the interface by the gas evolution from the composite binder combined with the deionizing properties of the gas. In any event, the current limiting device of the present invention is effective in limiting the short-circuited current so that the other components of the circuit are not harmed by the short circuit.

After the short-circuited current is interrupted, it is believed that the current limiting device, of the present invention, when properly designed, returns or reforms into its nonseparated state due to compressive pressure which acts to push the separated layers together. It is believed that once the layers of the current limiting device have returned to the nonseparated state or the low resistance state, the current limiting device is fully operational for future current-limiting operations in response to other short-circuit conductors.

Alternate embodiments of the current limiting device of the present invention can be made by employing a parallel current path containing a resistor, varistor, or other linear or nonlinear elements to achieve goals such as controlling the maximum voltage that may appear across the current limiting device in a particular circuit or to provide an alternative path for some of the circuit energy in order to increase the usable lifetime of the current limiting device.

Further, in accordance with the invention, third phase fillers can be added to the current limiting device. This third phase filler is usable to improve specific properties of the composite, such as the mechanical properties; dielectric properties; or to provide arc-quenching properties or flame-retardant properties. Materials which could be used as a third phase filler in the composite material include: a filler selected from reinforcing fillers, such as, fumed silica, or extending fillers, such as, precipitated silica and mixtures thereof. Other fillers can include titanium dioxide, lithopone, zinc oxide, diatomaceous silicate, silica aerogel, iron oxide, diatomaceous earth, calcium carbonate, silazane treated silicas, silicone treated silicas, glass fibers, magnesium oxide, chromic oxide, zirconium oxide, alpha-quartz, calcined clay, carbon, graphite, cork, cotton sodium bicarbonate, boric acid, alumina-hydrate, etc.. Further, other additives may include: impact modifiers for preventing damage to the current limiter such as cracking upon sudden impact; flame retardant for preventing flame formation and/or inhibiting flame formation in the current limiter; dyes and colorants for providing specific

color components in response to customer requirements; UV screens for preventing reduction in component physical properties due to exposure to sunlight or other forms of UV radiation.

The invention in accordance with the invention further comprises binder material having a low pyrolysis or vaporization temperature (<800°C) such as: a thermoplastic (for example, polytetrafluoroethylene, poly(ethyleneglycol), polyethylene, polycarbonate, polyimide, polyamide, polymethylmethacrylate, polyester etc.); a thermoset plastic (for example, epoxy, polyester, polyurethane, phenolic, alkyd); an elastomer (for example, silicone (polyorganosiloxane), (poly)urethane, isoprene rubber, neoprene, etc.); an organic or inorganic crystal; combined with an electrically conducting filler, such as a conducting filler where a substantial fraction of the electrical current is carried by a low pyrolysis temperature material, such as an organic conductor.

In accordance with another preferred embodiment of the invention, the binder material in the current limiting device can be eliminated altogether. A pure organic conductor can be utilized in place of the composite material, as long as an inhomogeneous resistance structure is maintained within the current limiting device.

## Claims

### 1. A current limiting device comprising:

at least two electrodes;  
 an electrically conducting composite material between said electrodes, said composite material comprising (A) a binder with a pyrolysis or vaporization temperature, at which significant gas evolution occurs, below 800°C, and (B) an electrically conductive filler, wherein the electrically conducting filler comprises a low pyrolysis temperature material;  
 interfaces between said electrodes and said composite material;  
 an inhomogeneous distribution of resistance at said interfaces whereby, during a short circuit, adiabatic resistive heating at said interfaces causes rapid thermal expansion and vaporization of said binder resulting in at least a partial physical separation at said interfaces; and  
 means for exerting compressive pressure on said composite material.

2. The device of claim 1, where the low pyrolysis temperature conductive filler material is selected from the group consisting of conductive polymers comprising polythiophene, polypyrrole, polyaniline, and organic conductive materials.

3. The device of claim 2, wherein the low pyrolysis temperature conductive filler material is an organic conductive material comprising tetrathiafulvalene-

tetracyanoquinodimethane.

4. The device of claim 2, wherein the low pyrolysis temperature conductive filler material is used with at least one of a metal or ceramic conductive filler.

5. The device of Claim 1, wherein the compressive pressure provided by the exerting means is applied in a direction perpendicular to the at least one, relatively thin layer.

6. The device of Claim 1, wherein the electrically conducting composite material comprises at least one thermoplastic selected from the group consisting of:

polytetrafluoroethylene, poly(ethyleneglycol), polyethylene, polycarbonate, polyimide, polyamide, polymethylmethacrylate, polyester.

7. The device of Claim 1, wherein the electrically conducting composite material comprises at least one thermoset plastic selected from the group consisting of:

epoxy, polyester, polyurethane, phenolic containing resin, alkyd containing resin, and an elastomer.

8. The device of Claim 7, wherein the elastomer comprises at least one elastomer selected from the group consisting of:

silicone, polyurethane, isoprene rubber, and neoprene.

9. The device of Claim 1, wherein the electrically conducting material comprises at least one metal selected from the group consisting of:

nickel, silver and aluminum.

10. The device of Claim 1, wherein the composite material has no PTC effect.

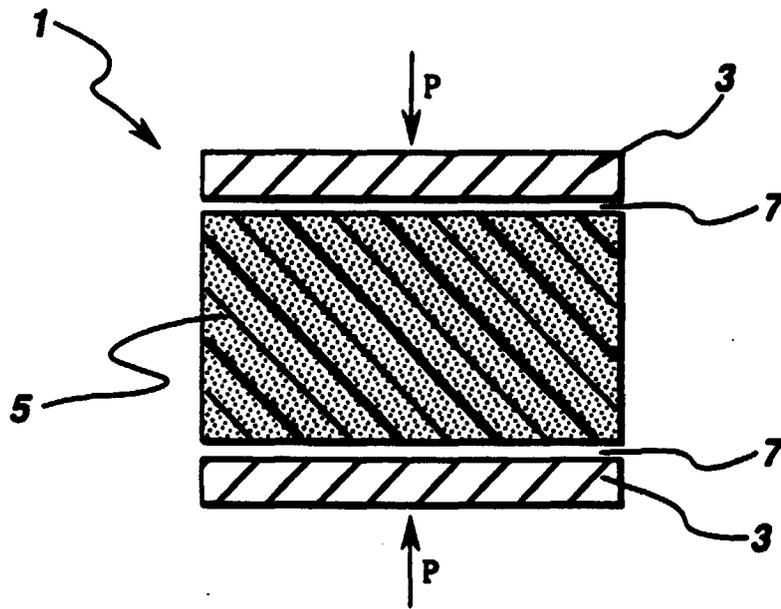


FIG. 1



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EUROPEAN SEARCH REPORT

Application Number  
EP 97 31 0300

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,Y A	EP 0 640 995 A (ABB RESEARCH LTD) * column 2, line 53 - column 5, line 19; claims 1,3,5,6,11; figures 1,2 * ---	1,6 5,9	H01C1/00 H01C7/13 H01C7/12
Y A	US 4 293 452 A (FOX ROBERT B ET AL) * column 1, line 45 - column 6, line 43; claims 1,4 * ---	1,6 3	
D,P, Y A	EP 0 762 439 A (GEN ELECTRIC) * the whole document * ---	1,6 5,7-10	
A	DE 43 30 607 A (SIEMENS AG) * column 1, line 63 - column 5, line 16; claims 1,7,8,11,12; figures 6A-6D * ---	1,5,6	
A	US 5 106 540 A (BARMA PRADEEP ET AL) * the whole document * ---	1,4,6	
A	WO 94 23433 A (HYPERION CATALYSIS INT) * page 1, line 14 - page 1, line 19 * -----	1,2	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			H01C
Place of search	Date of completion of the search	Examiner	
THE HAGUE	8 April 1998	Gorun, M	
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

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