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(54) **Overvoltage protection devices including a varistor member and an electrical conductive fusing member**

(57) An overvoltage protection device includes first and second electrically conductive electrode members (130, 120) and a varistor member (110) formed of a varistor material (172) and electrically connected with each of the first and second electrode members. The overvoltage protection device has an integral fail-safe mechanism operative to electrically short circuit the first and second electrode members about the varistor member by fusing the meltable member (140) in the overvoltage protection device (134) by using an electric arc. The overvoltage protection device further includes an electrically insulating spacer member (144) electrically isolating the fusing metal member (140) from the electrodes; the electric arc disintegrates the spacer member and extends across the gap (G1, G3 and G2) to fuse the meltable/fusing member (140).

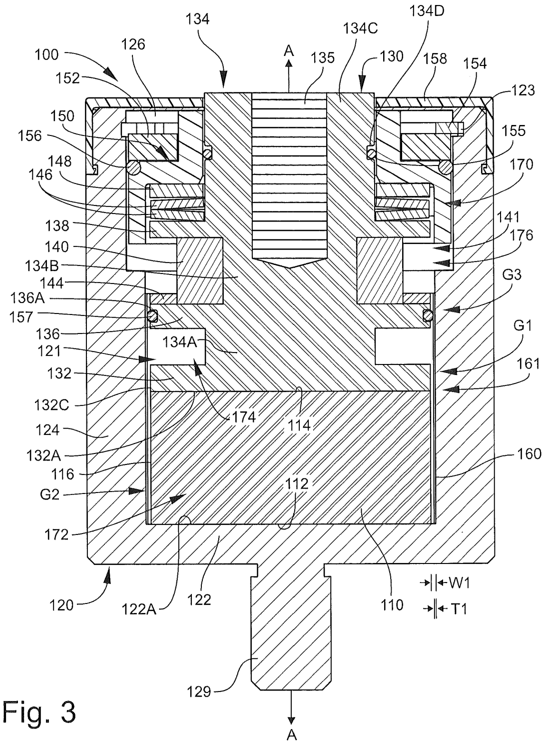

Fig. 3

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Description

Field of the Invention

[0001] The present invention relates to voltage surge protection devices and, more particularly, to a voltage surge protection device including a varistor member.

Background of the Invention

[0002] Frequently, excessive voltage is applied across service lines that deliver power to residences and commercial and institutional facilities. Such excess voltage or voltage spikes may result from lightning strikes, for example. The voltage surges are of particular concern in telecommunications distribution centers, hospitals and other facilities where equipment damage caused by voltage surges and resulting down time may be very costly.

[0003] Typically, one or more varistors (*i.e.*, voltage dependent resistors) are used to protect a facility from voltage surges. Generally, the varistor is connected directly across an AC input and in parallel with the protected circuit. The varistor has a characteristic clamping voltage such that, responsive to a voltage increase beyond a prescribed voltage, the varistor forms a low resistance shunt path for the overvoltage current that reduces the potential for damage to the sensitive components. Typically, a line fuse may be provided in the protective circuit and this line fuse may be blown or weakened by the surge current or the failure of the varistor element.

[0004] Varistors have been constructed according to several designs for different applications. For heavy-duty applications (*e.g.*, surge current capability in the range of from about 60 to 200 kA) such as protection of telecommunications facilities, block varistors are commonly employed. A block varistor typically includes a disk-shaped varistor element potted in an epoxy or plastic housing. The varistor disk is formed by pressure casting a metal oxide material, such as zinc oxide, or other suitable material such as silicon carbide. Copper, or other electrically conductive material, is flame sprayed onto the opposed surfaces of the disk. Ring-shaped electrodes are bonded to the coated opposed surfaces and the disk and electrode assembly is enclosed within the plastic housing. Examples of such block varistors include Product No. SIOV-B860K250, available from Siemens Matsushita Components GmbH & Co. KG and Product No. V271BA60, available from Harris Corporation.

[0005] Another varistor design includes a high-energy varistor disk housed in a disk diode case. The diode case has opposed electrode plates and the varistor disk is positioned therebetween. One or both of the electrodes include a spring member disposed between the electrode plate and the varistor disk to hold the varistor disk in place. The spring member or members provide only a relatively small area of contact with the varistor disk.

[0006] Another type of overvoltage protection device employing a varistor wafer is the Strikesorb™ surge protection module available from Raycap Corporation of Greece, which may form a part of a Rayvoss™ transient voltage surge suppression system. (*See,* for example, U.S. Patent No. 6,038,119, U.S. Patent No. 6,430,020 and U.S. Patent No. 7,433,169.

[0007] Varistor-based overvoltage protection devices (*e.g.*, of the epoxy-shielded type) are commonly designed with an open circuit failure mode using an internal thermal disconnector or overcurrent disconnector to disconnect the device in case of failure. Other varistor-based overvoltage protection devices have a short circuit as a failure mode. For example, some epoxy-shielded devices use a thermal disconnector to switch to a short circuit path. However, many of these devices have very limited short circuit current withstand capabilities.

Summary of the Invention

[0008] According to embodiments of the present invention, an overvoltage protection device includes first and second electrically conductive electrode members and a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members. The overvoltage protection device has an integral fail-safe mechanism operative to electrically short circuit the first and second electrode members about the varistor member by fusing first and second metal surfaces in the overvoltage protection device to one another using an electric arc.

[0009] According to some embodiments, the fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member.

[0010] In some embodiments, the first and second metal surfaces are separated by a gap having a width in the range of from about 0.2 mm to 1 mm, and the electric arc extends across the gap to fuse the first and second metal surfaces.

[0011] According to some embodiments, the first and second metal surfaces are separated by a gap, the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another, and the electric arc disintegrates the spacer member and extends across the gap to fuse the first and second metal surfaces. In some embodiments, the spacer member is formed of a polymeric material having a thickness in the range of from about 0.1 mm to 0.5 mm.

[0012] According to some embodiments, the first metal surface is a surface of the first electrode member and the second metal surface is a surface of the second electrode member. In some embodiments, the first electrode includes a housing having a metal housing sidewall and defining a housing chamber, the varistor member and at least a portion of the second electrode are disposed in the housing chamber, and the first metal surface is a surface of the housing sidewall. In some embodiments, the varistor member has first and second opposed, generally planar varistor contact surfaces, the housing includes an electrode wall having a first electrode contact surface engaging the first varistor contact surface, the second electrode includes a head positioned in the housing chamber, the head including a second electrode contact surface engaging the second varistor contact surface and a head peripheral surface surrounding the second electrode contact surface, and the second metal surface is located on the head peripheral surface. The overvoltage protection device may include a buffer chamber on a side of the head opposite the second electrode contact surface, wherein the buffer chamber is configured to limit propagation of electric arc away from the head.

[0013] The overvoltage protection device may include a biasing device biasing at least one of the first and second electrode members against the varistor member.

[0014] In some embodiments, the fail-safe mechanism is a first fail-safe mechanism and the overvoltage protection device further includes an integral second fail-safe mechanism. The second fail-safe mechanism includes an electrically conductive meltable member. The meltable member is responsive to heat in the overvoltage protection device to melt and form a current flow path between the first and second electrode members through the meltable member. In some embodiments, the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another, and the meltable member has a greater melting point temperature than a melting point temperature of the spacer member. According to some embodiments, the first fail-safe mechanism is operative to fuse the first and second metal surfaces at a prescribed region, and the overvoltage protection device includes a sealing member between the prescribed region and the meltable member. According to some embodiments, the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member sufficient to generate an arc, and the second fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member in response to a short circuit failure of the varistor member not sufficient to generate an arc.

[0015] According to some embodiments, the fail-safe mechanism is a first fail-safe mechanism, the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member, the overvoltage protection device further includes an integral second fail-safe mechanism, the second fail-safe mechanism including an electrically conductive meltable member, wherein the meltable member is responsive to heat in the overvoltage protection device to melt and form a current flow path between the first and second electrode members through the meltable member, the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member sufficient to generate an arc, the second fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member in response to a short circuit failure of the varistor member that is not sufficient to generate an arc, the varistor member has first and second opposed, generally planar varistor contact surfaces, the first electrode includes a housing defining a housing chamber and having a metal housing sidewall and an electrode wall, the electrode wall having a first electrode contact surface engaging the first varistor contact surface, the varistor member is disposed in the housing chamber, the second electrode includes a head positioned in the housing chamber, the head including a second electrode contact surface engaging the second varistor contact surface and a head peripheral surface surrounding the second electrode contact surface, the first metal surface is a surface of the housing sidewall, the second metal surface is located on the head peripheral surface, the first and second metal surfaces are separated by a gap having a width in the range of from about 0.2 mm to 1 mm, the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another, the electric arc disintegrates the spacer member and extends across the gap to fuse the first and second metal surfaces, and the spacer member is formed of a polymeric material having a thickness in the range of from about 0.1 mm to 0.5 mm.

[0016] According to method embodiments of the present invention, a method for providing overvoltage protection includes providing an overvoltage protection device including: first and second electrically conductive electrode members; a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members; and an integral fail-safe mechanism operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in the overvoltage protection device to one another using an electric arc. The method further includes directing current between the first and second electrode members through the varistor member during an overvoltage event.

[0017] According to embodiments of the present invention, an overvoltage protection device includes first and second electrically conductive electrode members and a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members. The overvoltage protection device has an integral first fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a first set of operating conditions. The overvoltage protection device also has an integral second fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a second set of operating conditions different from the first set of operating conditions.

[0018] According to some embodiments, the first and second sets of operating conditions each include at least one of an overheating event and an arcing event. In some embodiments, the first set of operating conditions includes an arcing event, and the second set of operating conditions includes an overheating event.

[0019] According to method embodiments of the present invention, a method for providing overvoltage protection includes providing an overvoltage protection device including: first and second electrically conductive electrode members; a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members; an integral first fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a first set of operating conditions; and an integral second fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a second set of operating conditions different from the first set of operating conditions. The method further includes directing current between the first and second electrode members through the varistor member during an overvoltage event.

[0020] Further features, advantages and details of the present invention will be appreciated by those of ordinary skill in the art from a reading of the figures and the detailed description of the preferred embodiments that follow, such description being merely illustrative of the present invention.

Brief Description of the Drawings

[0021] The accompanying drawings, which form a part of the specification, illustrate embodiments of the present invention.

[0022] **Figure 1** is an exploded, perspective view of an overvoltage protection device according to embodiments of the present invention.

[0023] **Figure 2** is a perspective view of the overvoltage protection device of **Figure 1.**

[0024] **Figure 3** is a cross-sectional view of the overvoltage protection device of **Figure 1** taken along the line **3-3** of **Figure 2.**

[0025] **Figure 4** is a cross-sectional view of the overvoltage protection device of **Figure 1** taken along the line **3-3** of **Figure 2,** wherein a meltable member of the overvoltage protection device has been reconfigured by melting to bypass the varistor wafer.

[0026] **Figure 5** is an enlarged, fragmentary, cross-sectional view of the overvoltage protection device of **Figure 1** taken along the line **3-3** illustrating a failure site in a varistor wafer and arcs propagating through the overvoltage protection device.

[0027] **Figure 6** is an enlarged, fragmentary, cross-sectional view of the overvoltage protection device of **Figure 1** taken along the line **3-3,** wherein a fused interface has been formed by the arcing of **Figure 5** to bypass the varistor wafer.

[0028] **Figure 7** is a schematic diagram representing a circuit including the overvoltage protection device of **Figure 1** according to embodiments of the present invention.

Detailed Description of Embodiments of the Invention

[0029] The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which illustrative embodiments of the invention are shown. In the drawings, the relative sizes of regions or features may be exaggerated for clarity. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art.

[0030] It will be understood that when an element is referred to as being "coupled" or "connected" to another element, it can be directly coupled or connected to the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly coupled" or "directly connected" to another element, there are no intervening elements present. Like numbers refer to like elements throughout.

[0031] In addition, spatially relative terms, such as "under", "below", "lower", "over", "upper" and the like, may be used herein for ease of description to describe one element or feature's relationship to another element(s) or feature(s) as illustrated in the figures. It will be understood that the spatially relative terms are intended to encompass different orientations of the device in use or operation in addition to the orientation depicted in the figures. For example, if the device in the figures is turned over, elements described as "under" or "beneath" other elements or features would then be oriented "over" the other elements or features. Thus, the exemplary term "under" can encompass both an orientation of over and under. The device may be otherwise oriented (rotated 90 degrees or at other orientations) and the spatially relative descriptors used herein interpreted accordingly.

[0032] Well-known functions or constructions may not be described in detail for brevity and/or clarity.

[0033] As used herein the expression "and/or" includes any and all combinations of one or more of the associated listed items.

[0034] The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[0035] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs. It will be further understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[0036] As used herein, "monolithic" means an object that is a single, unitary piece formed or composed of a material without joints or seams.

[0037] As used herein, the term "wafer" means a substrate having a thickness which is relatively small compared to its diameter, length or width dimensions.

[0038] With reference to **Figures 1-7,** an overvoltage protection device according to embodiments of the present invention is shown therein and designated **100.** The device **100** has a lengthwise axis **A-A (Figure 2).** The device **100** includes a first electrode or housing **120,** a piston-shaped second electrode **130,** a varistor member (herein, "the varistor wafer") **110** between the housing **120** and the electrode **130,** and other components as discussed in more detail below. The device **100** further includes an integral first fail-safe mechanism, arrangement, feature or system **161** and an integral second fail-safe mechanism, arrangement, feature or system **141.** The fail-safe systems **141, 161** are each adapted to prevent or inhibit overheating or thermal runaway of the overvoltage protection device, as discussed in more detail below.

[0039] With reference to **Figures 1-3,** the housing **120** has an end electrode wall **122 (Figure 3)** and a cylindrical sidewall **124** extending from the electrode wall **122.** The sidewall **124** and the electrode wall **122** form a chamber or cavity **121** communicating with an opening **126.** A threaded post or stud **129** extends outwardly from housing **120.** The electrode **130** has a head **132** disposed in the cavity **121** and an integral shaft **134** that projects outwardly through the opening **126.** The varistor wafer **110** is disposed in the cavity **121** between and in contact with each of the electrode wall **122** and the head **132.**

[0040] In use, the device **100** may be connected directly across an AC or DC input (for example, in an electrical service utility box). Service lines are connected directly or indirectly to each of the electrode shaft **134** and the housing post **129** such that an electrical flow path is provided through the electrode **130,** the varistor wafer **110,** the housing electrode wall **122** and the housing post **129.** Ordinarily, in the absence of an overvoltage condition, the varistor wafer **110** provides high electrical resistance such that no significant current flows through the device **100** as it appears electrically as an open circuit. In the event of an overvoltage condition (relative to the design voltage of the device), the resistance of the varistor wafer **110** decreases rapidly, allowing current to flow through the device **100** and create a shunt path for current flow to protect other components of an associated electrical system. The general use and application of overvoltage protectors such as varistor devices is well known to those of skill in the art and, accordingly, will not be further detailed herein.

[0041] Turning to the construction of the device **100** in greater detail, the first fail-safe system **161** includes an electrically insulating spacer member or membrane **160** disposed in the cavity **121.** The second fail-safe system **141** includes an electrically conductive meltable member **140** and a meltable member insulating ring **144** disposed in the cavity **121.** The device **100** further includes spring washers **146,** a flat washer **148,** an insulating member **150,** an end cap **152,** a clip **154,** an O-ring **155,** an O-ring **156,** an O-ring **157,** and a cover **158** over the cavity **121.** Each of these components is described more fully below.

[0042] The electrode wall **122** of the housing **120** has an inwardly facing, substantially planar contact surface **122A.** An annular slot **123** is formed in the inner surface of the sidewall **124.** According to some embodiments, the housing **120** is formed of aluminum. However, any suitable electrically conductive metal may be used. According to some embodiments, the housing **120** is unitary and, in some embodiments, monolithic. The housing **120** as illustrated is cylindrically shaped, but may be shaped differently.

[0043] As best seen in **Figure 3,** the head **132** of the electrode **130** has a substantially planar contact surface **132A** that faces the contact surface **122A** of the electrode wall **122.** A circumferential peripheral sidewall surface **132C** surrounds the contact surface **132A.** The shaft **134** has a lower portion **134A,** an intermediate portion **134B,** and an upper portion **134C.** According to some embodiments, each shaft portion **134A, 134B, 134C** has a diameter of from about 0.79 to 1 inch. An integral, annular, lower flange **136** extends radially outwardly from the shaft **134** between the shaft portions **134A** and **134B.** An integral, annular, upper flange **138** extends radially outwardly from the shaft **134** between the shaft portions **134B** and **134C.** An annular, sidewardly opening groove **136A** is defined in the peripheral sidewall of the flange **136.** A threaded bore **135** is formed in the end of the shaft **134** to receive a bolt for securing a bus bar or other electrical connector to the electrode **130.** An annular, sidewardly opening groove **134D** is defined in the shaft portion **134C.**

[0044] According to some embodiments, the electrode **130** is formed of aluminum and, in some embodiments, the housing sidewall **124** and the electrode **130** are both formed of aluminum. However, any suitable electrically conductive metal may be used. According to some embodiments, the electrode **130** is unitary and, in some embodiments, monolithic.

[0045] An annular gap **G1** is defined between the head peripheral sidewall surface **132C** and the nearest adjacent surface of the sidewall **124.** A gap **G2** is defined between the varistor **110** and the nearest adjacent surface of the sidewall **124.** A gap **G3** is defined between the lower flange **136** and the nearest adjacent surface of the sidewall **124.** There may be a gap defined between the membrane **160** and the surface **132C** and/or the sidewall **124,** as shown for example. Alternatively, the membrane **160** may be substantially in contact with surface **132C** and the sidewall **124** (*i.e.,* the gaps **G1, G2, G3** may be substantially completely filled by the membrane **160).**

[0046] According to some embodiments, each gap **G1, G2, G3** has a width **W1 (Figure 3)** in the range of from about 0.2 to 1 mm and, in some embodiments, in the range of from about 0.5 to 0.75 mm.

[0047] With reference to **Figure 3,** the housing **120** and the end cap **152** collectively define an enclosed device chamber **170.** A varistor subchamber **172** is defined by the head **132,** the electrode wall **122** and a portion of the sidewall **124.** An extinguishing or buffer subchamber **174** is defined by the head **132,** the flange **136** and a portion of the sidewall **124.** A meltable member subchamber **176** is defined by the flange **136,** the flange **138** and a portion of the sidewall **124.**

[0048] The membrane **160** is mounted around the electrode **130** between the electrode **130** and the sidewall **124** in the chamber **170.** The membrane **160** is annular and surrounds the varistor **110,** the head **132,** the lower shaft portion **134A,** and the lower flange **136.** In some embodiments and as shown, the membrane **160** is a relatively thin, cylindrical, tubular piece or sleeve. The membrane **160** is interposed radially between the sidewall **124** and each of the varistor **110,** the head peripheral sidewall surface **132C,** and the flange **136.** Except as discussed below, the membrane **160** electrically isolates the electrode **130** from the housing **120.** According to some embodiments, the membrane **160** contacts the sidewall **124.**

[0049] The membrane **160** is formed of a dielectric or electrically insulating material having high melting and combustion temperatures, but which can be disintegrated (such as by melting, burning, combusting or vaporizing) when subjected to an electric arc or the high temperatures created by an electric arc. According to some embodiments, the membrane **160** is formed of a high temperature polymer and, in some embodiments, a high temperature thermoplastic. In some embodiments, the membrane **160** is formed of polyetherimide (PEI), such as ULTEM™ thermoplastic available from SABIC of Saudi Arabia. In some embodiments, the membrane **160** is formed of non-reinforced polyetherimide.

[0050] According to some embodiments, the membrane **160** is formed of a material having a melting point greater than the melting point of the meltable member **140.** According to some embodiments, the membrane **160** is formed of a material having a melting point in the range of from about 120 to 200 °C and, according to some embodiments, in the range of from about 140 to 160 °C.

[0051] According to some embodiments, the membrane **160** material can withstand a voltage of 25 kV per mm of thickness.

[0052] According to some embodiments, the membrane **160** has a thickness **T1 (Figure 3)** in the range of from about 0.1 to 0.5 mm and, in some embodiments, in the range of from about 0.3 to 0.4 mm.

[0053] The meltable member **140** is mounted on the electrode **130** in the subchamber **176.** The meltable member **140** is annular and surrounds the intermediate shaft portion **134B,** which is disposed in a central passage of the meltable member **140.** In some embodiments and as shown, the meltable member **140** is a cylindrical, tubular piece or sleeve. According to some embodiments, the meltable member **140** contacts the intermediate shaft portion **134B** and, according to some embodiments, the meltable member **140** contacts the intermediate shaft portion **134B** along substantially the full length of the intermediate shaft portion **134B** and the full length of the meltable member **140.** The meltable member **140** also engages the lower surface of the flange **138** and the top surface of the flange **136.** The meltable member **140** is spaced apart from the sidewall **124** a distance sufficient to electrically isolate the meltable member **140** from the sidewall **124.**

[0054] The meltable member **140** is formed of a heat-meltable, electrically conductive material. According to some embodiments, the meltable member **140** is formed of metal. According to some embodiments, the meltable member **140** is formed of an electrically conductive metal alloy. According to some embodiments, the meltable member **140** is formed of a metal alloy from the group consisting of aluminum alloy, zinc alloy, and/or tin alloy. However, any suitable electrically conductive metal may be used.

[0055] According to some embodiments, the meltable member **140** is selected such that its melting point is greater than a prescribed maximum standard operating temperature. The maximum standard operating temperature may be the greatest temperature expected in the meltable member **140** during normal operation (including handling overvoltage surges within the designed for range of the device **100)** but not during operation which, if left unchecked, would result in thermal runaway. According to some embodiments, the meltable member **140** is formed of a material having a melting point in the range of from about 80 to 160 °C and, according to some embodiments, in the range of from about 80 to 120 °C. According to some embodiments, the melting point of the meltable member **140** is at least 20 °C less than the melting points of the housing **120,** the electrode **130,** the insulator ring **150,** and the membrane **160** and, according to some embodiments, at least 40 °C less than the melting points of those components.

[0056] According to some embodiments, the meltable member **140** has an electrical conductivity in the range of from about 0.5 x 10^6 Siemens/meter (S/m) to 4 x 10^7 S/m and, according to some embodiments, in the range of from about 1 x 10^6 S/m to 3 x 10^6 S/m.

[0057] The meltable member **140** can be mounted on the electrode **130** in any suitable manner. According to some embodiments, the meltable member **140** is cast or molded onto the electrode **130.** According to some embodiments, the meltable member **140** is mechanically secured onto the electrode **130.** According to some embodiments, the meltable member **140** is unitary and, in some embodiments, monolithic.

[0058] The varistor wafer **110** has first and second opposed, substantially planar contact surfaces **112.** The varistor wafer **110** is interposed between the contact surfaces **122A** and **132A.** As described in more detail below, the head **132** and the wall **122** are mechanically loaded against the varistor wafer **110** to ensure firm and uniform engagement between the surfaces **132A, 122A** and the respective opposed surfaces **112, 114** of the varistor wafer **110.**

[0059] The varistor wafer **110** has a circumferential, peripheral sidewall surface **116.** According to some embodiments, the varistor wafer **110** is disk-shaped. However, the varistor wafer **110** may be formed in other shapes. The thickness and the diameter of the varistor wafer **110** will depend on the varistor characteristics desired for the particular application. The varistor wafer **110** may include a wafer of varistor material coated on either side with a conductive coating so that the exposed surfaces of the coatings serve as the contact surfaces. The coatings can be formed of aluminum, copper or silver, for example.

[0060] The varistor material may be any suitable material conventionally used for varistors, namely, a material exhibiting a nonlinear resistance characteristic with applied voltage. Preferably, the resistance becomes very low when a prescribed voltage is exceeded. The varistor material may be a doped metal oxide or silicon carbide, for example. Suitable metal oxides include zinc oxide compounds.

[0061] The spring washers **146** surround the upper shaft portion **134B** and engage the upper surface of the flange **138.** Each spring washer **146** includes a hole that receives the upper shaft portion **134C** of the electrode **130.** The lowermost spring washer **146** abuts the top face of the flange **138.** According to some embodiments, the clearance between the spring washer hole and the shaft portion **134C** is in the range of from about 0.015 to 0.035 inch. The spring washers **146** may be formed of a resilient material. According to some embodiments and as illustrated, the spring washers **146** are Belleville washers formed of spring steel. While two spring washers **146** are shown, more or fewer may be used.

[0062] The flat metal washer **148** is interposed between the spring washer **146** and the insulator ring **150** with the shaft portion **134C** extending through a hole formed in the washer **148.** The washer **148** serves to distribute the mechanical load of the spring washer **146** to prevent the spring washer from cutting into the insulator ring **150.**

[0063] The insulator ring **150** overlies and abuts the washer **148.** The insulator ring **150** has a main body ring **150A,** a cylindrical upper flange or collar **150B** extending upwardly from the main body ring **150A,** and a cylindrical lower flange or collar **150C** extending downwardly from the main body ring **150A.** A hole **150D** receives the shaft portion **134B.** According to some embodiments, the clearance between the hole **150D** and the shaft portion **134B** is in range of from about 0.025 to 0.065 inch. The main body ring **150A** and the collars **150B, 150C** may be bonded or integrally molded. An upwardly and outwardly opening peripheral groove **150E** is formed in the top corner of the main body ring **150A.**

[0064] The insulator ring **150** is preferably formed of a dielectric or electrically insulating material having high melting and combustion temperatures. The insulator ring **150** may be formed of polycarbonate, ceramic or a high temperature polymer, for example. According to some embodiments, the insulator ring **150** is formed of a material having a melting point greater than the melting point of the meltable member **140.**

[0065] The end cap **152** overlies and abuts the insulator ring **150.** The end cap **152** has a hole **152A** that receives the shaft portion **134C.** According to some embodiments, the clearance between the hole **152A** and the shaft portion **134C** is in the range of from about 0.1 to 0.2 inch. The end cap **152** may be formed of aluminum, for example.

[0066] The clip **154** is resilient and truncated ring shaped. The clip **154** is partly received in the slot **123** and partly extends radially inwardly from the inner wall of the housing **120** to limit outward axial displacement of the end cap **152.** The clip **154** may be formed of spring steel.

[0067] The cover **158** is configured to cover the end cap **152** and has a hole **158A** through which the shaft **134** extends. The cover **158** is formed of an electrically insulating material and serves to insure a desired creepage distance between the electrode **130** and the end cap **152** or housing **120.**

[0068] The cover **158** may be formed of any suitable electrically insulating material having a sufficiently high melting temperature. The cover **158** may be formed of polycarbonate, ceramic or a high temperature polymer, for example. According to some embodiments, the cover **158** is formed of a material having a melting point greater than the melting point of the meltable member **140.**

[0069] The O-ring **155** is positioned in the groove **134D** so that it is captured between the shaft **134** and the insulator ring **150.** The O-ring **156** is positioned in the groove **159** such that it is captured between the end cap **152** and the insulator ring **150.** The O-ring **157** is positioned in the groove **136A** such that it is captured between the flange **136** and the sidewall **124.** When installed, the O-rings **156, 157** are compressed so that they are biased against and form a seal between the adjacent interfacing surfaces. In an overvoltage event, byproducts such as hot gases and fragments from the wafer **110** may fill or scatter into the cavity chamber **170.** These byproducts may be constrained or prevented by the O-rings **156, 157** from escaping the overvoltage protection device **100** through the housing opening **126.**

[0070] The O-rings **155, 156, 157** may be formed of the same or different materials. According to some embodiments, the O-rings **155, 156, 157** are formed of a resilient material, such as an elastomer. According to some embodiments, the O-rings **155, 156, 157** are formed of rubber. The O-rings **155, 156, 157** may be formed of a fluorocarbon rubber such as VITON™ available from DuPont. Other rubbers such as butyl rubber may also be used. According to some embodiments, the rubber has a durometer of between about 60 and 100 Shore A. According to some embodiments, the melting point of each of the O-rings **155, 156, 157** is greater than the melting point of the meltable member **140.**

[0071] When assembled as shown in **Figures 2** and **3,** the O-ring **157** seals the subchambers **172, 174** containing the varistor **110,** and the O-rings **155, 156** and **157** seal the subchamber **174** containing the meltable member **140.**

[0072] As noted above and as best shown in **Figure 3,** the electrode head **132** and the electrode wall **122** are persistently biased or loaded against the varistor wafer **110** to ensure firm and uniform engagement between the wafer surfaces **112, 114** and the surfaces **122A, 132A.** This aspect of the device **100** may be appreciated by considering a method according to the present invention for assembling the device **100.** The O-rings **156, 157** are installed in the grooves **150E, 136A.** The meltable member **140** is mounted on the shaft portion **134B** using any suitable technique (*e.g.*, casting). The varistor wafer **110** is placed in the cavity **121** such that the wafer surface **112** engages the contact surface **122A.** The electrode **130** is inserted into the cavity **121** such that the contact surface **132A** engages the varistor wafer surface **114.** The spring washers **146** are slid down the shaft portion **134C** and placed over the flange **138.** The washer **148,** the insulator ring **150,** and the end cap **152** are slid down the shaft portion **134C** and over the spring washers **146.** A jig (not shown) or other suitable device is used to force the end cap **152** down, in turn deflecting the spring washers **146.** While the end cap **152** is still under the load of the jig, the clip **154** is compressed and inserted into the slot **123.** The clip **154** is then released and allowed to return to its original diameter, whereupon it partly fills the slot and partly extends radially inward into the cavity **121** from the slot **123.** The clip **154** and the slot **123** thereby serve to maintain the load on the end cap **152** to partially deflect the spring washers **146.** The loading of the end cap **152** onto the insulator ring **150** and from the insulator ring onto the spring washer **146** is in turn transferred to the head **132.** In this way, the varistor wafer **110** is sandwiched (clamped) between the head **132** and the electrode wall **122.** The cover **158** is installed over the end cap **152.**

[0073] The varistor **110** may be constructed and operate in conventional or known, or similar, manner. As is well known, a varistor has an innate nominal clamping voltage VNOM (sometimes referred to as the "breakdown voltage" or simply the "varistor voltage") at which the varistor begins to conduct current. Below the VNOM, the varistor will not pass current. Above the VNOM, the varistor will conduct a current (*i.e.,* a leakage current or a surge current). The VNOM of a varistor is typically specified as the measured voltage across the varistor with a DC current of 1mA.

[0074] As is well known, a varistor has three modes of operation. In a first normal mode, up to a nominal voltage, the varistor is practically an electrical insulator. In a second normal mode, when the varistor is subjected to an overvoltage, the varistor temporarily and reversibly becomes an electrical conductor during the overvoltage condition and returns to the first mode thereafter. In a third mode (the so-called end of life mode), the varistor is effectively depleted and becomes a permanent, non-reversible electrical conductor.

[0075] The varistor **110** also has an innate maximum clamping voltage VC (sometimes referred to as simply the "clamping voltage"). The maximum clamping voltage VC is defined as the maximum voltage measured across the varistor when a specified current is applied to the varistor over time according to a standard protocol.

[0076] As discussed above, in the absence of an overvoltage condition, the varistor wafer **110** provides high resistance such that no current flows through the device **100** as it appears electrically as an open circuit. That is, ordinarily the varistor **110** passes no current. The electrodes **130** and the housing are electrically isolated from one another by the varistor **110,** the gaps **G1, G2, G3,** the membrane **160,** the insulator ring **150** and the cover **158.** In the event of an overcurrent surge event (typically transient; *e.g.*, lightning strike) or an overvoltage condition or event (typically longer in duration than an overcurrent surge event) exceeding VNOM, the resistance of the varistor wafer decreases rapidly, allowing current to flow through the device **100** and create a shunt path for current flow to protect other components of an associated electrical system. Normally, the varistor **110** recovers from these events without significant overheating of the device **100.**

[0077] The VNOM of a given varistor begins at a certain value and over time could degrade to a lower effective VNOM value as a result of varistor aging. Typically, a varistor is initially rated for a "maximum continuous operating voltage" (MCOV), indicating that the VNOM of the varistor exceeds the rated MCOV when first placed in service. For example, the rated MCOV of a selected varistor may be 1500V, but may drop to 1300V due to aging.

[0078] Varistor aging (*i.e.*, degradation resulting in reduction of the VNOM) can be caused by surge currents or continuous leakage currents (during continuous overvoltage events) applied to the varistor in service, as well as by passage of time with the nominal voltage applied on the varistor (rare case, typically caused by low quality varistors). Aging degradation is generally thermally induced.

[0079] Varistors have multiple failure modes. These failure modes may be caused by aging or a surge of sufficient magnitude and duration. The failure modes include: 1) the varistor **110** fails as a short circuit; and 2) the varistor 110 fails as a linear resistance (aging of the varistor). A short circuit failure typically manifests as a localized pinhole or puncture site (herein, "the failure site") extending through the thickness of the varistor **110.** This failure site creates a path for current flow between the two electrodes of a low resistance, but high enough to generate ohmic losses and cause overheating of the device **100** even at low fault currents. Sufficiently large fault current through the varistor **110** can melt the varistor in the region of the failure site and generate an electric arc. A varistor failure as a linear resistance will cause the conduction of a limited current through the varistor that will result in a buildup of heat. This heat buildup may result in catastrophic thermal runaway and the device temperature may exceed a prescribed maximum temperature. For example, the maximum allowable temperature for the exterior surfaces of the device may be set by code or standard to prevent combustion of adjacent components. In some cases, the current through the failed varistor could also be limited by the power system itself (*e.g.*, ground resistance in the system or in photovoltaic (PV) power source applications where the fault current depends on the power generation capability of the system at the time of the failure) resulting in a progressive build up of temperature, even if the varistor failure is a short circuit. There are cases where there is a limited leakage current flow through the varistor due to extended in time overvoltage conditions due to power system failures, for example. These conditions may lead to temperature build up in the device, such as when the varistor has failed as a linear resistance and could possibly lead to the failure of the varistor either as a linear resistance or as a short circuit as described above.

[0080] One way to avoid such thermal runaway is to interrupt the current through the device **100** using a fuse that blows prior to the occurrence of overheat in the device **100.** However, as discussed below, in some cases this approach is undesirable as it may cause damage to other important components in an associated circuit or leave the load unprotected after disconnecting the surge protective device. In addition, in some applications the current could be lower than the rating of the fuse.

[0081] In some cases, the device **100** may assume an "end of life" mode in which the varistor wafer is depleted in full or in part (*i.e.,* in an "end of life" state), leading to an end of life failure. When the varistor **110** of the device **100** reaches its end of life, the device **100** will become substantially a short circuit with a very low but non-zero ohmic resistance.

[0082] As a result, in an end of life condition, a fault current will continuously flow through the varistor **110** even in the absence of an overvoltage condition. As a result, notwithstanding the short circuit provided by the end of life device **100,** the fault current may be insufficient to trip or blow an associated breaker or fuse. In this case, the current may continue to flow through the varistor **110,** thereby generating heat from ohmic losses in the varistor **110.** If the condition is permitted to persist, the heat generated in the device **100** may build up until the housing **120** melts or explodes. Such an event may be regarded as catastrophic. If the fault current is of sufficient magnitude, the fault current will induce or generate electric arcing through and around the varistor **110** (herein, an "arcing event"). Such an arcing event may rapidly generate additional heat in the device **100** and/or may cause localized damage to other components of the device **100.**

[0083] The first fail-safe system **161** and the second fail-safe system **141** are each adapted and configured to electrically short circuit the current applied to the device **100** around the varistor **110** to prevent or reduce the generation of heat in the varistor. In this way, the fail-safe systems **141, 161** can operate as switches to bypass the varistor **110** and prevent overheating and catastrophic failure as described above. According to embodiments of the invention, the fail-safe systems **141, 161** operate independently of one another. More particularly, in some embodiments, the fail-safe system **161** will operate to short circuit the device **100** when a first type or set of operating conditions are experienced by the device **100** and the fail-safe system **141** will operate to short circuit the device **100** when a second type or set of operating conditions, different from the first, are experienced by the device **100.** That is, under different circumstances, the fail-safe system **161** may operate or execute first or the fail-safe system **141** may operate or execute first. Ordinarily, though not necessarily, only one of the fail-safe systems will execute, whereupon the conditions necessary to invoke the other fail-safe system will be prevented from arising.

[0084] The operation of the fail-safe systems **141, 161** will be described in more detail hereinbelow. As used herein, a fail-safe system is "triggered" upon occurrence of the conditions necessary to cause the fail-safe system to operate as described to short circuit the electrodes **120, 130.**

[0085] Turning to the fail-safe system **141** in more detail, when heated to a threshold temperature, the meltable member **140** will flow to bridge and electrically connect the electrodes **120, 130.** The meltable member **140** thereby redirects the current applied to the device **100** to bypass the varistor **110** so that the current induced heating of the varistor **110** ceases. The fail-safe system **141** may thereby serve to prevent or inhibit thermal runaway without requiring that the current through the device

100 be interrupted.

[0086] More particularly, the meltable member **140** initially has a first configuration as shown in **Figures 1** and **3** such that it does not electrically couple the electrode **130** and the housing **120** except through the head **132.** Upon the occurrence of a heat buildup event, the electrode **130** is thereby heated. The meltable member **140** is also heated directly and/or by the electrode **130.** During normal operation, the temperature in the meltable member **140** remains below its melting point so that the meltable member **140** remains in solid form. However, when the temperature of the meltable member **140** exceeds its melting point, the meltable member **140** melts (in full or in part) and flows by force of gravity into a second configuration different from the first configuration. When the device **100** is vertically oriented, the melted meltable member **140** accumulates in the lower portion of the subchamber **176** as a reconfigured meltable member **140A** (which may be molten in whole or in part) as shown in **Figure 4.** The meltable member **140A** bridges or short circuits the electrode **130** to the housing **120** to bypass the varistor **110.** That is, a new direct flow path or paths are provided from the surface of the electrode portion **134B** to the surfaces of the housing sidewall **124** through the meltable member **140A.** According to some embodiments, at least some of these flow paths do not include the varistor wafer **110.**

[0087] The reconfigured meltable member **140A** is typically contained in the chamber **176.** The insulating ring **144** is positioned in the chamber **176** to provide a better flow path for the meltable member **140.** More particularly, the insulating ring **144** serves as a spacer to direct the flow of the molten member **140** over the upper end section of the membrane **160.** If the molten member **140** were permitted to flow directly into the membrane **160,** the membrane **160** may prevent or jeopardize a quick and reliable engagement between the member **140** and the sidewall **124.** The membrane **160** may extend above the top edge of the flange **136** in order to provide sufficient electrical creepage distance between the flange **136** and the sidewall **124.**

[0088] According to some embodiments, the fail-safe system **141** can be triggered by at least two alternative triggering sets of operating conditions, as follows.

[0089] The fail-safe system **141** can be triggered by heat generated in the varistor **110** by a leakage current. More particularly, when the voltage across the varistor **110** exceeds the nominal clamping voltage VNOM, a leakage current will pass through the varistor **110** and generate heat therein from ohmic losses. This may occur because the VNOM has dropped due to varistor **110** aging and/or because the voltage applied by the circuit across the device **100** has increased.

[0090] The fail-safe system **141** can also be triggered when the varistor **110** fails as a short circuit. In this case, the varistor **110** will generate heat from a fault current through the short circuit failure site (*e.g.*, a pinhole **118** as illustrated in **Figure 5).** The fault current generates heat (from high localized ohmic loss heating at the pinhole) in and adjacent the varistor **110.** As discussed below, a fail-short varistor may trigger the first fail-safe system **161** instead of the second fail-safe system **141,** depending on the magnitude of the fault current and other conditions.

[0091] With reference to **Figures 3, 5** and **6,** the first fail-safe system **161** can be triggered when the varistor **110** fails as a short circuit. In this case, arcing will occur adjacent and within a short circuit failure site **118.** More particularly, the arcing will occur between the varistor **110** and one or both of the electrodes **120, 130** at the varistor-electrode contact interfaces **112/122A, 114/132A.** The arcing will propagate radially outwardly toward the housing sidewall **124.** The arcing may travel from the electrode wall **122** of the housing **120** up the housing sidewall **120** (i. e., with the arc extending between the varistor sidewall **116** and the housing sidewall **124)** and/or may travel from the varistor upper contact face **114** to the sidewall **132C** of the electrode head **132.** Ultimately, the arcing propagates up the housing sidewall **124** such that arcing occurs directly between the outer peripheral sidewall **132C** of the electrode head **132** and the adjacent surface of the housing sidewall **124.** This latter arcing causes a metal surface portion **137** of the head sidewall **132C** and a metal surface portion **127** of the housing sidewall **124** to fuse or bond directly to one another in a prescribed region at a bonding or fusing site **164** to form a bonded or fused interface portion, or region **162 (Figure 6).** For example, **Figure 5** shows an exemplary varistor short circuit failure site or pinhole **118** wherein an electric arc **A1** has been generated by a fault current. The arc **A1** may propagate as an arc **A2** along the housing contact surface **122A** and up the sidewall **124** as an arc **A3** (across the gap **G1** from the varistor sidewall surface **116** to the sidewall **124** surface) to ultimately form an arc **A4** at the fusing site **164.** The arc **A4** fuses or bonds the surfaces and portions **127, 137.** Alternatively or additionally, the arc **A1** may propagate as an arc **A5** along the electrode contact surface **132A** to ultimately form the arc **A4** at the fusing site **164.** In some embodiments, the electrodes are both formed of aluminum or aluminum alloy, so that the bond is direct aluminum-to-aluminum, which can provide particularly low ohmic resistance. The fusing or bonding may occur by welding induced by the arc. In this way, the electrodes **120, 130** are shorted at the interface **162** to bypass the varistor **110** so that the current induced heating of the varistor **110** ceases.

[0092] The electrical insulation membrane **160** is provided between the housing sidewall **124** and the electrode head **132** and the varistor **110** to provide electrical isolation in normal operation. However, the membrane **160** is formed of a material that is quickly melted or vaporized by the arcing so that the membrane **160** does not unduly impede the propagation of the arc or the bonding of the electrodes **120, 130** as described.

[0093] The chamber **174** provides a break between the adjacent surfaces of the electrode **130** and the housing

120 to extinguish the electric arc (*i.e.,* to prevent the arc from continuing up the sidewall **124).** The chamber **174** reduces the time required to terminate the arc and facilitates more rapid formation of the bonded interface **162.**

[0094] In the event of a fail-short varistor, either of the first and second fail-safe systems **161, 141** may be triggered or activated, in which case it is unlikely that the other will be. The first fail-safe system **161** requires a fault current sufficient to create the arcing, whereas the second fail-safe system **141** does not. When sufficient fault current is present to create the arcing, the first fail-safe system **161** will typically execute and form the electrode short circuit before the second fail-safe system **141** can form the meltable member short. However, if the applied current is insufficient to generate the arcing, the fault current will continue to heat the device **100** until the second fail-safe system **141** is activated. Thus, where a fail-short varistor is the trigger, the second fail-safe system **141** will operate for relatively low current and the first fail-safe system **161** will operate for relatively high current.

[0095] Thus, the meltable member **140A** and the fused interface **162** each provide a direct electrical contact surface or a low resistance bridge between the electrode **130** and the housing **120** and an enlarged current flow path (*i.e.,* a lower resistance short circuit) via the meltable member **140A** or the fused site **162.** In this way, the fault or leakage current is directed away from the varistor **110.** The arcing, ohmic heating and/or other phenomena inducing heat generation are diminished or eliminated, and thermal runaway and/or excessive overheat of the device **100** can be prevented. The device **100** may thereby convert to a relatively low resistance element capable of maintaining a relatively high current safely (*i.e.,* without catastrophic destruction of the device). The fail-safe systems **141, 161** can thus serve to protect the device **100** from catastrophic failure during its end of life mode. The present invention can provide a safe end of life mechanism for a varistor-based overvoltage device. It will be appreciated that the device **100** may be rendered unusable thereafter as an overvoltage protection device, but catastrophic destruction (*e.g.*, resulting in combustion temperature, explosion, or release of materials from the device **100)** is avoided.

[0096] According to some embodiments, the meltable member **140A** bypass and the fused interface **162** bypass each have an ohmic resistance of less than about 1 mOhm.

[0097] In some embodiments, the device **100** may be effectively employed in any orientation. For example, the device **100** may be deployed in a vertical orientation or a horizontal orientation. When the meltable member **140** is melted by an overheat generation event, the meltable member **140** will flow to the lower portion of the chamber **176** where it forms a reconfigured meltable member (which may be molten in whole or in part) that bridges the electrode **130** and the housing **120** as discussed above. The chamber **176** is sealed so that the molten meltable member **140** does not flow out of the chamber **176.**

[0098] With reference to **Figure 7,** an electrical circuit **30** according to embodiments of the present invention is shown schematically therein. The circuit **30** includes a power supply **32,** an overcurrent protection device (*e.g.*, a circuit breaker **34),** a protected load **36,** ground **40,** and the overvoltage protection device **100.** The device **100** may be mounted in an electrical service utility box, for example. The power supply **32** may be an AC or DC supply and provides power to the load **36.** The load **36** may be any suitable device, system, equipment or the like (*e.g.*, an electrical appliance, a cellular communications transmission tower, etc.). The device **100** is connected in parallel with the load **36.** In normal use, the device **100** will operate as an open circuit so that current is directed to the load **36.** In an overvoltage event, the resistance of the varistor wafer will drop rapidly so that overcurrent is prevented from damaging the load **36.** The circuit breaker **34** may trip open. However, in some cases, the device **100** may be subjected to a current exceeding the capacity of the varistor wafer **110,** causing excessive heat to be generating by arcing, etc. as described above. The fail-safe system **141** or the fail-safe system **161** will actuate to short circuit the device **100** as discussed above. The short circuiting of the device **100** will in turn trip the circuit breaker **34** to open. In this manner, the load **36** may be protected from a power surge or overcurrent event. Additionally, the device **100** may safely conduct a continuous current.

[0099] Notably, the device **100** will continue to short circuit the circuit **30** following the overcurrent event. As a result, the circuit breaker **34** cannot be reset, which notifies an operator that the device **100** must be repaired or replaced. If, alternatively, the branch of the device **100** were interrupted rather than short circuited, the circuit breaker **34** could be closed and the operator may be unaware that the load **36** is no longer protected by a functional overvoltage protection device.

[0100] Overvoltage protection devices according to embodiments of the present invention (*e.g.*, the device **100)** may provide a number of advantages in addition to those mentioned above. The devices may be formed so to have a relatively compact form factor. The devices may be retrofittable for installation in place of similar type overvoltage protection devices not having a meltable member as described herein. In particular, the present devices may have the same length dimension, as such previous devices.

[0101] According to some embodiments, overvoltage protection devices of the present invention (*e.g.*, the device **100)** are adapted such that when the fail-safe system **141** or the fail-safe system **161** is triggered to short circuit the overvoltage protection device, the conductivity of the overvoltage protection device is at least as great as the conductivity of the feed and exit cables connected to the device.

[0102] According to some embodiments, overvoltage protection devices of the present invention (*e.g.*, the device **100)** are adapted to sustain a current of 1000 amps for at least seven hours without occurrence of a breach of the housing (*e.g.*, the housing **120** or **220)** or achieving an external surface temperature in excess of 80 degrees Kelvin.

[0103] Overvoltage protection devices (*e.g.*, the device **100)** as disclosed herein can be particularly well-suited or advantageous when employed in a direct current (DC) circuit or system where the current conducted by the varistor **110** is very high. According to some embodiments, the device **100** is configured such that, when the fail-safe system **161** is triggered, the device **100** can withstand a short circuit current of at least 2 kA for more than 200 ms, and a permanent current flow of at least 700 A without overheating. The maximum temperature rise should not be more than 120 degrees Kelvin and the temperature rise five minutes after the failure of the device should not exceed 80 degrees Kelvin during the permanent current flow.

[0104] While meltable member **140** as described above is mounted so that it surrounds and is in contact with the electrode **130,** according to other embodiments of the present invention, a meltable member may instead or additionally be mounted elsewhere in a device. For example, a meltable member (*e.g.*, a sleeve or liner of the meltable material) may be mounted on the inner surface of the sidewall **124** and/or the underside of the flange **138.** Likewise, the meltable member may be shaped differently in accordance with some embodiments of the invention. For example, according to some embodiments, the meltable member is not tubular and/or symmetric with respect to the chamber, the electrode, and/or the housing.

[0105] According to some embodiments, the areas of engagement between each of the contact surfaces (*e.g.*, the contact surfaces **122A, 132A)** and the varistor wafer surfaces (*e.g.*, the wafer surfaces **112, 114)** is at least 0.5 square inches.

[0106] According to some embodiments, the biased electrodes **120, 130** apply a load to the varistor **110** in the range of from 100 lbf and 1000 lbf depending on its surface area.

[0107] According to some embodiments, the combined thermal mass of the housing **120** and the electrode **130** is substantially greater than the thermal mass of the varistor wafer **110.** As used herein, the term "thermal mass" means the product of the specific heat of the material or materials of the object (*e.g.*, the varistor wafer **110)** multiplied by the mass or masses of the material or materials of the object. That is, the thermal mass is the quantity of energy required to raise one gram of the material or materials of the object by one degree centigrade times the mass or masses of the material or materials in the object. According to some embodiments, the thermal mass of at least one of the electrode head **132** and the electrode wall **122** is substantially greater than the thermal mass of the varistor wafer **110.** According to some embodiments, the thermal mass of at least one of the electrode head **132** and the electrode wall **122** is at least two times the thermal mass of the varistor wafer **110,** and, according to some embodiments, at least ten times as great. According to some embodiments, the combined thermal masses of the head **132** and the wall **122** are substantially greater than the thermal mass of the varistor wafer **110,** according to some embodiments at least two times the thermal mass of the wafer **110** and, according to some embodiments, at least ten times as great.

[0108] Methods for forming the several components of the overvoltage protection devices of the present invention will be apparent to those of skill in the art in view of the foregoing description. For example, the housing **120,** the electrode **130,** and the end cap **152** may be formed by machining, casting or impact molding. Each of these elements may be unitarily formed or formed of multiple components fixedly joined, by welding, for example.

[0109] Multiple varistor wafers (not shown) may be stacked and sandwiched between the electrode head and the center wall. The outer surfaces of the uppermost and lowermost varistor wafers would serve as the wafer contact surfaces. However, the properties of the varistor wafer are preferably modified by changing the thickness of a single varistor wafer rather than stacking a plurality of varistor wafers.

[0110] As discussed above, the spring washers **146** are Belleville washers. Belleville washers may be used to apply relatively high loading without requiring substantial axial space. However, other types of biasing means may be used in addition to or in place of the Belleville washer or washers. Suitable alternative biasing means include one or more coil springs, wave washers or spiral washers.

[0111] Many alterations and modifications may be made by those having ordinary skill in the art, given the benefit of present disclosure, without departing from the spirit and scope of the invention. Therefore, it must be understood that the illustrated embodiments have been set forth only for the purposes of example, and that it should not be taken as limiting the invention as defined by the following claims. The following claims, therefore, are to be read to include not only the combination of elements which are literally set forth but all equivalent elements for performing substantially the same function in substantially the same way to obtain substantially the same result. The claims are thus to be understood to include what is specifically illustrated and described above, what is conceptually equivalent, and also what incorporates the essential idea of the invention.

Claims

1. An overvoltage protection device comprising:

    first and second electrically conductive electrode members;

a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members; and

an integral fail-safe mechanism operative to electrically short circuit the first and second electrode members about the varistor member by fusing first and second metal surfaces in the overvoltage protection device to one another using an electric arc.

2. The overvoltage protection device of Claim 1 wherein the fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member.

3. The overvoltage protection device of Claim 1 wherein:

the first and second metal surfaces are separated by a gap having a width in the range of from about 0.2 mm to 1 mm; and

the electric arc extends across the gap to fuse the first and second metal surfaces.

4. The overvoltage protection device of Claim 1 wherein:

the first and second metal surfaces are separated by a gap;

the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another; and

the electric arc disintegrates the spacer member and extends across the gap to fuse the first and second metal surfaces.

5. The overvoltage protection device of Claim 4 wherein the spacer member is formed of a polymeric material having a thickness in the range of from about 0.1 mm to 0.5 mm.

6. The overvoltage protection device of Claim 1 wherein the first metal surface is a surface of the first electrode member and the second metal surface is a surface of the second electrode member.

7. The overvoltage protection device of Claim 6 wherein:

the first electrode includes a housing having a metal housing sidewall and defining a housing chamber;

the varistor member and at least a portion of the second electrode are disposed in the housing chamber; and

the first metal surface is a surface of the housing sidewall.

8. The overvoltage protection device of Claim 7 wherein:

the varistor member has first and second opposed, generally planar varistor contact surfaces;

the housing includes an electrode wall having a first electrode contact surface engaging the first varistor contact surface;

the second electrode includes a head positioned in the housing chamber, the head including a second electrode contact surface engaging the second varistor contact surface and a head peripheral surface surrounding the second electrode contact surface; and

the second metal surface is located on the head peripheral surface.

9. The overvoltage protection device of Claim 8 including a buffer chamber on a side of the head opposite the second electrode contact surface, wherein the buffer chamber is configured to limit propagation of electric arc away from the head.

10. The overvoltage protection device of Claim 1 including a biasing device biasing at least one of the first and second electrode members against the varistor member.

11. The overvoltage protection device of Claim 1 wherein the fail-safe mechanism is a first fail-safe mechanism and further including an integral second fail-safe mechanism, the second fail-safe mechanism including an electrically conductive meltable member, wherein the meltable member is responsive to heat in the overvoltage protection device to melt and form a current flow path between the first and second electrode members through the meltable member.

12. The overvoltage protection device of Claim 11 wherein:

the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another; and

the meltable member has a greater melting point temperature than a melting point temperature of the spacer member.

13. The overvoltage protection device of Claim 11 wherein:

the first fail-safe mechanism is operative to fuse the first and second metal surfaces at a pre-

scribed region; and
the overvoltage protection device includes a sealing member between the prescribed region and the meltable member.

14. The overvoltage protection device of Claim 11 wherein:

the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member sufficient to generate an arc; and
the second fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member in response to a short circuit failure of the varistor member not sufficient to generate an arc.

15. The overvoltage protection device of Claim 1 wherein:

the fail-safe mechanism is a first fail-safe mechanism;
the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member;
the overvoltage protection device further includes an integral second fail-safe mechanism, the second fail-safe mechanism including an electrically conductive meltable member, wherein the meltable member is responsive to heat in the overvoltage protection device to melt and form a current flow path between the first and second electrode members through the meltable member;
the first fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in response to a short circuit failure of the varistor member sufficient to generate an arc;
the second fail-safe mechanism is operative to electrically short circuit the first and second electrode members about the varistor member in response to a short circuit failure of the varistor member that is not sufficient to generate an arc;
the varistor member has first and second opposed, generally planar varistor contact surfaces;
the first electrode includes a housing defining a housing chamber and having a metal housing sidewall and an electrode wall, the electrode wall having a first electrode contact surface engaging the first varistor contact surface;
the varistor member is disposed in the housing chamber;
the second electrode includes a head positioned in the housing chamber, the head including a second electrode contact surface engaging the second varistor contact surface and a head peripheral surface surrounding the second electrode contact surface;
the first metal surface is a surface of the housing sidewall;
the second metal surface is located on the head peripheral surface;
the first and second metal surfaces are separated by a gap having a width in the range of from about 0.2 mm to 1 mm;
the overvoltage protection device further includes an electrically insulating spacer member electrically isolating the first and second metal surfaces from one another;
the electric arc disintegrates the spacer member and extends across the gap to fuse the first and second metal surfaces; and
the spacer member is formed of a polymeric material having a thickness in the range of from about 0.1 mm to 0.5 mm.

16. A method for providing overvoltage protection, the method comprising:

providing an overvoltage protection device including:

first and second electrically conductive electrode members;
a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members; and
an integral fail-safe mechanism operative to electrically short circuit the first and second electrode members about the varistor member by fusing the first and second metal surfaces in the overvoltage protection device to one another using an electric arc; and

directing current between the first and second electrode members through the varistor member during an overvoltage event.

17. An overvoltage protection device comprising:

first and second electrically conductive electrode members;
a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members;
an integral first fail-safe mechanism configured

to electrically short circuit the first and second electrode members about the varistor member when triggered by a first set of operating conditions; and

an integral second fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a second set of operating conditions different from the first set of operating conditions.

18. The overvoltage protection device of Claim 17 wherein the first and second sets of operating conditions each include at least one of an overheating event and an arcing event.

19. The overvoltage protection device of Claim 18 wherein:

the first set of operating conditions includes an arcing event; and

the second set of operating conditions includes an overheating event.

20. A method for providing overvoltage protection, the method comprising:

providing an overvoltage protection device including:

first and second electrically conductive electrode members;

a varistor member formed of a varistor material and electrically connected with each of the first and second electrode members;

an integral first fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a first set of operating conditions; and

an integral second fail-safe mechanism configured to electrically short circuit the first and second electrode members about the varistor member when triggered by a second set of operating conditions different from the first set of operating conditions; and

directing current between the first and second electrode members through the varistor member during an overvoltage event.

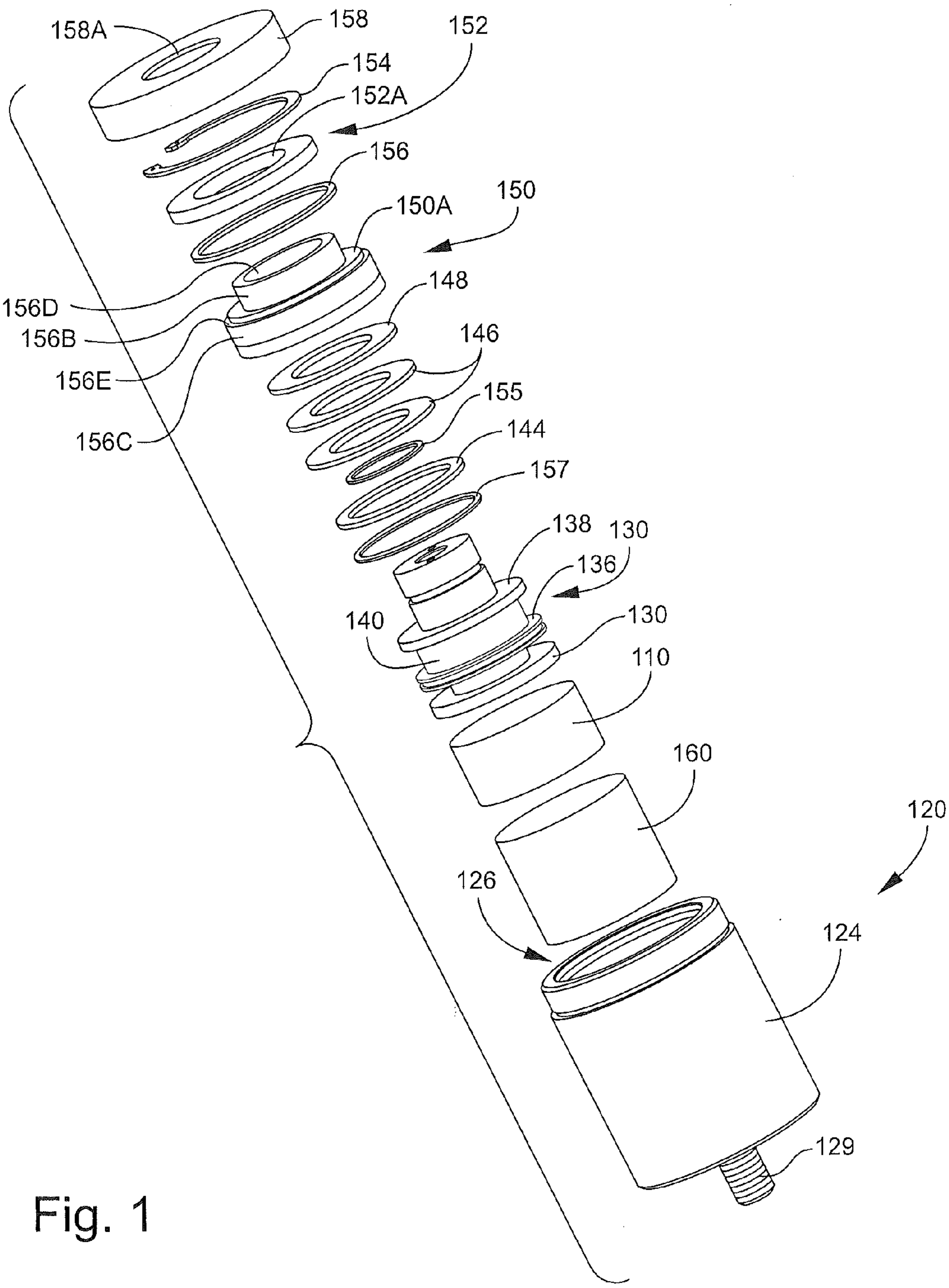
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Fig. 1

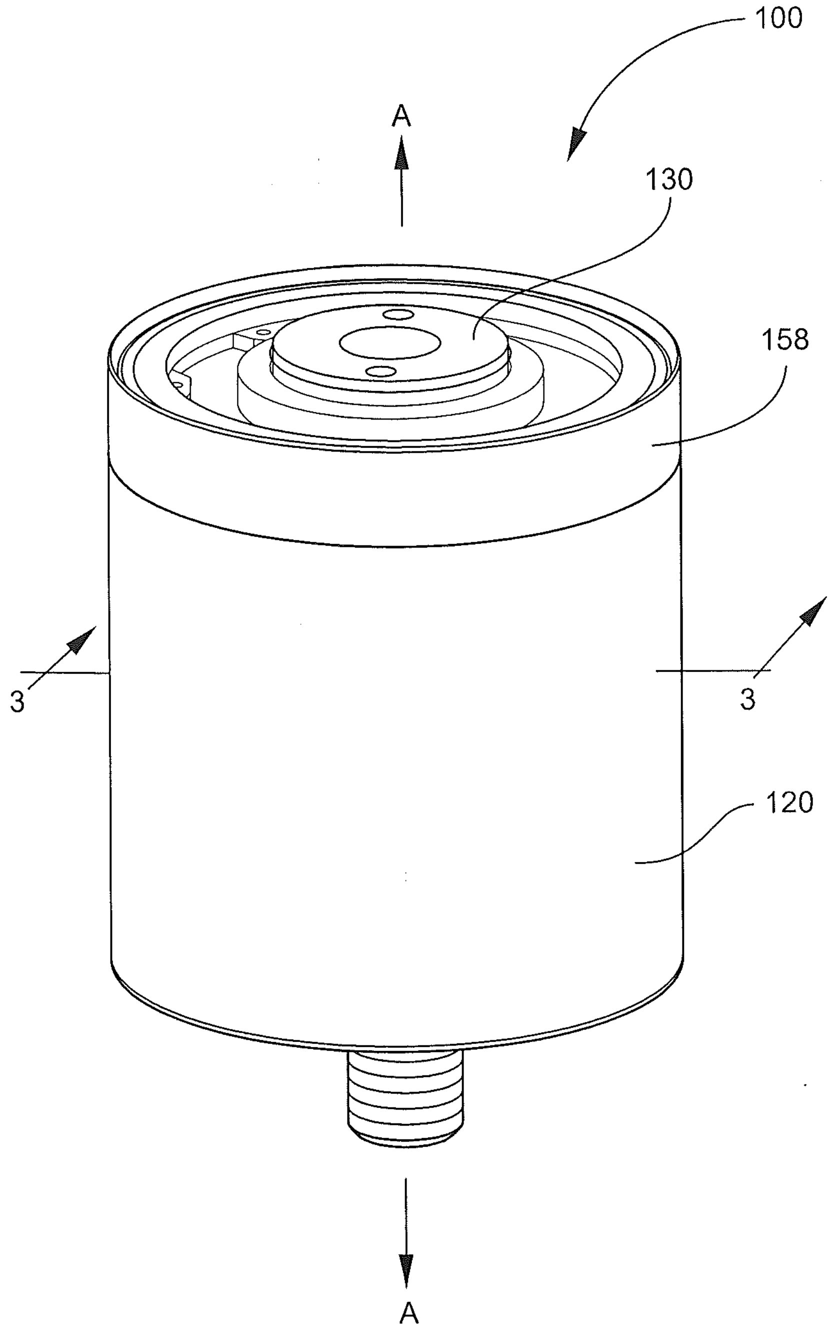

Fig. 2

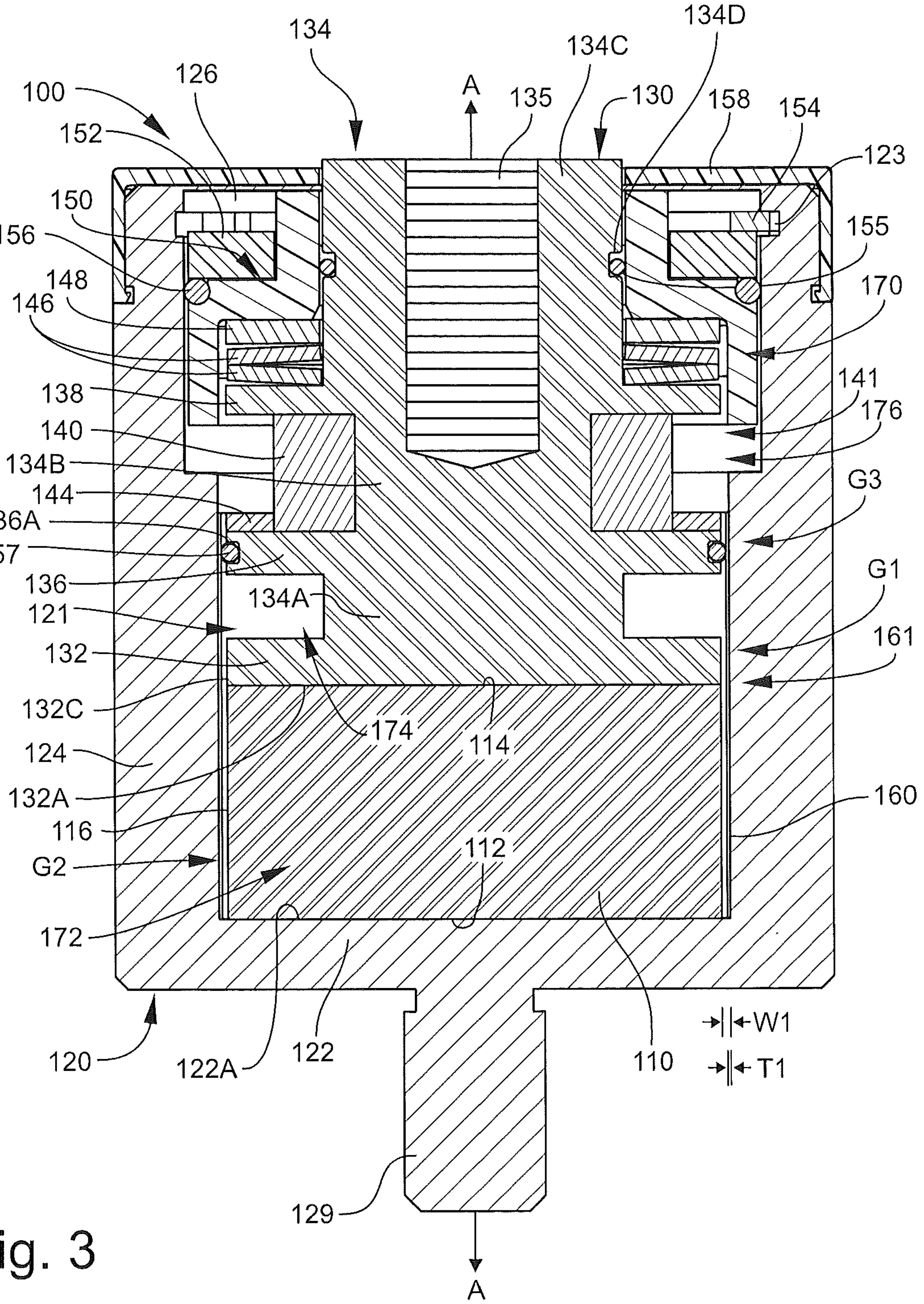

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Fig. 3

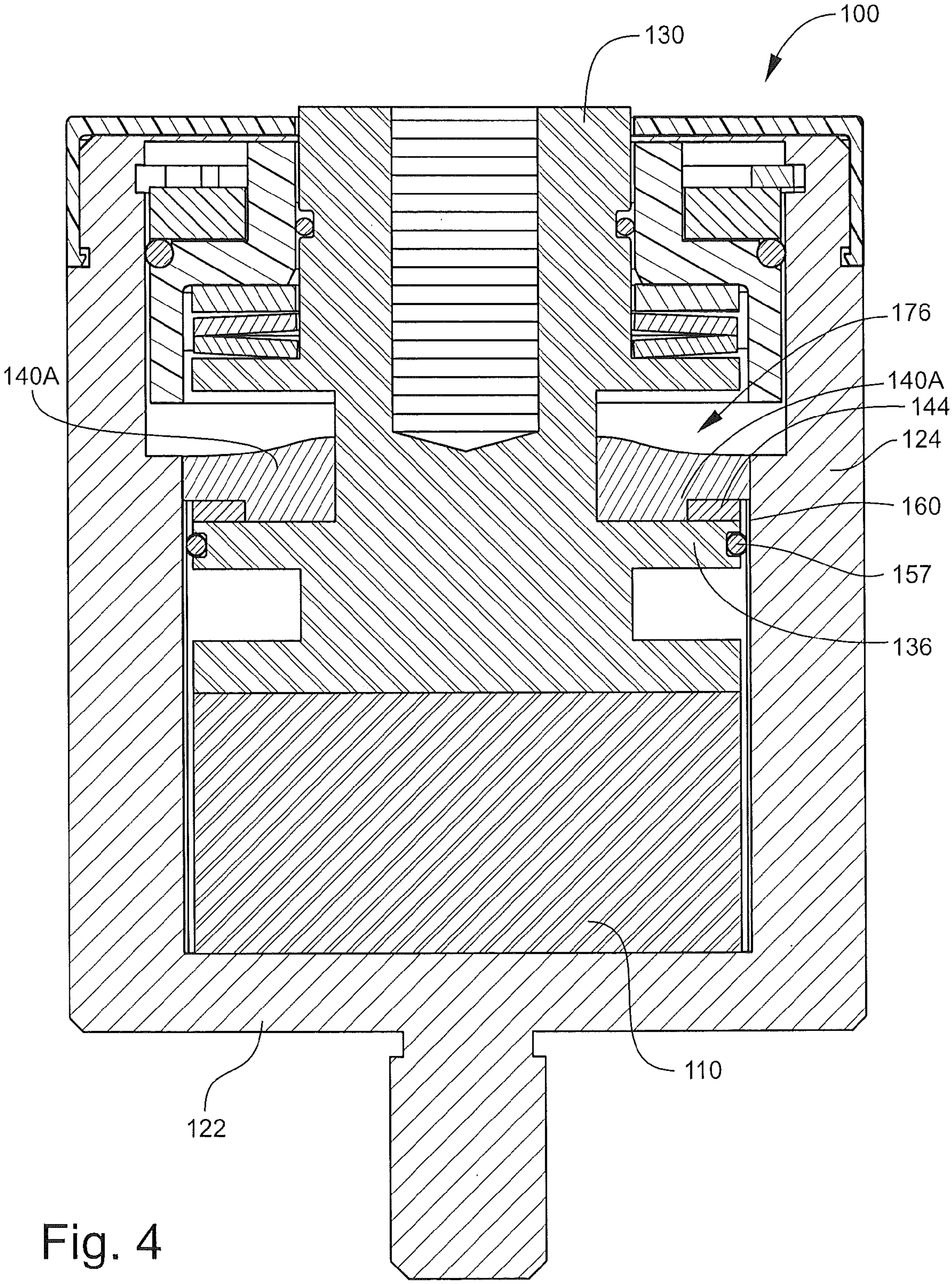

Fig. 4

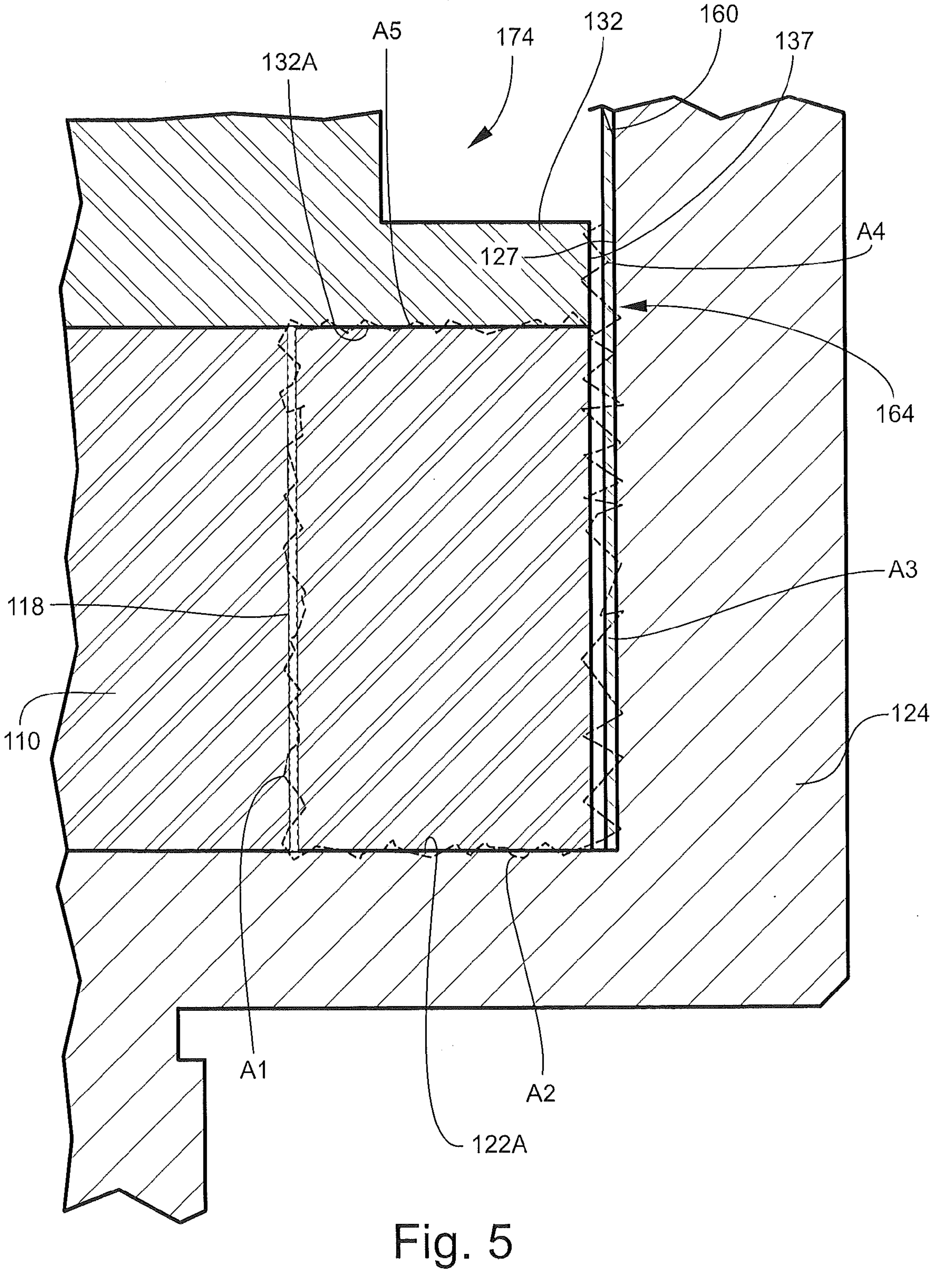

Fig. 5

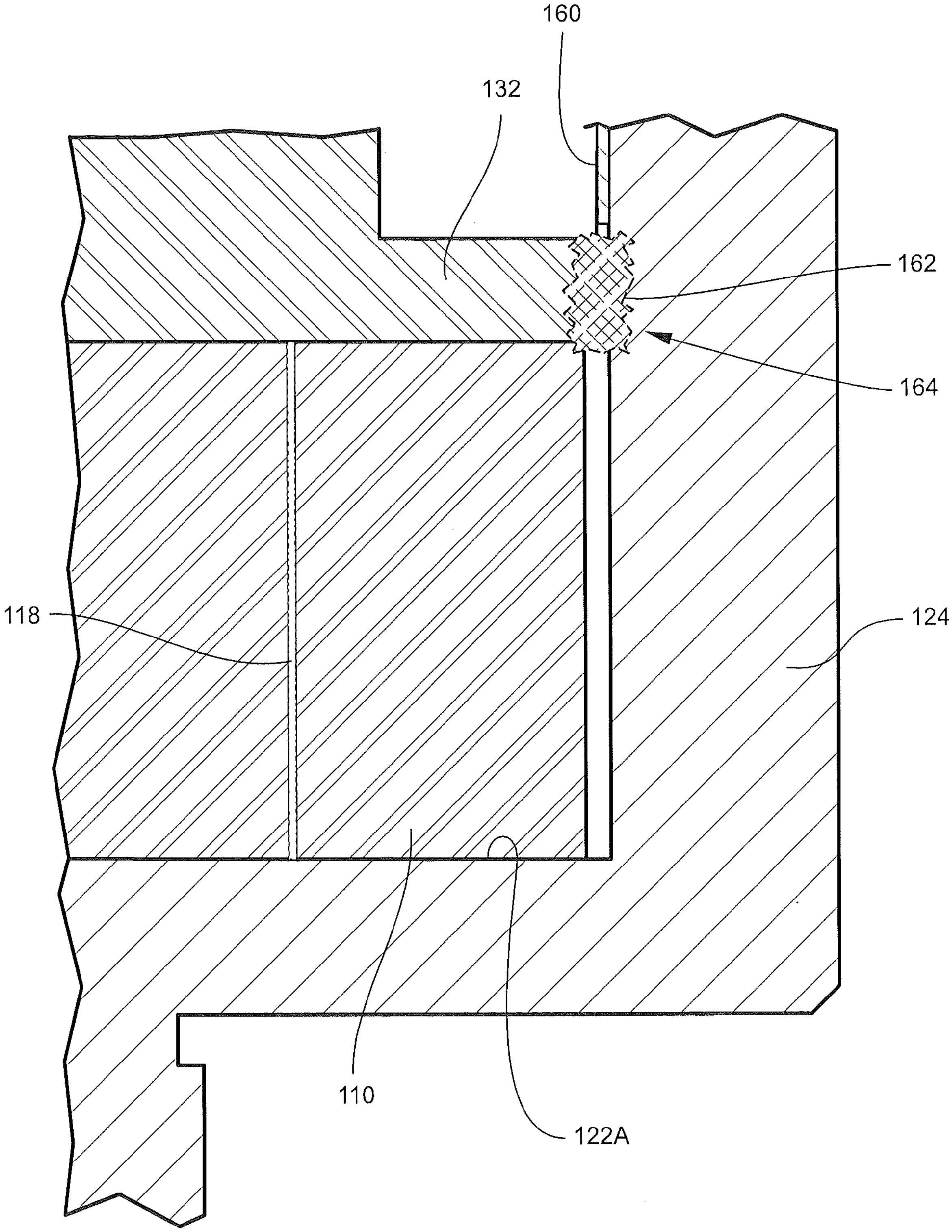

Fig. 6

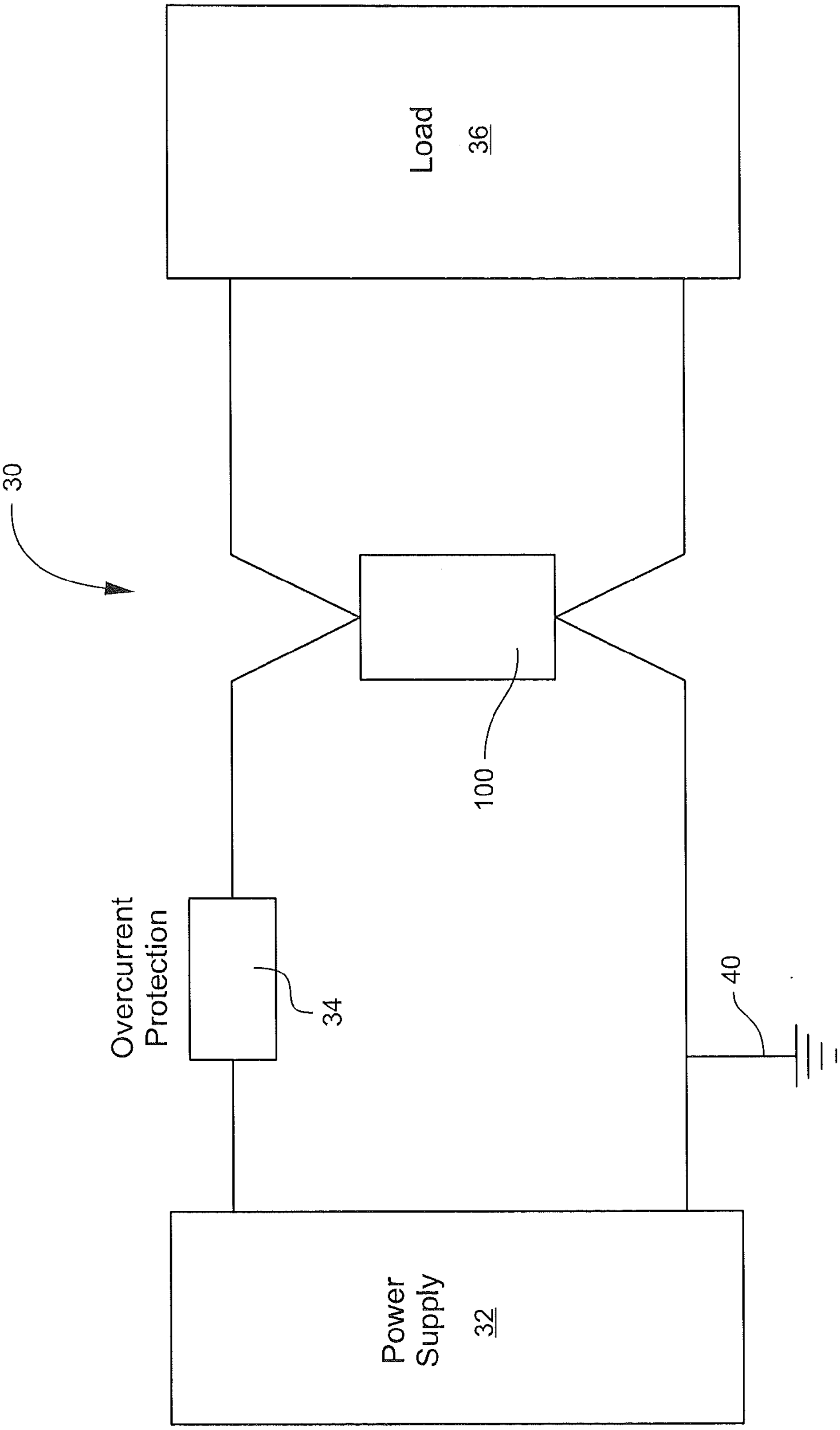

Fig. 7

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EUROPEAN SEARCH REPORT

Application Number
EP 12 17 7955

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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H01T

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	20 February 2013	Dessaux, Christophe

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