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(54) **OVERVOLTAGE PROTECTION DEVICE INCLUDING MULTIPLE VARISTOR WAFERS**

ÜBERSpannungSSchutzVORRIChtung MIT MEHREREN VARISTORWAFERN

DISPOSITIF DE PROTECTION CONTRE LES SURTENSIONS COMPRENANT DE MULTIPLES
TRONÇONS DE VARISTANCE

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Description

FIELD OF THE INVENTION

[0001] The present disclosure relates to circuit protection devices and, more particularly, to overvoltage protection devices and methods.

BACKGROUND

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

[0003] Typically, sensitive electronic equipment may be protected against transient overvoltages and surge currents using Surge Protective Devices (SPDs). For example, brief reference is made to **FIG. 1**, which is a system including conventional overvoltage and surge protection. An overvoltage protection device **12** may be installed at a power input of equipment to be protected **50**, which is typically protected against overcurrents when it fails. Typical failure mode of an SPD is a short circuit. The overcurrent protection typically employed is a combination of an internal thermal disconnect to protect the device from overheating due to increased leakage currents and an external fuse to protect the device from higher fault currents. Different SPD technologies may avoid the use of the internal thermal disconnect because, in the event of failure, they change their operation mode to a low ohmic resistance. In this manner, the device can withstand significant short circuit currents. In this regard, there may be no operational need for an internal thermal disconnect. Further to the above, some embodiments that exhibit even higher short circuit withstand capabilities may also be protected only by the main circuit breaker of the installation without the need for a dedicated branch fuse.

[0004] Brief reference is now made to **FIG. 2**, which is a block diagram of a system including conventional surge protection. As illustrated, a three phase line may be connected to and supply electrical energy to one or more transformers **66**, which may in turn supply three phase electrical power to a main circuit breaker **68**. The three phase electrical power may be provided to one or more distribution panels **62**. As illustrated, the three voltage lines of the three phase electrical power may be designated as **L1**, **L2** and **L3** and a neutral line may be designated as **N**. In some embodiments, the neutral line **N** may be conductively coupled to an earth ground.

[0005] Some embodiments include surge protective devices (SPDs) **15**. As illustrated, each of the SPDs **15**

may be connected between respective ones of **L1**, **L2** and **L3**, and neutral (**N**). The SPD **15** may protect other equipment in the installation such as the distribution panel among others. In addition, the SPDs may be used to protect all equipment in case of prolonged overvoltages. However, such a condition may force the SPD to conduct a limited current for a prolonged period of time, which may result in the overheating of the SPD and possibly its failure (depending on the energy withstand capabilities the SPD can absorb and the level and duration of the overvoltage condition). A typical operating voltage of an SPD **15** in the present example may be about 400V (for 690V L-L systems). In this regard, the SPDs **15** will each perform as an insulator and thus not conduct current during normal operating conditions. In some embodiments, the operating voltage of the SPD's **15** is sufficiently higher than the normal line-to-neutral voltage to ensure that the SPD **15** will continue to perform as an insulator even in cases in which the system voltage increases due to overvoltage conditions that might arise as a result of a loss of neutral or other power system issues.

[0006] In the event of a surge current in, for example, **L1**, protection of power system load devices may necessitate providing a current path to ground for the excess current of the surge current. The surge current may generate a transient overvoltage between **L1** and **N**. Since the transient overvoltage significantly exceeds that operating voltage of SPD **15**, the SPD **15** will become conductive, allowing the excess current to flow from **L1** through SPD **15** to the neutral **N**. Once the surge current has been conducted to **N**, the overvoltage condition ends and the SPD **15** may become non-conducting again. However, in some cases, one or more SPD's **15** may begin to allow a leakage current to be conducted even at voltages that are lower than the operating voltage of the SPD's **15**. Such conditions may occur in the case of an SPD deteriorating.

[0007] As provided above, devices for protecting equipment from excess voltage or current spikes (transient overvoltages and surge currents) may include including varistors (for example, metal oxide varistors (MOVs) and/or silicon carbide varistors).

US 2013/0335869 A1 describes an overvoltage protection device including first and second electrically conductive electrode members and a varistor member.

US 2015/103462 A1 describes an overvoltage protection device having a metal safety element.

US 2016/276821 A1 describes devices for overvoltage, overcurrent and arc flash protection.

CA 2,098,365 A1 describes a surge arrester particularly suited for secondary side protection of distribution transformers with low-voltage, high-energy,

varistor disk.

SUMMARY

[0008] There is provided an overvoltage protection device as claimed in the appended claims. 5

[0009] These and other objects and/or aspects of the present invention are explained in detail in the specification set forth below.

BRIEF DRAWING DESCRIPTION

[0010] The accompanying figures are included to provide a further understanding of embodiments of the present invention, and are incorporated in and constitute a part of this specification. The drawings illustrate some embodiments of the present invention and, together with the description, serve to explain principles of the present invention.

FIG. 1 is a block diagram of a system including conventional surge protection.

FIG. 2 is a block diagram of a system including conventional surge protection. 25

FIG. 3 is a perspective view of an overvoltage protection device.

FIG. 4 is an exploded, perspective view of the overvoltage protection device of **FIG. 3**. 30

FIG. 5 is a cross-sectional view of the overvoltage protection device of **FIG. 3** taken along the line 5-5 of **FIG. 3**. 35

FIG. 6 is a perspective view of a varistor assembly forming a part of the overvoltage protection device of **FIG. 3**. 40

FIG. 7 is an exploded, perspective view of the varistor assembly of **FIG. 6**.

FIG. 8 is a cross-sectional view of the varistor assembly of **FIG. 6** taken along the line 8-8 of **FIG. 6**. 45

FIG. 9 is a schematic diagram representing an electrical circuit of the varistor assembly of **FIG. 6**.

FIG. 10 is a perspective view of an overvoltage protection device. 50

FIG. 11 is an exploded, perspective view of the overvoltage protection device of **FIG. 10**.

FIG. 12 is a cross-sectional view of the overvoltage protection device of **FIG. 10** taken along the line 12-12 of **FIG. 10**. 55

FIG. 13 is a cross-sectional view of an overvoltage protection device.

FIG. 14 is a cross-sectional view of an overvoltage protection device.

FIG. 15 is a perspective view of an overvoltage protection device.

FIG. 16 is a cross-sectional view of the overvoltage protection device of **FIG. 15** taken along the line 16-16 of **FIG. 15**.

FIG. 17 is a cross-sectional view of an overvoltage protection device according to embodiments of the invention.

FIG. 18 is an exploded, perspective view of the overvoltage protection device of **FIG. 17**.

FIG. 19 is a cross-sectional view of the overvoltage protection device of **FIG. 17** taken along the line 19-19 of **FIG. 17**.

FIG. 20 is a top view of a void filling member forming a part of the overvoltage protection device of **FIG. 17**.

FIG. 21 is a cross-sectional view of an overvoltage protection device according further embodiments of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0011] FIGS. 17-21 show embodiments in accordance with the claimed invention. FIGS. 3-16 show some of the features of the claimed invention and provide understanding of the claimed invention. 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.

[0012] 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.

[0013] 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.

[0014] Well-known functions or constructions may not be described in detail for brevity and/or clarity.

[0015] As used herein the expression "and/or" includes any and all combinations of one or more of the associated listed items.

[0016] 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.

[0017] 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.

[0018] As used herein, "monolithic" means an object that is a single, unitary piece formed or composed of a material without joints or seams.

[0019] As used herein, the term "wafer" means a substrate having a thickness which is relatively small compared to its diameter, length or width dimensions.

[0020] With reference to FIGS. 1-9, a modular surge protective device (SPD) or overvoltage protection device is shown therein and designated 100. In accordance with some embodiments, the overvoltage protection device 100 is used as an SPD in an electrical circuit as discussed above. For example, overvoltage protection devices 100 may be used in place of the SPD 12 in the system of FIG. 1 or in place of the SPDs 15 in the system of FIG. 2.

[0021] The overvoltage protection device 100 is configured as a unit or module having a lengthwise axis A-A

(FIG. 5). The overvoltage protection device 100 includes a first electrode or housing 122, a piston-shaped second electrode 124, four spring washers 128E, a flat washer 128D, an insulating ring member 128C, two O-rings 130A, 130B, an end cap 128A, a retention clip 128B, a melttable member 132, and an insulator sleeve 134.

[0022] The overvoltage protection device 100 further includes a varistor assembly 150 according to embodiments of the present invention. The varistor assembly 150 includes a first varistor member 152, a second varistor member 154, a third varistor wafer 156, a first internal interconnect member 160, a second internal interconnect member 162, and a bonding agent 164.

[0023] The overvoltage protection device 100 may further include an integral fail-safe mechanism, arrangement, feature or system 102. The fail-safe system 102 is adapted to prevent or inhibit overheating or thermal runaway of the overvoltage protection device, as discussed in more detail below.

[0024] The components 122, 124, 128A-C collectively form a housing assembly 121 defining a sealed, enclosed chamber 126. The components 122, 124, 128A-E, 132 and 150 are disposed axially between the housing 122 and the electrode 124 along the lengthwise axis A-A, in the enclosed chamber 126.

[0025] The housing 122 has an end electrode wall 122A and an integral cylindrical sidewall 122B extending from the electrode wall 122A. The sidewall 122B and the electrode wall 122A form a chamber or cavity 122C communicating with an opening 122D. A threaded post 122E projects axially outwardly from the electrode wall 122A.

[0026] The electrode wall 122A has an inwardly facing, substantially planar contact surface 122G. An annular clip slot 122H is formed in the inner surface of the sidewall 122B. According to some embodiments, the housing 122 is formed of aluminum. However, any suitable electrically conductive metal may be used. According to some embodiments, the housing 122 is unitary and, in some embodiments, monolithic. The housing 122 as illustrated is cylindrically shaped, but may be shaped differently.

[0027] The inner electrode 124 has a head 124A disposed in the cavity 122C and an integral shaft 122B that projects outwardly through the opening 122D.

[0028] The head 124A has a substantially planar contact surface 124C that faces the contact surface 122G of the electrode wall 122A. A pair of integral, annular, axially spaced apart flanges 124D extend radially outwardly from the shaft 124B and define an annular, sidewardly opening groove 124E therebetween. A threaded bore 124F is formed in the end of the shaft 124B to receive a bolt for securing the electrode 124 to a busbar, for example. An annular, sidewardly opening groove 124G is defined in the shaft 124B.

[0029] According to some embodiments, the electrode 124 is formed of aluminum. However, any suitable electrically conductive metal may be used. According to some embodiments, the electrode 124 is unitary and, in some

embodiments, monolithic.

[0030] The electrodes **122**, **124**, the insulating ring **128C** and the end cap **128A** collectively define an enclosed chamber **126** containing the meltable member **132** and the varistor assembly **150**.

[0031] An annular gap is defined radially between the head **124A** and the nearest adjacent surface of the sidewall **122B**. According to some embodiments, the gap has a radial width in the range of from about 1 to 15 mm.

[0032] The meltable member **132** is annular and is mounted on the electrode **124** in the groove **124E**. The meltable member **132** is spaced apart from the sidewall **122B** a distance sufficient to electrically isolate the meltable member **132** from the sidewall **122B**.

[0033] The meltable member **132** is formed of a heat-meltable, electrically conductive material. According to some embodiments, the meltable member **132** is formed of metal. According to some embodiments, the meltable member **132** is formed of an electrically conductive metal alloy. According to some embodiments, the meltable member **132** 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.

[0034] According to some embodiments, the meltable member **132** 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 **132** during normal operation (including handling overvoltage surges within the designed for range of the system) but not during operation which, if left unchecked, would result in thermal runaway. According to some embodiments, the meltable member **132** 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 130 to 150 °C. According to some embodiments, the melting point of the meltable member **132** is at least 20 °C less than the melting points of the housing **122** and the electrode **124** and, according to some embodiments, at least 40 °C less than the melting points of those components.

[0035] According to some embodiments, the meltable member **132** has an electrical conductivity in the range of from about 0.5×10^6 Siemens/meter (S/m) to 4×10^7 S/m and, according to some embodiments, in the range of from about 1×10^6 S/m to 3×10^6 S/m.

[0036] The three varistor wafers **152**, **154**, **156** and the two interconnect members **160**, **162** are axially stacked in the chamber **126** between the electrode head **124** and the electrode wall **122** and form the varistor assembly **150**. The interconnect members **160**, **162** electrically interconnect the wafers **152**, **154**, **156** and the electrodes **122**, **124** in the manner represented in the schematic electrical diagram of **FIG. 9**.

[0037] According to some embodiments, each varistor wafer **152**, **154**, **156** is a varistor wafer (*i.e.*, is wafer- or disk-shaped). In some embodiments, each varistor wafer

152, **154**, **156** is circular in shape and has a substantially uniform thickness. However, varistor wafers **152**, **154**, **156** may be formed in other shapes. The thickness and the diameter of the varistor wafers **152**, **154**, **156** will depend on the varistor characteristics desired for the particular application.

[0038] In some embodiments, each varistor wafer **152**, **154**, **156** has a diameter **D1** to thickness **T1** ratio of at least 3. In some embodiments, the thickness **T1** (**FIG. 8**) of each varistor wafer **152**, **154**, **156** is in the range of from about 0.5 to 15 mm. In some embodiments, the diameter **D1** (**FIG. 8**) of each varistor wafer **152**, **154**, **156** is in the range of from about 20 to 100 mm.

[0039] The varistor wafer **152** has first and second opposed, substantially planar contact surfaces **152U**, **152L** and a peripheral edge **152E**. The varistor wafer **154** has first and second opposed, substantially planar contact surfaces **154U**, **154L** and a peripheral edge **154E**. The varistor wafer **156** has first and second opposed, substantially planar contact surfaces **156U**, **156L** and a peripheral edge **156E**.

[0040] 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.

[0041] Each varistor wafer **152**, **154**, **156** may include a wafer of varistor material coated on either side with a conductive coating **157** so that the exposed surfaces of the coatings serve as the contact surfaces **152U**, **152L**, **154U**, **154L**, **156U**, **156L**. The coatings can be metallization formed of aluminum, copper or silver, for example. Alternatively, the bare surfaces of the varistor material may serve as the contact surfaces **152U**, **152L**, **154U**, **154L**, **156U**, **156L**.

[0042] The interconnect members **160**, **162** are electrically conductive. The interconnect member **160** includes a pair of axially spaced apart, disk-shaped contact portions **160U**, **160L** joined by a bridge portion **160B**. The interconnect member **162** includes a pair of axially spaced apart, disk-shaped contact portions **162U**, **162L** joined by a bridge portion **162B**.

[0043] According to some embodiments, each contact portion **160U**, **160L**, **162U**, **162L** is substantially planar, relatively thin and wafer- or disk-shaped. In some embodiments, each contact portion **160U**, **160L**, **162U**, **162L** has a diameter **D2** (**FIG. 8**) to thickness **T2** (**FIG. 8**) ratio of at least 15. In some embodiments, the thickness **T2** of each contact portion **160U**, **160L**, **162U**, **162L** is in the range of from about 0.1 to 3 mm. In some embodiments, the diameter **D2** of each contact portion **160U**, **160L**, **162U**, **162L** is in the range of from about 20 to 100 mm.

[0044] According to some embodiments, each contact portion **160U**, **160L**, **162U**, **162L** does not have any through holes extending through the thickness of the

contact portion.

[0045] In some embodiments, the width W3 (FIG. 6) of each bridge portion 160B, 162B is in the range of from about 2 mm to 10 mm. The cross-sectional area of each bridge portion 160B, 162B should be large enough to withstand the short circuit current that may flow through the SPD after a possible failure of one or more of the varistor wafers 152, 154, 156.

[0046] According to some embodiments, the interconnect members 160, 162 are formed of copper. However, any suitable electrically conductive metal may be used. According to some embodiments, the interconnect members 160, 162 are unitary and, in some embodiments, monolithic.

[0047] In the varistor assembly 150, the varistor wafer 154 is interposed or sandwiched between the varistor wafers 152, 156, the varistor wafers 152, 154, 156 are interposed or sandwiched between the interconnect members 160, 162, and the interconnect members 160, 162 are interleaved with one another as shown in FIGS. 6 and 8. The contact portion 160U engages the contact surface 152U. The contact portion 160L engages the contact surfaces 154L and 156U. The contact portion 162U engages the contact surfaces 152L and 154U. The contact portion 162L engages the contact surface 156L. Each said engagement forms an intimate physical or mechanical contact between the identified interconnect member contact portions and varistor contact surfaces. Each said engagement forms a direct electrical connection or coupling between the identified interconnect member contact portions and varistor contact surfaces. The contact portions 160U and 162L form or serve as the outer electrode contact surfaces of the varistor assembly 150.

[0048] Each bridge portion 160B, 162B includes a pair of tab sections 163 (extending radially outwardly from the contact portions 160U, 160L or 162, 162L) and an axially extending connecting section 165 connecting the tab sections 163 and radially spaced apart from the adjacent peripheral edges of the varistor wafers 152, 154, 156. In some embodiments, each connecting section 165 is located a distance D3 (FIG. 8) from the adjacent peripheral edges of the varistor wafers 152, 154, 156. In some embodiments, the distance D3 is in the range of from about 0.5 to 15mm.

[0049] According to some embodiments and as shown, there are no electrical insulators interposed between the components 152, 154, 156, 160, 162.

[0050] In some embodiments, the varistor wafers 152, 154, 156 are secured to one another by the bonding agent 164. According to some embodiments, the bonding agent 164 is located at and secures the adjacent varistor wafers 152, 154, 156 at their peripheral edges. In some embodiments, the bonding agent 164 is provided as a plurality of discrete, spaced apart patches or spots of the bonding agent 164. The bonding is used to keep the components of the varistor assembly 150 in place during transportation and assembly of the overvoltage protec-

tion device 100.

[0051] In some embodiments and as shown in FIGS. 5, 6 and 7, the bonding agent 164 includes a bonding agent portion or portions 164' located within the bridge portions 160, 162B between each bridge portion 160B, 162B and the adjacent edges of the varistor wafers 152, 154, 156. In this way, these bonding agent portions 164' can serve as electrical insulators that electrically insulate the bridge portions 160B, 162B from the edges of the varistor wafers 152, 154, 156.

[0052] According to some embodiments, the bonding agent 164 is an adhesive. As used herein, adhesive refers to adhesives and glues derived from natural and/or synthetic sources. The adhesive is a polymer that bonds to the surfaces to be bonded (e.g., the edge surfaces of the varistor wafers 152, 154, 156). The adhesive may be any suitable adhesive. In some embodiments, adhesive 164 is secures the varistor wafers 152, 154, 156 at their peripheral edges and are discrete, spaced apart patches or spots located about the peripheral edges.

[0053] In some embodiments, the adhesive 164 is a cyanoacrylate-based adhesive or an epoxy-based adhesive. Suitable cyanoacrylate adhesives may include Permabond 737 adhesive available from Permabond Engineering Adhesives, Inc. of the United States of America.

[0054] In some embodiments, the adhesive has a high operating temperature, above 40 °C, does not contain any solvent, and has a high dielectric strength (e.g., above 5kV/mm).

[0055] In some embodiments, the outer periphery of each coating 157 is radially inset from the outer periphery of the varistor wafer 152, 154, 156, and the outer periphery of each contact portion 160U, 160L, 162U, 162L is radially inset from the outer periphery of the coating 157.

[0056] In other embodiments, the varistor wafers 152, 154, 156 are mechanically secured and electrically directly connected to the respective contact portions 160U, 160L, 162U, 162L by an electrically conductive solder.

[0057] The varistor assembly 150 can be assembled as follows in accordance with embodiments of the invention.

[0058] The interconnect members 160, 162 may be pre-bent into the shapes shown in FIG. 7.

[0059] In some embodiments, each contact portion 160U, 160L, 162U, 162L covers and engages at least 40% of the surface area of the corresponding mating varistor wafer surface 152U, 152L, 154U, 154L, 156U, 156L.

[0060] The varistor wafers 152, 154, 156 and the interconnect members 160, 162 are stacked and interleaved in the order and relation as shown in FIGS. 6 and 8. This assembly may be assembled in or placed, after assembly, in a fixture to laterally align the varistor wafers 152, 154, 156 and the interconnect members 160, 162 with respect to one another. In some embodiments, the varistor wafers 152, 154, 156 and the interconnect members 160, 162 are substantially coaxially aligned.

[0061] The aligned components **152, 154, 156, 160, 162** are axially compressively loaded, pressed or clamped together (e.g., using the fixture or an additional external clamping or loading device) and into intimate contact. The bonding agent **164** is then applied to the peripheral edges **152E, 154E, 156E** of the varistor wafers **152, 154, 156** at locations as discussed above, and cured. The varistor assembly **150** is thus formed. Once the bonding agent **164** has cured, the external loading device is removed from the varistor assembly **150**.

[0062] The insulator sleeve **134** is tubular and generally cylindrical. According to some embodiments, the insulator sleeve **134** is formed of a high temperature polymer and, in some embodiments, a high temperature thermoplastic. In some embodiments, the insulator sleeve **134** is formed of polyetherimide (PEI), such as ULTEM™ thermoplastic available from SABIC of Saudi Arabia. In some embodiments, the insulator member **134** is formed of non-reinforced polyetherimide.

[0063] According to some embodiments, the insulator sleeve **134** is formed of a material having a melting point greater than the melting point of the meltable member **132**. According to some embodiments, the insulator sleeve **134** is formed of a material having a melting point in the range of from about 120 to 200 °C.

[0064] According to some embodiments, the insulator sleeve **134** material can withstand a voltage of 25 kV per mm of thickness.

[0065] According to some embodiments, the insulator sleeve **134** has a thickness in the range of from about 0.1 to 2 mm.

[0066] The spring washers **128E** surround the shaft **124B**. Each spring washer **128E** includes a hole that receives the shaft **124B**. The lowermost spring washer **128E** abuts the top face of the head **124A**. According to some embodiments, the clearance between the spring washer hole and the shaft **124B** is in the range of from about 0.015 to 0.035 inch. The spring washers **128E** may be formed of a resilient material. According to some embodiments and as illustrated, the spring washers **128E** are wave washers (as shown) or Belleville washers formed of spring steel. While two spring washers **128E** are shown, more or fewer may be used. The springs may be provided in a different stack arrangement such as in series, parallel, or series and parallel.

[0067] The flat metal washer **128D** is interposed between the uppermost spring washer **128E** and the insulator ring **128C** with the shaft **124B** extending through a hole formed in the washer **128D**. The washer **128D** serves to distribute the mechanical load of the upper spring washer **128E** to prevent the spring washer **128E** from cutting into the insulator ring **128C**.

[0068] The insulator ring **128C** overlies and abuts the washer **128D**. The insulator ring **128C** has a main body ring and a cylindrical upper flange or collar extending upwardly from the main body ring. A hole receives the shaft **124B**. According to some embodiments, the clearance between the hole and the shaft **124B** is in range of

from about 0.025 to 0.065 inch. An upwardly and outwardly opening peripheral groove is formed in the top corner of the main body ring.

[0069] The insulator ring **128C** is preferably formed of a dielectric or electrically insulating material having high melting and combustion temperatures. The insulator ring **128C** may be formed of polycarbonate, ceramic or a high temperature polymer, for example.

[0070] The end cap **128A** overlies and abuts the insulator ring **128C**. The end cap **128A** has a hole that receives the shaft **124B**. According to some embodiments, the clearance between the hole and the shaft **124B** is in the range of from about 0.1 to 0.2 inch. The end cap **128A** may be formed of aluminum, for example.

[0071] The clip **128B** is resilient and truncated ring shaped. The clip **128B** is partly received in the slot **122H** and partly extends radially inwardly from the inner wall of the housing **122** to limit outward axial displacement of the end cap **128A**. The clip **128B** may be formed of spring steel.

[0072] The O-ring **130B** is positioned in the groove **124G** so that it is captured between the shaft **124B** and the insulator ring **128C**. The O-ring **130A** is positioned in the groove in the insulator ring **128C** such that it is captured between the insulating member **128C** and the sidewall **122B**. When installed, the O-rings **130A, 130B** are compressed so that they are biased against and form a seal between the adjacent interfacing surfaces. In an overvoltage or failure event, byproducts such as hot gases and fragments from the varistor wafers **152, 154, 156** may fill or scatter into the cavity chamber **126**. These byproducts may be constrained or prevented by the O-rings **130A, 130B** from escaping the overvoltage protection device **100** through the housing opening **122D**.

[0073] The O-rings **130A, 130B** may be formed of the same or different materials. According to some embodiments, the O-rings **130A, 130B** are formed of a resilient material, such as an elastomer. According to some embodiments, the O-rings **130A, 130B** are formed of rubber. The O-rings **130A, 130B** 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.

[0074] The electrode head **124A** and the housing end wall **122A** are persistently biased or loaded against the varistor assembly **150** along a load or clamping axis **C-C** (FIG. 5) in directions **F** to ensure firm and uniform engagement between the above-identified interfacing contact surfaces. This aspect of the unit **100** may be appreciated by considering a method according to the present invention for assembling the unit **100**, as described below. In some embodiments, the clamping axis **C-C** is substantially coincident with the axis **A-A** (FIG. 5).

[0075] The components **152, 154, 156, 160, 162, 164** are assembled as described above to form the varistor assembly **150**. The varistor assembly **150** is placed in the

cavity **122C** such that the lower contact surface or portion **162L** of the interconnect member **162** engages the contact surface **122G** of the end wall **122A**.

[0076] The O-rings **130A**, **130B** are installed in their respective grooves.

[0077] The head **124A** is inserted into the cavity **122C** such that the contact surface **124C** engages the upper contact surface or portion **160U** of the interconnect member **160**.

[0078] The spring washers **128E** are slid down the shaft **124B**. The washer **128D**, the insulator ring **128C**, and the end cap **128A** are slid down the shaft **124B** and over the spring washers **128E**. A jig (not shown) or other suitable device is used to force the end cap **128A** down, in turn deflecting the spring washers **128E**. While the end cap **128A** is still under the load of the jig, the clip **128B** is compressed and inserted into the slot **122H**. The clip **128B** 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 from the slot **122H**. The clip **128B** and the slot **122H** thereby serve to maintain the load on the end cap **128A** to partially deflect the spring washers **128E**. The loading of the end cap **128A** onto the insulator ring **128C** and from the insulator ring onto the spring washers is in turn transferred to the head **124A**. In this way, the varistor assembly **150** is sandwiched (clamped) between the head **124A** and the electrode wall **122A**.

[0079] When the overvoltage protection device **100** is assembled, the housing **122**, the electrode **124**, the insulating member **128C**, the end cap **128A**, the clip **128B**, and the O-rings **130A**, **130B** collectively form a unit housing or housing assembly **121** containing the components in the chamber **126**.

[0080] In the assembled overvoltage protection device **100**, the large, planar contact surfaces of the components **122A**, **124A**, **152**, **154**, **156**, **160**, **162** can ensure reliable and consistent electrical contact and connection between the components during an overvoltage or surge current event. The head **124A** and the end wall **122A** are mechanically loaded against these components to ensure firm and uniform engagement between the mating contact surfaces.

[0081] Advantageously, the overvoltage protection device **100** integrates three varistor wafers **152**, **154**, **156** in electrical parallel in the same modular device, so that energy can be shared between the varistor wafers **152**, **154**, **156** during electrical conduction.

[0082] The design of the overvoltage protection device **100** provides compressive loading of the varistor wafers **152**, **154**, **156** in a single modular unit. The overvoltage protection device **100** provides suitable electrical interconnections between the electrodes **122**, **124** and the varistor wafers **152**, **154**, **156**, while retaining a compact form factor and providing proper thermal dissipation of energy from the varistor wafers **152**, **154**, **156**.

[0083] The construction of the overvoltage protection device **100** provides a safe failure mode for the device.

During use, one or more of the varistor wafers **152**, **154**, **156** may be damaged by overheating and may generate arcing inside the housing assembly **121**. The housing assembly **121** can contain the damage (e.g., debris, gases and immediate heat) within the overvoltage protection device **100**, so that the overvoltage protection device **100** fails safely. In this way, the overvoltage protection device **100** can prevent or reduce any damage to adjacent equipment (e.g., switch gear equipment in the cabinet) and harm to personnel. In this manner, the overvoltage protection device **100** can enhance the safety of equipment and personnel.

[0084] Additionally, the overvoltage protection device **100** provides a fail-safe mechanism in response to end of life mode in one of more of the varistor wafers **152**, **154**, **156**. In case of a failure of a varistor wafer **152**, **154**, **156**, a fault current will be conducted between the corresponding line and the neutral line. 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.

[0085] As is known, a varistor has three modes of operation. In a first normal mode (discussed above), up to a nominal voltage, the varistor is practically an electrical insulator. In a second normal mode (also discussed above), 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.

[0086] The varistor also has an innate clamping voltage VC (sometimes referred to as simply the "clamping voltage"). The 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.

[0087] In the absence of an overvoltage condition, the varistor wafer **152**, **154**, **156** provides high resistance such that no current flows through the overvoltage protection device **100** as it appears electrically as an open circuit. That is, ordinarily the varistor passes no current. 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 overvoltage protection device **100** and create a shunt path for current flow to protect other components of an associated electrical system. Normally, the varistor recovers from these events without significant overheating of the overvoltage protection device **100**.

[0088] Varistors have multiple failure modes. The failure modes include: 1) the varistor fails as a short circuit; and 2) the varistor fails as a linear resistance. The failure of the varistor to a short circuit or to a linear resistance may be caused by the conduction of a single or multiple surge currents of sufficient magnitude and duration or by a single or multiple continuous overvoltage events that will drive a sufficient current through the varistor.

[0089] A short circuit failure typically manifests as a localized pinhole or puncture site (herein, "the failure site") extending through the thickness of the varistor. 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 even at low fault currents. Sufficiently large fault current through the varistor can melt the varistor in the region of the failure site and generate an electric arc.

[0090] 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. If the leakage current is not interrupted at a certain period of time, the overheating will result eventually in the failure of the varistor to a short circuit as defined above.

[0091] 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 photo-voltaic (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.

[0092] As discussed above, in some cases the overvoltage protection device **100** may assume an "end of life" mode in which a varistor wafer **152, 154, 156** 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 reaches its end of life, the overvoltage protection device **100** will become substantially a short circuit with a very low but non-zero ohmic resistance. As a result, in an end of life condition, a fault current will continuously flow through the varistor even in the absence of an overvoltage condition. In this case, the melttable member **132** can operate as a fail-safe mechanism that bypasses the failed varistor and creates a permanent low-ohmic short circuit between the terminals of the overvoltage protection device **100** in

the manner described in U.S. Patent No. 7,433,169.

[0093] The melttable member **132** is adapted and configured to operate as a thermal disconnect to electrically short circuit the current applied to the associated overvoltage protection device **100** around the varistor wafers **152, 154, 156** to prevent or reduce the generation of heat in the varistors. In this way, the melttable member **132** can operate as switch to bypass the varistor wafers **152, 154, 156** and prevent overheating and catastrophic failure as described above. 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 **122A, 124A**.

[0094] When heated to a threshold temperature, the melttable member **132** will flow to bridge and electrically connect the electrodes **122A, 124A**. The melttable member **132** thereby redirects the current applied to the overvoltage protection device **100** to bypass the varistors **152, 154, 156** so that the current induced heating of the varistor ceases. The melttable member **132** may thereby serve to prevent or inhibit thermal runaway (caused by or generated in a varistor **152, 154, 156**) without requiring that the current through the overvoltage protection device **100** be interrupted.

[0095] More particularly, the melttable member **132** initially has a first configuration as shown in **FIG. 5** such that it does not electrically couple the electrode **124** and the housing **122** except through the head **124A**. Upon the occurrence of a heat buildup event, the electrode **124** is thereby heated. The melttable member **132** is also heated directly and/or by the electrode **124**. During normal operation, the temperature in the melttable member **132** remains below its melting point so that the melttable member **132** remains in solid form. However, when the temperature of the melttable member **132** exceeds its melting point, the melttable member **132** melts (in full or in part) and flows by force of gravity into a second configuration different from the first configuration. The melttable member **132** bridges or short circuits the electrode **124** to the housing **122** to bypass the varistor wafers **152, 154, 156**. That is, a new direct flow path or paths are provided from the surface of the electrode **124** to the surface of the housing sidewall **122B** through the melttable member **132**. According to some embodiments, at least some of these flow paths do not include the varistor wafers **152, 154, 156**.

[0096] According to some embodiments, the overvoltage protection device **100** is adapted such that when the melttable member **132** is triggered to short circuit the overvoltage protection device **100**, the conductivity of the overvoltage protection device **100** is at least as great as the conductivity of the feed and exit cables connected to the device.

[0097] Electrical protection devices according to embodiments of the present invention 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 surge protective devices not having circuits as described herein. In particular, the present devices may have the same length dimension as such previous devices.

[0098] There are applications when there is a requirement for an SPD having a lower residual voltage at the same nominal operating voltage. For example, this is a requirement for some telecom applications rated for -48 Vdc systems. If an SPD is used that includes a varistor (e.g., an MOV), a typical continuous operation voltage V_c for such a varistor is 100 Vdc. However, this SPD will have a residual voltage V_{res} of around 300V or more. It would be beneficial for the better protection of the equipment to use SPDs with a residual voltage V_{res} much lower than these levels (i.e., close to 100V).

[0099] Typically, in order to reduce the residual voltage of an SPD, manufacturers have used a technology other than varistors, such as SADs or TVS diodes. These components have a much lower residual voltage than MOVs for the same continuous operating voltage V_c . For example, a TVS diode for this application may have a residual voltage of 100 V. But SADs and TVS diodes typically cannot conduct the surge currents of significant energies that are expected in such applications. For that reason, many manufacturers have used multiple SADs and/or TVS diodes in parallel to achieve higher energy withstand capabilities during surge current conduction.

[0100] In the overvoltage protection device 100, the varistor wafers 152, 154, 156 are connected in electrical parallel to reduce the residual voltage V_{res} of the overvoltage protection device 100.

[0101] In some embodiments, each varistor wafer 152, 154, 156 is rated for 60 Vdc (continuous operating voltage; V_c) instead of 100 Vdc that is typical for this application. Further, the use of three varistors in parallel reduces even further the clamping voltage of the SPD at a given surge current (as compared to using a single varistor), as each varistor will conduct only a fraction of the overall surge current (the clamping voltage depends on the conducted surge current, the higher the conducted surge current the higher the clamping voltage of the varistor). For the telecom applications (nominal voltage of -48Vdc), the resultant residual voltage is around 140 V at a surge current of 5 kA.

[0102] In some embodiments, the overvoltage protection device 100 is used in a DC power system and, in some embodiments, in a protection circuit of -48Vdc telecommunications equipment. The device 100 may also be used in AC or other DC applications.

[0103] The reduction of the rated voltage of the varistor wafers 152, 154, 156 makes the varistor wafers 152, 154, 156 thinner and sensitive to significant temperature variations. Therefore, how the stack of varistor wafers is held in place and assembled inside the overvoltage protection device 100 is important.

[0104] As mentioned above, in some embodiments the varistor wafers varistor wafers 152, 154, 156 may be secured to the interconnect members 160, 162 and/or

each other using solder. However, the use of solder may damage the varistor wafer. The high temperature required to melt the soldering material and the different coefficients of elasticity between the varistor material and the solder may create micro cracks in the varistor. Loading on the varistor wafer by electrodes may also cause cracks in the varistor wafer. These cracks as well as flux or impurities that intrude into the cracks can progressively damage and thereby derate the varistor. Intruding flux may create a conductive path on the edge of a crack that increases leakage current, which can lead to failure of the varistor wafer. These risks are particularly of concern in the case of relatively thin (e.g., less than about 2 mm) ceramic varistor wafers.

[0105] Further, to avoid mechanical damage on the varistor due to different thermal expansion between the varistor and the interconnect members 160, 162, the shape of the interconnect member contact portions should be round with a hole in the middle. The hole may decrease the uniform distribution of the current over the surface of the varistor. The hole may also reduce the energy withstand capability of the varistor during surge currents, as it will significantly decrease the heat shrink capabilities of the varistor and increase the contact resistance and overall strength of the stack forming the varistor assembly 150.

[0106] As discussed above, in some embodiments, the varistor wafers 152, 154, 156 are stacked in parallel and bonded or adhered together by adhesive 164 on their edges 152E, 154E, 156E. The adhesive 164 on the edges 152E, 154E, 156E provides a compact assembly for transport and manipulation in production of the varistor assembly 150 and the device 100.

[0107] Moreover, the adhesive 164 rectifies the above mentioned issues. The adhesive holds the varistor wafers 152, 154, 156 and the interconnect members 160, 162 together for handling without introducing heating, solder and flux that may cause micro cracks and introduce conductive paths as discussed above.

[0108] The adhesive permits the use of the contact portions 160U, 160L, 162U, 162L of the interconnect members that do not include holes within their peripheries (i.e., are full face electrodes). As a result, the energy withstand capability of the varistor assembly 150 during surge events is increased. The contact resistances between the varistor wafers 152, 154, 156 and the interconnect members 160, 162 are reduced. The expected residual voltage during surges is thereby reduced.

[0109] According to some embodiments, the areas of engagement between each of the electrode contact surfaces and the varistor contact surfaces are each at least one square inch.

[0110] According to some embodiments, the biased electrodes (e.g., the electrodes 122 and 124) apply a load to the varistors along the axis C-C in the range of from about 2000 lbf and about 26000 lbf (8896N and 115654N) depending on its surface area.

[0111] According to some embodiments, the combined

thermal mass of the housing (e.g., the housing **122**) and the electrode (e.g., the electrode **124**) is substantially greater than the thermal mass of each of the varistors captured therebetween. The greater the ratio between the thermal mass of the housing and electrodes and the thermal mass of the varistors, the better the varistors will be preserved during exposure to surge currents and TOV events and therefore the longer the lifetime of the SPD. As used herein, the term "thermal mass" means the product of the specific heat of the material or materials of the object 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 and the electrode wall is substantially greater than the thermal mass of the varistor. According to some embodiments, the thermal mass of at least one of the electrode head and the electrode wall is at least two times the thermal mass of the varistor, and, according to some embodiments, at least ten times as great. According to some embodiments, the combined thermal masses of the head and the electrode wall are substantially greater than the thermal mass of the varistor, according to some embodiments at least two times the thermal mass of the varistor and, according to some embodiments, at least ten times as great.

[0112] As discussed above, the spring washers **128E** are Belleville or wave washers. Belleville or wave 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 or wave washers. Suitable alternative biasing means include one or more coil springs or spiral washers.

[0113] The varistor assembly **150** includes three varistors and two interconnect members. However, varistor assemblies according to further embodiments may include more than three varistors stacked and connected in electrical parallel as described. For example, a varistor assembly can include five varistors stacked and connected in electrical parallel by three interconnect members.

[0114] With reference to **FIGS. 10-12**, a modular overvoltage protection unit **200** according to further embodiments of the invention is shown therein. The overvoltage protection unit **200** can be used in the same manner and for the same purpose as the overvoltage protection device **100**, except that the unit **200** is generally operationally equivalent to two if the overvoltage protection devices **100**.

[0115] The overvoltage protection unit **200** includes a housing assembly **221** and two SPD internal component sets or submodules **211, 212**.

[0116] The housing assembly **221** includes a first electrode or housing **223** and a cover **226**. The housing **223** is

unitary and, in some embodiments, monolithic. The housing **223** is formed of an electrically conductive metal such as aluminum. The housing **223** includes two integral housing electrode wall portions **222**. Each housing electrode portion **222** includes an electrode wall **222A**, a sidewall **222B**, a cavity **222C**, and a top opening **222D** corresponding to the features **122A, 122B, 122C** and **122D**, respectively, of the device **100**.

[0117] The cover **226** is substantially plate-shaped and has a profile matching that of the housing **223**. The cover **226** has two electrode openings **226A** and six fastening bores **226B** defined therein. According to some embodiments, the cover **226** is formed of an electrically conductive material. In some embodiments, the cover **226** is formed of a metal and, in some embodiments, are formed of aluminum.

[0118] The SPD submodules **211, 212** each include an electrode **224**, a meltable member **232**, an insulator sleeve **234**, and a varistor assembly **250** corresponding to the components **124, 132, 134**, and **150**, respectively, of the device **100**. Each SPD submodule **211, 212** further includes an elastomeric insulator member **239**.

[0119] The insulator members **239** are formed of an electrically insulating, resilient, elastomeric material. According to some embodiments, the insulator members **239** are formed of a material having a hardness in the range of from about 60 Shore A to 85 Shore A. According to some embodiments, the insulator members **239** are formed of rubber. According to some embodiments, the insulator members **239** are formed of silicone rubber. Suitable materials for the insulator members **239** may include KE-5612G or KE-5606 silicone rubber available from Shin-Etsu Chemical Co. Ltd.

[0120] Each SPD submodule **211, 212** is disposed in respective one of the housing cavities **222C**. The cover **226** is secured to the housing **223** by bolts **5**. The cover **226** captures the SPD submodules **211, 212** and axially compresses the elastomeric insulators **239** thereof. The SPD submodule **211** and its electrode wall **222A** form a first overvoltage protection device corresponding to the device **100**. The SPD submodule **212** and its electrode wall **222A** form a second overvoltage protection device corresponding to the device **100**.

[0121] When the unit **200** is assembled, the insulator member **239** of each SPD submodule **211, 212** is captured between the cover **226** and the electrode upper flange **224D** and axially compressed (i.e., axially loaded and elastically deformed from its relaxed state) so that the insulator member **239** serves as a biasing member and applies a persistent axial pressure or load to the electrode **224** and the cover **226**. The insulator member **239** also serves to electrically insulate the housing **223** from the electrode **224**. The compressed insulator member **239** can also form a seal to constrain or prevent overvoltage event byproducts, such as hot gases and fragments from the varistor wafers of the varistor assembly **250** from escaping the unit **200** through the corresponding housing opening **222D**.

[0122] The varistor assemblies **250** can provide the same advantages in the unit **200** as discussed above for the varistor assembly **150**. Each varistor assembly **250** includes adhesive **264** corresponding to the adhesive **164**, **164'**.

[0123] In other embodiments, the SPD submodules **211**, **212** can employ separate springs and insulating rings as described with regard to the device **100**.

[0124] In further embodiments, each SPD submodule **211**, **212** can include a single varistor wafer in place of the multi-varistor varistor assembly **250**.

[0125] With reference to **FIG. 13**, a modular overvoltage protection device **300** according to further embodiments of the invention is shown therein. The overvoltage protection unit **300** can be used in the same manner and for the same purpose as the overvoltage protection device **100**. The overvoltage protection device **300** is constructed in the same manner as the overvoltage protection device **100**, except as follows.

[0126] The overvoltage protection device **300** includes a varistor assembly **350** corresponding to the varistor assembly **150**, except as follows. The varistor assembly **350** includes five varistor wafers **352**, **353**, **354**, **355**, **356**, four interconnect members **360**, **362**, **366**, **368**, and bonding agents **364**. The varistor wafers **352**, **353**, **354**, **355**, **b** correspond to and are formed in the same manner as the varistor wafers **152**, **154**, **156**. The interconnect members **360**, **362**, **366**, **368** correspond to and are formed in the same manner as the interconnect members **160**, **162**. The bonding agents **364** correspond to the bonding agents **164**, **164'**. The five varistor wafers **352**, **353**, **354**, **355**, **356** are axially stacked, bonded and connected in electrical parallel by the four interconnect members **360**, **362**, **366**, **368**.

[0127] With reference to **FIG. 14**, a modular overvoltage protection unit **400** according to further embodiments of the invention is shown therein. The overvoltage protection device **400** can be used in the same manner and for the same purpose as the overvoltage protection device **100**. The overvoltage protection device **300** is constructed in the same manner as the overvoltage protection device **100**, except as follows.

[0128] The overvoltage protection device **400** includes a varistor assembly **450** corresponding to the varistor assembly **150**, except as follows. The varistor assembly **450** includes two varistor wafers **452**, **454**, two interconnect members **460**, **462**, bonding agents **464** and an electrical insulator wafer **457**. The varistor wafers **452**, **454** correspond to and are formed in the same manner as the varistor wafers **152**, **154**, **156**. The interconnect members **460**, **462** correspond to and are formed in the same manner as the interconnect members **160**, **162**. The bonding agents **464** correspond to the bonding agents **164**, **164'**. The insulator wafer **457** is formed of an electrically insulating material. Suitable electrical insulating materials may include ULTEM™ 1000 thermoplastic available from SABIC, mica, or polyester film such as DYFILM™ polyester film available from Coveme of Italy,

for example. The two varistor wafers **452**, **454** are axially stacked and connected in electrical parallel by the two interconnect members **460**, **462**. The insulator wafer **457** is axially interposed or stacked between the varistor wafers **452**, **454** to prevent short circuiting between the opposing faces of the varistor wafers **452**, **454**.

[0129] With reference to **FIGS. 15** and **16**, a modular overvoltage protection device **500** is shown therein. The overvoltage protection device **500** can be used in the same manner and for the same purpose as the overvoltage protection device **100**.

[0130] The overvoltage protection device **500** is constructed as one half of the unit **200** (**FIG. 12**). The device **500** includes a housing assembly **521** that is one half of the housing assembly **221** and an SPD internal component set **512** corresponding to the submodule **212**.

[0131] With reference to **FIGS. 17-20**, a modular overvoltage protection device **600** according to embodiments of the invention is shown therein. The overvoltage protection device **600** can be used in the same manner and for the same purpose as the overvoltage protection device **100**. The overvoltage protection device **600** is constructed in the same manner as the overvoltage protection device **100**, except as follows.

[0132] The overvoltage protection device **600** includes a varistor assembly **650** corresponding to the varistor assembly **150**, except as follows. The varistor assembly **650** includes three varistor wafers **652**, **654**, **656** and two interconnect members **660**, **662**. The varistor wafers **652**, **654**, **656** correspond to and are formed in the same manner as the varistor wafers **152**, **154**, **156**. The interconnect members **660**, **662** correspond to and are formed in the same manner as the interconnect members **160**, **162**. The varistor wafers **652**, **654**, **656** are axially stacked and connected in electrical parallel by the interconnect members **660**, **662** as discussed above for the device **100**.

[0133] The overvoltage protection device **600** further includes an electrically insulating void filling member or sleeve **636**. The sleeve **636** includes a side wall **636A** defining a through passage **636B**. The passage **636** extends from an upper opening **636C** to a lower opening **636D**. A pair of laterally opposing, axially extending receiver channels **636E** are defined in the inner surface **636F** of the side wall **636A**.

[0134] The sleeve **636** is tubular and has an outer surface **636G** that is generally cylindrical. According to some embodiments, the sleeve **636** is formed of a high temperature polymer and, in some embodiments, a high temperature thermoplastic. In some embodiments, the sleeve **636** is formed of polyetherimide (PEI), such as ULTEM™ thermoplastic available from SABIC of Saudi Arabia. In some embodiments, the sleeve **636** is formed of non-reinforced polyetherimide. In some embodiments, the sleeve **636** is formed of an electrically insulating ceramic.

[0135] According to some embodiments, the sleeve **636** is formed of a material having a melting point greater

than the melting point of the meltable member **632**. According to some embodiments, the sleeve **636** is formed of a material having a melting point in the range of from about 120 to 200 °C.

[0136] According to some embodiments, the sleeve **636** material can withstand a voltage of 25 kV per mm of thickness.

[0137] According to some embodiments, the sleeve side wall **636A** has a nominal thickness **T5** (FIG. 20) of at least 2 mm, in some embodiments at least 4 mm, and in some embodiments in the range of from about 2 to 15 mm. According to some embodiments, the depth **D5** of each receiver channel **636E** is at least 1 mm and, in some embodiments, in the range of from about 1 to 12 mm.

[0138] The internal chamber **627** of the housing assembly **621** of the overvoltage protection device **600** includes a first subchamber **627A** and a second subchamber **627B** in fluid communication with the first subchamber **627A**. Prior to melting of the meltable member **632**, the electrode **624** and the meltable member **632** occupy the first subchamber **627A**. The varistor assembly **650** occupies a central volume of the second subchamber **627B** such that a remaining tubular void or gap volume **627C** of the second subchamber **627B** remains unoccupied by the varistor assembly **650**. The gap volume **627C** is the space or volume extending radially between the varistor assembly **650** and the inner surface **622H** of the sidewall **622B** of the housing electrode **622**. The void filling sleeve **636** occupies the gap volume **627C** and surrounds the varistor assembly **650**.

[0139] The receiver recesses or channels **636E** and the bridge portions **660B**, **662B** of the interconnect members **660**, **662** are relatively sized and assembled such that each of the bridge portions **660B**, **662B** is received and seated in a respective one of the receiver channels **636E**. The remainder of the sleeve inner surface **636F** generally conforms to the peripheral profiles of the varistor wafers **652**, **654**, **654**.

[0140] Thus, as can be appreciated from FIGS. 17 and 19, the inner surface **636F** generally conforms to the outer shape of the varistor assembly **650**. The cylindrical outer surface **636G** generally conforms to the inner shape of the inner wall surface **622H** of the housing electrode **622**. In some embodiments, the gap between the inner surface **636F** and the varistor wafers **652**, **654**, **654** is less than 2 mm. In some embodiments, the gap between the outer surface **636G** and the inner wall surface **622H** is less than 0.5 mm.

[0141] The varistor wafers **652**, **654**, **656** are relatively thick so that the overall height of the varistor assembly **650** is increased as compared to that of the varistor assembly **150**, for example. As a result, the gap void or volume **627C** surrounding the varistor assembly **650** is relatively large. Additionally, the bridge portions **660B**, **662B** project radially outwardly beyond the peripheral edges of the varistors **652**, **654**, **656**. Because the inner surface **622H** of the housing electrode **622** is cylindrical, the required spacing between the bridge portions **660B**,

662B and the inner surface **622B** creates relatively large gaps around the remainder of the varistor assembly **650**.

[0142] In the absence of the void filling sleeve **636**, this large gap volume **627C** could compromise the intended operation of the meltable member **632** and the fail-safe mechanism **602**. In particular, the volume of the melted meltable member **632** may not be sufficient to bridge the electrodes **622** and **624** to short circuit the electrodes **622**, **624**, depending on the orientation of the device **600** when the meltable member **632** is melted. The spacer sleeve **636** occupies the gap volume **627C** and thereby reduces or limits the amount or volume of the meltable member **632** that can flow into the gap volume **627C** when the meltable member **632** becomes molten. In this way, the void filling member **636** ensures that a greater and reliably sufficient quantity of the melted meltable member is retained in the first subchamber **627A** to make simultaneous contact with the two electrodes **622**, **624**.

[0143] In some embodiments, the void filling sleeve **636** occupies at least 50 percent of the gap volume **627C** and, in some embodiments, at least 80 percent. In some embodiments, the void filling sleeve **636** has a volume in the range of from about 100 mm³ to 100,000 mm³ and, in some embodiments, the volume is about 21,000 mm³.

[0144] While the illustrated void filling member **636** is configured as a unitary, tubular sleeve having axially extending receiver channels **636E** defined therein, other configurations and constructions may be employed. For example, the channels **636E** may be replaced with radially extending bores that do not extend to the ends of the sleeve. The void filling member **636** may be replaced with two or more void filling members that are configured and arranged to occupy the gap volume **627C** to the degree and with the dimensions discussed above. The two or more void filling members may be axially stacked and or may each surround the varistor assembly **650** by less than 360 degrees.

[0145] With reference to FIG. 21, a modular overvoltage protection device **700** according to further embodiments of the invention is shown therein. The overvoltage protection device **700** can be used in the same manner and for the same purpose as the overvoltage protection device **600**. The overvoltage protection device **700** is constructed in the same manner as the overvoltage protection device **600**, except as follows. The device **700** includes a varistor assembly **750** corresponding to the varistor assembly **650**, and a void filling member **736** corresponding to the void filling member **636**.

[0146] The overvoltage protection device **700** includes an elastomeric insulator member **739** corresponding to the elastomeric insulator member **239** (FIG. 12). The insulator member **739** is captured between the cover **726** and the electrode upper flange **724D** and axially compressed (*i.e.*, axially loaded and elastically deformed from its relaxed state) so that the insulator member **739** serves as a biasing member and applies a persistent axial pressure or load to the electrode **724** and the cover **726**, as described with regard to the unit **200**.

[0147] It will be appreciated that various aspects as disclosed herein can be used in different combinations. For example, an elastomeric insulator member corresponding to the elastomeric insulator member **239** can be used on place of the springs and end insulator members (e.g., insulator member **128C**) of the overvoltage protection devices **100, 300, 400, 600**. The varistor assemblies of each device **100-700** can be replaced with a varistor assembly of another one of the devices **100-700** (e.g., the five-wafer varistor assembly **350** or the two-wafer varistor assembly **450** can be used in place of the varistor assembly **650** in the device **600**).

[0148] 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 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.

Claims

1. An overvoltage protection device (600) comprising:

a first electrode member (622);
 a second electrode member (624);
 a varistor (652, 654, or 656) interposed between and electrically connected to each of the first and second electrode members;
 an electrically conductive meltable member (632), wherein the meltable member is responsive to heat in the overvoltage protection device to melt and form an electrical short circuit path across the first and second electrode members; and
 a void filling member (636) surrounding at least a portion of the varistor, wherein the void filling member is formed of an electrically insulating material;
 wherein:

the overvoltage protection device includes a sidewall (622B) defining a chamber (627), the chamber including a first subchamber (627A) and a second subchamber (627B) in fluid communication with the first subchamber;
 the meltable member is disposed in the first subchamber (627A);
 the varistor is disposed in the second subchamber (627B) and a gap volume (627C) is defined between the varistor and the sidewall in the second subchamber;
 the void filling member is disposed in the gap volume to limit a flow of the meltable member into the gap volume (627C); and

the varistor (652) is a first varistor wafer,

characterised in that the overvoltage protection device includes:

a second varistor wafer (654 or 656) formed of a varistor material; and
 an electrically conductive interconnect member (660 or 662) connecting the first and second varistor wafers in electrical parallel between the first and second electrode members (622, 624);
 wherein the first and second varistor wafers are axially stacked between the first and second electrode members (622, 624);
 the void filling member (636) includes a receiver recess (636E); and
 a portion (660B or 662B) of the interconnect member extends outwardly beyond the first and second varistor wafers and is disposed in the receiver recess (636E).

2. The overvoltage protection device of Claim 1 wherein the void filling member (636) is formed of an electrically insulating ceramic.

3. The overvoltage protection device of Claim 1 wherein the void filling member (636) occupies at least 50 percent of the gap volume.

4. The overvoltage protection device of Claim 1 wherein the void filling member (636) includes a tubular void filling sleeve that surrounds the varistor wafer (652, 654, or 656).

5. The overvoltage protection device of Claim 4 wherein:

the void filling sleeve (636) includes an inner surface (636F) that generally conforms to an outer shape of the varistor (652, 654, or 656); and
 the void filling sleeve includes an outer surface (636G) that generally conforms to the shape of an inner wall surface of the sidewall (622B).

6. The overvoltage protection device of Claim 5 wherein:

a gap between the inner surface (636F) of the void filling sleeve and the varistor (652) is less than 2 mm; and
 a gap between the outer surface (636G) of the void filling sleeve and the inner wall surface of the sidewall (622B) is less than 0.5 mm.

7. The overvoltage protection device of Claim 4 wherein the void filling sleeve (636) includes a sleeve side

wall (636A) having a nominal thickness (T5) of at least 2 mm.

8. The overvoltage protection device of Claim 4 where-
in the void filling sleeve (636) is unitary. 5
9. The overvoltage protection device of Claim 1 where-
in the receiver recess (636E) is an axially extending
channel defined in an inner surface (636F) of the void
filling member (636). 10
10. The overvoltage protection device of Claim 1 where-
in the receiver recess (636E) has a depth (D5) in the
range of from about 1 to 12 mm. 15
11. The overvoltage protection device of Claim 1 where-
in the void filling member (636) is formed of a high
temperature thermoplastic.
12. The overvoltage protection device of Claim 1 where-
in the void filling member (636) is formed of a material
having a melting point in the range of from about 120
to 200 °C, or wherein the void filling member (636) is
formed of a material that can withstand a voltage of
25 kV per mm of thickness. 20 25
13. The overvoltage protection device of Claim 1 where-
in the void filling member (636) has a volume in the
range of from about 100 mm³ to 100,000 mm³. 30
14. The overvoltage protection device of Claim 1 where-
in:
the first electrode member (622) includes a
housing electrode including the sidewall (622B) and an end wall (122A) integral with the sidewall; 35
the sidewall (622B) and the end wall (122A)
collectively define the chamber (627);
the second electrode member (624) extends
into the chamber (627); and 40
the housing electrode is unitarily formed of me-
tal. 45

Patentansprüche

1. Überspannungsschutzvorrichtung (600), umfas-
send: 50

Ein erstes Elektrodenelement (622);
ein zweites Elektrodenelement (624);
einen Varistor (652, 654 oder 656), der zwischen
jedem der ersten und zweiten Elektrodenele-
mente angeordnet und elektrisch mit diesen
verbunden ist; 55
ein elektrisch leitendes, schmelzbares Element
(632), wobei das schmelzbare Element auf Hit-

ze in der Überspannungsschutzvorrichtung rea-
giert, um zu schmelzen und einen elektrischen
Kurzschlusspfad über die ersten und zweiten
Elektrodenelemente zu bilden; und
Ein Hohlraumfüllelement (636), welches min-
destens einen Abschnitt des Varistors umgibt,
wobei das Hohlraumfüllelement aus einem
elektrisch isolierenden Material geformt ist;
wobei:

Die Überspannungsschutzvorrichtung eine
Seitenwand (622B) einschließt, die eine
Kammer (627) definiert, wobei die Kammer
eine erste Unterkammer (627A) und eine
zweite Unterkammer (627B) in Flüssig-
keitsverbindung mit der ersten Unterkam-
mer einschließt;
das schmelzbare Element in der ersten
Unterkammer (627A) angeordnet ist;
der Varistor in der zweiten Unterkammer
(627B) angeordnet ist und ein Spaltvolu-
men (627C) zwischen dem Varistor und
der Seitenwand in der zweiten Unterkam-
mer definiert ist;
das Hohlraumfüllelement im Spaltvolumen
angeordnet ist, um einen Fluss des
schmelzbaren Elements in das Spaltvolu-
men (627C) zu begrenzen; und

der Varistor (652) ein erster Varistor-Wafer ist,
dadurch gekennzeichnet, dass die Überspan-
nungsschutzvorrichtung umfasst:

Einen zweiten Varistor-Wafer (654 oder 656),
der aus einem Varistormaterial gebildet ist; und
ein elektrisch leitendes Verbindungselement
(660 oder 662) die ersten und zweiten Varis-
tor-Wafer in elektrischer Parallelschaltung zwi-
schen den ersten und zweiten Elektrodenele-
menten (622, 624 verbindet);
wobei die ersten und zweiten Varistor-Wafer
axial zwischen den ersten und zweiten Elektro-
denelementen (622, 624) gestapelt sind;
das Hohlraumfüllelement (636) eine Aufnahme-
vertiefung (636E) einschließt; und
sich ein Abschnitt (660B oder 662B) des Ver-
bindungselements nach außen über die ersten
und zweiten Varistor-Wafer hinaus erstreckt und
in der Aufnahmevertiefung (636E) angeordnet
ist.

2. Überspannungsschutzvorrichtung nach Anspruch
1, wobei das Hohlraumfüllelement (636) aus elekt-
risch isolierender Keramik gebildet ist.
3. Überspannungsschutzvorrichtung nach Anspruch
1, wobei das Hohlraumfüllelement (636) mindestens
50 Prozent des Spaltvolumens einnimmt.

4. Überspannungsschutzvorrichtung nach Anspruch 1, wobei das Hohlraumfüllelement (636) eine röhrenförmige Hohlraumfüllhülse einschließt, die den Varistor-Wafer (652, 654 oder 656) umgibt. 5
5. Überspannungsschutzvorrichtung nach Anspruch 4, wobei:
- Die Hohlraumfüllhülse (636) einen Innenfläche (636F) umfasst, die generell einer Außenform des Varistors (652, 654 oder 656) entspricht; und 10
- die Hohlraumfüllhülse umfasst eine Außenfläche (636G), die generell der Form einer Innenwandfläche der Seitenwand (622B) entspricht. 15
6. Überspannungsschutzvorrichtung nach Anspruch 5, wobei:
- Ein Spalt zwischen der Innenfläche (636F) der Hohlraumfüllhülse und dem Varistor (652) geringer als 2 mm ist; und 20
- ein Spalt zwischen der Außenfläche (636G) der Hohlraumfüllhülse und der Innenwandfläche der Seitenwand (622B) geringer als 0,5 mm ist. 25
7. Überspannungsschutzvorrichtung nach Anspruch 4, wobei die Hohlraumfüllhülse (636) eine Hülseseitenwand (636A) umfasst, die eine nominale Dicke (T5) von mindestens 2 mm aufweist. 30
8. Überspannungsschutzvorrichtung nach Anspruch 4, wobei die Hohlraumfüllhülse (636) einheitlich ist.
9. Überspannungsschutzvorrichtung nach Anspruch 1, wobei die Aufnahmevertiefung (636E) ein sich axial erstreckender Kanal ist, der in einer Innenfläche (636F) des Hohlraumfüllelements (636) definiert ist. 35
10. Überspannungsschutzvorrichtung nach Anspruch 1, wobei die Aufnahmevertiefung (636E) eine Tiefe (D5) im Bereich von ca. 1 bis 12 mm aufweist. 40
11. Überspannungsschutzvorrichtung nach Anspruch 1, wobei das Hohlraumfüllelement (636) aus Hochtemperatur-Thermoplast geformt ist. 45
12. Überspannungsschutzvorrichtung nach Anspruch 1, wobei das Hohlraumfüllelement (636) aus einem Material gebildet ist, welches einen Schmelzpunkt im Bereich von ca. 120 bis 200 °C aufweist, oder wobei das Hohlraumfüllelement (636) aus einem Material gebildet ist, das einer Spannung von 25 kV pro mm Dicke widerstehen kann. 50
13. Überspannungsschutzvorrichtung nach Anspruch 1, wobei das Hohlraumfüllelement (636) ein Volumen im Bereich von ca. 100 mm³ bis 100.000 mm³ aufweist. 55

men im Bereich von ca. 100 mm³ bis 100.000 mm³ aufweist.

14. Überspannungsschutzvorrichtung nach Anspruch 1, wobei:

Das erste Elektrodenelement (622) eine Gehäuseelektrode umfasst, welche die Seitenwand (622B) und eine, mit der Seitenwand integrale Endwand (122A) umfasst, die Seitenwand (622B) und die Endwand (122A) gemeinsam die Kammer (627) definieren; sich das zweite Elektrodenelement (624) in die Kammer (627) erstreckt; und die Gehäuseelektrode einheitlich aus Metall geformt ist.

Revendications

1. Dispositif de protection contre les surtensions (600) comprenant :

un premier élément électrode (622) ;
un deuxième élément électrode (624) ;
une varistance (652, 654, ou 656) interposée entre les premier et deuxième éléments électrodes et connectée électriquement à chacun de ceux-ci ;
un élément fusible électriquement conducteur (632), dans lequel l'élément fusible est réactif à la chaleur dans le dispositif de protection contre les surtensions pour fondre et former un trajet de court-circuit électrique aux bornes des premier et deuxième éléments électrodes ; et
un élément de comblement de vide (636) entourant au moins une portion de la varistance, dans lequel l'élément de comblement de vide est formé d'un matériau électriquement isolant ;
dans lequel :

le dispositif de protection contre les surtensions comporte une paroi latérale (622B) définissant une chambre (627), la chambre comportant une première chambre secondaire (627A) et une deuxième chambre secondaire (627B) en communication fluide avec la première chambre secondaire ;
l'élément fusible est disposé dans la première chambre secondaire (627A) ;
la varistance est disposée dans la deuxième chambre secondaire (627B) et un volume d'écartement (627C) est défini entre la varistance et la paroi latérale dans la deuxième chambre secondaire ;
l'élément de comblement de vide est disposé dans le volume d'écartement pour

- limiter un écoulement de l'élément fusible dans le volume d'écartement (627C) ; et
- la varistance (652) est une première plaquette de varistance, **caractérisé en ce que** le dispositif de protection contre les surtensions comporte :
- une deuxième plaquette de varistance (654 ou 656) formée d'un matériau à varistance ; et
 - un élément d'interconnexion électriquement conducteur (660 ou 662) connectant les première et deuxième plaquettes de varistance en parallèle électriquement entre les premier et deuxième éléments électrodes (622, 624) ; dans lequel les première et deuxième plaquettes de varistance sont empilées axialement entre les premier et deuxième éléments électrodes (622, 624) ;
 - l'élément de comblement de vide (636) comporte un évidement récepteur (636E) ; et
 - une portion (660B ou 662B) de l'élément d'interconnexion s'étend vers l'extérieur au-delà des première et deuxième plaquettes de varistance et est disposée dans l'évidement récepteur (636E).
2. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) est formé d'une céramique électriquement isolante.
 3. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) occupe au moins 50 pour cent du volume d'écartement.
 4. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) comporte un manchon de comblement de vide tubulaire qui entoure la plaquette de varistance (652, 654, ou 656).
 5. Dispositif de protection contre les surtensions selon la revendication 4 dans lequel :
 - le manchon de comblement de vide (636) comporte une surface interne (636F) qui épouse de manière générale une forme externe de la varistance (652, 654, ou 656) ; et
 - le manchon de comblement de vide comporte une surface externe (636G) qui épouse de manière générale la forme d'une surface de paroi interne de la paroi latérale (622B).
 6. Dispositif de protection contre les surtensions selon la revendication 5 dans lequel :
 - un écartement entre la surface interne (636F) du
- manchon de comblement de vide et la varistance (652) est inférieur à 2 mm ; et
- un écartement entre la surface externe (636G) du manchon de comblement de vide et la surface de paroi interne de la paroi latérale (622B) est inférieur à 0,5 mm.
7. Dispositif de protection contre les surtensions selon la revendication 4 dans lequel le manchon de comblement de vide (636) comporte une paroi latérale de manchon (636A) ayant une épaisseur nominale (T5) d'au moins 2 mm.
 8. Dispositif de protection contre les surtensions selon la revendication 4 dans lequel le manchon de comblement de vide (636) est unitaire.
 9. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'évidement récepteur (636E) est un canal en extension axiale défini dans une surface interne (636F) de l'élément de comblement de vide (636).
 10. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'évidement récepteur (636E) a une profondeur (D5) dans la plage d'environ 1 à 12 mm.
 11. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) est formé d'un thermoplastique haute température.
 12. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) est formé d'un matériau ayant un point de fusion dans la plage d'environ 120 à 200 °C, ou dans lequel l'élément de comblement de vide (636) est formé d'un matériau qui peut supporter une tension de 25 kV par mm d'épaisseur.
 13. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel l'élément de comblement de vide (636) a un volume dans la plage d'environ 100 mm³ à 100 000 mm³.
 14. Dispositif de protection contre les surtensions selon la revendication 1 dans lequel :
 - le premier élément électrode (622) comporte une électrode boîtier comportant la paroi latérale (622B) et une paroi terminale (122A) solidaire de la paroi latérale ;
 - la paroi latérale (622B) et la paroi terminale (122A) définissent collectivement la chambre (627) ;
 - le deuxième élément électrode (624) s'étend dans la chambre (627) ; et

l'électrode boîtier est formée unitairement de métal.

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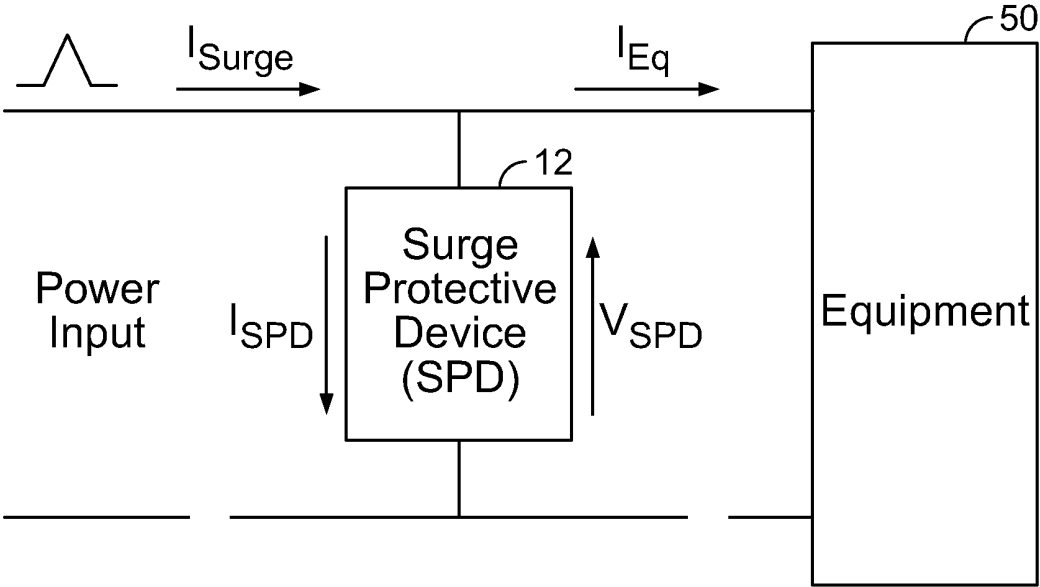


FIG. 1
(Prior Art)

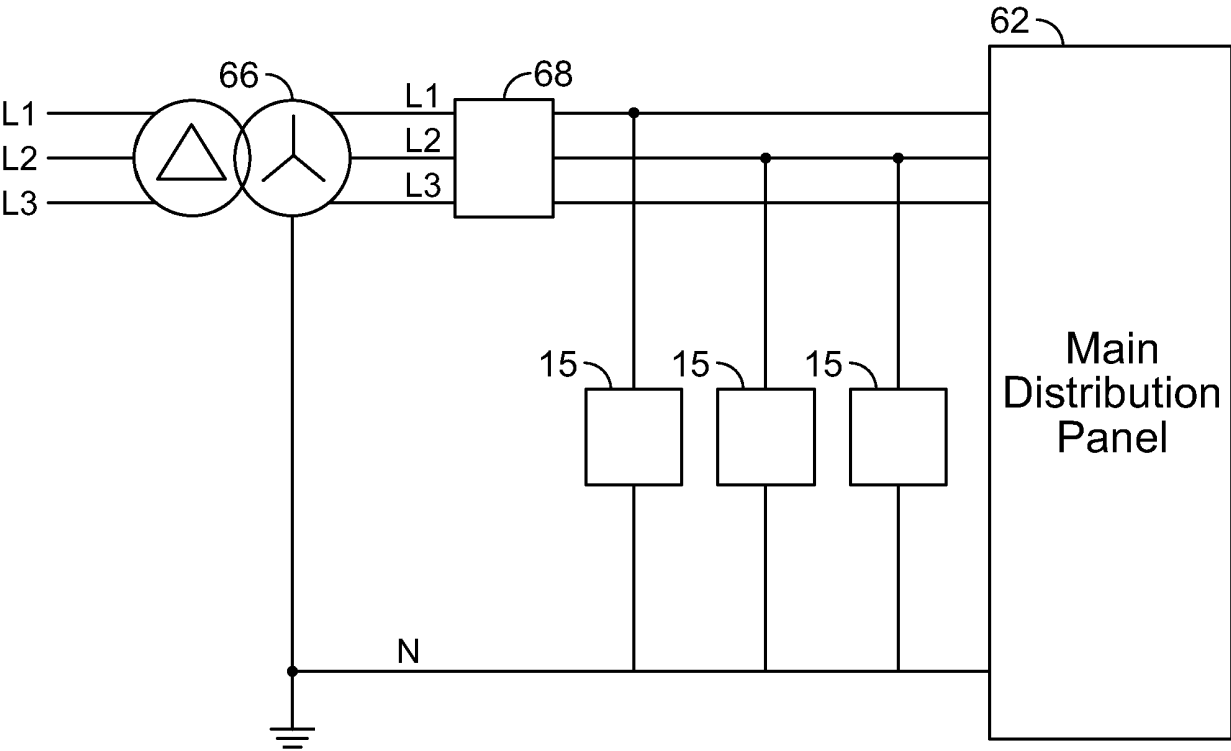


FIG. 2
(Prior Art)

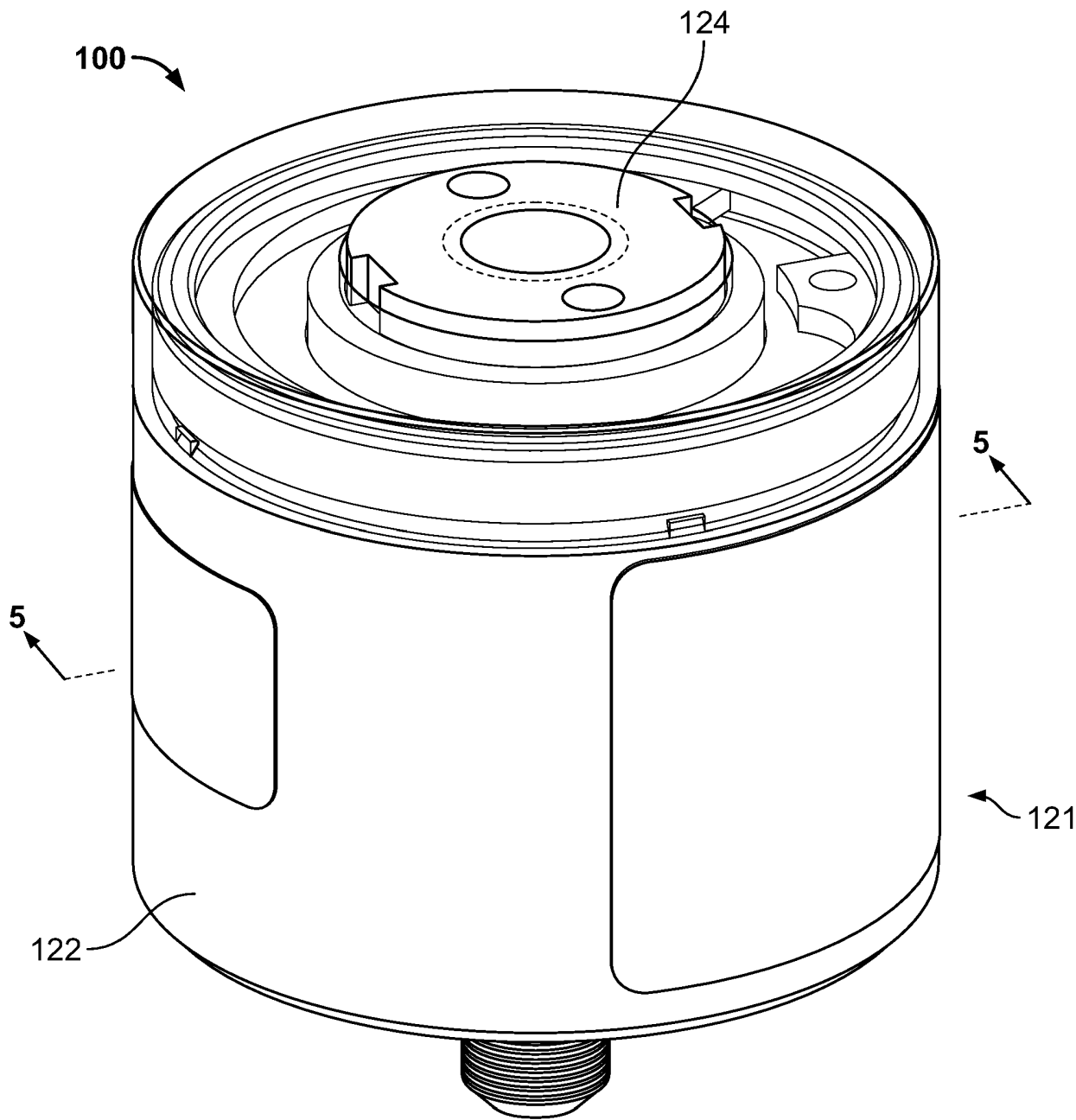


FIG. 3

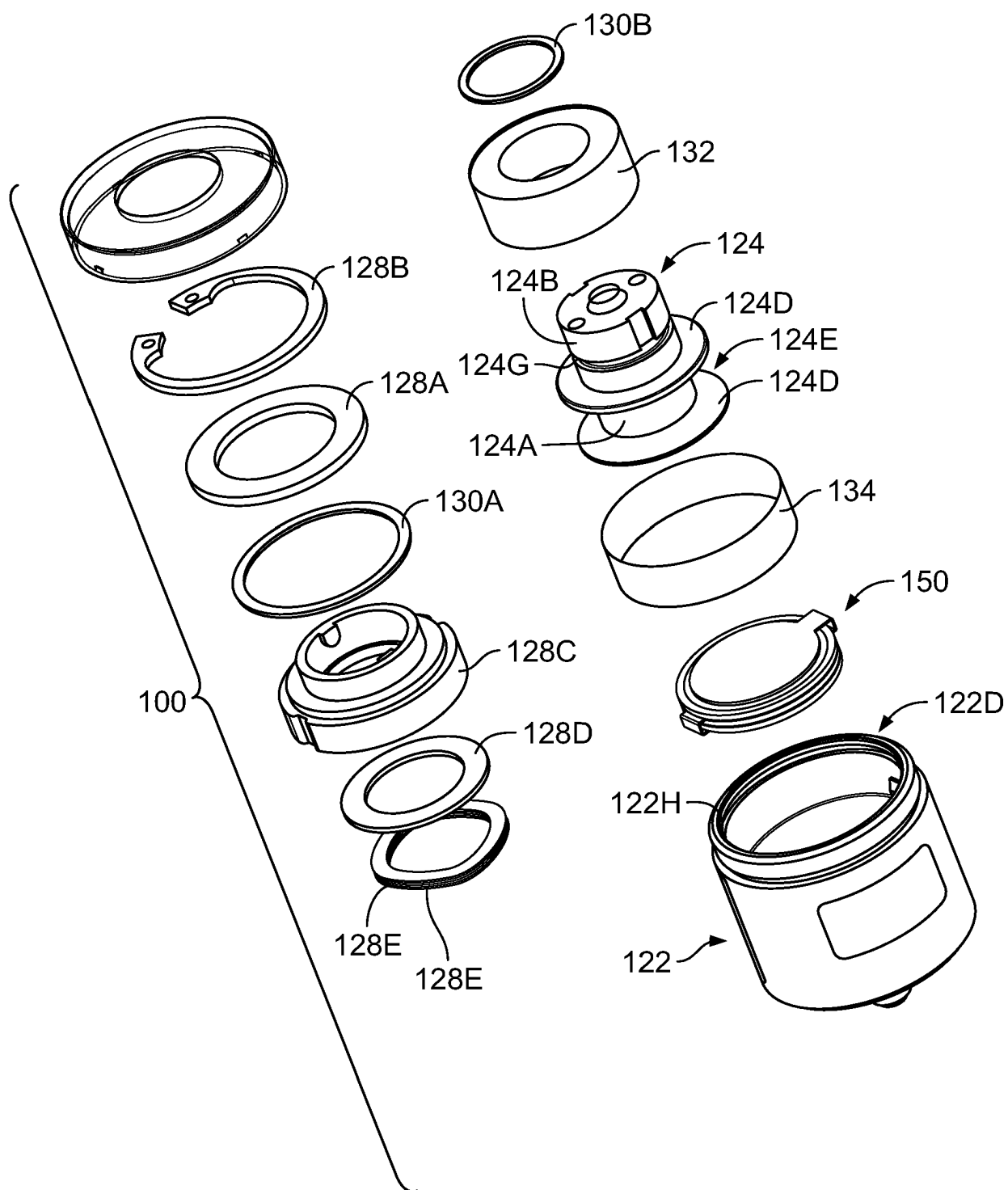


FIG. 4

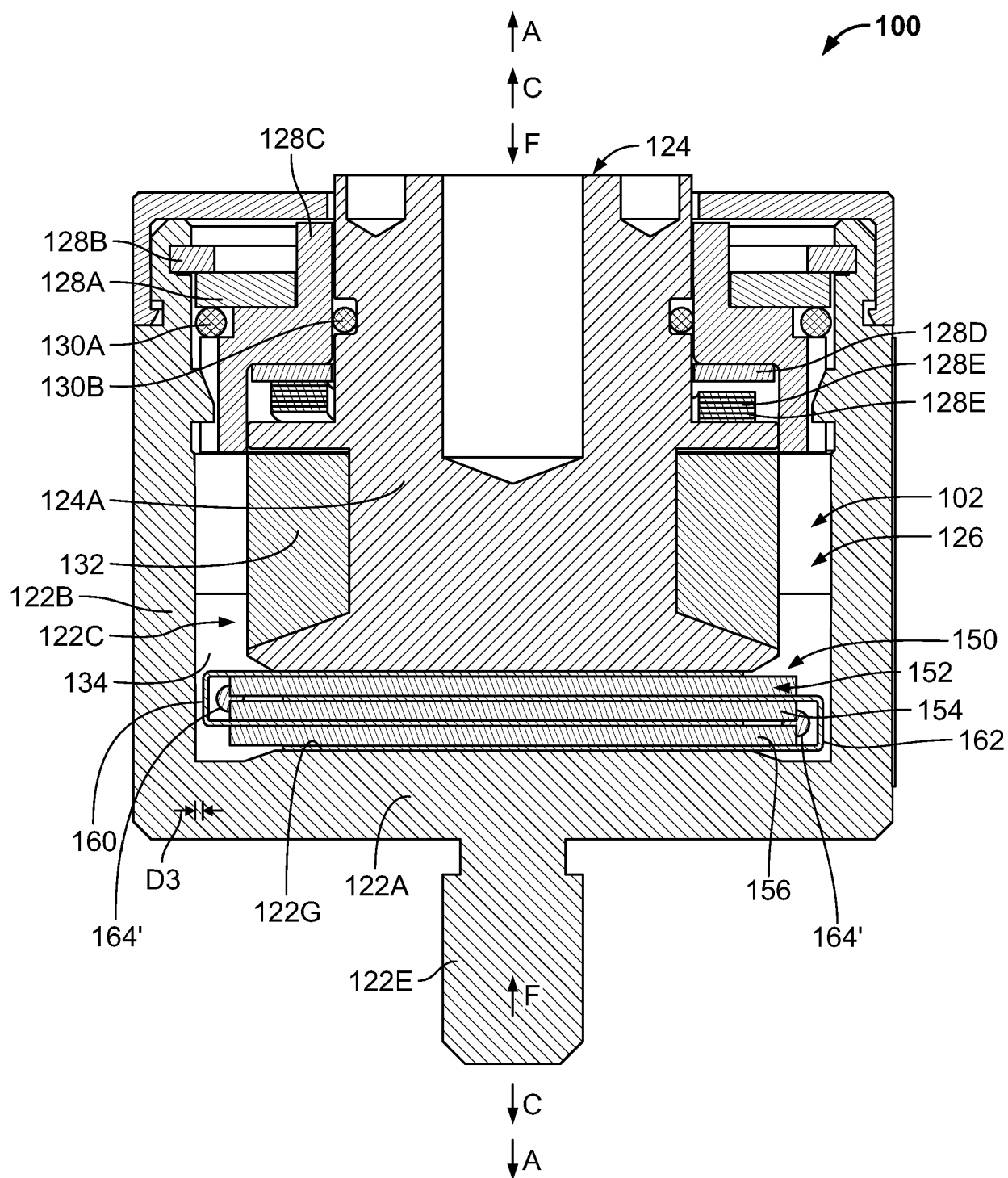


FIG. 5

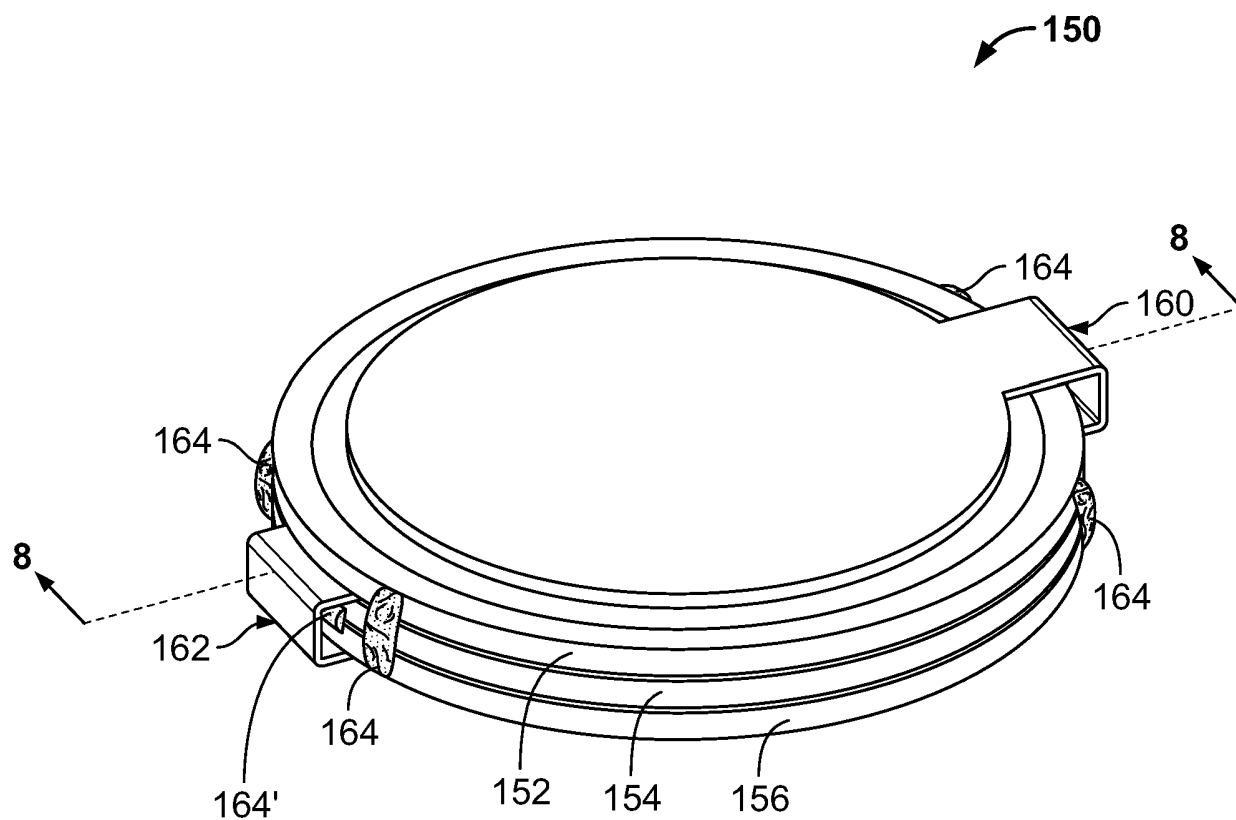


FIG. 6

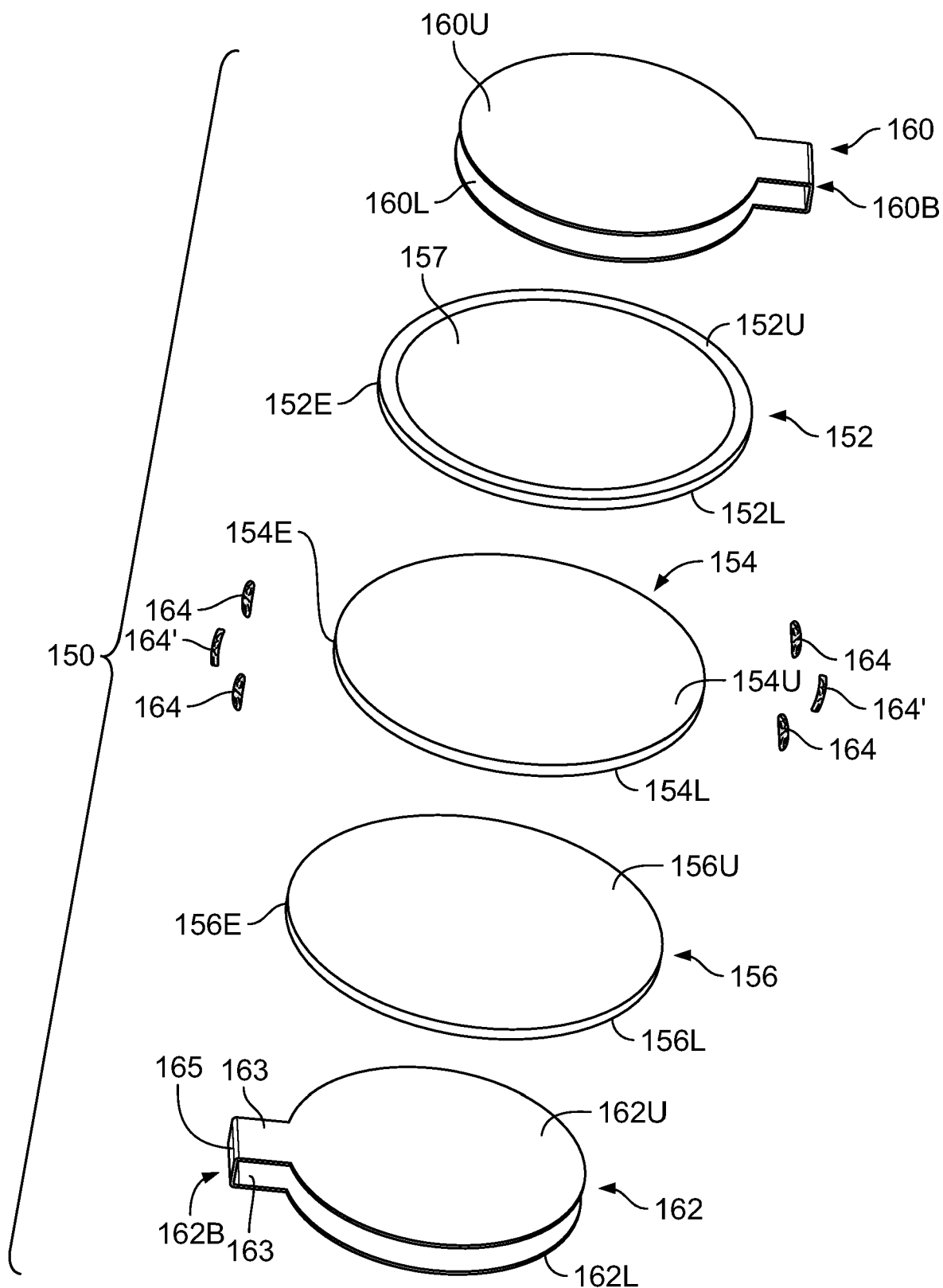


FIG. 7

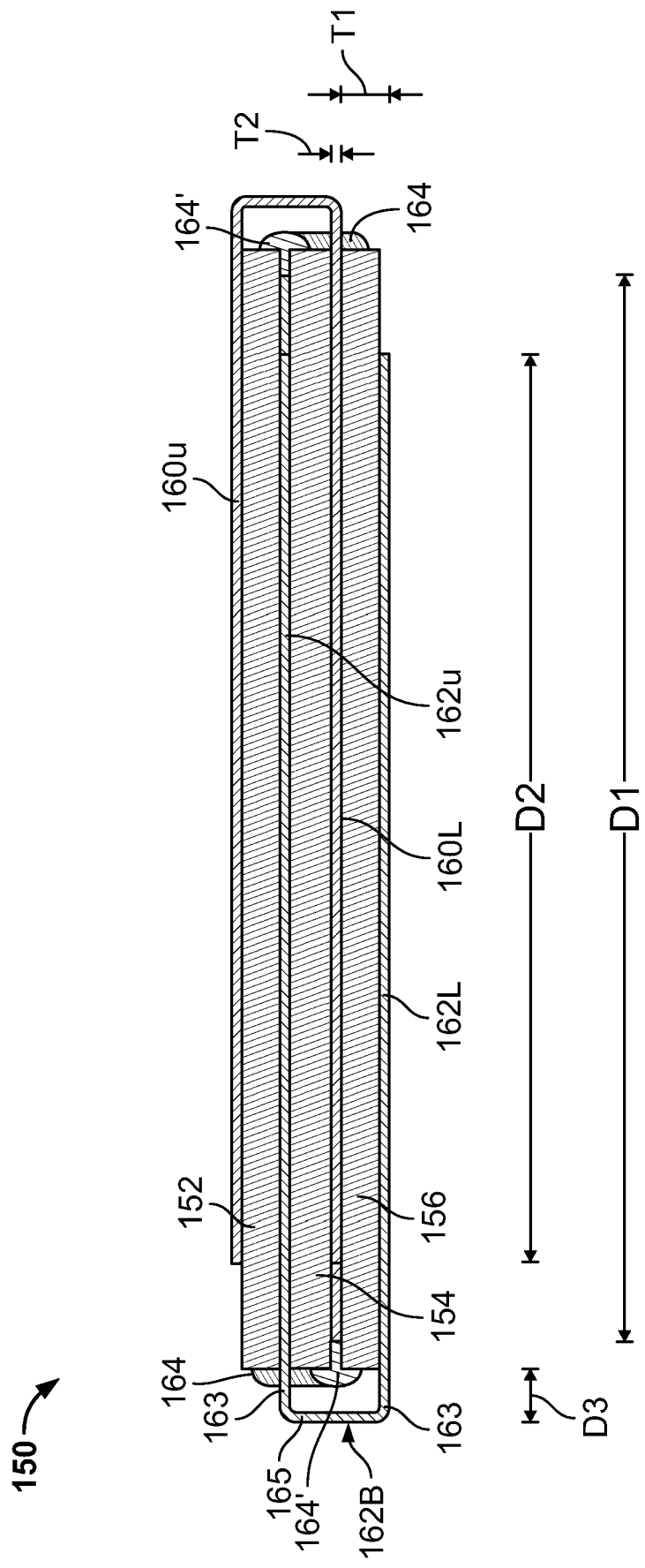


FIG. 8

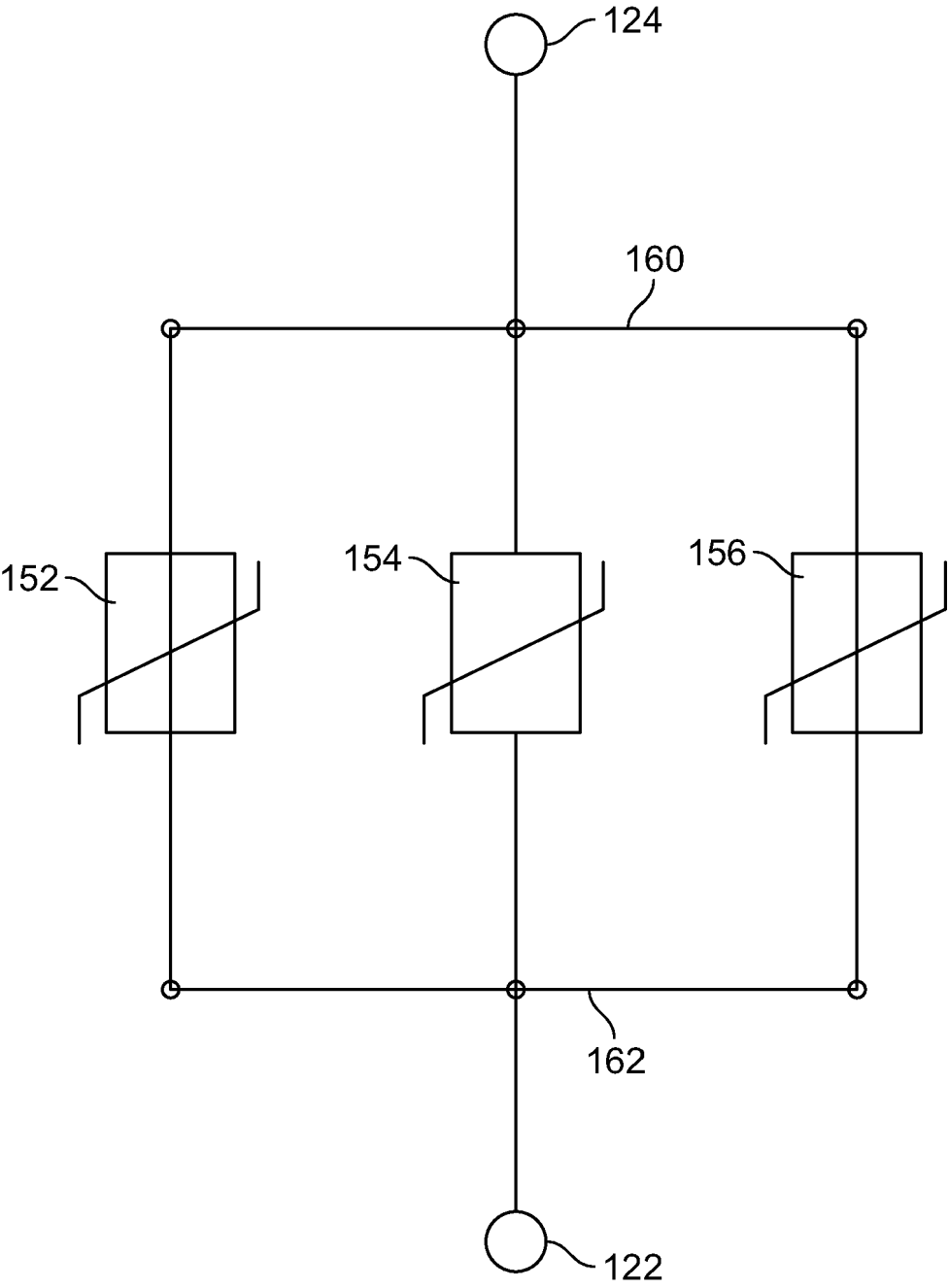


FIG. 9

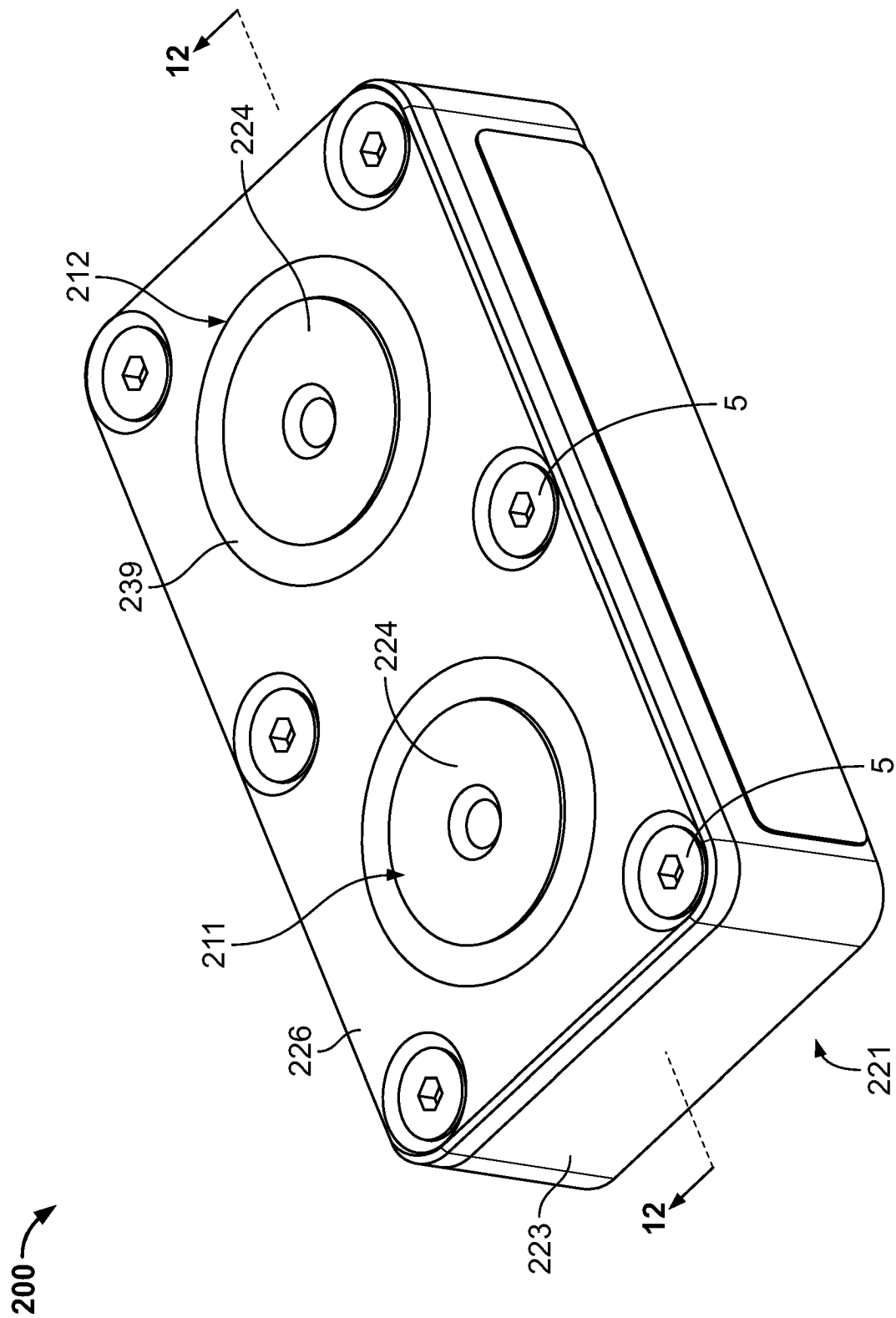


FIG. 10

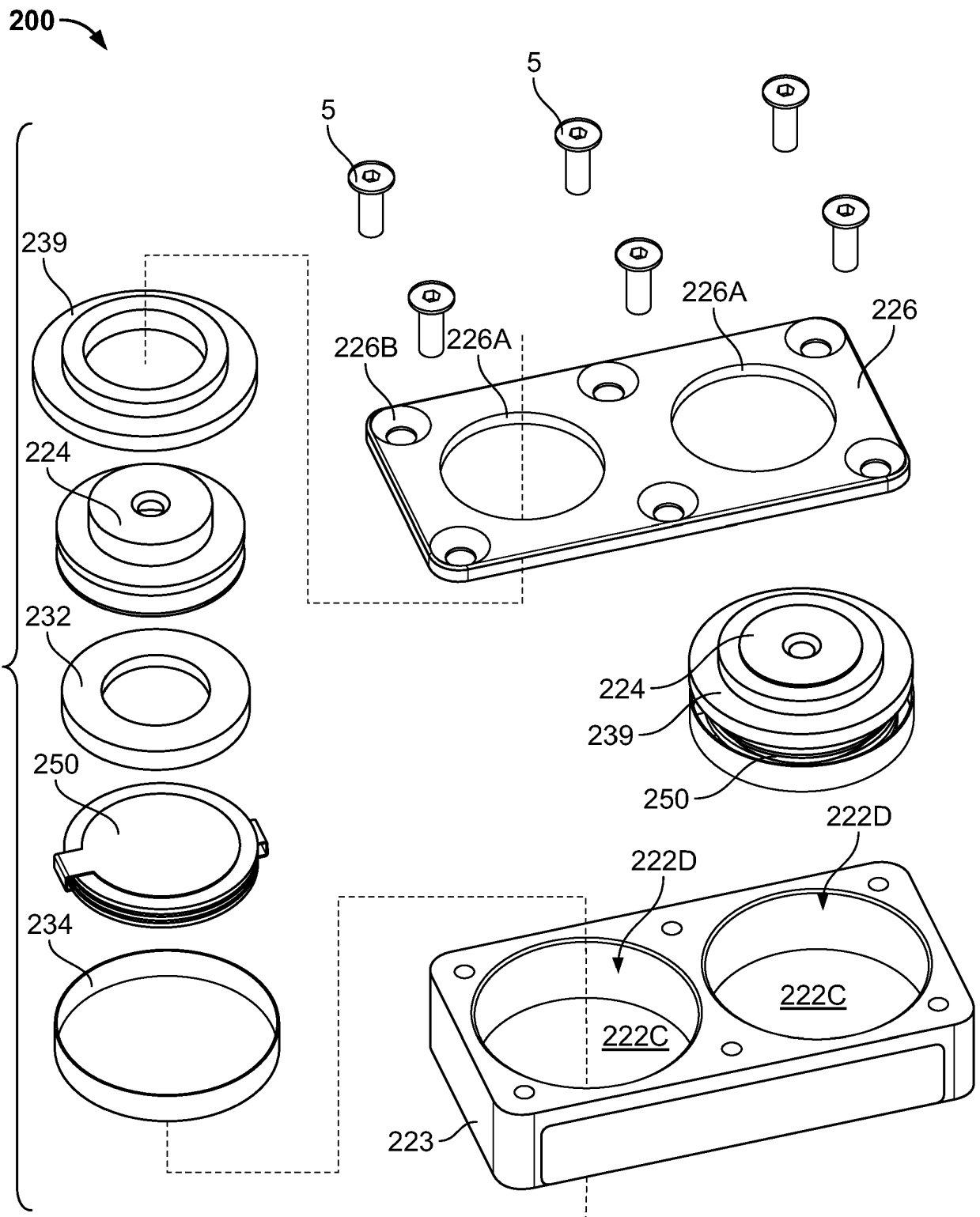


FIG. 11

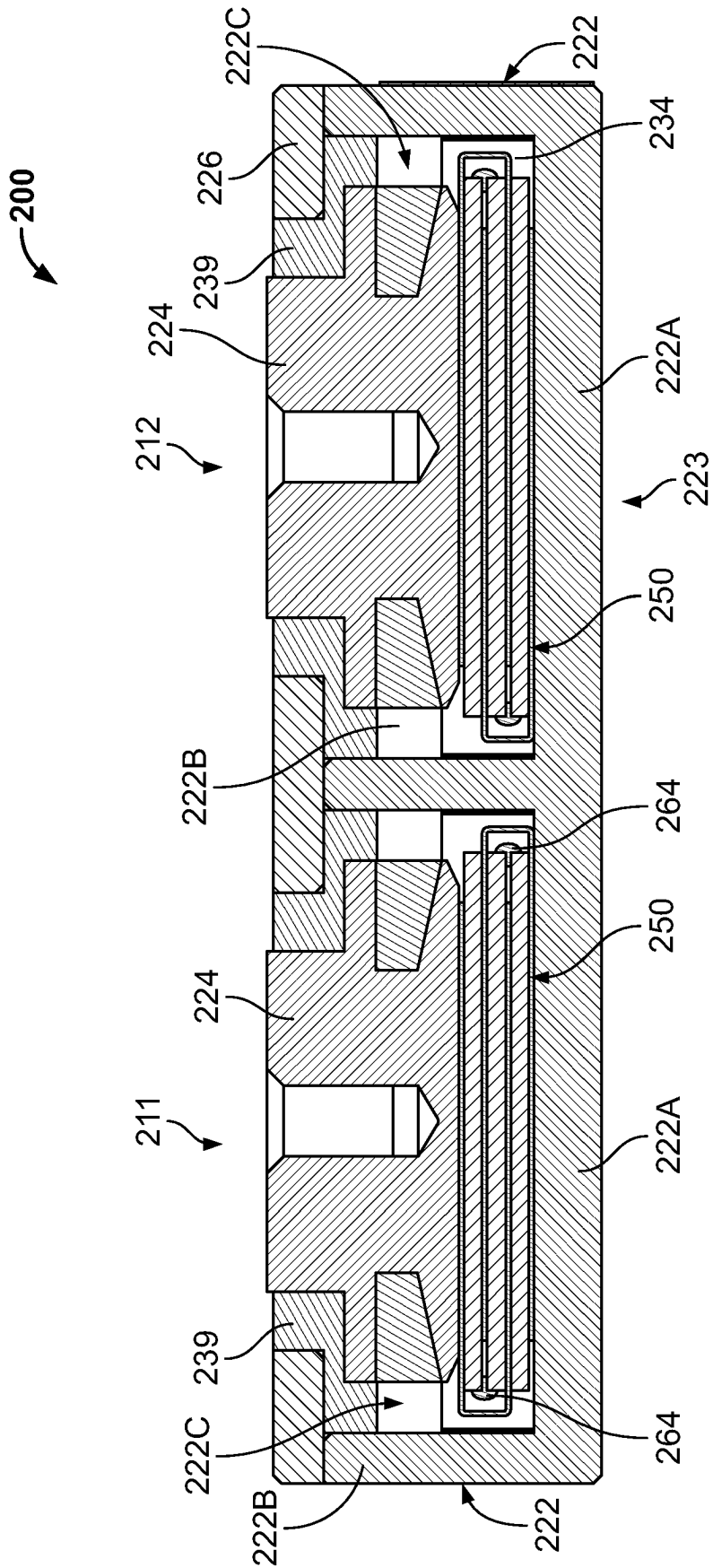


FIG. 12

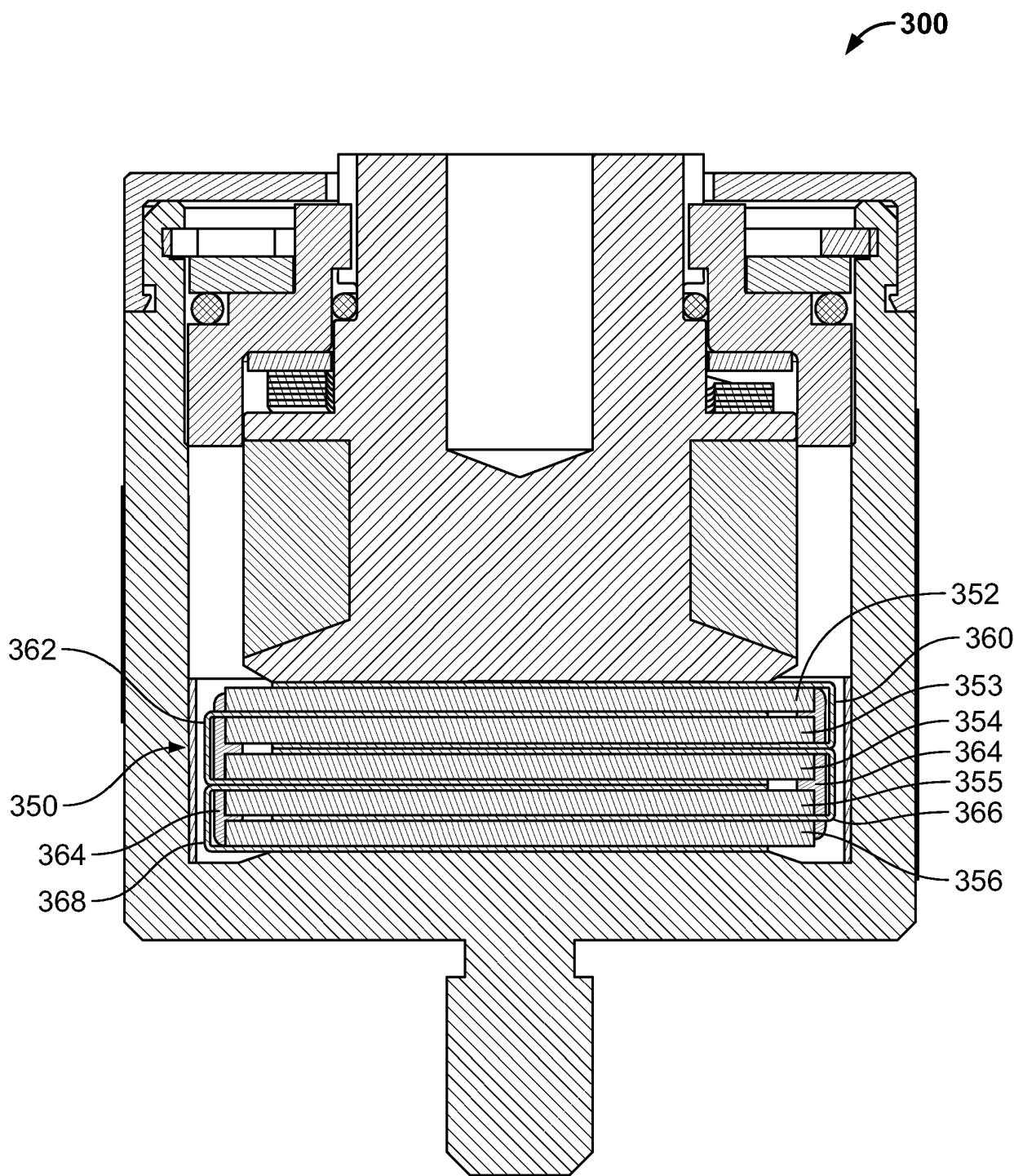


FIG. 13

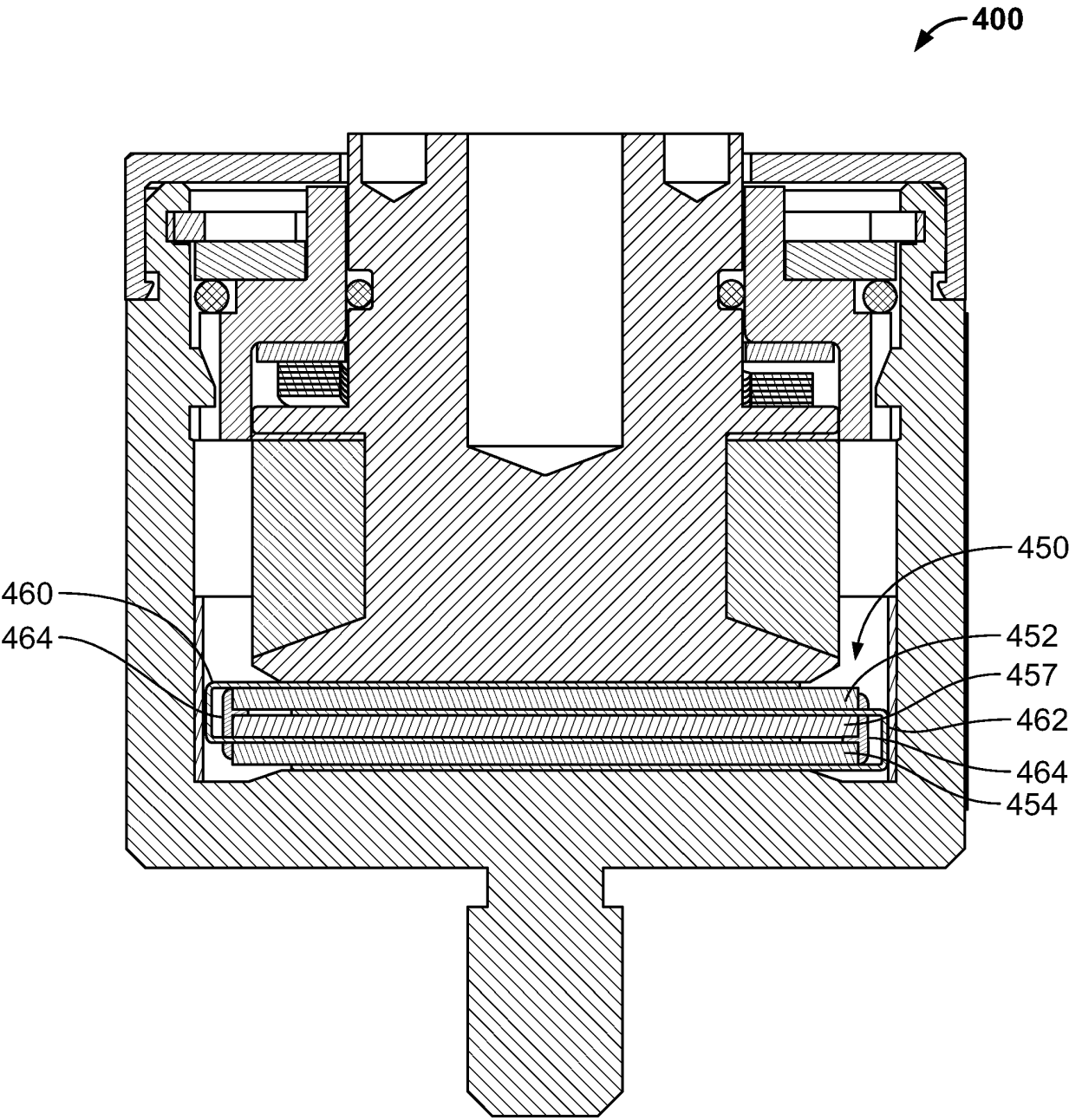


FIG. 14

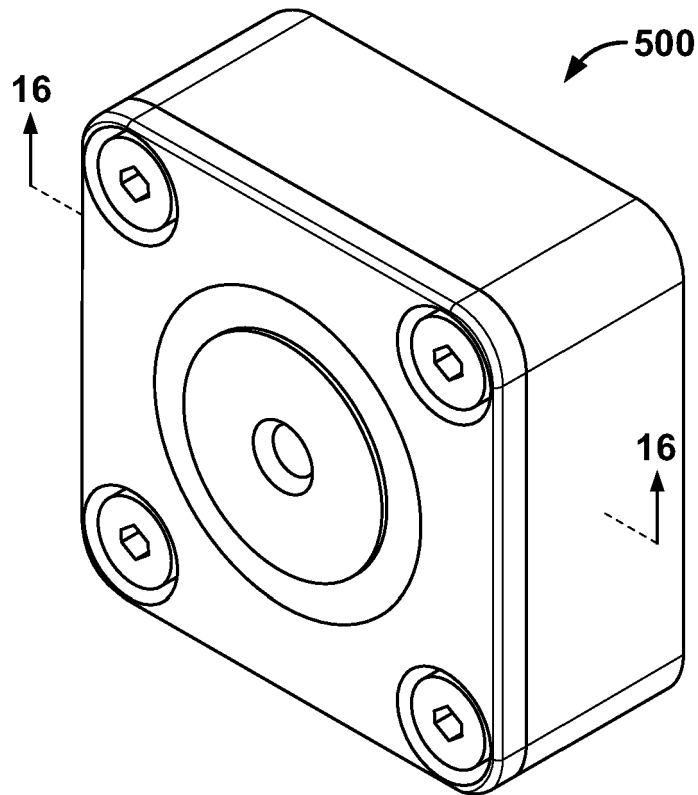


FIG. 15

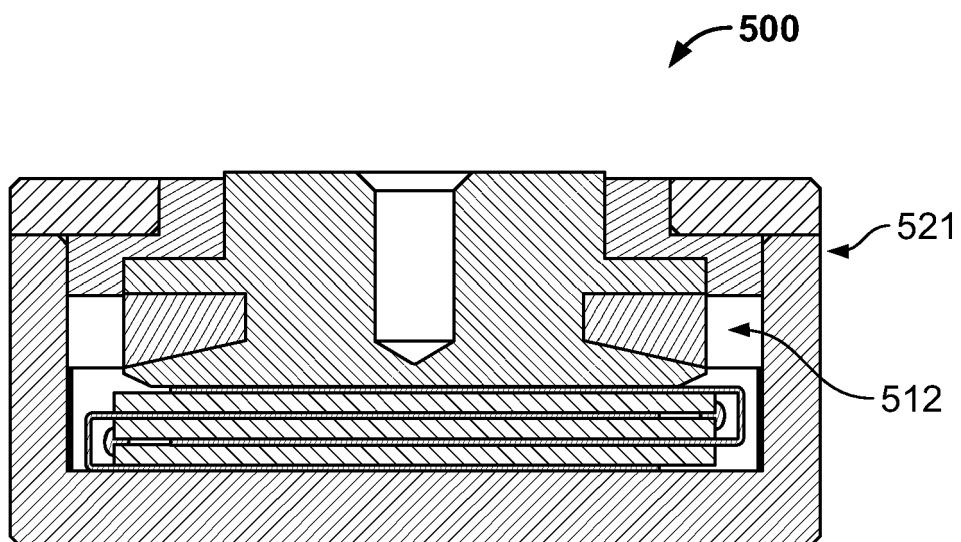


FIG. 16

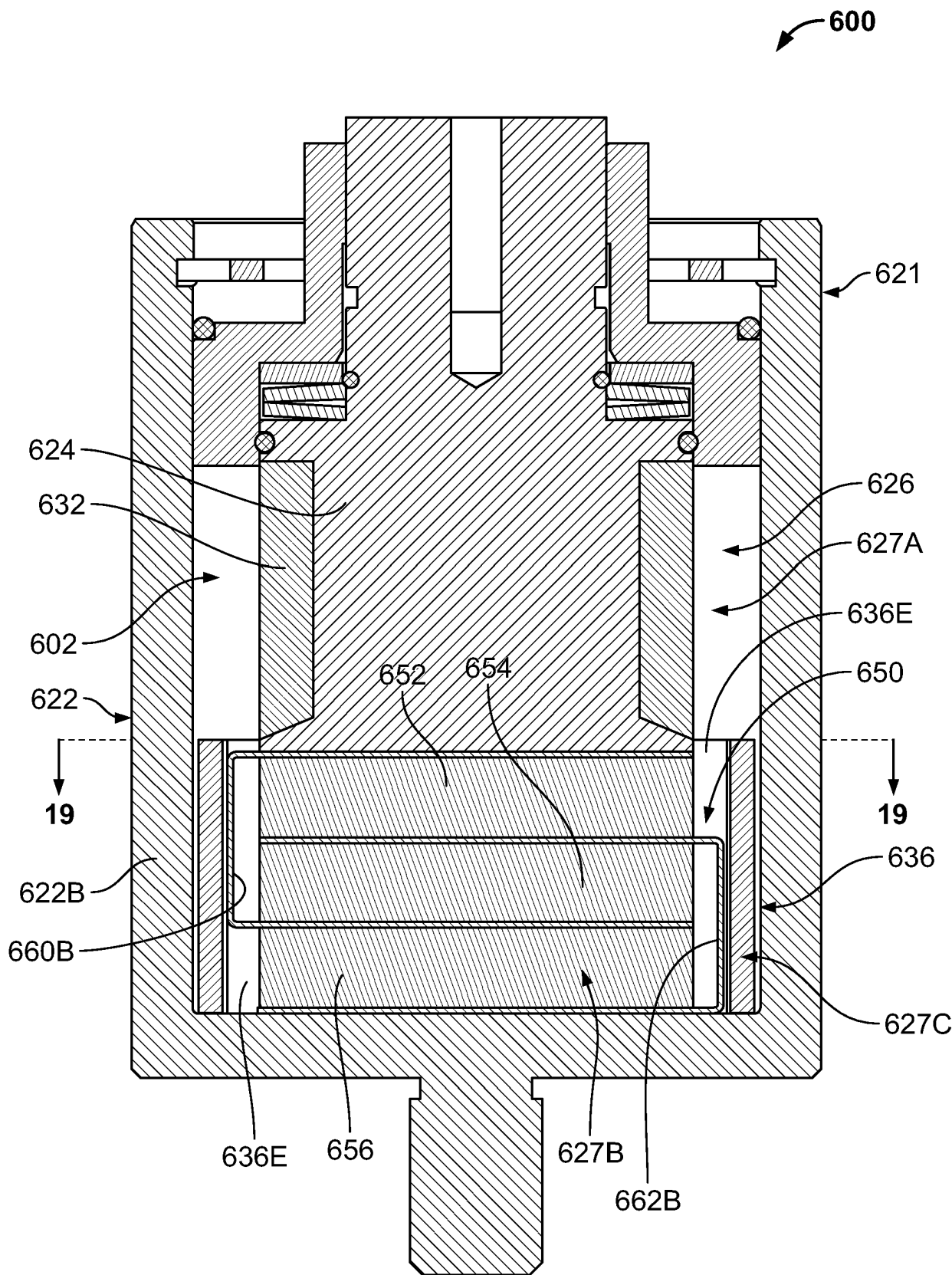


FIG. 17

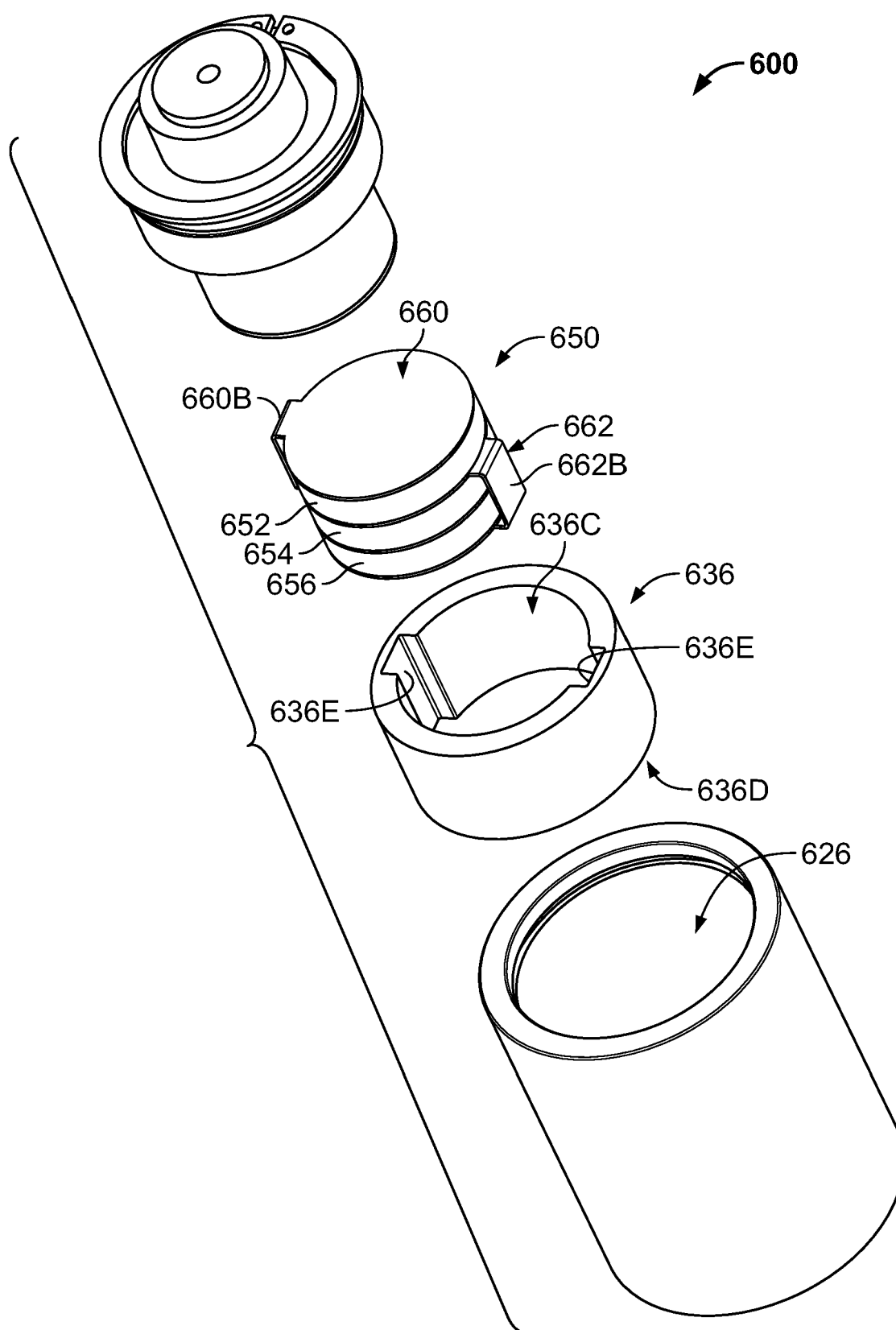


FIG. 18

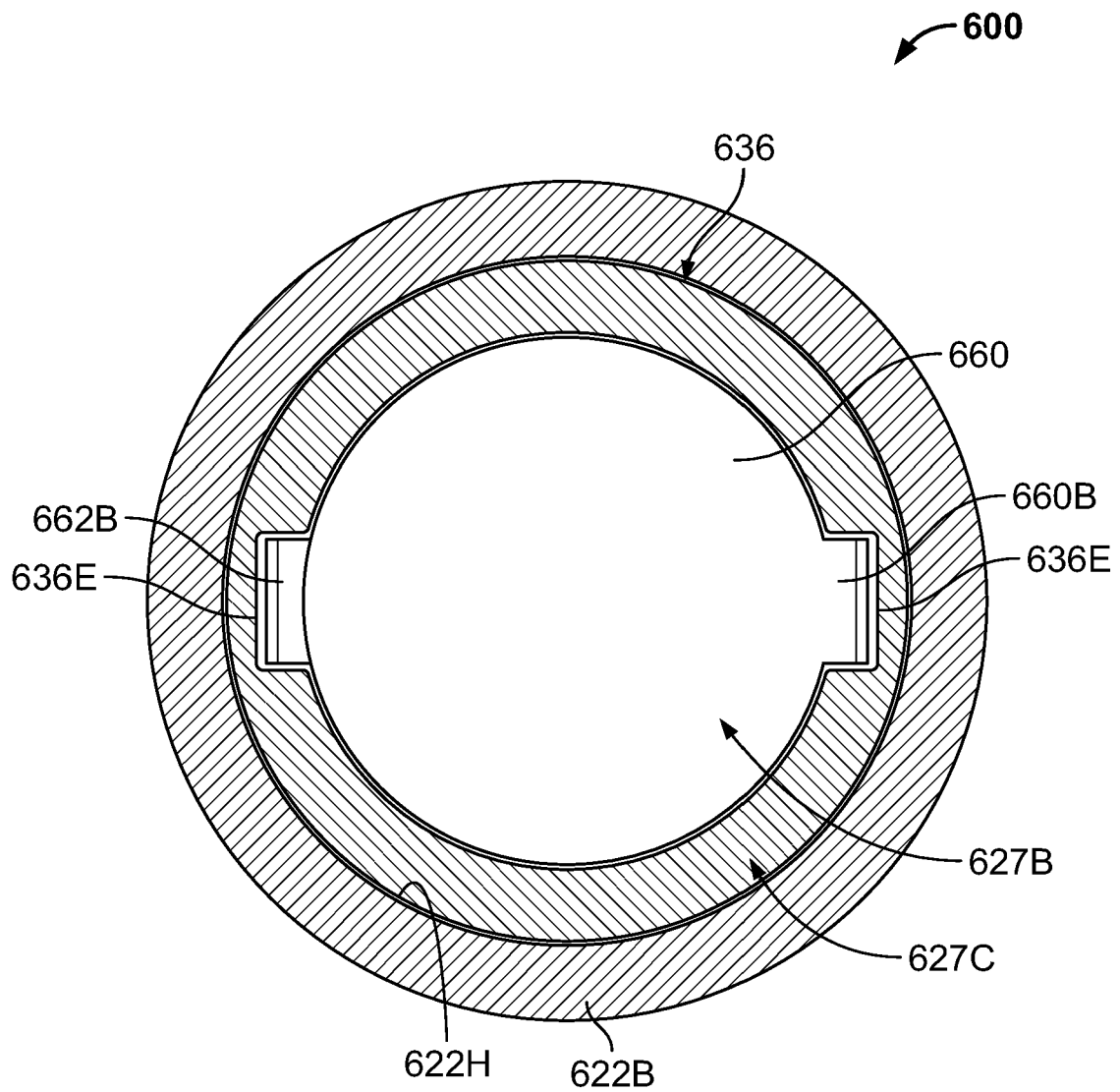


FIG. 19

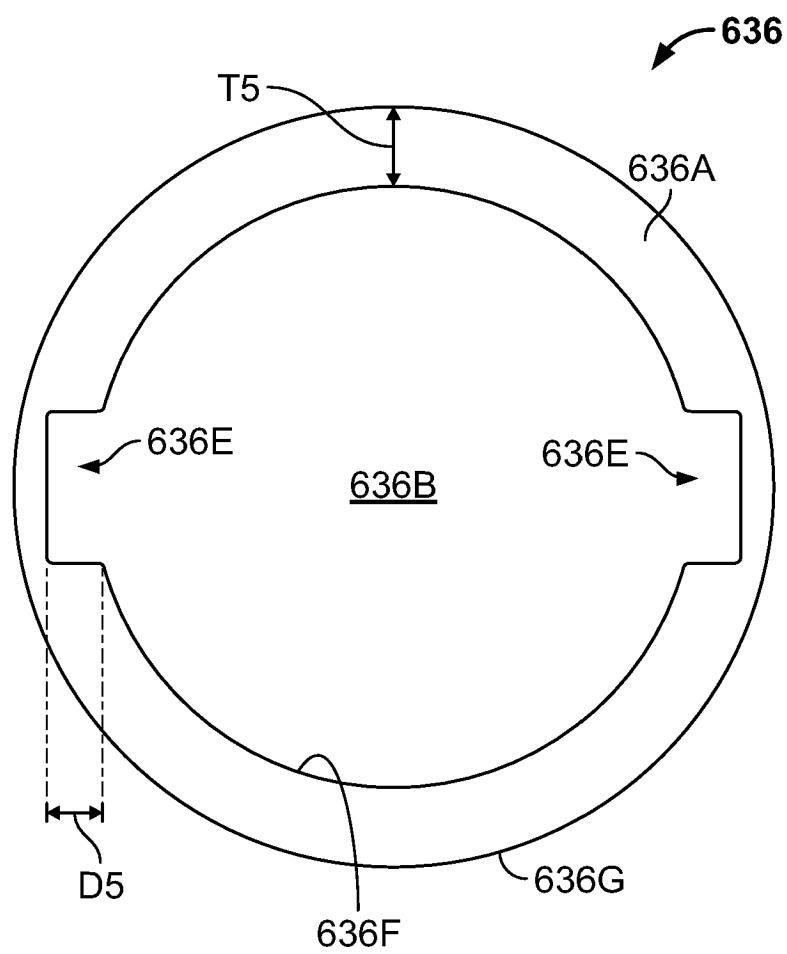


FIG. 20

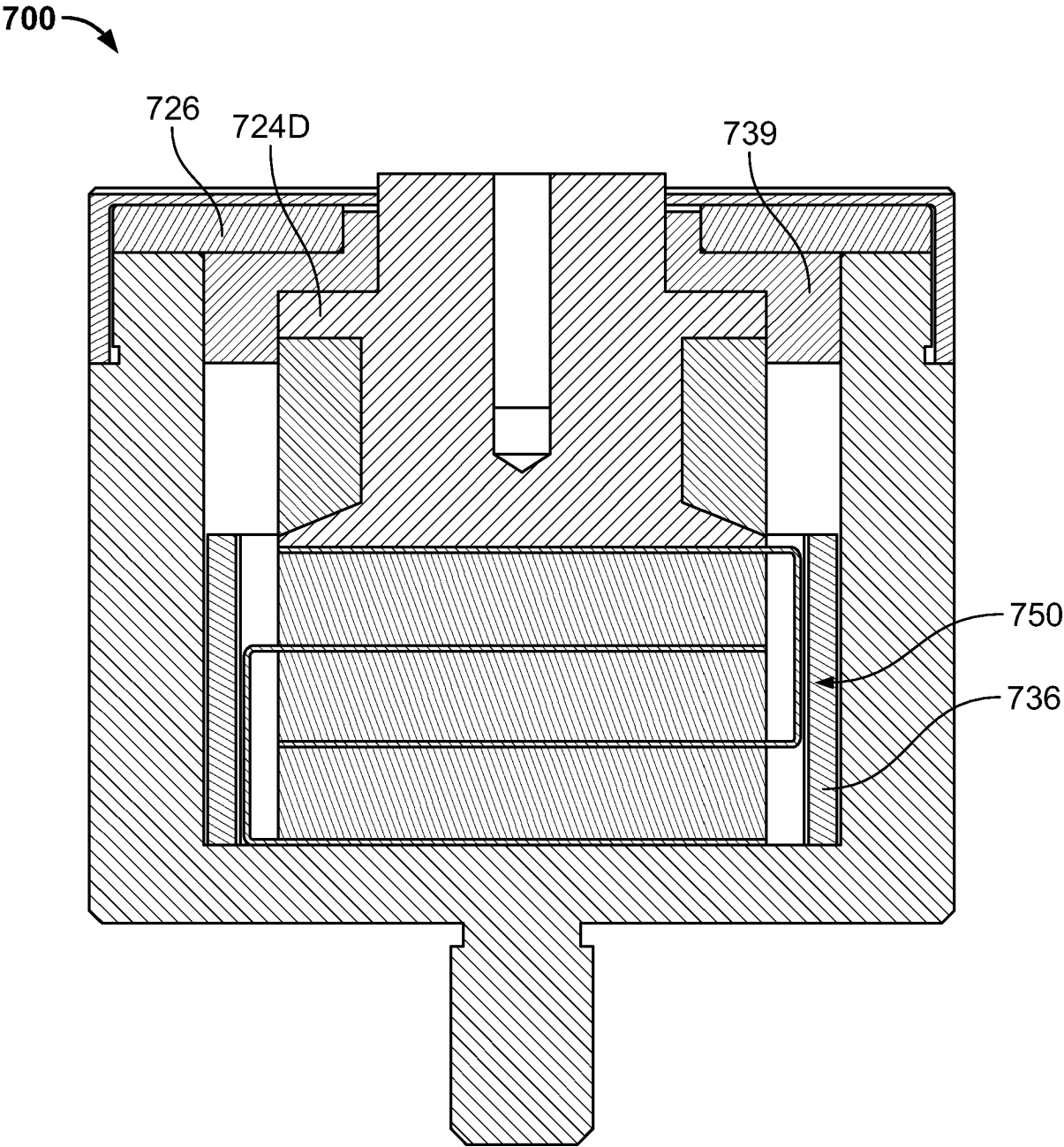


FIG. 21

REFERENCES CITED IN THE DESCRIPTION

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