United States Patent

Cooper

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[54] **ELECTRICAL SURGE DIVERTING CONNECTOR**

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[73] Assignee: **The United States of America as represented by the United States Atomic Energy Commission**

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[52] **U.S. Cl.** **317/61,** 313/51, 317/62

[51] **Int. Cl.** **H02h 9/04**

[58] **Field of Search** 339/111; 317/61, 61.5, 62; 313/51, 312, 318

[56] **References Cited**

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[57] **ABSTRACT**

An electrical connector which provides lightning protection by facilitating arcing of electrical surges over the end of an insulator and cooperating conductive surface employing dielectric to stimulate arc-over and thus substantially reduce breakdown voltage.

11 Claims, 5 Drawing Figures

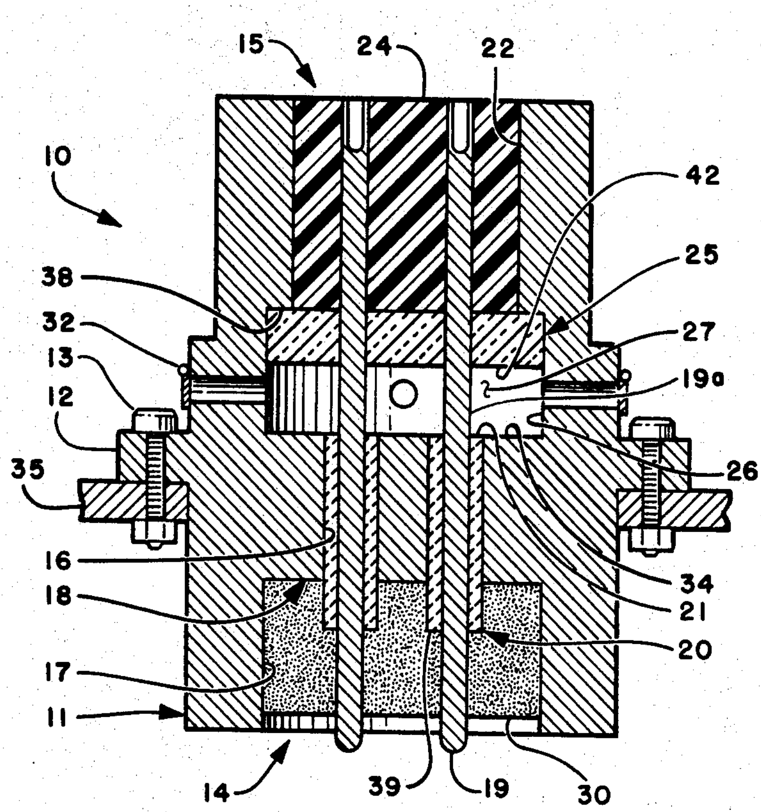

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FIG. 1

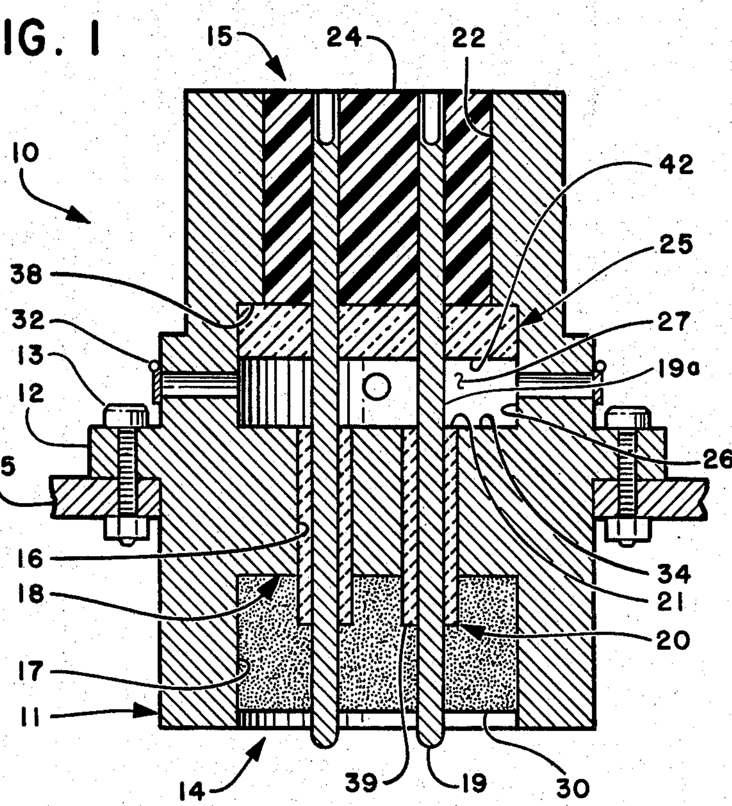


FIG. 2

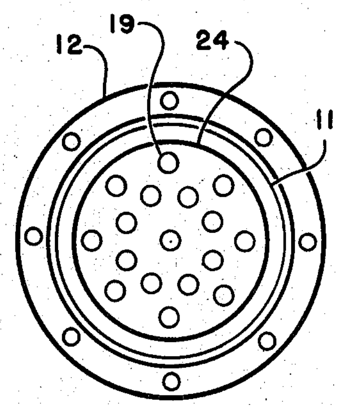


FIG. 3

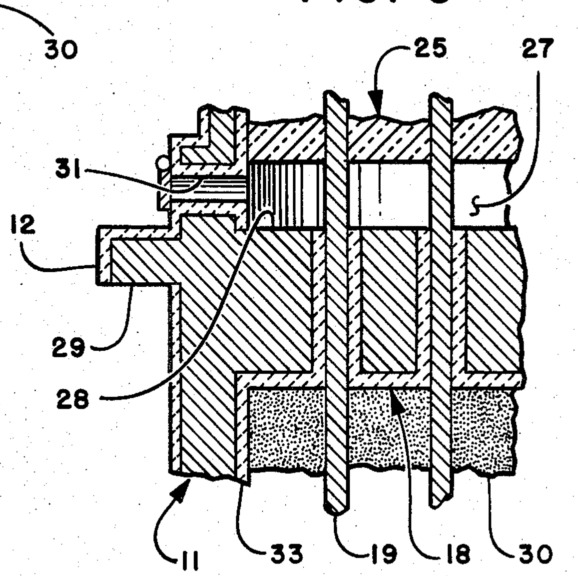
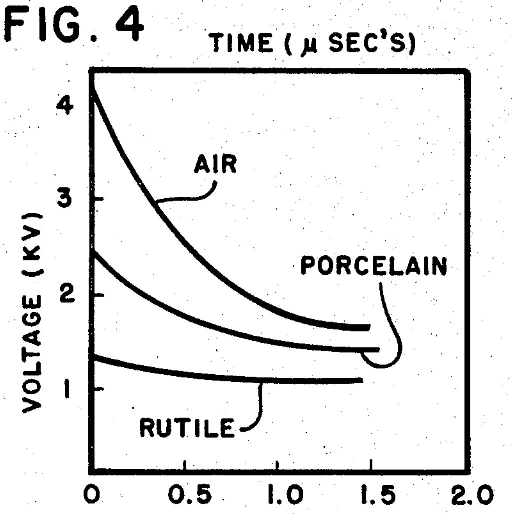
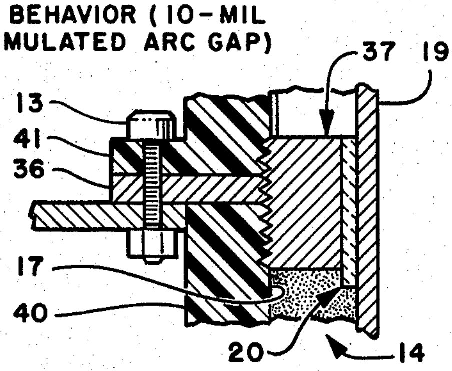


FIG. 4



IMPULSE-RATIO BEHAVIOR (10-MIL DIELECTRIC-STIMULATED ARC GAP)

FIG. 5



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ELECTRICAL SURGE DIVERTING CONNECTOR

BACKGROUND OF INVENTION

Lightning can be a serious hazard to missiles and aircraft. Possible adverse effects include structural damage, fuel detonation, component burnout or malfunction, and ignition of explosives. An unlikely but objectionable effect would be the accidental detonation of on-board explosives.

Not only is a lightning strike upon a missile or aircraft possible, but such a strike can be triggered by the vehicle's entry into a properly charged region. This triggering can take place even in areas where there is no apparent lightning activity. Since missiles and aircraft cannot always be operated in ideal weather, the potential lightning hazard must be considered in detail, especially with regard to safety.

Characterization of the lightning threat is difficult because its intensity and the unpredictability of strike locations and time make measurements difficult. However, a considerable amount of data is available. A typical lightning strike comprises multiple pulses of high current superimposed on a relatively small continuing or "follow-on" current. Pulses are distinguished by relatively steep leading edges and more slowly and decaying trailing edges. Current can flow in either direction, but negative charge is lowered to ground in most strikes. Further, it has been demonstrated that lightning characteristics in striking a tall building are different than the characteristics of lightning striking an open field, a missile or an aircraft in flight.

From a study of the data available, it may be concluded that there is an average of three pulses per stroke with a maximum value of more than thirty; peak currents average about 20,000 amperes (kA) with maximum values of over 200 kA; rise times average about 2.5 micro (*u*) seconds (sec) with minimum times as short as 0.3 *u* sec; follow-on current averages about 250 amperes (A) with maximum values over 1 kA; and total strike duration averages about 0.2 seconds with maximum values greater than 1 second.

In order to provide lightning protection against the lightning characteristics such as outlined above, various approaches have been tried; varistor stacks, air gaps, gas tubes, zener devices, fuses, lightning rods, filters, energy activated switches, etc. However, there has not been provided essentially 100 percent reliability against strokes in excess of 200,000 amperes and within electrical connector size constraints.

SUMMARY OF INVENTION

In view of the limitations and problems as noted above, it is an object of this invention to provide a novel electrical surge diverting connector which overcomes prior art limitations.

It is an object of this invention to provide a lightning arrestor electrical connector suitable for use on aircraft, missiles, weapons, etc.

It is an object of this invention to provide a current and voltage overload switching electrical connector that is structurally simple, mechanically well supported, and has very good transient impulse-ratio responses.

It is an object of this invention to provide a lightning arrestor electrical connector which has high protection probability, high fail-safe probability, and high power handling capability.

Various other objects and advantages will appear and be understood from the following description of the invention and are particularly pointed out hereinafter in connection with the appended claims. Various changes in design, details, materials, etc., as described herein may be made by those skilled in the art without departing from the scope and principles of the invention as brought out in the appended claims. It should be noted that the description of this invention is not intended to restrict or limit the use of this device to lightning arrestors but may be used wherever compact, current or voltage overload switching means are required.

The invention comprises a current or voltage overload switching electrical connector which makes use of dielectrics to facilitate or stimulate an arc at a reduced voltage, which feature permits excellent equipment protection and compact electrical connector structure.

DESCRIPTION OF DRAWING

FIG. 1 is a cross-sectional side view of one embodiment of this invention;

FIG. 2 is an end view of another arrangement of this invention;

FIG. 3 is a cross-sectional, fragmentary view of another embodiment of this invention;

FIG. 4 is a graph plotted for linear ramp waveforms with varying rise time which represents values for the breakdown voltage vs time aspect with rutile, porcelain and air as parameters; and

FIG. 5 is a fragmentary, cross-sectional view of a modified form of this invention.

DETAILED DESCRIPTION

FIG. 1 is illustrative of one embodiment of electrical surge diverting electrical connector **10** which incorporates features of this invention. Electrical connector **10** may include an electrically conductive, generally tubular housing **11** which may have a plurality of ports **31** therethrough which may be at circumferentially spaced locations, and also having flange or other supporting means **12** for mounting said electrical connector **10** on a body or member **35** having apparatus or materials therein or associated therewith which are desired to be protected. Flange means **12** may also be used to conduct and dissipate the electrical energy received from a lightning strike to the body **35** on which flange means **12** may be mounted through suitable attaching and other conductive interconnecting means **13**. Generally tubular housing **11** may also include opposing, partially bored or otherwise hollowed out passageways **14** and **15** which may be called the output end passageway **14** and input end passageway **15**. While FIG. 1 shows ports **31** located on the input end **15** above flange means **12**, the flange **12** could be located at any suitable location even being beyond the ports **31** on the input end **15** side. An apertured first wall portion **25** may be located extending transversely of housing **11** adjacent ports **31** and a second apertured wall portion **18** may extend transversely of housing **11** adjacent ports **31** at a location spaced from first wall portion **25** so as to form with first wall portion **25** an intermediate discharge chamber **27** in communication with ports **31** and second wall portion **18**. Second wall portion **18** may have an exposed electrically conductive surface **34** disposed toward discharge chamber **27** and electrically communicating with electrically conductive housing **11**.

An appropriate number and arrangement of electrical conductors or conductor pins **19** extend through the apertures of the first and second wall portions **25**, **18** and have exposed electrically conductive areas **19a** adjacent electrically conductive surface **34**. FIG. 2 shows one elevation or end view of an embodiment containing 17 conductors which may be used. More or less conductors in the same or different arrangements may be successfully used.

Electrically insulating sleeve means **20** encircle the conductors **19** and maintain the conductors **19** in spaced relationship with the second wall portion **18** and from electrically conductive surface **34**. Sleeve portions ends **21** terminate at locations substantially devoid of projection beyond electrically conductive surface **34** into discharge chamber **27**. Electrical surges may therefore divert from conductors **19**, across the sleeve end **21**, to electrically conductive surface **34** and on to housing **11**.

Sleeve means **20** may be of any appropriate material such as rutile, alumina, barium titanate and the like. Dielectric material having a dielectric constant greater than about 4 and preferably greater than about **50** gives good results. Dielectric constants referred to herein have been measured at frequencies below about 10^8 cycles per second and are generally constant in this region at room temperature of about 25° C. The surface **21** of this high dielectric constant electrically insulating sleeve means **20** is adapted to assist in initiating an arc-over to the second wall portion **18**, i.e., the dielectric sleeve means **20** facilitates or stimulates an arc from a conductor **19** to the second wall portion **18**, and on to the exterior or walls of the body **35** containing apparatus and equipment sought to be protected, using a dielectric simulated arc (DSA).

A suitable potting material **30**, such as certain silicones like room temperature vulcanizing castable silicone rubber, or polysulfide or epoxy potting material may generally encase the electrical conductors **19** and may generally fill the output end passageway **14** in a sealing relationship with the second wall portion **18**. At the input end passageway **15**, a moldable plastic electrically insulative member **24**, which may be such as long glass fiber-filled diallyl phthalate or other suitable filled or unfilled insulating material, such as an epoxy material, generally encases said electrical conductors **19** and may be bounded in a first portion of said input end passageway by the passageway bore wall **22**, the end of the input end passageway **15**, and by a first wall portion **25** of appropriate material. First wall portion **25** has been made of dielectric material such as borosilicate glass. The distance between any conductor **19** and any other conductive surface or wall should be greater than the wall thickness of sleeve **20**. This insures that breakdown occurs across surface **21** and not across surface **42** although nothing said here is intended to restrict the use of this invention to embodiments having sleeve means **20** only on one wall since side wall **25** could just as well be used, either alone or in conjunction with the sleeve **20** of second wall portion **18**, as an arc-over surface. The discharge chamber **27** housed by housing **11** and first and second wall portions **25**, **18** has the electrical conductors **19** passing therethrough, and may be formed as an extension of bored end **15** as an expansion of bore wall **22** with a supporting shoulder **38** and receiving location for first wall portion **25**. The electrical connector housing **11** may include venting means or ports **31** communicating between the exterior of housing **11** and discharge chamber **27** to relieve gas pressure of gases (not shown) created during operation of the electrical connector **10**. Housing **11** may also be made without ports or vents, or may have the vents permanently plugged, if it is determined that the amount of heat and pressure buildup will not cause such a pressure differential such as to be detrimental to or disruptive of operation of the connector. These venting means **31** may otherwise be normally closed with suitable sealing means such as frictionally retained caps, hinged, or otherwise attached dust seals **32** to prevent atmospheric contamination or corrosion of the chamber surfaces, but the seal means need not provide a permanent or hermetic seal. Means **31** may also be used to purge the chamber **27** with an appropriate gas in order to reduce the breakdown voltage and/or to reduce the pressure so as to again result in a reduced breakdown voltage. Further, presence of ports or vents **31** assists in cleaning the discharge chamber during manufacturing of these connectors.

In operation, breakdown may initiate by means of an arc at the surface **21** of the electrically insulating sleeve means **20**, the arc going from conductor **19** to electrically conductive surface **34** of wall **18**, and usually forming at a potential lower than the value for air breakdown and thus providing a further advantage over prior art devices that depended only on air or an inert gas breakdown. In addition, a dielectric stimulated arc breakdown may have enhanced impulse ratios (response to fast transients) as will be discussed later.

Sleeve **20** may be of any suitable insulative material but sleeves having good discharge breakdown characteristics as described below may typically be of alumina, rutile, barium titanate and the like. Materials with high dielectric constants such as greater than about 4 and preferably greater than about 50 tend to show lower static-breakdown voltages and lower impulse ratios and are more suitable for this type of arc-over stimulation service. Thus alumina (Al_2O_3), with a dielectric constant of about 8 readily fits into this type of application since it is easily machined and its temperature coefficient of expansion is compatible with widely used conductor materials. Rutile (TiO_2), which has a dielectric constant varying between about 50 and about 100 with a typical value of about 80 is also more brittle but has been found satisfactory in stimulating an arc and thus reducing the threshold voltage. Barium titanate ($BaTiO_3$), although found to be a good DSA dielectric since it has a dielectric constant varying between about 1000 and about 5000 with a typical value of about 4000 is a more difficult material structurally.

The efficiency of a dielectric to initiate arc-over is seen when comparing voltage requirements for air versus a rutile sleeve which may have 75 mil inside diameter and 10 mil wall thickness. In order for an arc to bridge the same air gap, 1.4 kilovolts (kV) are required. The presence of a rutile dielectric will reduce the voltage further to about 1 kV.

In order to provide protection against current or voltage surges in applications such as above, the transient characteristics of the excursions and the resulting discharge should be determined. Given a particular waveform (usually a ramp), the ratio of the breakdown under transient conditions to that under static conditions is called the impulse ratio. Impulse ratio values in air using ramp input waveforms generally range from about 2 to about 6, using alumina as a dielectric from about 1 to about 1.8, and using rutile from about 0.9 to about 1.2. The general trend of the impulse ratio data is shown in FIG. 4, plotted for linear ramp input waveform with varying rise times for a 10 mil dielectric stimulated arc gap.

The surface configuration and condition of second wall portion **18**, conductors **19**, and electrically insulating sleeve means **20** at the junction points may affect arc-over characteristics. Good results may be obtained by having the electrically conductive surface **34** flush with the sleeve portion end surface **21**. The effect of the sleeve end **21** not projecting to a point flush or even with surface **34** results in an increase in the breakdown voltage although, depending upon the use of the connector, the increase may still be within operable limits. This effect does not affect the breakdown voltage to a significant degree unless the difference in projection is substantial. When the angle of contact between end **21** and conductor **19** is slightly off perpendicular, the lowest breakdown voltages occur, other factors being constant. However, this optimum angle is polarity sensitive and, since electrical current surges from lightning strikes have dual polarity, two optimum angles are formed, depending upon polarity of surge. The breakdown voltages for a perpendicular angle of contact, plus or minus about 15°, are not far from minimum and the use of this angle does away with polarity sensitivity as well as provide an angle close to optimum. The use of this perpendicular angle of contact, plus or minus about 15°, facilitates manufacture of these connectors. Failure to maintain the tolerance from perpendicular does result in a slight increase of breakdown voltage but generally will allow the connectors to remain operable.

Surface **39** of sleeve **20** may extend a suitable distance beyond the wall portion **18** into potting material **30**. This increased distance makes it more difficult for arc-over to occur at surface **39** versus surface **21** as well as prevents movement of the sleeve **20** from the location in which it was set. Connectors of this invention wherein surface **39** was from about 0.05 inches to about 0.1 inches from support wall **18** have been successful. Electrically insulating sleeve **20** wall thickness may vary depending upon the breakdown voltage desired, type of conductor, current expected, etc., but may normally be between 0.005 and about 0.030 inches.

The ratio of distance between conductors **19** or between a conductor **19** and wall **26** across surface **42** of electrically insulative first wall portion **25** to the wall thickness of sleeve **20** should be generally greater than one. This will vary depending upon the type of materials used but maintenance about this value will effectively prevent arc-over across surface **42**. A small gap between the sleeve **20** and the second wall portion **18** or between the sleeve **20** and the conductor or pin **19** may have the effect of increasing field intensification in the gap, with greater increases in field intensification being obtained by using higher relative dielectric constant sleeve means **20**. Microscopic dielectric surface irregularities may enhance the arc-over process because of increased field intensification. Surface **21** roughness is preferably kept below about 1 mil rms.

The conductors **19** may be made of any suitable material and in the quantity required for the function to be performed. Electrical connectors of this invention having **32** conductors of an iron-nickel-cobalt composition, specifically about 29% Ni, about 17% Co, and about 54% Fe, or also about 52% Ni and about 48% Fe, have been successfully made and used. These alloys' thermal expansion rate is compatible with alumina and rutile. Electrical conductors **19** should have a coefficient of thermal expansion within about 30 percent of the coefficient of thermal expansion of the electrically insulating sleeve means **20** and preferably should be about equal. Conductors **19** may have means for interconnecting with appropriate electrical leads and may be cables, wires, pins, etc. Further, these need not be only as long as the housing but could be an electrical conductor line passing through body **35** and interconnecting equipment outside of and inside of body **35**.

The housing **11** may also be made of any suitable material, conductive or nonconductive, depending upon economic and safety factors considered. Some suitable conductive materials are stainless steel, aluminum, copper, nickel, and alloys thereof such as 80% Ni - - - 20% Co alloy. Housings made from **321** and **347** series stainless steels and having wall portion **18** made of **303** and **304** series stainless steels have been successfully used. The housing **11** may be made in segments such as to facilitate manufacturing and assembly processes as long as means providing current conduction from the second wall portion **18** to the exterior body **35** are provided. FIG. **5** is a cross-sectional, fragmentary view of one embodiment of this invention wherein the housing **40**, **41** is made up of a suitable material which may be plastic or otherwise nonmetallic. Means **36** are provided for conducting overload currents to exterior body **35**. As shown in FIGS. **3** and **5**, the second wall portions **18** and **37** respectively, may be either integral with the housing or a separate component with threaded, or the like, means to position and retain the support wall within the housing.

First wall portion **25** may be a low dielectric constant insulative member of any suitable material, such as borosilicate glass, as long as the material selected is not affected by the heat and gases generated in operation of this device, and as long as the operating characteristics of the connector are not adversely affected thereby. The specific dielectric constant of first wall portion **25** is not as significant here, as explained above, as the ratio of the distance between conductive surfaces (such as conductors **19** and conductive surface **26**) to the wall thickness of sleeve **20**, which ratio should be generally greater than one. In general, the material of wall portion **25** may have a lower dielectric constant than the dielectric sleeve means **20**. Suitable material for first wall portion **25**, such as borosilicate glass, are well known and used in the art. In addition, any polysulfide, silicone rubber, epoxy or the like potting material may be used for member **30** as long as a general seal is maintained in the environment in which this connector is to be used.

The electrical connector of this invention may be used at ambient pressure with air or a suitable gas such as neon, hydrogen, argon and mixtures thereof, or at reduced pressure with air and/or a gas from the group listed. Using a 1 mm gap, at pressures less than 5 mm mercury, breakdown voltage is high because of a scarcity of neutral molecules. As the pressure increases, breakdown voltage decreases towards a minimum. Thus, in an air environment with a 1 mm gap, breakdown voltage is minimized at from about 3 to about 7 mm mercury; in hydrogen, at from about 10 to about 20 mm mercury; neon at from about 20 to about 50 mm mercury; and for argon at from about 5 to about 20 mm mercury.

A desirable embodiment of this invention for some instances, as shown in FIG. 3, may use an aluminum alloy body such as A1 60661–T6 series material which has the second wall portion **18** and flange means **29** as integral parts thereof. Here the body is machined to the desired shape and anodized so that the resulting anodic coating **33** constitutes the sleeve means equivalent to sleeve means **20** of FIG. **1**. This embodiment may eliminate what may be a tedious and generally more expensive need for making dielectric sleeves to a certain dimension to fit over the conductors and within the apertures of the support wall. Conductivity is maintained by grinding or removing the anodic coating off the support wall surface **28** and, secondly, by removing the coating off a suitable electrical connector location where contact is made with the body being protected such as the exterior side of the housing in the area of the mounting flange **29**. This grinding can be eliminated by the use of appropriate techniques such as masking prior to anodizing.

Although these devices may fail under high-current lightning strikes, fail-safe protection can be facilitated by fusing connector pins. This means that for severe lightning strikes, the affected connector pins may explode causing molten metal to be deposited around the air chamber, reducing the pin-to-shell breakdown voltage or shorting pins to the metal shell. The explosive nature of the pin failure seems to reliably give the desired deposition of metal around the air chamber. The ease with which this can occur relative to the difficulty of eating completely through the metal housing provides a large measure of fail-safe confidence for this invention.

Techniques within the skill of the art to prevent electrical leakage at places other than where arc-over is to occur, may be used. Such techniques are well known in the art and include the use of appropriate adhesives at junctures of dissimilar materials.

What is claimed is:

1. An electrical connector for diverting electrical surges comprising an electrically conductive generally tubular housing, a first apertured wall portion extending transversely of said housing, a second apertured wall portion extending transversely of said housing at a location spaced from said first wall portion forming with said first wall portion an intermediate discharge chamber and said second wall portion having an exposed electrically conductive surface disposed toward said discharge chamber and electrically communicating with said electrically conductive housing, electrical conductors extending through said apertures and said discharge chamber each having exposed electrically conductive areas adjacent said electrically conductive surface, electrically insulating sleeve means encircling said conductors and maintaining them spaced from said second wall portion and from said electrically conductive surface and having sleeve portion ends terminating at locations substantially devoid of projection beyond said electrically conductive surface into said discharge chamber, whereby electrical surges divert from said conductors across said sleeve portion ends to said electrically conductive surface within said discharge chamber and thence to said housing.

2. The electrical connector of claim **1** wherein said generally tubular housing is provided with a plurality of ports therethrough at circumferentially spaced locations and communicating with said intermediate discharge chamber.

3. The electrical connector of claim **2** wherein sealing means is provided over said ports for venting said discharge chamber.

4. The electrical connector of claim **1** wherein said tubular housing and said second wall portion are a unitary conductive metal structure.

5. The electrical connector of claim **1** wherein said electrically insulating sleeve means has a dielectric constant, measured at frequencies below about 10^8 cycles per second at room temperature of about 25° C, of greater than about 4 and wherein said sleeve means is taken from the group consisting of alumina, rutile, barium titanate and combinations thereof which have a substantially constant dielectric constant at frequencies below about 10^8 cycles per second at about 25° C.

6. The electrical connector of claim **1** wherein the electrical conductors are of about 50 to 54 percent nickel and about 50 to 46 percent ion, and wherein said electrical conductors have coefficients of thermal expansion within about 30 percent of the coefficient of thermal expansion of said electrically insulating sleeve means.

7. The electrical connector of claim **1** wherein said sleeve portions ends are substantially flush with said electrically conductive surface.

8. The electrical connector of claim **1**, including gas taken from the group consisting of neon, hydrogen, argon and mixtures thereof disposed in said discharge chamber.

9. The electrical connector of claim **8** wherein said discharge chamber is at a pressure of from about 10 mm to about 20 mm of mercury.

10. The electrical connector of claim **1** wherein said discharge chamber is at a pressure of from about 3 mm to about 7 mm of mercury.

11. The electrical connector of claim **1** wherein the sleeve means has a wall thickness of from about 0.005 inches to about 0.030 inches.

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