Nov. 16, 1948. J. R. McFARLIN 2,453,719

EXCESSIVE POTENTIAL DISCHARGE DEVICE

Filed Aug. 12, 1942 3 Sheets-Sheet 1

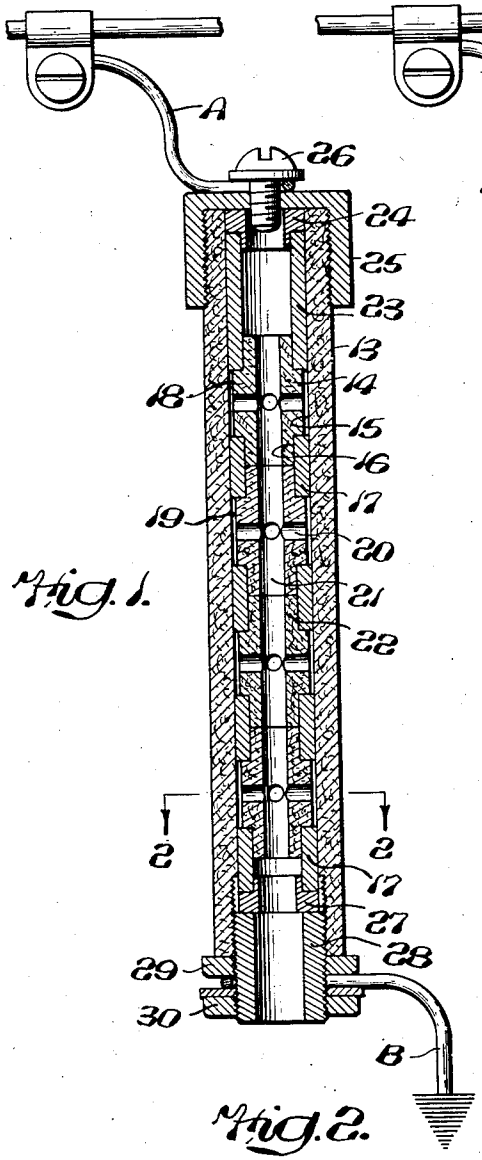



Fig. 1.

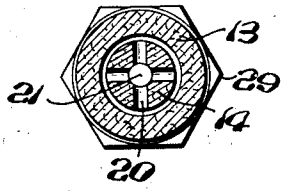



Fig. 2.

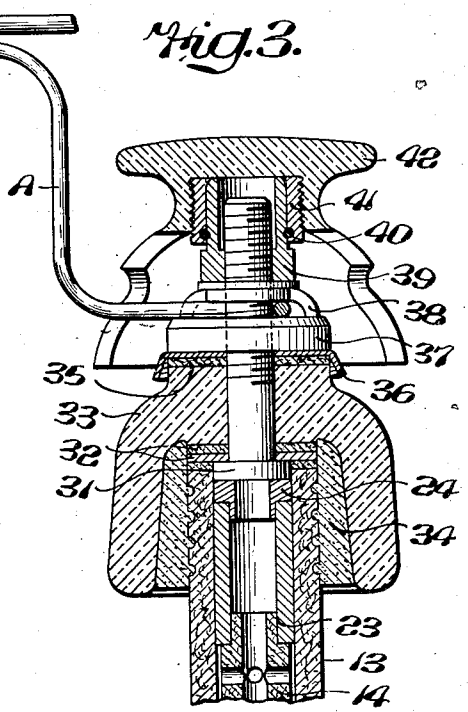



Fig. 3.

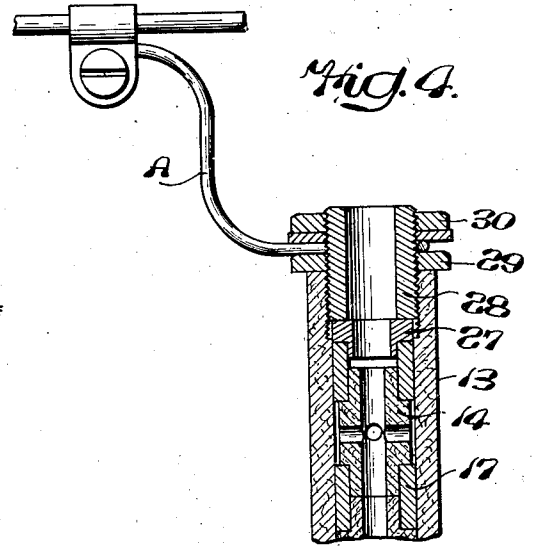



Fig. 4.

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EXCESSIVE POTENTIAL DISCHARGE DEVICE

Filed Aug. 12, 1942 3 Sheets-Sheet 2

Fig. 6.

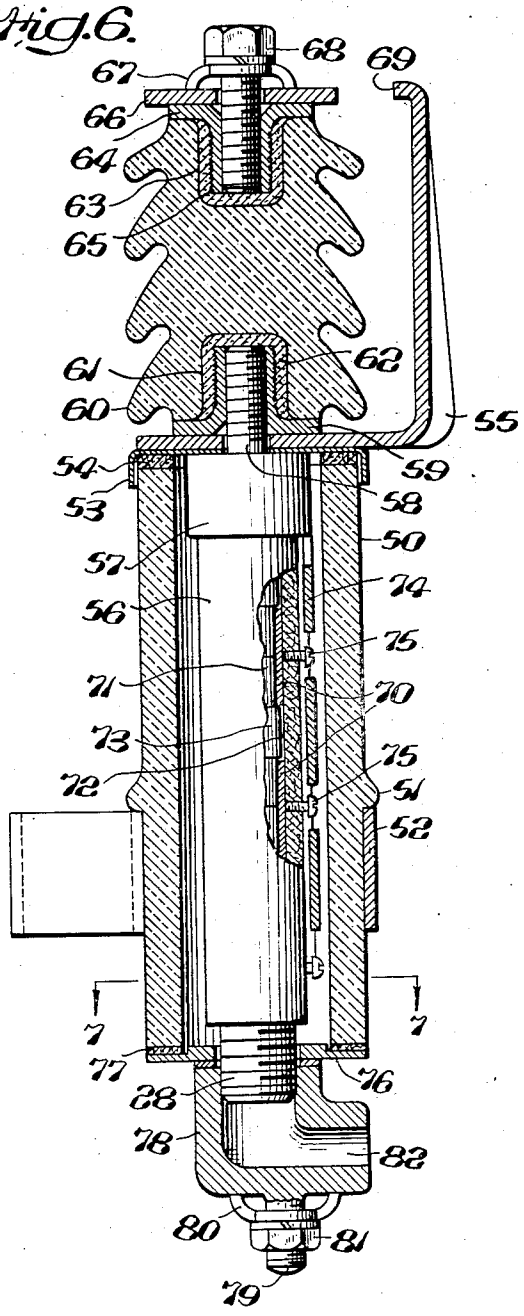



Fig. 7.

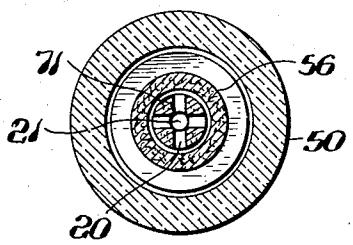
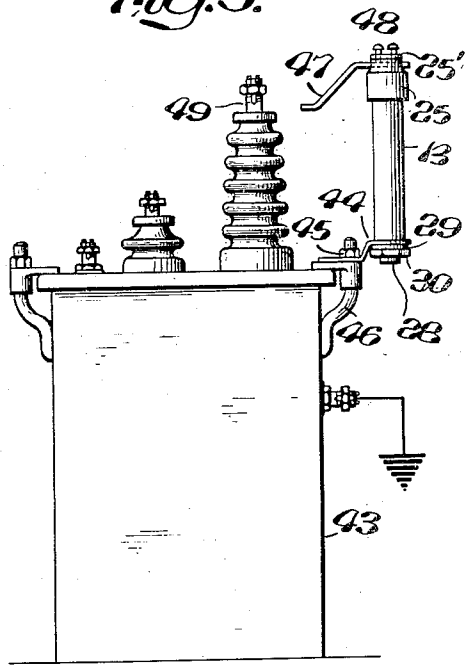



Fig. 5.




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EXCESSIVE POTENTIAL DISCHARGE DEVICE

Filed Aug. 12, 1942 3 Sheets-Sheet 3

Fig. 8.

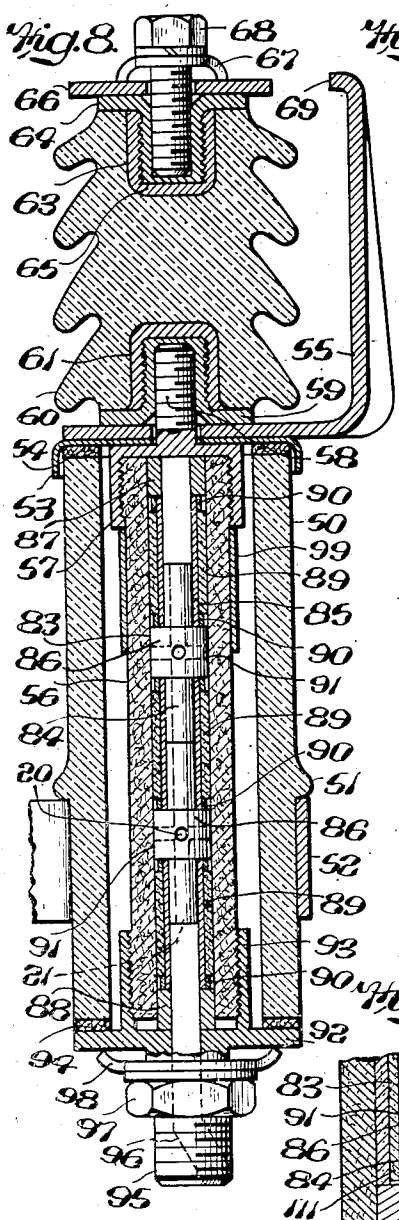



Fig. 9.

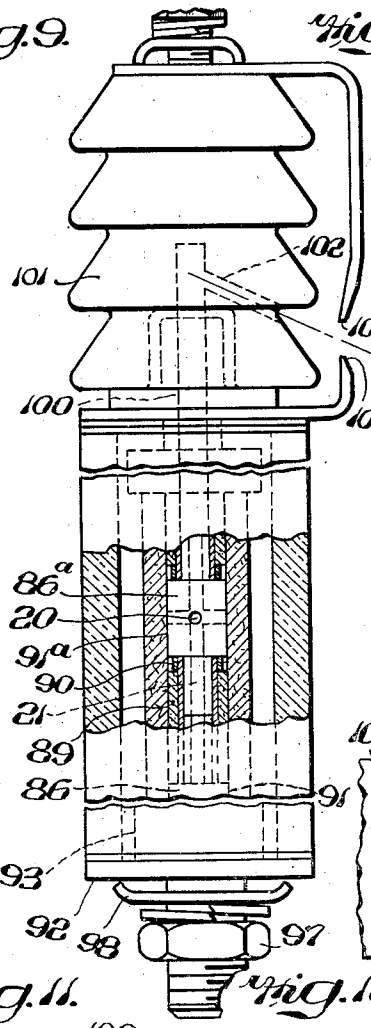



Fig. 10.

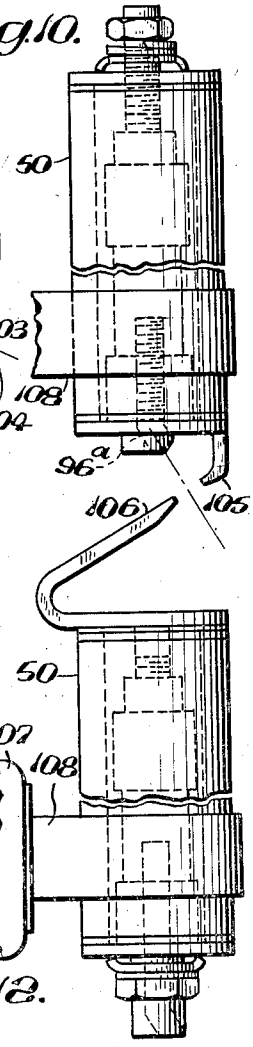



Fig. 11.

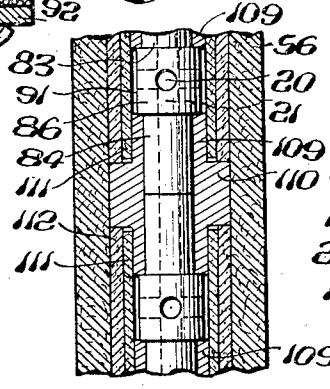
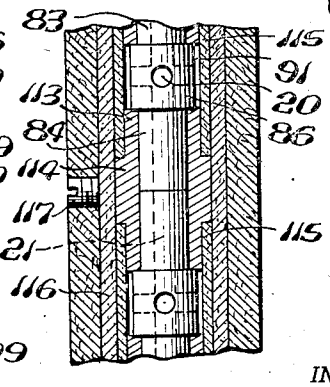



Fig. 12.




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Patented Nov. 16, 1948 2,453,719

# UNITED STATES PATENT OFFICE

2,453,719

## EXCESSIVE POTENTIAL DISCHARGE DEVICE

John Robert McFarlin, Philadelphia, Pa., assignor to Electric Service Manufacturing Company, a corporation of Pennsylvania

Application August 12, 1942, Serial No. 454,594

13 Claims. (Cl. 175—30)

1

My invention is a protective device for discharging excessive electrical potentials from electrical circuits or equipment and for quickly suppressing arcs maintained by dynamic or follow current, if present, across gaps or spaces ionized by the high potential discharge.

Protective devices of the type to which my invention relates are utilized for discharging to ground surges caused by lightning to protect the insulation of electrical circuits and equipment from the effects of the excess voltages impressed thereon by the lightning and are commonly, and herein, referred to as "lightning arresters" or "arresters" regardless of their actual use. They are also used for limiting injurious voltages from other sources which tend to puncture, flash-over or otherwise deteriorate insulation unless an arrester is connected in shunt therewith, as, for instance, between the tank and windings of a transformer; between the primary and secondary windings of a transformer, or between the tank or either winding of a transformer and earth. Such devices are particularly useful where the potential is too great to permit the interruption of an arc by the normal de-ionization of gas which occurs at the first current zero of an alternating current wave. They are characterized by their provision of a path for the ready discharge of high potential current but containing a gap or gaps having an aggregate width too great to be flashed-over by the normally applied dynamic potential and by their provision of means for interrupting a "follow-current" arc, if present, and restoring its original operating conditions.

My improvements are embodied in a protective discharge device comprising a non-conductive housing containing a plurality of gap electrodes, an arc confining slot or slots between electrodes and a centrally located tube containing a pressure relief passage communicating through ports in the tube with the slot or slots.

The electrodes and slots are arranged in series in alternation with one another and surround the axially disposed relief passage which communicates in parallel with the arc slots when more than one of the latter are employed.

Preferably each arc slot is bounded laterally by concentrically curved, spaced walls, and hence has, in transverse cross section, the shape of a narrow rectangular slot bent around and spaced from an axis.

The ends of each arc slot are closed by ends of gap electrodes, and the peripheral surface of each gap electrode preferably contacts the inner surface of the housing and is shielded thereby from

2

destructive action of arc gases. If, however, the device is so designed as to permit generation of sufficient pressure in the slots to cause bulging of the housing wall away from the outer surfaces of the electrodes, the latter may be protected from the arc gases by sleeving a shield thereon.

Some or all of the lateral walls of the slots and the wall sections or shields surrounding the electrodes are preferably composed of or contain gas generating substances activated by an arc to produce de-ionizing gases. Thus the pressure and turbulence produced in air-filled constricting arc slots by arc discharges therethrough may be augmented by the generation of de-ionizing gas in the slots from a gas generating substance contacted by the arc and preferably forming one or more of the walls of the slots. For some uses, the gas generating substances may be wholly or partly dispensed with where the arc itself creates sufficient pressure and turbulence to facilitate its extinction at a current zero.

In a protective device containing arc gaps in series, there is generally a tendency for disproportionately higher percentages of the total voltage to be impressed across the gaps nearest the line connection of the device. In my improved device I may utilize this characteristic of series gaps or I may adjust the voltage gradient to a uniform value per unit length of insulator or gap by shunting the gaps with resistance, which may be accomplished in a number of ways, so that voltage distribution across the series may be controlled by inter-gap resistance rather than by inter-gap and gap-ground capacitance.

The normal characteristics of the gaps may also be altered by shielding, that is, by surrounding a section of the device adjacent to the gaps either with metallic tubes, a winding of wire or by placing in proximity thereto metallic strips which, due to capacitative effects, modify the electrostatic field. Such shields may be made from either magnetically or non-magnetically permeable material and are preferably electrically connected to either the line or ground terminal of the device and insulated from the gap electrodes, although in lieu of this they may be electrically connected to either the line electrode of the first line gap or the ground electrode of the last ground gap, being insulated from all other gap electrodes.

The voltage impressed across the different gaps may also be proportioned by varying the axial lengths of the respective slots between gap electrodes in inverse proportion to the percentages of the total voltage normally impressed

across the respective arc gaps when the gap electrodes are equally spaced.

The proportioning, adjustment or shielding of the gaps offers a control in the design of the device for the purpose of varying the initial operation of the device, that is, its impulse breakdown voltage value and characteristics. Control following initial operation may be effected by proportioning the sizes of the pressure relief vents from the respective slots so that the pressures in such slots are the same or different from one another, and in other ways hereinafter described.

In my device, direct transmission of gas pressure from one arc confining slot or space to the next is minimized or prevented by the gap electrodes and housing or sleeve surrounding the electrodes and the gas from each slot is vented in parallel into a common discharge passage so that uniform, progressive or otherwise different gas pressures in the different slots may be maintained as desired to meet particular conditions. The width of the arc slots may be so designed as to produce optimum suppressive effects on the arcs without any necessity for providing for the escape through one slot of gas generated in other slots. The areas of the vents between the arc slots and pressure relief passage may be so proportioned to the areas of the slots and passage and the volume of generated gas that the pressure in the arc slots may be so controlled as to produce optimum effects on the arc independently of the spacing of the walls of the arc slots. In other words, slot widths and gas pressures, both of which exercise profound influences on arcing and arcs, may be independently provided for and so co-related with one another and with the character and location of the gas-generating substance as to provide maximum arc suppression without endangering the structure by destructive gas pressure in any part thereof.

The pressure relief passage to which the arc slots are vented may discharge at one or both ends of the device through a port or ports so disposed that streamers expelled therefrom cannot short-circuit any portion of the device or facilitate flash-over between the terminal electrodes thereof. If desired, the discharge port or ports from the pressure relief passage may be so disposed as to expel a blast, of non-ionized gas and de-ionized gas under pressure, into the path of an external arc to assist in the suppression of an arc formed between electrodes of an arrester or between electrodes of series-arranged arresters or between electrodes of arresters connected respectively with phases of a multi-phase system on the ground side thereof.

The characteristic features and advantages of my improvements will further appear from the following description and the accompanying drawings in illustration thereof.

In the drawings, Fig. 1 is a longitudinal sectional view of a simple form of protective device embodying certain features of my invention; Fig. 2 is a transverse sectional view on the line 2—2 of Fig. 1; Fig. 3 is a fragmentary longitudinal sectional view of a protective device similar to that shown in Fig. 1 with a modified top closure; Fig. 4 is a fragmentary sectional view of a protective device similar to that shown in Fig. 1 but provided with similar blast discharge ports at the upper and lower ends thereof; Fig. 5 shows a protective device generally similar to that illustrated in Fig. 1 mounted in shunt between the line terminal and grounded tank of a transformer; Fig. 6 is a longitudinal sectional view, with parts broken away, of a further developed protective device embodying features of my invention; Fig. 7 is a transverse sectional view on the line 7—7 of Fig. 6; Fig. 8 is a longitudinal sectional view of a protective device generally similar to that shown in Fig. 6 but having the internal gap electrodes encircled by shielding sleeves and sundry details modified; Fig. 9 is a longitudinal elevation, with parts broken away of a further modified protective device having an external arc gap aligned with the blast discharge port; Fig. 10 shows an assembly of protective devices with an arc gap between them aligned with the blast discharge port from one of the devices; and Figs. 11 and 12 are fragmentary sectional views illustrating the partial shunting of arc gaps by resistors tending to equalize the voltages across arc slots.

In the embodiment of my invention illustrated in Figs. 1 to 5 of the drawings, a cylindrical tubular member 13 encloses a concentric, sectional tubular member 14 which is air-spaced from the inner wall 15 of the member 13 and contains peripheral grooves 16 forming seats for annular gap electrodes 17. The electrodes 17 are arranged in series with one another and project peripherally slightly beyond the peripheral, equilinear surface sections 18 of the tube 14 which lie between the grooves 16. The electrodes 17 preferably make a close slip fit with the inner surface 15 of the tube 13 and center therein the tube 14 so that the concentrically curved concave wall 15 of the tube 13 and convex wall sections 18 of the tube 14 form arc slots or spaces 19 of substantially uniform narrow radial width. Such width is exaggerated in the drawings for the sake of clearness, and in practice is generally of the order of $\frac{1}{1000}$'' or less when used in connection with ordinary distribution circuits. The gap electrodes 17 separate the arc slots 19 from one another; the slots 19 being arranged in series and in alternation with the series gap electrodes 17.

Each arc slot 19 surrounds, and communicates through one or more vent ports 20 with, an axial pressure relief passage 21 extending axially through the center of the tube 14 so that pressure, resulting from the action of arcs in the arc slots 19, may be relieved through the ports 20 and passage 21 without injury to the tubes 13 and 14 and without being transmitted from one to another of the arc slots 19, which may be substantially pressure-sealed from one another by the gap electrodes 17.

The tubes 13 and 14 may both be composed of fused material, such as porcelain, steatite, glass, or Bakelite, and in such case the pressure results from thermal expansion of air in the slots 19. But preferably one or both tubes 13 and 14 are composed of or contain thermally activated gas-generating material and hence the pressure resulting from air expansion is augmented by the generation and expansion of non-ionized gas from the heat-activated gas-generating substances of which either or both of the tubes 13 and 14 are, wholly or partly, composed. The most convenient and satisfactory gas-generating substance for such use is hard fibre, or horn fibre, but other suitable substances may be used, if desired, such as boric acid or compositions containing it. To increase its weatherproofness and durability, the tube 13 may be made of an inner lamina of such fibre surrounded by an outer lamina of resinous material, such as Bakelite or varnish.

The inner tube 14 is preferably built up from end-abutted complementary similar tubular elements each containing a section of the axial

passage 21 and four equi-distant radial passages 20 extending from the axial passage 21 to a peripheral surface section 18. Each element has end sections 22 which are of reduced diameter, and complementary pairs of reduced end sections 22 of adjacent elements are telescoped within opposite ends of a metallic ring electrode 17 and form the groove 16 in which the electrode is seated. The electrodes make close slip fits with the peripheries of the ends 22 of each element and act as ferrules minimizing, or substantially preventing, any radial expansion, splitting or bursting of the tubular elements from the effects of moisture, heat, or pressure.

Inner tubes 14 of various lengths may be built up by assembling the requisite numbers of standardized tubular elements and electrodes 17 for the construction of arresters of various ratings. These inner tubes 14 of various lengths may be housed within outer tubes 13 of complementary lengths, or, within limits, outer tubes of a given length may be used as housings for different length inner tubes by the use of conducting spacers, or of electrodes of different lengths, between the end elements of the inner tube 14 and the terminal electrodes of the protective device.

For example, in Fig. 1, the inner tube 14 is built up of four abutted fibre elements, the uppermost of which is spaced axially from the top of the tube 13 by the interposition of an elongated electrode 23 and bushing 24 between the upper element and a metallic screw cap 25 screwed onto the externally threaded upper end of the tube 13 to provide an external terminal electrode for the attachment of a line conductor A by means of a screw 26. The lowermost fibre element of the tube 14 is spaced from the bottom of the tube 13 by an electrode 17, bushing 27 and exteriorly threaded hollow nipple 28, which is screwed into the interiorly threaded lower end of the tube 13 to press toward one another and axially align the fibre elements of the tube 14 and the conducting members 27, 17, 23, 24 and 25. The nipple 28 has threaded thereon complementary nuts 29 and 30 between which may be gripped a ground conductor B.

It will be apparent that by varying the number and size of the elements 28, 27, 17, 23 and 24 a greater or lesser number of fibre tube elements may be housed within the tube 13 with consequent variation in the number of arc slots 19 and changes in electrical characteristics of the device. Arresters for low voltage circuits or equipment may require but one arc slot and hence have an inner tube 14 comprising but a single standardized tubular element, such as described, with ring electrodes 17 on the reduced ends thereof and connected with, or forming, terminal electrodes of the device.

The conducting and arcing members 28, 27, 17, 23, 24 and 25 are preferably made from iron or ferrous alloy to minimize burning or melting and strengthen the arrester and its parts against splitting or bursting.

It is desirable for manufacturing economy that the tube 14 be symmetrically made up of standardized elements with resulting series arc slots 19 of equal length, but, when it is desired that the total voltage impressed on the device be subdivided substantially uniformly across the successive arc slots, the length of the successive slot lengths may be progressively shortened by the use of progressively shorter elements or resistors or shields may be used as hereinafter described.

In lieu of the simple screw cap end closure of Fig. 1, I may provide an insulating end closure for the tubes and an insulated shield covering the connection between a line or a ground conductor and a terminal electrode, as illustrated in Fig. 3. In this construction, the conducting end bushing 24 has seated thereon the head of a conducting stud 31 having a shank passing through apertured washers 32 and the apertured top of an insulating concave cap or hood 33. The cap is permanently bonded to the grooved end of the tube 13 by a suitable cement 34 which forms a fluid-tight joint between the periphery of the tube 13 and the skirt of the cap 33.

A sealing gasket 35 is pressed against the stud 31 and cap 33 by a flanged washer 36 and nut 37. The nut 37 has an upper face extending substantially normal to the axis of the stud 31 to form a bearing surface complementary to the dished apertured member 38 which is sleeved on the stud 31 and has lips projecting toward the surface of the nut 37 within the limits thereof to form a cup-like member which may be pressed into binding engagement with a line or ground conductor A by a threaded nut 39. The nut 39 contains a peripheral groove forming a seat for a split annular spring 40 engaged in an annular groove on the inner surface of a bushing 41 in the rotatable concave cap or hood 42. This cap 42 has a slotted flaring skirt to permit the passage of the conductor A, which is gripped between the members 38 and 37. The caps 33 and 42 minimize the possibility of accidental contact with live parts of the device as well as provide shields against inclement weather.

While it is generally desirable that a closure be provided for one end of the arrester, this is by no means essential, as both ends of the arrester may be left open to atmosphere and the upper end thereof provided with terminal elements 27, 28, 29 and 30 as shown in Fig. 4, similar to those used at the bottom of the arrester, as shown in Fig. 1.

Whether the arrester be open at both ends or have one end closed, it is electrically immaterial which end is connected with line and which end with ground when the arc forming and suppressing elements in the arrester are electrically symmetrical, as in Figs. 1 to 4, but where provision is made for equi-potential distribution across the gaps, as hereinafter described, the installation of the arrester should be made to maintain such distribution by connecting the appropriate ends thereof with line and ground respectively.

The protective device need not be connected with continuous line and ground leads but may sometimes advantageously be so mounted as to provide an external arc gap auxiliary to the internal gap or gaps of the arrester itself. For example, as illustrated in Fig. 5, an external arc gap may be provided between an arrester electrode and a conducting member whose potential is to be equalized with that of a member on which the arrester is grounded. As shown in this figure, a grounded transformer tank 43 has an apertured, bent conducting bracket 44 secured by a nut 45 to a usual tank-cover clamp 46. The nipple 28 of an arrester, similar to that shown in Fig. 1, is passed through an aperture in the bracket 44 and secured in place by tightening up the nuts 29 and 30 on the nipple 28 against the bracket 44. The top ferrule 25 of the arrester has a slotted extension 25' in which a bent gap electrode 47 is adjustably secured by screws 48 so that its outer end may be positioned in desired spaced relation to the primary circuit connector and bushing cap 49 of the

transformer. By suitably adjusting the bent electrode 47 relatively to the bushing cap 49 an external arc gap is provided which will be broken down whenever the potential difference between the transformer primary and transformer tank becomes sufficiently great to endanger the installation and thereby permit equalization of the potentials of tank 43 and cap 49 through the arrester.

When more complete protection of the arrester from weather is desired than is afforded by the caps of Figs. 1 and 5, and particularly when the external tube 13 is composed of fibre or paper, or when metallic sleeves or wire windings encircle the external tube 13 to equalize gap voltages, or reinforce the external tube 13, the arrester may be enclosed in a ceramic housing of porcelain, glass or other non-conducting material, and such housing used as a mounting for external gap electrodes, as illustrated in Figs. 6 to 10 inclusive.

In the adaptations of my invention, illustrated in Figs. 6 to 8 inclusive, a cylindrical porcelain tube 50, having a peripheral bead 51 for the engagement of an encircling mounting bracket 52, has its upper end covered by an apertured flanged cap 53 crimped over a sealing gasket 54 and supporting an L-shaped gas-electrode 55. An arrester tube 56, generally similar to the tube 13, has threaded thereon a ferrule or cap 57 provided with a threaded stud 58 extending through the apertured cap 53 and electrode 55 for the engagement of a nut 59 screwed thereon and drawing tightly together the parts through which it passes.

An insulator 60, having a ribbed periphery, contains a socket 61 in which the nut 59 is secured by suitable cement 62. The opposite end of the insulator contains a socket 63 in which a flanged nut 64 is secured by suitable cement 65.

A disk contact 66 rests on the flange of the nut 64 and a complementary dished contact 67 is movable toward the contact 66, to grip a line or ground conductor, by a headed stud 68 threaded in the nut 64.

The disk 66 lies substantially in the plane of the inturned end 69 of an arm of the gap electrode 55 and forms therewith an external arc gap in series with arc gaps within the tube 56.

The provision of external gap electrodes, such as 66 and 69, is particularly useful in preventing the formation of corona discharge between internal gap electrodes and eliminating danger of carbonization of the material of the tubes in installations where high voltage is continuously applied between line and ground terminals. The external gap may be made of a width sufficient to electrically normally isolate the arrester from the line conductor under given dynamic voltage conditions, but such external gap will break down or arc over when harmful excess voltages are impressed thereon and thereby bring the arrester into action to discharge the excess potential and to thereafter interrupt any flow of follow current which the external gap is incapable of interrupting.

In the protective device shown in Figs. 6 and 7, the elements within the tube 56 are similar to the elements within the tube 13 but the gap electrodes 70 and elements of the sectional inner hollow tube 71 are larger and fewer in number than the corresponding parts 17 and 14. The gap electrodes 70 discharge across the narrow arc slots 72 formed between the outer tube 56 and the enlarged parts 73 of the inner tube 71 in the same manner as described in connection with Fig. 1 excepting that the potentials across the gaps are substantially equalized by the shunt high resistances 74 connected with the cap 57 and with the respective electrodes 70 by the screws 75.

The lower end of the tube 50 of Figs. 6 and 7 may be closed by an apertured disk 76, which is held in place, and pressed against a peripheral sealing gasket 77, by an interiorly threaded nipple 78 screwed on to the projecting end of the nipple 28. The nipple 78 is provided with a conductor connector comprising a stud 79, dished clamp 80 and nut 81 and is so bent that its discharge port 82 discharges gases at an angle to the axis of the arrester so as to emit a blast of non-ionized and de-ionized gases which may be directed between external electrodes of an adjacent arrester to aid in extinguishing follow current flowing between such external electrodes.

The elements within the tube 56 of Fig. 8 are so modified as to expose to the arc streams a smaller area of metal and a larger area of gas generating material than do the corresponding elements of the devices of Figs. 1 to 7, particularly when the pressure generated in the arc slots becomes so great as to bulge the outer tube 56.

The sectional inner tube 83 of this modification is generally similar to the inner tube 71 and the reduced end sections 84 of its elements are telescoped into abutting relation with one another within thin walled metallic sleeves 85 which extend between the protruding collars 86 of the tube 83 and between such collars and the end electrodes 87 and 88.

The conducting sleeves 85 are closely encircled by sleeves 89 which are shorter than the sleeves 85 and are composed of non-conducting and preferably gas generating material, such as hard fibre. Conducting metallic rings 90 are sleeved on the sleeves 85 at the ends of the sleeves 89 and, inter alia, form gap electrodes at the ends of arc slots 91 between the tubes 56 and protuberances 86. The arc slots are vented through ports 20 and an axial passage 21, as hereinbefore described. Should the pressure in the arc slots 91 rise sufficiently high to bulge the tube 56, the outer peripheries of the metallic sleeves 85 are protected from the corroding action of the arc gases by the sleeves 89. The outer surfaces of the latter liberate additional deionizing gases to help quench the arc.

By such construction the evolution of non-deionizing gas may be reduced and the generation of deionizing is augmented, since a relatively small amount of metal and a relatively large amount of deionizing gas generating material are exposed to the arc stream. The dynamic failure value of the device is thereby raised.

The bottom electrode 88 is supported and positioned by an apertured bottom closure 92 which has an internally threaded flange 93 screwed on the bottom of the tube 56 and causing the closure 92 to compress the gasket 94 against the bottom of the tube 50. The encirclement of the lower end of the tube 56 by the external metal ferrule 93 provides greater resistance to bursting than does the use of internal bushings shown in Figs. 1 and 6 and where high pressures are probable, particularly at the discharge end of a tube, external ferrules should be used rather than internal bushings.

The closure 92 has a threaded boss 95 depending therefrom and containing an angular passage

96 to vent the gases from the device in a desired direction. A nut 97 is threaded on the boss 95 to press the clamp 98 into wire holding relation to the closure 92.

To tend to equalize the potential across the arc gaps, a metallic shield 99 may be provided which projects downward from the ferrule 57 partly across the upper arc slot 91 to modify the electrostatic field thereof.

Fig. 9 shows a protective device similar to that shown in Fig. 8 but in which the electrical potentials across the constricted arc slots are equalized or modified by making the upper cylindrical protuberance 86a and arc slot 91a longer than the lower cylindrical protuberance 86 and arc slot 91, which latter are the same as the correspondingly numbered parts of Fig. 8. In the device of Fig. 9 the blast from the central pressure release passage 21 is discharged upwardly through a passage 100 extending through the top of the protective device and partway through the insulator 101. The passage 100 discharges through a downwardly inclined passage 102 which is aligned with an external arc gap between the gap electrodes 103 and 104 which are fixed respectively on the insulator 101 and between the insulator 101 and the cap of the protective device. The bottom boss of the protective device may be made solid or may be apertured, as shown in Fig. 8.

As illustrated in Fig. 10, protective devices generally similar to those shown in Fig. 8 may be denuded of the top insulators and external gap electrodes shown in such figure and provided respectively with complementary external gap electrodes 105 and 106. Two or more protective devices so equipped may be mounted in series on an insulating base 107 by brackets 108 holding the protective devices and their external gap electrodes in fixed relation to one another so that the gap between the electrodes 105 and 106 is aligned with the discharge port 96a at the end of one of the arresters.

In Fig. 11 there is shown a modified construction in which the inner sectional tube 83 has the reduced ends 84 of its elements abutted against one another within gap electrodes 109 having enlarged shoulders or median rings 110. The reduced ends of adjacent electrodes 109 have sleeved thereon the fibre tubes 111 and silicon carbide tubes 112. The silicon carbide tubes contact and provide between the electrodes 109 shunt paths of high resistivity to dynamic current and low resistivity to lightning and further tend to equalize potentials across the arc slots 91 formed between the tubes 111 and the enlarged portions 86 of the tubes 83. This assembly of elements may be housed in any of the tubes 13 or 56 and used with or without external arc gaps.

In Fig. 12, there is shown a modified construction in which the inner tube 83 has the reduced ends 84 of its elements abutted against one another within gap electrodes 113 having enlarged shoulders or median rings 114. The reduced ends of adjacent electrodes 113 have sleeved thereon the fibre tubes 115 cooperating with the enlarged sections 86 of the tubes 83 to form arc slots 91. These elements are enclosed within an impregnated resistance tube 116, which may be composed of fibre, silicon carbide, or other suitable material and held within a tube 56 or 13 by a set screw 117.

It will, of course, be understood that when the gaps are graded or their electrostatic fields are modified by shields or resistors connected with line or ground terminals the protective device should be so installed as to maintain the predetermined ratios of potentials across the arc slots.

My experiments indicate that, for optimum operating results with my invention, the distance between concentric walls of the arc slots and the gas pressures therein should be coordinated with one another and with the fault current of the circuit at the point at which a particular device is installed to secure minimum desirable impedance voltage drop and maximum arc suppression and dynamic failure voltage under the specific conditions applying.

Many factors enter into the actual operation of protective devices, such as ground resistances, severity and characteristics of the lightning discharges, and it may be economically unjustifiable to design and market devices specifically designed to exactly meet particular circuit conditions to which each device would be subjected at the point of its installation. But my improvements render practicable the production of inexpensive and simple arresters satisfactorily meeting various circuit conditions, for my invention makes practicable the production of protective devices of various voltage ratings largely from standardized elements, with low impulse breakdown voltage, high dynamic failure voltages, high surge carrying capacity, high arc suppressing ability, substantially uniform voltage distribution, simple and effective regulation of the gas pressures generated, and simple and adequate reinforcing means preventing splitting or bursting of the tubes and permitting the use of thinner tubes than would otherwise be compatible with the pressures generated and which also perform electrical functions.

Protective devices embodying my invention designed for use on circuits of low voltage rating may have but a single gas evolving slot but a plurality of gas evolving slots are preferable in protective devices designed for use on circuits having a voltage rating higher than, say, 3 kv. By dividing the all-over length of the arc discharge into several sections, instead of concentrating it in a single arc slot, the pressures resulting from the discharge are distributed over a wider wall area, with consequent reduction of the tendency to distortion of the arc slot walls and bursting of the tubes. Hence higher surge currents may be safely discharged by a device having a given thickness of outer tube where a plurality of gas evolving arc slots are employed than would be possible if the device contained a single gas evolving slot of a length equal to the aggregate of the lengths of the multiple slots. The dynamic failure voltage of a given device, and hence its commercial rating, is dependent, amongst other factors, on the width of the arc slots. Less widening or distortion of arc slots occurs when using multiple slots than where a single slot is used equal in length to the aggregate length of the shorter slots. Hence my devices are preferably constructed with multiple gas generating arc slots so as to retain to an optimum degree high dynamic failure voltage characteristics and the capacity for discharging heavy surge currents.

The voltage ratings of arresters constructed largely from standardized elements may be varied (a) by varying the number of arc gaps within the arrester by changing the number of tubular spacing elements and electrodes; or (b) by varying the gas-generating capacity by making either or both the inner and outer walls of one or more narrow arc slots of a gas-generating substance, or some or all arc slot wall sec-

tions of a ceramic or non-gas-generating material; or (c) by changing the gas pressure in the arc slots by altering the sizes of the radial passages through which the arc slots discharge into the pressure release passage, or the size of the pressure relief passage; or by using terminal electrodes containing gas venting apertures at one or both ends of the arrester; or (d) by the use of external arc gaps.

The formation of arc slots between concentric concave and convex surfaces of outer and inner tubular members minimizes the disruptive action of generated pressures and provides a greatly increased surge carrying capacity and arc suppressing ability as compared with the surge carrying capacity and arc suppressing ability of arc slots of comparable area formed by axial or radial passages or by passages of crescent cross-section lying between eccentric concave and convex surfaces of telescoped members. The communication of the respective arc slots in parallel with an axial pressure relief passage permits rapid diffusion of generated gases throughout the arc slots; tends to equalize pressure in the arc slots, and tends to cause a more or less evenly distributed flow of gases from the arc slots into the discharge channel.

The concentricity of the inner and outer surfaces of the arc slot walls, with consequent uniformity in the spacing of such walls, tends to minimize concentration of arc discharges at any point in the perimeter of an electrode and to diffuse the arc discharge completely around the perimeter so that all parts of the arc are close to gas-generating or cooling surfaces of the arc-slots and the turbulence of generated or expanded gases will penetrate thoroughly throughout the arc.

Moreover the formation of arc slots between concentric surface of telescoped tubular members facilitates accurate control of the width of the arc slots. The walls of arc slots should not be so close together as to sufficiently impede discharge of surge current that voltage of sufficient magnitude is built up across a given tubular element to cause a flash-over over the entire element rather than through the arc slot alone, nor should the surfaces of the arc slots be so far apart as to permit free discharge of an arc unaffected or little affected by the proximity of the concentric walls and the gas generated therefrom.

Any tendency of an arc to flash over an entire tubular element, instead of passing through the adjacent arc slot, is effectively minimized in my arrester by telescoping reduced ends of the inner tubular elements in hollow tubular electrodes so far that the length of the arc slot is less than one-half the flash-over distance between opposing electrodes exteriorly of the arc slot and by limiting the pressure developed in the slots below that causing a flash-over through the relief passage. The proportioning of the length of the flash-over distances through the arc slot and exteriorly of the arc slot may vary considerably, but generally it is desirable to make the flash-over distance exteriorly of any arc slot from two to three times the flash-over distance through the arc slot itself. This arrangement also insures that the flash-over distance between terminal electrodes, exteriorly of the outer tube, will be considerably longer than the aggregate of the internal flash-over distances through the arc slots so that the arc discharge will always take place through the arc slots and the follow current will be extinguished in the manner intended.

For instance, in an arrester rated at 9.0 kv., such as illustrated in Fig. 1, the flash-over distance between gap electrodes 17 through each arc-slot 19 is less than one-half of the flash-over distance between such opposing electrodes 17 exteriorly of such arc slot 19, and the external flash-over distance between the terminal members 25 and 29 is over three times the aggregate internal flash-over distances through the several arc slots 19.

In this embodiment, the distance between concentric walls of each arc-slot 19 is approximately only one two hundred and fiftieth of the length of the arc-slot 19 between adjacent gap electrodes 17 and the circumferential length of the arc slot is approximately three and one-half times the distance through the arc slot between adjacent gap electrodes. Such proportions afford a desirable extended wall area relatively to the cross-sectional area of the arc slot, but are not unduly critical and may be varied somewhat to meet different conditions, and some or all of these relationships may be changed in arresters of similar rating but different detailed design.

I have found that, in a typical embodiment of my invention having a 9 kv. rating, a decrease from .028" to about .001" in the spacing between the concentric inner and outer surfaces of arc slots 19 resulted in an increase in the dynamic failure voltage of the arrester from approximately 16,500 volts to above 23,000 volts, other factors being constant. At the point of maximum dynamic failure voltage, the arc-slot pressure was apparently just under that required to bulge the lateral walls of the arc-slots or to cause a flash-over between electrodes through the relief passage; the gas vents and relief passage being so proportioned as to substantially maintain such pressure during arcing.

While higher values of dynamic failure voltage are associated with narrow arc slots, other factors besides the spacing between the concentric walls should be given consideration in designing an arrester for a particular use. For instance, the clearance between the concentric surfaces should not be so close that small changes in dimensions resulting from atmospheric conditions or manufacturing tolerances will adversely affect the normal operation of the device. Again the character and area of the gas-generating surface and the capacity of the pressure vents and discharge passage should be taken into consideration since the de-ionizing effects of the arc-slots and gas are influenced by the pressure in the arc slots and such pressure should not be so high as to bulge the walls and increase the cross sectional area of the slots nor so low as to detract from the arc quenching effect of high pressures.

When the effective areas of the pressure vents and relief passage are so large that the internal pressure in the arc slots during arcing is below what may be deemed an optimum or critical pressure, the dynamic failure voltage of the arrester will be decreased; whereas, if the effective areas of the pressure vents and relief passage are so small that the internal pressure in the arc slots builds up sufficiently to bulge the walls and increase the width of the arc-slots, the dynamic failure voltage of the arrester will be lowered.

In the typical embodiment of my invention for use on a 9000 volt circuit, above referred to and illustrated in Fig. 1, it was found that a desirable dynamic failure voltage, considerably higher than

the normal operating voltage of a circuit, was obtainable when the discharge passage 21 was approximately $\frac{5}{32}$ of an inch in diameter and each of the four vent holes per element was approximately $\frac{1}{8}$ of an inch in diameter. Any substantial increase or decrease in the discharge passage area (other factors remaining the same) resulted in a marked decrease in dynamic failure voltage value. The determination of the optimum area of the relief passage, in a given design of device having given arc-slot widths, vent port areas and tube strength, for use with some maximum value of surge current of given wave shape which the device may be designed to discharge, is determinable by incrementally increasing the relief passage area from a datum preventing explosion (and thereby incrementally increasing the dynamic failure value) to an area above which the dynamic failure value again begins to decrease.

Having described my invention, I claim:

1. An arc interrupter comprising non-conducting means including a tubular element having end sections of smaller diameter than an intermediate section thereof, electrode rings sleeved on said reduced end sections and having peripheral surfaces projecting beyond the peripheral surface of said intermediate section, and a housing for said electrodes and element and having a wall complementary with said intermediate section of the latter and forming therewith an arc slot between said electrodes.

2. An arc interrupter comprising non-conducting means having complementary inner and outer concentric walls forming a curved arc slot, and gap electrodes positioned to form an arc in said slot, said means containing communicating pressure-discharge passages one of which extends substantially parallel with said arc slot and forms a continuous passage from end to end of said means without intersecting said slot and the other of which extends through said inner wall and communicates with said arc slot.

3. An arc interrupter comprising non-conducting means containing a pressure relief passage and a sleeve cooperating with said means and forming therewith arc slots arranged in series with one another and adjacent to said passage and communicating therewith in parallel, gap electrodes arranged in series with one another and with said slots, said electrodes alternating with said slots, terminal electrodes adjacent to the ends of said means with a direct flash-over distance between them greater than the aggregate of the flash-over distances between the adjacent gap electrodes, said passage having a discharge port remoter from one than from the other of the terminal electrodes, the flash-over distance between said port and the remoter terminal electrode being greater than the direct flash-over distance between the terminal electrodes.

4. An arc interrupter comprising a plurality of non-conducting tubular members, one of which is disposed within and spaced from the other, electrodes intersecting the space between said members to form arc slots in series with one another, said inner member containing an axially extending pressure relief passage and ports connecting said passage with said slots in parallel, said electrodes being arranged in series along one of said members and discharging through said slots, one of said members comprising thermally activated gas generating material.

5. An arc interrupter comprising a tubular outer member and a tubular inner member, said members having complementary concentrically curved spaced walls, electrodes intersecting the space between said walls to form arc confining slots arranged in series with one another, said inner member including a plurality of similar elements each having reduced end portions, said electrodes being sleeved on reduced ends of adjacent elements, each of said elements containing communicating pressure release passages one of which communicates with an arc confining space between adjacent electrodes and another of which communicates with a complementary passage of an adjoining element.

6. An excess-potential discharge apparatus comprising insulating means containing a pressure relief passage and also containing a slot, electrodes intersecting said slot to form arc confining slots arranged in series with one another and communicating with said passage in parallel, said spaced electrodes being arranged in series within said means and alternating with said arc confining slots, and spaced gap electrodes in series with said first named gap electrodes and disposed without said means, said means including current-responsive gas-generating material activated upon flow of current and said passage having a port discharging transversely to the space between said external gap electrodes.

7. An excess-potential discharge apparatus comprising a tubular member, a reenforcing ferrule encircling one end of said member and forming a terminal electrode, a series of gap electrodes within said member, a tubular element between said electrodes and forming with said first named member concentric curved walls for an arc slot between said electrodes, and a bushing screwed on the other end of said tubular member for tightening up the electrode and element assembly and forming a terminal electrode, one of said walls comprising a gas-generating substance.

8. An excess voltage discharge apparatus comprising a housing containing gap-electrodes and walls forming an arc slot through which one of said electrodes discharges to the other, one of said walls comprising a gas-generating substance activated by the discharge, gap-electrodes forming an arc gap exteriorly of said housing, and means for directing transversely to an arc formed between said last named electrodes gas-generated within said housing by a discharge through said slot.

9. An excess voltage discharge apparatus comprising means having spaced walls, gap-electrodes intersecting the space between said walls and forming a plurality of narrow slots arranged in series, one of said walls containing a gas-generating substance, said gap-electrodes being arranged in series and discharging through said slots, said means containing a pressure discharge passage substantially parallel with said slots and with which said slots are connected in parallel, and terminal electrodes in series with said gap electrodes, said passage damping the discharge of gas from said slots and maintaining therein during arcing a super-atmospheric pressure.

10. An excess voltage discharge apparatus comprising means containing a pressure relief passage and having relatively rigid walls surrounding said passage and spaced to form a narrow arc slot, one of said walls containing a port through which said slot communicates with said passage, and gap electrodes at the ends of said arc slot, said passage and vent being so pro-

portioned as to maintain in said arc slot during arcing a pressure just below that required to bulge one of said walls sufficiently to lower the voltage drop between the electrodes.

11. An excess voltage discharge apparatus comprising a tube containing a pressure relief passage and having an enlarged portion containing a port communicating with said passage, gap electrodes sleeved on said tube and spaced by the enlarged portion thereof, non-conducting shields sleeved on said gap electrodes, and a tube surrounding said shields and forming with the enlarged portion of the first named tube an arc slot between said electrodes.

12. An excess voltage discharge apparatus comprising a tube containing a pressure discharge passage and having spaced enlarged portions each containing a port communicating with said passage, gap electrodes sleeved on said tube and spaced by the enlarged portions thereof, shields sleeved on said electrodes and coacting with said enlarged portions to form arc slots between electrodes aforesaid, and a tubular resistor surrounding and in electrical contact with a plurality of said electrodes, and a housing for said tube electrodes, shields and sleeve.

13. An excess voltage discharge apparatus comprising a tube containing a pressure discharge passage and having an enlarged portion containing a port communicating with said passage, conducting members sleeved on said tube and spaced by said enlarged portion, rings encircling said tube adjacent to the enlarged portion thereof and a housing for said tube conducting members and rings and forming with said enlarged portion an arc slot communicating with said passage through said vent.

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