Dec. 7, 1965 E. H. YONKERS 3,222,566

VALVE TYPE LIGHTNING ARRESTER

Original Filed Oct. 27, 1958 2 Sheets-Sheet 1

Fig. 1

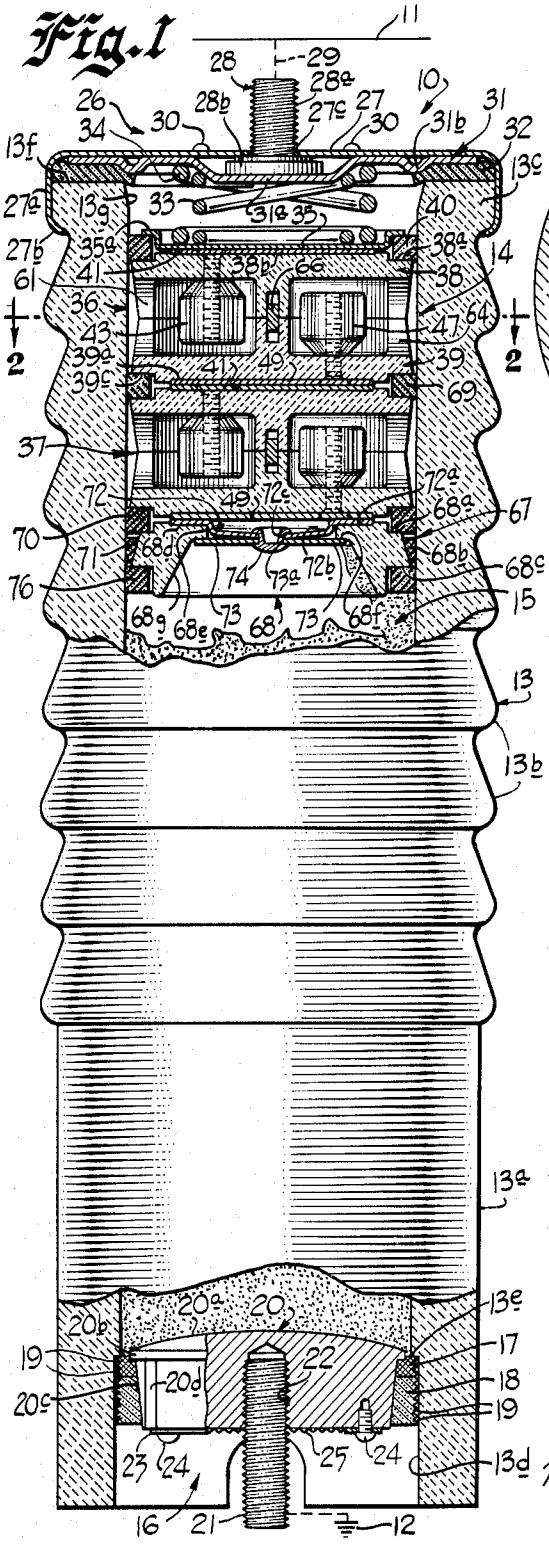


Fig. 2

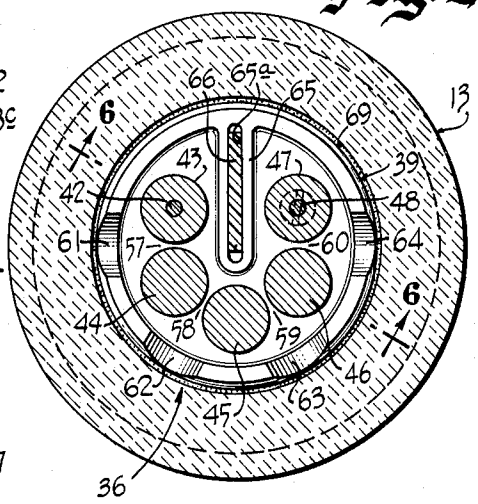
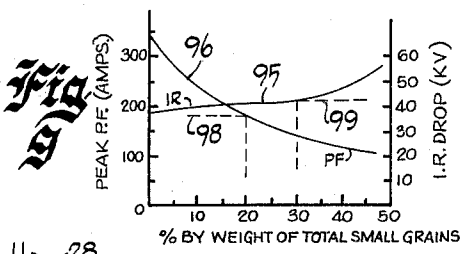
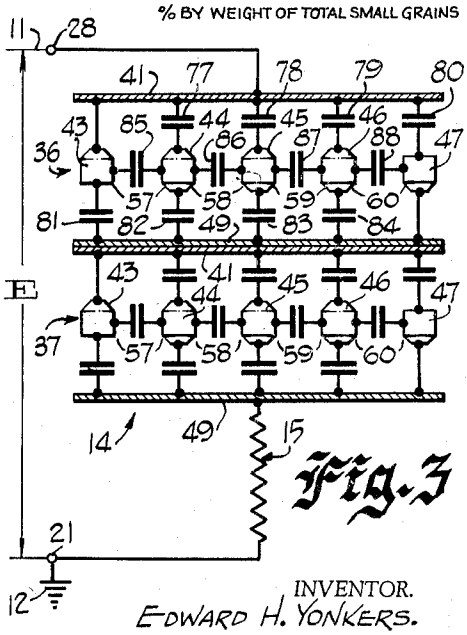


Fig. 3





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VALVE TYPE LIGHTNING ARRESTER

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Fig. 4

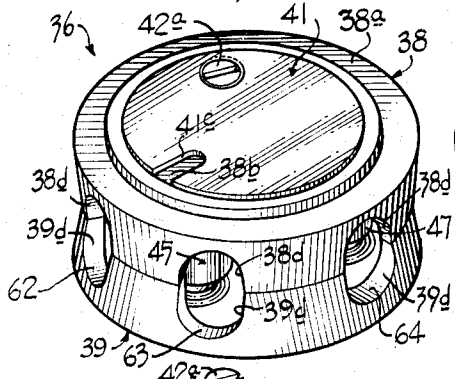
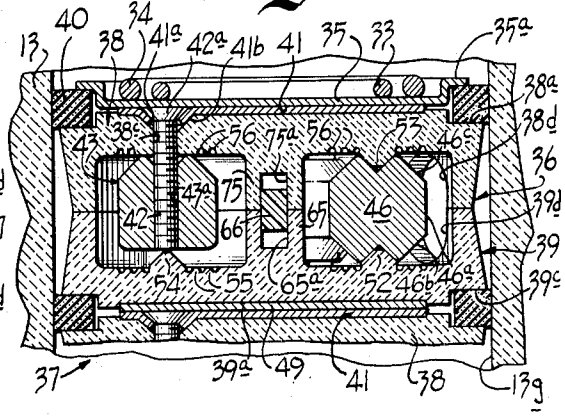
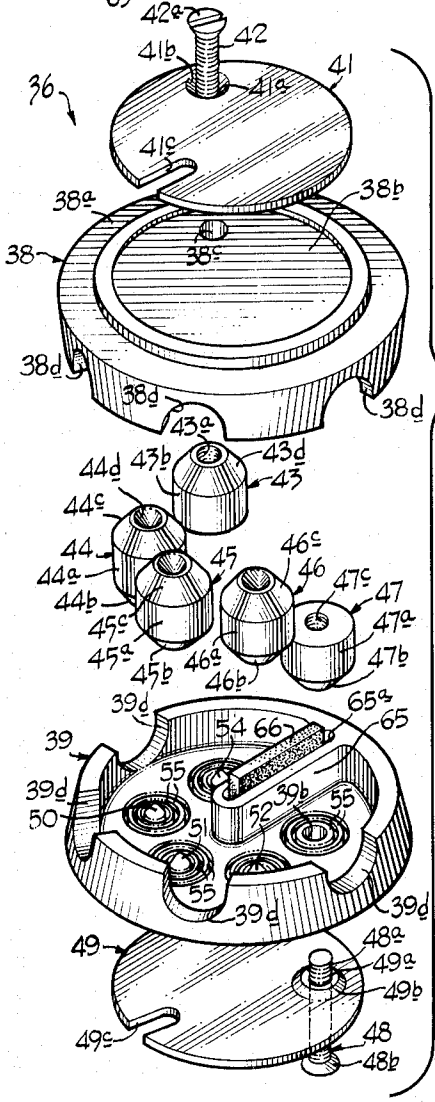


Fig. 6





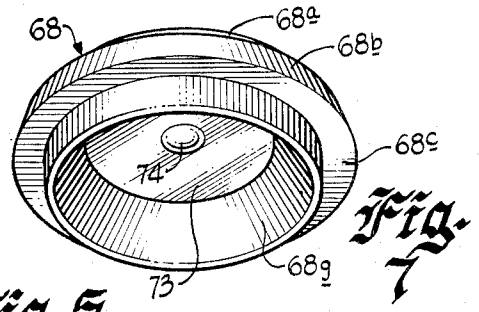
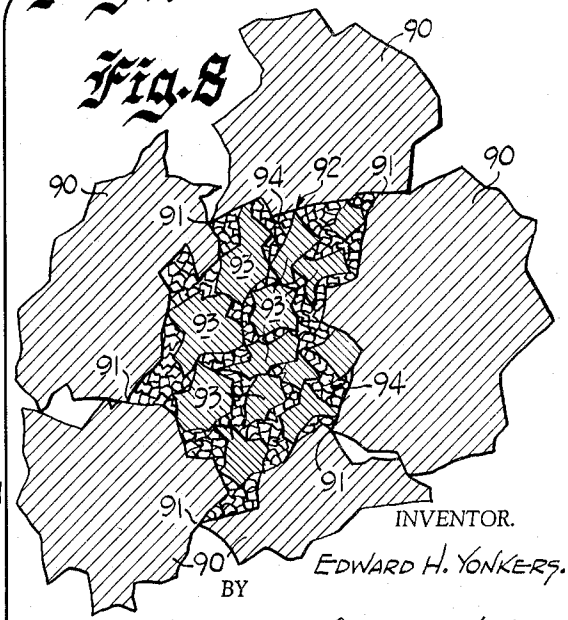


Fig. 7

Fig. 5

Fig. 8



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VALVE TYPE LIGHTNING ARRESTER

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Continuation of abandoned application Ser. No. 769,737, Oct. 27, 1958. This application Nov. 16, 1961, Ser. No. 157,293

5 Claims. (Cl. 315—36)

The present invention relates to a new and improved lightning arrester and is, more particularly, concerned with improvements in lightning arresters of the valve type employing a variable resistance valve element connected in series with one or more isolating gaps. This application is a continuation of the copending application, Serial No. 769,737, filed October 27, 1958, now abandoned and assigned to the same assignee as the present invention.

Lightning arresters are employed in electrical power transmission systems to provide protection against abnormal voltages existing on a power distribution line as a result of surges resulting from lightning, switching disturbances or other causes of this nature. The function of the lightning arrester is to provide a low resistance path to ground in order to prevent the occurrence of excess voltages caused by disturbances of the type described and, at the same time, to present a relatively high resistance under normal operation conditions so that the diversion of power current from the line is insignificant. An ideal lightning arrester would switch from its low resistance condition to its high resistance condition as soon as the abnormal surge has been dissipated, thus limiting the flow of power follow current to the period actually required to restore the system to normal operation.

To accomplish these results a lightning arrester consists of a characteristic element connected in series with one or more isolating gaps which function to keep the major portion of the normal system voltage off of the characteristic element in the absence of surges. The characteristic element serves to bypass to ground surge current resulting from abnormal line voltages and to interrupt the flow of system follow current as soon as the abnormal condition has been dissipated. There are in use at the present time two types of lightning arresters, namely, expulsion type arresters employing as their characteristic element gas evolving dielectric material in a restricted arcing chamber provided with gas vents and valve type arresters employing a nonlinear resistance or valving material as their characteristic element. The valving material has a high resistance for voltages of the order of the system voltage and has a very low resistance for voltages in excess of the normal system voltage. Expulsion type arresters are widely used on exposed circuits, particularly in systems where lightning conditions are severe, due to the fact that they are able to withstand direct lightning strokes and continue to furnish protection even under such severe conditions. However, expulsion arresters have the disadvantage that they provide a relatively unimpeded path to ground for follow current with the result that the latter current may flow at levels which, under certain conditions, approach the magnitude of the available fault current. Valve arresters, on the other hand, do not function effectively under heavy lightning conditions because the valving materials presently available do not reach sufficiently low resistance levels with sufficient rapidity to provide complete surge protection but, since these arresters do include a non-linear resistance in the path to ground, they are capable of limiting follow current to insignificant levels regardless of the magnitude of the available system fault current. For all of the reasons discussed above, expulsion arresters are generally preferred

in rural areas where lightning conditions are severe while valve arresters are preferred for use in urban areas where system fault currents are already very high and are becoming even higher with the increased consumption of electric power. As indicated above, the present invention relates to lightning arresters of the latter type and is specifically concerned with improvements both in the construction of the isolating gaps and in the valve element itself.

In conducting the experiments leading to the development of the present invention a considerable amount of research was devoted to a study of the characteristics of materials which could possibly be used as the valve material. Ideally such material should be capable of withstanding temperatures in the range of 3000° to 4000° F. without melting, subliming or decomposing and, in addition, its electrical resistance characteristic must be extremely non-linear, that is, for all of the reasons described above, the material must have a low resistance for high voltage and a high resistance for low voltage. Moreover, the change in resistance with applied voltage must be reversible and must be capable of many repetitions without significant change in the electrical characteristics so that the lightning arrester will have a long operating life. Granular silicon carbide comes closest to satisfying all of the requirements enumerated above. However, a single silicon carbide crystal or a fused mass of silicon carbide will not perform the function of extreme nonlinear resistance to effect the desired valve action, since the volume resistivity of silicon carbide is relatively low and constant under a fixed temperature. To perform as an adequate nonlinear resistor, the silicon carbide must be in the form of grains touching one another and having a size and basic volume resistivity of the proper values.

Silicon carbide grains of the type suitable for use in lightning arrestors are in the form of extremely hard irregular crystals. Therefore, even under high pressure, contiguous crystals make contact in very small areas, practically point contacts. Furthermore, a thin insulating film of silicon dioxide forms over the surface of silicon carbide. Thus, the small area contacts plus the dielectric film cause the intergranular resistance to be high compared with the volume resistivity of the solid silicon carbide.

When voltage is applied to such a system of grains, the oxide film breaks down at the contacts; then as the flow of current increases, the material in the region of the sharp point contacts heats and the resistance of the system decreases.

Such sharp point contacts will be hereinafter termed "intergranular gates" since they serve to block or permit the passage of current in accordance with the applied voltage. In valve arresters employing granular nonlinear resistor elements, excessive surge current flowing through one region of the arrester creates a low resistance path so that all of the available current tends to pass through that particular region which may be referred to as a "hot channel." When a surge current of sufficient magnitude and duration passes through the hot channel it may fuse the grains and modify them to form a permanently low resistance path.

These fused channels are called "fulgurites" and may eliminate the ability of the valve element to limit follow current in which case the arrester will be completely destroyed by excessive system current.

The described tendency toward the formation of hot channels becomes more pronounced as the size of the silicon carbide grains is increased and is less pronounced as the gain size decreases. However, the discharge voltage (voltage produced by surge current) of the valve material increases as the grain size decreases due to the increased number of intergranular gates per unit arrester length.

Thus, the problem of channeling in the valve material cannot be solved merely by decreasing the size of the grains. It has also been found that in arresters of prior design problems are frequently encountered with respect to "flashover" along the path extending adjacent the inner walls of the housing for the valve material. Such a condition results in the formation of a hot channel with the deleterious results described above.

One of the primary objects of the present invention is to provide a new and improved resistance or valve material for use as the valve element in a lightning arrester.

Another object of the invention is to provide a new granular resistance material or valve element which eliminates or severely impedes the formation of hot channels either in the body of the granular material or along its outer surface.

Still another object of the invention is to provide a new and improved valve material for use in valve type lightning arresters in order to permit the arrester to withstand relatively long duration lightning surges and switching faults without permanently altering the characteristics of the material.

A further object of the invention is to provide a new and improved valve material having much more permanent characteristics than materials heretofore employed.

A still further object of the invention is to provide a highly refractory granular material capable of withstanding temperatures up to 4000° F. and having no tendency for chemical reaction or change even under severe treatment.

It is also an object of the invention to provide a resistance material capable of withstanding many duty cycle operations without progressive increase in follow current.

As indicated above, the present invention is also concerned with improvements in the construction of the isolating gaps connected in series with the characteristic element. One of the advantages of the isolating gap structure of the present invention resides in the fact that it results in a lightning arrester of reduced height when compared with prior art arresters of equivalent voltage rating.

In valve arrester operation the series gaps must not only isolate the valve or characteristic element from system voltage during normal periods, but the gap system must also cut off or quench the follow current after the abnormal surge conditions subside. Another advantage of the gap structure of the present system is that it provides additional arc quenching power by virtue of the spiral arrangement of individual gap elements.

Still another important object of the invention is to provide a quenching structure arranged to cause moveout and elongation of the arcs struck between the gap electrodes without the use of auxiliary blowout apparatus.

A still further object of the invention is to provide a quenching structure having a lower impulse sparkover voltage than prior art arrangements of equivalent line voltage rating.

It is also an object of the invention to provide a quenching structure capable of interrupting considerably more follow current than prior art arrangements of equivalent voltage rating.

The invention has for a further object the provision of a lightning arrester employing a quenching structure formed by a plurality of integral sub-units each containing a number of horizontally spaced apart electrodes defining a set of arc gaps, with the number of such sub-units employed being variable in order to permit the construction of arresters having different voltage ratings without requiring complete redesign of the valve element and other component parts of the arrester.

The invention has for another object the provision of a new and improved quenching structure and a new and improved valve element cooperating to form a lightning arrester which, when compared with valve type arresters of prior design, is more rugged in operation, is smaller in size, possesses improved protective ability and has more stable operating characteristics.

The foregoing and other objects are realized in accordance with the present invention by providing a lightning arrester having a valve element electrically connected in series with quenching or isolating structure for the purpose of providing a relatively low resistance path to ground for surge currents resulting from abnormal voltages above a predetermined value and for also providing a relatively high resistance to limit power follow current flowing after the abnormal voltage condition has subsided. The valve element is formed by a mass of silicon carbide grains touching one another having a basic resistivity and grain size selected to provide the desired operating characteristic. These basic grains occupy the lower portion of the housing and are in sharp point grain-to-grain engagement with voids therebetween. In accordance with the present invention, these voids are substantially filled in two or three stages with silicon carbide particles considerably smaller than the basic grains. Specifically, the voids between the basic grains are partially filled with particles to disturb the point-to-point contact between the basic grains. The voids between the intermediate size particles are than substantially filled with much smaller silicon carbide particles, hereinafter called fines, and the intermediate and fine particles are packed around the basic grain junctions by vibration and pressure in order to provide a high density silicon carbide mass. The intermediate and fine particles serve as a cooling medium and are thermally coupled to the intergranular gates between the basic grains with the result that the gates are rapidly cooled after the abnormal voltage subsides. By cooling the gate regions very quickly, the silicon carbide grain system regains its relative high resistance and follow current is limited to levels which are readily quenched or interrupted by the gap system. The intermediate and fine particles fill the space between the basic grains and the inner wall of the housing thus preventing channeling or flashover along the outer surfaces of the mass by forming high resistance paths having relatively large numbers of intergranular gates. Since the intermediate and fine particles have much higher intergranular resistance than the basic grains due to the smaller area of contact between the grains and since the mixture of intermediate and fine particles filling each of the voids between the basic grains contain a large number of these high resistance gates, the intermediate and fine particles do not carry appreciable current and, hence, do not directly affect either the surge resistance or the power current resistance of the basic grains. The intermediate and fine particles are highly refractory like the basic grains and can withstand temperatures up to 4000° F. and, in addition, are of the same material as the basic grains so that there is no tendency for chemical reaction or physical change even under the most severe conditions.

The isolating and quenching gap structure is made up of one or more integral sub units disposed within the housing and, when more than one such unit is employed they are placed one above the other on top of the valve element. The number of sub units employed is determined by the voltage rating of the lightning arrester. For example, each sub unit consists of four gaps in a dielectric box suitable for operating at 3 kilovolt maximum. Two such boxes will function at 6 kilovolt, three at 9 kilovolt and so on. Each unit comprises a plurality of horizontally spaced apart, circularly arranged gap electrodes contained within a relatively small housing formed of dielectric material. Thin, conducting discs or wafers are arranged on the top and bottom of each housing to cooperate with the gap electrodes to define capacitors for effecting uniform voltage distribution between the gap boxes which are arranged in series. The wafers on the different units provide unit-to-unit electrical connections with the wafer on the top of the uppermost unit being connected to the upper terminal of the arrester and the wafer on the bottom of the lowermost unit being connected to the valve element. The circular arrangement of the gap electrodes provides

a spiral path for the current flowing through the gap system so that a magnetic field is produced which tends to cooperate with the gas pressure created by the arc heat in the closed center of the housing to move the arcs outwardly from the center of each unit causing them to elongate and cool which aids in their extinguishment. The housings are also constructed to prevent short circuits from metal beads formed by the action of the arcs. The arrangement is such that a rugged arrester of small size and improved protective ability is achieved while maintaining a very simple structure.

The invention both as to its organization and manner of operation, together with further objects and advantages will best be understood by reference to the following detailed description taken in conjunction with the accompanying drawings wherein:

FIG. 1 is a partly broken away, partly sectional view illustrating a valve type lightning arrester characterized by the features of the present invention;

FIG. 2 is a sectional view taken along a line substantially corresponding to the line **2—2** in FIG. 1 and showing particularly the construction of one of the quenching gap units;

FIG. 3 is a schematic diagram illustrating the various capacitances cooperating to effect uniform voltage distribution across the individual arc gaps of the quenching structure;

FIG. 4 is a perspective view showing one of the gap units employed in the quenching structure;

FIG. 5 is an exploded view showing the component element making up the unit illustrated in FIG. 4;

FIG. 6 is an enlarged, fragmentary, sectional view taken along a line substantially corresponding to the line **6—6** in FIG. 2;

FIG. 7 is a perspective view showing a cap employed between the quenching structure and the valve element of the lightning arrester illustrated in FIG. 1;

FIG. 8 is a greatly enlarged, fragmentary view showing the grain structure making up the valve element of the lightning arrester illustrated in FIG. 1; and

FIG. 9 is a curve showing the relationship between the composition of the valve element, the sparkover voltage of the valve element and the power current.

Referring now to the drawings and particularly to FIG. 1 thereof, the present invention is there illustrated in the form of a lightning arrester **10** adapted to be connected between a line conductor **11** and ground **12** for the purpose of protecting associated equipment (not shown). The lightning arrester **10** comprises a generally cylindrical housing **13** formed of suitable insulating material such as glazed porcelain. The exterior of the housing preferably includes a lower uniform diameter portion **13***a* and an upper fluted or grooved portion **13***b* including an annular end sections **13***c*.

The lightning arrester **10** includes an isolating and quenchig gap structure indicated generally by the reference numeral **14** disposed within the upper end of the cylindrical housing **13** and electrically connected in series with a valve element indicated generally by the reference numeral **15**. The valve element as described more fully hereinafter comprises silicon carbide grains or particles retained within the housing **13** by means of a lower end assembly **16**. The latter assembly fits within a countersunk portion **13***d* at the lower end of the housing **13** and includes a sealing ring **17** preferably formed of asbestos and retained within the housing by means of cement or sealing material indicated at **18**. To enhance the adhering action between the cement **18**, the ring **17** and the inner wall of the countersunk portion **13***d*, sand particles indicated at **19** are fired into the countersunk portion during the glazing process employed in forming the housing **13**. The asbestos ring **17** is seated against an annular shoulder **13***e* formed by the countersunk portion **13***d* and cooperates with the cement **18** to retain a terminal block **20** in position. The block **20** is provided with a domed upper surface **20***a* in order to guide the discharge toward the center portion of the arrester. An annular lip **20***b* on the block **20** is seated against the gasket **17** for the purpose of preventing the terminal block from being withdrawn through the open lower end of the housing. The peripheral surface **20***c* of the terminal block is frusto-conical in shape or is inclined downwardly toward the longitudinal axis of the housing **13** so that this surface cooperates with the ring **17** and the cement **18** to prevent the terminal block from being pulled out of the housing. The external surface of the block is provided with a plurality of spaced apart ribs **20***d* which are embedded into the cement and the ring for the purpose of preventing the terminal block from turning when an electrical connection is made to a lower terminal post **21** threaded into a tapped axial bore **22** extending partly through the block **20**. In this connection, it will be recognized that the downwardly protruding end of the terminal post **21** is adapted to receive an electrical terminal connected to the ground indicated at **12**. A terminal clamp plate **23** is secured to the underside of the block **20** by means of machine screws **24** and is provided with corrugations or projections **25** extending axially of the terminal post **21** for the purpose of digging into the electrical terminal connection to prevent the latter from being turned about the terminal post.

The upper end of the housing **13** is closed by means of an upper end assembly indicated generally by the reference numeral **26**. The latter assembly includes a conducting cap **27** provided with an annular flange **27***a* depending downwardly and having its extreme end **27***b* crimped or spun over the annular section **13***c* at the top of the housing. The conducting cap **27** is provided with a central opening **27***c* accommodating a terminal post **28** which is adapted to receive an electrical terminal unit leading to the power line **11** as indicated by broken line **29**. The terminal unit assembled upon post **28** is prevented from turning or rotating by means of raised projections **30** formed on the conducting cap **27**. The terminal post **28** includes an externally threaded stem portion **28***a* for receiving the terminal unit and an enlarged head portion **28***b* which is resistance welded to the underside of the conducting cap **27** and is retained in position by means of a conducting disc **31**. The latter disc includes a depressed center portion **31***a* accommodating the head **28***b* of the terminal post and an annular deformation **31***b* formed near the periphery of the disc for the purpose of cooperating with an annular, resilient, insulating ring or gasket **32** to seal the upper end of the housing. More specifically, the annular gasket **32** arrests upon the flat upper end **13***f* of the housing and has its inner periphery extending slightly beyond a tapered or chamfered portion **13***g* formed on the inner periphery of the housing at its upper end. The inner end of the sealing ring **32** is pressed firmly against the upper end of the housing by the annular deformation **31***b*, thereby forming a tight seal to prevent the entrance of moisture or other foreign particles into the interior of the housing.

The quenching structure **14** and the valve element **15** are urged together by means of a pair of concentric compression springs **33** and **34** acting between the conducting disc **31** and the upper end of the quenching structure. The springs **33** and **34** are centered and maintained in position by the depressed center portion **31***a* of the conducting disc and the lower ends of these springs are seated within a spring retaining plate **35** having a spun lip **35***a*.

As is illustrated in FIG. 1, the quenching structure **14** comprises a number of integral sub-units or gap boxes stacked one upon the other within the housing **13**. Each sub unit contains a ring of gap elements and carries a voltage rating which, in the design shown, is 3 kilovolt per sub unit. The arrestor **10** in the form illustrated in FIG. 1 is a 6 kilovolt arrester and employs two sub units identified by the reference numerals **36** and **37**. Since these two units are identical in construction, only one will be described in detail. Each unit includes a flat, hollow,

cylindrical housing formed by upper and lower housing members 38 and 39 each of which is preferably made of ceramic or other suitable insulating material. The upper housing member 38 is provided with an annular recess 38*a* (FIGS. 1, 4 and 5) extending around its upper periphery and cooperating with the spun lip 35*a* of the spring retaining plate 35 to form a groove or recess for accommodating an annular insulating gasket 40 which is snugly seated against the inner wall of the housing 13 to prevent a flashover along the exterior of the quenching structure 14. The upper housing member 38 is also provided with a circular recess 38*b*, best shown in FIG. 5 of the drawings, for the purpose of accommodating a conducting wafer 41 which is secured to the upper housing member by means of a machine screw 42 passing through an opening 41*a* in the wafer 41 and through an opening 38*c* in the upper housing member. The wafer 41 may be chamfered adjacent the opening 41*a* as indicated at 41*b* for the purpose of receiving the head 42*a* of the machine screw 42. The wafer 41 is also provided with a peripheral notch or slot 41*c* which serves as a guide to make certain that the wafer is attached in proper position upon the top of the upper housing member 37 when the gap unit is assembled.

The stem of the machine screw 42 extends into the interior of the gap unit housing and is threaded into an axial bore 43*a* defined in a spark gap electrode 43. The latter electrode includes a cylindrical body portion 43*b* and an upper end portion 43*c* of frusto-conical shape seated against the underside of the upper housing member 38. The electrode 43 is connected in a circular arrangement with a plurality of spaced apart electrodes 44, 45, 46 and 47, these electrodes being spaced along an imaginary circle having its center coinciding with that of the gap unit. The electrode 47 is identical to the electrode 43 described above and includes a cylindrical body portion 47*a* and a frusto-conical end portion 47*b* seated against the upper surface of the lower housing member 39. The electrode 47 further includes a tapped axial bore 47*c* accommodating the threaded stem 48*a* of a machine screw 48 which is similar to the machine screw 42 described above in that it cooperates with the electrode 47 to secure a lower conducting wafer 49 to the underside of the lower housing member 39. To this end, the wafer 49 is disposed within a circular recess 39*a* defined in the undersurface of the lower housing member 39. The machine screw 48 passes through aligned openings 49*a* and 39*b* respectively defined in the wafer 49 and in the lower housing member 39 and the head portion 48*b* of the machine screw is seated within a chamfered recess 49*b* surrounding the opening 49*a* so that it forms a continuous flat surface with the bottom of the wafer. The wafer 49 is provided with a slot or notch 49*c* for alignment with the slot 41*c* in the upper conducting wafer 41 when the spark gap unit is assembled.

The spark gap electrodes 44, 45 and 46 are identical in consumption and each includes a central cylindrical body portion disposed between frustro-conical end portions. The central portion of the electrode 44 is designated by the reference character 44*a*, while the lower end portion is indicated at 44*b* and the upper end portion is identified by the reference numeral 44*c*. A similar numbering arrangement is employed for the electrodes 45 and 46. The electrodes 44, 45 and 46 are held in fixed position within the gap unit housing by means of a set of upwardly extending projections or teats 50, 51 and 52 formed on the lower housing member 39 and a similar set of teats 53 (FIG. 6) formed on the upper housing member 38. Specifically, the lower teat 50 fits within a conically shaped recess formed in the lower end 44*b* of the electrode 44 while, at the same time, a similar recess 44*d* (FIG. 5) formed in the end portion 44*c* receives one of the upper teats 53, whereby the electrode 44 is mounted in fixed position within the housing but is free to rotate about its longitudinal axis. The electrodes 45 and 46 are also supported between the housing members 38 and 39 for rotation about their longitudinal axis by a mounting arrangement like that described above for the electrode 44. The lower housing member 39 is also provided with an upwardly extending teat 54 similar to the teats 50, 51 and 52 previously described, but as is illustrated in FIG. 5, the teat 54 is spaced slightly from the lower end of the intial electrode 43. Each of the teats 50 to 54, inclusive, and the opening 39*b* in the lower housing member is centered with respect to a plurality of concentric annular grooves 55 which increase the insulation surface and prevent the formation of continuous sputtered metal films between consecutive electrodes. Since the housing members 38 and 39 are identical in construction, similar sets of concentric grooves 56 (FIG. 6) surround the opening 38*c* and each of the teats 53 on the upper housing member 38. Each of the gap electrodes is supported upon the upper and lower teats surrounded by but spaced from the sets of concentric grooves which enhance the effectiveness of the insulation between the gap electrodes, thus providing further insurance against excessive leakage current and surface flashover. As is illustrated in FIG. 2, the electrode 43 cooperates with the electrode 44 to define a first spark gap 57 while the electrode 44 cooperates with the electrode 45 to provide a second spark gap 58. In similar manner, the electrode 45 cooperates with the electrode 46 to define a third spark 59 while the electrode 46 cooperates with the final electrode 47 of the gap unit to form a fourth spark gap 60. The four gaps 57, 58, 59 and 60 are connected in series between the upper conducting wafer 41 and the lower conducting wafer 49. The side wall of the upper housing member 38 is provided with a plurality of spaced apart somewhat semicircular notches 38*d* cooperating with a similar set of notches 39*b* formed in the side wall of the lower housing member 39 to form a set of vent openings identified in FIG. 2 by the reference numerals 61, 62, 63 and 64. The vent openings 61, 62, 63 and 64 are respectively aligned radially of the housing with the arc gaps 57, 58, 59 and 60, thus allowing gases created within the housing by the action of the arcs to flow radially outward for the purpose of moving the arcs spanning the gaps toward the periphery or exterior of the gap unit housing. The upper housing is provided with an elongated rib 75 (FIG. 6) extending radially inward from its outer periphery toward the center and having an elongated slot or recess 73*a* therein. A similar rib 65 is formed on the lower housing member 39 and it too is provided with an elongated opening 65*a* coextensive with and in alignment with the elongated recesses 65*a* and 75*a* for the purpose of preventing the upper and lower housing members 38 and 39 from turning with respect to each other. The ribs 65 and 75 and the block 66 also prevent arcing between the initial electrode 43 and the final or terminal electrode 47 of the gap unit.

For a 3 kilovolt lightning arrestor, the quenching gap 14 is provided with only one of the gap units 36 described above and the second gap unit 37 may be eliminated. In this event, an electrical connection is made from the lower conducting wafer 49 to the valve element 15, through a connecting assembly indicated generally by the reference numeral 67. For a six kilovolt lightning arrestor, however, two of the gap units 36 and 37 are stacked one upon the other within the housing 13 as shown in FIG. 6 with the connecting assembly 67 in engagement with the conducting wafer 49 on the lower unit 37. For a 9 kilovolt arrester, three gap units are employed in stacked relationship with the upper unit being connected to the spring retaining plate 35 and with the lowermost unit being connected to the assembly 67 and so on. When a multiple gap unit is assembled, electrical connection between the individual units is provided by engagement between the lower conducting wafer 49 on the upper unit and the upper conducting wafer 41 on the lower unit. As is best shown in FIGS. 1 and 6, the lower housing member 39 is provided with an annular peripheral recess 39*c* cooperating with the recess 38*a* in the upper

housing member of the adjacent gap unit to receive an insulating gasket **69** which is similar to the gasket **40** described above.

In the construction of valve arresters of various voltage ratings, the size of the characteristics element must be varied in addition to appropriately varying the number of gap units. Thus, for a given type of arrester such as the distribution type herein described, the required voltage rating steps such as 3, 6, 9, 12, 15 and 18 kilovolts are achieved with optimum cost economy by keeping the cross section uniform and varying only the axial length. This permits the same components to be used for all ratings. As is best shown in FIGS. 1 and 7 of the drawings, the connecting assembly **67** includes an annular cap **68** formed of ceramic or other suitable insulating material and having an upper annular peripheral recess **68***a* coacting with the recess **39***c* formed in the lower housing member **39** of the lowermost gap unit to receive an insulating gasket **70** similar to the gaskets **40** and **69** previously described. The cap **68** is provided with a downwardly and outwardly tapering peripheral wall **68***b* terminating adjacent a lower annular peripheral recess **68***c* which serves to accommodate another insulating gasket **76** cooperating with the gasket **70** to prevent electrical sparkover along the walls of the housing **13** between the conducting wafer **49** on the lowermost gap unit and the valve material. To the same end, insulating material **71** is disposed within the space defined between the inner wall of the housing **13** and the tapered peripheral wall **68***b* of the insulating cap **68**. The upper face of the cap **68** is provided with an annular recess **68***d* for receiving the outwardly extending lip **72***a* of a conducting ring **72** having a depressed center portion **72***b* which fits within the center opening **68***e* of the cap. The upper surface of the lip **72***a* is seated against the underside of the conducting wafer **49** on the lowermost gap unit **37** for the purpose of providing an electrical connection from the quenching gap assembly **14** to the connectting assembly **67**. The conducting ring **72** is electrically connected to a lower conducting disc **73** by means of a rivet **74** passing through rivet receiving openings **72***c* and **73***a*. The disc **73** is dimensioned so that its peripheral edge underlies an annular shoulder **68***f* formed on the underside of the cap **68**. The cap **68** is further provided with a downwardly and outwardly tapering inner wall which when placed under axial pressure from the springs **33** and **34** produces components of force acting radially inward on the upper portion of the silicon carbide grains. This reduces wall friction and tends to compact the grains toward the center along the axis, so that the path of minimum resistance through the silicon carbide grains is directed to to the surface of the disc **73**, which in turn is maintained in pressured contact with the upper surface of the grains by this same system.

In view of the foregoing description it will be observed that excessive voltage between the conducting line **11** and ground **12** causes current to flow from the upper terminal assembly **26** through the springs **33** and **34**, through the spring retaining plate **35**, through the conducting wafer **41** and the machine screw **42** of the upper gap unit **36**, across the spark gaps **57**, **58**, **59** and **60** of the unit **36**, through machine screw **48**, through conducting wafer **49** of the unit **36** and to the unit **37** through its conducting wafer **41**. The current then traverses the spark gaps of the unit **37** and passes from the lower conducting wafer **49** of this unit to the assembly **67** before flowing through the valve element **15** to the lower terminal assembly **16**. Thus, in a multiple gap construction, the current traversing each gap unit passes in a circular path or turn and, in passing through one or more such turns, a magnetic field is created which produces a force tending to move the arcs outwardly from the center of each gap unit toward its outer periphery. This magnetic effect is developed without the use of complicated, space consuming auxiliary arc blowout structure. The described magnetic effect coacts with the force of the gases in passing outwardly toward the openings **61**, **62**, **63** and **64** to elongate the arcs spanning the gaps in order to aid in extinguishing them. Each of the gap units is compactly arranged and formed in a relatively thin layer so that the overall height of the lightning arrester is minimized.

In addition to these effective arc quenching features, this gap system provides other advantages arising from the distribution of capacitance throughout the gap system as depicted in FIG. 3. The first advantage is that each gap unit as a whole acts as a capacitance of sufficient and certain value so that when a plurality of gap units are employed in series, the voltage which occurs before sparkover is divided equally among the several gap units.

This "voltage dividing capacitance" comes from the total capacitance between the top and bottom plates **35** and **41** of each gap box. This is made up of the plates themselves acting through the air and ceramic dielectric plus the components of capacitance due to the individual gap electrodes. In FIG. 3 these capacitances are shown as **77**, **78**, **79**, **80** in series with **81**, **82**, **83**, **84**. This series multiple system of capacitance is equal to the corresponding set in the next or other successive gap units.

A second and very important feature of this gap unit design derives from a unique distribution of capacitance within each gap unit. In addition to the group of equal interplate capacitances, **77**, **78**, **79**, **80**, **81**, **82**, **83**, **84**, there is a group of equal capacitances **85**, **86**, **87** and **88** between individual gap electrodes. If the interplate capacitances were reduced to zero, then the voltage applied to a gap unit would be divided equally between each of the four gaps **85**, **86**, **87**, and **88** and the impulse sparkover would be commensurated with that of a single gap spaced at a distance equal to the sum of the four individual gaps. However, if the interplate capacitances are several times greater than the interelectrode capacitances, which condition obtains in the present invention, then the interplate capacitances control the voltage appearing upon the three floating electrodes **44**, **45** and **46** and maintains this voltage at one-half the voltage appearing on the gap unit as a whole before sparkover.

Thus, prior to sparkover one-half of the applied voltage will appear between electrodes **43** and **44**, and the other half will occur between electrodes **46** and **47**; substantially, no voltage will appear between electrodes **44** and **45**, and **45** and **46**. This condition favors cascading or sequence sparkover of the individual gaps and causes the gap system as a whole to sparkover more quickly and at lower impulse values. In this case, the four gaps sparkover at approximately one-half the value at which they would sparkover if disposed in uniform series arrangement. A lower impulse sparkover value is highly desirable since it provides the arrester with improved protective characteristics.

Turning now to the construction of the valve element **15** which forms an important part of the present invention, it will be recalled from the foregoing description that this valve consists of silicon carbide grains or particles filling the lower portion of the housing **13**. In accordance with an important feature of the present invention, silicon carbide particles of carefully selected but different sizes are employed to form the valve element with the basic or larger particles **90** shown in FIG. 8 being selected to establish the electrical characteristics desired. A sufficient quantity of these particles is employed within the space between the connecting assembly **67** and the lower terminal assembly **16** to establish a point-to-point contact between the basic particles **90**, thus forming intergranular gates **91** of the type described above. A portion of this space has been left blank in FIG. 1 to make room for the reference numerals but it should be understood that the valve material actually extends into engagement with the underside of the cap **68** and the disc **73**.

The grains of silicon carbon as purchased generally

have contours including a number of sharp points as shown in FIG. 8. While the particles could be ground or tumbled to remove the points and sharp edges and to form particles more rounded in shape, the pointed or sharp cornered particles are preferred because the intergranular contacts or gates formed by such particles are smaller in size and provide higher follow current resistance. Before considering the packing arrangement of the present invention, a few basic facts concerning the geometry of "sphere packs" should be reviewed. Assuming that the volume of the space to be filled is very large as compared with the volume of uniform size spheres which are used to fill the space, it should be observed that the same percentage of unfilled space or voids will result regardless of the diameter of the spheres. Stated in another way, the percentage of void space in a given volume is nearly the same whether it is filled with 1 inch spheres or fine sand. The percentage of voids or unoccupied space will, however, vary with the packing arrangement selected. For example, the spheres can be set up in parallel rows with diameters through contact points forming a rectilinear grid with similar layers directly above one another forming a simple cubic lattice like the NaCl crystal. In such a pack each sphere is in contact with only six neighboring spheres and the fill will be only 52.36% of the volume containing the pack (assuming perfect boundary conditions). This number in the cubic pack results from the ratio of the volume of the sphere and the volume of the cube when the side of the cube equals the diameter of the sphere.

Now the most dense packing of spheres of the same diameter occurs when the spheres are arranged in offset rows so that diameters through points of contact form a grid of equilateral triangles in each layer. Successive layers are offset so that each layer fits into the recesses of contiguous layers. There are two such offset positions, each yielding the same maximum density; one layer sequence forms the crystal lattice known as "face centered cubic" and the other sequence results in the "close packed hexagonal" structure. Both of these are very common crystal forms. Most metals crystalize into one or the other and sometimes both of these forms. They represent the most dense sphere pack that is possible and both of them will fill a container up to 74.05% of its full volume. (Again assuming perfect boundary conditions.) In both of these forms each sphere is in contact with 12 of its neighbors. If tangent planes are constructed at each of the twelve contact points on the unit sphere they will intersect to form either of two very interesting polyhedra, one is the rhombic dodecabedron arising from the "face centered cubic" form and the other is the trapeso-rhombic-dodecabedron resulting from the "close packed hexagonal" form. Both fill space without voids and are of exactly the same volume when formed on spheres of the same diameter. The volume of the rhombic dodecabedron is equal to $2(\sqrt{2R})^3$ where R is the radius of inscribed sphere. The percentage of the fill in the case of these maximum density sphere packs may be found by the ratio of the volume of the unit sphere to the volume of the associated 100% space filling polyhedron. Thus,

$$V \text{ (sphere)} = 4/3\pi R^3 = .5236 \text{ cu. units}$$

$$V \text{ (polyhedron)} = 2(\sqrt{2R})^3 = .7071 \text{ cu. units}$$

$$\text{Percent fill} = \frac{.5236}{.7071} = 74.05\%$$

From this it is clear that spheres of the same diameter will fill the volume of a container somewhere between 52% and 74% depending upon the boundary conditions and the form of the pack.

In accordance with one grain packing arrangement which yields excellent valve arrester performance, basic silicon carbide grains of a specific controlled volume resistivity and 60 mesh size were employed. These basic grains alone introduced into the valve element volume 15 so as to fill the space between electrodes 20 and 73 under pressure and vibration would provide the required basic grain network having sharp intergranular contacts with approximately one-third of the volume remaining void due to spaces between the basic grains as shown in FIG. 8 between the grains 90.

Now if the complete arrester is operated with the valve element in this condition, that is, basic grains only, the performance will be better than satisfactory with respect to protection from surge effects since the discharge voltage or IR drop will be relatively low, but the amount of follow current permitted to flow after the surge subsides will be excessive with the selected parameters. This is shown on the chart FIG. 9 where the condition described above is represented by the ordinate values which occur for 0% of small grains.

In an arrangement like that shown in FIG. 8, the voids between the basic grains could accept up to 40% of the original volume in an intermediate size grain, and likewise the voids between the intermediate grains could accept still finer grains to the extent of 40% of the 40% voids or 16% of the original volume. Now it is important to maintain the intergranular contacts between the basic grains and, as a result, the quantity of intermediate and fine grains introduced is preferably less than the total available void spaces. This stepped size grain system may be generally defined in relative geometrical terms, for example:

	Grain Size (average diameter)	Volume (cubic unit)
1st Step—Basic Grains	1	1
2nd Step—Intermediate	1/6 to 1/4	1/4 to 1/3
3rd Step—Fine 1	1/25 to 1/16	1/16 to 1/9
Possible 4th Step—Fine 2	1/125 to 1/64	1/64 to 1/27

In the formation of the valve element, the three grain sizes are carefully mixed in the selected proportions, such as: $1+1/4+1/16=1.31$ volume units. This 1.31 volume is then vibration packed so as to occupy close to unit volume, thus demonstrating the void filling process.

The size of the basic grains is determined by the electrical properties of the silicon carbide in relation to the particular function it is to perform. For example, a suitable distribution type valve arrester can be produced with basic grains of 36 grit or average diameter of .02 provided it is composed of silicon carbide of relatively high volume resistivity. However, there are practical advantages in employing smaller basic grains such as 60 grit (.010 dia.) with lower volume resistivity.

In the packing theory, there is no particular limit to the minimum size of the grains that could be used to fill the voids in each preceding step. But in practice, there are two limitations; first, if the difference in the size of the successive steps is too great, the mix tends to separate and, secondly, when extremely fine particles are employed it is difficult to produce a high density pack because of trapped air.

Thus, in the present invention, I have found the following specific values produce valve arresters with very effective performance chiracteristics.

	Grit Size	Quantity Relative Volume, cu. units
Basic Grains	60 grit (.010" ave. dia.)	100
2nd Step (intermediate)	220 grit (.0025" ave. dia.)	25
3rd Step (fine)	600 grit (.00063" ave. dia.)	6

This system of grain steps is schematically depicted in two dimensional sections in FIG. 8 where the basic grains are represented by 90, the second stage or intermediate size grains are indicated at 93, and the third stage or fine

grains are identified as **94**. The major portion of the current which flows through the arrester passes through the contact points between the basic grains **90**. The regions immediately surrounding the contact points **91** heat up and act as variable resistance gates and form the basis for the overall non-linear resistance function which is further enhanced by the oxide films that form over the grain surfaces when the arrester is inactive. The intermediate and fine particles are packed around and are thermally coupled to the junctions or gates **91** of the basic grains, and, as a consequence, they serve as a cooling medium for cooling the gates very rapidly after the overvoltage which opened the gates has subsided. The rapid cooling of the basic particles in the region of the gates **91** restores the resistance of the silicon carbide, the silicon dioxide film very quickly reforms and the resistance of the valve element **15** as a whole increases by a factor of 10 or more with the result that the power follow current is confronted by a relatively high impedance path so that its magnitude is limited to insignificant levels regardless of the available fault current. The pressure applied to the valve element through the quenching gap structure **14** and the connecting assembly **67** by the springs **33** and **34** functions to maintain a tight pack of the particles making up the valve element **15**. An important feature of the three stage grain pack is that the fines pack out against the inner walls of the housing reducing voids in this critical region to a minimum and providing a relatively high resistance path to eliminate the tendency to flashover the outer surfaces of the valve element.

The intermediate and fine particles do not carry appreciable surge or fault current in view of the fact that they have much greater intergranular resistance than the basic grains due to the smaller area of contact therebetween and also in view of the large number of high resistance gates in the paths formed by the smaller particles. Thus, when the proper quantities of the intermediate and fine particles are employed their presence does not appreciably effect either the surge resistance or the power current resistance of the basic grains. Since the intermediate and fine particles are of the same material as the basic grains there is no tendency of chemical reaction or physical change even under high temperatures encountered within the lightning arrester **10**. All of the particles **90**, **93** and **94** are highly refractory and are able to withstand temperatures up to 4000° F.

The curve shown in FIG. 9 illustrates the relationship between the power follow current and the IR voltage drop across the valve element with a change in the percentage by weight of the total amount of small and intermediate size grains. Curves similar to those shown in FIG. 9 and indicated by reference numerals **95** and **96** were produced by actual tests employing a number of different combinations of intermediate and fine particles without changing the size of the basic grain particles. In these curves, the change in the percentage by weight of the total amount of small and fine particles is plotted as the abscissa of both of the curves **95** and **96**. The curves **95** represents the variation in IR drop across the valve element as the percentage by weight of the intermediate and fine particles is varied and, to this end, the right hand side of the graph contains a scale indicating the IR drop in kilovolts. The curve **96** represents the change in power follow current with a change in the percentage by weight of the intermediate and fine grains and the scale appearing at the left hand side of the curve indicates the peak power follow current in amperes. The horizontal line **98** represents the tolerable power follow current for a lightning arrester of the voltage rating tested, and hence, all areas of the curve **96** lying above this horizontal line are beyond the usable range of the arrester. The horizontal line **99** represents the tolerable IR drop in the lightning arrester having the voltage rating of that tested and, as a result, all portions of the curve **95** lying above the horizontal line **99** represent an unusable portion or range. Thus, it will be observed that the usable range of the percentage by weight of the intermediate and fine particles lies between 20 and 30%. This means that the total weight of the intermediate and fine particles must be greater than about 20% of the total weight of the mix or pack, and, at the same time, should be less than about 30% of the total weight of the mix. With basic grains of somewhat different size this range may change slightly. The portion of the curve **96** lying above the horizontal line **98** represents the region where an insufficient quantity of small and intermediate size particles is provided so that the heat created at each of the junctions **91** is not carried off rapidly enough to reduce the power follow current to the tolerable range. The portion of the curve **95** lying above the horizontal line **99** represents the region where an excessive amount of intermediate and fine particles is employed so that the basic grain particles are being forced apart to increase the sparkover voltage or IR drop of the valve element. Such a condition cannot be tolerated because it provides insufficient protection for the equipment connected to the line **11**. The chart of FIG. 9 shows that the addition of 25% by weight of combined intermediate and fine particles increased the IR drop or discharge voltage by only 10% but reduced the follow current to less than half of the value which occurs with the basic grains alone.

In view of the foregoing description, it will be recognized that the enumerated and other objects and advantages have been achieved by the lightning arrester illustrated in the drawings and described above. The described construction is extremely rugged, is compactly arranged and yet provides improved protecting qualities. In addition, the construction is simple and inexpensive both because it employs a minimum number of parts and because a number of the parts employed particularly in the quenching structure **14** are duplicates and can be manufactured at very small cost by mass production techniques.

While a particular embodiment of the invention has been shown and described, it will be understood that various modifications will occur to those skilled in this art and, it is, therefore, contemplated by the appended claims to cover all such modifications that fall within the true spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. For use in a lightning arrester a quenching structure including at least one spark gap unit having a somewhat cylindrically shaped gap unit housing formed by upper and lower housing members, a first conducting plate secured to the top of the upper housing member, a second conducting plate secured to the bottom of the lower housing member, a plurality of spaced apart spark gap electrodes mounted upon said upper and lower housing members, said electrodes being arranged along a circle having a center substantially coinciding with the longitudinal axis of the housing and defining a series of spark gaps, means securing a first of said electrodes to said upper housing member and providing an electrical connection to said first plate, means securing a second of said electrodes to said lower housing member and providing an electrical connection to said second plate, a plurality of spaced apart projections extending upwardly from the lower housing member respectively supporting the lower ends of the remaining electrodes, and a similar group of projections extending downwardly from the upper housing member and respectively aligned vertically with the projections on the lower housing member for supporting the upper ends of said remaining electrodes.

2. The structure defined by claim **1** wherein said lower housing member is provided with sets of concentric grooves with each such set being located below one of the electrodes.

3. For use in a lightning arrester, a quenching structure including at least one spark gap unit having a somewhat cylindrically shaped housing formed by upper and lower housing members, a first conducting plate secured to the top of the upper housing member, a second conducting plate secured to the bottom of the lower housing member, a plurality of spaced apart spark gap electrodes mounted upon said upper and lower housing members, said electrodes being arranged along a circle having a center substantially coinciding with the axis of the housing and defining a series of spark gaps, means securing a first of said electrodes to said upper housing member and providing an electrical connection to said first plate, means securing a second of said electrodes to said lower housing member and providing an electrical connection to said second plate, a plurality of spaced apart projections extending upwardly from the lower housing member respectively supporting the lower ends of the remaining electrodes, and a similar group of projections extending downwardly from the upper housing member and respectively aligned vertically with the projections on the lower housing member for supporting the upper ends of said remaining electrodes.

4. For use in a lightning arrester, a quenching structure including at least one spark gap unit having a somewhat cylindrically shaped housing formed by upper and lower housing members, a first conducting plate secured to the top of the upper housing member, a second conducting plate secured to the bottom of the lower housing member, a plurality of spaced apart spark gap electrodes mounted upon said upper and lower housing members, said electrodes being arranged along a circle having a center substantially coinciding with the axis of the housing and defining a series of spark gaps, means securing a first of said electrodes to said upper housing member and providing an electrical connection to said first plate, means securing a second of said electrodes to said lower housing member and providing an electrical connection to said second plate, and means rotatably supporting the remaining electrodes within the housing in spaced apart positions between said first and second electrodes.

5. For use in a lightning arrester, a quenching structure including a housing, a first conducting plate secured to the top of the housing, a second conducting plate secured to the bottom of the housing, a plurality of horizontally spaced apart spark gap electrodes mounted within said housing and defining a series of spark gaps, means securing a first of said electrodes to said housing and providing an electrical connection to said first plate, means securing a second of said electrodes to said housing and providing an electrical connection to said second plate, and means supporting the remaining electrodes within the housing in spaced apart positions disposed between the first and second electrodes.

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