

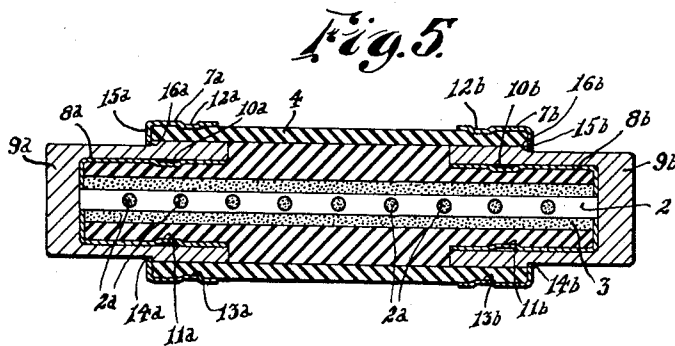
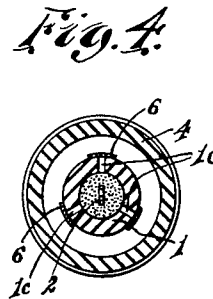
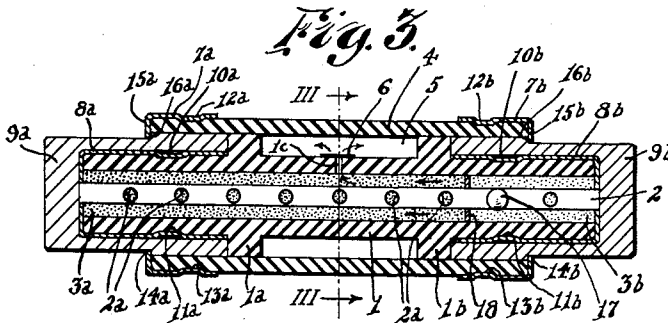
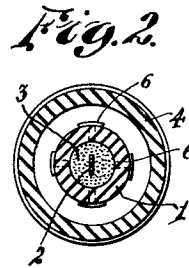
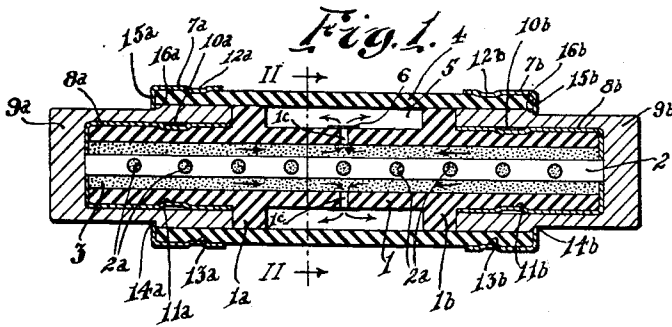
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CURRENT-LIMITING FUSE

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CURRENT-LIMITING FUSE

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This invention relates to fuses and more particularly to fuses of the current-limiting type. The term current-limiting fuse is generally applied to any fuse which limits the flow of current in a circuit to a substantially smaller value than the available short-circuit current of the circuit. The highest current which a current-limiting fuse permits to pass is referred to as the let-through current.

The current-limiting effect of most current-limiting fuses is due to the interaction of the metal vapors resulting from vaporization of the link of the fuse and an inert pulverulent filler by which the link is surrounded. The link consists not necessarily but generally of silver because silver has a relatively high conductivity in its solid state, while its vapors have a relatively low conductivity unless their temperature is particularly high. In other words, at a given temperature slightly above the boiling point of silver the percentage of ionized silver is relatively low, resulting in a relatively small conductivity of silver vapors at this temperature range. If a fuse link made of silver is vaporized in an inert pulverulent filler such as quartz sand, which practically does not evolve any gases under the heat of the arc, the silver vapors resulting from vaporization of the link are rapidly reduced to a low temperature where they will not support a flow of current. Though the duration of arcing through the labyrinth path formed by the interstices between the particles of granules of the filler may be, or actually is, extremely short, a portion of the particles melt or fuse and form a fulgurite or semi-conductor. The semi-conductor or fulgurite resulting from fusion and sintering of quartz particles is in the nature of a glass body, and as it cools down to ambient temperature it loses its conductivity and turns into an insulator. Metal vapors which diffuse in the pulverulent filler beyond the immediate arcing zone condense on the large surfaces of the quartz particles and form a silver-quartz conglomerate which has an extremely high resistance and which, for any practical purpose, may be considered as an insulator.

Sometimes current-limiting fuses are used to interrupt only fault currents of short-circuit current proportions and the interruption of relatively small overloads of inadmissible duration is referred to some other serially related device such as, for instance, an automatic circuit breaker. If it is only required of a current-limiting fuse to control fault currents of large magnitude, then the ability of the fuse to interrupt the circuit in which it is inserted needs to be tested only for the range of high currents which it is required to interrupt. If, however, the fuse is required to control currents of load proportions as well as currents of short-circuit current proportions, then it must be tested for the entire large current range at which it is required to operate.

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I have discovered that current-limiting fuses of the silver-link quartz-sand-filler type and similar current-limiting fuses which had consistently performed their interrupting duty when tested in the power laboratory have in some way failed in the field. This behavior appeared strange since the interrupting duties to which the fuses were subjected in the power laboratory were even more severe than the interrupting duties to which they were subjected in the field. A careful investigation of the above fact revealed that the failures in the field occurred a considerable time after successful interruption of the circuit by the fuse. The fuse casing would gradually be heated after successful interruption, become charred and finally burst. The tendency of post interruption failure appeared to be relatively high at load currents of relatively small magnitude and excessive duration. I concluded that post interruption failure of fuses was, at least in part, due to a follow-current that would flow through the fulgurite or semi-conductor by which the fuse link had been substituted, which follow-current would result in the dissipation of additional amounts of heat that would exceed the heat absorbing capacity of the fuse structure and would cause a destruction thereof. The correctness of this hypothesis was later verified by tests.

I ascertained that there was a relation between post interruption failure and the amount of arc energy dissipated during the interrupting process. When an interruption of small current arcing would last during a plurality of half cycles, the arc energy would tend to be large. Moreover, on the occurrence of small protracted overloads, the arc extinguishing filler would tend to be intensely preheated before melting of the link. The combination of intense preheating before initiation of the interrupting process and of relatively large arc energy tends to raise the temperature of the arc-quenching filler and that of the casing to such an extent that the fuse may be caused to fail on account of a relatively small follow-current through the fulgurite or fused quartz semi-conductor formed during the interrupting process proper.

It is, therefore, one object of this invention to provide a current-limiting fuse which is not subject to post interruption failure.

Since post interruption failure of current-limiting fuses is, at least in part, due to heating of the arc-quenching filler and of the casing of the fuse by the follow-current flowing through the fulgurite or semi-conductor resulting from the operation of the fuse, post interruption failure can be avoided by producing one or more gas jets along the semi-conductor, i. e., in a direction longitudinally thereof, whereby the semi-conductor is cooled by heat convection and a more rapid conversion of the semi-conductor into an insulator is effected.

It is, therefore, another object of this invention to provide a current-limiting fuse which includes

means for producing one or more suitable gas flows for cooling the fulgurite or semi-conductor resulting from the operation of the fuse.

Another object of the invention is to provide a current-limiting fuse which is particularly suitable for the voltage range of 1000 volts and higher voltages and which is more compact than prior-art current-limiting fuses for that voltage range.

In carrying out my invention I prefer to use fuse links of which substantially the entire length consists of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area. Links having a geometrical configuration of this type are being used in high voltage current-limiting fuses to produce series arcs and for other reasons. The application of fuse links having a geometrical configuration of this type to fuses having a voltage rating in the neighborhood of 1000 volts makes it possible to distribute the thermal duty of the arc quenching filler relatively evenly over the entire filler body which is a factor tending to permit a reduction of the overall size of the fuse and more particularly of the internal space of the fuse casing. If a current-limiting fuse having a variable cross-sectional area section as above described is subjected to fault currents in the nature of short-circuit currents, all of the portions of relatively small cross-sectional area fuse and vaporize almost simultaneously, resulting in the formation of arclets in series. Frequently only a part of each intermediate relatively large cross-section portion of the link is completely vaporized during the interrupting process. The fulgurite or semi-conductor formed under such conditions consists actually of a string of small spaced fulgurites or semi-conductors and intermediate portions of more or less solid metal. The interrupting process in a current-limiting fuse having a variable cross-sectional area section, as above described, is quite different if the fuse is subjected to relatively small protracted fault currents. In this case there are appreciable intervals of time between initiation of arcing at various relatively small cross-sectional area portions. Generally the arc gap first formed is being progressively enlarged by vaporization of the link until the gap is of sufficient length to effect final interruption of the circuit. Because of these facts the fulgurite or semi-conductor formed in current-limiting fuses of the silver-link quartz-sand-filler type which are provided with links having a variable cross-sectional area section, as above described, is generally continuous when such fuses are subjected to small protracted overload currents.

Where a current-limiting fuse is required to interrupt both large and small fault currents at a predetermined voltage rating, this requirement may be met in various ways by resorting to various fuse links having different geometrical configurations, including different lengths and different cross-sectional areas. It is desirable to select among the variety of possible link configurations and link sizes the link configuration and size for which substantially the same length is required both for interruption of relatively high and interruption of relatively low currents. The shortest length required for interruption of both relatively low and relatively high fault currents depends, as I have found,

also upon the grain size of the pulverulent fulgurite-forming arc-quenching filler.

Post interruption failures of fuses occur or become more serious when the size of the casing of the fuse and consequently the volume of the fulgurite-forming arc-quenching filler and the heat absorbing capacity of the entire fuse structure are greatly reduced. It is only then that it becomes necessary or desirable to provide fuses with means for producing a flow of gas for cooling the fulgurite or semi-conductor resulting from the interrupting process.

The establishment of a fulgurite cooling flow of gas in the fuse requires the provision of venting means permitting the escape of gaseous products out of the link-receiving casing into an enclosed space where the hot gaseous products are trapped to prevent them from causing any harm, and in particular to prevent them from causing any electric breakdown. Except for appropriately positioned venting means the link-receiving casing ought to be completely, or at least substantially, gas tight.

Current-limiting fuses of the silver-link quartz-sand-filler type are generally not provided with venting means. Designers of such fuses make it a point to dispense with venting means since the arc-quenching filler in such fuses is inert or non-gas evolving. In fact, the maximum pressures observed in conventional current-limiting fuses of the silver-link quartz-sand-filler type are relatively low which enables the use of fuse casings which have but relatively little mechanical strength as, for instance, glass or ceramic materials.

Utmost simplification and compactness require that the fuse link be arranged in substantially coaxial relation in the link-receiving casing and extends straight between the ends thereof. I have found that it is possible to reduce the diameter of the casing of current-limiting fuses of this type to about twice or three times the width of a link consisting of a metal strip having a plurality of serially related relatively small cross-sectional area portions and relatively large cross-sectional area portions, as above described. Though it is possible to produce current-limiting fuses which operate successfully in spite of a reduction in size of the above order, the properties of such fuses differ significantly from the properties of comparable relatively larger prior-art current-limiting fuses. While relatively low internal pressure is a typical feature of prior-art current-limiting fuses of the silver-link quartz-sand-filler type, the internal pressure in minimum fuses of the contemplated type is extremely high. I have found it necessary or desirable to provide the minimum size fuses according to this invention with triple caps on each end thereof to withstand the pressure generated within the link-receiving casing. The large amount of pressure in these fuses results primarily from metal vapors and from the heat generated by the follow-current rather than from the evolution of gaseous products from gas evolving substances, and such substances may be entirely dispensed with. If not entirely dispensed with, they must be arranged in a certain way, as will be more fully set forth below.

In fuses according to this invention the mechanical strength of the link-receiving casing is less than required to withstand the total pressure resulting from the partial vapor pressure due to the vaporization of a preponderant portion of the length of the above referred-to variable cross-

sectional area section of the fuse link, and the partial pressure due to the follow-current through the fulgurite formed upon fusion of a portion of the arc-quenching filler. The partial vapor pressure can be determined from a measurement of the internal volume of the link-receiving casing and the amount of link metal vaporized during the arcing period. The partial pressure due to the flow of a follow-current through the fulgurite may be determined by an oscillographic investigation of the post interruption period of the fuse. If the link-receiving casing were designed to withstand the high pressure which develops in the fuse, this would require such thickness of the walls of the link-receiving casing as to off-set the reduction of space requirements due to the decrease of the internal link-receiving space within the fuse casing. Provision of a judiciously selected venting means enables the use of link-receiving casings of more limited mechanical strength. It is, however, desirable to use tubular materials of considerable mechanical strength for manufacturing the link-receiving casing such as laminated materials including layers of spun and woven glass fibers impregnated with a heat resisting plastic substance.

For a better understanding of my invention reference may be had to the accompanying drawing in which:

Fig. 1 is a substantially central longitudinal section through a fuse constructed in accordance with my invention with certain of its parts shown in elevation;

Fig. 2 is a transverse cross-sectional view of the fuse shown in Fig. 1 taken along the line II—II thereof;

Fig. 3 is a substantially central longitudinal section through a modified form of fuse constructed in accordance with my invention with certain parts thereof shown in elevation;

Fig. 4 is a transverse cross-sectional view of the fuse shown in Fig. 2 taken along line III—III thereof; and

Fig. 5 is a section similar to those in Figs. 1 and 3 showing another fuse structure embodying my invention.

Like reference signs have been applied in all figures to designate corresponding parts.

Referring now to Figs. 1 and 2, reference numeral 1 has been applied to a casing in which the silver link 2 is mounted. The link 2 might be of a metal other than silver such as, for instance, zinc, but for the reasons stated above silver is preferable. Link 2 is provided with a plurality of circular equi-distant perforations or holes 2a which determine the points where fusion of the link is initiated, at least when the fault current and its rate of rise are high. Link 2 is in intimate contact substantially along its entire length with the quartz filler 3. The perforations or holes 2a form portions of reduced cross-sectional area of which each comprises two parallel current paths, one on either side of each hole or perforation. Since each portion of reduced cross-sectional area comprises two fusible current paths, two arcs or arclets in parallel will be initiated at each point of reduced cross-sectional area. Because of the formation of pairs of arcs in parallel, the ratio of active quartz surface to arc diameter will be large, resulting in most effective cooling of the arc. Arcs in parallel are unstable and, therefore, there will be a tendency for one of the two arcs or arclets in parallel to extinguish almost instantly upon its initiation.

The other of each pair of arcs or arclets in parallel extinguishes soon thereafter. Upon extinction of the serially related pairs of parallel arclets the space which was originally occupied by the fuse link and thereafter occupied by the arc is finally occupied by a glass-like body resulting from the fusion of the quartz filler immediately adjacent the arcing zone. As mentioned before, that body may consist of a plurality of spaced fulgurite elements with residual metal particles in the gaps therebetween. As long as that body is relatively hot it is a fairly good conductor of electricity. It turns into an insulator of high dielectric strength and ohmic resistance as it cools down to ambient temperature.

Immediately upon interruption of the circuit by vaporization of the link 2 and fusion of the surrounding quartz filler 3 the full line potential prevails across the glass-like semi-conductor resulting from the fusion of the quartz filler. The full line potential tends to cause continued flow of current through the semi-conductor and though the rate of current flow is generally very small and may appear to be insignificant, yet the resulting I^2R losses may be sufficiently large to critically delay the cooling of the semi-conductor. In such instances a post interruption failure is likely to occur.

As mentioned above, interruption of low currents differs in certain respects from interruption of high currents. In the first instance there is a tendency that but one single arc gap will be formed resulting in the formation of one single continuous fulgurite rather than of a string of spaced fulgurites. This is probably a factor tending to make the successful interruption of small load currents, particularly of the minimum fusing current, more onerous than the interruption of relatively high current.

The means for avoidance of post interruption failures will now be more fully described.

The casing 1 of the fuse is provided with a pair of external spaced radial flanges 1a and 1b which support an outer casing or tubular member 3 in coaxial relation with casing 1. Flanges 1a, 1b and the outer casing 4 define jointly a substantially closed toroidal chamber 5. Both casings 1 and 4 consist preferably of a suitable laminated material, e. g., spun and woven glass fibers which are impregnated with a suitable plastic. Casing 1 is provided with a plurality of radial bores 1c which are angularly related and arranged in a common transverse plane, as can best be seen in Fig. 1. The bores 1c are situated about midway between the axially outer ends of casing 1 and fuse link 2 and they interconnect the center region of casing 1 with the chamber 5. Because of this particular configuration there is a tendency for the gases formed by vaporization of the fuse link 2 and by heating the air in the interstices between the quartz granules to produce a pair of opposite gas flows enveloping and cooling the fulgurite or semi-conductor formed upon fusion of the link 2 and of the adjacent mass of quartz filler 3. These two opposite gas flows have been clearly indicated by arrows in Fig. 1. Both gas flows meet in the center region of the fuse, turn about 90 degrees and escape through the passages 1c into the chamber 5. In order to preclude the quartz sand within casing 2 to leak into the chamber 5, the openings or passages 1c are normally obstructed by adhesive cellulosic tape 6. Upon blowing of the fuse under overload conditions the tape is rapidly de-

stroyed by heat and pressure within casing 1, thus permitting the formation of the two above referred-to opposite gas flows in a direction longitudinally of the fulgurite or semi-conductor formed by fusion of a portion of the quartz filler. If the fuse is subjected to fault currents of short-circuit current proportions, the tape seal 6 remains unaffected, i. e., it is not being destroyed.

A pair of caps 7a, 7b is provided on the ends of casing or outer shell 4. Another pair of caps 8a, 8b is provided on the ends of the casing 1, which casing is longer than the casing or outer shell 4 and projects beyond the ends thereof. The ends of casing 1 are provided with an additional or outer pair of caps 9a, 9b. Each end of link 2 is secured, as by welding or soldering, to one of caps 8a, 8b and each of caps 8a, 8b has a circular indentation 10a, 10b engaging one of a pair of circular grooves 11a, 11b in casing 1. Each of the pair of caps 9a, 9b covers one of the pair of caps 8a, 8b and is in metallic contact therewith. Each of the pairs of caps 7a, 7b has on the lateral surface thereof a circular indentation 12a, 12b engaging one of a pair of circular grooves 13a, 13b in casing or outer shell 4. The caps 7a, 7b are each provided with a central aperture 14a, 14b on their top portion 15a and 15b, respectively. Caps 9a and 9b project through the apertures 14a and 14b in the top portions 15a, 15b of caps 7a, 7b. The top portions of caps 7a, 7b engage a shoulder portion 16a, 16b on each of caps 9a, 9b to prevent removal of said caps from casing 1. The axially inner ends of caps 9a, 9b enter toroidal spaces defined by casing 1 and shell 4. The above described triple cap arrangement provides for a great amount of mechanical strength required in spite of the complete absence of gas evolving substances mainly because of the relative large ratio between the amount of metal vaporized by the heat of the arc to the internal volume of the link-receiving casing 1.

The amount of metal vaporized by the heat of the arc is proportional to the arc energy dissipated during the interrupting process. It is possible to decrease progressively the ratio of arc energy dissipated during the interrupting process to internal volume of the fuse-link and quartz-sand-filler-receiving casing. The smaller that ratio, the more compact the design of the fuse, the higher mechanical strength requirements, which is in accordance with the laws of thermodynamics. The triple cap feature combined with the dual casing feature described above in connection with Figs. 1 and 2 permit a reduction of the size of the fuse structure and more particularly of the filler volume to an extent such as, to my knowledge, has never been achieved heretofore in fuses capable to perform a similar interrupting duty. Figs. 1 and 2 of the drawing represent in about natural size a current-limiting fuse capable of controlling D.-C. circuits having an available short-circuit current above 80,000 amperes at a rated voltage of 1000 volts. The let-through current of the fuse is in the order of 3,500 amperes and its current rating 30 amperes. When interrupting short-circuits the clearing time is in the order of $\frac{1}{900}$ seconds. The fuse is capable of interrupting both short-circuit currents and relatively small overload currents of inadmissible duration and is not subject to post interruption failures even at the critical minimum fusing current range.

I have found that when making a drastic reduction of fuse size, strength requirements tend to be more stringent when there are impurities in

the quartz-sand-filler. When the quantity of impurities in the filler sand becomes appreciable and when the fuse is called upon to interrupt very small overloads of inadmissible duration, for instance, if it is required to carry 110% of the rated current permanently and to interrupt protracted overloads as low as 130% of the rated current, then I prefer to use the structure shown in Figs. 3 and 4 of the drawing. This structure includes means for evolving a limited amount of gas when interrupting small protracted overloads used for scavenging out of the link and filler-receiving casing of the fuse the vapors resulting from vaporization of the fuse link.

It is well known in the art to provide fuse links of silver with a metal element having a lower fusing point than silver and adapted to form an alloy with silver having a lower fusing point than silver. If a silver link of a current-limiting quartz-sand-filler fuse is provided with such a metal element, the interrupting process will generally be initiated at small protracted overloads at the point where the metal element is located. The arc gap formed upon arc initiation will grow progressively due to continued arcing and the arc will be extinguished upon having reached a predetermined length, provided that the cooling action of the surrounding quartz filler is sufficiently intense. The gap length formed will depend upon the amount of arc energy which is being dissipated during the interrupting process and the arc gap is being bridged by a fulgurite or semi-conductor which is in the nature of glass since it is produced by the fusion of quartz sand. Perhaps the interrupting process is actually more complex on account of chemical reactions which may take place in addition to the more obvious thermal processes, and I do not wish to limit my invention by referring merely to the thermal aspects of the interrupting process. However, the effectiveness of my invention may be fully explained by reference to thermal aspects only.

If a silver link is provided with an alloy-forming element which reduces the fusing temperature of the link at the point where it is located, then initial gap formation at low current interruptions is generally limited to the neighborhood of the fusing-temperature-reducing element. In a fuse having an alloy-forming fusing-point-reducing element it may be sufficient to produce a single gas flow for cooling the semi-conductor resulting from the fusion of quartz sand rather than a pair of semi-conductor cooling gas currents which flow in opposite directions. The double flow feature may, however, be retained where it is desired or necessary to establish more effective cooling conditions, and in that particular instance the fuse link ought to be provided with two alloy-forming elements, one adjacent each end of the link. Figs. 3 and 4 show an embodiment of a preferred structure which involves one single alloy-forming element.

The fuse link 2 shown in Fig. 3 has a plurality of portions of reduced cross-sectional area and a plurality of portions of relatively larger cross-sectional area intermediate said reduced cross-sectional area portions. Each reduced cross-sectional area portion has a hole 2a laterally bounded by a pair of metallic current paths in parallel. The link 2 is provided with an insert 17 in one of said holes 2a remote from the center of the link. The insert 17 may be in the general shape of a rivet and it consists of a metal having a lower fusing point than the metal of

which the fuse link 2 is made and adapted to form an alloy with the metal of which the fuse link is made having a lower fusing point than the metal of which the fuse link is made. If the fuse link is made of silver the insert 17 may consist of tin. An inert semi-conductor-forming pulverulent filler 3a, such as quartz sand, is arranged in intimate contact with the portions of the link remote from insert 17, and a pulverulent filler 3b evolving gaseous products under the heat of the arc as, for instance, chemically pure chalk, is arranged in intimate contact with the portion of the link 2 adjacent the lower fusing point insert 17. The quartz filler 3a and the chalk filler 3b are preferably separated by a disc 18 equal in diameter to the internal diameter of casing 1.

The fuse shown in Figs. 3 and 4 operates in the same way as the fuse shown in Figs. 1 and 2 inasmuch as interruption of currents of large magnitude is concerned. Its operation is different from the operation of the fuse shown in Figs. 1 and 2 inasmuch as the interruption of relatively small protracted overloads is concerned. On the occurrence of such overloads fusion and arcing are initiated at the point where the insert 17 is located. The vapors resulting from vaporization of the alloy formed by the silver of link 2 and the metal of element 17 are highly ionized. These vapors diffuse from the right of the fuse to the left and, in so doing, are effectively cooled and deionized by the large total surface of the quartz-sand-filler over which they travel. A certain amount of metal vapor may escape through the bores 1c upon having broken the bore-controlling tape seal 6. A good deal of the metal vapors will condense on the relatively cool surfaces of the quartz particles and thus be rendered harmless. Gases evolved from the chalk filler 3b and flowing toward the passage means 1c will dilute and cool the ionized metal vapors and tend to scavenge these vapors out of the casing into the cooling and deionizing chamber 5. There is no danger of electric breakdown across the cooling and deionizing chamber 5 because the gaseous products which flow into it have a relatively large dielectric strength which exceeds the potential across the terminals of the fuse. The evolution of gas by the chalk filler continues as the width of the arc gap grows and a fulgurite is formed and after the arc has been extinguished and substituted by the fulgurite. The fulgurite or semi-conductor is then cooled by the post arcing flow of gaseous products emanating from the chalk filler 3b and flowing to the passage means 1c. Thus rate of cooling of the fulgurite or semi-conductor is sufficiently accelerated to prevent any post interruption failure of the fuse.

It is of considerable importance to properly choose the average grain size of the quartz filler and the size of the passage means or bores 1c to achieve interruption of small protracted overloads without signs of post interruption distress. The interstices between the filler particles and the vent openings 1c of the casing 1 must be of sufficient size to permit development of sufficiently rapid flow conditions. The flow of hot gases through the interstices of the quartz filler is obviously highly turbulent which tends to increase the rate of deionization of the arc products but tends also to increase the flow resistance. To keep the flow resistance sufficiently low the grain size of the quartz filler should be relatively coarse as, for instance, 30/40 mesh size. Considerably finer grain size of the filler, as used in many modern current-limiting fuses of the silver-link quartz

sand type, may have its advantages, but it is adverse to effective interruption of small currents and more particularly to formation of an effective flow of gas in a direction longitudinally of the fulgurite. I have found that for the purpose of effectively controlling small currents, the grain size of the filler should be coarser than 60 mesh and this is particularly important if the filler contains some impurities. The flow resistance through the passage means or bores 1c must be kept sufficiently low by judicious selection of their cross-sectional area. The cross-sectional area of each of the bores 1c should by far exceed the average grain size, and this requires the provision of a means, such as the adhesive tape seal 6, which normally prevents the leakage of filler out of the casing into the deionizing chamber 5, but is easily destroyed by heat and pressure to permit the outflow of gaseous products of arcing. As mentioned before, the adhesive tape seal remains generally intact at the interruption of large currents, but is destroyed at the interruption of small currents. The strength of the seal 6 is deliberately so selected that the seal remains unimpaired by the relatively small pressures resulting from the interruption of currents of short-circuit current proportions. The fuse structure shown in Figs. 3 and 4 is provided with three venting bores or passages 1c which are angularly related, or displaced, 120 degrees, and have a diameter of .04 inch. The number and diameter of the venting passages 1c may vary but must always lie within the limits required for producing an effective scavenging flow from the point of gas generation in a direction substantially longitudinally of the link 2 toward the center of the fuse. The configuration of the venting passages ought to be circular in order to produce a gas flow which envelops the entire substantially cylindrical surface of the fulgurite.

While the triple cap, dual casing structures shown in Figs. 1 to 4 are primarily intended for current-limiting fuses wherein there is a scavenging gas flow, or a plurality of such gas flows, in a direction longitudinally of the fulgurite, such triple cap, dual casing structures may be applied also in cases where no scavenging flow action is required for cooling a fulgurite, but where it is desired to impart a relatively high degree of mechanical strength to a fuse of one kind or another. Fig. 5 shows a fuse which has the triple cap, dual casing feature without having any means for producing an internal gas flow in a direction longitudinally of the fuse and without having any gas receiving and gas cooling chamber arranged between the outer and the inner fuse casing. Like reference signs are applied in Fig. 5 and in Figs. 1 to 4 to indicate similar parts and, therefore, the structure of Fig. 5 will be readily understood without a separate description thereof.

In each of the illustrated embodiments of the invention, the described flow of gases in the directions of the arrows may involve some pulsation, with some flow of gases in the opposite directions.

Having disclosed three preferred embodiments of my invention, it is desired that the same be not limited to any particular structures disclosed. It will be obvious to any person skilled in the art that many modifications and changes may be made without departing from the broad spirit and scope of my invention. Therefore it is desired that the invention be interpreted as broadly

as possible and that it be limited only as required by the prior state of the art.

I claim as my invention:

1. A current-limiting fuse comprising a first tubular casing, a second tubular casing arranged in spaced coaxial relation in said first casing, means for closing the toroidal spaced formed between said first casing and said second casing at the axial ends thereof, a fuse link arranged in substantially coaxial relation in said second casing and extending straight between the ends thereof, a non-gas evolving granular fulgurite-forming filler in said second casing in immediate contact with said link, passage means arranged substantially at the center of said second casing and the center of said link for the passage of gases from said second casing into said first casing, the cross-sectional area of said passage means exceeding the average grain size of said filler, and pressure responsive sealing means for controlling said passage means, said passage means being the only way of escape of gaseous products from said second casing.

2. A current-limiting fuse comprising a tubular casing, a fuse link arranged in substantially coaxial relation with regard to said casing and extending straight between the ends thereof, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, an inert arc-quenching filler of the fulgurite-forming type in intimate contact with said link, and means tending to produce a pair of opposite gas flows enveloping the fulgurite formed upon vaporization of a substantial portion of said link and fusion of a substantial portion of said filler, said means tending to produce said pairs of gas flows including a plurality of angularly related passage means arranged in said casing substantially adjacent the center of said variable cross-sectional area section of said link, and means defining an outwardly closed chamber in communication with said passage means, said chamber being of shorter length than said casing and in coaxial relation thereto.

3. A current-limiting fuse comprising a tubular casing, a fuse link arranged in substantially coaxial relation with regard to said casing and extending straight between the ends thereof, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, an inert arc-extinguishing filler of the fulgurite-forming type in intimate contact with said link and means tending to produce a pair of opposite gas flows in a direction substantially longitudinally of the fulgurite formed upon vaporization of a portion of said link and fusion of a portion of said filler, said means tending to produce said pair of gas flows including a plurality of angularly related passage means provided in said casing substantially adjacent the center of said variable cross-sectional area section of said link, and means defining an outwardly closed chamber in communication with said passage means, said chamber being of shorter length than said casing and in coaxial relation thereto, said chamber defining means including a pair of external radial axially spaced flanges on said casing and a tubular member having an

internal diameter substantially equal to the diameter of said flanges.

4. A current-limiting fuse comprising a first relatively short and relatively wide tubular casing, a second relatively long and relatively narrow tubular casing arranged in spaced coaxial relation in said first casing and extending beyond both ends thereof, said second casing having a pair of spaced external radial flanges for closing said first casing, a fuse link arranged in substantially coaxial relation in said second casing and extending straight between the ends thereof, an inert granular fulgurite-forming filler in said second casing in intimate contact with said link, passage means arranged substantially at the center of said second casing and the center of said link for the passage of gaseous products from said second casing into said first casing, the cross-sectional area of said passage means exceeding the average grain size of said filler, and pressure responsive sealing means for normally closing said passage means, said passage means being the only way of escape of gaseous products from said second casing.

5. A current-limiting fuse comprising a first tubular casing, a second tubular casing arranged in spaced coaxial relation in said first casing, means for axially closing said first casing, separate means for axially closing said second casing, a fuse link arranged in substantially coaxial relation with regard to said second casing and extending straight between the closed ends thereof, substantially the entire length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related equi-distant portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, and inert fulgurite-forming arc extinguishing filler in said second casing in immediate contact with said link, the dimensions of said link and the arc extinguishing capacity of said filler being so related as to result in vaporization of a preponderant portion of the length of said variable cross-sectional area section of said link on the occurrence of relatively small protracted fault currents, the volume of said second casing being relatively small and the mechanical strength thereof less than required to withstand on interruption of relatively small protracted fault currents the total pressure including the partial vapor pressure due to the vaporization of said preponderant portion of the length of said variable cross-sectional area section of said link and the partial pressure due to the flow of a follow-current through the fulgurite formed upon fusion of a portion of said filler, means for the passage of gaseous products from said second casing into said first casing arranged close to the center of said variable cross-sectional area section of said link, said passage means being the only way of escape of gaseous products from said second casing.

6. A current-limiting fuse comprising a first relatively short and relatively wide casing, a second relatively long and relatively narrow casing arranged in spaced coaxial relation in said first casing and projecting beyond both ends thereof, said second casing having a pair of spaced external flanges for closing said first casing, a first pair of caps one on each end of said first casing, a second pair of caps one on each end of said second casing, each of said first pair of caps having a central aperture through which one of said second pair of caps projects and each of said

second pair of caps having a shoulder portion in engagement with one of said first pair of caps, a fuse link arranged in substantially coaxial relation in said second casing and extending straight between said second pair of caps, an inert fulgurite-forming filler in said second casing in intimate contact with said link, passage means arranged substantially at the center of said second casing and substantially adjacent the center of said link for permitting the escape of gaseous products from said second casing into said first casing, and pressure responsive sealing means for controlling the flow of gaseous products through said passage means.

7. A current-limiting fuse comprising a first tubular casing, a second tubular casing arranged in spaced relation in said first casing, means arranged substantially at the center of said second casing for venting said second casing into the spaced formed between said first casing and said second casing, a fuse link arranged in said second casing and comprising a low melting point means for initiating circuit interruption at relatively small protracted overloads, said low melting point means being arranged adjacent an axially outer end of said link, a pulverulent inert semi-conductor-forming-filler in said second casing in intimate contact with a substantial portion of said link remote from said low melting point means, and a pulverulent filler evolving gas under the heat of the arc arranged in intimate contact with the portion of said link immediately adjacent said low melting point means.

8. A current-limiting fuse comprising a first tubular casing, a second tubular casing arranged in coaxial spaced relation in said first casing, said second casing having a pair of radial flanges jointly defining with said first casing a substantially closed deionizing chamber, passage means arranged remote from the ends of said second casing permitting the escape of gaseous products from said second casing into said deionizing chamber, a fuse link arranged in said second casing, said link having a plurality of portions of reduced cross-section and a plurality of portions of relatively larger cross-section intermediate said reduced cross-section portions, each said reduced cross-section portion having a hole laterally bounded by a pair of current paths in parallel, an insert in one of said holes remote from the center of said link, said insert consisting of a metal having a lower fusing point than the metal of which said link is made and adapted to form an alloy with the metal of which said link is made having a lower fusing point than the metal of which said link is made, an inert semi-conductor-forming pulverulent filler in said second casing in intimate contact with the portion of said link remote from said insert, and a pulverulent filler evolving gas under the heat of the arc arranged in intimate contact with the portion of said link adjacent said low fusing point insert.

9. A fuse comprising a flat relatively short and relatively wide casing, a second relatively long and relatively narrow casing arranged in spaced coaxial relation in said first casing and projecting beyond both ends thereof, external radial axially spaced flange means on said second casing engaging the inner surface of said first casing, passage means in said second casing for permitting the escape of gaseous products from said second casing into said first casing, a fuse link arranged in said second casing, a pulverulent arc-quenching filler in said second casing in im-

mediate contact with said link, a first pair of caps one on each end of said first casing, a second pair of caps one on each end of said second casing and in conductive relation with said link, each of said first pair of caps having a central aperture for the passage of one of said second pair of caps and each of said second pair of caps having a shoulder portion in abutting relation with one of said first pair of caps.

10. A fuse comprising a first relatively short and relatively wide casing, a second relatively long and relatively narrow casing arranged in spaced coaxial relation in said first casing and projecting beyond both ends thereof, external radial axially spaced flange means on said second casing substantially equal in diameter to the internal diameter of said first casing, passage means in said second casing for permitting the escape of gaseous products from said second casing into said first casing, a fuse link arranged in substantially coaxial relation in said second casing and extending straight between the end portions thereof, a pulverulent arc-quenching filler in said second casing in immediate contact with said link, a first pair of caps one on each end of said first casing, a second pair of caps one on each end of said second casing, a third pair of caps one on each end of said second casing, each end of said link being secured to one of said third pair of caps and each of said third pair of caps having a circular lateral indentation engaging one of a pair of circular grooves in said second casing, each of said second pair of caps covering and surrounding one of said third pair of caps and being in metallic contact therewith, and each of said first pair of caps having on the lateral surface thereof a circular indentation engaging one of a pair of circular grooves in said first casing and on the top portion thereof a circular aperture for the passage of one of said second pair of caps, said top portion of each of said first pair of caps also engaging a shoulder portion on each of said second pair of caps.

11. A current-limiting fuse comprising casing means defining a radially outer substantially closed chamber and a radially inner substantially closed chamber, a fuse link arranged within and in substantially coaxial relation with regard to said radially inner chamber and extending straight between the ends thereof, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, an inert arc-quenching filler of the fulgurite-forming type in intimate contact with the major portion of said variable cross-sectional area section, said variable cross-sectional area section being adapted to vaporize in said filler on the occurrence of small protracted overloads along a substantial portion thereof, a plurality of angularly related passages arranged in a common transverse plane for interconnecting said radially inner chamber and said radially outer chamber, means for initiating fusion of said link at a temperature below the fusing point of the metal of which said link is made, said fusion initiating means being arranged in axially spaced relation from said common transverse plane, and a pulverulent gas evolving arc-quenching filler in intimate contact with the portion of said link where said fusion initiating means is located.

12. A current-limiting fuse comprising a first

relatively short and relatively wide tubular casing, a second relatively long and relatively narrow tubular casing arranged in spaced coaxial relation in said first casing and projecting beyond both ends thereof, external radial axially spaced flanges on and forming an integral part of said second casing, said flanges being substantially equal in diameter to the internal diameter of said first casing, passage means in said second casing for releasing gaseous products from said second casing into said first casing, pressure responsive sealing means for controlling said passage means, said passage means including a plurality of angularly related passages arranged substantially in a common transverse plane, a fuse link arranged within and in substantially coaxial relation with regard to said second casing and extending straight between the ends thereof, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, each said relatively large cross-sectional area portions having a hole laterally bounded by a pair of current paths in parallel, a pulverulent quartz filler in intimate contact with the major portion of said variable cross-sectional area section, means for initiating fusion of said link at a temperature below the fusing point of the metal of which said link is made, said fusion initiating means being arranged in axially spaced relation from said passage means in said second casing, and a pulverulent arc-quenching filler evolving gas under the heat of the arc arranged in intimate contact with the portion of said link where said fusion initiating means is located to produce upon initiation of fusion of said link a flow of relatively cool gas in a direction substantially longitudinally of said second casing toward said passage means in said second casing.

13. A current-limiting fuse comprising a first relatively short and relatively wide casing, a second relatively long and relatively narrow casing arranged in coaxial relation with respect to and within said first casing, said second casing comprising an axially inner section equal in diameter to the internal diameter of said first casing and axially outer sections of smaller diameter projecting beyond both ends of said first casing, a fuse link arranged in substantially coaxial relation in said second casing and extending straight between the ends thereof, a pulverulent filler in said second casing in immediate contact with said link, a first pair of caps one on each end of said first casing, a second pair of caps one on each end of said second casing, a third pair of caps one on each end of said second casing, each end of said link being secured to one of said third pair of caps and each of said third pair of caps having substantially the same configuration as said axially outer sections of said second casing, each of said second pair of caps covering one of said third pair of caps and extending into one of a pair of toroidal spaces formed between the axially outer ends of said first casing and the axially outer ends of said second casing, each of said third pair of caps having a circular aperture on the top portion thereof for the passage of one of said second pair of caps and engaging a shoulder portion on each of said second pair of caps to prevent removal thereof from said second casing.

14. A current-limiting fuse comprising a first relatively short and relatively wide casing, a second relatively long and relatively narrow casing arranged in coaxial relation with respect to and within said first casing, said second casing comprising an axially inner section equal in diameter to the internal diameter of said first casing and axially outer sections of smaller diameter projecting beyond both ends of said first casing, a fuse link arranged in substantially coaxial relation to and within said second casing and extending straight between the ends thereof, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, a pulverulent quartz-filler in intimate contact with the major portion of said variable cross-sectional area section, a first pair of caps one on each end of said first casing, a second pair of caps one on each end of said second casing, a third pair of caps one on each end of said second casing, each end of said link being secured to one of said third pair of caps and each of said third pair of caps having substantially the same configuration as said axially outer sections of said second casing, each of said second pair of caps covering one of said third pair of caps and extending into one of a pair of toroidal spaces formed between the axially outer ends of said first casing and the axially outer ends of said second casing, each of said first pair of caps having a circular aperture on the top portion thereof for the passage of one of said second pair of caps.

15. A current-limiting fuse for the 1000 volt rating range comprising a straight fuse link of sheet metal, the preponderance of the length of said link consisting of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area, a cylindrical casing of laminated material wherein said link is mounted in coaxial relation, the internal diameter of said casing being less than three times the width of said link, said link being surrounded by a granular quartz-filler the average grain size of which is coarser than 60 mesh, and means tending to produce at least one flow of gas in a direction longitudinally of the fulgurite formed upon vaporization of said link due to a fault current of relatively small magnitude and inadmissible duration, said means including passage means in said casing, sealing means for controlling said passage means, said sealing means being adapted to be unaffected by the relatively small pressures generated in said casing during the interruption of currents of short-circuit current proportions and to be destroyed by pressure during the interruption of fault currents of relatively small magnitude and inadmissible duration, and means defining an outwardly closed chamber in communication with said passage means permitting the escape of gaseous products from said casing upon destruction of said sealing means.

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No references cited.