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CIRCUIT INTERRUPTER

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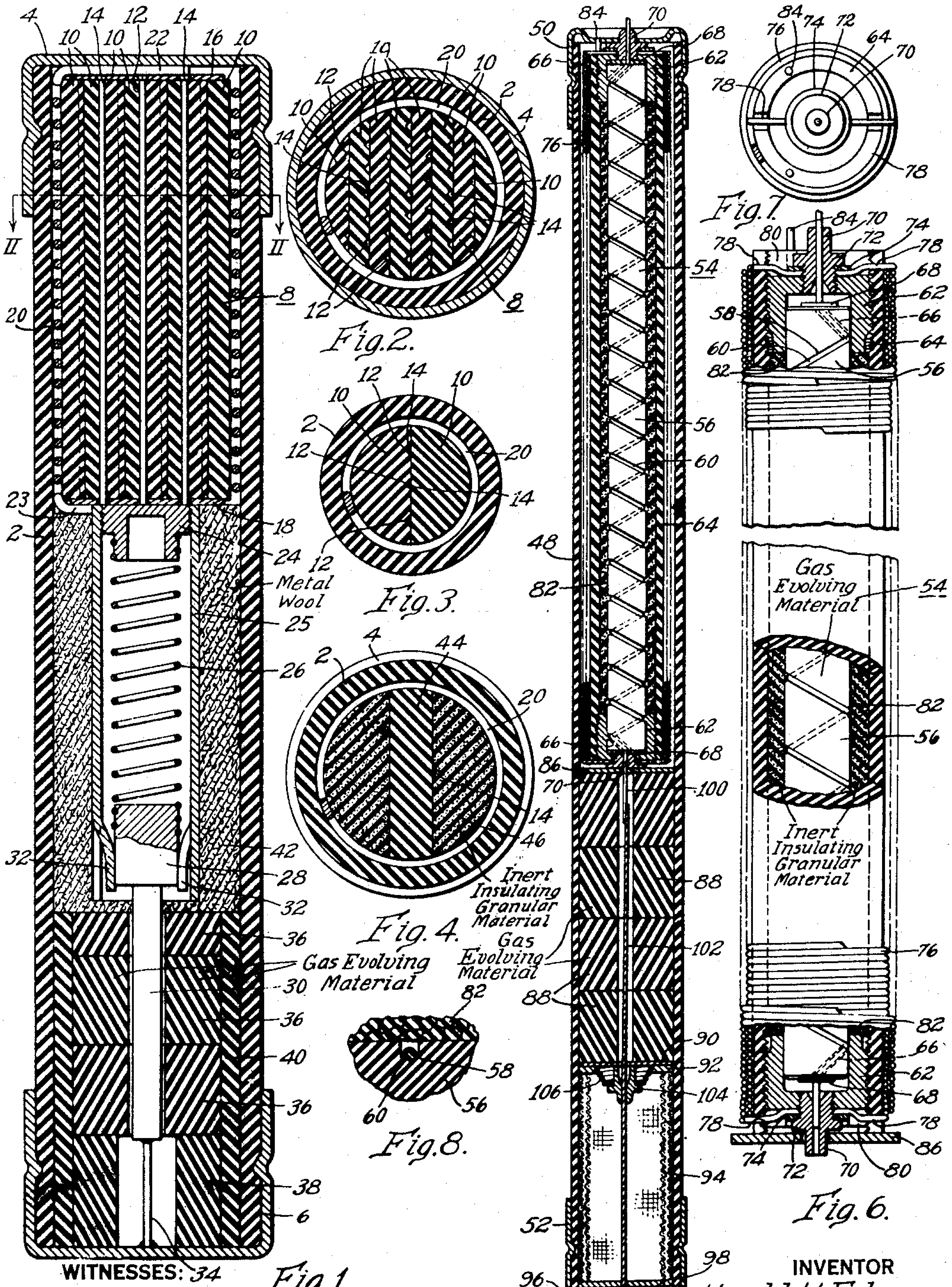

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CIRCUIT INTERRUPTER

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This invention relates generally to electric circuit interrupters, especially to circuit interrupters of the fuse type, and to high-voltage interrupters capable of limiting the fault current on interruption fast enough to prevent surges.

It is pointed out in the copending applications of H. L. Rawlins, Serial No. 357,393, filed September 19, 1940, issued December 21, 1943 as Patent No. 2,337,495, and A. P. Strom, Serial No. 357,395, filed September 19, 1940, issued December 21, 1943 as Patent No. 2,337,504, and both assigned to the same assignee as this invention, that in order to prevent dangerous surges in the circuit it is necessary that a current-limiting action be instituted rapidly enough to limit the first half cycle of fault current. To do this, the limiting action must become effective in less than a half cycle, preferably in a small fraction of a half cycle after the fault current starts to build up. The above-mentioned copending applications and H. L. Rawlins et al. Patent No. 2,309,013, issued January 19, 1943, to the same assignee of this invention, disclose various current-limiting fuse structures utilizing, in general, a fusible element in parallel with a current-limiting resistor with means restricting the arc formed upon melting of the fusible element to an extent such that the arc voltage is built up to a value high enough to transfer all of the current to the resistor in less than a half cycle, and preferably in a small fraction of a half cycle on the order of time of a few hundred microseconds. Such structures also include a second fusible element in series with at least the resistor to finally interrupt the current as limited by the resistor.

This invention, as embodied in high-voltage fuses, contemplates a general arrangement similar to those of the above-mentioned patents, and one object of this invention is to provide an improved current-limiting fuse structure of this general type which is smaller in size and more efficient in operation than those known heretofore.

Another object of this invention is to provide a fuse of the type described wherein the component parts thereof are arranged in a novel manner within an enclosure.

Another object of this invention is to provide novel means confining an arc to produce an arc voltage which will rise to a predetermined high value at an extremely rapid rate.

Another object of this invention is to provide a novel unitary arrangement of fusible means and shunt resistance.

Another object of this invention is to provide novel means for rapidly disposing of metal vapor formed upon fusion of a confined fusible element so as to rapidly decrease the conductivity of the arc path.

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A further object of this invention is to provide different embodiments of fuses of the type described especially constructed and arranged for most efficient operation at different voltage and current ratings, respectively.

Another object of this invention is to provide novel means for rapidly removing metal vapor from an arc path and condensing said vapor outside the arc into finely divided, separated metal particles.

Another object of this invention is to provide in a device of the type described, a positively acting series fuse within the same enclosure with the resistor and shunt fuse to insure positive circuit interruption.

Another object of this invention is to provide a totally enclosed fuse structure having a novel arrangement of means therein for preventing the development of excessive pressure within the fuse enclosure during circuit interruption.

These and other objects of this invention will become more apparent upon consideration of the following detailed description of preferred embodiments thereof, when taken in connection with the attached drawing, in which:

Figure 1 is a central longitudinal section of a fuse embodying this invention;

Fig. 2 is a transverse section of the fuse shown in Fig. 1 taken substantially on the line II—II thereof;

Fig. 3 is a transverse section of a fuse similar to that shown in Fig. 1, but slightly modified in form;

Fig. 4 is another transverse section of a fuse illustrating another modification;

Fig. 5 is a central longitudinal section of another form of fuse embodying this invention;

Fig. 6 is an enlarged elevation view of the current-limiting structure used in the fuse shown in Fig. 5, with portions thereof shown in section;

Fig. 7 is a top plan view of the structure shown in Fig. 6; and

Fig. 8 is an enlarged fragmentary section of the shunt fuse wire supporting means of the fuse shown in Figs. 5 to 7.

The particular fuse structure shown in Figs. 1 and 2 is especially designed for high current ratings, such as 100 or 200 amperes and above. A tubular holder 2 of insulating material, such for example as fiber or a molded insulation mational, forms the outer casing for the fuse illustrated in Figs. 1 and 2, and is provided with end terminal caps 4 and 6 closing the ends of the tube. Terminal caps 4 and 6 may be secured in position over the ends of tube 2 in any desired manner, such for example as by indenting the side walls of the cap into the material of tube 2, as illustrated. Current-limiting structure 8 is provided in the upper end of tube 2 as viewed in Fig. 1. This current-limiting structure is made up of a plurality of flat plates 10 of an insulation material to be described, with each plate provided with a plurality of longitudinally extending shallow and narrow grooves 12 on one side thereof. The plates are assembled in side-by-side relation with the grooves on each plate facing the ungrooved side of the adjacent plate, and fuse wires 14 are positioned in the grooves. The number of grooves 12 and fuse wires 14 will be determined by the continuous current rating of the fuse as will be explained hereinafter. The plates are held in assembled relation and cemented together under high pressure. After the cement has hardened, the assembly may be mounted on a lathe and turned to the cylindrical form shown on the drawing. Terminal plates 16 and 18 are provided at each end of current-limiting structure 8, and are apertured for the reception of the ends of fuse wires 14 so that the wires may be secured to the plates as by soldering or the like. A resistance wire 20, which may be iron, nickel, Monel or other nickel alloy steel, is tightly wound about the assembled plates 10, and acts as a banding wire opposing separation of the plates. One end 22 of resistance wire 20 is bent over into engagement with terminal plate 16, so as to be positioned between terminal plate 16 and terminal cap 4 when the current-limiting structure 8 is assembled within tube 2. The other end 23 of resistance wire 20 is bent over to engage terminal plate 18. Both ends of resistance wire 20 may be electrically and mechanically secured to the terminal plates in any desired manner, such for example as by soldering or the like.

As previously stated, and as pointed out in the above-identified patents, it is necessary, in order to obtain a current-limiting action which is effective to limit the first half cycle of fault current, that very fast fuse wires be provided, and that extremely rapid transfer of the current be made to a resistance or other current-limiting means. It will be noted that resistance wire 20 is connected in parallel with the parallel fuse wires 14. The fuse wires themselves are preferably of a material having a high conductivity. This enables the use of fuse wires of very small cross-section. It is also desirable that the fuse wires have a low specific heat to obtain fast blowing on high overcurrents, and that the temperature coefficient of resistance of the wires be relatively high so that their resistance will increase a relatively rapid rate just prior to blowing. Silver is one material which has all these characteristics and, therefore, is preferred for use as fuse wires 14. The number of plates used is determined by the number of fuse wires required to carry the load current. This may be readily determined after ascertaining the maximum size of wires which can be used. The size of the fuse wires is limited primarily by the time required to build up a sufficient arc voltage to transfer the current to the resistance wire 20. This transfer must occur in less than a half cycle, preferably in a small fraction of the half cycle on the order of a few microseconds, in order to exert any limiting action on the first half cycle of arcing current. The factors which contribute to the amount of time required to build up an arc voltage of sufficient magnitude are the amount of metallic vapor formed upon fusion of the fuse wires and the time required to disperse or remove this vapor from the arc path in order to increase the resistance thereof. Another factor is the size of the arc passage. Generally speaking, the smaller the arc passage the higher the arc voltage. In practice, the arc passages, in this instance grooves 12, are limited only by the size of fuse wires 14. In other words, arc passages or grooves 12 have their cross-section determined by the cross-section of the fuse wires. Consequently, the fuse wires must be kept small to limit the amount of metal vapor and to keep the cross section of the arc passages small.

In order to dispose of the metallic vapor formed in arc passages or grooves 12, plates 10 are preferably made of a high temperature resistant ceramic material, at least for high current ratings. This ceramic material should be of the type which retains its dielectric strength when in contact with an electric arc. Such a ceramic material does not evolve any gases when in contact with an electric arc, but should be relatively porous so that the metallic vapors can penetrate the pores in plates 10 to be condensed therein in the form of metal particles spaced by the material of the plates at points outside the arc path, so that they no longer are capable of conducting any current. Natural soapstone is another material which may be used for plates 14, because it is porous and, in addition, evolves some vapor when in contact with an electric arc, with a substantial portion of the vapor being steam. This assists in raising the arc voltage to help obtain a fast current-limiting action. These and other materials having the same characteristics have the advantage that the fuse wires enclosed therein can operate at relatively high temperatures without damaging the plate structure. Other materials, such as fiber and certain synthetic resins, have the advantage of being excellent gas-evolving materials, and hence contribute in this respect to obtain a quick rise in arc voltage, but have the disadvantage that the fuse elements must operate at relatively low temperatures to avoid damage to the plates. With fuses of high current rating, this means either that larger fuse wires must be employed, or more fuse wires in parallel must be provided, which, as pointed out above, results in a poorer current-limiting action principally because more time will be required to melt the larger wires and the current will reach a higher value before the fuse wires melt. Another factor is that more time will be required to effect actual current transfer to the resistance, since larger arc passages will be required where larger fuse wires are used, and in either case a greater amount of metal vapor will be formed which will, generally, require more time to dispose of.

As pointed out above, resistance wire 20 acts as a banding wire to prevent separation of plates 10 due to pressures developed upon vaporizing the fuse wires. Ordinarily, of course, resistance wire 20 carries but a small fraction of the normal load current even though it is connected in parallel with the fuse wires, because it is of considerably higher resistance.

Upon operation of the current-limiting structure described above, a fault current will rapidly increase the temperature of the fuse wires which, with the high temperature coefficient of resistance of the wires when of silver, will increase the resistance thereof up to the time of actual fusion to approximately five times their normal resistance. Secondly, the actual fusion of the fuse wires is accompanied by a further increase in resistance to a value approximately twelve times their initial cold resistance. As soon as the fuse wires melt, a high arc voltage is induced by virtue of the small size of the arc passages or grooves 12 in which the arcs are confined, and as pointed out above, the greater this restriction and confinement of the arc, the higher the arc voltage obtained, and the speed at which it builds up is correspondingly increased. Another important factor contributing to the rapid rate at which the arc voltage builds up to a value high enough to cause transfer of all of the current to resistor wire 20, is the removal of metallic vapor from the arc passages or grooves 12 by their absorption in the porous plate structure. The increase in resistance of the current path through the fuse wires up to the time of the formation of an arc contributes to slowing up the rate of current rise through the limiter, and the high arc voltage produced upon melting of the fuse wires and striking of the arcs prevents any further increase in current and actually reduces the current to a value below that flowing at the time of fusion. The shunt resistance wire 20 serves as a means for absorbing the inductive energy of the system, thus limiting the extremely high inductive voltage surge that would otherwise accompany the drastic change in current. The ohmic value of this resistance is so chosen that the maximum current peak passed by the fuse when current flows through the resistance wire will not create a voltage surge in excess of that allowable on the system. The high-speed transfer of current to resistance wire 20 obtained with the structure described above, reduces the arcing time so that the arc energy is kept low and no dangerous internal pressures are developed. The resistance wire is preferably of a material which has a high temperature coefficient of resistance, such as the metals or alloys referred to above, so that the current flowing in the resistance after transfer thereto is rapidly reduced in value so that it may be readily interrupted at the first current zero by the series fuse, to be described.

The series fuse is connected in series between the current-limiting structure 8 and terminal cap 6, and occupies the remaining portion of tube 2. A tube 25 of conducting material, such as copper or the like, has its upper end secured to terminal plate 18 in any desired manner, such for example as by brazing or the like. A supporting plug 24 is threaded into the upper end of conducting tube 25 and has a reduced portion on which is secured the upper end of coil tension spring 26. The other end of spring 26 is secured to a contact head 28 formed on an arcing rod 30 which is normally maintained at the position shown in Fig. 1 by a fusible element 34 secured thereto and to terminal cap 6. Fusible element 34 also maintains tension spring 26 in an extended position, and maintains contact head 28 at a position at which it is engaged by contact tongues 32 bent inwardly from the material of conducting tube 25. Arcing rod 30 is positioned in a passage through a plurality of blocks 36 and 38 of a material capable of evolving an arc-extinguishing gas when in proximity to an electric arc, such as boric acid, fiber, a synthetic resin or the like. The block 38 of this material provided adjacent terminal cap 6 immediately surrounding fusible element 34 is provided with a larger passage than blocks 36. It will be noted that the upper end of the arc passage through blocks 36 and 38 is open to the inner end of tube 2, and communicates with the space between tube 2 and conducting tube 25 through the openings formed by contact tongues 32 and through the space between upper block 36 and the lower end of conducting tube 25. This space between tube 2 and conducting tube 25 is filled with some good heat-conducting material, such for example as a shredded metal waste or metal wool, such as copper or steel turnings, so that gases produced upon drawing an arc through the arc passage in blocks 36 and 38 will be cooled and condensed, thus preventing the building up of any dangerous pressure within the fuse enclosure. For this reason the preferred material for use as blocks 36 and 38 is boric acid which evolves a gas most of which is condensable.

It has already been shown that the electric circuit through the current-limiting structure 8 comprises parallel circuits through fuse wires 14 on the one hand and the resistance wire 20 on the other hand, extending from terminal cap 4. The series fuse, as the name implies, is arranged in series between the current-limiting structure and terminal cap 6, and this circuit may be traced from terminal plate 18 through conducting tube 25, contact tongues 32, contact head 28, arcing rod 30 and fusible element 34 to terminal cap 6. It will be noted that conducting tube 25 and contact tongues 32 shunt out tension spring 26, so that normally the spring 26, having a relatively high resistance, carries little, if any, current. However, when fusible element 34 melts, contact head 28 on the arcing rod is moved upwardly out of engagement with the contact tongues 32, so that spring 26 will carry the current during arcing. This, however, is such a short period of time that the function of spring 26 in drawing the arc through the arc passages in blocks 36 is not hindered. The purpose of the series fuse is threefold. It is the portion of the complete fuse which determines the melting time-current characteristics of the fuse, because the fusible element 34 thereof has a lower melting point than fuse wires 14, and will melt on moderate overloads without operation of the current-limiting structure at all. On high-current overloads and short-circuits, the series fuse interrupts the current as limited by resistance wire 20 when the current-limiting structure has operated, and inserts a gap in the circuit capable of withstanding restored system voltage.

The operation of the complete fuse is as follows: On moderate overloads, where neither fusible element melts prior to the first current peak, the series fuse element 34 will melt and spring 26 will withdraw arcing rod 30 through the bore in gas-evolving blocks 36, and the gases evolved will deionize the arc path to interrupt the circuit. The gases evolved by the arc are condensed by heat-conducting material 42, so that no dangerous pressures develop within the fuse enclosure. In operations on moderate overloads, the fuse wires 14 of the current-limiting structure may not melt, because they have a higher capacity than fusible element 34. However, on high fault currents, where the fuse elements melt before the current reaches its first peak, fuse wires 14 will melt immediately, probably at the same time fusible element 34 melts, and the current will be transferred to resistance wire 20 as previously described in an extremely short time. When this occurs, the current is limited to a relatively low value which will be easily interrupted by the series fuse. Consequently, on operations of this type, the duty of the series fuse is very light, so that final and complete interruption occurs at the first current zero.

It will be observed that not only does the particular fuse shown in Figs. 1 and 2 provide an efficient current-limiting action and current interruption, but that pressures within the fuse are kept at a safe value both due to arcs struck in the current-limiting structure and arcs struck by the series fuse, so that a totally enclosed structure is possible without employing a relatively heavy construction. Furthermore, because of the particular arrangement and nature of the various parts of the fuse the size of the entire structure can be made very small.

In Fig. 3, there is illustrated a fuse which may be identical with that shown in Figs. 1 and 2, but is adapted for lower current ratings, so that fewer parallel fuse wires 14 are required in the current-limiting structure. Fig. 3 illustrates but three parallel fuse wires, and further illustrates that these require but two insulating plates 10. Obviously, fuses of intermediate ratings may be readily made up by forming the current-limiting structure of as many plates 10 as are required to provide arc passages or grooves 12 for the number of parallel fuse wires 14 which may be required to carry the rated current. Obviously, the structure shown in Fig. 3 will operate in a current-limiting structure with a series fuse such as that shown in Fig. 1, in substantially the same manner as the specific construction illustrated in Figs. 1 and 2, and accordingly such operation will not be repeated.

In Fig. 4, a somewhat different current-limiting structure is shown in that a single bar 44 is provided centrally of fuse tube 2, and fuse wires 14 are supported at opposite sides of bar 44. Resistance wire 20 may be wound about bar 44 after the fuse wires are in place, and then after the current-limiting structure is inserted into tube 2, the space between bar 44 and current-limiting wire 20 is filled with a finely divided inert insulating material 46, such as sand.

In the operation of the embodiment of the invention shown in Fig. 4, granular insulating material 46 forms a porous structure for receiving the metallic vapors caused by fusion of fusible elements 14. Furthermore, supporting bar 44 may be of a porous material like plates 10, previously described, but preferably is of a material which is capable of evolving an arc-extinguishing gas when in proximity to an electric arc, so that when fuse wires melt and an arc is struck, the arc-extinguishing gas evolved from supporting bar 44 will pass laterally through the arc paths and carry the metal vapor in the arc path therewith and into granular material 46 where the vapor will be condensed in the form of spaced metallic particles positioned outside of the arc path. Accordingly, the gas blast evolved from supporting bar 44 not only supplies arc-extinguishing gas to the arc path to increase the voltage of the arc, but also removes conducting metal vapors from the arc path and disperses this vapor at a position outside of the arc path. Thus a means is provided in this embodiment of the invention for positively removing metal vapor from the arc path, and consequently increasing the arc voltage and the speed at which the arc voltage builds up to obtain quick transfer of the current to resistance wire 20. This gas blast evolved from supporting bar 44 not only causes a dispersion of metallic particles outside of the arc path, but also prevents the formation of fulgurites or fused metallic silicides along the arc path which are electrical conductors. The formation of such conductors or semi-conductors along the arc path is a characteristic of prior art fuses utilizing inert granular materials, such as sand, along the arc path, and this characteristic is avoided by the general construction shown in Fig. 4, in the manner pointed out above.

The current-limiting structure of Fig. 4 thus is capable of producing a high arc voltage in a very short time, to obtain transfer of the current to resistance wire 20 soon enough to limit the first half cycle of arcing current. Furthermore, this current-limiting structure is designed for use with a series fuse like the current-limiting structure 8 of Fig. 1, and when so combined is operable in substantially the same manner as the fuse of Fig. 1, so that this operation will not be repeated in connection with this embodiment of the invention.

Figs. 5 to 8 illustrate a further modified form of fuse having an outer fuse tube 48 which may be of the same material as the fuse tube 2 described in connection with the embodiments of invention shown in Figs. 1 to 4. Fuse tube 48 is provided with end terminal caps 50 and 52 which may be secured over the ends of fuse tube 48 in a manner to close the ends of the tube, by indenting the caps in the manner shown. This fuse is provided with a current-limiting structure 54 more particularly shown in Fig. 6 of the drawing. Current-limiting structure 54 comprises a supporting central rod 56 of an insulating material capable of evolving an arc-extinguishing gas when in proximity to an electric arc, such for example as fiber or a molded insulation material. Supporting rod 56 has a spiral groove 58 cut or turned on its exterior surface for the reception of a fuse wire 60 which, preferably, is of the same material as fuse wires 14 previously described. Fuse wire 60 is placed in the bottom of groove 58, and the width of the groove is chosen so that the wire is essentially in contact with the bottom and sides of the groove. Furthermore, the depth of groove 58 is preferably greater than the diameter of the fuse wire so that the wire is essentially restricted in a space barely larger than the wire. Although but a single spiral groove 58 is shown, it will be obvious to persons skilled in the art that for higher current ratings a plurality of wires 60 may be provided in parallel grooves. As in the case of arc passages or grooves 12 described in connection with the embodiment of invention shown in Figs. 1 to 3, the minimum width of spiral groove 58 is determined by the size of fuse wire 60 employed, and the size and number of these wires may be determined in the same manner pointed out in connection with the first-mentioned embodiment of the invention.

A supporting cap 62 is provided over each end of supporting rod 56, and these caps are preferably of a good electrically conducting material, such as copper or brass. Caps 62 are exteriorly threaded for threading into the outer ends of an outer tube 64 also of insulating material, such as fiber or the like. Supporting rod 56 is provided at the ends of groove 58 with diagonally extending bores 66 extending from the ends of groove 58 to substantially the center of each end of the rod. These bores 66 are for receiving the ends of fuse wire 60 after the wire is positioned in groove 58, so that the ends may extend substantially centrally from the ends of supporting rod 56. Fuse wire 60 may be held in place for assembly purposes, by holding discs 68 which may be slipped over the ends of the wires and soldered in position, to prevent the wire coming out of groove 58. A terminal plug 70 having a central flange 72, is adapted to be threaded into a central opening in each supporting cap 62, and each plug 70 is provided with a central bore for receiving the ends of fuse wire 60. A washer 74 is positioned beneath the flange 72 of each terminal plug for a purpose to be described. In this embodiment of the invention, shunt resistance wire 76 is wound in a double layer on outer tube 64. This resistance wire is helically wound on the tube with the first layer wound in one direction, and the second layer wound in the opposite direction to neutralize the inductance of the coil. The resistance wire 76 is provided with insulation which is, however, as thin as is mechanically and electrically possible, so that the two layers of wire are in very intimate contact to reduce inductance to an absolute minimum. Furthermore, the diameter of the resistance wire is chosen to be as small as possible consistent with adequate thermal capacity, to reduce skin effect. On high current fuses where higher thermal capacity of the resistance is required, more than two layers of smaller resistance wires may be used to reduce this skin effect. Resistance wire 76, like the wire 20 previously described, is preferably of a material having a high temperature coefficient of resistance so that the current-limiting effect thereof increases after the current is transferred to it. After the resistance wire 76 is wound in place, the ends of the wire forming each layer of winding are directed annularly inwardly through opposed slots 78 formed in the ends of outer tube 64, to lie in a diametrically disposed aligned slot 80 provided in supporting cap 62, to be secured beneath flange 72 of terminal plug 70, so as to be electrically and mechanically connected in parallel with the fuse wire 60. Prior to assembly of both supporting caps 62, the space between supporting rod 56 and outer tube 64 is filled with an inert granular insulating material 82, preferably one having high thermal capacity, such as sand or the like.

In the operation of current-limiting structure 54, current-limiting action and a rapidly built up high arc voltage are obtained in several ways. First, the fault current increases the resistance of the current path provided by fuse wire 60 up to twelve times its initial cold resistance in the same manner as fuse wires 14 previously described. Also a very high arc voltage is provided as soon as the fuse wire 60 melts because of the intimate and restrictive nature of slot 58 on the arm. This embodiment of the invention also utilizes a gas-evolving material as the arc restricting means which causes turbulence in the arc path to further increase the arc voltage, and furthermore blows transversely through the arc path to carry the metallic vapors out of the arc path to still further increase the arc voltage. Also, an inert material 82 of high thermal capacity and of granular nature is employed for the condensation of such metallic vapors and for cooling the gases evolved from the arc restricting means. All of these factors contribute to the production of a high arc voltage at a very rapid rate, on the order of a few hundred microseconds, to obtain effective limitation of the first half cycle of fault current. The increase in resistance up to the formation of an arc slows up the rate of rise of fault current, and the high arc voltage produced upon fusion of the fuse wire 60 causes extremely rapid transfer of the current to resistance wire 76 and prevents any further increase in current. As a matter of fact, the current is actually reduced in value to a value below that at the time of fusion of fuse wire 60.

The ohmic value of shunt resistance wire 76 is chosen in the same manner as the value of resistance wire 20 previously described, and it will be noted that resistance wire 76 is arranged so as to be non-inductive, thus permitting easier transfer of the current to the resistance wire from the parallel path.

Current-limiting structure 54 is assembled in outer fuse tube 48 by means of terminal plug 70, the outer end of which is received in a substantially central aperture provided in terminal cap 50. It will be noted that the current-limiting structure is provided with a key pin 84, projecting from the upper end thereof to be received in an offset aperture provided in terminal cap 50, for preventing rotation of the current-limiting structure about the longitudinal axis of tube 48. After assembly of the current-limiting structure with terminal cap 50, the openings in the cap are sealed and the structure secured in position—for example, as by soldering plug 70 and projection 84 in their respective apertures.

A positioning disc 86 is slipped over the lower terminal plug 70 of the current-limiting structure, to engage the upper end of a stack of blocks 88 having aligned passages therethrough forming an elongated arc passage. Blocks 88 are of a material which is capable of evolving an arc-extinguishing gas when in proximity to an electric arc, such for example as boric acid, a synthetic resin or fiber. A supporting disc 90 is provided at the lower end of the stack of blocks 88, and is supported by a washer 92 seated on the upper end of good heat-conducting material 94 positioned in engagement with the inner walls of tube 48. Heat-conducting material 94 may be of any desired material of this type, preferably a metallic mesh or fabric made of a good heat-conducting material such as copper or the like.

A supporting disc 98 is provided at the lower end of heat-conducting material 94, and intermediate this disc and terminal cap 52 is a disc 96 engaging the end of fuse tube 48. A short fusible wire 100 is received in the passage through lower terminal plug 70 and is connected to a flexible conductor 102, which is, in turn, connected with terminal cap 52 by any suitable securing means, such as solder or the like. At a point adjacent the bottom of lower insulating block 88, the flexible conductor 102 is provided with a collar 104 secured thereto, as by crimping or the like, to support a helical compression spring 106 in a compressed condition between the collar and supporting disc 90. Spring 106 is normally maintained in compressed condition by fusible element 100, so that upon fusion of the fusible element, spring 106 is operable to move the upper end of flexible conductor 102 downwardly through the passage in insulating blocks 88 to extend the arc and subject it to the gases evolved from blocks 88. Such gases may escape through the lower end of the passage through the blocks and come into contact with heat-conducting material 94 so as to be cooled and condensed thereby.

The operation of the fuse shown in Figs. 5 to

8 is quite similar to the previously described operation in connection with the embodiments of invention shown in Figs. 1 to 4. Thus, on light overloads the circuit will be interrupted solely by operation of the series fuse, while on heavy overloads and short-circuits the current-limiting structure will operate first to limit the current in the manner previously described, and the current as limited will be readily interrupted by the series fuse.

From the foregoing, it will be apparent that this invention provides a fuse construction adapted to limit currents fast enough so as to check the rise of the first half cycle of dangerous fault current. Moreover, fault currents of any magnitude are positively and speedily interrupted at the first current zero after the fusible element melts by a spring operated series fuse. The current limitation produced by the fuse of this invention is accomplished without voltage surges, and may be used on circuits of various frequencies by choosing a resistor of proper thermal characteristics. The resulting composite fuse structure capable of operating in the above manner may be made very small in size, and be totally enclosed, because no high internal pressures are developed. Furthermore, because of the simplicity of the construction a fuse which is very rugged is provided.

More specifically, fuses constructed in accordance with this invention utilize current-limiting structures operating to restrict the arc to obtain the high arc voltage necessary to effect limitation of the first half cycle of fault current, with gas-evolving material forming the arc restricting means to additionally assist in raising the arc voltage and with inert granular material in proximity with the fuse to receive and condense metallic vapors in the arc path and cool the gases evolved from the arc restricting means. Furthermore, there is specifically disclosed herein a non-inductive metallic resistance in parallel with a fuse in a current-limiting structure, for absorbing the inductive energy of the system incident to current limitation. All forms of the invention illustrated are adapted for use with a series, calibrated, spring operated fuse to insert a positive non-conducting gap in the circuit after operation of the fuse, regardless of the magnitude of fault current interrupted. Another important feature of the invention is the provision of a shunt resistance having a positive temperature coefficient of resistance to reduce the current in the resistance so that a relatively small series fuse can be used to easily interrupt the current as limited by the resistance.

Having described preferred embodiments of the invention in accordance with the patent statutes it is desired that the invention be not limited to these particular constructions, inasmuch as it will be apparent to persons skilled in the art that many changes and modifications may be made in these particular structures, some of which have been indicated in the foregoing description, without departing from the broad spirit and scope of this invention. Accordingly, it is desired that the invention be interpreted as broadly as possible and that it be limited only as required by the prior art.

I claim as my invention:

1. In a fuse, a fuse tube of insulating material, terminal caps secured to the ends of said tube for closing the ends of said tube, current-limiting structure in said tube adjacent one end thereof, said current-limiting structure including at least

one fuse wire extending generally longitudinally of said tube and annular resistance means concentric with said fuse wire and insulated therefrom, said fuse wire and resistance means electrically connected in parallel at least when said wire melts, series fusible means for interrupting the circuit, said series fusible means occupying the remaining space in said tube and serially connected with said current-limiting structure between said terminal caps, said series fusible means including a fusible element and an arc passage in which the arc formed upon fusion of said fusible element is established, said arc passage having wall portions of a material which when in proximity to an electric arc is capable of evolving an arc-extinguishing gas a substantial portion of which is condensable, and condensing means in said tube at one end of said arc passage.

2. Current-limiting structure, comprising solid means of an inert porous insulating material forming at least one arc passage, fusible means having at least the major portion thereof confined in said passage for striking an arc in response to the passage of currents above a predetermined value through said structure so that metallic vapor due to fusion of such major part of the fusible means will be received and condensed in dispersed relation in the pores of said porous material, and said arc passage being relatively long and having at least one transverse dimension small enough to restrict the arc sufficiently to cause the arc voltage to rise in less than a half cycle to a relatively high value.

3. Current-limiting structure, comprising solid means of a porous ceramic insulating material forming at least one arc passage, fusible means having at least the major portion thereof confined in said passage for striking an arc in response to the passage of currents above a predetermined value through said structure so that metallic vapor due to fusion of such major part of the fusible means will be received and condensed in dispersed relation in the pores of said porous material, and said arc passage being relatively long and having at least one transverse dimension small enough to intimately contact and restrict the arc sufficiently to cause the arc voltage to rise in less than a half cycle to a relatively high value.

4. Current-limiting structure comprising at least two relatively long members of insulating material having complementary longitudinally extending surfaces adapted to be in intimate engagement when said members are secured together, a fuse wire, one of said surfaces having at least one longitudinally extending groove therein for receiving said wire, a resistance wire wound about said members to resist separation of said members, and said resistance wire electrically connected in parallel with said fuse wire at least when said wire melts.

5. Current-limiting structure, comprising a plurality of relatively long parallel members of insulating material, said members having facing complementary longitudinally extending surfaces adapted to be in intimate engagement when said members are secured together, one of each set of said facing complementary surfaces having at least one longitudinally extending groove therein, a fuse wire in each of said grooves, a resistance wire wound about said members to prevent separation of said members, and said resistance wire electrically connected in parallel with said fuse wires at least when said fuse wires melt.

6. Current-limiting structure, comprising solid means of insulating material capable of evolving an arc-extinguishing gas when in proximity with an electric arc forming at least one arc passage, means for striking an arc in said passage in response to the passage of currents above a predetermined value through said structure, annular resistance means arranged about said insulating means and electrically connected in parallel with said arc establishing means at least when an arc is established, and said arc passage being relatively long and having at least one transverse dimension small enough to restrict the arc sufficiently to cause the arc voltage to rise in less than a half cycle to a value high enough to cause transfer of the current to said resistance means.

7. In a circuit interrupter, arc establishing means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least one side of the path of an arc struck by said arc establishing means, said insulating material being directly exposed to substantially the entire length of said path, and means responsive to the establishment of an arc by said arc establishing means to cause a blast of unionized gas to flow through substantially the entire length of the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

8. In a fuse, fusible means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least one side of said fusible means, said insulating material being directly exposed to substantially the entire length of said fusible means, and means responsive to fusion of said fusible means to cause a blast of unionized gas to flow through substantially the entire length of the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

9. In a circuit interrupter, arc establishing means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least one side of the path of an arc struck by said arc establishing means, said insulating material being directly exposed to substantially the entire length of said path, and means of an insulating material capable of evolving an arc-extinguishing gas when in proximity to an electric arc supported in proximity with at least the opposite side of said arc path along substantially the entire length thereof to cause a blast of unionized gas to flow through substantially the entire length of the arc in a direction toward said granular insulating material to disperse the metal vapor in the arc through said granular insulating material where it is condensed in finely divided form outside the arc path.

10. In a fuse, fusible means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least one side of said fusible means, said insulating material being directly exposed to substantially the entire length of said fusible means, and means of an insulating material capable of evolving an arc-extinguishing gas when in proximity to an electric arc supported in proximity with at least the opposite side of said fusible means along substantially the entire length thereof.

11. In a circuit interrupter, arc establishing means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least the major portion of one side of the path of an arc struck by said arc establishing means, and means of a solid, porous inert insulating material supported in proximity with and directly exposed to at least the major portion of the opposite side of said arc path so the metal vapor in the arc may be condensed in said insulating materials outside the arc path.

12. In a circuit interrupter, solid means of insulating material forming an arc passage substantially U-shaped in cross-section, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, and means for establishing an arc in said passage, whereby, in response to the establishment of an arc in said passage, a blast of unionized gas is caused to flow through the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

13. In a circuit interrupter, solid means of insulating material forming an arc passage substantially U-shaped in cross-section, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, and a fuse wire in said passage for establishing an arc in said passage, whereby, in response to the establishment of an arc in said passage, a blast of unionized gas is caused to flow through the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

14. A current-limiting structure, comprising a tube of insulating material, solid means of insulating material disposed within said tube extending longitudinally thereof and spaced from the inner walls of said tube, a fuse wire spirally wound on said insulating means, at least the portions of said insulating means engaged by said wire being of a material capable of evolving an arc-extinguishing gas when in proximity to an electric arc, and the space between said insulating means and tube being filled with a finely divided inert insulating material.

15. A current-limiting structure, comprising a tube of insulating material, solid means of insulating material disposed within said tube extending longitudinally thereof and spaced from the inner walls of said tube, a continuous narrow spiral groove formed on the exterior of said insulating means, a fuse wire spirally wound on said insulating means in said groove, at least the walls of said groove being of a material capable of evolving an arc-extinguishing gas when in proximity to an electric arc, and the space between said insulating means and tube being filled with a finely divided inert insulating material.

16. A current-limiting structure, comprising a tube of insulating material, solid means of insulating material disposed within said tube extend-

ing longitudinally thereof and spaced from the inner walls of said tube, a fuse wire extending through said tube and supported on said insulating means, the space between said insulating means and tube being filled with a finely divided inert insulating material, and a resistance wire connected in parallel with said fuse wire at least when said wire melts, said resistance wire having a thin layer of insulation thereon and being spirally wound on said tube with adjacent coils thereof in engagement.

17. A current-limiting structure, comprising a tube of insulating material, solid means of insulating material disposed within said tube extending longitudinally thereof and spaced from the inner walls of said tube, a fuse wire extending through said tube and supported on said insulating means, the space between said insulating means and tube being filled with a finely divided inert insulating material, resistance means mounted on the outside of said tube and electrically connected in parallel with said fuse wire at least when said wire melts, said resistance means comprising an inner layer of resistance wire spirally wound on said tube in one direction, and an outer layer of resistance wire electrically connected in parallel with the wire of said first layer and spirally wound on said first layer in the opposite direction.

18. In a fuse, a fuse tube of solid insulating material having the ends thereof closed, spaced terminals on said tube, current-limiting means and fusible means connected in series between said terminals, said current-limiting means comprising second fusible means and resistor means connected in parallel at least when said fusable means melts, and said resistor means comprising at least one resistance wire coiled about said second fusible means.

19. In a fuse, a fuse tube of solid insulating material having the ends thereof closed, spaced terminals on said tube, current-limiting means and fusible means connected in series between said terminals, said current-limiting means comprising second fusible means and resistor means connected in parallel at least when said fusible means melts, means in proximity to said second fusible means responsive to the arc formed upon fusion of said second fusible means to cause the arc voltage to rise in less than a half cycle to a value sufficient to transfer the current to said resistor means, and said resistor means comprising at least one resistance wire coiled about said second fusible means and said means in proximity thereto.

20. A current-limiting structure, comprising a tube of insulating material, resistance means mounted on the outside of said tube and comprising an inner layer of resistance wire spirally wound in one direction, and an outer layer of resistance wire electrically connected in parallel with the wire of said first layer and spirally wound on said first layer in the opposite direction, fusible means in said tube and connected in a parallel circuit with said resistance wire, at least when said fusible means melts, and means in said tube in proximity to said fusible means for causing the voltage of the arc formed upon fusion of said fusible means to rise in less than a half cycle to a value high enough to transfer the current to said resistance wire.

21. In a circuit interrupter arc establishing means, a mass of inert insulating material of granular form having a high thermal capacity, means supporting said insulating material in proximity to at least one side of the path of an arc struck by said arc establishing means, said insulating material being directly exposed to substantially the entire length of said path, and means of a solid insulating material capable of evolving an arc-extinguishing gas when in proximity to an electric arc supported in proximity with at least the opposite side of said arc path along substantially the entire length thereof to cause a blast of unionized gas to flow through substantially the entire length of the arc in a direction toward said granular insulating material to disperse the metal vapor in the arc through said granular insulating material where it is condensed in finely divided form outside the arc path.

22. In a fuse, means of a solid insulating material which is capable of evolving an arc-extinguishing gas when in proximity to an electric arc, an adjacent means of finely divided inert insulating material, and fusible means at least the major portion of which is interposed between and directly exposed to said mass and said solid means.

23. In a circuit interrupter, solid means of insulating material forming a long narrow arc passage which is open along one side, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, and means for establishing an arc in said passage, whereby, in response to the establishment of an arc in said passage, a blast of un-ionized gas is caused to flow through the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

24. In a circuit interrupter, solid means of insulating material having a long narrow groove in a surface thereof forming an arc passage, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, and means for establishing an arc in said passage, whereby, in response to the establishment of an arc in said passage, a blast of un-ionized gas is caused to flow through the arc in a direction toward said insulating material to disperse the metal vapor in the arc through said insulating material where it is condensed in finely divided metal particles outside the arc path.

25. In a circuit interrupter, solid means of insulating material forming a long narrow arc passage which is open along one side, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, a fuse wire in said passage for establishing an arc therein, and said passage being of substantially the same width as the diameter of said wire.

26. In a circuit interrupter, solid means of insulating material forming a long narrow arc passage which is open along one side, at least inner wall portions of said passage being of a material capable of evolving an arc-extinguishing gas when in proximity with an electric arc, a mass of finely divided inert insulating material positioned at least across the open side of said passage, a fuse wire in said passage for establishing an arc there-

in, and said passage being of substantially the same width as but deeper than the diameter of said wire.

27. In a circuit interrupter, arc establishing means, means of a solid insulating material which is capable of evolving an arc extinguishing gas when in proximity to an electric arc supported at least partly about said arc path at least along a substantial portion of the length of said path in arc confining relation, said solid material being open at one side, and a mass of finely divided inert insulating material supported in proximity to at least said one side of said solid material, whereby when an arc is struck a blast of unionized gas will be evolved from said solid material and be directed transversely through the arc and into said inert material.

28. In a circuit interrupter, arc establishing means, means of a solid insulating material which is capable of evolving an arc extinguishing gas when in proximity to an electric arc supported at least partly about said arc path at least along a substantial portion of the length of said path, sail solid material forming a narrow arc passage of a size to restrict the cross section of said arc, said passage being open at one side, and a mass of finely divided inert insulating material supported in proximity to at least said one side of said solid material, whereby when an arc is struck a blast of unionized gas will be evolved from said

solid material and be directed transversely through the arc and into said inert material.

29. Current-limiting means comprising, fusible means including at least one fuse wire, resistor means connected in parallel circuit relation with said fusible means at least when said fusible means blows, and a mass of finely divided inert insulating material in proximity to at least a substantial portion of the length of said fusible means.

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