Dec. 27, 1966 F. J. KOZACKA 3,294,937

TIME LAG DUAL ELEMENT FUSE HAVING MEANS FOR PRECLUDING ARC INITIATION ADJACENT TERMINALS

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FIG. 1

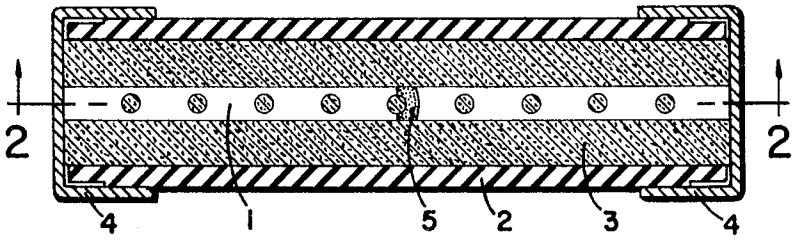


FIG. 2

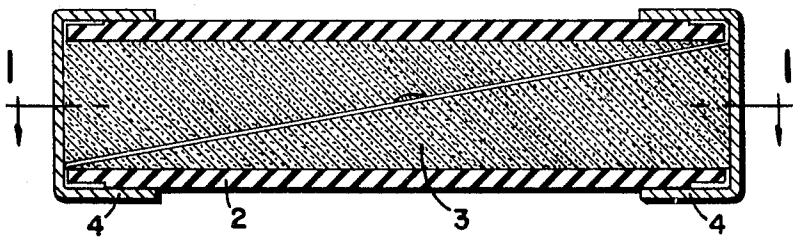


FIG. 3

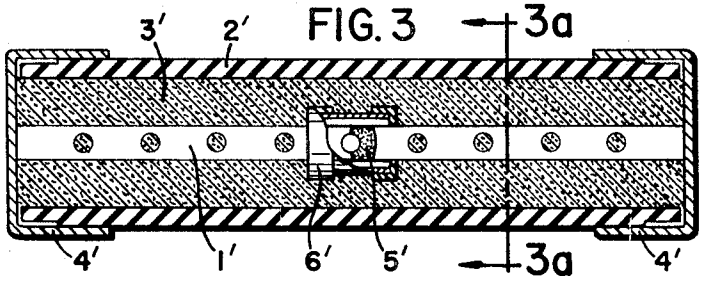


FIG. 4

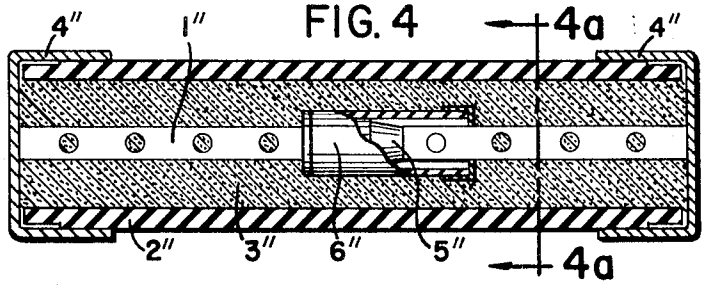


FIG. 3a

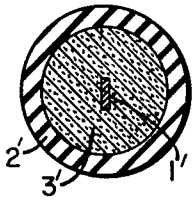
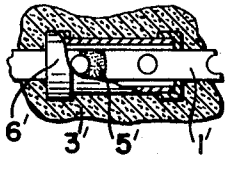


FIG. 3b



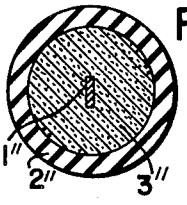


FIG. 4a

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FIG. 5a

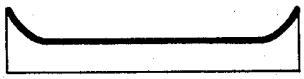


FIG. 5b

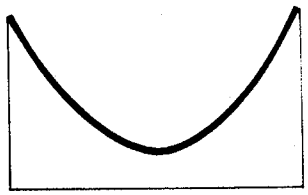


FIG. 5c

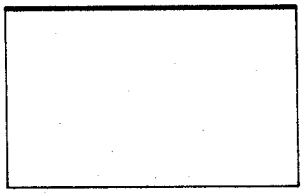


FIG. 6a



FIG. 6b



FIG. 6c

FIG. 7a

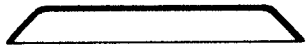


FIG. 7b

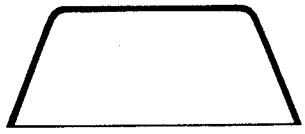


FIG. 7c

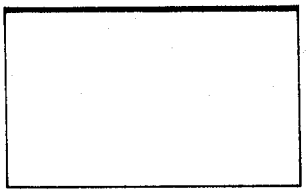


FIG. 8a

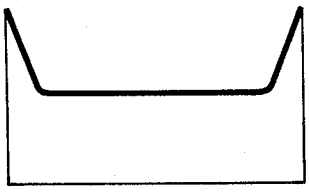


FIG. 8b

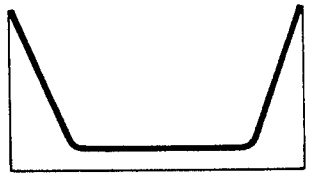


FIG. 8c

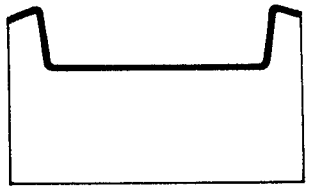


FIG. 9

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FIG. 10

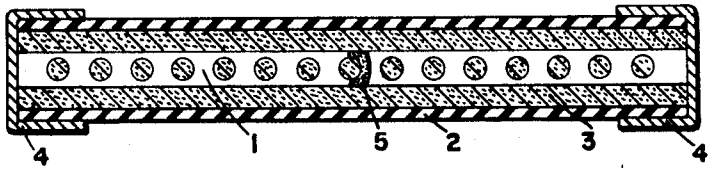
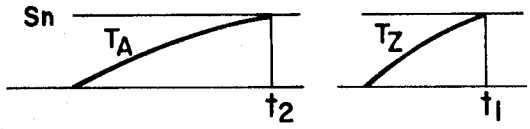
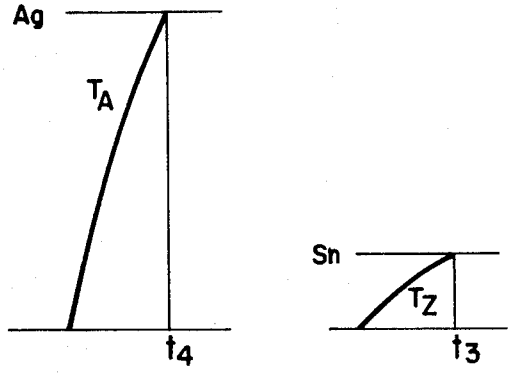


FIG. 10a



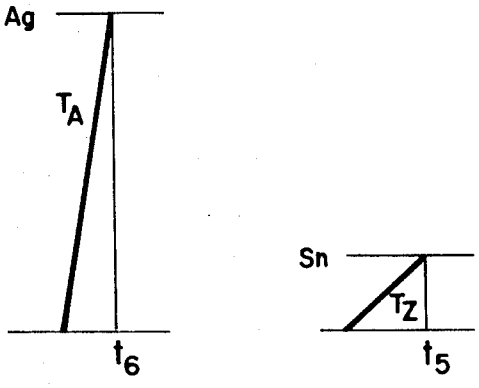
$t_1 \ll t_2$

FIG. 10b



$t_3 = t_4$

FIG. 10c



$t_5 \gg t_6$

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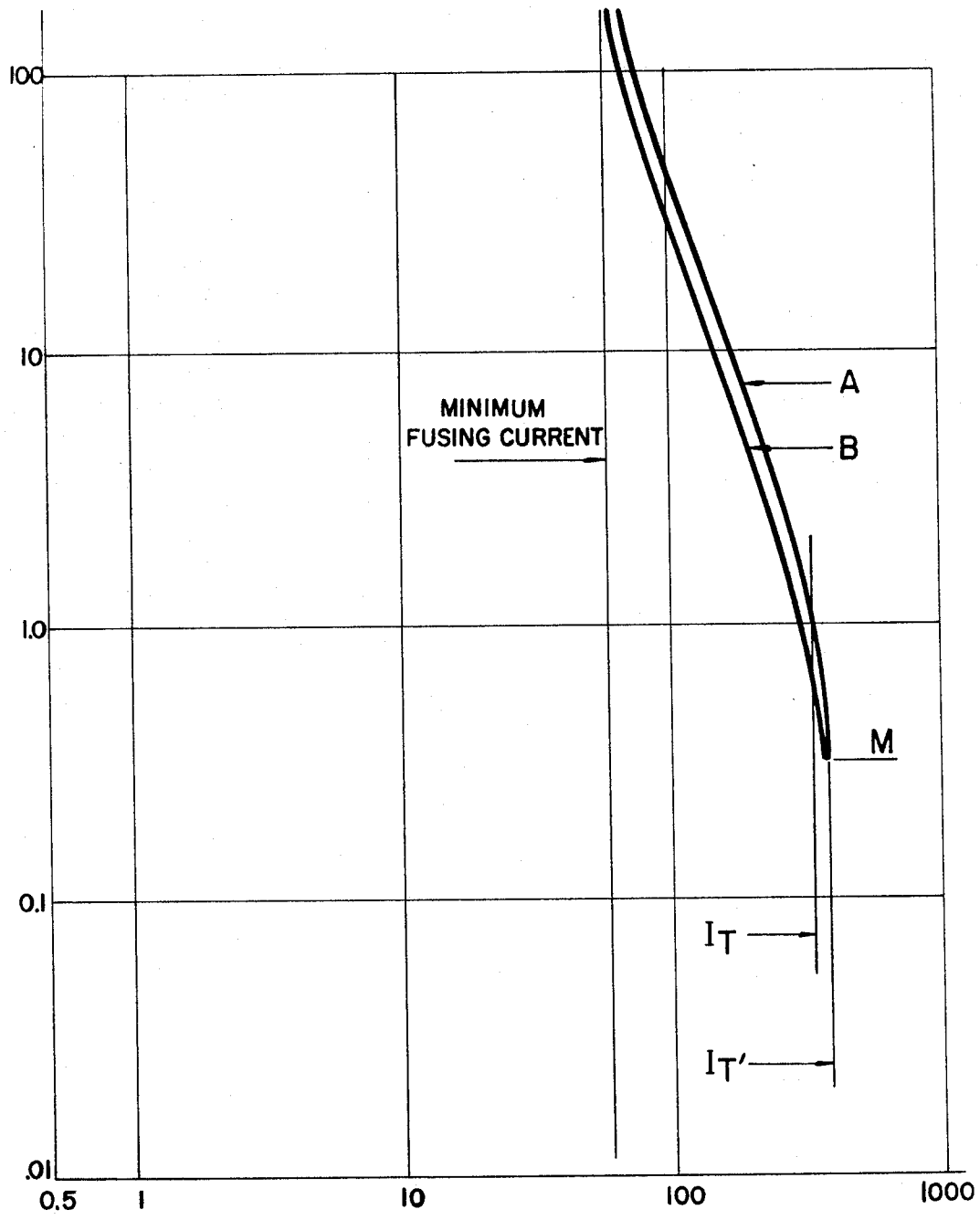


FIG. 11

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United States Patent Office 3,294,937
Patented Dec. 27, 1966

3,294,937

TIME LAG DUAL ELEMENT FUSE HAVING MEANS FOR PRECLUDING ARC INITIATION ADJACENT TERMINALS

Frederick J. Kozacka, South Hampton, N.H., assignor to The Chase-Shawmuth Company, Newburyport, Mass.

Filed June 3, 1965, Ser. No. 461,079
11 Claims. (Cl. 200—120)

This invention relates to electric fuses, and more particularly to electric fuses which blow after predetermined time delays at the occurrence of relatively small protracted overloads, and which blow instantly at the occurrence of major fault currents.

Fuses of this description have been known for many years, and are being applied extensively. In recent years fuses of this description have been subject to a kind of failure which was apparently not observed heretofore, and not accounted for.

It is, therefore, one object of this invention to determine the reasons underlying the above referred-to kind of failure, and to provide electric fuses not subject to that particular kind of failure.

Fuses of the above description generally include a fuse link having a plurality of serially related points of reduced cross-sectional area, or necks. These points of reduced cross-sectional area or necks fuse at the occurrence of major fault currents, and then form serially related multibreaks. Fuses of the above description further include a fusible element of a metal having a lower fusing point than the metal of which the aforementioned fuse link is made, which fusible element causes interruption of the circuit with predetermined time delays at the occurrence of relatively small protracted overloads. The fusible element having a lower fusing point than the metal of which the fuse link is made may be in the form of an overlay on the fuse link, or in the form of a rivet insert. Fusion of such an overlay, or rivet insert, under the action of predetermined overload currents takes predetermined periods of time which are primarily responsible for the time delay action of such fuses. The fused overlay metal, or rivet metal, respectively, severs the base metal, or fuse link metal proper, by a metallurgical reaction in the nature of a diffusion process, thus initiating interruption of the overloaded circuit.

The fusible element of a metal having a lower fusing point than the metal of which the fuse link is made may also take the form of a bridge conductively interconnecting two spaced sections of the fuse link.

The fusible element of a metal having a lower fusing point than the metal of which the fuse link proper is made may also take the form of a solder joint between two current-carrying parts spring-biased to separate upon fusion of the solder joint and forming a circuit interrupting gap therebetween upon separation from each other.

In fuses of this description there occurs—up to a predetermined current intensity—the formation of a single break at which the circuit is interrupted, this single break being located at the point where the aforementioned fusible element having a relatively low fusing point is arranged. When the current intensity is increased and a critical current intensity reached, the point of initial break shifts from the point where the low fusing point fusible

element is located to axially outer points of reduced cross-sectional area, or necks, of the fuse link. The critical current at which this shift of the point of initial break occurs may be referred-to as the transfer current. The transfer current for various time-lag fuses having the same current rating varies depending upon the particular design thereof. The transfer current may be in the order of ten times the rated current of the fuse, though higher values as well as lower values of transfer current have been observed.

I have discovered that time-lag fuses of the above description may have a tendency to fail when subjected to currents in the order of the transfer current, or slightly exceeding the transfer current.

It is, therefore, another object of this invention to provide time-lag fuses of the above description not subject to a tendency to fail when blowing after having been caused to carry a critical overload current.

I have further discovered that in prior art fuses of the above description which fail when subjected to such a critical overload current, their failure is due to a shift of the point of initial arc formation from the fusible element whose fusing point in relatively low to an axially outer point of reduced cross-sectional area of the link, or neck, thereof. To be more specific, there is a tendency of the point of initial arc formation to shift to a point of reduced cross-sectional area, or neck, immediately adjacent to a terminal cap, or ferrule, or other terminal element, of the fuse. The back burn length from that particular point of the fuse link to the terminal cap, ferrule, or other terminal element, may be too short to develop the arc voltage required to interrupt the critical transfer current, or a current slightly in excess of the same. Therefore the arc burns into the terminal cap, ferrule, or other terminal element which, in turn, results in total failure of the fuse.

It is, therefore, another object of the invention to provide electric time-lag fuses not subject to the tendency of forming a break immediately adjacent to a terminal cap, ferrule, or other terminal element thereof, concomitant with the occurrence of a critical load current that cannot safely be interrupted at such a break.

If the current carried by a given fuse is substantially increased beyond and above the critical transfer current, the danger of failure of the particular fuse does not prevail any longer. This may be due to the fact that the increase of the current results in the formation of multibreaks along the fuse link, generating an aggregate arc-voltage sufficiently high to interrupt the excess current. Under such circumstances an initial break may form immediately adjacent a terminal cap, ferrule, or other terminal element, but while the arc is burning at that particular point of the fuse link other series break form, raising the aggregate arc voltage to a sufficiently high level to safely interrupt the circuit.

It is, therefore, another object of this invention to provide electric fuses including specific means which increase the critical current at which the point of initial break formation transfers away from the low fusing point element of the fuse to some other point of the fuse link to such an extent that the fuses are capable of safely interrupting the increased transfer current.

It is apparent from the foregoing that the particular kind of failure which this invention seeks to avoid is a

failure resulting from the specific magnitude of the fusing current at which the transfer of the initial point of break occurs in a particular design. Such a failure may briefly be referred-to as transfer current failure, and will so be referred-to hereafter.

It is, therefore, another object of this invention to provide electric fuses which avoid transfer current failure, and are not subject to transfer current failure.

Considering a particular fuse structure wherein transfer current failure occurs at a specific current intensity, at which current intensity the point of initial break shifts from the point of the fuse structure where the low fusing point fusible element is located to a point of reduced cross-sectional area of the fuse link which is relatively close to a terminal cap, ferrule, or other terminal element, of the fuse. This shift at a critical current of the point of initial break formation to an axially outer end of the fuse link is due to a particular temperature distribution in the fuse structure at the critical current. The undesirable shift of the initial point of break to one of the axially outer ends of the fuse link means can be avoided by appropriately controlling the temperature distribution along the fuse structure. To be more specific, such an undesirable shift can be avoided by providing means controlling the temperature distribution along the fuse structure in such a fashion that when the current intensity is reached and slightly exceeded at which, in the absence of temperature distribution control means, the hottest point of the fuse link means is situated relatively close to one of the axially outer ends of the fuse link means, the hottest point of the fuse link means coincides with the center region thereof on account of the presence of the aforementioned temperature distribution control means.

It is, therefore, another object of this invention to provide electric fuses having such temperature distribution control means. Such temperature distribution control means are means tending to limit, or reduce, heat transfer from points of reduced cross-sectional area of a fuse link situated immediately adjacent to the low fusing point fusible element to the surrounding pulverulent arc-quenching filler. In such a fuse a multiple transfer of the point of initial break formation may occur, i.e. at a given critical current the point of initial break formation may shift from the point where the low fusing point fusible element is located to an axially inner point of reduced cross-sectional area of the fuse link and, at a higher critical current, another shift of the point of initial break formation may occur to an axially outer point of reduced cross-sectional area of the fuse link. The latter shift does not involve the danger of transfer current failure because it occurs at a much higher current intensity than the shift which occurs initially.

The distribution of temperature along a fuse link, or fusible element, depends on the magnitude of the current it carries, its geometry and material constants, the geometry and material constants of the pulverulent arc-quenching filler, the geometry and material constants of the casing or fuse tube housing the fuse link, or fusible element, and the nature of the terminals by which the fuse is connected into an electric circuit. If the current carried by a fuse is relatively low, and the time during which the current is carried prior to blowing of the fuse is relatively long, the time available for heat to be conducted away from the center region of the fuse structure towards the terminals thereof is relatively long and the temperature distribution along the fuse link or fusible element is significantly affected by heat transfer phenomena. In such instances the general form of the heat distribution curve is parabolic. On the other hand, if the current carried by the fuse link, or fusible element, is high and the heat generation is correspondingly high and the blowing time short, the time prior to blowing available for heat transfer becomes so small as to minimize the effects of heat transfer phenomena. In such instances the heat distribution along the fuse link, or fusible element, and particularly its center region, becomes more uniform. If heat dissipation can be entirely neglected a fusible element having a uniform cross-sectional area throughout the length yields a rectangular, or flat top, temperature distribution curve.

The phenomenon of the transfer of the point of initial break formation from one point along the fusible element to another occurs at currents which neither yield the familiar parabolic temperature distribution, nor the familiar flat top temperature distribution, along the fuse link or fusible element. A transfer of the point of initial break formation from the center region of a fuse link to the axially outer regions thereof occurs when the temperature at the center region of the fuse link is less than at the axially outer regions thereof. If the transfer current is relatively low in a given fuse structure, i.e. if the critical current is relatively low at which the point of initial break-formation and arc-initiation is shifted from the center of the fuse structure to an axially outer end thereof, then no break other than a single break at the axially outer ends of the fuse structure may be formed. If the transfer current of that particular fuse structure can be increased, and the blowing time incident to the occurrence of the transfer current as well as heat transfer phenomena during the pre-arcing period reduced, the temperature distribution under transfer current conditions may be rendered more uniform, which is conductive to more effective interruption of an overloaded circuit.

It is, therefore, another object of this invention to provide electric time-lag fuses wherein the temperature distribution is controlled by means tending to equalize under transfer current conditions the temperature distribution along the fuse link.

Further objects and advantages of the invention will become apparent as this description proceeds, and the features of novelty which characterize the invention will be pointed out with particularly in the claims annexed to, and forming part of, this specification.

For a better understanding of the invention reference may be had to the accompanying drawings wheren

FIG. 1 is a longitudinal section of a prior art fuse tending to be subject to transfer current failure, the section being taken substantially along **1—1** of FIG. 2;

FIG. 2 is a longitudinal section of the structure of FIG. 1 taken substantially along **2—2** of FIG. 1;

FIG. 3 is a longitudinal section of the structure of FIG. 1 upon having been modified according to the present invention;

FIG. 3*a* is a transverse section of the structure of FIG. 3 taken along 3*a*—3*a* of FIG. 3;

FIG. 3*b* is a modified detail of FIG. 3;

FIG. 4 is a longitudinal section of another time-lag fuse embodying this invention;

FIG. 4*a* is a transverse section of the structure of FIG. 4 taken along **4***a*—**4***a* of FIG. 4;

FIGS. 5*a*–5*c*; 6*a*–6*c*; 7*a*–7*c*; 8*a*–8*c* and FIG. 9 are diagrams illustrating possible heat distribution in electric fuses;

FIGS. 10–10*c* are related diagrams illustrating temperatures at different points of a fuse structure under different overloads; and

FIG. 11 shows the time-current-curve of a fuse structure according to FIGS. 4 and 4*a* and the time-current-curve of an identical fuse structure except for the absence in it of a sleeve structure of insulating material surrounding the fuse link and mounted thereon and defining a void around the center region of the fuse link.

Referring now to FIGS. 1 and 2, the fuse structure shown therein comprises a ribbon fuse link **1**, preferably of silver or copper, arranged in a tubular casing **2** of insulating material and surrounded by a body of arc-quenching filler **3**, preferably quartz sand. The ends of ribbon fuse link **1** are bent around the rims of tubular casing **2** to the outer surface thereof. A pair of ferrules

or terminal caps 4 is mounted on the axially outer ends of casing 2, overlapping, or extending over, the portions of fuse link 1 situated on the outer surface of casing 2. The ends of ribbon fuse link 1 in engagement with ferrules or terminal caps 4 are conductively connected to the latter by solder joints (not shown). Fuse link 1 is provided with nine circular perforations defining nine serially related points of reduced cross-sectional area, or necks. An overlay 5 of tin, or of an alloy of tin, or of another metal having a substantially lower fusing point than the metal of which fuse link 1 proper is made, is arranged in the center of fuse link 1 immediately adjacent to the circular center perforation thereof. Overlay 5 is preferably positioned in accordance with the teachings of U.S. Patent 2,988,620 to Frederick J. Kozacka, Time-Lag Fuses, June 13, 1961, assigned to the same assignee as the instant application.

At currents which are a low multiple of the rated current of the fuse structure of FIGS. 1 and 2 the point of reduced cross-section, or neck, situated at the center of ribbon fuse link 1 is the point of the fuse link having the highest temperature. Hence overlay 5 melts and severs fuse link 1 by a metallurgical reaction involving interdiffusion of metals. An arc is kindled at the break thus formed, and the arc voltage increases as the arc burns back in opposite directions toward ferrules or terminal caps 4. When the arc gap has reached a given length, less than the total length of fuse link 1, the arc voltage is sufficiently high and the arc current sufficiently low to preclude re-ignition of the arc following a zero of the arc current. At currents which are a high multiple of the rated current of the fuse structure, e.g. 30 times its rated current, all serially related points of reduced cross-sectional area reach substantially simultaneously the fusing point of the base metal—preferably silver or copper—of which fuse link 1 is made. Hence a plurality of series break is formed which may result in such a high arc voltage that the current begins to decay instantly and reaches zero before the time of natural current zero. At a critical current i_T, or transfer current, the point of arc initiation shifts from overlay 5 to, say, the point at the left end of fuse link 1 where the last axially outer perforation is located. Since the back-burn-length available to the left of that perforation is relatively limited, and since the arc voltage generated at the single break is too low to result in rapid arc extinction, the arc is likely to burn into left ferrule or cap 4, resulting in the emission of hot ionized products of arcing. These are likely to short-circuit circuits whose path is adjacent to the faulted fuse. This may result in serious damage, down-time, and even a major disaster.

In FIGS. 3 and 3*a* the same reference characters as in FIGS. 1 and 2, with a prime added have been applied to designate like parts. This fuse link 1′ having nine serially related points of reduced cross-sectional area formed by circular perforations is housed in a casing 2′ of insulating material filled with a pulverulent arc-quenching filler 3′, preferably quartz sand. Terminal caps 4′ conductively interconnected by fuse link or fusible element 1′ close the ends of casing 2′. Link-severing overlay 5′ of a metal having a lower fusing point than the base metal of which link 1′ is made is arranged immediately adjacent to the center perforation of link 1′. Sleeve or receptacle 6′ of insulating material is arranged inside of casing 1′ in spaced relation thereto. Sleeve or receptacle 6′ is arranged in coaxial relation to casing 2′ and has a substantially smaller diameter than casing 2′. The former is embedded in the body of pulverulent arc-quenching filler 3′ and surrounds but the center portion of the link 1′ where its center perforation and overlay 5′ are located. Sleeve or receptacle 6′ defines a void surrounding overlay 5′ and precluding access of arc-quenching filler 3′ to overlay 5′. Hence sleeve or receptacle 6′ is a thermal insulating means limiting heat exchange between overlay 5′ and arc-quenching filler 3′.

The structure of FIG. 3*b* differs from that of FIG. 3 only to the extent that in the former several points of reduced cross-sectional area of link 1′ are arranged inside of sleeve or receptacle 6′.

The structure of FIGS. 4 and 4*a* is substantially identical with that of FIGS. 3 and 3*a*, except for the fact that in the former a pair of axially spaced fuse link sections have been substituted for the single fuse link of FIGS. 3 and 3*a*, and for the fact that in the former a thermally responsive overload switching device has been substituted for the low fusing point overlay 5′ of FIGS. 3 and 3*a*. In FIGS. 4 and 4*a* and in FIGS. 3 and 3*a* like parts have been designated by the same reference characters, however, in FIGS. 4 and 4*a* two prime signs were added rather than but a single prime. Thus the structure of FIGS. 4 and 4*a* comprises a pair of axially spaced fuse link sections 1″ arranged in a tubular casing 2″ of insulating material which is filled with a pulverulent arc-quenching filler 3″. Reference character 5″ has been applied to generally indicate a switching device having relatively movable spring biased contacts maintained by solder joints in one of the limit positions thereof and normally conductively interconnecting fuse link sections 1″. Structures of the kind diagrammatically shown in FIG. 4 and designated therein by reference character 5″ are well known in the art and, therefore, need not to be described in detail in this context. For details concerning such structures reference may be had to United States Patent 2,321,711 to Elmer H. Taylor, June 15, 1943 Fusible Electric Protective Device, assigned to the same assignee as the present invention. Switching device 5″ is enclosed in a cylindrical receptacle, or sleeve, 6″ of insulating material mounted on and supported by fuse link sections 1″. Switching device 5″ and the two fuse link sections 1″ are connected in series and they conductively interconnect ferrules or terminal caps 4″ mounted on casing 2″.

All overload currents up to a critical overload current are interrupted in the structures of FIGS. 3, 3*a*, 4 and 4*a* by the formation of a single break at 5′, or at 5″, respectively. Major fault currents are interrupted in the structures of FIGS. 3, 3*a*, 4 and 4*a* by the simultaneous formation of series breaks in ribbon link 1′, or ribbon link sections 1″, respectively. When a critical overload current is reached in the structures of FIGS. 3, 3*a*, 4 and 4*a*, the point of initial break formation shifts from 5′, or 5″, respectively, axially outwardly to a point adjacent caps 4′, or 4″, respectively, say, the perforation immediately adjacent the left ferrule or terminal cap.

Assuming the structures of FIGS. 1, 2, 3, 3*a* and 3*b* to be identical except for the absence of part 6′ in the structure of FIGS. 1 and 2, then the following inequality prevails

$$I_T' \gg I_T$$

wherein I_T' is the critical transfer current of the structure of FIGS. 3, 3*a* and 3*b*, and I_T the critical transfer current of the structure of FIGS. 1 and 2. The reasons underlying the above inequality will be considered below more in detail.

If the structures of FIGS. 3, 3*a*, 3*b*, 4 and 4*a* tend to significantly increase the transfer current over that of FIGS. 1 and 2, all other conditions remaining unchanged, then there is a smaller likelihood that the transfer of the point of arc initiation from the center region of the fuse structure to a point of reduced cross-sectional area close to the axially outer end of the link will result in a failure of the fuse.

A more complete understanding of this invention calls for a more complete understanding of temperature distribution in electric fuses. One might attempt to set up an equation for heat conduction and find a general solution thereof. This, however, is not practicable. All analytical solutions of temperature distribution in electric fuses which have been offered to date are based on specific assumptions which do not prevail in the instant

case. One frequently made assumption is, for instance, that heat exchange during the pre-arcing time may be neglected on account of the shortness of that time resulting from the magnitude of the fault current.

FIGS. 5*a*–5*c*; 6*a*–6*c*; 7*a*–7*c*; 8*a*–8*c* and 9 convey a concept of possible temperature distribution in fuses by considering a number of possible limit conditions. The above figures have been drawn on the assumption that heat generation is uniform throughout the finite, limited length of a fusible element, or fuse link of uniform cross-sectional area. FIGS. 5*a*–5*c* refer to a hypothetical fuse structure wherein there are axial heat losses, but no radial heat losses. FIG. 5*a* illustrates the case of zero heat losses, FIG. 5*b* the case of relatively small axial heat losses and FIG. 5*c* the case of relatively large heat losses. FIGS. 6*a*–6*c* are idealized temperature distribution curves referring to the three possibilities indicated in FIGS. 5*a*–5*c*. FIGS. 7*a*–7*c* refer to a hypothetical fuse structure wherein there are radial heat losses, but no axial heat losses. FIG. 7*a* illustrates the case of zero heat losses, FIG. 7*b* the case of relatively small radial heat losses and FIG. 7*c* the case of relatively large radial heat losses. FIGS. 8*a*–8*c* are idealized temperature distribution curves referring to the three possibilities indicated in FIGS. 7*a*–7*c*. It is apparent from a consideration of the above limit cases that in a fuse structure wherein the axial heat losses are relatively small (FIG. 5*b*, 6*b*) and the radial heat losses are relatively large (FIGS. 7*c*, 8*c*), the temperature adjacent the ends of the fuse link may exceed the temperature at the center region thereof. FIG. 9 shows diagrammatically the temperature distribution along a fuse link in case of relatively small axial and relatively large radial heat losses. Transfer current failures have been observed when axial heat losses are relatively small and radial heat losses relatively large.

FIG. 10 illustrates diagrammatically a prior art fuse structure wherein the axial heat losses may be expected to be relatively small on account of the relative length of the fuse link and the radial heat losses to be relatively large on account of the relatively small diameter of the casing, and which is likely to result in transfer current failure. FIGS. 10, 10*b* and 10*c* illustrate diagrammatically the temperature rise adjacent the axially outer end of the fusible element of FIGS. 10 and adjacent the center thereof plotted against time for three overload currents of different magnitude.

The structure of FIG. 10 is substantially the same as that shown in FIGS. 1 and 2, and the same reference characters have been applied in the three aforementioned figures to indicate like parts. Therefore FIG. 10 does not call for a separate description except an indication of the differences between it and the structure shown in FIGS. 1 and 2. The relative length of the fuse link of FIG. 10 exceeds that of FIGS. 1 and 2 and the number of perforations is larger in the structure of FIG. 10. This tends to greatly reduce axial heat flow. The spacing of the fuse link from the casing is relatively smaller in the structure of FIG. 10. This tends to greatly increase the radial heat flow.

When the fuse of FIG. 10 carries a predetermined relatively small overload current the temperature rises in the center of the fuse link according to T_Z, and at the point of reduced cross-sectional area farthest to the left the temperature rises according to T_A, as clearly shown in FIG. 10*a*. The generation of heat is substantially the same adjacent the center perforation and adjacent the perforation farthest to the left. The region of the last mentioned perforation is so effectively cooled by the left terminal element of the fuse that the rate of rise of T_A is less than the rate of rise of T_Z. At the time t_1 overlay **5** reaches its fusing point S*n* and this initiates the process of metal diffusion which results ultimately in an interruption of the current path through the fuse link. It takes the left axially outer end of the fuse link the time t_2 to reach the fusing point of the overlay metal, $t_2 > t_1$.

FIG. 10*b* shows the case of the critical overload current—which is higher than the overload current to which FIG. 10*a* refers—at which the overlay **5** reaches its fusing point S*n* substantially at the same time as the point of reduced cross-section farthest to the left of the fuse structure reaches the fusing point A*g* of silver. In that particular instance T_A has a much higher rate of rise than T_Z. While the increase of the overload current from the condition shown in FIG. 10*a* to that shown in FIG. 10*b* results in an increase of the rate of rise of both T_Z and T_A, the increase of the rate of rise of T_A is much higher than that of T_Z. At the critical transfer current $t_3 = t_4$ or, in words, the time t_3 required to bring overlay **5** up to the fusing point S*n* of the overlay metal is equal to the time required to bring the point of reduced cross-sectional area adjacent one end of the link to the fusing point A*g* of the base metal of the link.

FIG. 10*c* shows a situation of increased rates of rise T_Z and T_A resulting from a further increase of the overload current, the relative increase of the rate of rise of T_A exceeding the relative increase of the rate of rise of T_Z. As shown in FIG. 10*c* the point of reduced cross-sectional area adjacent the axially outer end of the fuse link reaches the fusing point A*g* of the base metal of the fuse link in a much shorter time t_6 than the time t_5 required for the overlay metal to reach its fusing point S*n*.

There is a certain ratio of axial to radial heat flow for any given overload current. This ratio decreases as the magnitude of the overload current increases. This change in ratio is responsible for the changes in the rate of rise of T_A and T_Z shown in FIGS. 10*a*–10*c* and discussed in connection with these figures. At relatively low overload currents the terminal caps are relatively effective heat sinks. Their effectivenes as heat sinks decreases with increasing overload currents because the time available for heat exchange decreases with increasing current intensity. At relatively high currents the terminal caps **4** turn into effective thermal shields minimizing radial radiant heat losses adjacent the ends of fuse link **1** and thus tending to increase the temperature at these regions.

In drawing FIGS. 10*a*–10*d* it has been assumed that the temperature of overlay **5** at the time of formation of a circuit interrupting break at this point is the fusing point S*n* of the overlay metal, and that the temperature at the axially outer ends of the fuse link at the time of formation of the circuit interrupting break at either of these points is the much higher fusing point A*g* of the base metal of the fuse link. At the former temperature radiation losses are minimal, but at the latter temperature significant. This becomes particularly apparent from a consideration of the "Stefan-Boltzmann law" which may be written as

$$e_B = K' . T^4$$

wherein e_B is the total emissitivity of a black body, K is a universal constant, the "Stefan-Boltzmann" constant (5.735×10^{-5} erg/sec.^{2} deg.^{4}), and T the absolute temperature. While a fuse structure is obviously not a black body, the "Stefan-Boltzmann law" is clearly applicable in view of Kirchhoff's emissive power law which states that the total emissive power of any object at any temperature is equal to a fraction of the emissive power of a black body at that temperature.

Tests can be made, and have been made, to determine the emisison of thermal radiation of fuse structures substantially the same as those according to FIGS. 1, 2 and 10. To this end a collimated infrared sensitive photoelectric cell was slidably arranged on a bar parallel to the longitudinal axes of the fuse structures. The acceptance angle of the cell was relatively small. The fuse structures were caused to carry their respective transfer current and readings were taken from a milliammeter connected to an amplifier under the control of the photoelectric cell. As long as the photoelectric cell was arranged in juxtaposition to the overlay **5** of a metal hav-

ing a relatively low fusing point, the meter did not indicate the presence of radiation. As the photoelectric cell was moved axially outwardly toward one of the terminal caps of the fuses, the meter indicated intense thermal radiation. The indication became zero when the photoelectric cell was juxtaposed to the perforation in the fuse link closest to the end of the fuse link. This is obviously due to the interposition of the ferrule or cap **4** between the fuse link and the photoelectric cell, coupled with the small acceptance angle of the latter.

There are certain casing materials which are highly absorbent for thermal radiation and there are other casing materials which absorb thermal radiation relatively little. The first kind of casing materials tends to result in a relatively small radial heat dissipation and the last mentioned kind of casing materials tends to result in a relatively large radial heat dissipation. Modern synthetic-resin-glass-cloth laminates as, for instance, melamine-glass-cloth-laminates, which are, at present, widely used as casing materials, absorb relatively little thermal radiation and are relatively good conductors of heat and are, therefore, conducive to relatively large radial heat dissipation. The use of quartz sand as arc-quenching filler is likewise conducive to relatively large radial heat dissipation. As a result, fuses having a casing of a synthetic-resin-glass-cloth laminate and having a filler of quartz sand as an arc-quenching medium may have a tendency of being cooled radially more effectively in the center region than at the axially outer ends thereof. This, in turn, makes the problem of avoiding transfer current failures particularly important in connection with such fuses.

As mentioned above FIGS. 10*a*–10*c* have been drawn on the assumption that the temperature of overlay **5** just prior to interruption of the circuit is the fusing point of the overlay metal. A similar assumption has been made in regard to the temperature at an axially outer end of the fuse link just prior to initial break formation at this point. These assumptions appear to be permissible to explain the phenomenon of the shift of the point of initial break formation as a relatively simple race between the rise in temperature at two points of the fuse link. FIGS. 10*a*–10*c* and their context are, however, great oversimplifications of actually prevailing conditions since the time when the fusing point of the respective metal is reached and the time of initial break formation do not actually coincide, and since the shapes of the rise in temperature versus time curves may actually be quite different from the simple shapes shown in FIGS. 10*a*–10*c*. This is particularly true in regard to the curve T_Z showing the temperature rise of the overlay plotted versus time. Actually such a curve rises significantly above the fusing temperature of the overlay metal and becomes very steep at the point of time at which the overlay severs completely the current path through the fuse link proper. In other words, the time at which the current path through the fuse link is ultimately severed does not coincide with the time at which the overlay **5** reaches its fusing point, there being a time-lag involved in the link-severing-process and the link-severing-process requiring a higher temperature for its completion than the fusing temperature of the overlay metal **5**. Similarly the axially outer end of the fuse link will not be severed at the time when the base metal of the fuse link reaches its fusing point, but at a later point of time. It is thus apparent that FIGS. 10*a*–10*c* have been drawn to explain the outcome of a rise in temperature race under simplified rather than actually prevailing conditions. The principle underlying the transfer current phenomenon is not affected by the way the process of initial break formation has been presented. It should, however, be kept in mind that FIGS. 10*a*–10*c* are of a diagrammatic rather than of a realistic nature.

The temperature distribution in the structure of FIGS. 4 and 4*a*—be it provided with receptacle or sleeve **6″**, or be it lacking such a receptacle or sleeve—is similar to, yet different from, the temperature distribution in the structure of FIGS. 3, 3*a* and 3*b*. This is due to the relatively larger mass and concomitant larger heat absorbing capacity involved in the spring-biased solder-joint-switching-device **6″**. The following table refers to a series of tests performed with a structure identical with that shown in FIGS. 4 and 4*a*, except for the absence of sleeve or receptacle **6″**. In this table the solder-joint break in the center of the fuse structure has been designated by the reference character **0** and the four points of reduced cross-sectional area, or four points of break, to the left and to the right of the center **0** have been designated by the reference characters **1**, **2**, **3** and **4**. A total of ten tests was performed at currents of 60, 90, 120, 150, 180, 250, 290, 340, 370 and 390 amps. The X sign in the table indicates the particular point in the fuse structure where the initial break was formed. It is apparent that for the range of 60–390 amps. one single break was formed at each test. In the range of 60–150 amps. initial break formation occurred in the center region of the fuse structure, in the range of 180–340 amps. initial break formation occurred at a point between the center region of the fuse structure and the point of reduced cross-section farthest to the right, and at 370 amps. and above arc initiation occurred at the point **4** of reduced cross-section farthest to the right. At much higher currents serially related multibreaks are formed at all points **1**–**4** to the left and to the right of point **0**.

4	3	2	1	0	1	2	3	4	Amps
				X					60
				X					90
				X					120
				X					150
						X			180
						X			250
							X		290
						X			340
								X	370
								X	390

The following table refers to a series of ten tests which were performed with a fuse structure identical to that shown in FIGS. 4 and 4*a*, i.e., a structure which included the receptacle or sleeve **6″**. The same reference characters are used in the table below as in the table above to indicate like points.

4	3	2	1	0	1	2	3	4	Amps.
				X					60
				X					90
				X					120
				X					150
						X			180
		X							250
					X				290
		X							340
					X				370
					X				390

It is apparent from the above table that the provision of receptacle or sleeve **6″** tends to maintain the point of initial break formation relatively close to the center region of the fuse link, i.e., to preclude its transfer to one of the axially outer ends of the fuse link portions **1″**,**1″**. To achieve such a transfer the current carried by the fuse must exceed 390 amps.

In FIG. 11 reference character A has been applied to indicate the time-current characteristics of a fuse structure as shown in FIGS. 4 and 4*a* but lacking the receptacle or sleeve **6″**, and reference character B has been applied to indicate the time-current characteristic of a fuse structure as shown in FIGS. 4 and 4*a*, i.e., a structure including the receptacle or sleeve **6″**. Both structures differ only by the absence, or presence, respectively, of recep-

tacle or sleeve member 6''. The time current characteristics A and B of both structures merge in the range of relatively low currents and the minimum fusing current of both structures is identical. In other words, if very low currents are being considered, heat exchange is so complete that the presence, or absence, respectively, of receptacle or sleeve member 6'' has no effect on temperature distribution and the process of fusion and interruption of the current path. If the current is high, the fusing times are so short as to make it permissible to neglect heat exchange phenomena. This is evidenced by the fact that characteristics A and B merge at a current equal to a multiple of the minimum fusing current. In other words, the presence, or absence, respectively, of receptacle or sleeve member 6'' has no effect on the high current side of the time current characteristics A and B. There is a limited current range within which the characteristic B is situated below the characteristic A. In that particular current range the fuse having receptacle or sleeve 6'' is faster than the fuse lacking receptacle or sleeve 6''. The vertical line I_T indicates the critical current of the specimen lacking receptacle or sleeve 6'' at which the point of initial break shifts one of the points of reduced cross-sectional area adjacent one of the ends of fuse link 1''. Characteristics A and B merge at the point M which corresponds to a current I_T', i.e., to the current of the structure of FIGS. 4 and 4*a* at which the point of initial break shifts to one of the points of reduced cross-sectional area adjacent one of the ends of fuse link 1''. The above referred-to inequality

$$I_T' \gg I_T$$

is thus clearly apparent from FIG. 11. The specific fuses to which FIG. 11 refers had transfer currents of about 400 amps., and 350 amps., respectively. The transfer current of 350 amps. was more than ten times the rated current of the fuse.

It is possible to readily control the transfer current within relatively wide limits by enclosing inside of sleeve or receptacle 6' and 6'', respectively, in addition to overlay 5' (FIGS. 3 and 3*a*) or part 5'' (FIGS. 4 and 4*a*) any desired number of points of reduced cross-sectional area of the fuse link. It is generally preferable to enclose receptacle or sleeve 6' or 6'' several points of reduced cross-sectional area of the fuse link as has been clearly shown in FIG. 3*b*.

While I have indicated above my theory underlying the phenomenon of transfer current failures it will be understood that the effectiveness of the remedial means for avoiding transfer current failures defined in the following claims does not depend upon the correctness of this theory.

It will also be understood that although but a few embodiments of the invention have been illustrated and described in detail, the invention is not limited thereto. The structures illustrated may be modified without departing from the spirit and scope of the invention as set forth in the accompanying claims.

I claim as my invention:

1. An electric time-lag fuse comprising in combination:
(a) a tubular casing of insulating material;
(b) a pair of terminal elements closing the ends of said casing;
(c) means inside said casing for conductively interconnecting said pair of terminal elements, said interconnecting means including ribbon fuse link means of a metal having a relatively high fusing point, said ribbon fuse link means having a predetermined cross-sectional area and defining a plurality of serially related points of reduced cross-sectional area, and said interconnecting means further including a mass of metal having a relatively low fusing point arranged in the center region of said casing and adapted to sever the current path through said interconnecting means on occurrence of overloads of excessive duration;
(d) a pulverulent arc-quenching filler inside said casing surrounding said ribbon fuse link means and said mass of metal, said arc-quenching filler, said pair of terminal elements, said interconnecting means and said casing forming a thermal system determining a critical current at which the point of initial break-formation transfers from said mass of metal to a point of said interconnecting means sufficiently close to one of said pair of terminal elements to result in burnback into said one of said pair of terminal elements; and
(e) a wall structure spaced from and enveloping said mass of metal and arranged between said casing and said mass of metal, closer to said mass of metal than to said casing and defining a chamber surrounding said mass of metal, precluding access of said arc-quenching filler to said mass of metal, tending to reduce heat losses from said mass of metal to said arc-quenching filler, and increasing the magnitude of the critical current at which the point of initial break-formation transfers from said mass of metal to a point of said interconnecting means closer to one of the ends of said casing than said mass of metal.

2. An electric time-lag fuse comprising in combination:
(a) a tubular casing of insulating material;
(b) a pair of terminal elements closing the ends of said casing;
(c) means inside said casing for conductively interconnecting said pair of terminal elements, said interconnecting means including ribbon fuse link means of a metal having a relatively high fusing point, said ribbon fuse link means having a predetermined cross-sectional area and defining a plurality of serially related points of reduced cross-sectional area, and said interconnecting means further including a mass of metal having a relatively low fusing point arranged in the center region of said casing and adapted to sever the current path through said interconnecting means on occurrence of overloads of excessive duration;
(d) a pulverulent arc-quenching filler inside said casing surrounding said ribbon fuse link means and said mass of metal, said arc-quenching filler, said pair of terminal elements, said interconnecting means and said casing forming a thermal system determining a critical current at which the point of initial break-formation transfers from said mass of metal to one of said plurality of points of reduced cross-sectional area of said fuse link means closer to one of said pair of terminal elements than said mass of metal; and
(e) a well structure spaced from, and jointly enveloping, several of, but less than all of, said plurality of points of reduced cross-sectional area and said mass of metal and arranged between said casing and said interconnecting means closer to said interconnecting means than to said casing and defining a chamber free from said arc-quenching filler surrounding said several of said plurality of points of reduced cross-sectional area and said mass of metal and tending to reduce heat transfer from said several of said plurality of points of reduced cross-sectional area and said mass of metal to said arc-quenching filler.

3. An electric time-lag fuse comprising in combination:
(a) a tubular casing of a synthetic resin-glass-cloth laminate;
(b) a pair of terminal elements closing the ends of said casing;
(c) means inside said casing for conductively interconnecting said pair of terminal elements, said interconnecting means including relatively narrow ribbon fuse link means of a metal having a relatively high

fusing point, said ribbon fuse link means having a predetermined cross-sectional area and defining a plurality of serially related points of reduced cross-sectional area, and said interconnecting means further including a mass of metal having a relatively low fusing point arranged in the center region of said casing and adapted to sever the current path through said interconnecting means on occurrence of overloads of excessive duration;

(d) a body of quartz sand inside said casing surrounding said ribbon fuse link means and said mass of metal, said body of quartz sand, said pair of terminal elements, said interconnecting means and said casing of synthetic resin-glass-cloth laminate forming a thermal system having such heat transfer characteristics that the temperature of one of said plurality of points of reduced cross-sectional area of said fuse link remote from the center thereof by far exceeds within a critical band of current intensities the temperature of said mass of metal having a relatively low fusing point; and

(e) a wall structure spaced from and enveloping said mass of metal and arranged between said casing and said mass of metal, closer to said mass of metal than to said casing and defining a chamber surrounding said mass of metal, precluding access of said body of quartz sand to said mass of metal and tending to reduce heat losses from said mass of metal to said body of quartz sand.

4. An electric time-lag fuse comprising in combination:

(a) a tubular casing of a synthetic-resin-glass-cloth laminate;

(b) a pair of terminal elements closing the ends of said casing;

(c) means inside said casing for conductively interconnecting said pair of terminal elements, said interconnecting means including relatively narrow ribbon fuse link means of a metal having a relatively high fusing point, said ribbon fuse link means having a predetermined cross-sectional area and defining a plurality of serially related points of reduced cross-sectional area, and said interconnecting means further including a mass of metal having a relatively low fusing point arranged in the center region of said casing and adapted to sever the current path through said interconnecting means on occurrence of overloads of excessive duration;

(d) a body of quartz and inside said casing surrounding said ribbon fuse link means and said mass of metal, said body of quartz sand, said pair of terminal elements, said interconnecting means and said casing of synthetic resin-glass-cloth laminate defining a thermal system having a critical current at the occurrence of which the point of initial beak-formation shifts from said mass of metal having a relatively low fusing point to one of said plurality of points of reduced cross-sectional area of said fuse link means closer to one of said pair of terminal elements than said mass of metal having a relatively low fusing point; and

(e) means for increasing the magnitude of said critical current, said critical current magnitude increasing means including a wall structure spaced from, and jointly enveloping, several of said plurality of points of reduced cross-sectional area and said mass of metal arranged between said casing and said fuse link means and defining a chamber surrounding said several of said plurality of points of reduced cross-sectional area and said mass of metal and segregating said several of said plurality of points of reduced cross-sectional area and said mass of metal from said body of quartz sand.

5. An electric time-lag fuse comprising in combination:

(a) a tubular casing of insulating material;

(b) a pair of terminal elements closing the ends of said casing;

(c) a fuse link of a metal having a relatively high fusing point inside said casing, said link having a plurality of serially related points of reduced cross-sectional area including one point of reduced cross-sectional area situated substantially at the center of said link;

(d) an overlay of a link-severing metal having a relatively low fusing point arranged on said link immediately adjacent said one point of reduced cross-sectional area thereof, said body of arc-quenching filler, said pair of terminal elements, said fuse link, said overlay and said casing defining a thermal system having a critical current at the occurrence of which current the point of initial break-formation shifts from said overlay to one of said points of reduced cross-sectional area of said fuse link situated closer to one of said pair of terminal elements than said overlay;

(e) a body of pulverulent arc-quenching filler inside said casing surrounding said link along the entire length thereof; and

(f) means for increasing the magnitude of said critical current, said magnitude of critical current increasing means including thermal insulating means radially spaced from said casing, embedded in said body of arc-quenching filler and mounted on and surrounding said link, said insulating means being locally limited to the space adjacent said one point of reduced cross-sectional area of said link and surrounding said overlay and limiting heat exchange between said overlay and said arc-quenching filler.

6. An electric time-lag fuse comprising in combination:

(a) a tubular casing of a synthetic-resin-in-glass-cloth laminate;

(b) a pair of terminal caps mounted on and closing the ends of said casing;

(c) a fuse link of a metal having a relatively high fusing point inside said casing, said link having a plurality of serially related points of reduced cross-sectional area, said plurality of points including a pair of axially outer points of reduced cross-sectional area each arranged inside of one of said pair of terminal caps and said plurality of points of reduced cross-sectional area further including one point of reduced cross-sectional area situated substantially at the center of said link;

(d) an overlay of a link-severing metal having a relatively low fusing point arranged on said link immediately adjacent said one point of reduced cross-sectional area thereof;

(e) a body of quartz sand inside said casing surrounding said link and said overlay, said body of quartz sand, said pair of terminal caps, said fuse link, said overlay and said casing defining a thermal system determining a critical current which, when carried by said fuse link for a predetermined period of time would cause a shift of the point of initial break-formation from said overlay to one of said pair of axially outer points of reduced cross-sectional area of said fuse link; and

(f) means for increasing the magnitude of said critical current, said magnitude of critical current increasing means including thermal insulating means radially spaced from said casing and enveloping said one point of reduced cross-sectional area of said link and said overlay and being embedded in said body of quartz sand, said insulating means being locally limited to the space adjacent said one point of reduced cross-sectional area of said link and limiting heat exchange between said overlay and said arc-quenching filler.

7. An electric time-lag fuse comprising in combination:

(a) a tubular casing of a synthetic-resin-glass-cloth laminate;

(b) a pair of terminal caps mounted on and closing the ends of said casing;

(c) a fuse link of a metal having a relatively high fusing point inside said casing, said link having a plurality of serially related points of reduced cross-sectional area, said plurality of points including a pair of axially outer points of reduced cross-sectional area each arranged inside of one of said pair of terminal caps and said plurality of points of reduced cross-sectional area further including one point of reduced cross-sectional area situated substantially at the center of said link;

(d) an overlay of a link-severing metal having a relatively low fusing point arranged on said link immediately adjacent said one point of reduced cross-sectional area thereof;

(e) a body of quartz sand inside said casing surrounding said link and said overlay, the thermal parameters of said body of quartz sand, said pair of terminal caps, said fuse link, said overlay and said casing establishing heat exchange conditions resulting in a shift of the point of initial break formation at a critical intensity of the current carried by said fuse link from the region of said overlay to one of said points of reduced cross-sectional area relatively remote from said center of said link; and

(f) means for increasing the intensity of said critical current, said intensity of critical current increasing means including thermal insulating means radially spaced from said casing and enveloping a portion of the total length of said link, said portion including said one point of reduced cross-sectional area of said link, said overlay and at least one additional point of said plurality of points of reduced cross-sectional area of said link, said thermal insulating means being embedded in said body of quartz sand and segregating said one point of reduced cross-sectional area of said link and overlay and said one additional point of said plurality of points of reduced cross-sectional area from said body of quartz sand and establishing a zone of relatively reduced heat flow from said link into said body of quartz sand.

8. An electric time-lag fuse comprising in combination:

(a) a tubular casing of insulating material;

(b) a pair of terminal elements closing the ends of said casing;

(c) a fuse link of a metal having a relatively high fusing point inside said casing, said link having a plurality of serially related points of reduced cross-sectional area and including a pair of sections each having an axial outer end conductively connected to one of said pair of terminal elements and having an axial inner end;

(d) a spring biased overload switching device including a solder joint and a pair of separable contacts normally maintained by said solder joint in the engaged position thereof, said switching device conductively interconnecting the axial inner end of each of said pair of link sections;

(e) a body of pulverulent arc-quenching filler inside said casing surrounding said link along the entire length thereof the heat exchange characteristics of said arc-quenching filler, said pair of terminal elements, said fuse link, said switching device and said casing establishing a critical current which when carried by said fuse link for a predetermined period of time results in a shift of the point of initial break-formation from the region of said switching device to one of said plurality of points of reduced cross-sectional area closer to one of said pair of terminal elements than said switching device; and

(f) means for increasing the magnitude of said critical current, said magnitude of critical current increasing means including a hollow receptacle coaxial with and spaced from said casing embedded in said body of arc-quenching filler and mounted on and surrounding said link, said receptacle being locally limited to the space around said switching device and one point of reduced cross-sectional area of said link situated substantially at the center region of said link, said receptacle defining a void surrounding said switching device and said one point of reduced cross-sectional area and precluding access of said arc-quenching filler to said switching device and said one point of reduced cross-sectional area.

9. An electric time-lag fuse comprising in combination:

(a) a tubular casing of insulating material having a predetermined cross-sectional area;

(b) a pair of terminal elements closing the ends of said casing;

(c) a ribbon fuse link of a metal having a relatively high fusing point inside said casing conductively interconnecting said pair of terminal elements, said link having a predetermined cross-sectional area and defining a plurality of serially related points of reduced cross-sectional area;

(d) a link-severing overlay of a metal having a relatively low fusing point supported by said link at the center region thereof;

(e) a pulverulent arc-quenching filler inside said casing surrounding said link and said overlay, said arc-quenching filler, said pair of terminal elements, said fuse link, said overlay and said casing having thermal properties establishing a critical transfer current resulting on occurrence thereof in a shift of the point of initial break-formation from the location of said overlay to one of said plurality of points of reduced cross-sectional area closer to one of said pair of terminal elements than said region of said overlay; and

(f) means for increasing the magnitude of said critical current, said magnitude of critical current increasing means including a tubular insulating sleeve having a substantially smaller cross-sectional area than said casing mounted on said link at said center region thereof in radially spaced relation from said overlay, said sleeve establishing a void between said overlay and said filler and reducing radial heat losses from said center region of said link into said filler.

10. In an electric time-lag fuse having a predetermined minimum fusing current and including a tubular casing of insulating material, a pair of terminal elements closing the ends of said casing, a ribbon fuse link of a metal having a relatively high fusing point inside said casing conductively interconnecting said pair of terminal elements and defining a plurality of serially related points of reduced cross-sectional area, a link-severing overlay of a metal having a relatively low fusing point supported on said link at the center region thereof, a pulverulent arc-quenching filler inside said casing surrounding said link and said overlay, said fuse being made of such materials and having such proportions that it has a transfer current causing, when exceeded, a shift of the point of initial break formation from said overlay to one axially outer of said plurality of serially related points of reduced cross-sectional area, the novel feature consisting in thermal insulating means immediately adjacent to and surrounding said overlay, said thermal insulating means having a heat absorbing capacity sufficiently small to preclude a change of said predetermined minimum fusing current by virtue of the presence thereof, and said thermal insulating means reducing the cooling of said overlay by the intermediary of said arc-quenching filler to such an extent as to result in a substantial increase of said transfer current.

11. In an electric time-lag fuse having a predetermined minimum fusing current and including a tubular casing of insulating material, a pair of terminal elements closing the ends of said casing, a ribbon fuse link of a metal having a relatively high fusing point inside said casing conductively interconnecting said pair of terminal ele-

ments and defining a plurality of serially related points of reduced cross-sectional area, a link-severing overlay of a metal having a relatively low fusing point supported on said link at the center region thereof, a pulverulent arc-quenching filler inside said casing surrounding said link and said overlay, said fuse being made of such materials and having such properties that it has a transfer current causing, when exceeded, a shift of the point of intial break formation from said overlay to one axially outer of said plurality of serially related points of reduced cross-sectional area, the novel feature consisting in a hollow receptacle of insulating material embedded in said body of arc-quenching filler mounted on said fuse link and limited to the center region thereof, said receptacle defining a void surrounding said overlay and limiting heat dissipation therefrom to said arc-quenching filler, the size and

mass of said receptacle being sufficiently small to preclude by virtue of the presence thereof any change of said predetermined minimum fusing current.

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