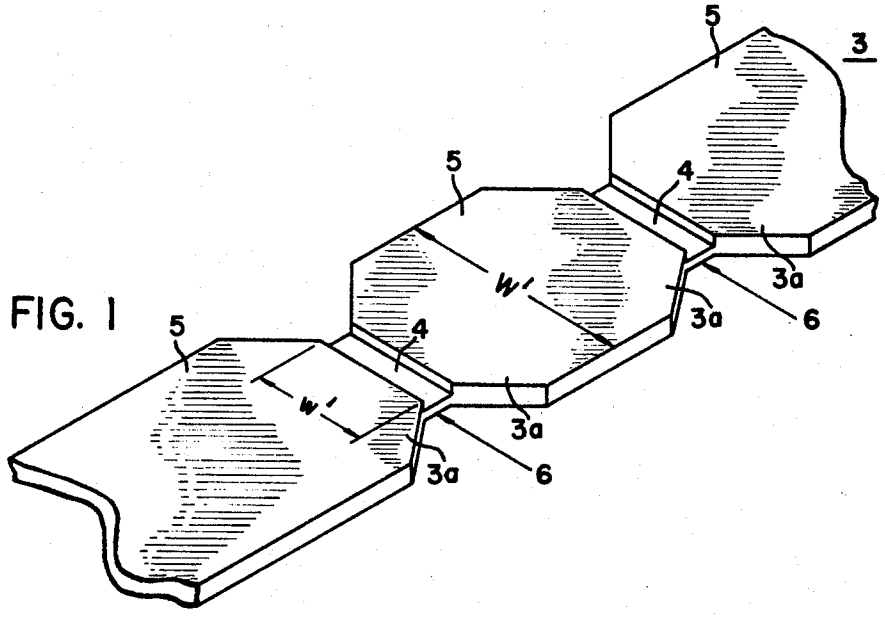
Nov. 26, 1968 E. SALZER 3,413,586

ELECTRIC CURRENT-LIMITING FUSE

Filed Aug. 7, 1967 3 Sheets-Sheet 1

FIG. 1




INVENTOR:

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Nov. 26, 1968 E. SALZER 3,413,586

ELECTRIC CURRENT-LIMITING FUSE

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FIG.2

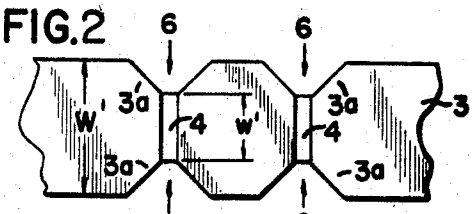



FIG.3

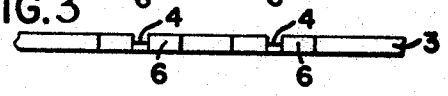



FIG.4

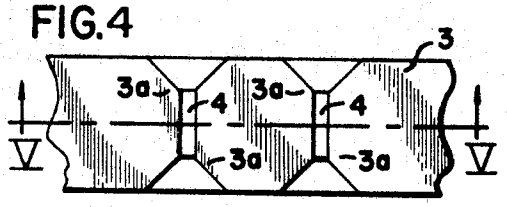



FIG.5




FIG.6

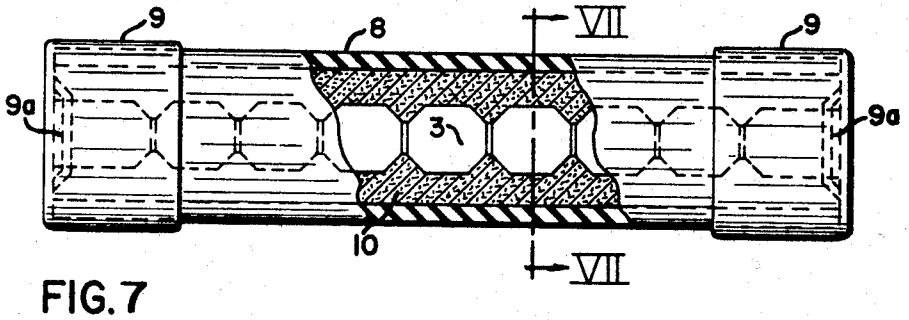
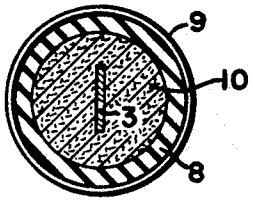



FIG.7




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Nov. 26, 1968 E. SALZER 3,413,586

ELECTRIC CURRENT-LIMITING FUSE

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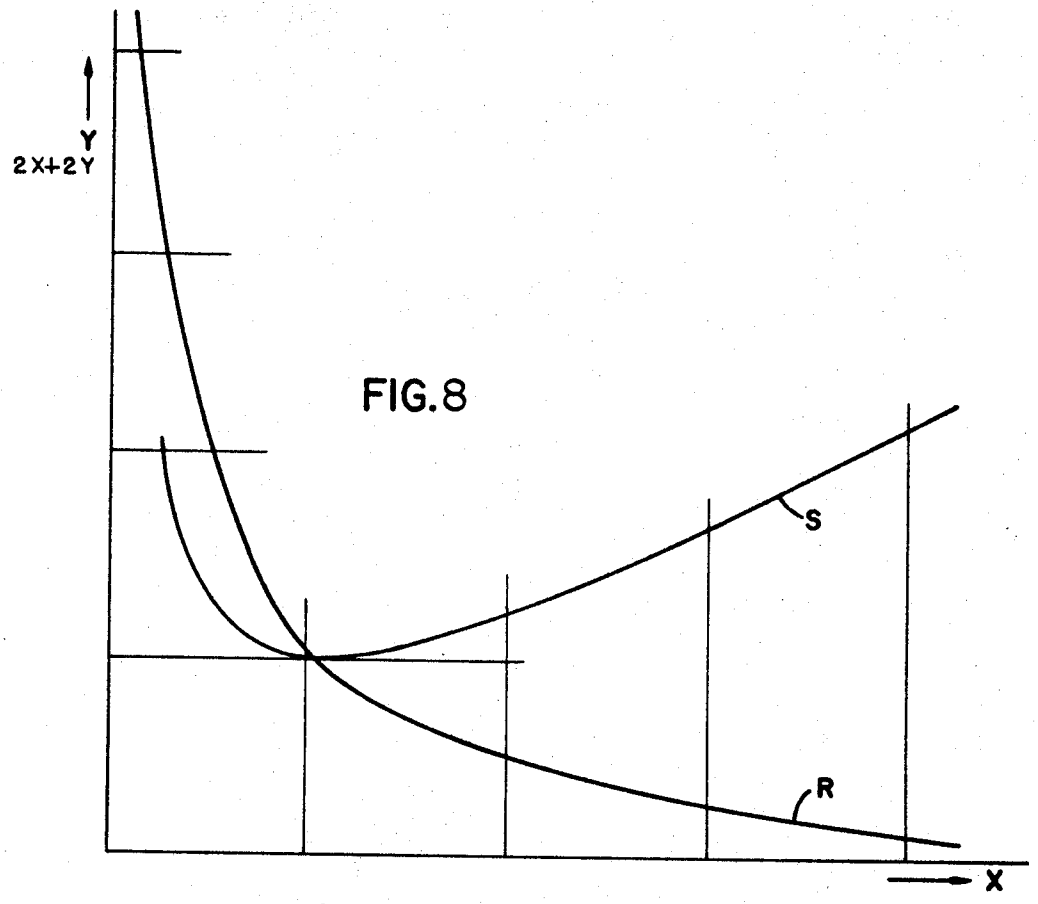



FIG.8

INVENTOR:

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United States Patent Office 3,413,586
Patented Nov. 26, 1968



3,413,586

# ELECTRIC CURRENT LIMITING FUSE

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Filed Aug. 7, 1967, Ser. No. 658,856
4 Claims. (Cl. 337—159)

## ABSTRACT OF THE DISCLOSURE

An electric current-limiting fuse including a ribbon fuse link, or ribbon fuse links, having at least one point of reduced cross-sectional area established by a groove-like recess and a local reduction of the thickness of the ribbon fuse link, or ribbon fuse links, at the point where the groove-like recess is located, the length of the recess, or the spacing between its open ends, being less than the width of the link or links.

*Prior state of the art*

With the advent of some particularly critical solid state devices as, for instance, certain power thyristors, the requirement for current-limiting fuses in regard to high current-carrying-capacity and in regard to reduced melting $i^2t$ and reducing arcing became more stringent.

In current-limiting fuses ribbon fuse link means produced by simple punching or blanking operations are generally acceptable up to a certain ratio of the cross-sectional area of the neck to the cross-sectional area of the link at the point of its largest width. When this ratio is extremely small the danger of damage to necks tends to become excessive. There are a number of causes which may account for damage to a neck if its cross-sectional area is very small.

(a) There is a probability that damaging stresses are set up during the die punching operation or blanking operation by which the fuse link is formed. (b) There is a probability that damaging stresses are set-up when the fuse link is handled during the process of assembly of the fuse. (c) There is a probability that damaging stresses are set-up as a result of thermal expansion and contraction of the fuse link and of other parts of the fuse during its normal current-carrying operation. (d) There is further a probability that damaging stresses are set-up as a result of mechanical environment condition such as, for instance, shock and vibrations.

The danger to necks of ribbon fuse links increases as the cross-sectional area of the necks is reduced. At ratios of 1:25 to 1:30 of the cross-sectional area of a high current density neck to the cross-sectional area of the wide portion of a ribbon fuse link, and smaller ratios of these two quantities, current-limiting fuse link structures tend to become too critical, i.e. the probability of neck failure becomes intolerably high.

All prior art current-limiting fuses wherein the points of reduced cross-sectional area of the ribbon fuse links are formed approximately by point heat sources tend to generate but relatively limited are voltages. This is due to the fact that in current-limiting fuses including fuse links of this description the area of the surface where there is an interaction between the arc at the time of its inception and the surrounding quartz sand is relatively limited. In order to generate sufficiently high arc voltages such fuse links must be provided with a relatively large number of series necks, or serially related points of reduced cross-sectional area. This, in turn, increases $i^2 \cdot r$ losses during the time the fuses are carrying a load current.

Prior art current-limiting fuses whose fuse links achieve



a local increase of current density by a local reduction of thickness rather than a local reduction of width are not subject to some of the aforementioned limitation. However, such fuses do not minimize both melting $i^2 \cdot t$ values and arcing $i^2 \cdot t$ values.

*Summary of the invention*

Fuses embodying this invention include a tubular casing of insulating material, a pair of electroconductive terminal elements closing the ends of said casing, and a body of quartz sand inside said casing. An integral ribbon of a current-limiting metal is immersed in said body of quartz sand and conductively interconnects said pair of terminal elements. The aforementionad fuse link has at least one point of reduced cross-sectional area and points of relatively large cross-sectional area. Said point of reduced cross-sectional area is established by a point of said link having reduced width and reduced thickness and consisting of a groove extending transversely across said link and having an open side, side walls and a bottom wall having a smaller thickness than the thickness of said link at said points of relatively large cross-sectional area, said link having a predetermined maximum width and a reduced width at the locus of said groove.

*Brief description of the drawings*

FIG. 1 is an isometric view of a ribbon fuse link for a current-limiting fuse embodying the present invention;

FIG. 2 is a top plan view of the structure of FIG. 1;

FIG. 3 is a side elevation of the structure of FIG. 1;

FIG. 4 is a top plan view of a modification of the structure of FIG. 1 including a support of insulating material for the fuse link;

FIG. 5 is a section along V—V of FIG. 4;

FIG. 6 is a side elevation of a complete fuse embodying this invention;

FIG. 7 is a section along VII—VII of FIG. 13; and

FIG. 8 is a plot showing dimensional characteristics of fuse links.

*Description of preferred embodiments*

The structures which are described below are intended to include very thin ribbons of a current-limiting metal, i.e. silver or copper, which might not lend themselves well as fuse links if they had any conventional fuse link geometry.

FIGS. 1 to 3 show a fuse link **3** having points **4** of reduced cross-sectional areas and points **5** of relatively large cross-sectional area. The ratio of the cross-sectional area of the points **5** of realtively large cross-sectional area to the cross-sectional area of the points **4** of reduced cross-sectional area is in the order of 20:1. It may be 25:1, or larger. The points **4** of reduced cross-sectional area are established by points of link **3** having a reduced thicknes forming grooves extending transversely across link **3**. Link **3** has a predetermined thickness D at the points **5** thereof of relatively large cross-sectional area. The thickness $d$ of link **3** at its points **4** of reduced cross-sectional area is less than its thickness at its points **5** of relatively large cross-sectional area.

The fuse link of FIGS. 1 to 3 is preferably of silver. It is intended to interrupt major fault currents, or short-circuit currents, but not overload currents.

The fuse link **3** shown in FIGS. 1–3 has a predetermined maximum width W' at its points of relatively large cross-sectional area and a reduced width $w'$ at the locus of its grooves **4**. The latter have a length w' which is less than the maximum width W' of ribbon fuse link **3**. A pair of regions **3***a* of relatively high current density—i.e. higher current density than at the points **5** of largest width W'—

is established at opposite sides of each of the aforementioned grooves **4**.

In other words, fuse link **3** is provided with a pair of substantially trapezoidal lateral incisions **6** at both ends of its groove **4**, thus resulting in the formation of the aforementioned regions **3***a* of relatively high current density.

The fuse link of FIGS. 1 to 3 is intended to clear major fault currents. Its incisions **6** and its zones or regions **3***a* of relatively high current density are conducive to burn-back and a concomitant delay in the decay of the arc voltage.

FIGS. 4 and 5 show a fuse link structure wherein the entire surface of a fuse link **3** remote from the open side of groove **4** therein is bonded to a strip **7** of insulating material evolving gases under the action of electric arcs.

The fuse link structure of FIGS. 4 and 5 has zones **3***a* of increased current density. As shown in FIGS. 4 and 5 ribbon fuse link **3** is supported on the side thereof adjacent the closed bottoms grooves **4** by a strip **7** of insulating material evolving gases under the heat of electric arcs, preferably a strip of melamine glass-cloth.

Referring now to FIGS. 6 and 7, numeral **8** has been applied therein to indicate a tubular casing of electric insulating material. Casing **8** is closed on both ends thereof by electroconductive terminal elements **9** in the form of caps or ferrules mounted on the ends of casing **8**. Casing **8** is filled with a body of quartz sand to which reference numeral **10** has been applied. Terminal elements **9** are conductively interconnected by an integral ribbon fuse link **3** of a current-limiting metal immersed in the body of quartz sand **10**. The fuse link **3** of FIGS. 6 and 7 has the same geometry as the fuse link **3** shown in FIGS. 1 to 3 and described in connection with these figures, however, this particular structure might be replaced in fuses according to FIGS. 6 and 7 by the structures shown in FIGS. 4 and 5. Ferrules or caps **9** form recesses filled with pools **9***a* of solidified solder and the ends of fuse link **3** project through openings in caps or ferrules **9** into the aforementioned pools **9***a* of solder and are conductively connected by the latter with ferrules or caps **9**.

Considering now the behavior of the bottom wall of grooves **4** when link **3** is subjected to forces or twisting couples causing torsional stressing of the bottom walls of grooves **4**. There is a tendency for a fuse link for a fuse embodying this invention to better withstand a point-heat-source type neck having the geometry which tendency is probably primarily due to the sharp edges required in a point-heat-source-type fuse link and prestresses resulting from punching such a fuse link. When a fuse link is being handled in the process of assembly of a fuse it is generally subjected to combined flexure and torsion.

The melting $i^2t$ value of a fuse link depends upon the material of which it is made, i.e. its latent heat of fusion and its mean resistivity, and the cross-sectional area F of the point where melting initiates. Hence, if a given set of conditions requires a predeterminable melting $i^2t$ value, having selected the appropriate metal of which the fuse link is to be made, this determines the cross-sectional area of the fuse link at the point where melting should initiate. While the cross-sectional area F of the point of initiation of melting and arcing is thus determined, the designer of the fuse is still free to select the geometry of the cross-section of the link where fusion and arcing is intended to initiate. Assuming that this cross-section is rectangular, then the sides of any rectangle having the area F to achieve a required melting $i^2t$ is given by the equation for an equilateral hyperbola, which is:

$$x \cdot y = F \tag{1}$$

wherein $x$ and $y$ are the two sides of the rectangle. The circumference or perimeter U of any such rectangle is given by the equation

$$U = 2x + 2y \tag{2}$$



The circumference becomes minimum when

$$x = y \text{ or } \frac{x}{y} = 1 \tag{3}$$

and

$$U = 4x \tag{4}$$

i.e. when the rectangle having the cross-section F turns into a square. The larger the ratio of the longer side $x$ of the rectangle to the shorter side $y$ thereof, the larger the perimeter of the rectangle.

The required current-carrying capacity of a ribbon fuse link largely determines the width W and thickness $\delta$ of the portions thereof where its cross-section is not reduced. If the portion or portions of reduced cross-section where melting and arcing are to be initiated are formed by a punching or blanking operation, the thickness of the points of reduced cross-section is equal to the thickness $\delta$ of the points of the fuse link where its cross-section is not reduced. The fact that the thickness of a ribbon fuse link at its point, or points, of reduced cross-section is equal to the thickness at its points of large cross-section is conducive to the critically small width of such a link at its point or points of reduced cross-section, whenever the required fusing $i^2t$ values and the required minimal cross-section are small. On the other hand, if the point or points of reduced cross-section are formed by one or more grooves, the length of the latter in a direction longitudinally thereof can be relatively substantial, all other conditions remaining unchanged, because the reduction in cross-section is effected in part by a reduction in thickness.

While the melting time of a fuse link is only affected by the area F but not by the geometry of its point or points of reduced cross-sectional area, this is not true in regard to the total interrupting time, i.e. the melting time plus the arcing time. Heat flow away from a given area may be expressed by the equation

$$Q = \frac{k \cdot A(\theta 2 - \theta 1)t}{d} \text{ cal.} \tag{5}$$

wherein Q is the number of calories transferred, $k$ is the coefficient of thermal conductivity (in the instance of a quartz-sand-filled fuse that of quartz sand), A the surface area, $t$ the time, and

$$\frac{\theta 2 - \theta 1}{d}$$

the temperature gradient. It is apparent from the above equation that heat transfer by conduction increases in proportion to surface area, and in proportion to time, all other conditions remaining unchanged.

Referring now to FIG. 8, the curve R shown therein is an equilateral hyperbola obtained by plotting the length $y$ of the side of a rectangle having a constant area F against the length $x$ of the other side thereof. In FIG. 8 curve S is a plot of the circumference $2x+2y$ of the rectangle of constant area F plotted against the length $x$ of one side thereof. It is apparent that the circumference $2x+2y$ reaches a minimum if $x=y$ and increases if

$$x \gtrless y$$

the increase of the circumference being very substantial as the length $x$ of the longer side of the rectangle is increased and the length of its shorter side decreased.

It is apparent from the above that the structures of FIGS. 1 to 5 make it possible to control within wide limits the circumference $2x+2y$ of any point of reduced cross-sectional area intended to initiate melting of the ribbon fuse link and formation of an arc-voltage-generating break. The circumference of the point of reduced cross-sectional area plotted at S in FIG. 8 determines the area A of heat conduction of Equation 5.

Considering melting of a ribbon fuse link under short-circuit conditions, i.e. operation of the fuse within its current-limiting range, given such condition, the time $t$ of Equation 5 is so small that the number of calories Q transferred is zero. The other limit condition is operation of a fuse in the range of its minimum fusing current. Then the time $t$ of Equation 5 is particularly long, and the quantity A thereof significant. In other words, the relatively large circumference of the points of reduced cross-section in the structures of FIGS. 1–5 results in a relatively large heat flow from these points. Consequently, the geometry of fuse links according to FIGS. 1–5 tends to increase the current rating of the fuse, or requires a smaller mass of metal for a given current rating. The geometry of fuse links according to FIGS. 1–5 further tends to result in a relatively large area of cooling following arc initiation and arc extinction. This, in turn, tends to reduce the arcing $i^2t$ of the fuse and to increase the cooling of the fulgurite resulting from the fusion of the surrounding quartz sand.

There are fundamental differences in regard to heat transfer during the melting time and during the arcing time of a current-limiting fuse. It is justifiable to assume that the melting $i^2t$ is a constant for any given fuse structure as long as the melting time is less than 10 milliseconds. This constancy law results from the fact that heat dissipation from a metallic conductor in solid or liquid state is negligible in extremely short intervals of time such as 10 milliseconds and less. Once the continuity of the metallic current path of a fuse link is broken and an arc or electric gas discharge substituted for the metallic current path, the situation in regard to heat transfer is entirely different from that prevailing during the melting period of the fuse link. During the arcing period the heat transfer occurring in intervals of time in the order of microseconds may mean the difference between failure or success of a current interrupting device. The melting temperature of silver is slightly less, and that of copper slightly more, than 1000° centigrade. When an arc is kindled the temperature of the arc path is in the order of many thousand degrees and thus the temperature gradient of Equation 5 is greatly increased and the area of heat flow becomes significant. The same remark in regard to the significance of the area of heat flow applies also to the post-arcing period of dielectric recovery involving much smaller temperature gradients than the arcing period, but relatively longer times during which dielectric recovery of the hot fulgurite is effected by heat conduction away from the latter.

During the arcing period cooling and deionization is effected by recombination of ions and diffusion of ions. Wherever there is a concentration gradient of ions, there is a flow of ions from regions of high concentration to regions of low concentration. The rate of change of ion concentration is analogous to heat flow. Therefore the relative increase of the boundary tube between quartz sand and the ionized metal vapors which form the arc path, and of the relative increase of the boundary area between fused quartz sand and relatively cool quartz sand, which both result from the geometric configuration of the fuse link shown in FIGS. 1–5 are responsible for an increase of heat dissipation during and following the arcing period.

It is thus apparent that the geometry of fuse links according to FIGS. 1 to 5, results in desirable mechanical performance characteristics as well as in desirable electrical and thermal performance characteristics. In some instances electrical and thermal performance characteristics may be virtually immaterial and in such instances the basic fuse link geometry according to FIG. 1 may be adopted only on account of its mechanical performance characteristics. In other instances mechanical performance characteristics may be virtually immaterial and in such instances the basic fuse link geometry according to FIG. 1 may be adopted only on account of its electrical and thermal performance characteristics. The structure of FIGS. 3 and 4 illustrates this point. Since the fuse link 3 of this structure is mounted on a support 7 of insulating material, support 7 eliminates the danger to the fuse link 3 by bending stresses and torsional stresses. The presence of support 7 makes it superfluous to give particular consideration to possible damage to the fuse link by bending and torsion. Here the formation of points of reduced cross-section by transverse grooves 4 results in desirable electrical and thermal performance characteristics, but the presence of transverse grooves 4 is not dictated by mechanical considerations. Subsequently the same applies to the structure of FIGS. 9 and 10.

There are a number of ways for making fuse links in accordance with this invention of which the combination of photosensitive resists and etching or chemical machining are the most desirable. This process is well known in the art and, therefore, does not need to be described in detail in this context. As a general rule, fuse links of current-limiting fuses are made of silver in which instance etching should preferably be performed with chromium trioxide sulfuric acid solutions (see P. F. Kury, "Etching Silver With Chromium Trioxide Sulfuric Acid Solutions," Journal of the Electrochemical Society, April 1956). In some instances it is desirable to combine stamping and etching steps. In the structure of FIGS. 1, 2 and 3 the lateral incisions 6 are preferably made by punching or blanking operations, and grooves 4 are formed by etching. The structure of FIGS. 11 and 12 may be produced by two successive etching steps, one for forming the grooves 4 and the other for forming the lateral incisions. A problem often encountered in combining photosensitive resists and etching operations is undercut resulting from acid erosion under areas covered by the acid resist. Undercut limits the thickness of stock that can be pierced chemically and still provide a near rectangular wall. The structure of FIGS. 1 to 3 does not require piercing by chemical action, and the walls of grooves 4 do not need to be near rectangular, as long as the tolerances between the points of reduced cross-sections are held within certain limits. These limits can readily be maintained by conventional photoresist etching methods.

Although this invention has been described in considerable detail, it is to be understood that such description of the invention is intended to be illustrative rather than limiting, as the invention may be variously embodied, and is to be interpreted as claimed.

I claim as my invention:

1. An electric current-limiting fuse comprising in combination

(a) a tubular casing of electric insulating material;

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

(c) a body of quartz sand inside said casing; and

(d) an integral ribbon fuse link of a current-limiting metal immersed in said body of quartz sand conductively interconnecting said pair of terminal elements, said fuse link having at least one point of reduced cross-sectional area and points of relatively large cross-sectional area, said point of reduced cross-sectional area being established by a progressive reduction of width and an abrupt reduction of thickness and consisting of a groove extending transversely across said link and being open on one side and having side walls and a bottom wall, said bottom wall having a smaller thickness than the thickness of said link at said points of relatively large cross-sectional area, and said link having a width at the locus of said groove less than the width thereof at said points of relatively large cross-sectional area.

2. An electric current-limiting fuse as specified in claim 1 wherein the width of said fuse link decreases substantially linearly from a maximum width to a minimum width at the ends of said groove establishing a pair of regions of relatively high current density immediately adjacent said groove at opposite sides thereof.

3. A current-limiting fuse as specified in claim 1 wherein the entire surface of said fuse link remote from said open end of said groove is bonded to a strip of an insulating material evolving gases under the action of electric arcs.

4. An electric current-limiting fuse as specified in claim 1 wherein the surface of said fuse link remote from said open side of said groove is bonded to a strip of an insulating material evolving gases under the action of electric arcs, said strip being of substantially uniform width along the entire length thereof and said fuse link exposing the surface of said strip of insulating material adjacent the open ends of said groove.



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H. B. GILSON, *Assistant Examiner.*

# UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

November 26, 1968

ıtent No. 3,413,586

Erwin Salzer

It is certified that error appears in the above identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 61, "arc" should read -- are --. Column 2, line 38, "13" hould read -- 6 --. Column 3, line 20, after "bottoms" insert -- of --; line 5, "for", second occurrence, should read -- of --; line 46, after "withstand" nsert -- torsional stresses than a comparable fuse link having --; line 47, ancel "having the geometry". Column 5, line 56, "tube" should read -- area --. olumn 6, line 12, "Subsequently" should read -- Substantially --; line 29, 11 and 12" should read -- 4 and 5 --.

Signed and sealed this 10th day of March 1970.

(SEAL)

Attest:

Edward M. Fletcher, Jr.

Attesting Officer

WILLIAM E. SCHUYLER, JR.

Commissioner of Patents