Sept. 22, 1953 F. J. KOZACKA 2,653,203

CURRENT-LIMITING FUSE

Filed Jan. 30, 1951 4 Sheets-Sheet 1

Fig. 1.

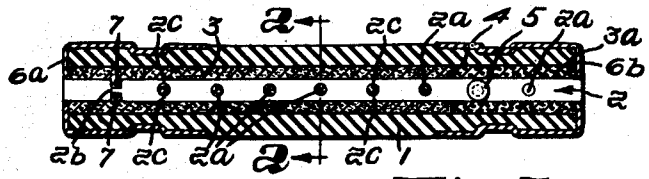


Fig. 2.

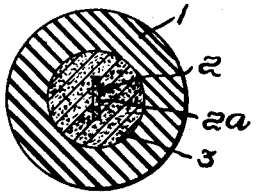


Fig. 3.

Fig. 4.

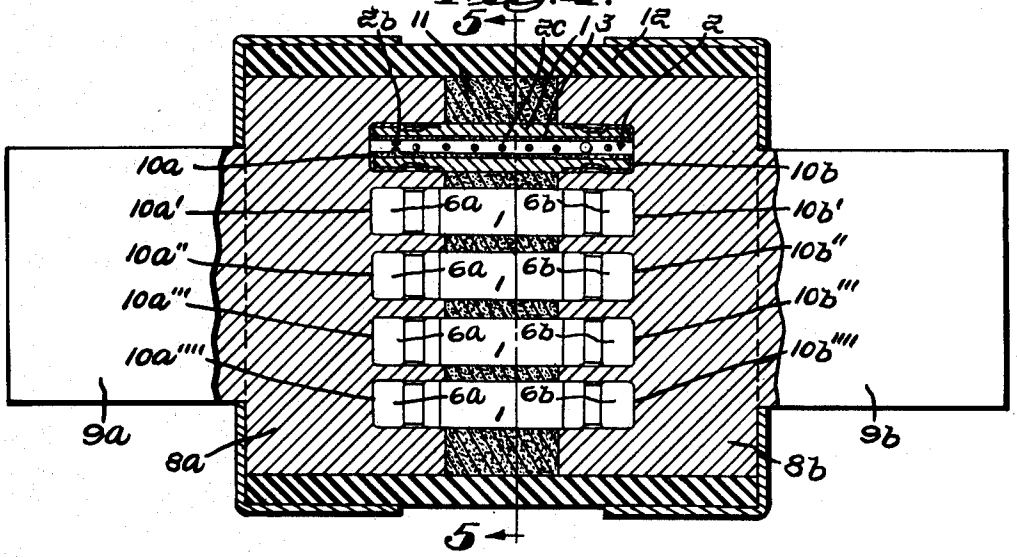
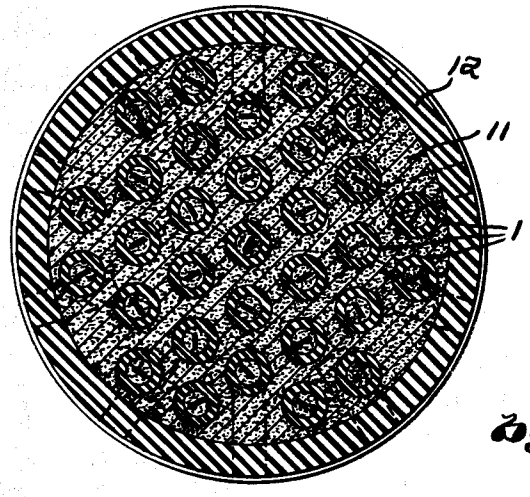


Fig. 5.



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CURRENT-LIMITING FUSE

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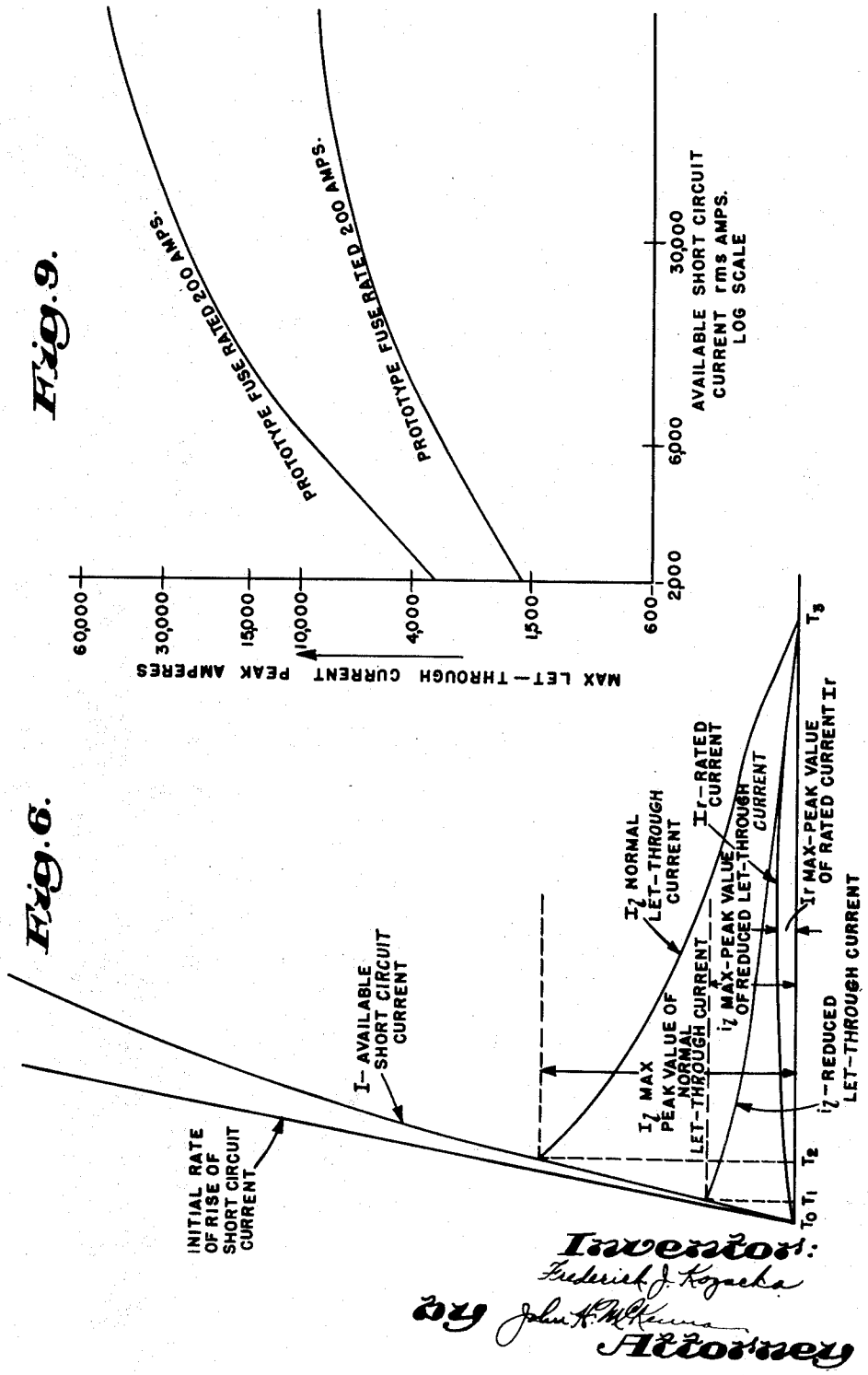

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CURRENT-LIMITING FUSE

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Fig. 7a.

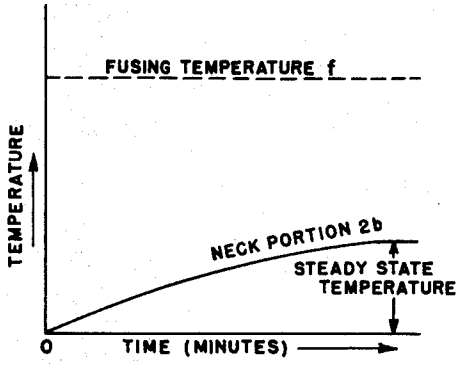


Fig. 7b.

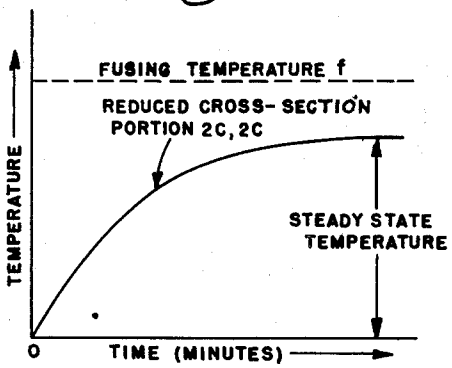


Fig. 8a.

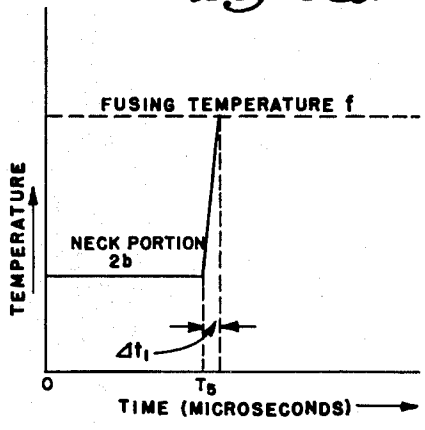
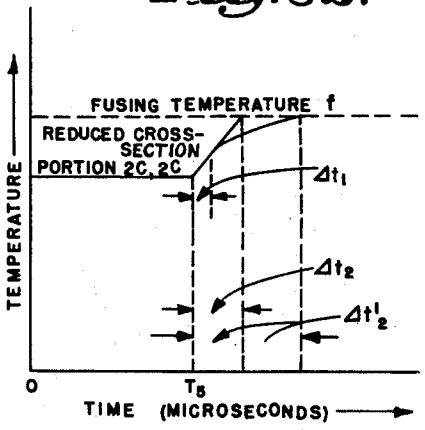


Fig. 8b.



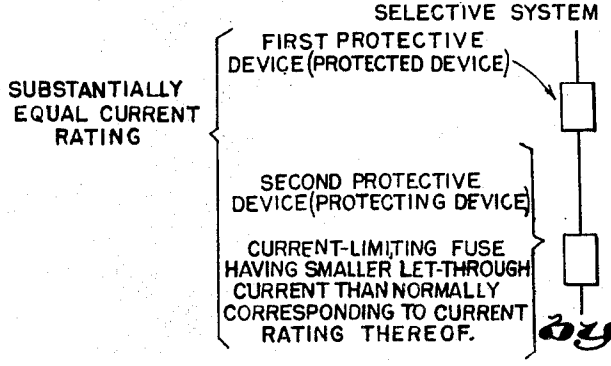


Fig. 13.

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Fig. 10.

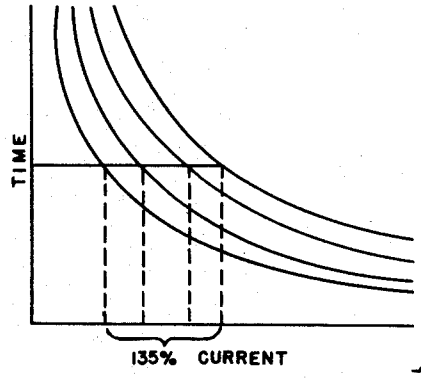


Fig. 11.

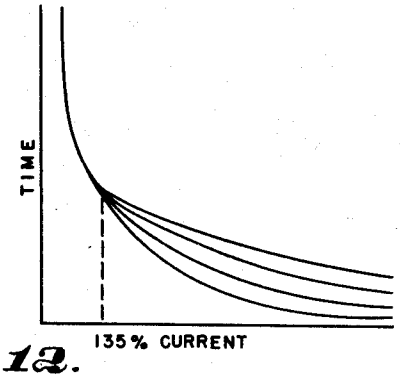
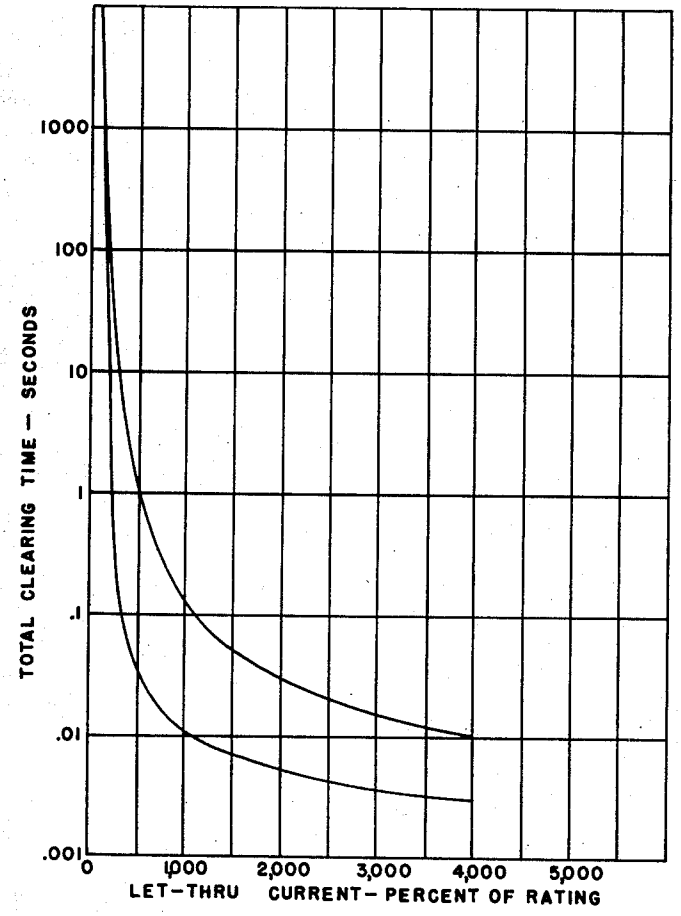


Fig. 12.



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Patented Sept. 22, 1953

2,653,203

UNITED STATES PATENT OFFICE

2,653,203

CURRENT-LIMITING FUSE

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Application January 30, 1951, Serial No. 208,548

27 Claims. (Cl. 200—120)

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This invention relates to the protection of electric circuits and the protection of electrical rotating machinery, apparatus and devices which are connected into electric circuits and it relates more particularly to fuses of the current-limiting type. The term current-limiting fuse is generally applied to fuses which limit the flow of current well below the highest short-circuit current which the circuit into which the fuse is inserted is able to produce. That current is referred to as the available short-circuit current, while the highest current which a current-limiting fuse permits to pass is referred to as the let-through current.

The current-limiting action of most current-limiting fuses is due to the interaction of the metal vapors resulting from the vaporization of the link of the fuse and an inert pulverulent arc quenching filler by which the link is surrounded. The link consists generally, though not necessarily, of silver because silver has a relatively high conductivity in its solid state, while its vapors are very poor conductors of electricity near the boiling point of silver. If a silver link is vaporized in a suitable pulverulent arc quenching filler as, for instance, quartz sand, the temperature of the silver vapors is rapidly reduced to a relatively low level where they are no longer a conductor of electricity. Though the duration of arcing through the labyrinth path formed by the interstices between the particles or granules of the arc quenching filler may be, or actually is, very short, a portion of the particles fuse and are sintered together. The slag-like body formed by fusing and sintering of filler particles is frequently referred to as fulgurite. It is a semi-conductor of electricity as long as it is at a fairly elevated temperature. As it cools down it turns into a non-conductor of electricity or insulator. Metal vapors which are blasted into the portions of the pulverulent arc quenching filler relatively remote from the arcing zone and which diffuse further toward the boundary walls of the fuse, i. e., the casing thereof, condense on the large cool surfaces of the filler particles and form a silver-quartz-conglomerate which has an extremely high electric resistance and may be considered as an insulator of electricity for all practical ends and purposes.

Short-circuit currents which circulate in an electric circuit subject all rotating electrical machinery, apparatus and devices through which they flow to electro-magnetic stresses and strains and cause a rise of temperature of the conductors through which they flow which may endanger

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any kind of organic insulating material and may even cause the thermal destruction thereof. The higher the short-circuit currents which may occur, the higher the required mechanical strengths of rotating electrical machinery, apparatus and devices which may be subjected to them. Thus electrical engineers are constrained to build mechanical strength into rotating electrical machinery, apparatus and devices which is never needed during their normal life except on rare occasions during small fractions of a second between the time of occurrence of a short-circuit and the interruption thereof by a suitable protective device. It is obviously incompatible with economic reasoning to design rotating electrical machinery, apparatus and devices for the extreme split second requirements of fault conditions rather than for normal all year round operating conditions. Prior to the application of current-limiting fuses rotating electrical machinery, apparatus and devices could not be designed on an economic basis since all designs had to be predicated on rare fault conditions rather than normal operating conditions which virtually prevail all of the time.

While it is true that mechanical strength requirements decrease as the duration of the action of the force decreases, thus making it possible to build less mechanical strength into rotating electrical machinery, apparatus and devices which are subjected to high mechanical stresses and strains but during relatively short times, yet this is only a mitigation of a principle which is inherently unsound since it consists in that the mechanical properties of rotating electrical machinery, apparatus and devices are not determined by their normal operating requirements and a relatively small safety factor but by abnormal fault conditions of tremendous magnitude which occur only at long intervals and prevail at worst for fractions of a second.

In a similar way electrical rotating machinery, apparatus and devices had to be designed to withstand the peaks of heat generation resulting from high short-circuit currents rather than the thermal losses involved in normal operation.

During the first fifty years of electric power generation, transmission and distribution there was no means which offered any remedy against the necessity of predicating any electrical design upon transient fault conditions rather than upon normal operating conditions. The first step in the direction toward a more rational and economic design of electrical rotating machinery, electrical apparatus and devices consisted in the

advent of the current-limiting fuse which made it possible to interrupt short-circuit currents extremely rapidly at relatively low values, i. e., before they reached the highest values which the circuit is capable of producing. This enabled a drastic reduction of the short-time ratings of rotating electrical machinery, electrical apparatus and devices.

Heretofore it was necessary to design rotating electrical machinery, apparatus and devices, even if protected by current-limiting fuses, in such a way as to render them capable of withstanding the relatively high let-through currents prevailing if the fuse was designed for high minimum fusing currents, i. e., if it had a high current carrying capacity. This limitation resulted from the fact that the current-limiting fuses which were known prior to this invention had a fixed or inflexible ratio between their minimum fusing current or rated current and their let-through current which was relatively small and could not be increased. This ratio and its inflexibility for any prototype of current-limiting fuses made it impossible heretofore to take full advantage of the potentialities inherent in the current-limiting principle. In other words, it was still necessary to design much more mechanical strength and thermal shock resistance into any piece of electrical equipment than is warranted by its normal operating conditions and reasonable safety factors.

It is, therefore, an object of this invention to provide a protective device in the nature of a current-limiting fuse permitting a drastic reduction of the mechanical strength and thermal shock resistance requirements compared to those which had to be imposed heretofore.

Another object of this invention is to provide means enabling electric systems and any type of electrical equipment associated therewith to be designed on a more economical basis than was possible heretofore.

Another object of the invention is to provide means enabling the use of electrical equipment having smaller short-time ratings than were required heretofore under the same or similar conditions, and enabling a reduction of the short-time ratings even though the available short-circuit current of the circuit in which the equipment is intended to be used is considerably increased.

Another object of the invention is to provide a type of current-limiting fuses which is designed in such a way that the let-through current can be determined independently, or substantially independently, from the minimum fusing current and the rated current thereof.

Another object of the invention is to provide a type of current-limiting fuses which enables an increase of the ratio of minimum fusing current to peak let-through current compared to prior art current-limiting fuses.

Another object of the invention is to provide a type of current-limiting fuses which makes it possible by minor changes in design to vary the ratio of rated current to let-through current.

Another object of the invention is to provide an improved current-limiting fuse which is particularly suitable for the higher end of the low voltage range, i. e., the range around 1000 volts.

A still further object of the invention is to provide a current-limiting fuse of very small overall size suitable for the highest available short-circuit currents that may occur in present day practice and in forseeable future practice.

In carrying out my invention I prefer to use fuse links of which substantially the entire length, or at least the preponderant portion thereof, consists of a variable cross-sectional area section having a relatively large number of serially related portions of relatively small cross-sectional area and intermediate portions of relatively large cross-sectional area.

Fuse links of this kind make it possible to distribute the thermal duty of the arc quenching filler relatively evenly over the entire filler body. This in turn tends to permit a reduction of the overall size of the fuse and more particularly of the internal space of the fuse casing. Fuse links of the above kind have a relatively even longitudinal temperature distribution and are therefore capable of forming rapidly a gap of the length required for interruption or a number of small gaps in series having the same effect. This in turn tends to limit the arcing time and the arc energy and makes it possible to limit the internal space of the fuse casing, or the required amount of arc quenching filler, respectively. Another factor tending to permit a decrease of the size of fuses according to this invention consists in the possibility of predetermining the let-through current irrespective of the minimum fusing current, thus enabling to limit the interrupted power on the occurrence of fault currents of short-circuit current proportions to any desired minimum value. The heat absorbing capacity and the volume of the arc quenching filler may be limited in proportion to the limitation of the interrupted power. The combined result of all these features is a drastic limitation of arc energy on interruption of small protracted overloads as well as on interruption of fault currents of short-circuit current proportions and this makes it possible to provide a current-limiting fuse having much smaller dimensions than any comparable current-limiting fuse known or proposed heretofore.

For a better understanding of my invention reference may be had to the accompanying drawings wherein:

Fig. 1 is a substantially central longitudinal section through a single fuse constructed in accordance with my invention. Certain parts of Fig. 1 are shown in elevation rather than in section;

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

Fig. 3 is a front view of a fuse link intended for fuses of the general type shown in Figs. 1 and 2;

Fig. 4 is a substantially central longitudinal section through a composite fuse which comprises a plurality of fuses of the kind shown in Figs. 1 and 2. Certain parts of Fig. 4 are shown in elevation rather than in section;

Fig. 5 is a transverse cross-sectional view of the fuse shown in Fig. 4 taken along the line 5—5 thereof;

Fig. 6 is a diagrammatic representation illustrating the mode of operation of fuses according to this invention in comparison to the mode of operation of prior art current-limiting fuses;

Figs. 7(*a*) and 7(*b*) are two diagrams which illustrate the behavior of a fuse embodying the invention under normal load conditions;

Figs. 8(*a*) and 8(*b*) are two diagrams which illustrate the behavior of a fuse embodying the

invention under fault currents of short-circuit current proportions;

Fig. 9 is the maximum let-through current versus available short-circuit current characteristic of a prototype prior art current-limiting fuse and of a current-limiting fuse of the same prototype changed, however, in accordance with this invention;

Fig. 10 illustrates a family of curves referring to a certain type of prior art current-limiting fuses. This figure shows the total clearing time in seconds plotted versus let-through current in amperes. Both the abscissae and the ordinates are drawn on a logarithmic scale;

Fig. 11 shows a family of curves of a kind similar to that shown in Fig. 10 but Fig. 11 refers to a group of fuses having the same rating yet differing as regards let-through current; and

Fig. 12 shows two total clearing time versus let-through current characteristics of which one refers to a prior art fuse and the other to the same fuse provided, however, with the let-through current control feature according to this invention.

Fig. 13 is a diagrammatic representation of a protective system embodying the invention and comprising a pair of serially connected fuses having the same current rating, yet operating selectively on the occurrence of high fault currents.

Like reference signs have been applied throughout all figures to designate like parts.

Referring now to Figs. 1 and 2, reference numeral 1 has been applied to a casing of laminated insulating material in which the ribbon-type link 2 of silver is mounted. The link 2 might be made of a metal other than silver, however, for the reasons stated above silver is preferable. Link 2 is provided with a plurality of equidistant circular perforations or holes 2*a*. Casing 1 is filled in part with a suitable sand filler 3. Clean chemically pure quartz sand is the preferred filler material for this type of fuses. The right end of casing 1 is filled with a gas evolving pulverulent material 3*a* such as chemically pure chalk. The pressure generated by the chalk filler 3*a* under the heat of the arc remains within reasonable limits since only a relatively short length of link 2 is surrounded by the gas evolving filler 3*a*. The increase of pressure within casing 1 due to the evolution of gas from filler 3*a* results in an increase of the dielectric strength of the space within the fuse in accordance with Paaschen's law. That portion of link 2 which is surrounded by the gas evolving filler 3*a* may be provided with an alloy-forming element 5 in the form of a tin rivet. Tin has a lower fusing point than silver and forms an alloy with silver which has a lower fusing point than silver. If tin rivet 5 is inserted in one of the holes 2*a*, fusion will generally be initiated on the occurrence of small protracted overloads at the point where the rivet 5 is situated. If, on the other hand, rivet 5 is omitted, fusion will generally be initiated on the occurrence of small protracted overloads at the restricted cross-section portion 2*c*, 2*c* formed adjacent the pair of circular holes 2*a* at the center of the link 2. It will be observed that each restricted cross-section portion 2*c*, 2*c* consists of two current paths in parallel. Upon vaporization of these two parallel current paths the gaps thus formed are occupied by a pair of small arclets in parallel. Since arclets in parallel are unstable, one arclet will extinguish very rapidly. The other arclet will follow course within a very short time.

It is important to avoid mixing of fillers 3 and 3*a* when the fuse is shipped or handled and, therefore, a partition 4 is arranged between fillers 3 and 3*a*.

It will be noted that the internal diameter of casing 1 is relatively small, i. e., it is in the range of twice the width of the fuse link 2. This reduction of size is due to the fact that the fuse is designed to limit arc energy more drastically than any current-limiting fuse known or proposed heretofore, and more particularly to the feature which will be described below enabling a reduction of the let-through current below the minimum values which were thought heretofore to be the lowest possible limit. On the other hand, the thickness of the wall of the casing 1 is considerable to provide the mechanical strength necessary because of the generation of a relatively high amount of pressure therein. Both ends of the fuse casing are closed by terminal caps or ferrules indicated by reference signs 6*a* and 6*b*. Fuse link 2 is conductively connected to the caps or ferrules 6*a*, 6*b* by suitable means such as, for instance, spot welds. Ferrules 6*a*, 6*b* are rolled into the casing 1 for added strength.

Fuse link 2 is also provided with a portion of reduced cross-section 2*b*. The portion of reduced cross-section 2*b* is smaller in cross-section than the sum of the cross-sections of the parallel current paths 2*c*, 2*c* formed laterally adjacent each hole 2*a*. The length of the portion of reduced cross-section 2*b* is relatively short and this limits the amount of heat which is being generated at this point. Since the geometry of the left side of the link 2 is different from the geometry of any point at the right side thereof (see Fig. 1), the thermal characteristics of both link sections will be different. The minimum fusing current is mainly determined by the right side of the link. Assuming that rivet 5 has been omitted, then fusion will be initiated on the occurrence of small protracted overloads at the point of reduced cross-section 2*c*, 2*c* at the center of link 2. The reduced cross-section portion 2*b* is formed by two lateral juxtaposed square notches 7. The geometry of the entire link and the design of the parts associated with it are determined in such a way that the ratio of the rate of heat generation to the rate of heat dissipation is larger for each reduced cross-section portion consisting of a pair of parallel current paths 2*c*, 2*c*, than for the neck portion 2*b* on the occurrence of currents having a relatively small rate of rise and larger for said neck portion 2*b* than said reduced cross-section portions 2*c*, 2*c* on the occurrence of overcurrents having a relatively rapid rate of rise.

If there is a small protracted overload the ratio of heat generation to heat dissipation will be relatively close to unity at the neck 2*b* because of the relatively short length of the same and because of the relatively large metal surfaces and masses immediately adjacent thereto, including the large cap 6*a*. Hence the rise of temperature at the neck portion 2*b* will be slow compared to that at the restricted cross-sectional area portions 2*c*, 2*c* where in case of small protracted overloads the ratio of heat generation to heat dissipation differs more from unity than at the neck 2*b*. Consequently, fusing and arcing will be initiated at the hottest of the serially related restricted cross-section portions 2*c*, 2*c* if and when the overload is small but protracted such as, for instance, hardly exceeding the minimum fusing current.

The behavior of the fuse is, however, very

different if the fault current is high and the rate of its rise high. A typical case of that nature would be the occurrance of a short-circuit current. The geometry of the serially related reduced cross-section portions 2c, 2c and of the portions of link 2 immediately adjacent said reduced cross-section portions of link 2 and the geometry of the neck portion 2b and of the immediately adjacent portions of link 2 are determined in such a way that the rise in temperature at the neck portion 2b is much more rapid than at the reduced cross-section portions 2c, 2c if the fuse is subjected to fault currents of short-circuit current proportions. The rise in temperature at the neck portion 2b will be so rapid as to cause fusion of the neck portion 2b in a small fraction of a half cycle of the current wave if the fuse is used in an A. C. circuit. If the fuse is used in a D. C. circuit fusion of the neck portion will occur in a comparatively short time upon initiation of the short circuit. In both cases arcing will last less than 1/120 second. In the A. C. case and in the D. C. case the interrupting time will generally be in the order of a few milliseconds, e. g., 2–10 milliseconds. The interrupting time is the interval between the fault initiation and arc extinction. The current required to fuse the neck 2b is the let-through current of the fuse. Vaporization of neck 2b acts like a trigger resulting in almost instant vaporization of the preponderant portion of the length of the link situated to the right of neck 2b as seen in Fig. 1.

It follows from the foregoing that fuses according to this invention are provided with a unitary fuse link 2 consisting of a strip or ribbon of sheet metal which has two dissimilar portions of reduced cross-section. The relatively wider of said portions determines the minimum fusing current while the relatively narrower of said portions determines the peak of the let-through current. The relatively narrower link portion 2b fuses in considerably less time than 1/120 of a second, generally in less than half a millisecond, on occurrence of fault currents in the nature of short-circuit currents because its heat dissipating ability is extremely small or negligible if the rate of rise of the fault current is high. The relatively narrow link portion 2b of the fuse link 2 remains at a lower temperature than the other portions 2c, 2c of reduced cross-section on the occurrence of fault currents of the same order as the minimum fusing current because its heat dissipating ability is extremely high if the rate of rise of the fault current is small, or the fault current is small. If the fault current is relatively small and tin rivet 5 is omitted, arc initiation will occur at the reduced cross-section portion 2c, 2c situated at the center of link 2. Fusion of the other reduced cross-section portions 2c, 2c will soon follow. The formation of a plurality of arclets in series effects more rapid inseration of arc resistance into the circuit than can be achieved by arc initiation at one point only and, therefore, tends to limit the arcing time and the arc energy.

If the fault current is relatively small and tin rivet 5 is in place, arc initiation at small protracted overloads will occur only at the point where the rivet 5 is situated. The arc gap thus formed will grow to the left and right, as seen in Fig. 1, preponderantly to the left since that portion of the link 2 is relatively warmer. The fact that the fuse link comprises a plurality of points of reduced cross-sectional area 2c, 2c situated adjacent the point of arc initiation causes more rapid formation of the length of the gap required for interruption of the circuit, since each of said points of reduced cross-sectional area 2c, 2c is at a relatively high temperature at the time when the arc is initiated at the point where rivet 5 is located. On account of the pre-heating of all points of reduced cross-sectional area 2c, 2c a relatively small amount of arc energy is required for vaporization of a sufficient length of the link to effect final circuit interruption.

Considering a fuse according to this invention having a link without tin rivet or similar means for local reduction of the fusing point, there is a critical value for protracted relatively high overloads at which, and above which, fusion of the link is initiated at the narrow neck portion 2b rather than at the reduced cross-section portion 2c, 2c situated at the center of the link. Similarly there is a critical rate of rise of current at which fusion is initiated at the neck portion 2b rather than at the reduced cross-section portion 2c, 2c situated at the center of the link. At protracted overloads which are below the critical overload value at which fusion is initiated at the neck portion 2b initial fusion may occur at a reduced cross-section portion 2c, 2c.

A similar shift of the point of initiation of fusion may be observed with fuses according to this invention having links which are provided with a tin rivet or a similar means for local reduction of the fusing point. A fuse according to Fig. 1 the link of which had the dimensions more fully stated below in connection with the description of Fig. 3 was found to have a minimum fusing current of 20 amperes. If subjected to continuous currents in the order of 20 amperes, fusion would be initiated at the point where rivet 5 was arranged. Upon increase of the overload to 40 amperes, initial fusion would occur at the neck 2b rather than at any of the portions of restricted cross-section 2c, 2c.

Referring now to Fig. 3, the ribbon-type fuse link of silver which is shown therein comprises eight series holes 2a each having a diameter of .046 inch. The centers of holes 2a are spaced .203 inch apart. The total length of the link is 3¼ inches, its width .086 inch and its thickness .003 inch. Upon mounting of the link in the casing of the fuse the length of the link is reduced to 2 inches. The length of the neck portion 2b which determines the let-through current is .031 inch and the width thereof .010 inch. The ratio of the cross-section of the neck 2b or its width, respectively, to the cross-section of the fuse link at its point of largest width, or to its width at these points, respectively, is in the order of 1:8.6 and this ratio proved to be rather critical. The distance between the left end of the link and the center of neck 2b and the distance between the right end of the link and the last hole 2a farthest to the right side of the link are each 1⅜ inch. The distance between the center of neck 2b and the center of the hole 2a farthest to the left side of the link is .203 inch. The ratio of the cross-sectional area of neck 2b to the cross-sectional area of each pair of current paths 2c, 2c is 1:4.

The metal parts 2b', 2b' formed by link 2 are arranged immediately adjacent the neck portion 2b and at opposite sides thereof. The metal parts 2c', 2c' are arranged immediately adjacent each reduced cross-section portion 2c, 2c

and at opposite sides thereof. The cross-sectional area of neck portion 2*b* determines the let-through current of the fuse in which link 2 is mounted. The cross-sectional area of the adjacent link sections 2*b'*, 2*b'* and their length and the parts with which they are in contact, including terminal cap 6*a*, cause a relatively rapid and intense cooling of the neck portion 2*b* as long as the link 2 is subjected to a relatively small overload. In spite of the fact that the cross-section of the reduced cross-section portions 2*c*, 2*c* is four times as high as the cross-section of neck portion 2*b*, the temperature of the former portion rises more rapidly on the occurrence of small protracted overloads on account of the fact that the intermediate link portions 2*c'*, 2*c'* are relatively ineffective cooling means since each intermediate link portion 2*c'*, 2*c'* is heated by two reduced cross-section portions 2*c*, 2*c*. The axially outer spot heated portions of link 2 form effective thermal insulators of the axially inner portion of link 2 and on account of this the temperature of the latter portion follows rapidly changes of current intensity within the lower overload range. In other words, the fact that fuse link 2 is provided with a plurality of reduced cross-section portions 2*c*, 2*c*, reduces the temperature gradient between the center of the link and the adjacent axially outer parts thereof and the smallness of said temperature gradient greatly increases the rate of change of temperature by which the center portion of the link responds to changes of current intensity within the overload range. Hence arc initiation occurs at the point of reduced cross-section 2*c*, 2*c* where the temperature of the link 2 is highest, if a fuse of which link 2 forms part is subjected to long protracted overloads such as, for instance, overloads in the range of the minimum fusing current and larger currents of load current proportions.

On the occurrence of large fault currents in the nature of short-circuit currents the rate of rise of current is so rapid that heat dissipation from the points of reduced cross-section 2*b* and 2*c*, 2*c* by radiation, conduction and convection is virtually zero and hence negligible. Therefore the fusing process is merely governed by the heat generated at the reduced cross-section portions 2*b* and 2*c*, 2*c* and the heat absorbing ability of the adjacent portions 2*b'*, 2*b'* and 2*c'*, 2*c'* and of any other parts of the fuse structure does not come into play. Consequently among all portions of reduced cross-section 2*b* and 2*c*, 2*c* that will melt soonest which has the smallest cross-sectional area. This is the neck portion 2*b*.

It is of considerable importance to properly choose the average grain size of the quartz filler for filling the individual fuse units. The flow of hot metal vapor through the interstices between the quartz particles is obviously highly turbulent and this tends to increase the rate of deionization of the arc products but tends to increase flow resistance. Quartz sand of 30/40 mesh size proved to be most satisfactory in fuses according to this invention.

Referring now to Fig. 6, line I_r indicates the rated current of a given current-limiting fuse and $I_{r\,max}$ the peak value of I_r. Line I indicates a completely asymmetrical short-circuit current. The short-circuit is initiated at the time T_0 and its initial rate of rise has been indicated by drawing a tangent to line I through point T_0. If a prior art current-limiting fuse is provided in the circuit, both the maximum let-through current and the rated current and also the minimum fusing current are determined by the cross-sectional area of the point of smallest cross-section of the fuse link. The rated current is determined by the prototype of fuse under consideration including many design factors among which the cross-sectional area of the point of smallest cross-section is one. The maximum let-through current depends only upon the point of smallest cross-section since heat exchange phenomena have very little, and practically no part in the heating of the point of smallest cross-section. There is, therefore, a fixed relation between rated current and maximum let-through current, i. e., any change of the one affects the other. To be more specific, any increase of the rated current results in an increase of the maximum let-through current, thus precluding to increase one and reduce the other. This applies to fuses of the type wherein both the interruption of relatively high currents and of relatively low currents is initiated by fusion of a unitary link and to fuses with a composite fuse link including a section of metal having a relatively low melting point wherein interruption of relatively low currents is initiated by fusion of the low melting point section. In the latter type of fuses a portion or portions of reduced cross-section serve to generate at least in part the heat required for fusing the low melting point section, and, therefore, in fuses of that kind the rated current and minimum fusing current and the let-through current are likewise in a fixed relation to each other.

In Fig. 6 line I_1 indicates the let-through current which is allowed to pass through a prior art current-limiting fuse wherein let-through current and rated current (and also minimum fusing current) are interdependent and any change of one of them has a marked effect upon the other. Line I_1 refers in particular to a current-limiting fuse of the type wherein any increase of the rated current (and minimum fusing current) results in a correspondingly large increase of the let-through current. The let-through current I_1 rises from T_0 to T_2 in substantially the same way as the available short-circuit current I. At T_2 the let-through current begins to decrease from its peak value $I_{1\,max}$ to zero. Actual current zero is reached about the time T_3 prior to the first natural zero of the current wave following fault inception.

In a fuse according to this invention having the same rated current I_r the fuse link is completely melted at a much earlier time and a gradual reduction of the let-through current from its peak value $i_{1\,max}$ to zero begins at the time T_1.

Actual current zero is reached about the time T_3, generally prior to that time.

It is apparent that

$$i_{1\,max} \ll I_{1\,max}$$

and this enables to include into the circuit rotating electrical machinery, apparatus and devices which have much smaller short-time ratings than was possible heretofore. The rotating electrical machinery, apparatus and devices which are applicable, if protected by fuses according to this invention, are unable to withstand impulse currents of the peak value $I_{1\,max}$ and duration T_0—T_2 and, therefore, cannot be used where merely prior art curent-limiting fuses with their fixed relationship between maximum

let-through current and rated current (and minimum fusing current) are relied upon for protection.

Since the arc energy which is dissipated during the arcing time is $\int i^2 \cdot r \cdot dt$ and since the let-through current values in the case of the prior art current-limiting fuses are much higher than in current-limiting fuses according to this invention, it is apparent from Fig. 6 that fuses according to this invention result in a substantial limitation of arc energy and consequently a substantial reduction of the bulk of the cooling means required for dissipating the arc energy and, therefore, in a corresponding reduction of the overall size of the fuse.

Referring now to Figs. 7(*a*) and 7(*b*), these two diagrams show the temperature of the neck portion 2*b* and the temperature of one of the reduced cross-section portions 2*c*, 2*c* near the center of the link plotted versus time. At the time 0 the neck portion 2*b* and the reduced cross-section portion 2*c*, 2*c* are at ambient temperature. Upon closing of the circuit at the time 0, the temperatures of portions 2*b* and 2*c*, 2*c* begin to rise. The rises of the temperatures of both follow different exponential curves. Though the cross-sectional area of the neck portion 2*b* is considerably smaller than the cross-sectional area of the reduced cross-section portion 2*c*, 2*c* under consideration, the rise in temperature of the former is smaller than that of the latter. It takes also more time for the neck portion 2*b* to reach its steady state temperature than for the reduced cross-section portion 2*c*, 2*c* under consideration to reach its steady state temperature. It has been assumed that the current to which the fuse is subjected is of permissible magnitude. Hence the temperature of the fuse link remains under the fusing temperature level which has been indicated by dotted lines *f* parallel to the abscissa.

The steady state temperature of the neck portion 2*b* is obviously less than the steady state temperature of the reduced cross-section portion 2*c*, 2*c*.

Assuming now that the load current would be increased, this would result in an increase of the steady state temperature of neck portion 2*b* and of the reduced cross-section portion 2*c*, 2*c*. In spite of its small cross-sectional area the rate of rise in temperature of the former would be less than that of the latter. If the increase of load current is sufficiently high to cause fusion of the link, the fusing temperature will be reached first by the reduced cross-section portion 2*c*, 2*c* and the neck portion 2*b* might never reach the fusing temperature of the metal of which the fuse link is made.

In drawing Fig. 8(*a*) and 8(*b*) it was assumed that the fuse was subjected for a considerable period of time prior to and at the time $t=0$ to the same load current as in the case shown in Figs. 7(*a*) and 7(*b*). Consequently, the neck portion 2*b* and the reduced cross-section portion 2*c*, 2*c* will be at their respective steady state temperature equal to the steady state temperatures shown in Figs. 7(*a*) and 7(*b*). It is assumed that a fault current of short-circuit current proportions is initiated at the time T_s. Consequently the temperature of both the neck portion 2*b* and the reduced cross-section portion 2*c*, 2*c* will then rise at a very rapid rate indicated by the temperature versus time characteristics of Figs. 8(*a*) and 8(*b*) wherein time is expressed in terms of microseconds. The neck portion 2*b* is cooled much more effectively than the reduced cross-section portion 2*c*, 2*c*. Yet, nevertheless, the rise in temperature of the former is much more rapid than the rise of temperature of the latter. This is due to the fact that heat generation at the neck portion 2*b* occurs at a more rapid rate than at the restricted cross-section portion 2*c*, 2*c* under consideration and that the rate of heat generation at 2*b* and at 2*c*, 2*c* is so rapid that their temperature is virtually unaffected by heat exchange phenomena which would take more time in order to have any significant effect upon temperature distribution along the link. After the interval Δt_1 following initiation of the fault current the fusing point of the neck portion 2*b* has been reached and the interrupting process proceeds from there on in normal fashion. If the temperature of the reduced cross-section portion 2*c*, 2*c* would continuously rise at its initial rate, reduced cross-section portion 2*c*, 2*c* would reach its fusing point after the interval Δt_2.

$$\Delta t_2 \gg \Delta t_1$$

Actually it takes more time for the reduced cross-section portion 2*c*, 2*c* to reach fusing temperature. This is mainly due to the fact that vaporization of the fuse link begins at the end of the time interval Δt_1 resulting in a considerable increase of the resistance of the current path through the fuse and a concomitant decrease of current flow. Because of that decrease of current flow the rate of increase of temperature of the reduced cross-section portion 2*c*, 2*c* decreases at the end of Δt_1 and it takes $\Delta t_2'$ rather than Δt_2 for the reduced cross-section portion 2*c*, 2*c* to reach fusing temperature.

$$\Delta t_2' \gg \Delta t_2$$

It is of considerable importance with regard to the desired operation of the fuse that the neck 2*b* which determines the maximum let-through current be arranged immediately adjacent one of the caps or ferrules 6*a*, 6*b* (see Fig. 1) rather than relatively close to the center of the fuse link 2. If the neck 2*b* is arranged relatively close to one of the axially outer ends of the fuse link, the cooling of neck 2*b* is increased on account of the relative nearness of the large mass of the terminal cap 6*a* and the relative remoteness of the additional points of relatively large heat generation formed by the reduced cross-section portions 2*c*, 2*c*. The cooling action of cap 6*a* upon neck 2*b* varies in accordance with ambient temperature conditions but is always so large as to keep the neck portion 2*b* at a lower temperature level than any of the restricted cross-section portions 2*c*, 2*c* as long as the current which flows through the fuse is of lesser magnitude than a short-circuit current. The fact that the rate of heat flow from neck 2*b* to cap 6*a* may widely vary with ambient temperature conditions has, therefore, no bearing upon the operation of the fuse.

Where high current carrying capacity is required which may be in the order of many hundreds of amperes or of the order of thousands of amperes, a plurality of fuse units of the type shown in Figs. 1 and 2 may be arranged in parallel in the circuit to be protected and integrated into one single self-contained structural unit. Such a composite fuse may have two terminal elements at opposite ends thereof to which a plurality of links may be directly secured so as to be in immediate contact with the terminal elements. However, this type of design has not been found as desirable for embodying the invention

in composite high current-carrying capacity current-limiting fuses as the structure shown in Figs. 4 and 5, particularly if the circuit voltage is relatively high, e. g. in the order of 1000 volts. Figs. 4 and 5 show a composite fuse structure having a very high current-carrying capacity particularly designed and adapted to limit the peak of the let-through current well below the order to which this could be achieved with any prior art current-limiting power fuse.

Referring now to Figs. 4 and 5, reference numerals 8*a* and 8*b* have been applied to two metal blocks which are preferably made of copper and are provided with blade contacts 9*a* and 9*b* intended for insertion into a fuse holder (not shown). Metal blocks 8*a* and 8*b* are provided with a plurality of pairs of substantially cylindrical recesses 10*a*, 10*b*; 10*a'*, 10*b'*; 10*a''*, 10*b''*; 10*a'''*, 10*b'''*; 10*a''''*, 10*b''''*. The fuse comprises a plurality of fuse units which are identical with the fuse unit shown in Figs. 1 and 2 and which are, therefore, only more or less diagrammatically illustrated in Figs. 4 and 5. Reference numeral 1 has been applied to the tubular casings of each of said plurality of fuse units and reference numerals 6*a*, 6*b* have been applied to the pair of terminal caps of which one is arranged at each end of each casing 1. Each of said pair of terminal caps 6*a*, 6*b* is inserted under pressure into one of said plurality of recesses 10*a*, 10*b*; 10*a'*, 10*b'*; 10*a''*, 10*b''*; etc. and tightly held therein to provide for minimum resistance to current and heat flow. The pulverulent cooling substance 11, e. g., quartz sand, is arranged in the spaces formed between casings 1. Intercasing filler 11 is a safety means in case that one of the casings 1 of the fuse units should burst under the pressure developed therein or in case that hot gases should leak out of the casings 1 without impairing the same. The insulating shield 12 is arranged between the blocks 8*a* and 8*b* and encloses the fuse units which are arranged between blocks 8*a* and 8*b* and the sand filler 11 arranged in the spaces formed between the fuse units. Each casing 1 accommodates a fuse link 2 and a link-surrounding inert arc-extinguishing filler 3, preferably clean quartz sand. Each link has a plurality of serially related portions 2*c*, 2*c* of reduced cross-section adapted to determine the minimum fusing current of the link. Each link has at least one additional neck portion 2*b* of smaller cross-section than said reduced cross-section portions 2*c*, 2*c*. The neck portions 2*b* are arranged immediately adjacent the terminal caps 6*a* and the terminal caps 6*a* are under considerable pressure in immediate contact with the block 8*a*. Hence block 8*a* will tend to considerably cool the neck portions 2*b* during the normal operation of the fuse and during times when the fuse is subjected to overload currents which have a relatively small rate of rise. Because of the combined cooling action of the caps 6*a* and the block 8*a* the necks 2*b* remain normally at a lower temperature than each of the serially related portions 2*c*, 2*c* of reduced cross-section, as clearly shown in Figs. 7(*a*) and 7(*b*).

Fig. 9 shows two maximum let-through current versus available short-circuit current characteristics. The maximum let-through current is measured in peak amperes and the available short-circuit current in R. M. S. amperes. Both the abscissae and the ordinates are drawn in a logarithmic scale. The upper curve refers to a prior art multiple link current-limiting fuse of a given prototype similar to the fuse shown in Fig. 4 but lacking any let-through current limiting neck means. The fuse is rated at 200 amperes. The lower curve refers to a fuse of the same prototype rated at 200 amperes and generally identical with the fuse to which the upper curve refers, except for the provision of let-through current-limiting neck portions in the nature of the neck portions 2*b* shown in Figs. 1 and 4. While the peak of the let-through current of the prior art fuse is way above 3000 peak amperes, if the available short-circuit current is 2000 R. M. S. amperes, the peak let-through current of the same fuse, upon being modified according to this invention, is reduced to the order of 1500 amperes. For the fuse which is modified according to this invention, the reduction of the peak let-through current holds true throughout the entire range of available short-circuit currents. If the available short-circuit currents is 100,000 R. M. S. amperes, the peak of the let-through current is way above 40,000 peak amperes for the prior art structure and merely a fraction of this for the structure according to this invention.

For low voltage circuits the ratio of peak current to total R. M. S. current—including a D. C. component—is in the order of 1.68. The upper curve in Fig. 9 shows that at available short-circuit currents of 2000 R. M. S. amperes and above the fuse permits the entire available short-circuit current—whose peak, on basis of the above 1.68 ratio is 3360 amperes—to pass. The current-limiting action of the fuse becomes effective only at considerably higher available short-circuit currents. The lower curve of Fig. 9 shows that the peak of the let-through current may be limited at the occurrence of short-circuit currents of relatively small magnitude at which no current-limiting action takes place in the prior art current-limiting fuse represented by the upper curve.

Fig. 10 shows the need of using fuses having different ratings for achieving selectivity when applying prior art current-limiting fuses.

Fig. 11 shows that four different fuses according to this invention which have the same rating operate selectively if the fault current is in excess of 135% of the rated current. In other words, by varying the let-through current a group of fuses may be obtained which permit cascading and limitation of interruption to the faulted section of the circuit.

In Fig. 12 the upper curve refers to a prior art current-limiting fuse and the lower curve to the same fuse with an added neck portion which determines the let-through current. The upper curve in Fig. 12 is one of the family shown in Fig. 10 and the lower curve one of the family shown in Fig. 11. The term let-through current applied to the abscissa of Fig. 9 refers to the current which the fuse permits to pass and includes load and overload currents well below the current range at which the current-limiting action occurs.

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

I claim as my invention:

1. A current-limiting fuse comprising a pair of link sections each consisting of a unitary strip of sheet metal, and each having a reduced cross-section portion of different cross-sectional area, one of said pair of link sections having a reduced cross-section portion of relatively large area being adapted when surrounded by a pulverulent arc-extinguishing material to have a required current-carrying capacity but having an excessive let-through current, the other of said pair of link sections having a reduced cross-section portion of relatively small area and a smaller let-through current than said one of said pair of link sections, and cooling means associated with said other of said pair of link sections sufficiently effective to keep the overload current carrying capacity thereof above the overload current carrying capacity of said one of said pair of link sections, said pair of link sections being serially arranged in a common pulverulent filler filled casing to combine required current-carrying capacity and required let-through current characteristic.

2. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-quenching filler, said fuse link having a plurality of substantially identical serially related portions of reduced cross-section and at least one serially related neck portion of smaller cross-section than said reduced cross-section portions, the geometry of said reduced cross-section portions and of the portions of said link immediately adjacent said reduced cross-section portions and the geometry of said neck portion and of the portions of said link immediately adjacent said neck portion being determined in such a way that the rise in temperature at said reduced cross-section portions is more rapid than at said neck portion if the flow of current in said link is in the nature of a relatively small protracted overload and that the rise in temperature at that neck portion is more rapid than at said reduced cross-section portions if the flow of current in said link is in the nature of a short-circuit current.

3. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-quenching filler, said fuse link having a plurality of portions of reduced cross-section and a plurality of portions of relatively large cross-section intermediate said reduced cross-section portions, the length of each said relatively larger cross-section portions being a multiple of the length of said reduced cross-section portions and each said reduced cross-section portions consisting of a pair of conductive elements forming separate parallel current paths, said fuse link further having at least one neck portion of smaller cross-section than said reduced cross-section portions, the dimensions of each constituent part of said link being determined in such a way that the ratio of the rate of heat generation to the rate of heat dissipation is larger for each said reduced cross-section portions than for said neck portion on the occurrence of overcurrents having a relatively small rate of rise and larger for said neck portion than said reduced cross-section portions on the occurrence of overcurrents in the nature of short-circuit currents.

4. A current-limiting fuse comprising a casing, a fuse link of silver mounted in said casing and surrounded by quartz sand, said link having a plurality of substantially identical circular perforations arranged along the center line thereof to form a plurality of portions of reduced cross-section, the spacing between said perforations exceeding the length thereof but being sufficiently small to cause dissipation of substantially the entire perforated length of said link on the occurrence of currents in the order of the minimum fusing current, said fuse link further having at least one neck portion formed by a pair of lateral notches and smaller in cross-section than each said reduced cross-section portions, the dimensions of each constituent part of said link being determined in such a way that the ratio of the rate of heat generation to the rate of heat dissipation is smaller for each said reduced cross-section portions than for said neck portion on the occurrence of overcurrents having a relatively rapid rate of rise.

5. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-quenching filler, said fuse link having a plurality of serially related portions of reduced cross-section and at least one serially related additional portion of smaller cross-section than said reduced cross-section portions, the geometry of said reduced cross-section portions and of said additional portion and the geometry of the portions of said link immediately adjacent said reduced cross-section portions and immediately adjacent said additional portion being determined in such a way that the ratio of the rate of heat generation at each said reduced cross-section portions to the rate of heat flow away from each said reduced cross-section portions to the portions of said link immediately adjacent said reduced cross-section portions exceeds the ratio of the rate of heat generation at said additional portion to the rate of heat flow away from said additional portion to the portions of said link immediately adjacent said additional portion on the occurrence of overcurrents having a relatively slow rate of rise, while said first mentioned ratio is smaller than said last mentioned ratio on the occurrence of overcurrents having a relatively high rate of rise.

6. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-quenching filler, said fuse link having a plurality of substantially identical perforations arranged along the center line thereof to form a plurality of serially related portions of reduced cross-section, the spacing of said reduced cross-section portions being sufficiently narrow to cause dissipation of the entire perforated length of said link on the occurrence of relatively small overcurrents, said fuse link having at least one serially related neck portion of smaller cross-section than each said reduced cross-section portions, said neck portion having at least the same current-carrying capacity as said reduced cross-section portions, and said neck portion being adapted to rise more rapidly in temperature than said reduced cross-section portions on the occurrence of overcurrents of short-circuit current proportions.

7. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by an arc-quenching filler, said fuse link having a plurality of serially related substantially identical portions of reduced cross-section adapted to fuse substantially simultaneously at the occurrence of small protracted overloads to distribute the thermal duty of said filler along a substantial portion of the length of said link, said

link further having an additional serially related portion of reduced cross-section adapted to carry higher currents than said reduced cross-section portions and to initiate arcing more rapidly than said reduced cross-section portions if the rate of rise of current is relatively high.

8. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-quenching filler, said fuse link including a plurality of serially related portions of reduced cross-section having a predetermined ratio of heat generation to heat dissipation and at least one additional portion of smaller cross-section than each of said plurality of reduced cross-section portions, said additional portion having a smaller ratio of heat generation to heat dissipation than each of said plurality of reduced cross-section portions whereby said plurality of reduced cross-section portions is caused to fuse initially at relatively small overloads and whereby said additional portion is caused to fuse initially at fault currents of short-circuit current proportions.

9. A current-limiting fuse comprising a tubular casing, a fuse link mounted in said casing and surrounded along a preponderant portion of the length thereof by an inert pulverulent arc-quenching filler, said fuse link having at least one portion of reduced cross-section proportioned to initiate fusing of said link at the occurrence of relatively small protracted overloads, said link having at least one additional portion of smaller cross-section than said reduced cross-section portion, the ratio of the cross-sectional area of said reduced cross-section portion to the cross-sectional area of said additional portion being of the order of 4:1, and cooling means associated with said additional portion to impart to said additional portion a higher current-carrying ability than the current-carrying ability of said portion of reduced cross-section.

10. A current-limiting fuse comprising a casing, a pair of terminal elements, one at each end of said casing, a fuse link interconnecting said terminal elements, mounted in said casing and surrounded by a pulverulent arc-quenching quartz filler, said link having a plurality of serially related substantially identical portions of reduced cross-section adapted to cause initial fusion at the occurrence of small protracted overloads at one of said reduced cross-section portions, said link having an additional serially related portion of smaller cross-section than said reduced cross-section portions, said additional portion being arranged immediately adjacent one of said terminal elements and cooled sufficiently effectively to increase the current-carrying ability thereof above the current-carrying ability of said reduced cross-section portions.

11. A current-limiting fuse comprising a tubular casing of laminated insulating material, a fuse link of silver mounted in said casing and surrounded along a preponderant portion of the length thereof by a quartz sand filler, said fuse link having at least one portion of reduced cross-section proportioned to initiate fusing of said link at the occurrence of relatively small protracted overloads, said link having at least one portion of smaller cross-section than said reduced cross-section portion proportioned to determine the let-through current of said fuse, and cooling means associated with said smaller cross-section portion to impart to said smaller cross-section portion a higher current-carrying ability than the current-carrying ability of said portion of reduced cross-section.

12. A current-limiting fuse comprising a tubular casing of laminated insulating material, a fuse link of silver mounted in said casing and surrounded along a preponderant portion of the length thereof by a quartz sand filler, said fuse link having at least a first portion of reduced cross-section designed to determine the let-through current of said fuse, said fuse link having at least a second portion of reduced cross-section but larger in cross-section than said first portion, first metallic cooling means formed by said link and associated with said first portion, second metallic cooling means formed by said link and associated with said second portion, the effectiveness of said first cooling means and the effectiveness of said second cooling means being related in such a way as to cause arc initiation on the occurrence of relatively high currents at said first portion and to cause arc initiation on the occurrence of relatively small protracted overloads at said second portion.

13. A current-limiting fuse comprising a pair of spaced metal blocks, a plurality of pairs of recesses in said metal blocks, one of each of said pairs of recesses being provided in one of said pair of metal blocks and the other of each of said pair of recesses being provided in the other of said pair of metal blocks, a plurality of tubular casings each having a pair of terminal caps, one on each end thereof, each said pair of terminal caps being inserted under pressure in one of said plurality of pairs of recesses and tightly held therein to provide for minimum resistance to heat flow, a pulverulent cooling substance in the spaces formed between said plurality of tubular casings, an insulating shield surrounding said pair of metal blocks and enclosing said pulverulent cooling substance, each of said plurality of tubular casings accommodating a fuse link and a link-surrounding pulverulent arc-extinguishing filler, each link having at least a portion of reduced cross-section adapted to determine the minimum fusing current of said link, and each link having at least an additional portion of smaller cross-section than said reduced cross-section portion, said portion of smaller cross-section being arranged immediately adjacent one of said pairs of metal blocks and adapted on account of the cooling action thereof to remain normally at a lower temperature than said reduced cross-section portion of said link.

14. A current-limiting fuse comprising a pair of spaced metal blocks, a plurality of pairs of recesses in said metal blocks, one of each of said pairs of recesses being provided in one of said pair of metal blocks and the other of each of said pairs of recesses being provided in the other of said pair of metal blocks, a plurality of tubular casings each having a pair of terminal caps, one on each end thereof, each said pair of terminal caps being inserted under pressure in one of said plurality of pairs of recesses and tightly held therein to provide for minimum resistance to current and heat flow, a pulverulent cooling substance in the spaces formed between said plurality of tubular casings, an insulating shield between said pair of metal blocks and enclosing said plurality of tubular casings and said pulverulent cooling substance, each of said plurality of tubular casings accommodating a fuse link and a link-surrounding pulverulent inert arc-extinguishing filler, each link having a plurality

of serially related portions of reduced cross-section adapted to determine the minimum fusing current of said link, and each link having at least one additional portion of smaller cross-section than said reduced cross-section portions, said portion of smaller cross-section being arranged immediately adjacent to one of said pair of metal blocks and adapted on account of the cooling action thereof to remain normally at a lower temperature than each of said plurality of serially related portions of reduced cross-section.

15. A current-limiting fuse comprising a casing, terminal elements on opposite ends of said casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-extinguishing filler, said fuse link having a plurality of serially related portions of reduced cross-section including one let-through current determining portion of smallest cross-section arranged immediately adjacent to one of said terminal elements, the length of said smallest cross-section portion being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said smallest cross-section portion so high that the rate of rise in temperature at said smallest cross-section portion is less rapid under load conditions and in the low overload range than at any other point of said link.

16. A current-limiting fuse comprising a casing, terminal elements on opposite ends of said casing, a fuse link of silver mounted in said casing and surrounded by quartz sand, said link having a plurality of serially related portions of reduced cross-section including a let-through current determining portion of smallest cross-section arranged immediately adjacent to one of said terminal elements, the length of said smallest cross-section portion being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said smallest cross-section portion so high that the rate of rise in temperature at said smallest cross-section portion is less rapid than at any other point of said link as long as the flow of current in said link is below a predetermined critical value.

17. A current-limiting fuse comprising a casing, terminal elements on opposite ends of said casing, a unitary fuse link mounted in said casing and surrounded by a pulverulent arc-extinguishing filler, said fuse link having a plurality of serially arranged portions of reduced cross-section and a plurality of portions of relatively large cross-section intermediate said reduced cross-section portions, said fuse link further having a let-through current determining neck of smaller cross-section than each of said reduced cross-section portions arranged immediately adjacent to one of said terminal elements, the length of said neck being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said neck so large that the rate of rise in temperature at said neck is less rapid under load conditions and in the low overload range than at any other point of said link.

18. A current limiting fuse comprising a casing, terminal elements on opposite ends of said casing, a unitary fuse link of silver mounted in said casing and surrounded by quartz sand, said link having a plurality of perforations arranged along the longitudinal axis thereof, said plurality of perforations producing a plurality of reduced cross-section portions each consisting of a pair of conductive elements forming separate parallel current paths, said fuse link further having a let-through current determining neck of smaller cross-section than each of said reduced cross-section portions arranged immediately adjacent to one of said terminal elements, the length of said neck being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said neck so large that the rate of rise in temperature at said neck is less than at any other point of said link as long as the flow of current in said link is below a predetermined critical value.

19. A current-limiting fuse comprising a pair of relatively massive spaced metal blocks, means defining a plurality of pairs of recesses in said pair of metal blocks, one of each of said pairs of recesses being provided in one of said pair of metal blocks and the other of each of said pairs of recesses being provided in the other of said pair of metal blocks, a plurality of tubular casings each having a pair of terminal caps, one on each end thereof, each of said tubular casings having annular grooves therein, and each of said pair of terminal caps having an annular flange portion depressed into a said casing groove to lock said pair of terminal caps on one of said plurality of tubular casings, each said pair of terminal caps being inserted under pressure in one of said plurality of pairs of recesses in said pair of metal blocks to provide for minimum resistance to current and heat flow and to effect rigid connections between the pair of metal blocks, each of said plurality of tubular casings accommodating a fuse link and a link-surrounding pulverulent inert arc-extinguishing filler, each link having a plurality of serially related portions of reduced cross-section adapted to determine the minimum fusing current of said link, and each link having at least one additional portion of smaller cross-section than said reduced cross-section portion, said portion of smaller cross-section being arranged immediately adjacent to one of said pair of metal blocks and adapted on account of the cooling action thereof to remain normally at a lower temperature than each of said plurality of serially related portions of reduced cross-section.

20. An electric system including a pair of cascaded protective devices having substantially the same current rating, at least one of said devices being a current-limiting fuse, said fuse comprising a casing, terminal elements on opposite ends of said casing, a fuse link mounted in said casing and surrounded by a pulverulent arc-extinguishing filler, said fuse link having a plurality of serially related portions of reduced cross-section including one let-through current determining portion of smallest cross-section arranged immediately adjacent to one of said terminal elements, the length of said smallest cross-section portion being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said smallest cross-section portion so high that the rate of rise in temperature at said smallest cross-section portion is less rapid under load and moderate overload conditions than at any other point of said link.

21. An electric system including a pair of cascaded protective devices having substantially the same current rating, at least one of said pair of devices being a current-limiting fuse, said fuse comprising a casing, terminal elements on op-

posite ends of said casing, a fuse link of silver mounted in said casing and surrounded by quartz sand, said link having a plurality of serially related portions of reduced cross-section including a let-through current determining portion of smallest cross-section arranged immediately adjacent to one of said terminal elements, the length of said smallest cross-section portion being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said smallest cross-section portion so high that the rate of rise in temperature at said smallest cross-section portion is less rapid than at any other point of said link as long as the flow of current in said link is below a predetermined critical value.

22. An electric system including a pair of cascaded protective devices having substantially the same current rating, at least one of said pair of devices being a current-limiting fuse, said fuse comprising a casing, terminal elements on opposite ends of said casing, a unitary fuse link mounted in said casing and surrounded by a pulverulent arc-extinguishing filler, said fuse link having a plurality of serially arranged portions of reduced cross-section and a plurality of portions of relatively large cross-section intermediate said reduced cross-section portions, said fuse link further having a let-through current determining neck of smaller cross-section than each of said reduced cross-section portions arranged immediately adjacent to one of said terminal elements, the length of said neck being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said neck so large that the rate of rise in temperature at said neck is less rapid under load and moderate overload conditions than at any other point of said link.

23. An electric system including a pair of cascaded protective devices having substantially the same current rating, at least one of said pair of devices being a current-limiting fuse, said fuse comprising a casing, terminal elements on opposite ends of said casing, a unitary fuse link of silver mounted in said casing and surrounded by quartz sand, said link having a plurality of perforations arranged along the longitudinal axis thereof, said plurality of perforations producing a plurality of reduced cross-section portions each consisting of a pair of conductive elements forming separate parallel current paths, said fuse link further having a let-through current determining neck of smaller cross-section than each of said reduced cross-section portions arranged immediately adjacent to one of said terminal elements, the length of said neck being so short and the combined heat dissipating ability of said one of said terminal elements and of the portions of said link adjacent said neck so large that the rate of rise in temperature at said neck is less rapid than at any other point of said link as long as the flow of current in said link is of smaller than a predetermined critical value.

24. A current-limiting fuse comprising a casing, a unitary fuse link consisting of a strip of sheet metal mounted within said casing and surrounded by a quartz filler, said strip of sheet metal having two portions of reduced cross-section having different cross-sectional areas, the relatively larger of said portions being adapted to determine the minimum fusing current, and cooling means associated with the relatively smaller of said portions having a sufficiently high heat dissipating ability to preclude fusion of said relatively smaller of said portions at currents of load proportions and at relatively small protracted overload currents.

25. A current-limiting fuse comprising a casing, a fuse link mounted in said casing and at least in part surrounded by a pulverulent quartz filler, said fuse link having a plurality of substantially identical serially related portions of reduced cross-section, said fuse link further having at least one serially related neck portion having a width in the order of ⅛ to ⅑ of the width of said link and of smaller cross-section than each of said reduced cross-section portions, said neck portion being arranged immediately adjacent an axially outer end of said link to impart to said neck portion at least the same current-carrying capacity as any of said reduced cross-section portions, each of said reduced cross-section portions being cooled relatively ineffectively to preclude the current-carrying capacity thereof from exceeding the current-carrying capacity of said neck portion.

26. A current-limiting fuse, comprising a casing, a fuse link of silver mounted within said casing at least in part surrounded by a pulverulent quartz filler, said fuse link having a plurality of substantially identical perforations arranged along the center line thereof to form a plurality of serially related portions of reduced cross-section, a tin rivet inserted into one of said perforations to reduce the fusing point of said link at the point thereof where said rivet is inserted therein, said link having at least one serially related neck portion having a width in the order of ⅛ to ⅑ of the width of said link, said neck portion being arranged immediately adjacent an axially outer end of said link to impart to said neck portion at least the same current carrying capacity as any of said reduced cross-section portions, each of said reduced cross-section portions being cooled relatively ineffectively to preclude the current-carrying capacity thereof from exceeding the current-carrying capacity of said neck portion.

27. A current-limiting fuse comprising a tubular casing, a fuse link mounted in said casing and surrounded by a pulverulent silicious filler along a preponderant portion of the length thereof, said link having metallic means associated with at least one portion thereof adapted to form an alloy with the metal of which said link is made at temperatures below the fusing point of said metal to initiate fusing of said link at the occurrence of relatively small protracted overloads, said link having at least one additional portion serially related to said alloy-forming portion having a width in the order of ⅛ to ⅑ of the width of said link, and cooling means associated with said additional portion to impart to said additional portion a higher current-carrying ability than the current-carrying ability of said alloy-forming portion.

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