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Rosen et al.

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[54] **ELECTRICAL FUSE**

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 74,429, Sept. 22, 1970, abandoned.

[30] **Foreign Application Priority Data**

Sept. 23, 1969 Great Britain 46794/69

[52] **U.S. Cl.** **337/161,** 337/159, 337/160, 337/290, 337/293, 337/295

[51] **Int. Cl.** **H01h 85/12**

[58] **Field of Search** 337/158, 159, 161, 240, 337/293, 295, 296, 297, 163

[56] **References Cited**

UNITED STATES PATENTS

2,223,959	12/1940	Lohausen	337/293 X
2,309,489	1/1943	Williams et al.	337/293 X
2,502,747	4/1950	Popp	337/163
2,667,549	1/1954	Fahnoe et al.	337/158 X
2,670,418	2/1954	Kozacka	337/161
2,769,877	11/1956	Sundt	337/297 X
3,287,525	11/1966	Mikulecky	337/161
3,611,239	10/1971	Kozacka	337/161

FOREIGN PATENTS OR APPLICATIONS

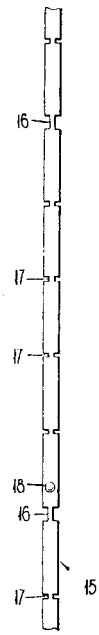
1,538,414	9/1969	Germany	337/161

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Assistant Examiner—Fred E. Bell
Attorney, Agent, or Firm—Misegades, Douglas & Levy

[57] **ABSTRACT**

A multi-element high-voltage fuse comprises a plurality of similar fuse elements connected in parallel, each element being a strip of fusible material having a plurality of first portions of reduced cross-section spaced along its length and, between each mutually adjacent pair of said first portions, a plurality of shorter second portions of reduced cross-section. Under short-circuit conditions, substantially all the first and second portions of all the elements fuse simultaneously. Under low overload conditions, the elements fuse one at a time, at their longer first portions only, but the conditions are such that multiple arcing occurs, at substantially all these longer first portions, leading to safe fuse operation, at lower values of overcurrent than in conventional designs; and since the longer first portions are much less numerous than the shorter second portions they have relatively little effect on the overall resistance of the fuse and thus on its current carrying capacity. Conversely, fewer parallel elements are required to achieve a given minimum breaking current, since a lower current density per element suffices to produce multiple arcing. Thus, for a given minimum breaking current, the fuse may be more compact and robust than hitherto. In general, each element should contain about one of the longer second portions per kilovolt of the voltage rating of the fuse, for safe operation of the fuse under low overload conditions.

10 Claims, 3 Drawing Figures



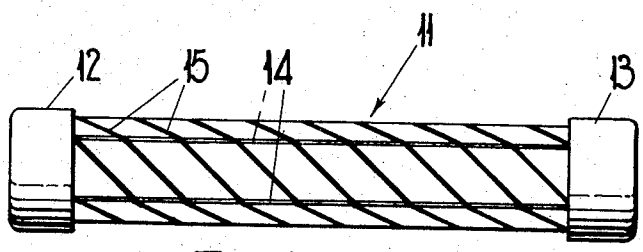


Fig.1

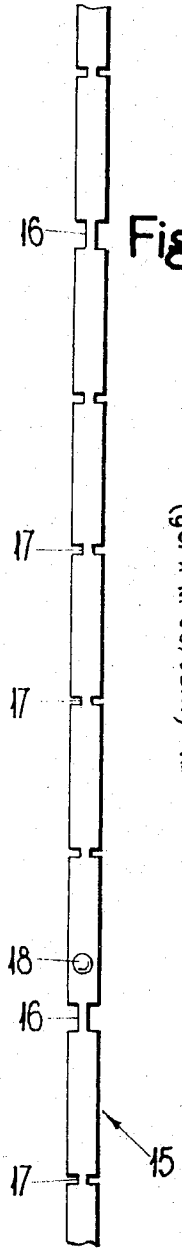


Fig.2

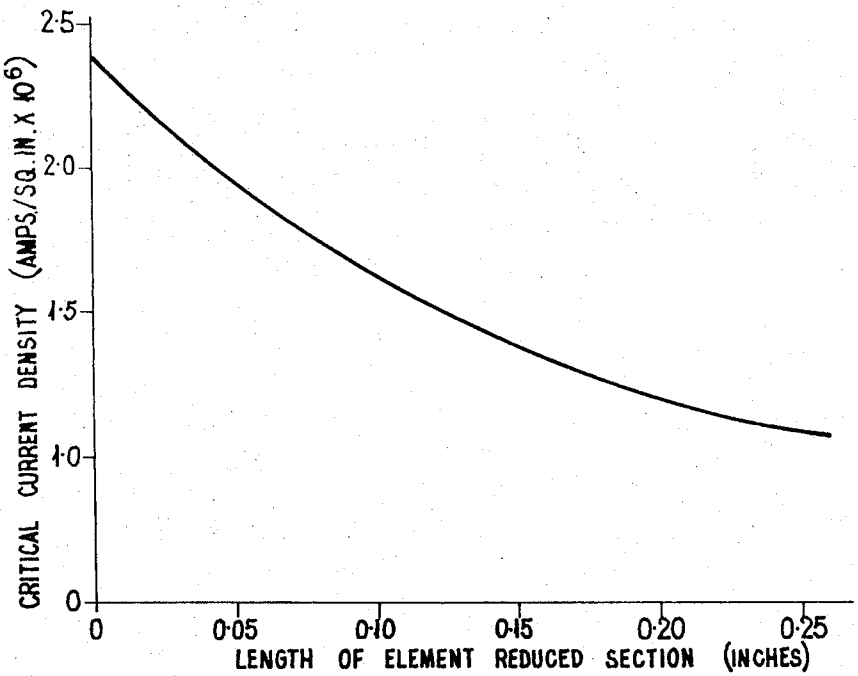


Fig.3

ELECTRICAL FUSE

CROSS-REFERENCES TO PERTINENT INFORMATION AND REFERENCES

This is a continuation-in-part application of Ser. No. 74,429, filed Sept. 22, 1970 now abandoned. Applicants claim the benefit of the right of priority under 35 U.S.C. 119, based on British application No. 46794/69, filed Sept. 23, 1969. Prior art references of cursory value are:

2,181,825	Wood	2,833,891	Jacobs
2,489,501	Rensner	3,287,525	Mikulecky
2,667,549	Fannoe	3,611,239	Kozacka
2,670,418	Kozacka	51742	Romania, patent
2,770,033	Kozacka	1,325,090	France, patent
		1,538,414	Germany, patent

This invention relates to electrical fuses and more particularly relates to high voltage fuses, of high rupturing capacity, designed for both low overcurrent and short-circuit duties.

Hitherto, high voltage fuses designed to give a good low overcurrent performance have principally employed either a large number of regularly notched strip elements, connected in parallel, or a small number of parallel-connected compound elements each made up from sections of silver strip and silver wire in series, the wire sections being best able to deal with overcurrent faults whilst the strip section, suitably notched, is best able to deal with short-circuit duties.

Such fuses however suffer from numerous disadvantages, the former type involving the danger of fracture in service by reason of the necessarily small cross-section of the notched necks in the large number of elements employed whereas the other type is difficult to fabricate and possesses a high electrical resistance resulting in an inferior current carrying capability for given body dimensions. Further, the latter type may afford a high energy "let-through" under short-circuit conditions.

Accordingly, it is an object of this invention to provide an improved fuse which obviates or at least largely mitigates these disadvantages.

According to the present invention, there is provided a multi-element high-voltage fuse comprising a plurality of similar parallel-connected fuse elements, wherein each fuse element comprises a fusible strip having a plurality of first portions of reduced cross-section spaced apart along the strip and, between each mutually adjacent pair of said first portions, a plurality of spaced-apart second portions of reduced cross-section, each of said second portions being shorter than each of said first portions.

In such a fuse according to the invention, each fuse element may include a plurality of first notches equidistantly spaced apart along the strip and forming the said first portions of reduced cross-section, and, between each mutually adjacent pair of said first portions so formed, a plurality of shorter second notches equidistantly spaced apart along the strip and forming said second portions of reduced cross-section.

In order that the invention may be fully understood, one embodiment thereof will now be described with reference to the accompanying drawing, in which:

FIG. 1 is an elevational view of the major parts of a typical fuse according to the invention,

FIG. 2 illustrates the construction of a fuse element comprised by the fuse shown in FIG. 1,

FIG. 3 is a graphical illustration of critical current density against notch length, with reference to a fuse element as shown in FIG. 2.

The fuse shown in FIG. 1 comprises an elongate electrically-insulating and temperature-resistant former 11 fitted with electrically conductive end caps 12 and 13. The former 11 has a plurality of equiangularly spaced radially projecting longitudinal ribs 14, and round it a plurality of fuse elements 15 are wound in generally helical form, the fuse elements 15 being thus supported on the tips of the ribs 14 and otherwise out of contact with the former 11. The two ends of each fuse element 15 are secured mechanically to the end caps 12 and 13 respectively, in electrical contact therewith. Apart from the details of the fuse elements 15, described below, this is, of course, a well known type of fuse construction and, as is also well known, the former 11 would in practice be surrounded by an outer fuse barrel (not shown) sealed to the end caps 12 and 13 and containing, in the enclosed space surrounding the former 11, a suitable arc-quenching material such as silica sand through which the fuse elements 15 extend.

Each fuse element 15, of which only the general disposition is indicated in FIG. 1, is constructed as shown in greater detail in FIG. 2. Each such element consists of a strip of electrically conductive fusible material, preferably silver, having its edges notched to provide a plurality of relatively long necks 16 of restricted cross-section and, between each mutually adjacent pair of the necks 16, a plurality of relatively short necks 17 of restricted cross-section. Thus each fuse element 15 has a greater number of the shorter necks 17 than it has of the longer necks 16.

In a fuse as described above and rated for use in a 10,000 volt supply circuit in which, in short circuit conditions, it may have to respond to a short-circuit current of 10,000 amps or more, each fuse element 15 may require to have some 30 or 40 of the shorter necks 17 whereas, as explained below, it need have only about 10 of the longer notches 16. For the same conditions of use, and to provide a satisfactory fusing response to a prolonged low overload (say, in the region of two to three times rated current), each fuse element 15 may be of silver strip having a width of 0.1 inches and a thickness of 0.0025 inches, each of the longer or shorter necks 16 or 17 may have a length of 0.2 inches or 0.02 inches respectively, each of the necks being about 0.025 inches in width and adjacent necks being about 0.5 inches apart. In general, the longer necks 16 may be between four and 12 times longer than the shorter necks 17, the distance between adjacent necks may be between two and four times the length of the longer necks, and the width of any of the necks may be between one-sixth and one-half that of the strip in which they are formed.

When a fuse according to the invention, and as above described, is subjected to short circuit conditions, the high current density in all the parallel-connected fuse elements 15 causes all or substantially all the necks 16 and 17 of all the elements 15 to fuse substantially simultaneously; and, momentarily, arcing occurs at all the gaps which result from fusing of the necks. As is well understood in the art, the number of necks provided in each element 15 is chosen sufficiently large,

having regard to the voltage rating of the fuse (i.e., the voltage in connection with which it is to be used), that the excess of this voltage over the total arc voltage of all the arcs occurring in series simultaneously in any one of the elements **15** is insufficient to maintain the stability of these arcs; and accordingly the arcing is extinguished almost instantaneously in all the elements **15.**

As is also well understood, under conditions of low overload in which the overload current is less than that at which the fuse will rupture instantaneously, the time required for a neck to fuse is dependent not only on the current density flowing through it but also on its length, since the temperature rise in the neck is reduced or made less rapid by heat losses to the full-width parts of the fuse element between which the neck extends and these heat losses are more significant for a short neck than they are for the central portion of a longer neck. In a given fuse, there is an inverse relation between the length of a neck and the minimum current density below which fusing of the neck will not occur because, at a temperature which is still less than the fusing temperature of the neck, the rate of heat loss from the neck will become equal to the rate at which heat is generated in the neck. Accordingly, a relatively low overload current, which is insufficient to cause fusing of the short necks **17,** may still be sufficient to cause fusing of the longer necks **16.**

The relationship between the lengths of the necks **16** and the minimum current density which will result in fusing of these necks is, not, however, the critical factor in the design of high voltage fuses with high rupturing capacity. In such fuses, the achievement of high rupturing capacity in respect of low overloads necessitates (a) the provision of a plurality of the longer necks **16** spaced from one another lengthwise of the fuse and electrically in series and (b) an arrangement whereby fusing and consequent arcing will occur simultaneously at a substantial number of these necks, whereby the energy released in the fuse as it fuses in response to a low overload will be spread over the length of the fuse rather than highly localised as it would be if fusing and arcing were to occur at only one or two of the necks, and whereby, furthermore, adequately rapid extinction of the arcing will be ensured. We have found that for any given type of fuse element with a plurality of necks **16** of given length, there is a critical current density (substantially higher than the minimum current density referred to above), below which only one or two of the necks **16** will fuse, whereas current densities above this critical value will result in fusing and arcing at all or substantially all the necks **16,** simultaneously. Accordingly, in designing a high voltage fuse with high rupturing capacity, for satisfactory operation in response to low overloads as well as to short circuit conditions, it is necessary to ensure that the current density to which the fuse elements will be subjected will exceed the critical current density during operation of the fuse in response to low overload conditions. If this is not done, the resulting highly localised and too-slowly extinguished arc energy will be liable to result in explosion or mechanical fracture of the fuse.

We have found, further, that the critical current density for the necks **16,** as referred to above, is a function of the lengths of these necks, as shown in FIG. **3** in which the legend: "Length of element reduced section" refers to the length of each neck **16.** As shown in FIG. **3,** increasing the lengths of the necks **16** has, initially, the effect of reducing quite markedly the critical current density which is required to produce substantial multiple arcing and consequent safe operation of the fuse in response to low overload conditions, but that further increases in the lengths of these necks have progressively less effect on the critical current density. Bearing in mind that each increase in the lengths of the necks **16** is accompanied by a corresponding increase in the resistance of the elements **15** and thus a corresponding decrease in the current carrying capacity of the fuse **11** (unless the cross-section of elements **15** is increased in compensation) it will be apparent that, for any required combination of current carrying capacity and response to low overload currents there is an optimum length for the necks **16.**

Further, we have found that at some value of breaking current, between a low overload current and a short circuit, the shorter notches **17** take over the main duty of interruption from the longer notches **16,** the actual value of this "transitional" current being dependent upon the ratio between the lengths of the longer and shorter necks.

Thus, having fixed the length of the longer necks **16** for optimum performance in response to a low overload, the shorter necks **17** are preferably, in order to minimise the resistance of these necks, made as short as possible consistent with the need to ensure that the transitional current will be sufficiently low (typically in the region of **1000** amps) for the longer necks **16** to handle with safety breaking currents which are just below this value.

Although a large total number of the notches **16** and **17** in series is necessary in order to achieve rapid extinction (usually within one half-cycle of the power supply) of the arcs which occur on fusing in response to a short circuit, thereby to limit severely the time during which the high short circuit current can produce a high rate of energy dissipation in the fuse, a comparatively small number of the necks **16** in series suffices to produce the slower extinction rate which is permissible of the arcs which occur at the necks **16** in response to a low overload. A slower arc extinction rate (say some 3–7 cycles of the supply power) in this latter case is permissible because the current flowing, and thus the instantaneous power dissipation within the fuse during arcing, is much less than in the case of a short circuit.

The foregoing discussion of the required response to the occurrence of a low overload has been presented in terms of a single fuse element formed with a plurality of the longer necks **16.** The relevance of this discussion to fuses according to the invention, which are provided not with a single fuse element but with a plurality of such elements in parallel, will be appreciated from the following description of the way in which the fuse described with reference to FIGS. **1** and **2** responds to a prolonged low overload current.

A prolonged low overload current of sufficient magnitude (i.e., producing in the necks **16** of each of the parallel-connected elements **15** a current density which is greater than the minimum current density referred to above) results, eventually, in a single one of the necks **16** of one of the elements **15** fusing first, to form a single gap in this element. Since this element is connected in parallel with several other elements **15** which are still intact, there is insufficient voltage across the said gap

to maintain an arc thereacross, and the arc is therefore extinguished substantially instantaneously. The current in the one element **15** is thus interrupted, and the current density in the necks **16** of the remaining elements **15** increases correspondingly. This results in a neck **16** of one of these other elements **15** fusing after only a short interval, to form another gap in which, similarly, the arc is quickly extinguished so that a further increase results in the current density in the necks **16** of the elements **15** which are then still intact. As successive elements **15** are thus interrupted, the current densities increase correspondingly in the necks **16** of the elements **15** still remaining intact; and by this means it is ensured that, at least in the last element remaining intact, the current density in the necks **16** will eventually exceed the critical current density, with the result that rupturing of this last element remaining intact occurs when all, or substantially all, its necks **16** fuse simultaneously.

Now when the necks **16** of this last element **15** fuse, there is no parallel-connected conductive path to hold down the voltage across the fuse to a level which is too low to maintain an arc (as was the case for, say, the first element **15** in which a single neck **16** fused but the arc thereacross was immediately extinguished as described above). However, when fusing occurs in the last remaining element **15** it occurs simultaneously at substantially all the necks **16** of that element, so that a corresponding plurality of arcs are produced in series; and, provided the number of these arcs is sufficiently large, the total arc voltage of all the arcs in series is correspondingly large and the excess, over this total arc voltage, of the voltage driving the overload current, will be insufficient to maintain these arcs which will therefore rapidly become extinguished. In practice, it is found that under low overload conditions (in which, in the element **15** which fuses last, the arc current and thus the instantaneous power dissipation in the fuse is much less, perhaps by a factor of **50,** than under short circuit conditions, so that much slower arc extinction, over, say, 3–7 cycles of the power supply, is permissible) the total arc voltage of the plurality of arcs in series will be sufficient to result in adequately rapid extinguishing of these arcs if the number of arcs involved is not less than the number of kilovolts of the supply voltage (i.e., of the voltage rating of the fuse appropriate to the situation).

Assuming, then, that the fuse is correctly rated for the situation in which it is being used, and that each of its elements **15** has the appropriate number of necks **16,** the last of its elements **15** will fuse and arc at all its necks **16** simultaneously and all these arcs will be extinguished with adequate rapidity. As soon as the current in this last element **15** is thus interrupted, the full supply voltage is applied across each of the other elements **15,** some of which have only one fused neck **16.** This results in an arc being struck again across the fused neck **16** of one (but only one) of these elements **15,** and the relatively high current density at all the other necks **16** of this one element **15** which are still intact causes them all to fuse simultaneously with a similarly adequate rate of extinction of all the arcs in series which result at the fused necks **16.** Then another, and subsequently each in turn (but only one at a time) of the elements **15** in which only one or a small number of the necks **16** had previously fused responds in the same way to the voltage to which all the elements **15** are subjected, until in each of the elements **15** all the necks **16** have been fused or at least so many have been fused that no arc can strike across them.

It will be understood that, although there may be appreciable time lags between the first stages of the above-described progressive rupture of the fuse under overload conditions, there is a progressive increase in the speed of the sequence of events and the later stages occur with great rapidity.

As noted above, the much lower arc currents which occur on response of the fuse to low overload conditions means that a much lower arc extinction rate can be permitted, consistent with safe operation of the fuse, and this in turn means that the number of "overload" necks **16** which must be provided in any one element **15,** in order to ensure that the corresponding number of arcs in series will have a sufficiently high total arc voltage to provide the requisite rate of extinction of all the arcs, is substantially less than the total number of "short circuit" necks **17** and necks **16** which must be provided in each element in order to ensure the much more rapid rate of arc extinction which is required under short-circuit conditions when the arc currents, and the power dissipation in the fuse, are higher. As a result of the relatively small number of "overload" necks **16** with which each element **15** is accordingly provided, the resistance of the fuse, and hence its current carrying capacity, are comparatively unaffected by these necks. Also, since multiple arcing at the necks **16** is achievable at relatively low current densities per element, due to the length of these necks, fuses according to the invention may employ fewer (and more robust) elements **15** for a given overload capability. It is, however, an essential feature of the invention that the fuse should comprise a plurality of elements in parallel, so that, on initial failure of each element in turn during subjection of the fuse to prolonged overload conditions, the current density in those remaining intact will increase progressively to such a level, exceeding the critical current density, that the initial failure of the last to fail will be by simultaneous fusing of all or most of its "overload" necks **16.**

It should be understood that, in known manner, each element **15** may be provided at spaced points along its length with spots or blobs of solder such as that shown at **18** in FIG. **2,** as a protection against long-continued overloads at a still lower level which would be insufficient to fuse the overload necks **16.** At the so-called M-effect zones so provided, the general heating of the element **15** which results from a prolonged low-level overload results in the solder blob **18** melting and its material gradually migrating into the still-solid body of the element **15** to form with the material thereof a eutectic solid solution of which the melting point is substantially less than that of the unalloyed material of the element **15,** so that the element **15** eventually fuses at the position of one of the blobs **18.** Once this occurs, a sequence of events follows which is similar to that, already described, which occurs when the fuse responds to an overload sufficient to fuse first one, and then all or most of the others, of the overload necks **16.** The fusing of one element **15** at one of its M-effect zones results in current through that element being interrupted and in an increase in current through the remaining elements **15,** so that either an M-effect zone or an overload neck **16** in one of those other elements **15**

will be caused to fuse in turn, leading to a progressive build-up or avalanche effect as above described.

Although the fuse element has been described with reference to the particular embodiment illustrated it is to be understood that various modifications may readily be made without departing from the scope of this invention. For example, the invention is not necessarily restricted to the use of notches having only two different lengths since one or more further groups of notches may be incorporated, dimensioned for optimum performance under conditions intermediate between a low overcurrent and a short-circuit, the lengths of these further groups being different from the other two mentioned.

It should also be understood that although the foregoing description has illustrated the invention only in terms of fuse elements having necks formed by notching the elements to reduce the cross-section at the necks, the invention is in general applicable also to fuses in which the fuse elements have the required portions of reduced cross-section formed in any other suitable manner, such as by forming apertures through the elements or transverse grooves across them.

We claim:

1. A multi-element high-voltage fuse comprising a plurality of similar parallel-connected fuse elements, wherein each fuse element comprises a fusible strip having a plurality of first portions (**16,16**) of reduced cross-section spaced apart along the strip and, interposed between each mutually adjacent pair of said first portion (**16,16**) a plurality of spaced-apart second portions (**17,17,17**) of reduced cross-section each of said second portions being essentially shorter in length that the length of each of said first portions.

2. A fuse as claimed in claim **1,** wherein each fuse element comprises at least one of said first portions per kilovolt of the voltage rating of the fuse.

3. A fuse as claimed in claim **1,** wherein the strips are notched to form said first and second portions.

4. A fuse as claimed in claim **2,** wherein the strips are notched to form said first and second portions.

5. A fuse as claimed in claim **1,** wherein the ratio of the lengths of said first and second portions is in the range from 4:1 to 12:1.

6. A fuse as claimed in claim **2,** wherein the ratio of the lengths of said first and second portions is in the range from 4:1 to 12:1.

7. A fuse as claimed in claim **3,** wherein the ratio of the lengths of said first and second portions is in the range from 4:1 to 12:1.

8. A fuse as claimed in claim **4,** wherein the ratio of the lengths of said first and second portions is in the range from 4:1 to 12:1.

9. A fuse as claimed in claim **1,** wherein each element is provided at spaced points along its length with spots of solder (**18**) as a protection against long continued overloads at a still lower level which would be insufficient to fuse the overload first portions (**16**).

10. A fuse as claimed in claim **1,** wherein said plurality of fuse elements are wound in generally helical form having the ends thereof in electrical contact with end caps.

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