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J. SLEPIAN ET AL

1,936,803

FUSE

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Fig. 1.

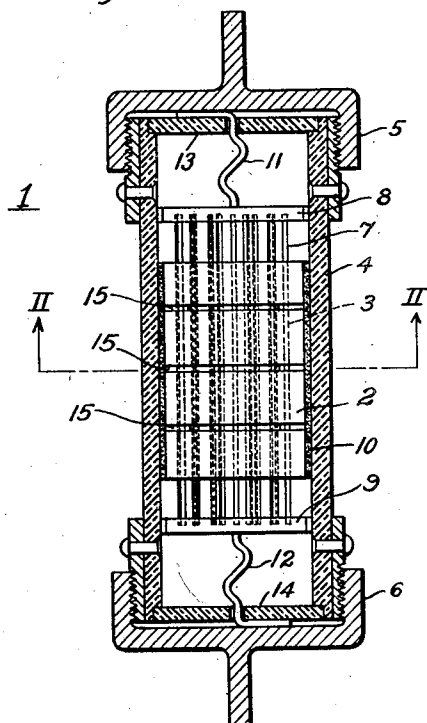


Fig. 2.

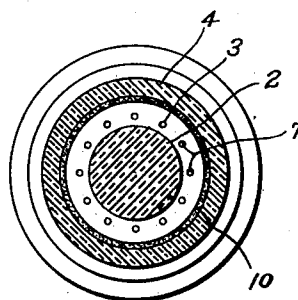


Fig. 3.

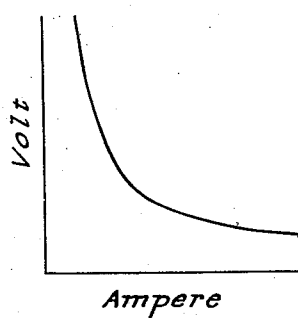
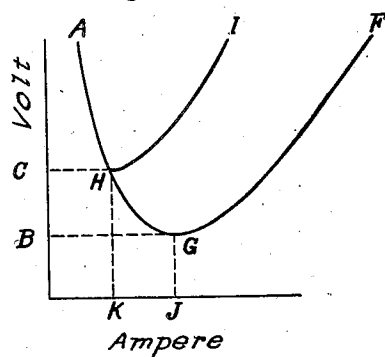


Fig. 4.



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FUSE

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Serial No. 240,747

13 Claims. (Cl. 200—131)

Our invention relates to electrical circuit interrupting devices and more particularly to high-voltage fuses for alternating-current circuits.

One object of our invention is to provide a fuse that shall be capable of interrupting high-voltage alternating-current circuits.

Another object of our invention is to provide a fuse for high-voltage circuits that shall not employ a liquid medium surrounding its fusible element.

Another object of our invention is to provide a fuse for high-voltage circuits that may be manufactured at such low cost that replacement of a ruptured fuse by a new one is cheaper than the factory renewal of the ruptured one.

A further object of our invention is to utilize an insulating medium to closely confine an arc and to so rapidly reduce the conductivity of the arc path upon the arc current passing through zero value that the arc is then permanently extinguished.

Heretofore, fuses for high-voltage alternating-current circuits have almost exclusively utilized a liquid medium, such as oil, carbon tetrachloride or the like to bring about the extinction of the arc when the current passes through zero value. This type of fuse requires a hermetically sealed tube which makes it an expensive piece of apparatus that must be returned, after rupture, to the manufacturer for renewal.

We have found that the arc resulting from the rupturing of a fuse on an alternating-current circuit in air may be fully interrupted and arc re-ignition prevented, even more effectively than in a liquid fuse, if it is distributed among a plurality of confining insulated recesses each of which limits the expansion of the arc therein until the decrease of the current in the course of its cycle results in an unstable condition existing among the aforesaid arc sections, as will be more fully explained hereinafter. Then, as the current further decreases, the several sections are extinguished in succession until, when the current reaches zero value, the arc finally becomes entirely extinct. All parts of the arcs being very close to the walls of the insulating channels, the ions which are responsible for the conductivity of the arc are enabled to very rapidly discharge to the walls and recombine there, so that the arc will not restrike in spite of the sub-

sequent exceedingly rapid increase of voltage between the fuse terminals.

Our invention will best be understood by referring to the drawing wherein:

Fig. 1 is a view, partly in section and partly in elevation, of a fuse embodying our invention.

Fig. 2 is a cross-sectional view of Fig. 1, taken on the section line II—II.

Fig. 3 is a volt-ampere curve representing the characteristic of stable operation of an unconfined arc in air, and

Fig. 4 is also a volt-ampere curve showing the relation of the arc voltage to the current during a stable operation when the arc completely fills an insulated confining medium.

Our invention comprises, in general, a fuse 1 that is provided with an insulating member 2 having perforations 3 of a number and diameter corresponding to the fuse rating and which is supported in a main body portion 4. Parallel arcs may be drawn into the confining channels 3 of the insulating member 2 where they will be sustained until a reduction of current in the course of its alternating cycle produces an unstable condition, resulting in the extinction of the arcs in succession as the current decreases. Upon the current reaching zero value, all of the arcs will have been extinguished and, after the voltage of the fuse terminals again increases, re-ignition of the arc will be prevented in a manner hereinafter more fully described.

A particular form of our invention is shown in the accompanying drawing in which the fuse 1 is constituted by the outer casing 4 having end terminals 5 and 6 that may be of any design employed in the art. Supported by cement 10 within the outer casing 4 is the insulating member 2 having perforations 3 through which fuse elements 7 extend and are connected at each of their ends to arcing plates 8 and 9. The arcing plates 8 and 9 are electrically connected to the terminals 5 and 6 by the shunts 11 and 12 clamped between the washers 13 and 14, and the end terminals 5 and 6. Slots 15 are provided along the circumference of the insulation member 2 to form passages joining the perforations 3 to be more fully explained hereinafter.

Assuming the fuse to be in its operating position, connected in a high-voltage alternating-current circuit, the current will pass through the terminals

5 and 6, shunts 11 and 12 and the arcing plates 8 and 9 to the fuse elements 7. If a short circuit occurs in the line, the latter are melted and the molten metal is expelled from the channels by the volatilization of a portion thereof near the middle of each channel. This will result in the establishment of a set of parallel arcs that will be confined within the walls of the perforations 3.

As, in the course of its cycle, the current approaches zero, the arcs become unstable and are extinguished one by one until, at the zero point, all the arcs will have been entirely extinguished. This having happened, the proximity of the confining walls brings about a rapid recombination of the ions of the arc path, and the conductivity therein is so reduced that re-ignition of the arc is prevented. It follows that the time required for completely interrupting the circuit by this means will be a half cycle of alternating current or less.

We have found that, if an alternating-current arc is confined to a narrow channel or hole of small section, comparatively high voltages per inch length of arc may be interrupted. Thus, at 60 cycles, in a $\frac{1}{8}$ inch hole, an arc will be interrupted in a circuit having 280 volts per inch of arc length; in a $\frac{2}{16}$ inch hole, 520 volts per inch may be interrupted, and in a $\frac{1}{4}$ inch hole, more than 1150 volts per inch may be interrupted. However, we find that, if the current in the arc in such small holes is too large, very large disruptive forces develop which the insulating material cannot withstand, or so much heat is developed as to destroy the material. We, therefore, employ a plurality of small holes and cause arcs in parallel to form in these holes and thus subdivide the current so that a destructively large current will not flow in any one hole. To understand how arcs in holes will operate in parallel, it is necessary to consider the volt-ampere characteristics of such confined arcs.

Experiments have shown that the voltage of an unrestricted arc in air is decreased as the current is increased, or, vice versa, as shown by the curve in Fig. 3, of the accompanying drawing. We have found, however, that, when the arc plays in a confining hole, the volt-ampere characteristic takes the form shown by the curve A G F in Fig. 4. We believe that the minimum point G of the curve occurs for that value of current which first produces an arc that entirely fills the recess within the insulating medium and that it is because of the confining action of the recess walls that an increase of current beyond this value results in the arc-voltage curve having an ascending characteristic which rises rapidly with increase in current. Thus, in the curve A H G F of Fig. 4, a current increase to the value J corresponds to a voltage decrease to a value B. Beyond the point G, on the curve, however, at which it is probable that the arc entirely fills the recess in the insulating medium and can no longer expand with a further increase of the current value, the voltage will rapidly increase with further rise of current, as illustrated by the portion G F of the curve. The point G represents the minimum voltage that can sustain an arc in the recess in question.

If, however, the recess should be so small that the filling thereof by the arc would occur at H the current would have increased only to the value K when this deviation from the open-arc characteristic occurred. This corresponds to the higher minimum voltage indicated at C. A further increase in the current value that would re-

sult in a rapid increase of arc voltage is illustrated by the curve HI in Fig. 4.

From Fig. 3 it can be shown that parallel arcs in free air cannot attain an equilibrium. It should be noted that Fig. 3 represents the relationship between arc current and voltage when conditions in the arc have attained a permanent and stable condition. When the arc current undergoes a change for any reason there is a transient condition, during which a new equilibrium is being attained in the arc, during which the arc current and voltage do not correspond to this curve. As soon as equilibrium is established and this transient condition has passed, the arc voltage and current have the relation shown by Fig. 3.

To show by means of Fig. 3 the above-mentioned inability of arcs to operate in parallel in free air, suppose two arcs momentarily to be carrying the same current; then voltages are of necessity the same. If, an instant later, one arc tends to take more than its share of current, there would need be a corresponding decrease in its voltage according to Fig. 3. However, the terminal voltage cannot decrease by the proper amount once the two arcs are directly in parallel. There will thus be an excess of applied terminal voltage over that required to maintain the arc, and this excess of voltage will act on the inductance of the arc circuit and cause the current to increase still further. Similarly, the arc which is taking less than its share of current will require more voltage for its maintenance than is applied at its terminals, and this deficiency will be supplied by the inductance of the arc circuit with corresponding further decrease in current. Parallel operation of arcs with static characteristics like Fig. 3 is thus impossible.

From Fig. 4, it can be shown that, if the parallel arcs have expanded to fill their insulated recesses, that is, if the current is great enough so that the resulting voltage is on the ascending side of the curve, then, upon an increase in current in any one of the arcs, there would, to maintain it in continuous operation at that current, have to be a corresponding increase in voltage. Since, because of the parallel connection, this increase of terminal voltage cannot take place, there will result a shift of current into the other arcs which will cause all of the arcs to again take equal currents. Arcs having static operating characteristics like Fig. 4 will thus operate in parallel without difficulty and with an even distribution of current between the various arc paths.

If our fuse is provided with too great a number of perforations, the current may not be great enough to expand the arcs to fill all the perforations. The voltage, therefore, will be on the descending side of the curve, resulting in an unstable condition and the extinguishing of one or more of the arcs until the remaining arcs will be of such number that, with the current flowing, they will fill their respective confining spaces. The arc voltage will be on the ascending branch of the curve and the parallel arc sections then existing will be in equilibrium. It, therefore, follows that a particular number, size and length of the perforations should be chosen for a particular duty for which the fuse is rated.

However, a sufficient number of perforations should always be selected for a given duty so that the arc voltage will be near the lower extremity of the curve, for this gives the minimum energy input into each perforation, and the minimum disruptive and destructive effect.

After the current has reached its maximum

value and is decreasing towards zero value, the arc voltage again changes to the descending branch of the curve and the arcs become unstable, resulting in their being extinguished one by one as the curve approaches zero value.

The rate of recombination of the ions in the arc paths is so very greatly increased by their close proximity to the wall of the perforations that, after the current passes through zero value, the voltage gradient required to restrike the arc between the terminals rises extremely rapidly. For the usual commercial circuit, we find it easy to build our fuse so that this required rate of rise of voltage is greater than the rate at which voltage applied from the line can rise and so the arc remains permanently extinguished.

It has been found from experiment that, when a relatively high-resistance short circuit occurs, all of the fuse wires will melt and if the current is only large enough to fill one hole, the other holes will be free of arc and the metal vapors therein will condense. If, when this condition is present, a dead short circuit occurs so that the current through the fuse builds up very rapidly, all of the current will be in one hole and the arc will not restrike in the other holes due to the said condensation of the metal vapors that would otherwise have formed a path for the arc. With such a large current in only one hole, destructive forces would be developed and the fuse destroyed. To overcome this possible condition and assure the operation of our type of fuse at all times, we provide our structure with lateral interconnecting passages 15 in predetermined spaced relation so that the gases from the single arc present in the said one hole will be forced through the lateral passages into the adjacent longitudinal holes. With the arc voltage increasing with increasing current, as described hereinbefore, arcs will be struck in the adjacent holes and the total current will divide satisfactorily in parallel arcs.

Accordingly, our invention comprises a fuse for high-voltage alternating currents that can be manufactured at a very low cost, that eliminates the necessity of having the fuse returned to the manufacturer for renewal since a new fuse can be substituted at very little expense. Our invention also eliminates the need of care in handling a high-voltage fuse as it has none of the fragile properties found in the ordinary high-voltage fuse employed today.

We do not wish to be restricted to the specific arrangement of parts herein set forth as various modifications thereof may be effected without departing from the spirit and scope of our invention. We desire, therefore, that only such limitations shall be imposed as are indicated in the appended claims.

We claim as our invention:

1. In a fuse structure, an insulating member having a plurality of channels, a plurality of parallel fuse elements singly disposed within the channels and united at their projecting ends and means for interconnecting the channels at intermediate points thereof.

2. The combination, in a fuse structure, of an insulating means provided with a plurality of perforations of narrow width, a plurality of fuse elements singly disposed within the perforations, and passages for uniting the perforations at intermediate points thereof.

3. In a fuse structure, an insulating member having a plurality of channels adjacent the periphery thereof, a plurality of parallel fuse elements singly disposed within the channels and

an interconnection for the said channels intermediate their ends.

4. In a fuse structure, an insulating member having a plurality of channels near the periphery thereof, a plurality of parallel fuse elements singly disposed within the channels and a plurality of passages interconnecting the said channels intermediate their ends.

5. In a fuse structure, an insulating member having a plurality of channels, some of said channels being disposed in the body of said insulating member and others of said channels being disposed at the surface of said insulating member to interconnect the first said channels and a casing tightly covering the said insulating members for sealing the last said channels.

6. In a fuse structure, an insulating member having a plurality of channels, some of said channels being disposed in the body of said insulating member and others of said channels being disposed at the surface of said insulating member to interconnect the first said channels, a fusible member in each channel in the body portion of the member and a casing tightly covering the said insulating members for sealing the last said channels.

7. The combination, in a fuse structure, of an insulating member provided with a plurality of perforations of narrow width interconnected intermediate their extremities, fuse elements singly disposed within said perforations.

8. A fuse structure of substantially unyielding insulating material having a plurality of insulated channels therein of small cross-section and a long length, and a plurality of parallel fuse elements singly disposed within the channels and integrally united at each of their projecting ends to form a terminal at each end of the fuse structure.

9. In a fuse structure, an insulating member of substantially rigid material having a plurality of channels therein of small cross-section and a long length, and a plurality of parallel fuse elements singly disposed within the channels and non-adjustably united at each of their projecting ends.

10. The combination, in a fuse structure, of an insulating member of substantially unyielding material provided with a plurality of perforations of narrow width, and a plurality of fuse elements singly disposed within the perforations and integrally connected together at both ends, said fuse elements being enclosed for a major portion of their length in said perforations.

11. In series with an electric circuit, a plurality of fuse elements integrally connected at both ends, each confined in a recess having rigid walls in an insulating medium, said recess confining the arc for the major portion of its length and the cross-section of said recesses being such that the heat generated within said recess, within one-half cycle, shall not cause insulation breakdown of its walls.

12. In series with an alternating-current circuit and apparatus supplied thereby, a fuse comprising a plurality of fuse elements integrally and permanently connected in parallel with each other, each confined in a channel through a substantially unyielding insulating material, the cross-section of each said channel along the major portion of the length of said fuse elements being such that the minimum alternating voltage capable of continuously maintaining an arc therein is approximately the same as the voltage of said circuit available at the terminals of said

fuse under the circuit conditions at which it is to operate to interrupt said circuit.

13. In a fuse structure, an insulating member having a plurality of perforations of small cross-section defined by rigid walls, a plurality of parallel fuse elements singly disposed within and enclosed by the perforations for a long length and fixed terminals to which the fuse elements are

electrically connected permanently at each of their projecting ends, whereby upon the rupturing of all of the fuse elements, arcs will be sustained between the terminals through the plurality of perforations.

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