May 5, 1964 P. C. JACOBS, JR 3,132,223

FUSIBLE PROTECTIVE DEVICES FOR CABLE PROTECTION

Filed June 19, 1961 2 Sheets-Sheet 1

Fig. 1

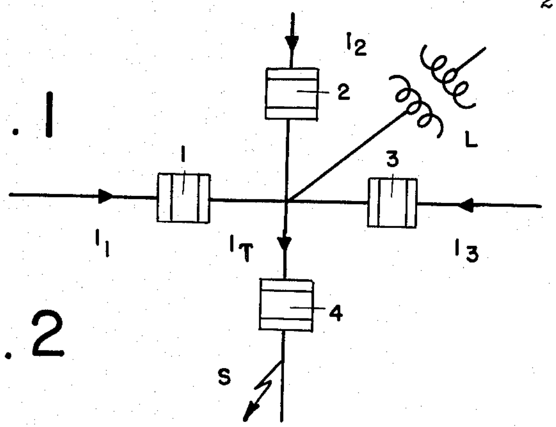


Fig. 2

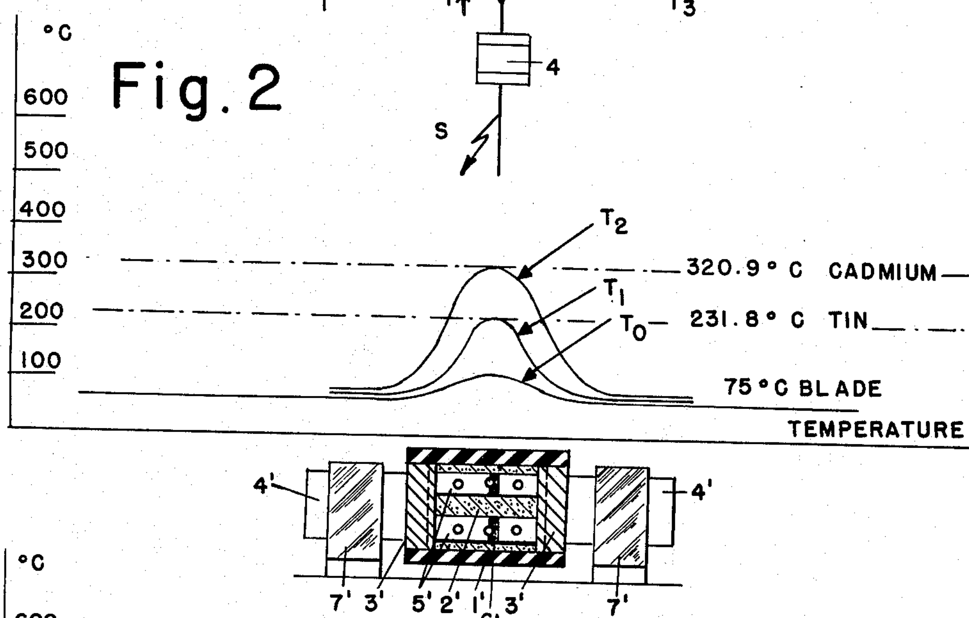
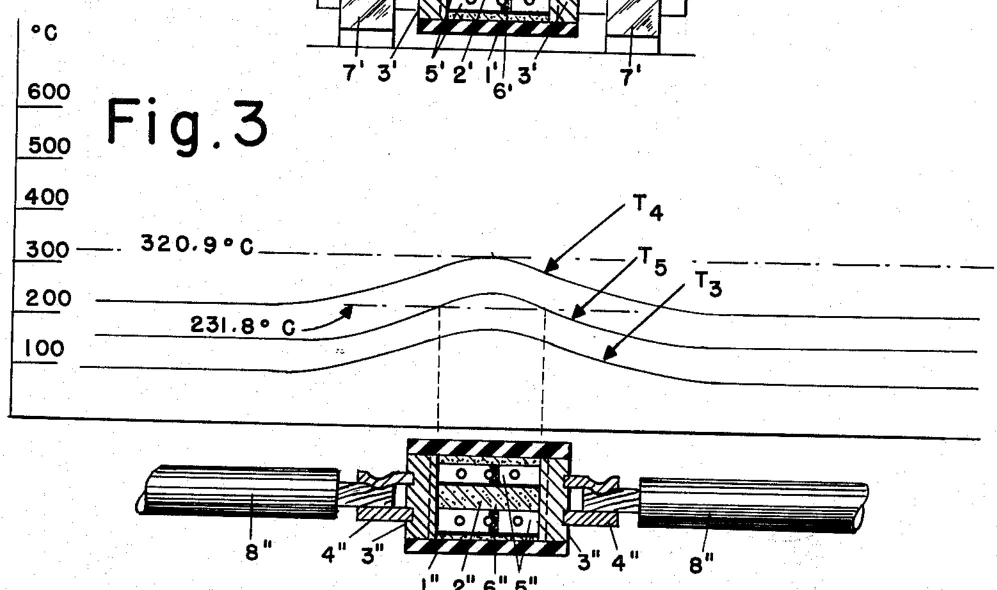


Fig. 3



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2 Sheets-Sheet 2

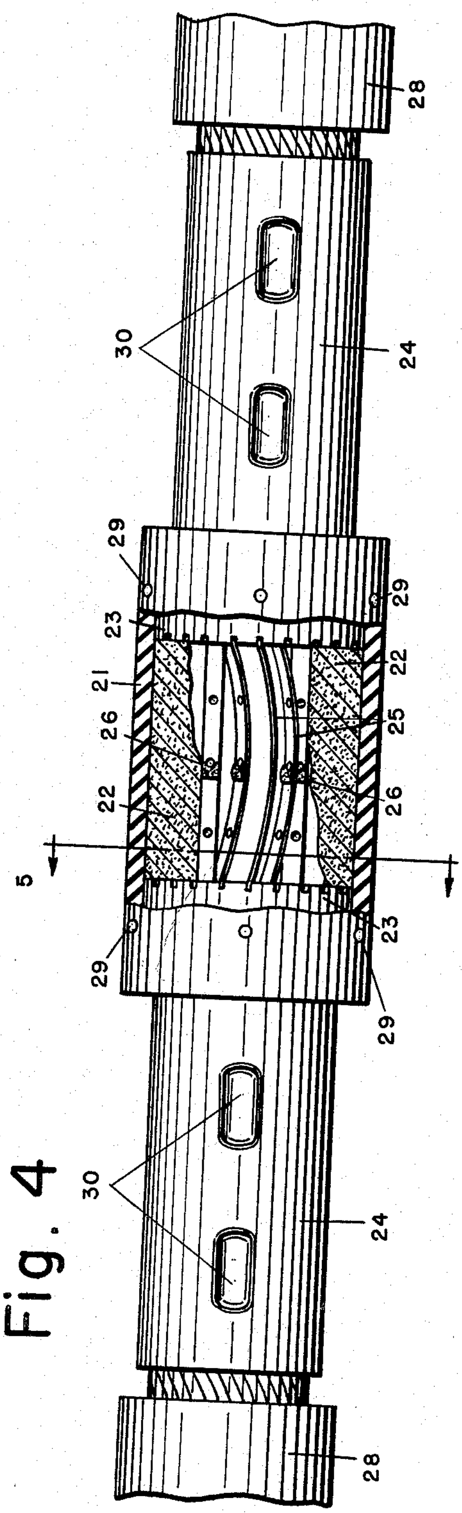

Fig. 4

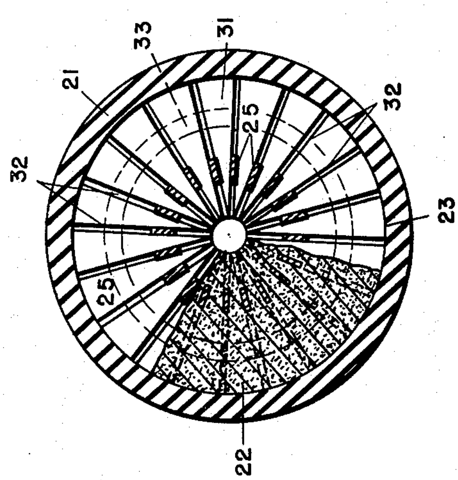

Fig. 5

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FUSIBLE PROTECTIVE DEVICES FOR CABLE PROTECTION

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7 Claims. (Cl. 200—120)

This invention has reference to cable protection, and more particularly to the protection of cable networks.

It is one of the objects of this invention to provide improved fusible protective means adapted for use in cable networks.

Another object of this invention is to provide fusible protective devices for use in cable networks which devices have substantially the same degree of interrupting capacity and selectivity normally only encountered in current-limiting fuses.

A current-limiting fuse of standard design is generally not suitable for use in cable networks.

It is, therefore, another object of this invention to provide devices in the nature of a current-limiting fuse adapted for service in cable networks.

It is possible to distinguish between two general classes of fusible protective devices for the protection of cable networks. In devices of one class the fusible element is formed by a relatively large mass of metal having a relatively low fusing point. These devices are selective because of the great time lag involved in their operation. The main disadvantage of this type of protective devices is their relatively limited interrupting capacity. In addition thereto this type of devices involves relatively high watt losses. Devices of the other above referred-to-classes include multiperforated ribbon-type fuse links of a metal such as silver, or copper, having a high conductivity and a high fusing point and they further include a pulverulent arc-quenching filler as, for instance, quartz sand.

This invention is concerned with the second type of fusible protective devices. While this invention proposes to apply some of the principles underlying the design of a current-limiting fuse it represents a drastic departure from prior art devices for the protection of cable networks designed along lines similar to a current-limiting fuse.

United States Patent 2,770,757 to William S. Edsall, November 13, 1956, "Arrangement for the Protection of Cables Against Short-Circuit Currents and Against Overloading" is concerned with a fusible device for the protection of cable networks designed along lines similar to those underlying the design of a current-limiting fuse.

The above Edsall device is a composite device of which one unit produces a circuit interrupting break on the occurrence of short-circuit currents and another unit produces a circuit interrupting break on the occurrence of overloads.

It is, therefore, another object of this invention to provide simplified fusible devices for the protection of cable networks designed along lines similar to those underlying the design of a current-limiting fuse but having one single integral unit for interrupting both short-circuit currents and overload currents.

The above Edsall device is predicated on the concept that the heat generated in the protective device should be minimized and that the heat required for its operation should mainly be furnished by the cable for the protection of which it is provided, and the above Edsall device is further predicated on the concept that the time-current characteristic of the protective device should follow as closely as possible the smoking point characteristic, or the insulation damage characteristic, of the cable.

The present invention follows in general the above

concepts as far as the source of heat for operating the device is concerned, but deviates drastically from the Edsall concept of matching the characteristic of the protective device with that of the cable. As long as it is the principal object of a cable protective device to extend the life of cables as much as reasonably possible, the characteristic of the protective device should necessarily match as close as possible the insulation damage characteristic of the cable. Considerations of continuity of service may, however, make it desirable to more or less drastically depart from the above Edsall doctrine of matching of characteristics.

It is, therefore, a further object of this invention to provide fusible protective devices for the protection of cable networks which are designed along lines similar to a current-limiting fuse but are adapted to maintain continuity of service even at the expense of the life of cables as long as there is no immediate explosion or fire hazard.

These and other objects of the invention and advantages thereof will become more apparent from the accompanying drawings and the following description of a preferred embodiment of the invention.

In the drawings

FIG. 1 is a diagrammatic representation of a portion of a cable network;

FIG. 2 shows diagrammatically or qualitatively the temperature distribution along a fuse structure which is inserted into a conventional fuse holder;

FIG. 3 shows diagrammatically or qualitatively the temperature distribution along a fusible protective device which is designed according to this invention;

FIG. 4 is in part a longitudinal section and in part a side elevation of a protective device embodying this invention; and

FIG. 5 shows the same device as FIG. 4 taken along 5—5 of FIG. 4.

Referring now to the drawings, and more particularly to FIG. 1 thereof showing a portion of a cable network, it has been assumed that a short-circuit has occurred at the point S causing fault currents I_1, I_2 and I_3 to flow in the sound cables of the network. If continuity of service is to be maintained the fuse **4** must blow to disconnect the short-circuited cable from the network, while fuses **1**, **2** and **3** must remain intact. In other words, fuses **1**, **2**, **3** and **4** must operate selectively. Assuming the current drawn by load L to be zero, or that load is connected to the particular point of the network, then the total current I_T flowing from the three sound cables through fuses **1**, **2** and **3** into the fault is given by the equation

$$I_T = I_1 + I_2 + I_3 \tag{1}$$

The largest of the three currents I_1, I_2 and I_3—which may be referred to as I_{max}—must not cause the fuse by which it is being carried to blow, whereas I_T must be sufficiently high to cause blowing of fuse **4**. The ratio

$$I_{max}/I_t = r \tag{2}$$

is a measure for the degree of selectivity required between fuses **1**, **2**, **3** and **4**. The fusible devices generally referred to as cable protectors achieve the degree of selectivity required by resorting to fusible elements involving a large mass and considerable delay times in the overload current range. This results in a critical limitation of interrupting capacity. Current-limiting fuses combine a high degree of selectivity with a high degree of interrupting capacity but generally do not lend themselves to the protection of underground cable networks. This is one of the reasons why it was not possible, heretofore, to achieve a satisfactory protection of underground cable networks.

FIG. 1 pre-supposes that fuses **1**, **2**, **3** and **4** are identical, and are subjected to excess currents of different magnitude. On occurrence of a short-circuit at the point S selective operation of the two fuses subjected to the highest currents I_{max} and I_T will occur if and when the condition is met that the sum of the fusing $\int i^2\cdot dt$ and of the arcing $\int i^2\cdot dt$ of fuse 4 carrying the current I_T is smaller than the fusing $\int i^2\cdot dt$ of the fuse carrying the current I_{max}. In current-limiting fuses designed to have the smallest possible let-through currents and the highest possible selectivity the fusing $\int i^2\cdot dt$ and the arcing $\int i^2\cdot dt$ are substantially equal. Therefore the condition for selective operation can be stated by the following inequality:

$$2r^2\int_0^{t_f} i^2\cdot dt<\int_0^{t_f} i^2\cdot dt \qquad (3)$$

wherein t_f is the fusing time and r the ratio defined by Equation 2. Hence

$$r<\sqrt{1/2} \qquad (4)$$

It will be understood that the above calculation has been made assuming that the currents under interruption are relatively high—short-circuit current—and the interrupting times sufficiently short to make is permissible to neglect heat exchange phenomena and to consider all $\int i^2\cdot dt$ values as being constants.

It is possible to plot the above ratio r against the available short-circuit current I_T. The ratio r decreases progressively as the total fault current I_T increases. Selectivity can readily be achieved in the overload range where the ratio r may be between 80% and 90%. In the current-limiting range to which inequalities 3 and 4 apply $r<\sqrt{1/2}\approx.70$. In other words, in the current-limiting range the ratio r becomes a constant approximately equal to .70. Therefore selectivity will be maintained in the current-limiting range as long as the highest partial current I_{max} is about 70%—but not more than 70%—of the total fault current I_T. It is noteworthy that this high degree of selectivity is compatible with the high interrupting capacity inherent in current-limiting fuses.

Current-limiting fuses progressively decrease the duration of the flow of fault currents as the magnitude of available fault currents increases. The total fusing and arcing $\int i^2\cdot dt$ then approaches a fixed value which is substantially equivalent to a fixed predetermined temperature rise for a cable of particular size. This suggests that current-limiting fuses be applied for the protection of cables provided that they can be adapted to meet all requirements of a cable protector.

The Standards for Safety "Fuses UL 198" Seventh Edition of the Underwriter Laboratories, Inc., April 1955 (reprinted July 1959) specify the permissible maximum temperature rise Δt above ambient air in degrees centigrade indicated in the table below.

Fuse rating in amps.	Δt on ferrules or on blades in ° C.
0-30	50
31–60	50
61–100	50
101–200	60
201–400	65
401–600	75

Maximum-peak transient temperatures may be somewhat higher.

The National Electrical Code 1959 specifies in article 310 thereof maximum operating temperatures of cables. The maximum operating temperature of moisture and heat resistant rubber cables has been specified to be 60° C., and the maximum operating temperature of silicone absestos cable has been specified to be 90° C. Maximum-peak transient cable temperatures may be somewhat higher. It is considered safe practice to allow maximum-peak transient temperatures of rubber cables up to 150° C.–175° C. admitting but a moderate reduction of the useful cable life. If continuity of service is considered a matter of prime importance, and progressive destructive

disintegration of organic cable insulation a matter of secondary importance, then a kind of current-limiting cable protector can be evolved along lines which will be outlined below more in detail.

Fusible current-limiting protective devices intended to afford short-circuit protection as well as overload protection should include multiperforated ribbon fuse link means of a metal having a fusing point in the order of 1000 deg. C., e.g. of silver or copper, and overload-responsive fuse-link-severing means having a substantially lower fusing point. Upon reaching their low fusing point the fuse-link-severing means sever the current path through the fuse link means. A fuse link in form of a multiperforated silver ribbon having an overlay of tin—whose fusing point is 232 deg. C.—will be severed by a metallurgical reaction between silver and tin when the latter is heated up to and beyond its fusing point. If it is intended to provide a protective fusible device allowing, in case of severe overloading, a relatively rapid progressive disintegration of organic cable insulation and effecting interruption of the overloaded circuit only in case the cable becomes a fire hazard, then the overload-responsive fuse-link-severing means must become operative only at higher temperatures than the fusing point of tin, preferably at temperatures in the range of 300 deg. C. An overlay of cadmium on a ribbon fuse link of silver or copper will well serve the purpose of an overload-responsive fuse-link-severing means, cadmium having a fusing point of 320.9 deg. C.

A cadmium overlay or other overload-responsive link-severing means becoming operative at a temperature in the order of 300 deg. C., if used in a conventional fuse or a current-limiting fuse does not give rise to any particular problems, but when such an overlay or other link severing means which becomes operative in the temperature range of 300 deg. C. is used in a fuse that inter-connects two lengths of cable, this gives rise to a thermal problem. The reason for this difference in behavior resides in the fact that in conventional fuses and current-limiting fuses there is a steep temperature gradient from the hot spot to points axially and radially spaced from the hot spot, whereas such a steep temperature gradient is lacking in a protective device of the contemplated nature. Therefore the casing of such a device will be subjected to very high temperatures. If the casing is made wholly or in part of an organic insulating material that is allowed to deteriorate progressively in the same fashion as the insulation of the cable is allowed to deteriorate, then the casing may not be able to withstand the pressure incident to a severe circuit interruption. It is, therefore, necessary to avoid thermal impairment of the casing material even though thermal impairment of the cable insulation is deemed permissible. Hence the casing must be made of a mechanically strong heat resistant material, preferably of a silicone-resin-glass-cloth laminate.

The fusible element or elements of a protective device intended to be connected into a cable should be able to rapidly dissipate the heat resulting from relatively short overloads. This can be achieved by providing the protective device with a pair of terminal elements including blocks of solid metal, e.g. in form of a pair of plugs closing the ends of the tubular casing or fuse tube. Such terminal elements are well known and used in the current-limiting fuse art and are shown, for instance, in U.S. Patent 2,658,974 to Frederick J. Kozacka, November 10, 1953, High Current Carrying Capacity Current-Limiting Fuses. It is hardly feasible to spot-weld fusible elements in ribbon-form to terminal elements in the form of blocks of solid metal as, for instance, terminal elements in the form of plugs of solid metal closing the ends of the casing or fuse tube. The only feasible or practical way of conductively connecting fusible elements in ribbon form to terminal elements in the form of blocks of solid metal is by way of soft soldering. It is common practice in current-limiting fuse technology to use tin solder or similar solder on a tin basis for establishing solder joints between the axially outer ends of ribbon-type fuse link means and terminal elements involving a relatively large mass of copper. Because of the differences between a normal current-limiting fuse and a cable protector of the kind under consideration, the use of tin solder, or of a similar solder on a tin basis, is not indicated in the latter case. This will now be explained more in detail in connection with FIGS. 2 and 3.

Referring now to FIG. 2, this figure illustrates diagrammatically a conventional current-limiting fuse. The current-limiting fuse shown in FIG. 2 comprises a tubular casing **1′** of insulating material, a pulverulent arc-quenching filler **2′** within casing **1′**, a pair of cylindrical copper blocks **3′** closing the ends of casing **1′** and a pair of blade contacts **4′**, each integral with one of copper blocks **3′**. Multiperforated fuse link means **5′** of a metal having a fusing point in the order of 1000 deg. C.—silver or copper—conductively interconnect plugs **3′**. To this end the axially inner surfaces of plugs **3′** may be provided with grooves into which the axially outer ends of link means **5′** may be inserted and which grooves may be filled with tin solder (not shown), or another soft solder which is comparable to tin solder. Each link means **5′** is provided near the center thereof with an overlay **6′** of tin. Overlays **6′** are fuse-link-severing means which, upon fusion thereof, sever the current path through fuse link means **5′** by a metallurgical reaction involving the dissolution of the high fusing point base metal—silver or copper—in the low fusing point overlay metal—tin—and the penetration of molecules of the low fusing point metal into the molecular structure of the high fusing point metal. The ends of blade contacts **4′** are inserted into a pair of fuse holder contacts **7′**. The curve T_0 indicates temperature distribution in a direction longitudinally of the device when the latter is carrying its rated current. The curve T_1 indicates the temperature distribution along the axis of the device assuming predetermined watt losses occurring therein. It is apparent from curve T_1 that the center of link means **5′** has reached the fusing point of tin—231.8 deg. C.—at which temperature the link-severing process by overlay **6′** is initiated. Assuming that the tin overlay **6′** is replaced by a link-severing overlay having a higher fusing point than tin, e.g. an overlay of cadmium whose fusing point is 320.9 deg. C. and further assuming that the wattage dissipated in the structure is increased to such an extent that the temperature of the hot-spot of the structure is raised to the fusing point of cadmium, this results in a temperature distribution as represented by the characteristic T_2. The temperature of the blade contacts **4′** when carrying the rated current is about 75 deg. C. It is apparent from FIG. 2 that the temperature of the blade contacts **4′** rises but slightly if the load is increased to such an extent as to result in temperature distribution curves T_1 and T_2. The particular temperature distribution illustrated in FIG. 2 is primarily due to the fact that the temperature of fuse holder contacts **7′** remains low even at currents which are a multiple of the current rating of the current-limiting fuse which is being supported by them.

In FIG. 3 the same numerals as in FIG. 2, however, with two primes added, have been applied to indicate like parts as in FIG. 2. Hence FIG. 3 does not call for a detailed description in regard to the structure illustrated therein. Numeral **8″** has been applied to indicate the ends of a cable inserted into tubular cable connector means **4″** forming integral parts of copper plugs **3″**. T_3 indicates the temperature distribution along the longitudinal axis of the device when the latter is carrying its rated current. T indicates the temperature distribution along the longitudinal axis of the device when carrying a current which—if supplemented by the heating action of cables **8″**—is sufficiently high to bring the hot-point of the structure to the fusing point of cadmium. When the hot-point of the structure reaches the fusing point of cadmium the temperature of the insulation of cable **8″** is way above the temperature which their rubber envelope can withstand without undergoing excessive deterioration.

It will be apparent from a comparison of FIGS. 2 and 3 that curves T_0 and T_3, on the one hand, and T_2 and T_4, on the other hand, are corresponding curves. The relation of curves T_0 and T_2 on the one hand, and of curves T_3 and T_4, on the other hand, is, however, quite different. This difference is particularly apparent when comparing the rise of temperature on blade contacts **4′** with the rise of the temperature at the cable connectors **4″**. As shown in FIG. 2 an increase of the load current from the rated current to that current which causes blowing by a metallurgical reaction results in a very small rise in temperature at the fuse holder contacts **7′**. FIG. 3 shows that a rise of the load current from the rated current to the current required to cause blowing of the cable protector by a metallurgical reaction results in a very high rise in temperature at the cable connectors **4″**. This difference is of considerable significance as will be explained below.

Referring again to FIG. 3, reference character T_5 has been applied to indicate the temperature distribution along the axis of the device when carrying a current that is sufficiently low not to result in blowing of the fuse even though extending over a long period of time. That particular current is, however, sufficiently high, to bring the terminal blocks **3″** above the temperature of 231.8 deg. C., the fusing temperature of tin. If tin or a similar low fusing point solder were used to conductively connect fuse links **5″** to terminal blocks **3″**, this would result in progressive ageing of these solder joints and ultimately in formation of breaks at the points where these solder joints are located. Therefore it is not permissible—as it is in case of conventional current-limiting fuses—to use tin solder for connecting the fuse links to the terminal blocks. This must be achieved by means of a solder having a much higher fusing point than tin, preferably in the order of 300 deg. C. Cadmium silver solder serves this purpose well. Such a solder may have a fusing point in the order of 338 deg. C.

It will be noted from curve T_4 that the solder joints between fuse links **5″** and copper blocks or copper plugs **3″** reach also a temperature in excess of the fusing point of tin when the current carried by the device is sufficiently high to bring overlays **6″** to the fusing point of cadmium, thus causing blowing of the cable protector. During the interrupting process the points of the fuse link where overlay **6″** is located will exceed the fusing point of cadmium and the solder joints between links **5″** and plugs **3″** may then exceed the fusing point of the solder of which these solder joints are made. A softening or even the fusion of the solder joints between parts **5″** and **3″** incident to blowing has no tendency to impair the sound operation of the device, whereas the gradual deterioration of these solder joints by currents not sufficiently high to cause fusion of overlays **6″** is likely to result in a dangerous condition and, therefore, must be precluded by all means.

Referring now to FIGS. 4 and 5, numeral **21** has been applied to indicate a tubular casing of a silicone-resin-glass-cloth laminate closed on the ends thereof by a pair of press-fitted copper plugs **23** held firmly in position by transverse steel pins **29**. A pair of tubular cable connectors **24** form integral parts of copper plugs **23**. Cable connectors **24** may be silver brazed to copper plugs **23**. To this end the axially outer surfaces of plugs **23** are provided with relatively wide circular grooves **33** into which cable connectors **24** are inserted. Cables **28** have bare ends inserted into cable connectors **24** and held therein by indentations **30** produced by an appropriate hydraulic press tool. The axially inner surfaces **31** of copper plugs **23** are provided with systems of relatively narrow radial grooves **32** into which multi-perforated ribbon type fuse links **25** of silver are inserted. The axially outer ends of fuse links **25** are soldered to plugs **23** by means of joints (not shown) of silver-cadmium solder having a fusing temperature above 320 deg. C. Each fuse link **25** is provided with an overlay **26** of cadmium, or an alloy of cadmium, having a fusing point in the order of 320 deg. C. As is apparent from FIG. 4 the lenght of fuse links **25** is greater than the spacing between copper plugs **23** and each link is slightly bent into convex shape. This makes links **25** less subject to mechanical damage. In FIG. 5 all grooves **32** are shown as containing a fusible element or fuse link **25**, but in FIG. 4 some of the fuse links shown in FIG. 5 have been omitted for the sake of clarity. Casing **21** is filled with a pulverulent arc-quenching filler **22** such as quartz sand, of which portions only have been indicated in FIGS. 4 and 5.

It will be understood that the invention is not limited to the preferred embodiment which has been shown and described, and that this embodiment may be modified and other embodiments made without departing from the broad spirit and scope of the invention as set forth in the accompanying claims.

I claim as my invention:

1. A fusible protective device for the protection of cable networks comprising a tubular casing of heat-resistant insulating material; a pulverulent arc-quenching filler within said casing; a pair of terminal elements closing the ends of said casing, each of said pair of terminal elements including a block of solid metal; tubular cable connector means arranged in coaxial relation to said casing forming an integral part of at least one of said pair of terminal elements; multiperforated ribbon fuse link means of a metal having a fusing point in the order of 1000 deg. C. submersed in said filler and conductively interconnecting said pair of terminal elements; overload-responsive fuse-link-severing means of a metal having a fusing point in the order of 300 deg. C. arranged adjacent the center of said fuse link means for severing upon fusion thereof by a metallurgical reaction the current-path through said fuse link means, and solder joints of a metal having a fusing point in the order of 300 deg. C. for establishing current paths of low resistance between said pair of terminal elements and said fuse link means.

2. A fusible protective device for the protection of cable networks comprising a tubular casing of heat-resistant insulating material; a pulverulent arc-quenching filler within said casing; a pair of metal plugs each press-fitted into and closing one of the ends of said casing; tubular cable connector means arranged in coaxial relation to said casing forming an integral part of at least one of said pair of terminal elements; multiperforated ribbon fuse link means of a metal having a relatively high fusing point submersed in said filler and conductively interconnecting said pair of metal plugs; overload-responsive means supported by said fuse link means arranged adjacent the center of said fuse link means and made of a metal having a fusing point intermediate said relatively high fusing point and the fusing point of tin and adapted upon reaching said intermediate fusing point to initiate severance of the current path through said fuse link means; solder joints for establishing current paths of low resistance between said pair of metal plugs and said fuse link means, and the constituent solder of said solder joints having a fusing point of the same order as said intermediate fusing point.

3. A fusible protective device for the protection of cable networks comprising a tubular casing of heat-resistant insulating material; a pulverulent arc-quenching filler within said casing; a pair of metal plugs each press-fitted into and closing one of the ends of said casing; tubular cable connector means arranged in coaxial relation to said casing forming an integral part of at least one of said pair of terminal elements; multiperforated fuse link means in ribbon form of a metal having a fusing point in the order of 1000° C. submersed in said filler and conductively interconnecting said pair of metal plugs; overload-responsive means supported by said fuse link means adjacent the

center thereof, said overload responsive means including a mass of cadmium adapted upon fusion thereof to sever the current path through said fuse link means, and solder joints including cadmium for establishing current paths of low resistance between said pair of plugs and said fuse link means.

4. A fusible protective device for the protection of cable networks comprising a tubular casing of a silicone-glass-cloth laminate; a pulverulent arc-quenching filler within said casing; a pair of terminal elements closing the ends of said casing, each of said pair of terminal elements including a block of solid metal; tubular cable connector means arranged in coaxial relation to said casing forming an integral part of at least one of said pair of terminal elements; multiperforated fuse link means in ribbon-form of a metal having a fusing point in the order of 1000° C. submersed in said filler and conductively interconnecting said pair of metal plugs; an overload-responsive overlay including cadmium on said fuse link means adjacent the center thereof for severing said fuse link means upon fusion of said overlay, and solder joints of a metal having a fusing point in the order of 300 deg. C. for establishing current paths of low resistance between said pair of terminal elements and said fuse link means.

5. A fusible protective device as specified in claim 4 wherein said fuse link means consist of silver and wherein said solder joints are of cadmium silver solder.

6. A fusible protective device for the protection of cable networks comprising a tubular casing of a silicone glass-cloth laminate; a pulverulent quartz filler within said casing; a pair of terminal plugs each press-fitted into said casing and closing one of the ends thereof; said pair of plugs having relatively wide circular grooves in the axially outer surfaces and relatively narrow grooves in the axially inner surfaces thereof, a pair of tubular cable connectors having ends inserted into said wide grooves and silver brazed to said pair of terminal plugs; multiperforated fuse link means of silver in ribbon form having ends inserted into said narrow grooves; an overlay including cadmium on said fuse link means arranged adjacent the center thereof for severing said fuse link means upon fusion of said overlay; and solder joints of a cadmium-silver solder having a fusing point in the order of 300 deg. C. in said narrow grooves for establishing current paths of low resistance between said pair of metal plugs and said fuse link means.

7. In combination a pair of cables having coaxial bare ends arranged in spaced relation and means for conductively interconnecting said ends, said interconnecting means including a pair of spaced terminal elements each defining a tubular recess for receiving one of said ends, multiperforated ribbon fuse link means of a metal having a fusing point in the order of 1000 deg. C. conductively interconnecting said pair of terminal elements, solder joints of a metal having a fusing point above the fusing point of tin and in the order of 300 deg. C. for establishing current paths of low resistance between said pair of terminal elements and the axially outer ends of said fuse link means; over-load-responsive overlay means including cadmium arranged on said fuse link means adjacent the center thereof, a casing of silicone-glass-cloth laminate housing said fuse link means, and a pulverulent arc-quenching filler inside said casing in physical engagement with said fuse link means.

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