United States Patent [19]

Mahieu et al.

[11] **3,863,187**

[45] **Jan. 28, 1975**

[54] **TOTAL RANGE FAULT INTERRUPTER**

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[73] Assignee: **A. B. Chance Company,** Centralia, Mo.

[22] Filed: **June 4, 1973**

[21] Appl. No.: **366,343**

[52] **U.S. Cl.** **337/162,** 337/159, 337/186, 337/229, 337/292

[51] **Int. Cl.** **H01h 85/04**

[58] **Field of Search** 337/158, 159, 161, 162, 337/186, 229, 292, 175

[56] **References Cited**

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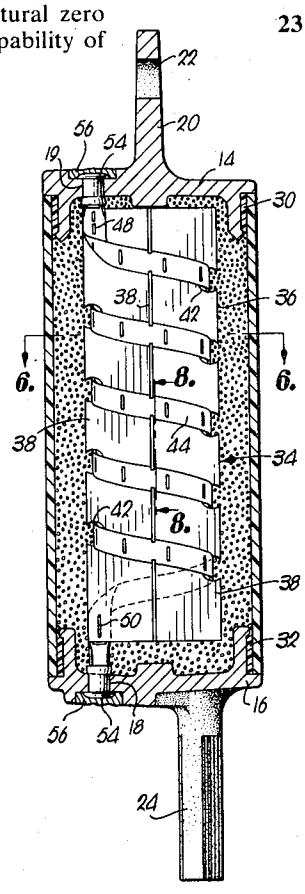
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Primary Examiner—J. D. Miller
Assistant Examiner—Fred E. Bell
Attorney, Agent, or Firm—Schmidt, Johnson, Hovey & Williams

[57] **ABSTRACT**

A lightweight, compact total range fault current interrupter is provided which is capable of interrupting a low magnitude fault current at the first natural zero point while at the same time having the capability of limiting high magnitude fault currents to insignificant values substantially ahead of the first natural zero point whereby the interrupter is operable to limit the electrical energy dissipated in the conductors carrying the fault current to a desired level in a manner functionally independent of fault current magnitude. The interrupter comprises low range current interrupting apparatus connected in electrical series relationship with unique high range current limiting fuse structure which in combination provide an appropriate, relatively narrow I^2t band response over the entire fault range and efficiently protects an electrical distribution circuit without impairing desirable coordination of the overall system. The fuse structure has an internal fuse assembly within an insulative housing therefor and includes a lightweight finned saddle member composed of synthetic resin material with an elongated metallic fusible element helically wrapped thereabout. The distal ends of the fusible element are electrically coupled to respective end caps which are integrally joined to opposed extremities of the housing and serve as a part of the current path through the fuse. External conductive connective structure on the outer faces of the end caps permit the fuse to be easily interposed within a circuit as a protective device. A method for the production of the lightweight internal assemblies is also disclosed, and includes attaching two longitudinal webs of relatively thin synthetic resin material along a common longitudinal axis to form four circumferentially spaced fins, forming cradle openings at predetermined points along the marginal edges of the fins, winding the fusible element about the finned structures, and then attaching opposite ends of the elements to the caps with novel attachment means.

23 Claims, 24 Drawing Figures



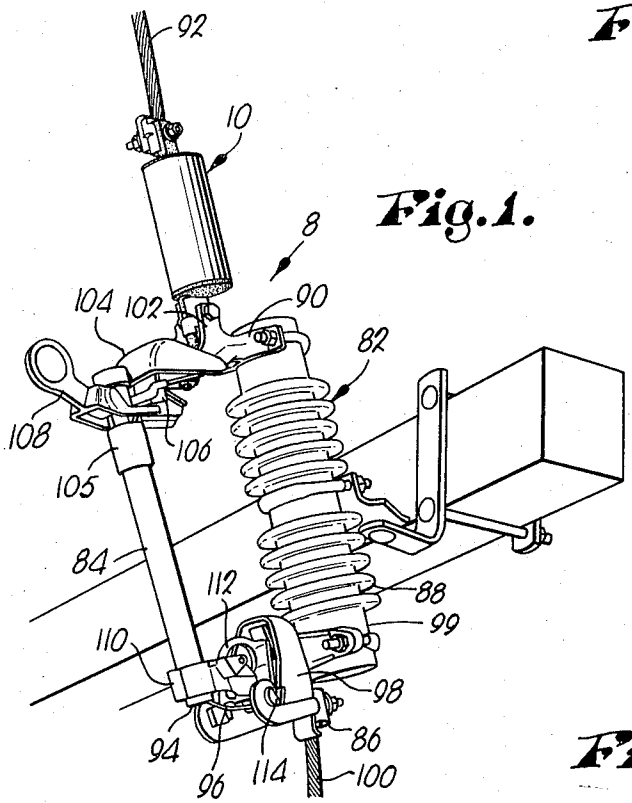


Fig.1.

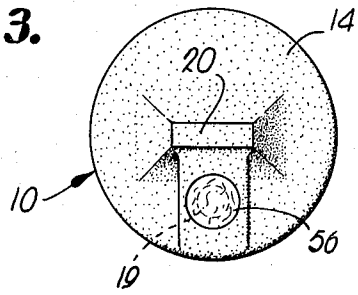


Fig.3.

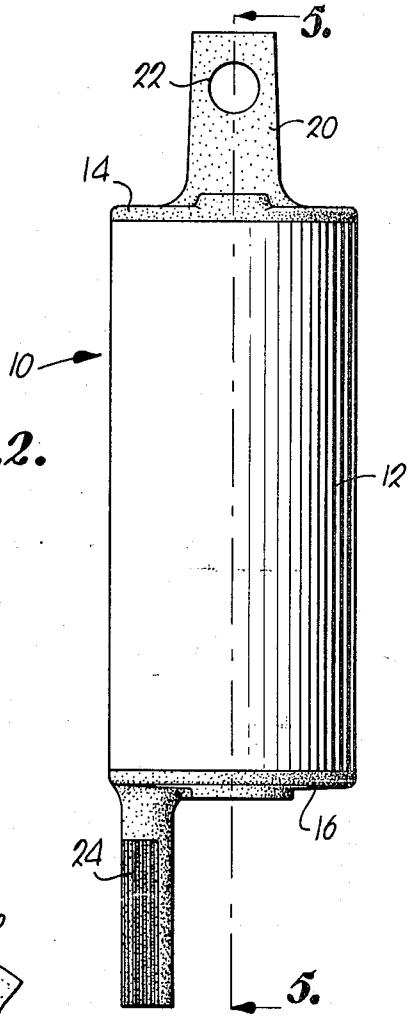


Fig.2.

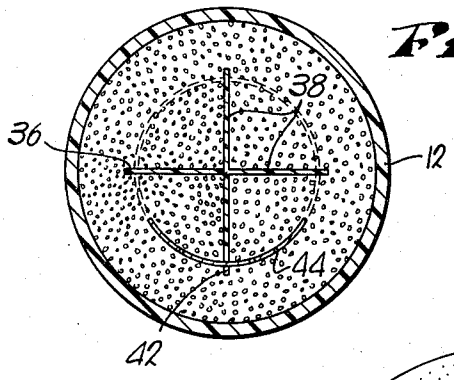


Fig.6.

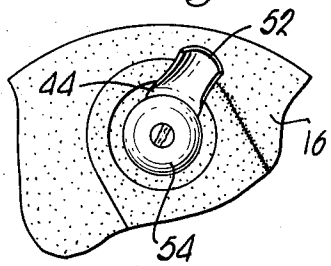


Fig.7.

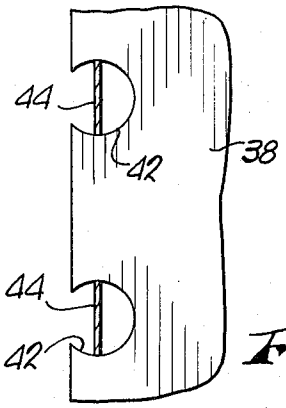


Fig.8.

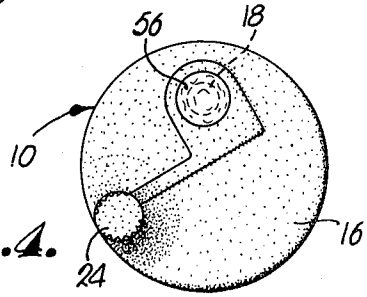


Fig.4.

Fig.5.

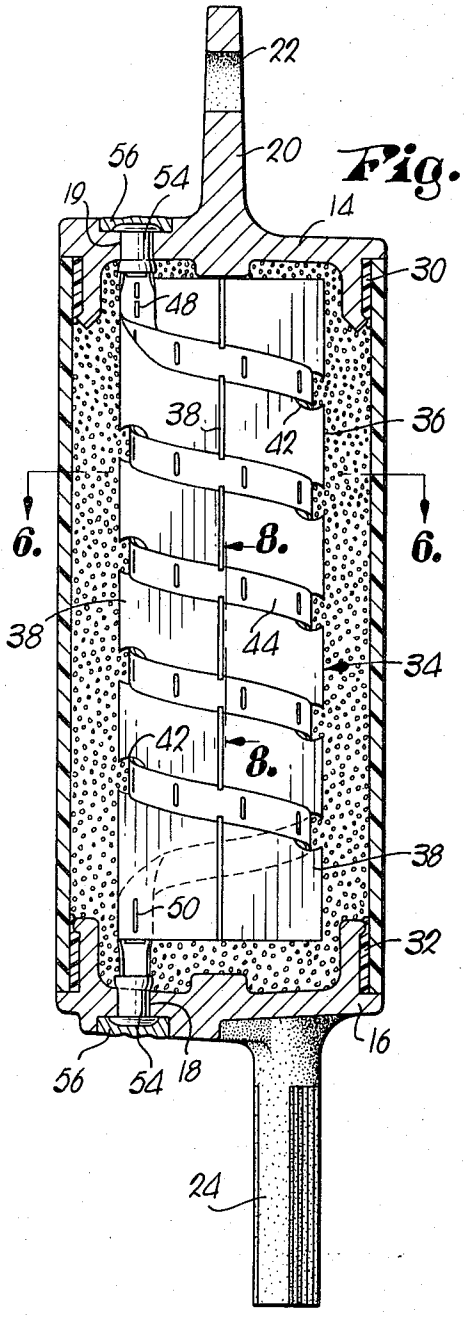
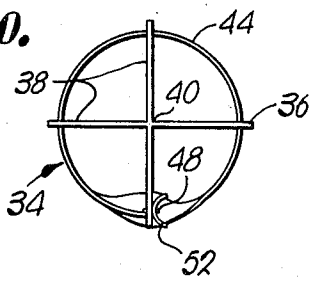


Fig.10.



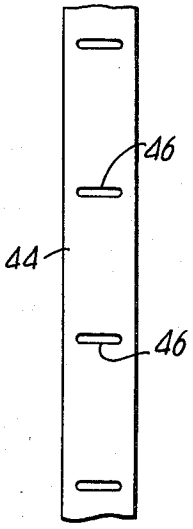


Fig.11.

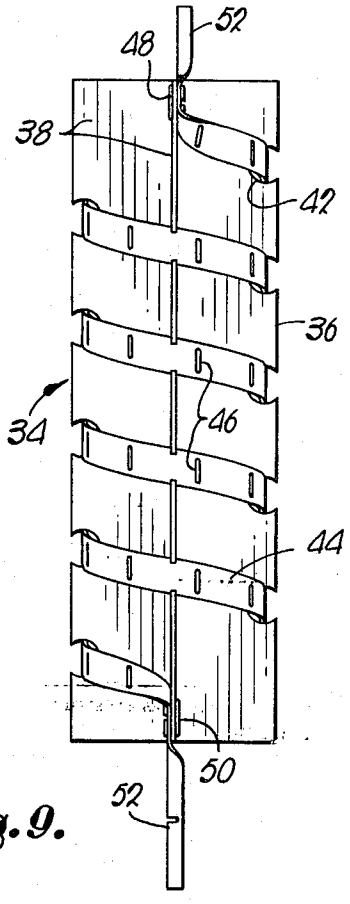
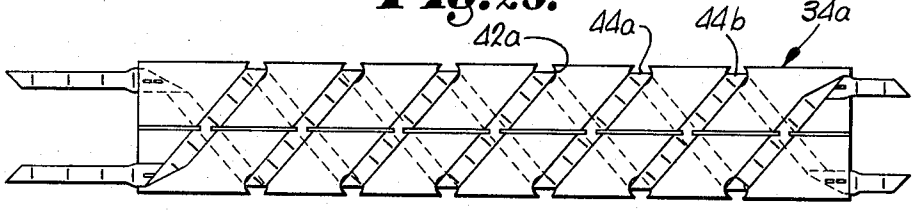


Fig.9.

Fig.23.



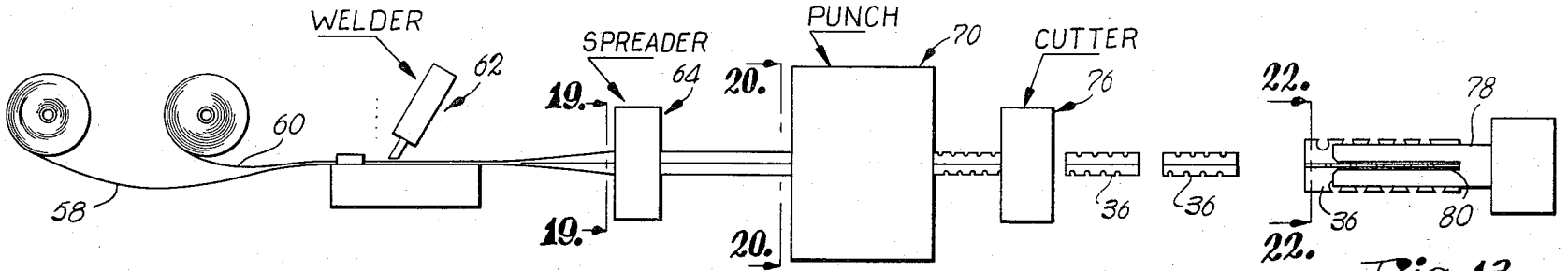


Fig.12.

Fig.13.

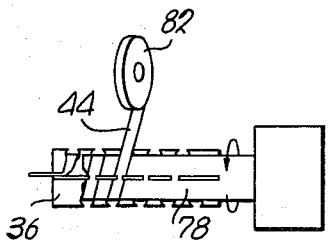


Fig.14.

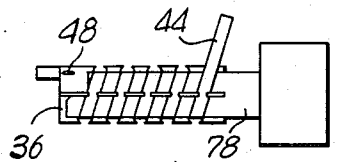


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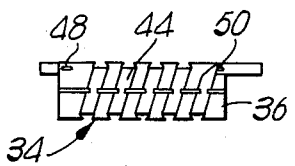


Fig.16.

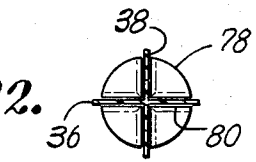


Fig.22.

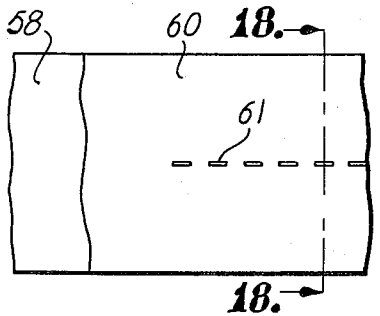


Fig.17.

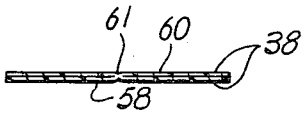


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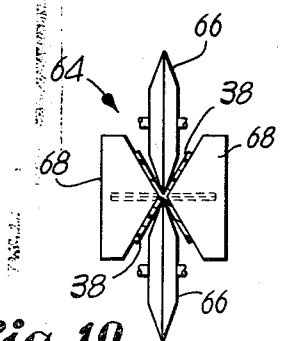


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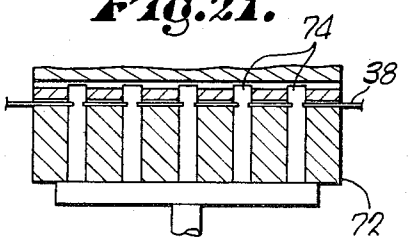
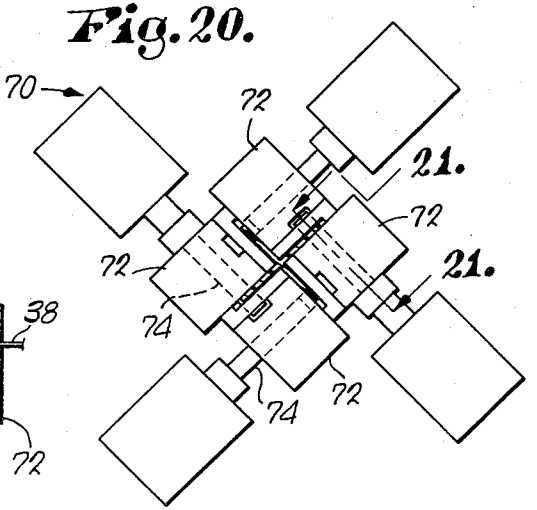


Fig.21.

Fig.20.



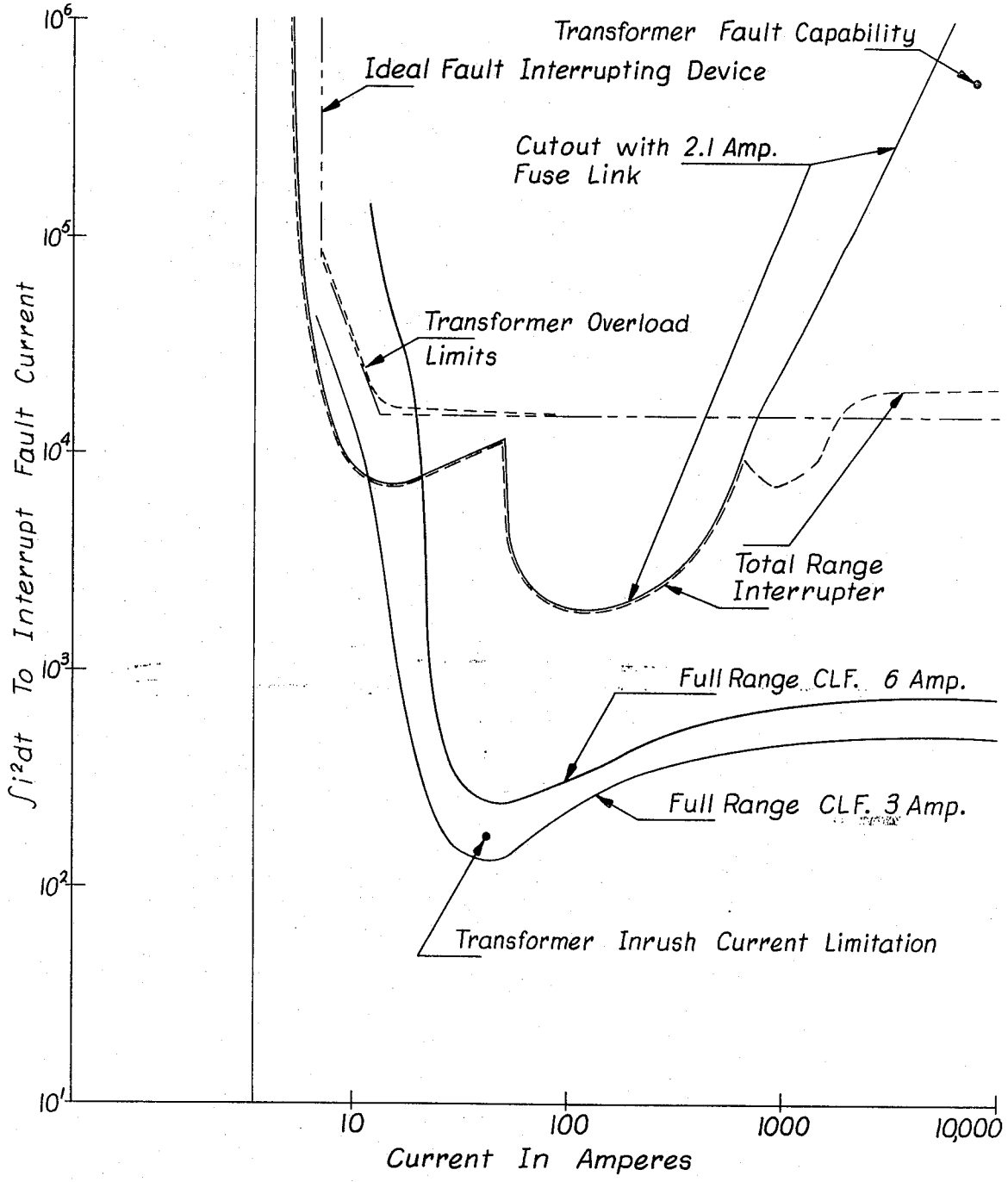

Transformer Fault Capability
Ideal Fault Interrupting Device
Cutout with 2.1 Amp. Fuse Link
Transformer Overload Limits
Total Range Interrupter
Full Range CLF. 6 Amp.
Full Range CLF. 3 Amp.
Transformer Inrush Current Limitation
$\int i^2 dt$ To Interrupt Fault Current
10^6
10^5
10^4
10^3
10^2
10^1
10
100
1000
10,000
Current In Amperes

Fig. 24.

TOTAL RANGE FAULT INTERRUPTER

BACKGROUND

The present invention is concerned with a total range fault interrupter designed to be interposed in an electrical circuit to protect the latter from the effects of fault currents without the explosive violence associated with conventional expulsion cutouts or the like. More particularly, it is concerned with a fuse that can be adapted to limit relatively high fault currents and which is connected in series with a low-range current interrupter to yield a full-range protective device that may be produced at minimum cost, is small in size, and allows excellent coordination with existing power distribution systems.

Conventional silver-sand current limiting fuses are large, bulky devices designed mainly for use in industrial plants for fusing machinery and internally wired circuits. Such fuses are generally elongated and very heavy, sometimes being up to several feet in length. They generally comprise an insulative housing carrying an elongated fusible element therewithin. Under the influence of a fault current, the fusible element severs or melts and an arc is produced within the fuse which is quickly suppressed by sand surrounding the fusible element. The latter is internally supported by being wound about a heavy insulative support member composed of porcelain or the like which is positively attached to opposed ends of the fuse housing.

The primary advantage of such current limiting fuses is that they are capable of limiting high range fault currents without exploding or otherwise creating danger to other electrical equipment in proximity thereto or to nearby workers. This characteristic is especially helpful in crowded work or residential areas where safe conditions must be maintained at all times.

With increasingly heavy consumer demand for electrical power, suppliers have necessarily resorted to the use of equipment capable of transmitting currents of higher magnitudes. Accordingly, a device with the high range characteristics of a current limiting fuse has been needed in order to protect the electrical transmission circuit from the effects of high as well as low level fault currents, while nevertheless remaining essentially violence-free in operation. Conventional expulsion cutouts are not usable in this context because they are generally capable of interrupting currents only up to about 20,000 amperes, while fault currents of twice that magnitude are sometimes experienced in practice. When a fault current of such high magnitude passes through a normal cutout, it is often completely blown up with excessive violence and noise, which can be an extremely dangerous result in residential or work areas. In addition, transformers supposedly protected by cutout devices have also blown up in the field because of excessive fault current loads imposed thereon notwithstanding the cutout protection provided therefor. However, when heavy, cumbersome current limiting fuses as described above are employed as protective devices in such cases, several important problems can arise.

The prime deficiency of such fuses is that they make it difficult to provide the required "coordination" of the transmission system which is essential to its proper operation. Coordination here refers to system protection at various levels down the circuit. Basically, it consists of "zones" along the system. For example, from the substation, there is generally a circuit breaker or a

power fuse. Going down the circuit away from the substation are sectionalizing devices which may be reclosures or cutouts on branch lines. These are conventionally fused at a lesser value than the circuit breaker of the substation but at a greater value than cutouts further down the circuit. Further out on the circuit from the branch cutouts, there are additional cutouts and then, finally, transformer applied cutouts. With these devices, each having varying minimum melting and total clearing times, there can be many zones of protection, and thus extremely good coordination of the entire system.

In order to minimize the number of customers interrupted from normal electrical service during abnormal conditions, the protective devices should be coordinated in a manner to sense, select and isolate the minimum amount of the electrical system in order to quickly isolate the troubled portion. When properly coordinated, the protective devices work together to always allow the device nearest the fault location to isolate the troubled portion of the electrical system first. If the protective devices do not function in proper coordination, then portions of the system which are not in trouble will be isolated causing outages to customers where an outage was unnecessary and consequently resulting in lost revenue to the utility. Hence, from a geographical point of view, the more zones isolated by a device, the more customers out of electrical service. Ideally, the more zones of protection a utility has, the smaller the area interrupted during abnormal conditions. Conversely, the fewer the zones, the larger the area isolated.

By virtue of the fact that normal current limiting fuses are of the full-range variety, when used alone they necessarily detract from the coordination of the overall electrical transmission system when used in place of expulsion cutouts. Moreover, because of their very steep time-current characteristic, full-range current limiting fuses do not always coordinate satisfactorily with other types of fuses and circuit protective devices. Nevertheless, because of the higher current ratings in use today, some utilities have been forced to utilize full-range current limiting fuses throughout their electrical distribution systems, thereby impairing the desirable coordination of the system.

Another related problem in the use of full-range current limiting fuses of the prior art is that they are extremely expensive and must be replaced frequently. This results from the full range operation of such fuses at all fault current levels, even those of a magnitude which could be safely interrupted by a conventional cutout. Therefore, even when a fault current of relatively small magnitude is experienced, such fuses respond to it and eventually sever thus necessitating their replacement at great cost.

The problem of expense is further compounded due to the physical size of such current limiting fuses. Because of their large, heavy construction, it is often necessary to provide extensive mechanical support therefor, which adds to the expense of initial installation as well as that of replacement.

Yet another problem associated with the use of such fuses has been the lack of an inexpensive means of determining whether or not the fuse has operated. While some fuses of the prior art have provided an indicating function, this has been achieved only at great expense and complexity, and is therefore objectionable. As can

be appreciated however, an indicating function is a very desirable property so that linemen can tell at a glance whether or not replacement is necessary in a particular case. Without such a capability, costly and time consuming testing of each fuse within the system is often required.

Therefore, there is a need in the art for a current limiting fuse device that is small in size and weight, inexpensive to replace, and usable with existing electrical distribution systems to yield good coordination while providing an inexpensive indicating function in order to determine whether a particular fuse has operated.

SUMMARY

Accordingly, it has been discovered that the foregoing problems can be overcome by providing a compact total range fault current interrupting assembly which is adapted to be interposed in an electrical circuit to protect the latter from the effects of fault currents. A fuse and cutout are combined to provide interruption of the circuit by a fault current exceeding any preselected magnitude. The fuse comprises an internal assembly having an elongated, insulative saddle member of synthetic resinous material provided with a plurality of relatively thin, circumferentially-spaced fins radiating from a longitudinal axis thereof, with at least one fusable element helically wrapped about the saddle member and attached thereto. The assembly is suspended within an elongated, closed housing by attachment of the distal ends of the fusible elements to the opposed end caps of the housing to define a current path through the latter. This connection is preferably accomplished by providing apertures in each of the caps and inserting the ends of the fusible elements therein, followed by mechanically and electrically connecting the element by means of expansion or "pop" rivets operatively placed within the apertures.

The fusible element is preferably wrapped about the saddle member in a helical fashion to provide a series of aligned, spaced convolutions along the length thereof. The element is attached to the saddle member by provision of a series of generally circular openings in communication with the marginal edges of each of the fins in predetermined relationship so that the fusible element can be helically wound as described. Such openings have a maximum diameter substantially equal to the width of the fusible element with each opening being of a lesser width at the outer edge of the fins. This allows insertion of the fusible element into respective generally circular "cradles", which can easily be accomplished on a continuous basis during manufacturing.

The fusible element is also provided with a series of spaced zones along the length thereof having decreased cross-sectional areas in relation to the remainder of the element; these areas are consequently of increased electrical resistance so that when a fault current of predetermined magnitude flows through the fuse, the element is substantially simultaneously severed at these points. Such action series to interrupt the current, thus protecting the remaining electrical components within the system.

When positioned within the closed housing, the saddle member and attached fusible element serve to cooperatively support and position the internal assembly, with the helical wrappings of the element being maintained in the necessary spaced relationship along the circumference of the saddle fins. The remaining free volume of the housing is filled with silica sand which is operable to quickly suppress the electrical arc formed upon the severance of the fusible element during operation of the fuse. In this way, the fuse acts to quickly interrupt a fault current of predetermined magnitude in order to protect the overall circuit.

By virtue of the fact that the saddle member is composed of relatively thin walled synthetic resin film and the fusible element of thin metallic material such as silver, it can be appreciated that the internal fuse assembly described above is extremely lightweight. Moreover, it has been discovered that a high range fuse (that is, one capable of limiting a current of up to 40,000 amps.) can be constructed from such materials which is extremely small in size. For example, a fuse having an 8.3 KV rating which can carry 30 amps. of current indefinitely can be manufactured of a size no larger than about 5-⅝ inches in length and 2-¼ inches in diameter. Hence, due to the fact that the current limiting fuse of the present invention is of such relatively small size and weight, it is a simple matter to install it as a protective device within an electrical circuit without the need for extensive mechanical support.

In one embodiment of the present invention, a current limiting fuse as described is electrically interconnected in series with a conventional expulsion drop-out type cutout to provide a device capable of limiting and interrupting a fault current of any magnitude. In the most preferred form, the fuse is connected ahead of the cutout. When performing its interrupting function, a very high resistance arc limits the peak letthrough current in the circuit. This has the advantage of limiting the energy that is dissipated in the cutout. The fuse link used in the cutout is still selected, as in the past, to interrupt fault currents which exceed the design loads which the unit protected by the interrupter device is adapted to handle.

When a current limiting fuse of the present invention and a cutout are thus selected and connected in series, the following additional advantages results are obtained. First, the overall device serves to limit fault currents above **500** amps. without the explosive violence associated with an unprotected cutout. Secondly, due to the comparative operational times of the two components, the expulsion cutout will operate under all otherwise damaging fault current situations; this provides the desirable indicator effect in that the fuse tube will be in the open, dropped, position, which indicates that at least the cutout component has operated. Thus, under the influence of a fault current which is insufficient to operate the current limiting fuse, the serially connected cutout will nonetheless blow. However, upon the introduction of a high fault current through the system, both the current limiting fuse and cutout will operate. Therefore, in either case a positive indicating function is provided which can easily be seen from ground level by linemen in the field by virtue of the fact that the fuse link is chosen of a value to always melt whether the fault be of a high impedance, low current value, or low impedance, high fault current value.

In preferred forms, the internal fuse assembly of the present invention can be continuously produced in the following manner. At least two webs of relatively thin, synthetic resin material such as Mylar are overlaid and simultaneously advanced. At the initial stage they are longitudinally connected or welded along a common

longitudinal line, thereby forming a saddle member having a plurality of fins radiating outwardly from a common longitudinal axis. The fins are next separated from one another to provide a circumferential spacing therebetween, and are subsequently punched along their marginal edges in order to provide the aforementioned web locking cradle means for the reception of the fusible element. The longitudinal webs are thereafter cut into discrete sections and the fusible element is wound thereabout, being received in the cradle means provided. In this way, the internal assembly of the fuse can be produced in a continuous, inexpensive fashion, and is lightweight and small in size, thus meeting the requirements of a successful current limiting fuse operable as described.

DRAWINGS

FIG. **1** is a perspective view of the current limiting fuse of the present invention mounted in series with a conventional expulsion cutout, the entire device being mounted on a crossarm;

FIG. **2** is a side elevational view of the current limiting fuse in accordance with the present invention;

FIG. **3** is a top elevational view of the fuse shown in FIG. **2**, showing the upstanding connection tang integral with the top cap of the fuse;

FIG. **4** is an elevational view showing the external face of the bottom cap of the fuse as shown in FIG. **2**, showing the integral, ribbed depending connection stud;

FIG. **5** is a cross-sectional view taken along sight line **5—5** of FIG. **2**, showing a current limiting fuse of the present invention in actual size;

FIG. **6** is a cross-sectional view taken along sight line **6—6** of FIG. **5**;

FIG. **7** is a fragmentary, elevational view showing one end of the fusible element extending through an aperture provided in the bottom cap shown in FIG. **4**, with an expansion rivet within the aperture providing a secure electrical and mechanical connection between the cap and fusible element;

FIG. **8** is a fragmentary, side elevational view along sight line **8—8** of FIG. **5**, showing the generally circular cradle apertures along the marginal edges of the saddle fins;

FIG. **9** is a side elevational view showing the internal fuse assembly of the present invention, prior to insertion within the fuse housing;

FIG. **10** is a top elevational view of the internal fuse assembly shown in FIG. **9**;

FIG. **11** is a fragmentary elevational view of a segment of the fusible element, showing spaced, transversely extending slots therein forming zones of decreased cross-sectional area;

FIG. **12** is a schematic view showing the initial steps in the preferred method of producing the internal fuse assemblies shown in FIG. **9**;

FIG. **13** is a schematic view showing a relatively thin-walled saddle member positioned within a holder prior to circumferential attachment of the fusible element thereabout;

FIG. **14** is a schematic representation of the fusible element being wound about the saddle member and being inserted within the cradle openings formed in the marginal edges of the radially extending fins thereof;

FIG. **15** is a schematic view showing the fusible element helically wound about the saddle member and received within the cradle openings of the saddle fins;

FIG. **16** is a side elevational view showing the completed internal fuse assembly ready for insertion into the fuse housing, with the distal ends of the fusible element being preformed for insertion within apertures provided in the end caps of the fuse housing;

FIG. **17** is a fragmentary, elevational view showing two continuous webs attached along a common longitudinal axis as the first step in forming the saddle member;

FIG. **18** is a sectional view taken along sight line **18—18** of FIG. **17**;

FIG. **19** is an elevational view taken along sight line **19—19** of FIG. **12**, showing the preferred method of spreading the connected web to form the circumferentially spaced fins;

FIG. **20** is a front elevational view taken along sight line **20—20** of FIG. **12**, showing the preferred apparatus for punching the marginal edges of the fins to form the cradle openings for the ultimate reception of the fusible element;

FIG. **21** is a fragmentary, sectional view showing the preferred apparatus for simultaneously punching a plurality of cradle openings along the marginal edges of the saddle fins;

FIG. **22** is a cross-sectional view taken along sight line **22-22** of FIG. **13**, showing the saddle member within the holder prior to circumferential attachment of the fusible element;

FIG. **23** is a side elevational view of an internal fuse assembly for use in a current limiting fuse, having two separate helically mounted fusible elements attached to the saddle member; and

FIG. **24** is a graphical representation of the fault current response of the total range interrupter of this invention in comparison with an ideal fault current interrupting device, one type of conventional cutout fuse link and two full range current limiting fuses.

DETAILED DESCRIPTION

A compact, lightweight, total range fault current interrupter is generally denoted by the numeral **8** in FIG. **1**, and includes as its principal components, a current limiting fuse **10** and cutout device **82.** The fuse **10** comprises an elongated hollow insulative housing **12** having closure means **14** and **16** integrally attached thereto in covering relationship to opposed ends thereof to present a closed body. Each of the closure means **14** and **16** is provided with apertures **18** and **19** therein respectively (see FIGS. **3** and **4**), and each has conductive connection structure on the external face thereof respectively adapted to permit the fuse **10** to be interposed within an electrical circuit to protect the latter from the effects of fault currents.

The upper closure cap **14** is preferably although not necessarily composed entirely of conductive metallic material and has an upstanding tang **20** integral therewith which is apertured as at **22** to facilitate electrical connection within the circuit. Similarly, lower cap **16** is composed of conductive metallic material and is provided with a depending ribbed stud **24.** While the closure means **14** and **16** are preferably composed of conductive material in their entirety, it is to be understood that the connective structure **20** and **24** can be of conductive material and electrically connected to the aper-

tures 18 and 19 to provide a current path through the fuse caps.

Turning now to FIG. 5, a cross-sectional view in actual size of a fuse according to the invention is shown. External housing 12 is hollow and cylindrical in shape and has closure means 14 and 16 integrally connected therewith and sealed by means of epoxy resin as at 30 and 32 in order to provide a closed, airtight seal. The relatively thinwalled housing 12 is preferably fabricated from a fiber reinforced thermosetting, synthetic resinous material such as epoxy resin. This provides good insulating qualities, and the resultant housing is strong and rugged yet light in weight. Connected closure means 14 and 16 are apertured respectively at 18 and 19 as described, and are adapted to receive the distal ends of the fusible element 44.

The internal fuse assembly 34 includes an elongated, insulative saddle member 36 which is composed of relatively thin synthetic resinous material and has a plurality of circumferentially spaced fins 38 radiating from a longitudinal axis 40 (see FIG. 10). In preferred forms, the saddle member is composed of synthetic polyethylene terephthalate resin film of from 5 to 10 mils thickness, sold by E. I. DuPont De Nemours & Co. of Wilmington, Delaware under the trademark "Mylar".

Attachment means are fashioned along the outer marginal edges of the fins 38 as at 42 for the attachment of circumferentially wound fusible element 44, later to be described. In preferred forms, the attachment means 42 comprises generally circular saddle openings in communication with the marginal edges of the fins. As best shown in FIG. 8, these saddle openings have a maximum diameter which is substantially equal to the width of the fusible element 44, and are of a smaller dimension at the extreme edges of the fins. In this way, the fusible element can be "snapped" into the flexible saddle structure to be frictionally held therein. Additionally, the cradle openings are preferably arranged along the marginal edges of the fins so that the fusible element 44 can be wound in a helical pattern about the circumference of saddle member 36, as shown in FIG. 9. Element 44 makes very minimal contact with the saddle support therefor, thus precluding the possibility of the Mylar film carbonizing during melting of portions of the element, to an extent that could result in arc restrike following initial arc formation and extinguishment thereof.

The elongated element 44 is preferably composed of elemental silver and is of substantially uniform cross-sectional area. A series of spaced transverse slots 46 is provided along the length thereof, to give zones of decreased cross-sectional area along the length of element 44 which consequently give zones of increased electrical resistance; therefore, as will be more fully explained below, when a fault current of predetermined magnitude flows through the element, the latter severs or melts at these points, causing interruption and thereby limiting of the fault current ahead of the first natural zero point.

The distal ends of the element 44 are stapled or otherwise affixed as at 48 and 50 to the saddle member 36. Additionally, the ends are preferably preformed into substantially semicircular cross-sectional configuration as at 52 which facilitates their insertion into apertures 18 and 19 respectively.

The fuse according to the invention can therefore be advantageously constructed in the following manner. First, housing 12 and one end cap 14 or 16 are integrally united; internal fuse assembly 34 is thereafter placed within the housing, with one distal end of element 44 extending into respective aperture 18 or 19. An expansion or "pop" rivet 54 is then inserted within the aperture to secure the element 44 therein and provide an electrical connection between the conductive cap and fusible element. The body is then almost filled with silica sand of from 30 to 70 mesh size, whereupon the remaining end cap is then integrally attached to the opposite end of the housing 12, with the free end of the fusible element 44 extending through the aperture provided therein. Additional sand is introduced into the body through the open end cap aperture to completely fill the body whereupon the connection is completed by insertion of a second rivet 54 within the open aperture. The respective heads of rivets 54 are preferably covered with solder or epoxy material as at 56 in order to insure an airtight seal within the housing of fuse 10.

While the fuse has been described as employing only a single fusible element 44, it is to be understood that a plurality of such elements 44*a* and 44*b* can be employed in a single fuse in the manner described (see FIG. 23). In such a case, the finned saddle 34*a* is provided with attachment means 42*a* for the reception of the separate fusible elements, and the caps 14 and 16 are provided with sufficient apertures to receive the distal ends thereof. Elements 44*a* and 44*b* are helically wound about the saddle member 34*a* such that they have substantially equal pitch lengths and are about one-half pitch out of phase so as to equally space the helical windings along the length of the saddle member.

As best shown in FIG. 5, the fusible element 44 in conjunction with saddle member 34 cooperatively act to position and support the overall internal fuse assembly 34 within housing 12. That is, contrary to the constructions of the prior art wherein a heavy porcelain or plastic support member was fixedly secured to the opposed end caps, the present lightweight construction remains properly positioned without the need of positive fixed supports. Moreover, this construction maintains the helical convolutions of the element 44 in an aligned, spaced relationship so that the fuse maintains its operability even when jostled or otherwise roughly handled.

As can be appreciated, the compact nature of the fuse according to the invention is achieved by virtue of the cooperative supporting action of the fusible element 44 and saddle member 34. When constructed as outlined above, the fuse is operable to limit fault currents of any desired magnitude.

Another feature of the present invention is the novel method discovered for the continuous production of internal fuse assemblies 34. In general, the method comprises providing at least two longitudinal webs of relatively thin, synthetic resin material which are longitudinally connected along a common line to form the finned saddle member. Attachment means are then formed at spaced, predetermined points along the outer marginal edges of the fins which are adapted to allow attachment of the fusible element thereto. The final step involves convolutionally winding the elongated fusible element onto the saddle member in a circumferential fashion.

Reference is made to FIGS. 12 to 22 inclusive for schematic illustrations of the steps involved in fabricating fuse assemblies 34. At least two continuous, elon-

gated webs **58** and **60** of relatively thin synthetic resin material such as Mylar plastic are first positioned such that they are in aligned, substantially overlying relationship, the webs being of substantially equal width. The webs are advanced through a first welding station **62** where they are longitudinally connected along a line substantially coincident with their common midpoints. This connection is preferably accomplished by means of an ultrasonic welder which intermittently or continuously attaches the webs along the aforementioned common line (see FIG. **17**). The welding thereby forms a unitary structure having four circumferentially-spaced fins of equal dimensions radiating from a common longitudinal axis.

The connected webs are thereafter advanced through a spreader **64** best shown in FIG. **19** which includes a pair of opposed spreading rollers **66** in conjunction with a pair of forms **68.** This spreads fins **38** to provide the circumferential spacing described above. Following spreading, the connected webs are directed through punch **70** which forms cradle openings **42** along the marginal edges of the fins at predetermined points. In preferred forms, this apparatus comprises four die cutters arranged about the path of the advancing webs and positioned to punch the latter along the marginal edges of the fins. As shown in FIGS. **20** and **21** die cutters **72** can be adapted to simultaneously cut a plurality of such openings in the fins in a single operation by means of a series of spaced die cutting punches **74.**

Upon emerging from the punch, the continuous, attached webs enter a cutting station **76** which transversely severs the attached webs to provide discrete saddle members **36** of appropriate length for use in the current limiting fuses. The discrete lengths are then placed within rotatable holders **78** which are longitudinally slotted as at **80** for the reception of the spaced fins **38.** As best shown in FIGS. **13** and **22,** the holder is generally cylindrical in shape with four slots fashioned therein for the reception of the spaced fins. Additionally, it is dimensioned such that the outer extremities of each of fins **38** projects beyond the cylindrical wall of the holder to allow the fusible element **44** to be wound thereabout without difficulty.

The final step involves winding fusible element **44** onto the saddle member **34** previously produced. Mandrel **82** is provided with a continuous, elongated supply of fusible element **44,** and holder **78** is rotated as shown in FIG. **14** in order to wind element **44** onto saddle member **34** in a helical pattern. After winding, the fusible element **44** is severed and the distal ends thereof are stapled as at **48** and **50** to secure the element to the saddle. The last step involves forming the extreme ends of element **44** such that they have a semicircular cross section; this facilitates the insertion of each of the distal ends into the apertures provided in the opposed closure means of the ultimate fuse, as described above. The completed internal fuse assembly can then be employed in conjunction with the remaining elements of the current limiting fuse described, and the latter can be constructed in accordance with the steps outlined.

When a current limiting fuse in accordance with the invention is interposed within an electrical circuit, and a fault current of magnitude sufficient to blow the fuse is experienced, the following is believed to occur. As the current enters the fuse, it experiences highest resistance at the point of minimum cross-sectional area along the length of the fusible element, i.e., at points coincident with the spaced transverse slots **46.** These zones of decreased cross-sectional area are substantially instantaneously vaporized and explode into individual arcs. The arcs lengthen as they continue to vaporize more of the silver fusible elements, and soon the sum of their voltage drops surpasses the normal system voltage. The high total arc voltage thus forces the fuse current to zero before it ever reaches the peak value of the available fault current. Simultaneously, the sand serves to suppress the arc by interposing a high arc resistance in its path. This causes the sand to partially vaporize along with the silver atoms (and in some instances, minor portions of the thermoplastic saddle member adjacent the fusible element) and both soon form a glassy matrix which is nonconductive. At this point, the current through the fuse is completely interrupted, and restriking of the arc is precluded because the dielectric path is sufficiently high to withstand any recovery voltage up to the maximum design voltage. As discussed above, the action of the current limiting fuse is silent and substantially nonventing as all of the energy of interruption is retained within the sealed housing **12.**

It has also been discovered that the compact, lightweight current limiting fuse structure of the invention has unique utility when used in conjunction with low range current interrupting apparatus such as a cutout to provide a total range fault current limiting device capable of interrupting low and high magnitude fault currents with substantially isoenergy dissipation within predetermined relatively narrow limits under all fault interruptions thereby. Referring specifically to FIG. **1,** device **8** is shown as being mounted upon the crossarm of an electrical pole. It comprises low range current interrupting apparatus such as dropout expulsion cutout **82** connected in electrical series relationship with the high range current limiting fuse structure **10.** Operable cutouts for use in connection with fuse structure **10** include the open cutouts shown in U.S. Pat. Nos. 2,611,054 and 2,629,794, open link cutouts as illustrated in U.S. Pat. No. 2,324,044, closed cutouts as in U.S. Pat. No. 2,669,214, liquid fuse cutouts as in U.S. Pat. No. 2,134,470, and oil cutouts as shown in U.S. Pat. No. 2,493,317.

The fuse structure **10** and current interrupting apparatus **82** are both physically and electrically interrelated to assure safe and efficient interruption of fault currents exceeding a preselected magnitude and are operable in combination to protect a circuit or piece of equipment while still allowing proper coordination of all of the protective devices in a transmission and distribution system. One particularly important use of interrupter **8** is in protecting distribution transformers from damaging overloads. In this connection it is to be recognized that the fuse link in cutout apparatus **82** should have melt characteristics which are optimum for protecting a particular transformer or the like from a damaging fault current while still allowing design loads to be imposed on the transformer windings without actuating interrupter **8.** Thus, the fuse link used in apparatus **82** should be selected in accordance with known cutout link guidelines taking into account the safe loading characteristics of the equipment to be protected, the degree of overload protection to be provided in the case of transformers, the load current at the point of applicaion, the fault current available at various locations on the system, the time current characteristics of

fuse links to be used on the system so that proper coordination thereof can be retained, and the type of protection to be provided by the fuse link.

In FIG. **24**, the typical transformer overload limits for a distribution type transformer are depicted by the dashed lines. For preferred operation, the fuse link chosen for use in cutout apparatus **82** forming a part of interrupter **8** (if it is to be used to protect a transformer having overload limits are shown in FIG. **24**) should be chosen such that its melt characteristics approach the transformer limits but remain to the left thereof and below the same. Typical clearing characteristics of a **2.1** amp. fuse link in a cutout as shown in the drawings hereof is indicated by the appropriately labeled solid line of FIG. **24**, but it can be seen that at high fault currents, the link total clearing curve is to the left of the transformer fault capability point which would result in possible explosion of the transformer. Thus, the interrupting characteristics of an ideal fault interrupter for the particular transformer limits shown can be schematically represented by the line made up of long dashes followed by two shorter dashes and which is appropriately labeled.

For comparison purposes, the characteristics of two typical full range current limiting fuses as heretofore marketed are also shown schematically in FIG. **24**. In the case of the **6** amp. full range fuse, the upper part of the curve is to the right of the transformer limit curve rendering the fuse unsatisfactory for this application. The **3** amp. current limiting fuse is to the left of the transformer overload curve, but drops below the transformer inrush current limitation point thus also making use of the **3** amp. fuse impractical for this application.

However, the interrupting characteristics of apparatus **8** embodying a **2.1** amp. fuse link are illustrated by the appropriately labeled dashed line of FIG. **24** and it can be seen in this instance that the link remains to the left and below the transformer limit line and is between the transformer fault capability point and the transformer inrush current limitation point.

It is thus apparent that when the high range current limiting fuse structure **10** is connected in electrical series relationship with cutout apparatus **82**, the total range interrupter **8** presented thereby functions in a synergistic manner with desirable characteristics which neither of the devices possesses alone. To cooperate, both fuses must carry the same fault current. Therefore, a fault (an unintentional flow of high magnitude electrical current from circuit to ground) must not occur between them. Since the possibility of a fault between the low range interrupting apparatus and the high range fuse structure increases with distance of separation, the two devices should be in direct physical contact or preferably as close together as possible.

One especially important advantage of the total range interrupting device is that it operates with much less noise and explosive force than experienced with the cutout alone. The high range fuse operates in the device to quickly limit high fault currents to such a level that they act only to blow the cutout in the normal safe manner. In addition, the fuse link of the cutout melts and causes the fuse tube to drop out and indicate a fault.

Fuse **10** is preferably wired in series with cutout **82** such that current normally flows through fuse **10** and thereafter through the cutout. Although the fuse or other current limitor could be physically located in a number of different places on the cutout, the arrangement shown in FIG. **1** is preferable for several reasons. First, conductive gas venting at the open lower end of the fuse link tube **84** during operation of the cutout is directed away from the fuse which is attached atop cutout **82**; if however, the fuse were connected to the lower terminal **86** thereof, this gas could serve to short out or otherwise damage the fuse. Similarly, the fuse link pigtail could electrically short out the limitor as it is ejected from the lower end of tube **84** during operation of cutout **82**.

The construction and operation of an expulsion dropout type cutout is described in detail in the patents identified above. However, in general it comprises an elongated insulative support **88** with first conductive means **90** attached to the support and adapted to connect with an incoming current source, for example conductor **92** through fuse **10**. An elongated, insulative, hollow fuse link tube **84** of lesser length than support **88** is releasably engaged to first conductive means **90** and depends therefrom, with the lower end **94** thereof being open. A fuse link **96** carried within the tube and conductively attached to the first means **90** is adapted to sever under the influence of a fault current of predetermined magnitude.

Second conductive means **98** is attached to insulative support **99** below first means **90** and spaced therefrom with the second means being adapted to electrically connect with a conductor **100** extending away from the cutout. Fuse link tail **96** extends from the open end **94** of fuse link tube **84** and electrically connects with the second means **98** to complete the current path through the cutout. The cutout also includes biasing means cooperable with the fuse link to urge tube **84** out of engagement with first member **90** when the fuse link severs, thereby causing an interruption of the electrical current through the cutout.

In the device particularly shown in FIG. **1**, the first member **90** includes connective portion **102** adapted to electrically connect with a ferrule portion of a current limitor such as stud **24** of the fuse **10** of the present invention. Also forming a part of first means **90** is hood casting **104** which carries a springable retention means **106** which tensionably holds fuse link tube **84** in its upright position. The tube **84** has a metallic ferrule **105** at its upper end with a pivotally mounted O-ring release member **108** straddling ferrule **105** and extending behind springable member **106**.

At the lower end **94** of tube **84**, a ferrule **110** is provided which is pivotally mounted to a rotary contact support member **112** which is in turn pivotally mounted within second connective means **98** by means of wrist pins **114**. Fuse link **96** extends out of open end **94** of the fuse link tube **84** and is secured to rotary contact member **112** on the underside thereof. Spring-loaded biasing means (not shown) are also provided on the underside of rotary contact member **112** which is tensionably restrained by the fuse link **96**.

Therefore, upon experiencing a fault current of sufficient magnitude, the fuse link **96** severs or melts, causing the biasing means to first drop tube **84** downwardly out of direct contact with the springable release member **108** then cause tube **104** to swing downwardly and outwardly away from first conductive means **90**, thereby interrupting the electrical current to the cutout and simultaneously providing an indication of operation to repairmen.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. Electrical fault interrupter apparatus for suppressing external arcing under fault conditions, as well as providing a double-fused, dual fault-current-range protected, high current handling, electrical coupling between a high voltage power line energized with an electrical potential of a first predetermined level and electrical power-accepting means to be energized from said line, said apparatus comprising:

a cut-out fuse device including

an elongate electrical insulator adapted to have a zone thereof intermediate its ends conventionally supported upon utility pole structure or the like,

a pair of electrically conductive assemblies mounted upon said insulator respectively adjacent the opposite ends of the latter and both extending laterally from said insulator in the same general direction and in spaced relationship to each other,

said assemblies at their respective zones of closest proximity to each other and to said zone of said insulator being physically separated by respective distances, which are sufficient to normally preclude arcing therebetween of an electrical potential of said first predetermined level or of level within a first range of levels next above said first predetermined level, but which are insufficient to preclude arcing therebetween of an electrical potential of level within a second range of levels above said first range of levels under certain fault and other conditions of weather, contamination and the like,

an elongate cut-out fuse link constructed to be actuated for interrupting an electrical circuit path therethrough in response to electrical current flow therethrough of a first predetermined magnitude, and

means for supporting said link in laterally spaced physical relationship to said insulator and in longitudinally extending physical relationship between said assemblies, and for electrically coupling said link in normally circuit-completing relationship between said assemblies;

a current-limiting fuse component including

a pair of spaced apart connection terminals, and

a fuse element electrically coupled between said terminals and constructed to be actuated for interrupting an electrical circuit path therethrough in response to electrical current flow therethrough of a second predetermined magnitude greater than said first magnitude,

said component having the property that, upon actuation of said fuse element to interrupt the normal circuit path therethrough in response to a fault-produced current flow therethrough at least equal to said second magnitude, a back-voltage potential, which is of level within said second range, is produced and presented at said terminals, and

means for supporting said current-limiting fuse component in physical disposition adjacent but beyond the extremity of the cut-out fuse device having one of said assemblies and one end of said insulator thereat with the one of said terminals being nearest said one assembly and the other of said terminals being displaced from said one assembly further than said one terminal in a direction generally away from said other assembly, and for electrically coupling said one terminal with said one assembly to place said fuse element of said current-limiting fuse component and said fuse link of said cut-out fuse device in series-coupled electrical relationship,

said other terminal and said other assembly presenting a pair of physically remote external connection points for the apparatus which are spaced apart a distance greater than any of the aforesaid respective distances, the one of said points represented by said other terminal being adapted and intended for electrical coupling with said line and the other of said points represented by said other assembly being adapted and intended for electrical coupling with said power-accepting means.

2. Apparatus as set forth in claim 1, wherein:

said cut-out fuse device further includes elongate cover means disposed around said fuse link and having an open end for blow-out of gases generated upon actuation of the device in a direction away from said current-limiting fuse component.

3. Apparatus as set forth in claim 1, wherein:

the longitudinal axes of said insulator and said fuse link are disposed to be generally upright, said one assembly is disposed adjacent the upper extremity of said cut-out fuse device, and said component is disposed above said one assembly.

4. A total range fault interrupter comprising the combination of:

low range current interrupting apparatus operative to interrupt fault currents of relatively low magnitude; and

high range current limiting fuse structure connected in series with said low range apparatus for interrupting all fault currents of high magnitude, said structure comprising:

an elongated, hollow insulative housing,

closure means integrally attached to said housing in covering relationship to opposed ends thereof to present a closed body, each of said closure means having conductive connective structure on the external face thereof respectively adapted to permit said fuse to be interposed within an electrical circuit,

at least one relatively thin, elongated fusible element within said housing, the distal ends of said element being adapted for electrical connection with said respective external connection structure of said closure means,

means electrically connecting each of said external connection structures with the distal ends of said fusible element to thereby create a current path through said fuse,

a series of spaced zones along the length of said element within the housing having decreased cross-sectional areas relative to the remainder of the element, the ratio of the maximum cross-sectional area to the minimum cross-sectional area thereof being sufficiently high to cause said high range fuse to limit fault currents only of said high magnitude by the severance of said element at said zones of decreased cross-sectional area,

an elongated, insulative saddle member of synthetic

resin material having a plurality of circumferentially-spaced fins, said fins being provided with spaced attachment means at predetermined points about the marginal edges thereof for the attachment of said fusible element,

said fusible element being helically wrapped about said saddle member and attached thereto by said attachment means to form an internal fuse assembly, said saddle member and fusible elements cooperatively acting to position and support each other within said housing with the convolutions of said elements being maintained in an aligned, spaced relationship about said saddle, and

pulverulent arc-suppressing material within said closed body in substantially surrounding relationship to the convolutions of said element, said material being characterized by the property of acting to quickly suppress the electrical arc formed upon the severing of said fusible element under the influence of a fault current;

said apparatus and the structure being cooperable to effect interruption of low and high magnitude fault currents with substantial isoenergy dissipation within predetermined relative narrow limits under all fault interruptions thereby.

5. A total range fault interrupter as set forth in claim **4** wherein said closure means is provided with apertures therein receiving respective distal ends of said fusible element and said means for electrically connecting the distal ends of said elements with said respective connective structure comprises:

mechanical connection means within said apertures adapted to seal said closed body and secure said distal ends of the fusible element therein; and

means electrically connecting said mechanical connection means and said respective external connection structure, thereby providing a current path through said fuse.

6. A total range fault interrupter as set forth in claim **5** wherein said mechanical connection means comprises expandable rivets operatively positioned in said apertures to secure said fusible elements within said housing.

7. A total range fault interrupter comprising the combination of:

low range current interrupting apparatus operative to interrupt fault currents of relatively low magnitude, said apparatus comprising

an elongated, substantially rigid insulative support member,

first conductive means attached to said support,

an elongated, insulative hollow fuse link tube of lesser length than said support releasably coupled to said first conductive means and depending therefrom, the lower end of said fuse link tube being open,

a fuse link carried within said tube conductively attached to said first means to provide a current path through said cutout, said link being operable to sever under the influence of a fault current of said low magnitude,

second conductive means attached to said support below said first conductive means and spaced therefrom, said second means being adapted to be electrically connected to a conductor extending away from said cutout, said fuse link extending from the lower end of said tube and electrically connecting with said second means, thereby completing the current path through said cutout, and

biasing means cooperable with said fuse link to urge said fuse link tube out of engagement with said first member when said fuse link severs to thereby interrupt the current path through said cutout;

high range current limiting fuse structure connected in series with said low range apparatus for interrupting all fault currents of high magnitude, said structure comprising

an elongated, hollow insulative housing,

closure means attached to said housing in covering relationship to opposed ends thereof to present a closed body, each of said closure means having conductive connection structure on the external face thereof respectively adapted to permit said fuse to be interposed within an electrical circuit,

at least one relatively thin, elongated fusible element within said housing, the distal ends of said element being adapted for electrical connection with said respective external connection structure of said closure means,

means electrically connecting each of said external connection structures with the distal ends of said fusible element to thereby create a current path through said fuse,

a series of spaced zones along the length of said element within the housing having decreased cross-sectional areas relative to the remainder of the element, the ratio of the maximum cross-sectional area to the minimum cross-sectional area thereof being sufficiently high to cause said high range fuse to limit fault currents only of said high magnitude by the severance of said element at said zones of decreased crosssectional area,

an elongated, insulative saddle member of synthetic resin material having a plurality of circumferentially-spaced fins, said fins being provided with spaced attachment means at predetermined points about the marginal edges thereof for the attachment of said fusible element,

said fusible element being helically wrapped about said saddle member and attached thereto by said attachment means to form an internal fuse assembly, said saddle member and fusible elements cooperatively acting to position and support each other within said housing with the convolutions of said elements being maintained in an aligned, spaced relationship about said saddle, and

pulverulent arc-suppressing material within said closed body in substantially surrounding relationship to the convolutions of said element, said material being characterized by the property of acting to quickly suppress the electrical arc forming upon the severing of said fusible element under the influence of a fault current;

said apparatus and the structure being cooperable to effect interruption of low and high magnitude fault currents with substantial isoenergy dissipation within predetermined relatively narrow limits under all fault interruptions thereby.

8. A compact current limiting fuse adapted to be interposed in an electrical circuit to protect the latter from the effects of fault currents comprising:

an elongated, hollow insulative housing;

closure means integrally attached to said housing in covering relationship to opposed ends thereof to present a closed body, each of said closure means having conductive connection structure on the external face thereof respectively adapted to permit said fuse to be interposed within an electrical circuit;

at least one relatively thin, elongated fusible element within said housing, the distal ends of said element being adapted for electrical connection with said respective external connection structure of said closure means;

means electrically connecting each of said external connection structures with the distal ends of said fusible element, thereby creating a current path through said fuse;

a series of spaced zones along the length of said element within said housing having decreased cross-sectional areas relative to the remainder of the element, thereby producing increased electrical resistance at said zones, whereby, under the influence of a fault current of predetermined magnitude, said element severs at least a sufficient number of said zones to effect a limiting of said current;

an elongated, saddle member of relatively thin, electrically insulative material having a plurality of circumferentially-spaced fins, said fins being provided with spaced attachment means at predetermined points about the marginal edges thereof for the attachment of said fusible element,

said fusible element being helically wrapped about said saddle member and attached thereto by said attachment means to form an internal fuse assembly, said saddle member and fusible elements cooperatively acting to position and support each other within said housing with the convolutions of said elements being maintained in an aligned, spaced relationship about said saddle; and

pulverulent arc-suppressing material within said closed body in substantially surrounding relationship to the convolutions of said element, said material being characterized by the property of acting to quickly suppress the electrical arc formed upon the severing of said fusible element under the influence of a fault current.

9. The current limiting fuse of claim **8** wherein said saddle member is fabricated of synthetic resin material.

10. The current limiting fuse of claim **8** wherein said housing is generally cylindrical in shape and composed of fiber reinforced, synthetic resin material.

11. The current limiting fuse of claim **8** wherein said closure means are composed of conductive material, and said conductive connective structure is integral therewith.

12. The current limiting fuse of claim **11** wherein said closure means is provided with apertures therein receiving respective distal ends of said fusible element and said means for electrically connecting the distal ends of said element with said respective external connective structure comprises:

mechanical connection means within said apertures adapted to seal said closed body and secure said distal ends of the fusible element therein; and

means electrically connecting said mechanical connection means and said respective external connection structure, thereby providing a current path through said fuse.

13. The current limiting fuse of claim **12** wherein said mechanical connection means comprises expandable rivets operatively positioned within said apertures to secure said fusible elements within said housing.

14. The current limiting fuse of claim **13** wherein the external heads of said rivets are covered with fusible solder material to insure a substantially airtight seal about said aperture.

15. The current limiting fuse of claim **8** wherein said fusible element is composed of elemental silver.

16. The current limiting fuse of claim **8** wherein said zones of reduced cross-sectional area are defined by spaced transverse slots formed in said fusible elements along the length thereof.

17. The current limiting fuse of claim **8** wherein said saddle member is composed of four circumferentially-spaced fins radially extending from a common longitudinal axis, the marginal edges of said fins being provided with a series of spaced cradle openings for the reception of said fusible element.

18. The current limiting fuse of claim **17** wherein said cradle openings comprise generally circular openings in communication with the marginal edges of said fins, the maximum width of said openings being substantially equal to the widths of said fusible elements with the widths of said openings at the extreme edges of said fins being smaller than the widths of said fusible elements.

19. The current limiting fuse of claim **8** wherein said attachment means are positioned about said fins in disposition to support the fusible element in a symmetrical helical pattern about said saddle, the longitudinal axes of said saddle and the helically wound element being substantially coincident.

20. The current limiting fuse of claim **8** wherein said pulverulent material is silica sand.

21. The current limiting fuse of claim **20** wherein said sand has an average mesh size within the range of **30** to **70.**

22. The current limiting fuse of claim **8** wherein said internal fuse assembly includes a single helically wound fusible element.

23. The current limiting fuse of claim **8** wherein two fusible elements are helically wound about said saddle member to form said internal fuse assembly, said separate helices being of substantially equal pitch and about one-half pitch out of phase respectively, thereby spacing the helical windings of said fusible elements along the length of said saddle.

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