Feb. 10, 1970 O. JENSEN 3,495,056

CURRENT LIMITING INTERRUPTER WITH ARC-INSERTED NON-LINEAR RESISTORS

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FIG. 1.

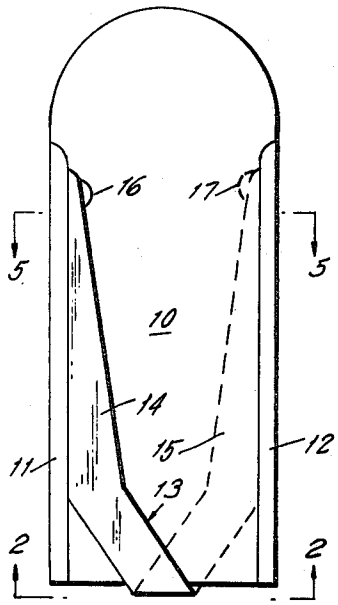

FIG. 3.

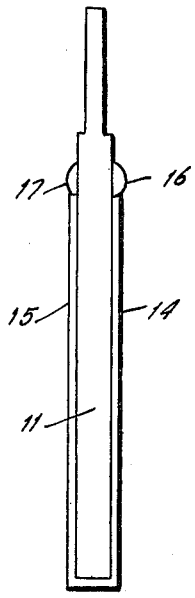

FIG. 2.

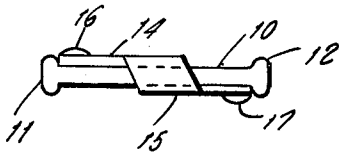

FIG. 4.

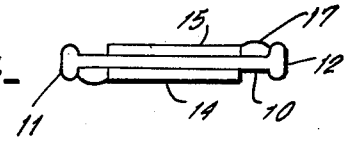

FIG. 5.

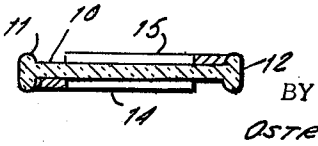

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FIG. 7

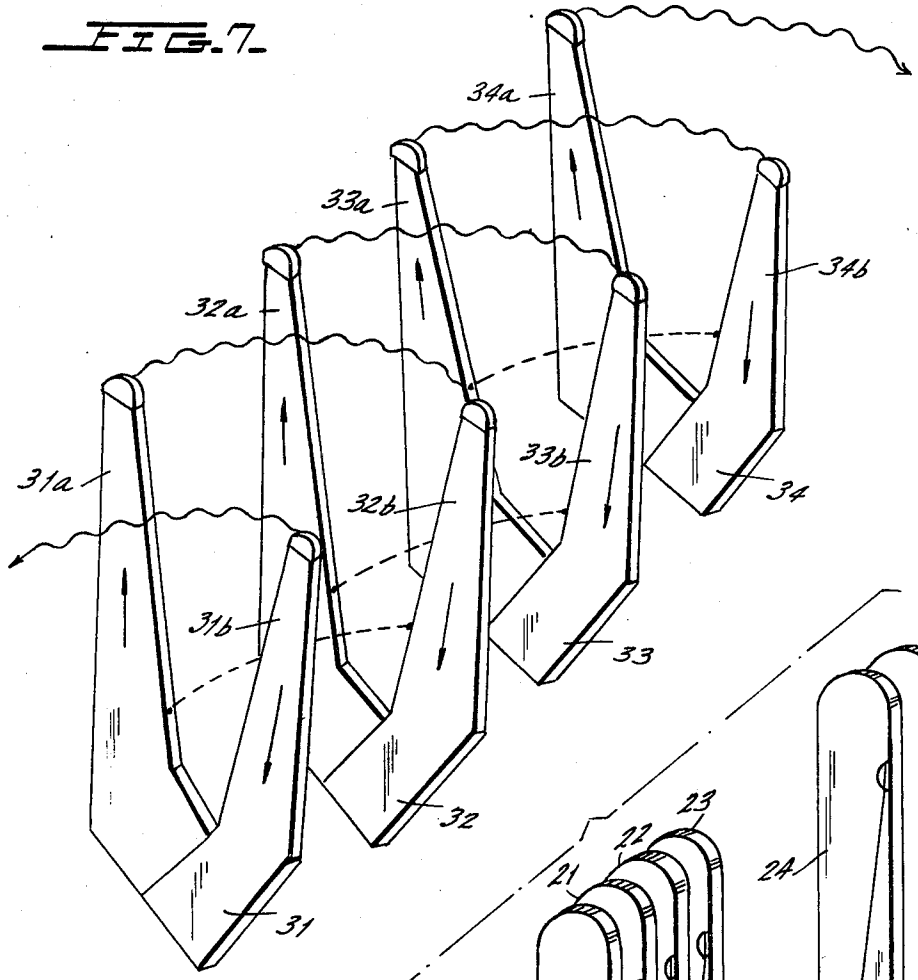
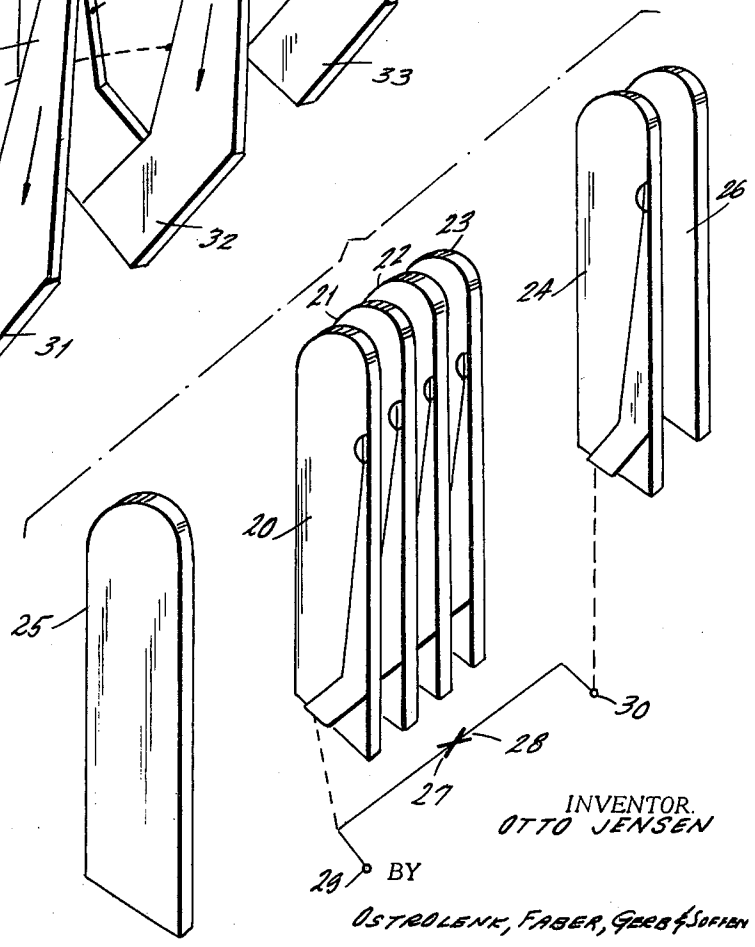


FIG. 6



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3,495,056

CURRENT LIMITING INTERRUPTER WITH ARC-INSERTED NON-LINEAR RESISTORS

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Int. Cl. H01h 9/30, 33/00
U.S. Cl. 200—147 2 Claims

ABSTRACT OF THE DISCLOSURE

A current-limiting arc plate having a central insulation body and a V-shaped conductor extending around the body, with the legs of the V extending up the sides of the plate and on opposite sides of the plate. The V-shaped conductor is made of a material having a high-temperature coefficient of resistance. A plurality of such plates are stacked in an arcing chamber such that the arcs between the plates define a solenoidal arc current path which tends to expand with the arc roots on each of the plates moving up the legs of the plates. The upward motion of the arc increases the resistance in the arc current circuit with a further resistance increase caused by the heating of the plates. Pure iron and tungsten are two materials which can be used for the V-shaped conductors.

This invention relates to a novel construction for an interrupter structure, and more specifically relates to novel means for using one or more arcs as a means of gradual but fast insertion of metallic resistance in a circuit to reduce and interrupt a fault current. In a specific application of the invention, a novel arrangement is provided for a solenoidal interrupter wherein the arc plates straddling the insulation plates to define a solenoidal current path are made of a high resistivity-temperature coefficient material, and are tapered in cross-section so that increased resistance is introduced into the arc path as the arc moves toward the top of the high resistivity-temperature coefficient plates.

Electric circuit interrupters operate on the principle of drawing an arc between separating contacts and then stretching and/or cooling the arc so as to cause its extinction. It is recognized in the art that the resistance of the arc and the manner in which that resistance is varied play an important role in the current interruption phenomenon. Insertion of resistance in a fault circuit tends to reduce the magnitude of the current. In D-C circuits, the inserted resistance causes a current zero necessary for interruption. In A-C circuits, the inserted resistance advances the occurrence of current zero.

The sudden insertion of a great amount of resistance can bring the current down to a zero value very rapidly, but this rapid change in the current causes a large self-induced voltage in the circuit inductance, which may subject the circuit insulation to harmful dielectric stresses. Therefore, the insertion of resistance must be effected in such a way as to limit the over-voltage caused by the change in the current. The ideal resistance should have a very small value when inserted and then be caused to increase continuously, so as to gradually reduce the current magnitude without too high a rate of change.

The arc drawn between two separating contacts has desirable resistance characteristics in this respect, since its resistance has a very low initial value and increases as the arc is lengthened and/or cooled. However, it has the following drawbacks:

(a) Its cross section, and therefore its conductance per unit length, increases with the instantaneous magnitude

of the current. This causes the IR voltage drop per unit length to be substantially constant. Therefore, in order to obtain the voltage drop required for extinction, it becomes necessary to subject the arc to considerable lengthening and/or cooling.

(b) The arc, being in effect a resistor, liberates a considerable amount of energy in the form of heat, which raises the temperature in the interrupting chamber. Immediately after an arc extinction at a current zero, the space previously occupied by the arc retains some residual ionization, due to the high temperature. This lowers the dielectric strength of said space and may be the cause of arc reignition.

The present invention is directed to an interrupter in which the main resistance inserted in the circuit is constituted by a plurality of metallic resistors, connected in series by electric arcs. Resistance insertion is effected by the travel of the arcs along the surface of resistor strips. The value of the inserted metallic resistance is practically zero, initially, and increases as the inserted length increases with the travel of the arc. Further increase in the inserted resistance is obtained from the change in resistivity of the metallic resistor strips as their temperature increases due to heat generated in them by current flow.

The mechanism for inserting metallic resistance makes use of the motor action produced on the arcs by the magnetic field in which they are located. In the particular embodiment hereby described, the metallic resistors and the arcs that connect them in series are arranged in a spatial relation that constitutes a solenoidal conducting path. In such an arrangement the successive arcs are subjected to forces tending to increase the mean diameter of the solenoid. Other embodiments utilizing the same principle are of course possible.

Structurally, the mechanism herein described consists in the addition of metallic resistance legs to the V-shaped conducting plates of the solenoidal interrupter described in U.S. Patent No. 2,868,927. In order to maximize the total resistance inserted at the end of the arc travel, the above legs should be made of high resistivity material. In order to cool the legs rapidly after operation, they must be in intimate contact with the ceramic plates. In order to minimize erosion on the tips where the arc roots at the end of its travel, the tips must be made of refractory material such as tungsten.

Thus, the essence of the invention consists in the substitution of a high electrical resistance metallic conductor for most of the arc in an air magnetic type interrupter. Arcs are retained, as a means for inserting and connecting in series the metallic resistors, as a form of moving slider to increase the inserted resistor length, and as a means for breaking the connection at current zero, but the resistance inserted is mostly in the metallic resistor, rather than in the arc. The arrangement possesses several advantages, as follows:

(a) The resistance being inserted increases continuously as the arcs travel up the legs, instead of varying inversely with the current.

(b) Most of the energy liberated during interruption will appear in the metallic resistance rather than in the arc, and therefore residual ionization after current zero will be minimized.

A further feature of the above concept consists in making the resistor legs of a material having a high temperature-resistivity coefficient such as to cause a tenfold increase in resistivity with a temperature increase of about 800° C., and in proportioning its mass and length so that the heat generated by current flow raises its temperature by the mentioned amount. Such a resistor has

a current limiting effect in the fault circuit where it is inserted.

The current limitation is produced by the mutual interaction between the current and the increasing resistance. The mechanism of that interaction is as follows: current flow i at any instant in response to the applied voltage e, is limited by the total resistance R and the inductance L in the circuit according to Kirchhoff's Law:

$$e=Ri+L\frac{di}{dt}$$

from which it follows that the instantaneous rate of change of the current can be expressed as

$$\frac{di}{dt}=\frac{1}{L}(e-Ri)$$

The total resistance R is constituted by the external circuit resistance R_c which remains substantially constant, and the resistance inserted by the interrupter r, which increases continuously during current flow. The resistance r is expressed as

$$r=1/A$$

where r is the resistivity, 1 the length and A the cross-section area of the inserted resistor. The initial increase in r is due to an increase in 1 as the arcs move up. Subsequent increases in r are due to heating by the current.

When the insertion of the resistor starts, the current i has some value i_0 and r has the value r_0 corresponding to the initial temperature of the resistor. The current increases at the initial rate

$$\left.\frac{di}{dt}\right|_0=\frac{1}{L}\left[e-(R_c+r)i_0\right]$$

The heat generated in the resistor by current flow increases its temperature, and its resistivity, causing an increase in the current product Ri and a decrease in the difference $e-Ri$. The current increments corresponding to successive intervals thus become smaller. When the instantaneous value of Ri equals the applied voltage e, the current levels off. Subsequent increases in r cause the product Ri to exceed e, and the rate of change of the current becomes negative, which means that the current decreases, approaching a zero value. At current zero, the arcs in the interrupter become extinguished and current flow stops. As the resistance r increases, the circuit power factor changes, approaching unity. If the resistor is properly dimensioned, the power factor will be very close to unity by the time that the circuit voltage goes through zero, which means that current zero will occur very nearly at voltage zero, the most favorable instant for arc interruption.

The current limiting effect is due to the continuous increase in the value of the inserted resistance, caused by the rise in temperature due to the heat generated by current flow. The heat storage capacity of the resistor must be such as to limit its ultimate temperature (at the current zero where the current flow is stopped), to a safe value. But it also must be sufficiently small so that the temperature increase in response to current flow occurs at a fast rate. For satisfactory operation, the dimensions of the resistor (total length and cross-section area), must be chosen within close limits related to its physical characteristics (resistivity, specific heat, temperature-resistivity, variation), and to the circuit constants (voltage, allowed maximum current). Departure from the critical dimensions results in either resistor burnout before the first current zero or inadequate current limitation.

It has been found that the values of resistor length and cross-section area required for optimum performance are related to the open circuit voltage peak (E_m) and to the allowed current peak (i_m) by expressions of the form

$\text{Length}=K_1E_m$, and
$\text{Area}=K_2i_m$

The values of the constants K_1 and K_2 are characteristic of the material of which the non-linear resistor is made. For pure iron, the values are

$K_1=0.151$ cm. per volt
$K_2=0.00255$ cm.^{2} per kiloampere

Accordingly, a primary object of this invention is to provide a novel arcing chamber which gradually inserts resistance into a faulted circuit.

Yet another object of this invention is to provide a novel arc runner for a solenoidal interrupter which is made of a high resistivity-temperature coefficient material, and which tapers down in area from the bottom of the V toward the top of the V.

These and other objects of this invention will become apparent from the following description when taken in connection with the drawings, in which:

FIGURE 1 is a front plan view of a single plate and V-shaped conductor therefor constructed in accordance with the invention.

FIGURE 2 is a bottom view of FIGURE 1.

FIGURE 3 is a side view of FIGURE 1.

FIGURE 4 is a top view of FIGURE 1.

FIGURE 5 is a cross-sectional view of FIGURE 1 taken across the line **5—5** in FIGURE 1.

FIGURE 6 is an exploded perspective view of an assemblage of plates of the type shown in FIGURES 1 through 5 to define an arc chamber in combination with a schematically illustrated pair of contacts.

FIGURE 7 schematically illustrates the solenoidal current path created in the arcing chamber of FIGURE 6.

Referring first to FIGURES 1 through 5, I have illustrated therein a typical plate and V-shaped conductor which could be used directly in the arc chamber of the type shown in U.S. Patent No. 2,868,927. More specifically, FIGURES 1 through 5 illustrate a ceramic plate **10** which has beaded edges **11** and **12**. A V-shaped conductor **13** which is made of a flat strip of high resistivity-temperature coefficient material is then provided with two extending legs **14** and **15** which straddle the plate **10**, and are nested within the side beads **11** and **12**, respectively, of the plate **10**. Note that each of legs **14** and **15** have a tapered cross-section which decreases from the bottom of the V-shaped conductor **13** toward the top thereof.

The V-shaped conductor **13** is then made of a high resistivity-temperature coefficient material such as pure iron or tungsten. Preferably, a pure iron material gives somewhat better results than pure tungsten, and has been found less expensive.

It is to be noted that by a high resistivity-temperature coefficient, I refer to a material which has a resistivity-temperature coefficient in the range of 0.0045 to 0.005 as contrasted to the prior art type of V-shaped conductor which was of copper material having a resistivity-temperature coefficient of 0.0038. (These values are values referred to 20° C.) Thus, the device of the invention provides at least a ten-fold change in resistance from a cold temperature, or room temperature, to arc current temperatures, or hot temperature.

Arcing tips of some suitable arc-resisting material such as tungsten are then placed on the upper ends of the V-shaped conductor shown as tungsten arcing tips **16** and **17**, respectively. The manner in which the arcing tips **16** and **17** are applied to the pure iron V-shaped conductor is well known to those skilled in the art, and, for example, the tips can be welded to the iron body.

An interrupting chamber may then be formed by stacking the plates shown in FIGURES 1 through 5 in parallel spaced relation with respect to one another in any desired manner such as the manner disclosed in the above noted U.S. Patent No. 2,868,927. For purposes of illustration, FIGURE 6 illustrates a plurality of plate assemblies **20** through **24** which are terminated by ceramic end plates **25** and **26** in an exploded perspective view, particularly to illustrate the parallel disposition of the various plates,

each of which are of the type shown in FIGURES 1 through 5. Further details of the use of such plates in an interrupter chamber is disclosed in copending application Ser. No. 474,006 filed July 22, 1965, in the name of Otto Jensen, entitled "Dual-Path Current Limiting Circuit Breaker," and assigned to the assignee of the instant application.

A pair of cooperating contacts are schematically illustrated in FIGURE 6 as contacts **27** and **28** which are connected to terminals **29** and **30**, respectively. FIGURE 6 further illustrates in a schematic fashion the connection of terminals **29** and **30** to the conductors of the end plates **20** and **24**, respectively, whereupon when the contacts **27** and **28** are opened, the arc of these contacts is connected in series with the various plates.

The solenoidal behavior of the arc is schematically illustrated in FIGURE 7 which shows the conductive plates in the absence of their respective ceramic spacers. Thus, FIGURE 7 illustrates four adjacent V-shaped conductors **31**, **32**, **33** and **34** which each have extending legs **31***a*–**31***b*, **32***a*–**32***b*, **33***a*–**33***b* and **34***a*–**34***b*. Note that each of V-shaped conductors **31** through **34** are identical to the conductor **13** of FIGURES 1 through 5, and that the legs of the conductors are terminated by a suitable arc-resistant material.

It will be further observed that the legs **31***a* and **32***b* are coplanar, and are spaced from one another in air between the ceramic plates which are straddled by conductors **31** and **32**. In a similar manner, legs **32***a* and **33***b* will be coplanar, while legs **33***a* and **34***b* will be coplanar.

Assuming now that an arc has been suitably introduced into the arc chamber, the initial current path will be the solenoidal path shown in dotted lines in FIGURE 7. That is to say, the arc will initially flow into the bottom of leg **31***b* and thence upwardly in leg **31***a*. Thereafter, there is an arc from leg **31***a* over to the coplanar spaced leg **32***b*, as illustrated in dotted lines, with the current path then going down in leg **32***b* and up leg **32***a* into the next arc from leg **32***a* to its coplanar leg **33***b*.

By following this initial current path, it will be seen that the current path is solenoidal so that a magnetic field is generated in the solenoidal current path tending to cause the solenoid diameter to expand. This causes the arc roots on the inner edges of the various legs of plates **31** through **34** to move upwardly until the arc finally roots at the top of each of the legs, as shown by the jagged line suggestive of the arc.

Once again the self-inductance of the solenoidal current path tends to cause the arcs at the tops of the coplanar legs to expand upwardly, thereby stretching and cooling the arc. Note that these arcs root upon the arc-resistant ends of the various legs.

Moreover, and since the material of plates **31** through **34** was selected to be of a high resistivity-temperature coefficient material, as current flows through the legs, its temperature and thus its resistance is gradually increased, thereby gradually introducing an increasing resistance into the faulted circuit. Moreover, and since the cross-sectional area of the various legs decreases as the arc moves upwardly, there will be a still further gradual increase in the resistance of the solenoidal current path.

All these effects of the novel construction contribute to cause a gradual increasing resistance into the solenoidal current path to avoid the appearance of a high induced voltage across the solenoidal current path.

Moreover, the novel construction of the high resistance leg extensions in the form of flat strips speeds the cooling of the metallic legs after the arc is successfully interrupted.

In a typical example, if the interrupter is used in a circuit having an open circuit peak voltage of 1,000 volts and an allowed current peak of 100,000 amperes, the total length of the resistor would be 151 centimeters. That is:

$$K_1E_m=0.151 \text{ cm./volt}\times 1000 \text{ volts}=151 \text{ cm.}$$

The cross-section area of the legs would be:

$$K_2i_m=0.00255 \text{ cm.}^2/\text{ka.}\times 100 \text{ ka.}=.255 \text{ cm.}^2.$$

Although this invention has been described with respect to its preferred embodiments, it should be understood that many variations and modifications will now be obvious to those skilled in the art.

The embodiments of the invention in which an exclusive privilege or property is claimed are defined as follows:

1. An arc interrupting device for an electrical circuit comprising a first elongated conductor, a second elongated conductor spaced from said first elongated conductor whereby an arc can be established between said first and second conductors; electrical circuit means connected to one end of each of said first and second elongated conductors; each of said first and second elongated conductors having a length substantially longer than their width; arc control means for causing the arc roots of an arc to move along said first and second conductors in a direction away from said one end of said first and second conductors and toward the opposite ends of said first and second conductors; said first and second conductors being of a material characterized in having a high resistivity-temperature coefficient of at least ten times the cold resistance thereof when arc currents flow through said conductors; the length of said first and second conductors being proportional to the voltage E_m and the cross-sectional area of said first and second conductors being proportional to the current i_m, wherein E_m is the open circuit peak voltage of said electrical circuit and i_m is the allowable peak current of said circuit.

2. The device substantially as set forth in claim **1** wherein said first and second conductors are of pure iron and have a total length of approximately 0.15 E_m cm. and cross-sectional areas of 0.00255 i_m cm.^{2} where E_m is the value, in volts, of the open circuit peak voltage of said circuit, and i_m is the value, in kiloamperes, of the allowable peak current of said circuit.

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ROBERT S. MACON, Primary Examiner

U.S. Cl. X.R.

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