Oct. 3, 1967 G. POLINKO, JR., ETAL 3,345,484

SHIELDING FOR A VACUUM TYPE CIRCUIT INTERRUPTER

Filed May 10, 1965

FIG. 1.

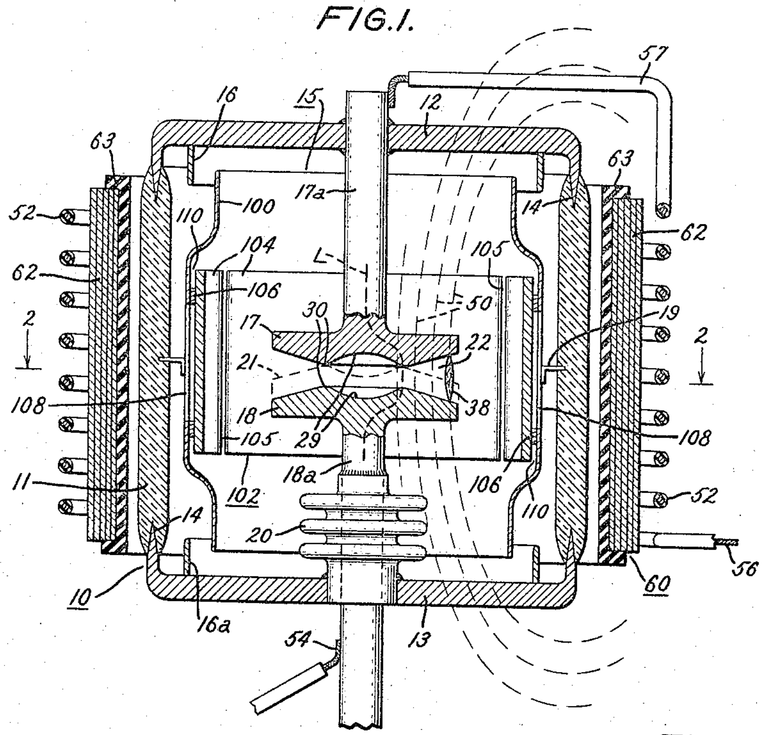


FIG. 2.

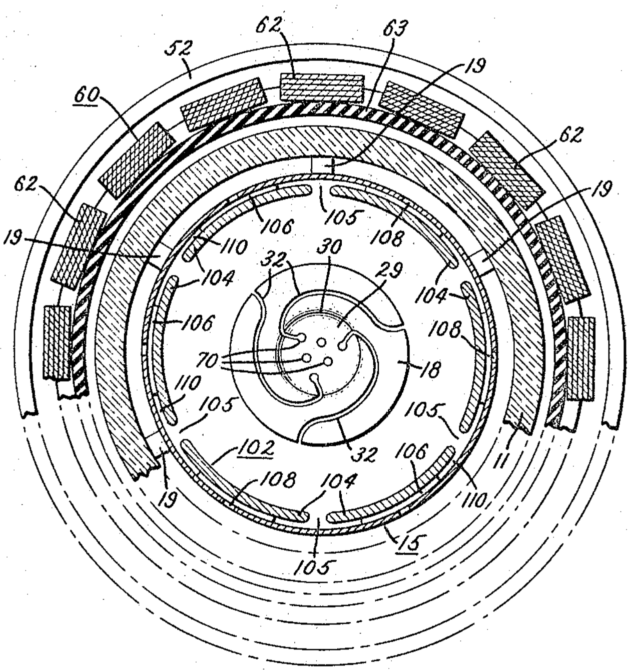
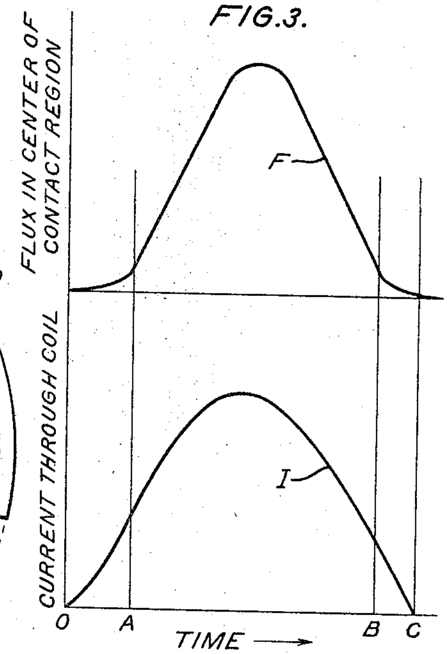


FIG. 3.



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United States Patent Office 3,345,484 Patented Oct. 3, 1967

3,345,484

SHIELDING FOR A VACUUM TYPE CIRCUIT INTERRUPTER

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Filed May 10, 1965, Ser. No. 454,282
6 Claims. (Cl. 200—144)

This invention relates to a vapor-condensing metal shield for a vacuum-type circuit interrupter and relates, more particularly, to means for reducing the eddy currents induced in such a shield by a varying magnetic field that extends axially of the interrupter.

The usual vacuum type interrupter comprises a pair of relatively movable contacts, or electrodes, that can be separated to establish an arcing gap therebetween across which an arc is formed. The arc vaporizes some of the electrode material to create a local atmosphere through which current flows until about the time a natural current zero is reached. When the current zero point is reached, the arc vanishes, and the usual recovery voltage transient builds up across the arcing gap. If the gap is able to withstand this recovery voltage transient, the arc is prevented from reigniting and interruption is completed.

In application Ser. No. 328,656, Lee, filed Dec. 6, 1963, (now abondoned, but replaced by continuation-in-part application S.N. 549,750, filed Apr. 20, 1966, and issued as Patent 3,321,599) and assigned to the assignee of the present invention, it is pointed out that the current interrupting capacity of the vacuum interrupter can be increased by applying to the arcing gap during high instantaneous currents an axial magnetic field that has its lines of force extending generally parallel to the arc. In order to achieve this improved performance, the magnetic field must be removed or at least reduced to a low strength during the period just prior to current zero and must be relatively strong during the period when the instantaneous current is high.

The interrupter of the aforesaid Lee application uses a coil connected in series with the contacts of the interrupter for developing the desired axial magnetic field. When the current through the contacts is high, this coil develops the desired high strength magnetic field, and when the current approaches zero, the magnetic field strength falls to the desired low value. But unless the eddy currents induced in certain parts of the interrupter by the magnetic field are held to a low value, they can cause the flux developed by the coil to lag appreciably behind the current and this will result in a relatively high magnetic field remaining across the gap when the current zero point is reached.

One part of the interrupter in which such eddy currents will be developed is the tubular vapor-condensing shield that surrounds the arcing gap. If the shield is a thin metallic member of a high resistivity metal, then the eddy currents induced therein will be relatively low, and only a small amount of flux will be present at current zero. But to improve the vapor-condensing efficiency of the shield, it is sometimes desirable to make the shield relatively thick and of a high conductivity metal, such as copper. In a shield of this character, relatively high eddy currents are induced which can result in a relatively large amount of flux being present at current zero.

An object of our invention is to provide a relatively thick shield of high conductivity metal which is so constructed that the eddy currents induced therein by a varying magnetic field extending axially of the arcing gap are limited to very low values.

Another object is to limit these eddy currents to low enough values to preclude the maintenance of a significant axial field at current zero.

Still another object is to construct the shield in such a manner that it is highly effective in intercepting and condensing electrode vapors emitted from the arcing gap and is not susceptible to having its eddy current-suppressing characteristics impaired by the condensation of such electrode vapors on the shield.

For a better understanding of our invention, reference may be had to the following description taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a cross-sectional view through a vacuum-type circuit interrupter embodying one form of our invention.

FIG. 2 is a cross-sectional view along the line 2—2 of FIG. 1.

FIG. 3 is a graphical representation of the current and magnetic field strength during an interrupting operation.

Referring now to the interrupter of FIG. 1, there is shown a highly evacuated envelope **10** comprising a casing **11** of suitable insulating material and a pair of metallic end caps **12** and **13** closing off the ends of the casing. Suitable seals **14** are provided between the end caps and the casing to render the envelope vacuum tight. The normal pressure within the envelope **10** under static conditions is lower than 10^{-4} mm. of mercury, so that a reasonable assurance is had that the mean free path for electrons will be longer than the potential breakdown paths in the envelope.

Located within the envelope **10** is a pair of relatively movable disk-shaped contacts, or electrodes, **17** and **18** shown in their separated or open-circuit position. When the contacts are separated, there is an arcing gap **22** located therebetween. The upper contact is a stationary contact suitably secured to a conductive rod **17*a***, which at its upper end is united to the upper end cap **12**. The lower contact **18** is a movable contact joined to a conductive operating rod **18*a***, which is suitably mounted for vertical movement. The operating rod **18*a*** projects through an opening in the lower end cap **13**, and a flexible metallic bellows **20** provides a seal about the rod **18*a*** to allow for vertical movement of the rod without impairing the vacuum inside the envelope **10**. As shown in FIG. 1, the bellows **20** is secured in sealed relationship at its respective opposite ends to the operating rod **18*a*** and the end cap **13**.

Coupled to the lower end of the operating rod **18*a***, suitable actuating means (not shown) is provided for driving the movable contact **18** upwardly into engagement with the stationary contact **17** so as to close the interrupter. The closed position of the movable contact is indicated by the dotted line **21**. The actuating means is also capable of returning the contact **18** to its illustrated solid-line position so as to open the interrupter. A circuit-opening operation will soon be explained in greater detail. A typical gap length when the contacts are fully separated is ½ inch.

The arc (indicated at **38**) that is established across the gap **22** between the electrodes upon contact-separation vaporizes some of the contact material, and these vapors are dispersed from the arcing gap **22** toward the envelope. In the illustrated interrupter, the internal insulating surfaces of the casing **11** are protected from the condensation of arc-generated metallic particles thereon by means of a tubular metallic shield generally indicated at **15**. This shield **15** is suitably supported on the casing **11** and preferably isolated from both end caps **12** and **13**. Suitable support brackets **19** attached to the outer periphery of the shield **15** are used in the illustrated embodiment for supporting the shield on casing **11**. The shield **15** acts to intercept and condense arc-generated metallic vapors before they can reach the casing **11**. To reduce the chances for vapor bypassing the shield **15**, a pair of end shields 16 and 16a are provided at opposite ends of the central shield. These end shields correspond to those disclosed and claimed in Patent No. 2,892,912, Greenwood et al. assigned to the assignee of the present invention.

All of the internal parts of the interrupter are substantially free of surface contaminants. In addition, the contacts 17 and 18 are effectively freed of gases absorbed internally of the contact body so as to preclude evolution of these gases during high current interruption.

Although this invention is not limited to any particular contact configuration, we prefer to use a contact configuration similar to that disclosed and claimed in U.S. Patent 2,949,520, Schneider, assigned to the assignee of the present invention. Accordingly, each contact is of a disk shape and has one of its major surfaces facing the other contact. The central region of each contact is formed with a recess 29 in this major surface, and an annular contact-making area 30 surrounds this recess. These annular contact-making areas 30 abut against each other when the contacts are in their closed or engaged position and are of such a diameter that the current flowing through the closed contacts follows a loop-shaped path L that bows outward, as is indicated by the dotted lines of FIG. 1. This loop-shaped path has a magnetic effect which tends in a well known manner to lengthen the loop. As a result, when the contacts are separated to form an arc such as 38 between the areas 30, the magnetic effect of current flowing through the loop shaped path will impel the arc radially outward.

As the arc terminals move toward the outer periphery of the disks 17 and 18, the arc 38 is subject to a circumferentially-acting magnetic force that tends to cause the arc to move circumferentially about the central axis of the disks. This circumferentially-acting magnetic force is preferably produced by series of slots 32 provided in the disks and extending from the outer periphery of the disks radially inward by generally spiral paths, as is shown in FIG. 2. These slots 32 correspond to similarly designated slots in the aforementioned Schneider patent and, thus, force the current flowing to or from an arc terminal located at substantially any angular point on the peripheral region of the disk to follow a path that has a net component extending generally tangentially with respect to the periphery in the vicinity of the arc. This tangential configuration of the current path causes a net tangential force component to be developed which tends to drive the arc in a circumferential direction about the contact.

As pointed out hereinabove, if the interrupter is to successfully interrupt the current at a given current zero, it must have built up sufficient dielectric strength across the gap between the contacts to withstand the usual recovery voltage transient that appears across the contacts immediately following the point at which current zero is reached. Whether or not the gap will have this much dielectric strength is largely dependent upon the extent to which the gap is free of arcing products by the time the recovery voltage transient is applied.

The extent to which the gap is free of arcing products depends to an important degree upon the ability of the interrupter, particularly the shield 15, to condense these arcing products. Ordinarily, no problem is encountered for low current interruptions since the quantity of arcing products generated by a low current arc is relatively small. But at high currents, much greater quantities of arcing products are generated, and there is a current level beyond which the interrupter can no longer condense these arcing products fast enough for the gap to withstand the recovery voltage transient.

In the aforementioned Lee application, it is pointed out that the current-interrupting capacity of a vacuum circuit interrupter can be materially increased by applying to the arcing gap during high instantaneous currents an axial magnetic field that has its lines of force extending generally parallel to the arc. In order to achieve this improved performance, the density of the magnetic field must be high during the period when the instantaneous current is high and must be reduced to a very low level during the period just prior to current zero. More specifically, when the instantaneous current is high, the magnetic field density in the arcing region must be high enough to produce a substantial reduction in the arc voltage as compared to that which would be present without the axial magnetic field. Just prior to current zero, the density of the axial magnetic field should be sufficiently low that there is no substantial impairment of the voltage withstand ability of the gap at current zero as compared to that of the gap when no magnetic field is present during this interval before current zero.

The reduced arc voltage that results from the high strength magnetic field appears to result from the tendency that such an axial magnetic field has to confine the arcing products about the arc. By reducing the arc voltage developed during high instantaneous currents, it is possible to reduce the energy input into the shield during high current interruptions. This reduced energy input reduces the temperature rise of the shield 15, thus preserving the ability of the shield to rapidly condense the arcing products generated during high current interruptions.

Generally speaking, the higher the arcing current, the greater is the field strength needed to produce the desired reduction in arc voltage. If the field strength is raised to the desired high level during high instantaneous currents, then an excessive field strength tends to be present just prior to current zero. In application S.N. 328,601, Greenwood and Porter, now Patent No. 3,283,103, filed Dec. 6, 1963, and assigned to the assignee of the present invention, an arrangement is disclosed for enabling the desired high field strength to be obtained during high instantaneous currents without producing an excessive field strength during the period just prior to current zero.

For developing the desired axial magnetic field, which is indicated at 50, a coil 52 having its turns surrounding the envelope 10 is provided and is connected in series with the contacts in the power circuit through the interrupter so that current flowing through the arc also flows through the coil. During arcing, the circuit through the interrupter and the coil 52 extends between a pair of opposed terminals 54 and 56 via the conductive rod 18a, contact 18, the arc 38, contact 17, rod 17a, connection 57 and coil 52. When current flows through coil 52, it creates a magnetic field 50 which has its lines of force extending generally parallel to the arc in the arcing gap.

For controlling the density of the magnetic field in the arcing gap, there is provided an annular iron core 60 that surrounds the casing 11 of the interrupter and is disposed between the casing 11 and the coil 52. The core 60 is made of a high permeability material such as silicon steel. Preferably, the core 60 is formed from strips of grain-oriented silicon steel arranged in stacks 62, circumferentially spaced about the interrupter casing 11 as best shown in FIG. 2. These stacks 62 are held in assembled relationship by suitable means including a cylinder 63 of insulating material disposed at the inner periphery of the core 60.

When the current through the interrupter and the series-connected coil 52 is low, the iron core 60 is unsaturated; and because of its high permeability, the core 60 acts as a flux shunt through which most of the flux developed by coil 52 is directed so that very little flux penetrates into the arcing gap 22. In other words, most of the flux that is located radially-inward of coil 52 then follows a path through core 60 rather than through the region disposed radially-inward of the core 60. When the current through the coil 52 rises to a high value, the core saturates at a predetermined current level, causing a rapid decrease in its permeability, and thus rendering it ineffective to act as a flux shunt for flux produced by current in excess of said predetermined level. A high percentage of this latter flux thus penetrates into the arcing gap, as is indicated in FIG. 1, and produces an axial field **50** of high density in the arcing gap during high instantaneous currents.

This relationship is illustrated in FIG. 3, where curve F depicts the flux in the center of the contact region during a period of high current such as might result from a short circuit. Such current is depicted in curve I plotted against the same time scale as curve F. The current is depicted as flowing for a complete half cycle from O to C. Between the instants O and A, the instantaneous current is relatively low and the iron core **60** is unsaturated. Thus, most of the flux is directed through the core, and very little penetrates into the contact region, as is indicated by the low flat portion of the flux curve F between O and A. Following the instant A, the core **60** begins saturating and the flux created by the additional current can no longer find a low reluctance path through the core **60**. Accordingly, a high percentage of this flux penetrates into the contact region, causing the flux curve F to rise at a much steeper rate. Shortly after the current reaches its peak, the flux also reaches its peak and then drops as the current drops. At the instant B, the current has dropped to a level that has restored the iron to its unsaturated condition, thus allowing the iron to shunt most of the flux through a path remote from the contact region. Some stray flux continues to appear in the contact region after the instant B, but this is a relatively small amount of flux as is illustrated by the low, relatively flat portion of the flux curve F extending from B to C.

As pointed out hereinabove, it is important that the magnetic field density be reduced to a very low value during the period just prior to current zero. This enables the arcing products to disperse from the arcing gap, thus permitting the gap at current zero to recover its voltage withstand ability to substantially the same extent as if no axial magnetic field had been present during the immediately preceding interval.

If the flux wave form had been approximately the same as that of the current, it will be apparent that the amount of flux at instant B would be a higher percentage of the maximum flux than is the case with the flux wave form F shown in FIG. 3. Thus, the presence of the core **60** produces a reduction in the amount of flux appearing just before current zero for a given maximum value of flux. This permits production of the desired high values of flux in the arcing gap during high currents without producing excessive flux during the period just prior to current zero.

It will be apparent from FIG. 3 that the more the flux lags the current (up to about 90 degrees), the higher will be the flux density during the crucial period just before current zero. This lag of the flux behind the current results primarily from eddy currents induced by the magnetic field in the conductive parts of the interrupter. To reduce these eddy currents to a tolerable level, the slots **32** in the contacts have been extended radially inward as far as possible, and holes **70** have been provided in the central region of the contacts, as depicted in FIG. 2. These slots break up the paths for eddy currents induced in the contact structure by the rapidly changing magnetic field **50**, and the holes add resistance to paths that remain. Also the end caps **12** and **13** have been formed of a high resistivity, low permeability material such as stainless steel in order to limit the eddy currents induced therein. The core **60** is laminated for the same purpose.

We are concerned in the present application with limiting the eddy currents induced in the metal shield **15**. If this shield **15** consisted only of a thin-wall tube of high resistivity metal, then the eddy currents flowing therethrough during the low flux period around current zero would be very low. But in the present application, we provide a shield of high-conductivity metal that has a relatively thick wall. This construction is advantageous

in that it more effectively limits the temperature rise of the shield during interruption and thus makes it more efficient as a vapor condenser. But, unless specially constructed, relatively high eddy currents can be induced in a shield of this construction, i.e., with thick walls of high conductivity metal.

Referring more specifically to the shield **15**, it will be noted that it comprises an outer tubular member **100** of a relatively thin-walled construction. This outer tubular member surrounds the arcing gap and extends longitudinally of the envelope **11** for substantial distances on opposite sides of the arcing gap. In one specific form of the invention, this outer member is of nickel. Disposed within this outer tubular member **100** is a tubular internal lining **102** of a relatively thick-walled construction. This liner **102** comprises a plurality of arcuate metal segments **104** spaced-apart circumferentially of the liner to render it discontinuous in a circumferential direction. The longitudinally-extending spaces between the segments are designated **105**. The segments **104** are preferably made of a highly conductive metal such as copper.

For fastening each of the segments **104** to the outer tubular member **100**, we provide a plurality of arcuate spacers **106** of a material that has a high resistivity in comparison to that of the segments **104** and the outer tubular member. A preferred material for these spacers is stainless steel. Each of the spacers **106** is suitably brazed at its respective opposite sides to the outer surface of a segment **104** and the inner surface of the tubular outer member **100**. The spacers are located near the longitudinally opposed ends of the segments **104**.

The axially-directed flux from coil **52** tends to induce eddy currents in the tubular liner **102** which flow in a direction circumferential of the liner. But the longitudinally-extending spaces **105** between the segments prevent these eddy currents from finding a direct path around the circumference of the tubular liner. While there is still a circumferentially-extending path at each end of the liner **102**, this path is through the high-resistivity stainless steel spacers and thus has a very high resistance. This high resistance severely limits any circumferentially-directed eddy currents induced in the liner **102**.

The high resistance of this path also results in a much lower time constant for any eddy currents in the liner **102**, thus causing these eddy currents to decay more rapidly when the axial magnetic field from the coil **52** is removed around current zero. This more rapid decay in the eddy currents also contributes to a reduction in the axial magnetic field present in the arcing gap around current zero. This time constant varies inversely with respect to the resistance of the above described circumferentially-extending path.

For reducing the magnitude of the eddy currents induced in the outer tubular member **100**, a plurality of longitudinally-extending slots **108** are provided in the outer tubular member. These slots extend longitudinally of the shield for substantial distances on opposite sides of the arcing gap **22**. The axially-directed flux from coil **52** tends to induce eddy currents which flow in a direction circumferential of tubular member **100**; but, in the central region of the tubular member **100** around the arcing gap **22**, the slots **108** prevent these eddy currents from finding a direct path circumferentially of the tubular member **100**. At the outer ends of the tubular member **100**, there is an uninterrupted cylindrical region providing a circumferentially-extending path for eddy currents. But these uninterrupted regions are longitudinally displaced so far from the arcing gap that eddy currents flowing therethrough do not produce a significant axial magnetic field in the arcing gap. The fact that the outer tubular member is of a thin walled construction and of a moderately high resistivity material, nickel, aids in this respect by keeping the eddy currents relatively low.

As stated hereinabove, electrode vapors will be projected radially outward from the arcing gap toward the insulating casing **11** during interruption. These vapors are prevented from traveling through the slots **108** by reason of the fact that the segments **104** are positioned between the arcing gap and the slots **108** and can thus intercept and condense the vapors before they can reach the slots.

Since the spacers **106** are located behind the segments **104** with respect to the arcing gap, it will be apparent that they are well protected from the condensation of arc generated electrode vapors thereon. By preventing such vapors from condensing on the spacers and thus forming a highly conductive coating on the spacers, we maintain their ability to interpose a high resistance in any circumferentially-extending path for eddy currents induced in liner **102**.

Arc-generated metallic vapors will condense on the exposed portions of the outer tubular member **100** that are in registry with the spaces **105**, but the resultant coating will not short out the spaces. This is because the inner surface of the outer tubular member **100** is spaced radially outward from the segments **104**. Thus, there is still a space **110** located radially outwardly of the segments **104** separating the segments **104** from the coating developed in registry with spaces **105**.

Although we prefer to construct the liner **102** of a plurality of discrete segments, our invention in its broader aspects is intended to comprehend a construction in which the liner is a tubular member with only a single longitudinally extending slot formed therein to render it circumferentially discontinuous.

While we have shown and described particular embodiments of our invention, it will be obvious to those skilled in the art that various changes and modifications may be made without departing from our invention in its broader aspects; and we, therefore, intend in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. An alternating current circuit interrupter of the vacuum type comprising:

(a) an evacuated envelope,
(b) a pair of electrodes within said envelope having a spaced-apart position defining an arcing gap therebetween across which an alternating current arc is established,
(c) a tubular vapor-condensing shield within said evacuated envelope surrounding said arcing gap,
(d) said tubular shield comprising:
  (i) an outer tubular metal member surrounding said arcing gap and having slots therein extending longitudinally thereof for substantial distances on longitudinally opposite sides of said arcing gap,
  (ii) a tubular internal liner for said outer tubular member generally aligned with said arcing gap and comprising a plurality of discrete metal segments spaced-apart circumferentially of said liner to render said liner discontinuous in a circumferential direction,
  (iii) fastening means for securing said segments to said outer tubular member in radially spaced-apart relationship to said outer tubular member,
  (iv) said fastening means being located between each of said segments and said tubular member in a position behind the associated segment with respect to said arcing gap,
  (v) said fastening means being of a material that has a high resistivity in comparison to that of said segments,
  (vi) said segments covering said slots to prevent metal vapor from said arcing gap from passing radially outward through said slots.

2. An alternating current circuit interrupter of the vacuum type comprising:

(a) an evacuated envelope,
(b) a pair of electrodes within said envelope having a spaced-apart position defining an arcing gap therebetween across which an alternating current arc is established,
(c) a tubular vapor-condensing shield within said evacuated envelope surrounding said arcing gap,
(d) said tubular shield comprising:
  (i) an outer tubular metal member surrounding said arcing gap and extending longitudinally of said envelope for substantial distances on opposite sides of said arcing gap,
  (ii) a tubular internal liner for said outer tubular member generally aligned with said arcing gap and having at least one longitudinally-extending discontinuity that renders said liner discontinuous in a circumferential direction,
  (iii) fastening means for securing said liner to said outer tubular member in radially spaced-apart relationship to said outer tubular member,
  (iv) said fastening means being located between said liner and said tubular member in a position behind said liner with respect to said arcing gap,
  (v) said fastening means being of a material that has a high resistivity in comparison to that of said liner.

3. The interrupter of claim **2** in which:

(a) said tubular member has at least one slot therein extending longitudinally of said member for substantial distances on longitudinally opposite sides of said arcing gap,
(b) and said tubular liner covers any slots in said outer tubular member to prevent metal vapor from said arcing gap from passing radially outward through any of said slots.

4. The interrupter of claim **2** in which:

(a) said tubular outer member is provided with eddy-current suppressing means for imposing a high resistance to currents flowing circumferentially of said tubular outer member in the region of said arcing gap,
(b) and said tubular liner covers said eddy-current suppressing means to prevent metal vapor from said arcing gap from reaching said eddy-current suppressing means.

5. The interrupter of claim **2** in which said fastening means comprises stainless steel spacers positioned between said liner and said tubular outer member.

6. The vacuum type circuit interrupter of claim **2** in combination with:

(a) means for developing across said arcing gap an axial magnetic field that has its lines of force extending generally parallel to the longitudinal axis of said arc,
(b) and means for controlling said magnetic field so that it has a high strength during high instantaneous currents and a very low strength just prior to a current zero.

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