MEANS FOR CONTROLLING PHASE RELATIONSHIP BETWEEN
FLUX AND CURRENT IN A VACUUM INTERRUPTER

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FIG. 1.

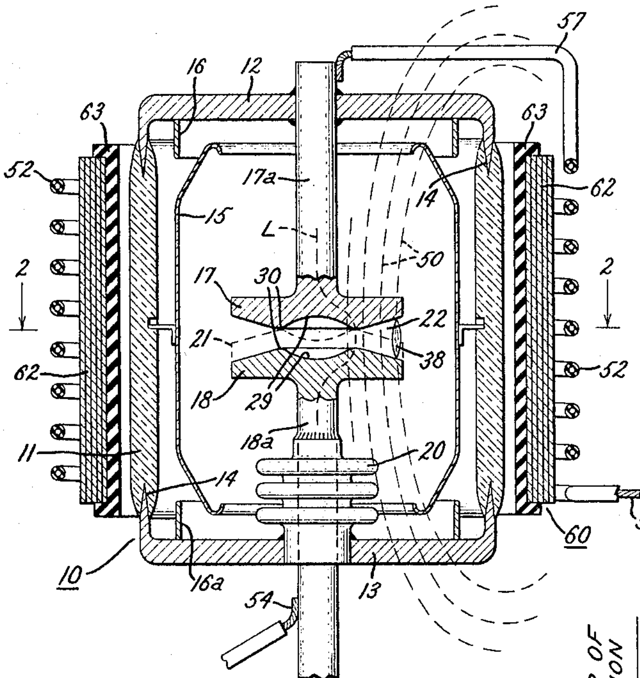


FIG. 3.

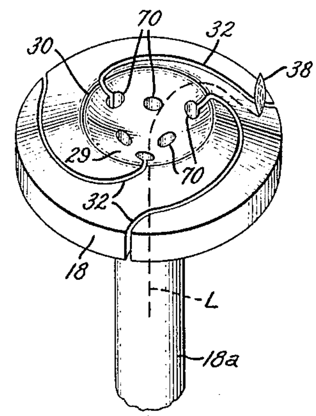


FIG. 2.

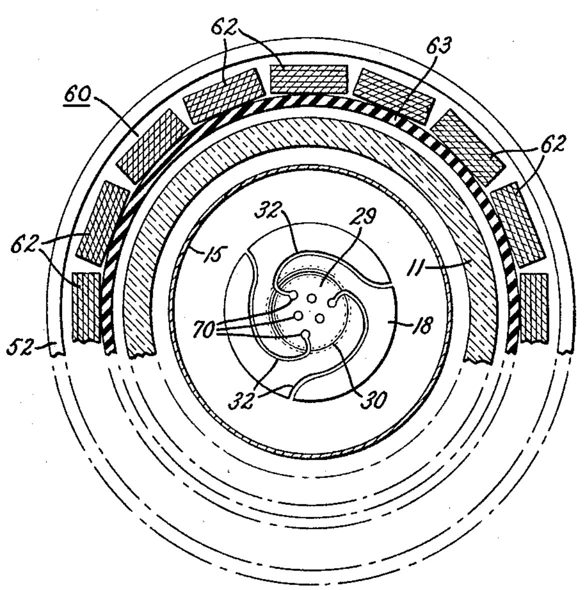
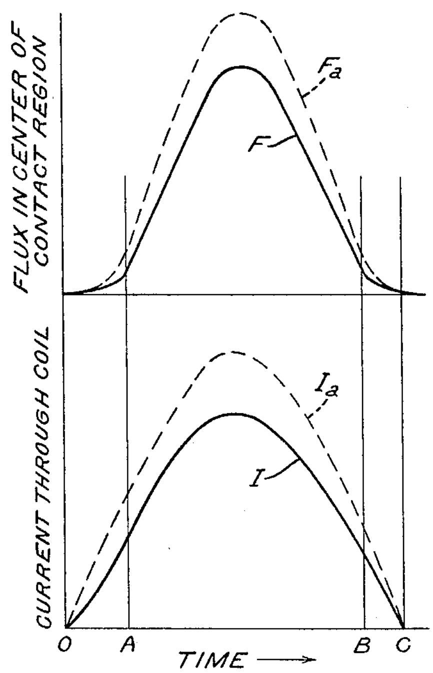


FIG. 4.



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MEANS FOR CONTROLLING PHASE RELATIONSHIP BETWEEN FLUX AND CURRENT IN A VACUUM INTERRUPTER

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This invention relates to a vacuum type circuit interrupter and, more particularly, to an alternating current vacuum type circuit interrupter of the general type disclosed and claimed in concurrently-filed application S.N. 328,656—Lee, assigned to the assignee of the present invention.

The usual vacuum type circuit 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 the aforementioned Lee application, it is pointed out that the current interrupting capacity of a vacuum interrupter can be increased by applying to the arcing gap during high instantaneous current 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 instaneous current is high.

A relatively simple way of producing a magnetic field that has a high strength during peak currents and a low strength during low currents is to utilize a coil connected in series with the contacts of the interrupter. A problem that is involved in this approach is that if the magnetic field strength is limited to the required low level during the period just prior to current zero, then the maximum field strength that can be obtained during high currents tends to be unduly limited. Or vice versa, if the field strength during high currents is raised to the required high levels, then an excessive field strength tends to be present just prior to current zero.

An object of our invention is to provide, for controlling the magnetic field in such an interrupter, an arrangement that is capable of holding the magnetic field strength to the required low level during the interval just prior to current zero without unduly limiting the maximum field strength that can be obtained during high instantaneous currents.

In carrying out our invention in one form, we provide a vacuum-type alternating current circuit interrupter that comprises a highly evacuated envelope and a pair of electrodes disposed within the envelope. The electrodes have a spaced-apart position in which they define a gap therebetween across which an arc is adapted to be formed. Field-producing means is provided for developing across the gap an axial magnetic field having its lines of force extending generally parallel to the longitudinal axis of the arc. This field-producing means is energized by a current that varies directly in accordance with the arcing current. Means including a saturable core of magnetic material spaced from the arcing gap is provided for shunting a high percentage of the flux developed by said field-producing means through a path remote from the gap during low arcing currents. The core is designed so that it saturates when the arcing current reaches a predetermined level that is substantially beneath the maximum instantaneous current that the interrupter is rated to interrupt. This core-saturation forces the flux produced by currents in excess of said predetermined level to follow a path that makes such flux available for the axial field across the gap.

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 an enlarged perspective view of a portion of the interrupter of FIGS. 1 and 2.

FIG. 4 is a graphical representation of the current and magnetic field strength during an interrupting operation of the interrupter of FIGS. 1–3.

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 15 suitably supported on the casing 11 and preferably isolated from both end caps 12 and 13. This shield 15 acts to intercept and condense arc-generated metallic vapors before they can reach the casing 11. To reduce the chances for vapor by-passing the shield 15, a pair of end shields 16 and 16*a* 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 surufaces 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 subjected 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. 3. 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 will be apparent from the path L shown in FIG. 3 leading from rod 18*a* to the terminal of an arc 38 on the outer periphery of contact 18. This tangential configuration of the current path causes the magnetic loop L to develop a net tangential force component 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 extendeding 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. The present invention is concerned with an arrangement that enables 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 18*a*, contact 18, the arc 38, contact 17, rod 17*a*, 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, we provide 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**. Thus, the core **60** may be thought of as being magnetically in parallel with the gap **22** and as forming for the flux a magnetic path bypassing the gap. 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. 4, 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.

In one typical embodiment of our invention, the iron core **60** was designed to saturate at 23,000 ampers. For currents above 23,000 ampers, an axial field appeared in the contact region high enough to reduce the arc voltage to a value less than half that which typically or normally appeared for corresponding instantaneous currents without the axial magnetic field. With a circuit voltage of 15.5 kv. R.M.S., asymmetrical currents with peak values as high as 65,000 ampers were interrupted by this interrupter. This 65,000 ampere peak current was approximately 50 percent higher than the maximum peak current that could typically be interrupted by interrupters of this same design, but without the axial magnetic field and the iron core.

By way of further example, suitable field strengths for the axial magnetic field in the arcing gap are 800 gausses at 20,000 amperes instantaneous current, 1600 gausses at 40,000 ampers, and 2,400 gausses at 60,000 amperes.

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 has 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 from F show in FIG. 4. Thus, the presence of the core **60** enables us to reduce the amount of flux appearing just before current zero for a given maximum value of flux. We therefore are able to produce 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.

Moreover, with our arrangement, the amount of flux appearing in the arcing region during the period just prior to current zero is relatively unaffected by substantial variations in the maximum flux during high currents. Thus, even if the maximum flux is substantially increased due to increased peak currents through the coil, there is little increase in the flux appearing in the contact region during the period just preceding current zero. This is illustrated in FIG. 4 by the dotted line curve F_a, which shows the flux in the arcing region during the higher currents depicted by the curve I*a*. Comparing curves F and F_a, it will be apparent that between instants A and B more flux appears in the contact region when the higher current I*a* is present. But note that the flux present just ahead of the current zero point C remains relatively unchanged despite this higher maximum flux. This is the case because the iron core **60** is unsaturated during the period just before current zero and can divert from the contact region the substantial added amounts of flux resulting from the higher instantaneous currents.

It will be apparent from FIG. 4 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. 3. 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. By thus reducing the eddy currents, the lag of the flux behind the current is limited to such an extent that only a small amount of flux remains in the contact region at current zero.

Tests made on an interrupter such as disclosed herein have shown that the density of the magnetic field remaining in the arcing gap at current zero is limited to less than 100 gausses even after current peaks which developed 2,000 and even 3,000 gausses in the arcing gap. A magnetic field of such strength at and immediately before current zero does not substantially impair the voltage withstand ability of the gap.

It is noted that the magnetic circuit for the flux that passes through the iron core **60** contains a large air gap about the outer periphery of the coil **52**. This large air gap restricts any residual magnetism in the iron so that the effect of the iron in controlling the flux density in the arcing region is independent of the polarity of the current flowing through the coil and is also independent of the previous history of the core from a magnetization view-point.

Although we prefer to locate the core **60** outside the casing **11**, our invention in its broader aspects also comprehends a core that is located inside the casing, but in such a position as to shunt flux away from the arching gap **22** during low currents.

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 that is adapted to interrupt arcing currents having a predetermined maximum instantaneous value comprising:

(a) a highly evacuated envelope,

(b) a pair of relatively movable contacts disposed within said envelope and separable to establish a gap therebetween across which an arc is adapted to be formed,

(c) field-producing means for developing across said gap an axial magnetic field that has its lines of force extending across said gap generally parallel to the longitudinal axis of said arc,

(d) means for causing said field-producing means to be energized by a current that varies directly in accordance with the arcing current,

(e) means including a saturable core of magnetic material spaced from said arcing gap and magnetically in parallel with said gap for shunting a high percentage of the flux developed by said field-producing means through a path remote from and bypassing said gap during low arcing currents,

(f) said saturable core saturating when said arcing current reaches a predetermined level that is substantially beneath said maximum instantaneous value so that flux resulting from arcing current in excess of said predetermined level of current is available to provide said axial magnetic field across said gap.

2. The alternating current circuit interrupter of claim **1** in which:

(a) during high values of instantaneous arcing current said axial magnetic field has sufficient flux density in said gap to substantially reduce the arc voltage as compared to the arc voltage normally developed during corresponding instantaneous currents without said axial magnetic field, and

(b) said axial magnetic field has a sufficiently low density during the period just preceding a current zero that follows a high value of instantaneous arcing current to enable said gap to recover its voltage withstand ability at current zero to substantially the same extent as said gap would without said axial magnetic field during said period.

3. An alternating current circuit interrupter of the vacuum type that is adapted to interrupt arcing currents having a predetermined maximum instantaneous value comprising:

(a) a highly evacuated envelope,

(b) a pair of relatively movable contacts disposed within said envelope and separable to establish a gap therebetween across which an arc is adapted to be formed,

(c) field-producing means including a coil connected in series with said contacts for developing across said gap an axial magnetic field that has its lines of force extending across said gap generally parallel to the longitudinal axis of said arc,

(d) means including a saturable core of magnetic material spaced from said arcing gap and magnetically in parallel with said gap for shunting a high percentage of the flux developed by said field-producing means through a path remote from and bypassing said gap during low arcing currents,

(e) said saturable core saturating at a predetermined level of current substantially beneath said maximum instantaneous value so that flux resulting from arcing current in excess of said predetermined level of current is available to provide said axial magnetic field across the gap.

4. An alternating current circuit interrupter of the vacuum type that is adapted to interrupt arcing currents having a predetermined maximum instantaneous value comprising:

(a) a highly evacuated envelope,

(b) a pair of relatively movable contacts disposed within said envelope and separable to establish a gap therebetween across which an arc is adapted to be formed,

(c) field-producing means including a coil connected in series with said contacts for developing across said gap an axial magnetic field that has its lines of force extending across said gap generally parallel to the longitudinal axis of said arc,

(d) means including a saturable core of magnetic material spaced from said arcing gap for shunting a high percentage of the flux developed by said field-producing means through a path remote from and bypassing said gap during low arcing currents,

(e) said saturable core saturating at a predetermined level of current substantially beneath said maximum instantaneous value so that flux resulting from arcing current in excess of said predetermined level of current is available to provide said axial magnetic field across the gap,

(f) said coil surrounding said envelope, and

(g) said saturable core being of a generating cylindrical form and being mounted about said evacuated envelope between said envelope and said coil.

5. An alternating current circuit interrupter of the vacuum type that is adapted to interrupt arcing currents having a predetermined maximum instantaneous value comprising:

(a) a highly evacuated envelope,

(b) a pair of relatively movable contacts disposed within said envelope and separable to establish a gap therebetween across which an arc is adapted to be formed,

(c) field-producing means including a coil connected in series with said contacts for developing across said gap an axial magnetic field that has its lines of force extending across said gap generally parallel to the longitudinal axis of said arc,

(d) means including a saturable core of magnetic material spaced from said arcing gap for shunting a high percentage of the flux developed by said field-producing means through a path remote from and bypassing said gap during low arcing currents,

(e) said saturable core saturating at a predetermined level of current substantially beneath said maximum instantaneous value so that flux resulting from arcing current in excess of said predetermined level of current is available to provide said axial magnetic field across the gap,

(f) and means for limiting the eddy currents induced in the interrupter structure by said axial magnetic field to such an extent that the flux in the arcing region at current zero is effectively eliminated.

6. An alternating-current circuit interrupter of the vacuum type that is adapted to interrupt arcing currents having a predetermined maximum instantaneous value comprising:

(a) a highly evacuated envelope,

(b) a pair of electrodes disposed within said envelope and defining a gap therebetween across which an arc is adapted to be formed,

(c) field-producing means for developing across said gap an axial magnetic field that has its lines of force extending across said gap generally parallel to the longitudinal axis of said arc,

(d) means for causing said field-producing means to be energized by a current that varies directly in accordance with the arcing current,

(e) means including a saturable core of magnetic material spaced from said arcing gap and magnetically in parallel with said gap for shunting a high percentage of the flux developed by said field-producing means through a path remote from and bypassing said gap during low arcing currents,

(f) said saturable core saturating when said arcing current reaches a predetermined level that is substantially beneath said maximum instantaneous value so that flux resulting from arcing current in excess of said predetermined level of current is available to provide said axial magnetic field across said gap.

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