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3,321,598

VACUUM-TYPE CIRCUIT INTERRUPTER WITH ARC-VOLTAGE LIMITING MEANS

Filed Nov. 16, 1964

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FIG. 5.
PRIOR ART

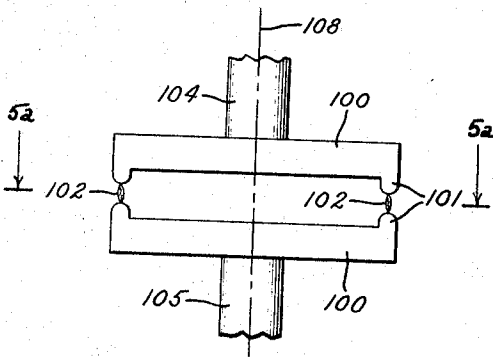


FIG. 5a.
PRIOR ART

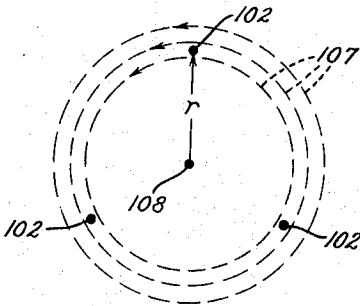


FIG. 7.

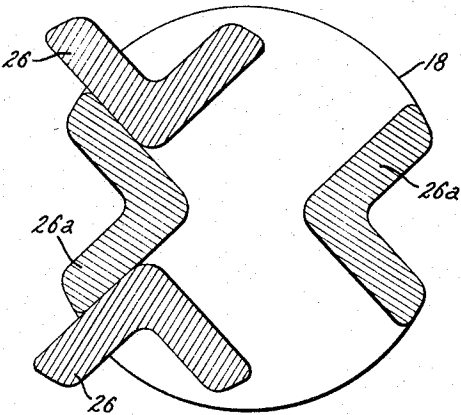


FIG. 6.

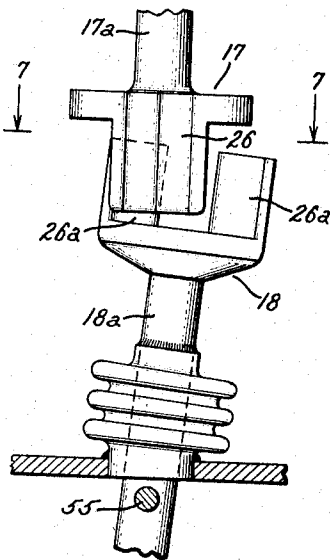
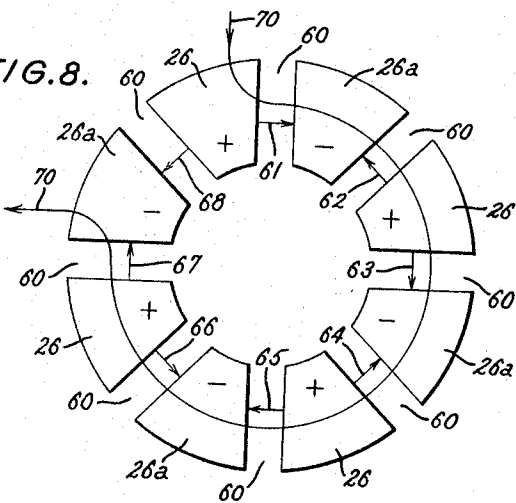


FIG. 8.



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FIG. 9.

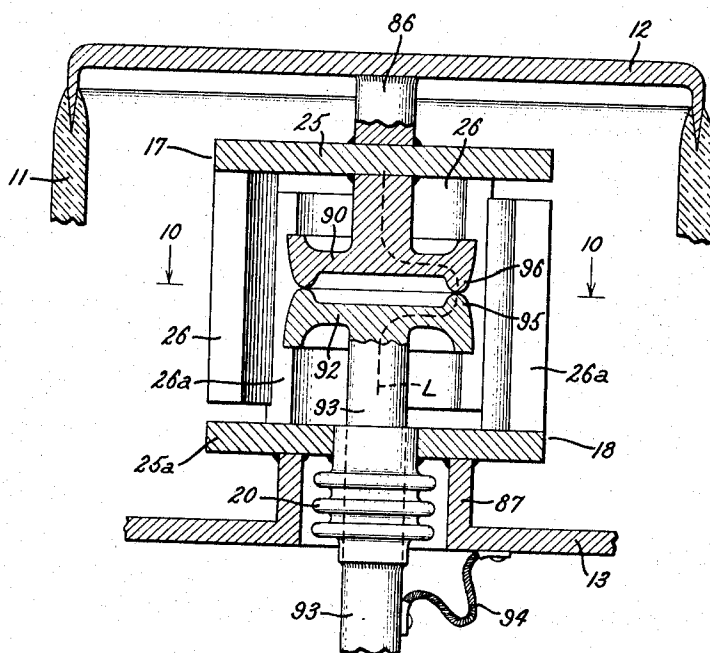
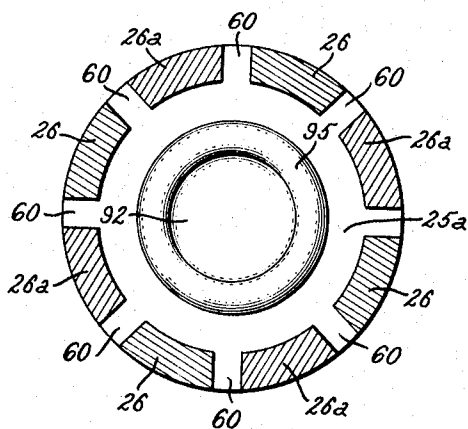


FIG. 10.



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**VACUUM-TYPE CIRCUIT INTERRUPTER WITH
 ARC-VOLTAGE LIMITING MEANS**
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 Electric Company, a corporation of New York
 Filed Nov. 16, 1964, Ser. No. 411,289
 11 Claims. (Cl. 200-144)

This invention relates to a vacuum-type circuit interrupter and, more particularly, to a vacuum-type circuit interrupter which includes means for limiting the arc voltage to a relatively low value, even during the interruption of high currents.

The usual vacuum-type circuit interrupter comprises a pair of separable contacts or electrodes disposed within a vacuum chamber. Circuit interruption is initiated by separating these electrodes to establish a gap 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, assuming that the current being interrupted is an alternating current. After the current zero point has been reached, the usual recovery voltage transient begins building up across the gap between the electrodes. If the gap is able to withstand this recovery voltage transient, the arc is prevented from reigniting and the interruption is complete.

Whether the gap will be able to withstand the recovery voltage transient is largely dependent upon the extent to which the gap is free of ionized arcing products when the recovery voltage transient is being applied. If, for example, the gap could be entirely freed of arcing products, the original vacuum, with its very high dielectric strength, would be available to withstand the recovery voltage transient. The extent to which the gap is free of ionized arcing products when the recovery voltage transient is applied depends to an important degree upon the ability of the interrupter to condense these hot arcing products prior to this instant. The more completely the interrupter condenses the arcing products prior to this instant, the more likely it is that the gap will succeed in withstanding the recovery voltage transient.

During low current interruptions, the interrupter ordinarily has no difficulty in condensing the arcing products with sufficient rapidity and completeness to withstand the recovery voltage transient. But, generally speaking, the higher is the current being interrupted, the greater is the volume of arcing products generated, and the more difficult it becomes to approach complete condensation of the arcing products in the available time.

One of the factors that detracts from the ability of the interrupter to completely condense the arcing products at a current zero following a period of high current is the high arc voltage that prior interrupters have typically developed during high currents. The term "arc voltage" denotes the voltage developed across the arc at any given instant. It has been found that for currents up to a few thousand amperes, the arc voltage is relatively low and substantially independent of total arc current. But above a few thousand amperes, it has been found that the arc voltage increases with arc current and can reach levels as high as 150 or more volts.

The higher this arc voltage, the higher will be the energy input into the interrupter. This higher energy input will result in a larger quantity of vapors being generated by the arc and in greater heating of the vapor-condensing parts adjacent the arcing gap. Both of these two latter factors tend to detract from the ability of the interrupter to effect a substantially complete condensation of the arc-generated vapors at a current zero and hence detract from the interrupting ability of the interrupter.

An object of my invention is to provide a vacuum in-

terrupter which includes means capable of maintaining the arc voltage relatively low during high current interruptions, so as to improve the ability of the interrupter to effect substantially complete condensation of the arcing products at a current zero.

Another object is to provide a plurality of separate arcing gaps between the interrupter electrodes and to develop parallel-connected arcs across these separate gaps during an interrupting operation.

Still another object is to force these parallel-connected arcs to burn with a relatively low arc voltage, even when the instantaneous current through the interrupter is high, for example 35,000 amperes or even higher.

Still another object is to cause these arcs to burn in a region where the magnetic field component extending perpendicular to each arc is exceptionally low as compared to the perpendicular magnetic field component that would be developed at corresponding total instantaneous currents with prior vacuum interrupter electrodes.

In carrying out my invention in one form, I provide a vacuum-type circuit interrupter that comprises a pair of electrodes having a spaced-apart position. Means defining a plurality of separate gaps electrically in parallel between said electrodes is provided. Across these gaps during a circuit-interrupting operation a plurality of parallel-connected arcs are formed. The gaps are so located that the magnetic field in any one gap resulting from the total current through the interrupter passing through any element adjacent said one gap is in a direction generally parallel to the arc or arcs in said one gap. Also, in any one gap, the magnetic field developed by current through the arc in any given other gap is in an opposite direction to the magnetic field developed by current through an arc in any of said other gaps immediately adjacent said given other gap. Means is further provided for affording free communication between said gaps for the vapors generated by arcing at said gaps.

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

FIG. 1 is a side elevational view partly in section showing a vacuum interrupter embodying one form of my invention.

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

FIG. 3 is an enlarged perspective view of the electrodes of the vacuum interrupter depicted in FIGS. 1 and 2.

FIG. 4 is a sectional view similar to FIG. 2 and illustrating certain magnetic field relationships.

FIG. 5 is a side elevational view partly in section of a prior art form of interrupter.

FIG. 5a is a sectional view taken along the line 5a-5a of FIG. 5.

FIG. 6 is a side elevational view illustrating another modified form of my invention.

FIG. 7 is a sectional view taken along the line 7-7 of FIG. 6.

FIG. 8 is a sectional view of still another modified form of my invention.

FIG. 9 is a partial side elevational view partly in section of a further modified form of my invention.

FIG. 10 is a sectional view taken along the line 10-10 of FIG. 9.

Referring now to 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 inside the envelope.

Located within the envelope 10 is a pair of relatively movable contacts or electrodes 17 and 18 shown in their separated or open-circuit position in FIG. 1. The upper electrode is a stationary electrode suitably secured to a conductive rod 17a, which at its upper end is united to the upper end cap 12. The lower electrode 18 is a movable electrode joined to a conductive operating rod 18a, which is suitably mounted for vertical movement. The operating rod 18a projects through an opening in the lower end cap 13, and a flexible metallic bellows 20 provides a seal about the rod 18a to allow 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 18a and the end cap 13.

Coupled to the lower end of the operating rod 18a, suitable actuating means (not shown) is provided for driving the movable lower electrode 18 upwardly into engagement with the stationary electrode 17 so as to close the interrupter. The actuating means is also capable of returning the lower electrode 18 to its illustrated position so as to open the interrupter. A circuit-opening operation will soon be explained in greater detail.

When the electrodes 17 and 18 are separated during a circuit-opening operation, arcing takes place therebetween in a manner soon to be described. This arcing vaporizes some of the electrode material, and the resulting vapors are dispersed from the region between the electrodes 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 electrically 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 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 electrodes 17 and 18 are effectively freed of gases absorbed internally of the electrode body so as to preclude evolution of these gases during high current interruptions. The electrodes are made of a non-refractory conductive metal, preferably copper.

The upper electrode 17 comprises a generally-annular body portion 25 and a plurality of fingers 26 projecting from the body portion 25 in a direction generally parallel to the central longitudinal axis of the electrode, this axis being depicted at 28 in FIG. 3. These fingers 26 may be thought of as being arranged in angularly-spaced relationship to each other about the periphery of an imaginary circle 29 encompassing the central longitudinal axis 28, as shown in FIG. 2.

The lower electrode 18 is of substantially the same construction as the upper electrode 17 and accordingly comprises a generally annular body portion 25a and a plurality of fingers 26a projecting therefrom in a direction generally parallel to the central longitudinal axis 28a of the lower electrode. These fingers 26a are also arranged in angularly-spaced relationship to each other about the periphery of a circle encompassing the longitudinal axis 28a of the lower electrode 18.

The two electrodes are so located with respect to each other that the fingers 26a of the lower electrode are located respectively between the fingers 26 of the upper electrode and are angularly spaced therefrom to form a

plurality of gaps 30 between the fingers of the two electrodes. Preferably, the two electrodes are so arranged that their central longitudinal axes 28 and 28a substantially coincide.

During an interrupting operation, arcs such as shown at 32, 33, 34 and 35 are established across these gaps 30 in a manner soon to be explained. At the instant depicted in FIG. 2, the upper electrode 17 with its two fingers 26 is assumed to be anodic and the lower electrode 18 with its two fingers 26a is assumed to be cathodic. The fingers 26 have therefore been designated with a plus (+) sign, and the fingers 26a have been designated with a minus (-) sign. Current may flow from the anode 17 to the cathode 18 via one finger 26 and either of the arcs 32 or 33 or via the other finger 26 and either of the arcs 34 or 35. It will therefore be apparent that the arcs 32, 33, 34 and 35 are electrically in parallel with each other, and the gaps 30 are also electrically in parallel with each other.

It should also be apparent from FIG. 2 that the length of the gaps 30, as considered along the length of the respective arcs formed therein, extends in a generally parallel direction to the periphery of the circle 29 and transversely with respect to the longitudinal axis 28 of the electrode 17.

When the lower electrode 18 is driven in an upward direction from its position of FIG. 1 to close the interrupter, the uppermost surfaces of the fingers 26a engage the underside 43 of the body portion 25 of the upper electrode. Actual contact between the two electrodes is preferably made on the uppermost surfaces of fingers 26a in regions 42 adjacent their radially-innermost edge, and current therefore flows between the two electrodes through these surface regions 42 when the interrupter is in its closed position. The contact-making surface regions, such as 42, on each electrode, are preferably made of a suitably non-refractory, weld-resistant metal, such as an alloy of copper and a small percentage of bismuth; but the remainder of each electrode is preferably made of pure copper.

When the lower electrode 18 is driven in a downward direction from its closed position to effect interruption of the circuit, an arc is established between the surfaces 42 and 43 of the two electrodes. This arc, assuming it is a high current arc, vaporizes a substantial amount of the electrode material, and the resulting metallic vapors are expelled in all directions away from the region of the arc. Since the gaps 30 communicate freely with the initial arcing region, a considerable quantity of these metallic vapors enters the gaps 30. Prior to this instant there is no arcing in the gaps 30, but as soon as the vapors do enter the gaps 30, an arc forms across at least one of these gaps, as indicated in FIG. 2 at 32, 33, 34, or 35. For reasons which will soon be explained, when the current is in excess of about 10,000 amperes, any arc across a gap 30 burns with a much lower arc voltage than the initial arc at the end of fingers 26. Thus, the current once flowing through the initial arc tends to be diverted into the arc or arcs in the gaps 30, thus causing the initial arc to be extinguished or to carry only that part of the total current that can be carried in the region with the low arc voltage of the arcs in gaps 30.

As will be apparent from FIG. 2, the gaps 30 freely communicate with one another. As a result of this free communication, any gap 30 that has not yet arced-over will receive arc-generated metallic vapors from one or more of the other gaps that is arcing. This will cause arcing to take place across the previously-intact gap 30, which will then generate metallic vapors to help ignite any other gap 30 that might be still intact. Finally, arcing will take place across all of the gaps, with the total current dividing between the parallel arcs 32, 33, 34, and 35 and any arc which might remain at the initial arcing region. In certain cases, each of these arcs 32-35 will divide into many smaller parallel arcs, and the current

across any gap will be divided between the smaller arcs.

In conventional vacuum interrupter electrode arrangements, the predominant magnetic field developed by the current which flows through the electrodes when an arc is present therebetween is a direction generally perpendicular to the arc. An important principle involved in the operation of my invention is that the arc voltage developed across a high current arc burning in a vacuum can be substantially reduced if the intensity of the magnetic field component extending perpendicular to the arc is sufficiently reduced below the values that are normally developed by this high current flowing through a conventional electrode configuration. Insofar as I am aware, this principle has not previously been recognized or effectively utilized in a vacuum circuit interrupter. I am able to utilize this principle by locating the gaps 30 so that the current flowing through the electrodes creates only a very low magnetic field extending perpendicular to the arcs in the gaps.

One of the factors responsible for limiting this perpendicular magnetic field to a very low value is the fact that the magnetic field generated by the total current flowing through any closely adjacent parts is in a direction generally parallel to the arcs in gaps 30, rather than perpendicular to the arcs. For example, the magnetic field generated by the total current flowing through the central rods 17a and 18a has a configuration such as depicted at 45 in FIG. 2. The dotted lines encircling the central axis 28 represent typical lines of magnetic force constituting this field 45. Note that these lines of force extend generally parallel to the arcs in the gaps 30 and have only a slight component extending perpendicular thereof. Hence, only a very slight perpendicular magnetic field results in the gaps 30 from current flowing through the adjacent parts (17a and 18a) carrying the total interrupter current.

Another factor responsible for limiting the perpendicular field in the gaps 30 to a very low value is the fact that in a given gap 30 the magnetic fields from the current through the arcs in the other gaps 30 tend to cancel out each other to a large extent. To illustrate this point, let us consider these particular magnetic fields in the gap 30 of FIG. 4 containing the arc 32. The direction of current through each arc at the instant illustrated is depicted by a small arrow adjacent the arc. Applying the right hand rule for determining the direction of the magnetic field, the magnetic field in the gap containing arc 32 that results from current flowing through the arc 33 will be in a downward direction (i.e., into the plane of the paper). This is indicated by the X marks 33M. The magnetic field in the gap containing arc 32 resulting from current through the arc 34 will, however, be upwardly (i.e., out of the plane of the paper, as indicated by the dots 34M). Since the magnetic field at 34M is an opposite direction to the magnetic field at 33M, these magnetic fields will tend to cancel each other. This cancellation in the gap containing arc 32 will not be complete, however, because the field at 33M is not quite as intense as that at 34M due to this gap location being slightly out of alignment with arc 33 but in alignment with arc 34. A small fraction of the field 34M will therefore remain uncanceled by the field 33M. This small remaining fraction which is in a direction out of the plane of the paper, will be available to cancel a portion of the field 35M, which results from the current through arc 35 and is in a direction into the plane of the paper.

This flux cancellation will not be complete in the arrangement depicted in FIG. 4, but it is substantial and effects a very significant reduction in the net perpendicular field resulting from current through the other arcs 33-35. Using the same analysis as above, it can be shown that the magnetic fields in any given gap 30 resulting from current through the arcs in the other gaps 30 tend to cancel out each other to a large extent. It can also be shown that substantially this same flux can-

cellation is present when the polarity of the two electrodes is reversed from that shown. From this explanation, it should be apparent that an important factor responsible for this flux cancellation is the fact that the flux in any one gap 30 (e.g., the gap with the arc 32) resulting from the current flowing through an arc (e.g., 34) in any given one of the other gaps 30 is in an opposite direction to the flux resulting from current through the arc (e.g., 33 or 35) in any of said other gaps immediately adjacent to said given other gap.

There will be some slight perpendicular magnetic field in each gap 30 resulting from the current flowing through the particular fingers 26 and 26a that are located immediately adjacent that particular gap, but this perpendicular magnetic field is so small that it does not detract significantly from the major reductions in perpendicular magnetic field resulting from the other factors described hereinabove. With respect to the perpendicular magnetic field in a given gap resulting from current through the immediately adjacent fingers 26 and 26a, it should be noted that only a small fraction of the total current is creating this magnetic field in view of the division of the total current into many parts, most of which flow through other parallel paths through the fingers. The current through the other paths through the fingers tends to create a predominantly axial magnetic field with respect to the arc under consideration and therefore does not add appreciably to the slight perpendicular magnetic field that is present.

With a pair of conventional butt contacts, made of copper and constructed as shown in U.S. Patent 2,949,520, Schneider, assigned to the assignee of the present invention, I have measured typical arc voltages of about 100 volts when interrupting peak arc currents of 35,000 amperes. But with the illustrated contact arrangement having the low perpendicular magnetic field and the contacts also made of copper, I have measured typical arc voltages of about 40 volts when interrupting peak arc currents of 40,000 amperes. At higher currents with the contacts of Patent 2,949,520, the arc voltages have risen even higher, for example, to about 120 volts at 50,000 amperes peak current and to about 130 volts at 60,000 amperes peak current. But in the illustrated arrangement, typical arc voltages have been 45 volts at 50,000 amperes peak current and 50 volts at 60,000 amperes peak current.

As pointed out hereinabove, the arc between the electrodes of FIGS. 1-4 is initially drawn between the surfaces 42 and 43. So long as the arc remains in this region, the magnetic field developed by current flowing through the electrodes is generally perpendicular to the arc. Hence, so long as the arc remains in this position, the arc voltage can rise toward the values developed in conventional interrupters. But as soon as one or more arcs are developed in the gaps 30, the initial arc between the surfaces 42 and 43 is extinguished or reduced in current magnitude and the arc voltage developed between the two electrodes abruptly drops to the low values described hereinabove.

To accelerate the initiation of arcs across the gaps 30, I prefer to shape the ends 42 of the fingers 26a so that contact is made in that area near the radially innermost region of the fingers. In this region there is less magnetic force tending to blow the initial arc and its arcing products radially outward. By lessening this radially outward force, a greater tendency is developed for the arcing products to travel radially inward of the electrodes toward the gaps 30, where they can cause ignition of the gaps.

To illustrate the magnetic field in an interrupter that has electrodes of a conventional configuration, FIGS. 5 and 5a have been included. Each electrode of FIG. 5 comprises a radially-extending disc 100 with an axially projecting annular portion 101 near its outer periphery that defines an arcing portion. When the interrupter is

closed, these electrodes normally engage each other on the portions 101. When the electrodes are separated, an arc or arcs 102 are established between these arcing portions 101. These arcs 102 are located in a region where the magnetic field extends predominantly perpendicular to the arcs. For example, the magnetic field resulting from the total current through the central supporting conductors 104 and 105 is directed along the generally circular path of the arrows 107 of FIG. 5a, which surround the longitudinal center line 108 of the electrodes. The arrows 107 extend at approximately right angles to the longitudinal axis of each arc. Assuming that the arcs 102 are symmetrically distributed about the center line 108, the intensity of the magnetic field component extending perpendicular to each arc of FIGS. 5 and 5a can be defined by the following expression:

$$H = \frac{0.2I}{r}$$

where H is the field intensity expressed in gilberts per centimeter, I is the total current flowing through the electrodes in amperes, and r is the radial distance in centimeters between the arc and the kernel or effective center line of the axially-directed current in the electrodes.

This kernel or effective center line in the electrode structure of FIGS. 5 and 5a is the central longitudinal axis 108 of the rods 104 and 105, and the radial distance r is shown in FIG. 5a measured from this axis. In the electrode structure of FIGS. 1-4, the kernel is the central longitudinal axis 28. The term kernel refers to an imaginary line along which all of the axially directed current may be considered as concentrated, and its location can be determined by known techniques, such as those described in Chapter 15 of *Electric and Magnetic Fields* by S. S. Attwood (Third Edition, 1949). If the arcs 102 are not symmetrically distributed about the center line 108 of FIGS. 5 and 5a or if only a single arc is present, the component of magnetic field perpendicular to the arc will have an even higher intensity than the above-noted $0.2I/r$ value present with symmetrically distributed arcs.

In the interrupters of my invention, the intensity of the component of the magnetic field extending perpendicular to an arc in gap 30 or 60 at a given radius from the kernel (28 in FIGS. 1-4) is much less than one-half the intensity of this perpendicular magnetic field for an arc located the same radial distance from the kernel 108 in the interrupter of FIGS. 5 and 5a, even if a symmetrical distribution of the arcs about 108 is assumed for FIGS. 5 and 5a. In the interrupter of FIGS. 5 and 5a, arcing portions 101 have been shown as continuous annuli but whether each of these portions is formed as a continuous annulus or a series of circumferentially-spaced axially-extending projections, the intensity of the magnetic field component extending perpendicular to an arc 102 will be at least as high as that defined by the above expression.

FIGS. 6 and 7 illustrate a modified embodiment which is constructed to permit the initial arc to be drawn in one of the gaps 30, thus eliminating the need for transferring the arc from a region of high perpendicular field, as was the case with the arrangement of FIGS. 1-4. In this modified embodiment of FIGS. 6 and 7, the lower electrode 18 and its operating rod 18a, instead of being mounted for vertical movement, are mounted for pivotal movement about a stationary pivot 55. When the interrupter is in its open position, the operating rod 18a occupies a vertical position corresponding to that shown in FIG. 1. Closing of the interrupter is effected by driving the operating rod in a clockwise direction (as viewed in FIG. 6) about the pivot 55 until it reaches its closed position of FIG. 6. Here one of the fingers 26a on the lower electrode engages two of the fingers 26 on the upper electrode, as best seen in FIG. 7.

Opening of the interrupter is effected by returning the operating rod 18a to its vertical position. When such movement occurs, an arc is initiated across one of the gaps 30 between the fingers 26 and 26a, and shortly thereafter across the remaining gaps 30 for the same reasons as described hereinabove. Thus, in this embodiment of FIGS. 6 and 7 all of the arcing takes place in a region of very low perpendicular magnetic field, and there is no opportunity to develop, for even very brief intervals, the high arc voltages associated with high perpendicular magnetic fields.

At one point in the hereinabove description, I have explained how in a given gap 30 the magnetic fields from the current through the arcs in the other gaps 30 can cancel out each other to a large extent. This flux cancellation can be made even more complete by providing each of the electrodes with a greater number of interleaving fingers than is illustrated in FIGS. 1-4. A cross-sectional view for such a modified pair of electrodes is depicted in FIG. 8. Here again the fingers forming part of one electrode are designated 26 and those forming part of the other electrode are designated 26a. The gaps between the fingers are designated 60 and the parallel connected arcs 61-68. Here again, the currents in adjacent gaps are in opposite directions; and, hence, the field in any one gap resulting from current flow through an arc in any given other gap is in an opposite direction to the field resulting from current through an arc in any of said other gaps immediately adjacent said given other gap.

Another way of explaining the flux cancellation in any one gap is by considering the net current flowing around the loop constituted by the arcs and the conductive structure interconnecting them, this loop being indicated at 70 in FIG. 8. Since the currents through adjacent arcs tend to cancel out each other, in view of their opposite directions, there is an uncanceled current flowing across only one gap apart from the gap where the flux is being considered. This current flows through only a slight portion of the loop and is also relatively small. Hence, it develops only a slight magnetic field component perpendicular to the arc at the gap under consideration.

By maintaining the arc voltage relatively low during high current interruptions, as described hereinabove, I can materially lower the energy input into the interrupter during such interruptions. This is highly desirable because the reduced power input results in a reduced quantity of vapors generated during interruption and in reduced heating of the vapor-condensing parts such as the shield 15. Both of these factors assist the interrupter in achieving substantially complete condensation of the arcing vapors at a current zero, thus improving the interrupter's ability to rapidly recover its dielectric strength and withstand the recovery voltage transient that appears immediately after the current zero point is reached.

In the interrupters described up to this point, provision is made for moving one set of interleaving fingers with respect to the other. I can avoid the necessity for such movement by constructing the interrupter as shown in FIGS. 9 and 10. Here, the upper electrode 17 comprises a cup-shaped member with fingers 26 projecting in a downward direction from its body portion 25. The lower electrode 18 comprises a cup-shaped member with fingers 26a projecting in an upward direction from its body portion 25a. The fingers 26 on one electrode interleave with the fingers 26a on the other electrode in the same general manner as in the other embodiments. These fingers 26 and 26a are spaced apart to define circumferentially-spaced gaps 60 therebetween in substantially the same manner as in FIG. 8. These gaps 60 are best shown in FIG. 10. Both of the electrodes 17 and 18 of FIG. 9 are fixed on the interrupter casing 11 by suitable means, such as axially-extending conductive members 86 and 87, to provide fixed gaps 60 of the desired length.

Centrally of the upper electrode 17 is a fixed contact 90 that is suitably brazed and therefore electrically con-

connected to the remainder of the upper electrode 17. Centrally of the lower electrode 18 is a movable contact 92 that is movable relative to the remainder of the lower electrode 18. The movable contact 92 is suitably joined to the upper end of a conductive rod 93 that extends freely through the body portion 25a of the lower electrode 18 to a position outside the evacuated envelope 11. A suitable bellows 20 provides a seal about the rod 93 while permitting relative movement of the rod with respect to the remainder of the electrode 18. The rod 93 and contact 92 joined thereto are electrically connected to the cup-shaped portion of the lower electrode 18 by suitable conductive means schematically shown at 94.

The lower contact 92 has an annular portion 95 projecting toward the other contact 90 and engaging a similar annular portion 96 on the other contact 90 when the interrupter is closed. When the lower contact 92 is withdrawn in a downward direction from the upper contact 90, an arc is drawn between portions 95 and 96. There is a radially-outwardly acting magnetic force on the arc due to the radially-outwardly bowing configuration of the current path L through the contacts. This magnetic force drives the arc terminals radially-outward along the adjacent surfaces of the contacts 90 and 92 and also projects the arcing products into the gaps 60 between the interleaving fingers 26 and 26a. This causes arcs to be established across the gaps 60. Assuming a high current (e.g., in excess of 10,000 amperes) is being interrupted, any arc across a gap 60 will burn with a much lower arc voltage than the initial arc between the contact portions 90 and 92. Thus, the current once flowing through the initial arc is diverted into the arc or arcs in the gaps 60, thus causing the initial arc to be extinguished or, in some cases, to carry only that part of the total current that can be carried in this region with the low arc voltage of the arcs in gaps 60.

As in the other embodiments, the gaps 60 of FIGS. 9 and 10 freely communicate with one another. As a result of this free communication, any gap 60 that has not yet arced over will receive arc-generated metallic vapors from one or more of the other gaps that is arcing. This will cause arcing to take place across the previously-intact gap 60, which will then generate metallic vapors to help ignite any other gap 60 that might still be intact. Finally, arcing will take place across all of the gaps 60, with the total current dividing between the parallel arcs.

In the interrupter of FIGS. 9 and 10, any arc across gap 60 is located in a region where the magnetic field component perpendicular to the arc is very low, for the same reasons as were explained in connection with the other embodiments. Accordingly, as in the other embodiments, the arc voltage developed across an arc in the gap 60 is relatively low. The initial arc in the interrupter of FIGS. 9 and 10 is drawn in a region where the magnetic field component perpendicular thereto is high. But the quick establishment of the arcs across gaps 60 prevents a high arc voltage from being developed across the initial arc.

It has been found that an interrupter constructed as shown in FIGS. 9 and 10 can operate with exceptional rapidity to transfer arcing from the space between the relatively movable contacts (90 and 92) to the space (gaps 60) between the relatively fixed electrode portions. In this regard, tests have shown that the interrupter of FIGS. 9 and 10 can effect this transfer at relatively low values of current in comparison to the currents required to effect such transfer in an interrupter that has its outer electrodes formed as two axially-spaced opposed rings or discs. An example of this latter type of interrupter is shown and claimed in application S.N. 184,704, Porter, now Patent 3,210,505, filed Apr. 3, 1962. In this latter interrupter, the gap between the outer electrode portions is in a region of high perpendicular magnetic field, and high current arcs across such gap will develop typically high arc voltages. It is believed that the ability of my

interrupter to limit the arc voltage across gaps 60 to relatively low values is an important factor in materially increasing the speed at which the above-described arc-transfer occurs.

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

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

1. A vacuum-type circuit interrupter comprising:

- (a) a pair of electrodes having a spaced-apart position,
- (b) means defining a plurality of separate gaps electrically in parallel between said electrodes,
- (c) means for forming parallel-connected arcs across said gaps during a circuit-interrupting operation,
- (d) said gaps being so located that:

- (i) the magnetic field in any one gap resulting from the total current through said interrupter passing through any element adjacent said one gap is in a direction generally parallel to the arc or arcs in said one gap, and
- (ii) in any one gap, the magnetic field produced by current through an arc in any given other gap is in an opposite direction to the magnetic field produced by current through an arc in any of said other gaps immediately adjacent said given other gap,

- (e) and means affording free communication between said gaps for the vapors generated by arcing at said gaps.

2. The vacuum-type circuit interrupter of claim 1 in which:

- (a) said means for forming arcs across said gaps comprises means for establishing an initial arc in a region outside of said gaps where the magnetic field component extending perpendicular to said initial arc is high compared to the magnetic field component extending perpendicular to an arc in one of said gaps, and

- (b) means is provided for affording free communication between the region of said initial arc and at least one of said gaps for vapors generated by said initial arc.

3. The vacuum type circuit interrupter of claim 1 in which means is provided for causing the initial arcing that takes place between said electrodes during a circuit-interrupting operation to occur in one of said gaps.

4. The vacuum type circuit interrupter of claim 1 in which:

- (a) means is provided for forming an initial arc between said electrodes in a region outside said gaps where the magnetic field component extending perpendicular to said initial arc is high compared to the magnetic field component extending perpendicular to an arc in one of said gaps,

- (b) means is provided for affording free communication between the region of said initial arc and at least one of said gaps for vapors generated by said initial arc, and

- (c) means is provided for causing the current flowing to said initial arc to follow a path in the region of the initial arc so shaped that said latter current has a magnetic effect urging said initial arc in a direction generally toward said gaps.

5. The vacuum-type circuit interrupter of claim 1 in combination with:

- (a) a first contact electrically connected to one of said electrodes,
- (b) a second contact electrically connected to the other of said electrodes and movable with respect to said other electrode,

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- (c) said second contact being engageable with said first contact and movable out of engagement with said first contact to initiate an arc between said contacts,
- (d) said contacts being located in a position disposed radially inwardly of said parallel-connected gaps, 5
- (e) and means for developing a radially-outwardly acting force on the arc initiated between said contacts that forces arcing products into one of said parallel-connected gaps and causes arcing across said one gap,
- (f) the space between said contacts being located in a position where the magnetic field extending transversely of the initial arc is high compared to the magnetic field extending transversely of an arc in said gaps. 10
6. A vacuum-type circuit interrupter comprising: 15
- (a) a pair of electrodes having a spaced-apart position, each of said electrodes having a centrally-located longitudinal axis,
- (b) each of said electrodes comprising a plurality of fingers extending generally parallel to said longitudinal axis and arranged in angularly-spaced relationship about the periphery of a closed curve encompassing said longitudinal axis, 20
- (c) the fingers of one electrode being located respectively between the fingers of the other electrode and angularly spaced therefrom to form a plurality of gaps electrically in parallel between the fingers of the two electrodes, 25
- (d) said gaps having a length extending in a direction generally parallel to the periphery of said curves and transversely of said longitudinal axes, 30
- (e) means for forming parallel-connected arcs along the length of said gaps during a circuit-interrupting operation,
- (f) and means affording free communication between said gaps for the vapors generated by arcing at said gaps. 35
7. The vacuum-type circuit interrupter of claim 6 in which: 40
- (a) said means for forming arcs across said gaps comprises means for establishing an initial arc in a region outside of said gaps where the magnetic field component extending perpendicular to said initial arc is high compared to the magnetic field component extending perpendicular to an arc in one of said gaps, 45
- and
- (b) means is provided for affording free communication between the region of said initial arc and at least one of said gaps for vapors generated by said initial arc. 50
8. The vacuum-type circuit interrupter of claim 6 in which: 55
- (a) a first contact electrically connected to one of said electrodes,
- (b) a second contact electrically connected to the other of said electrodes and movable with respect to said other electrode, 60
- (c) said second contact being engageable with said first contact and movable out of engagement with said first contact to initiate an arc between said contacts,
- (d) said contacts being located in a position disposed radially inwardly of said parallel-connected gaps, 65
- (e) and means for developing a radially-outwardly acting force on the arc initiated between said contacts that forces arcing products into one of said parallel-connected gaps and causes arcing across said one gap,
- (f) the space between said contacts being located in a position where the magnetic field extending transversely of the initial arc is high compared to the magnetic field extending transversely of an arc in said gaps. 70

9. A vacuum-type circuit interrupter comprising:
- (a) a pair of electrodes having an axially spaced-apart position,
- (b) means defining a plurality of separate gaps electrically in parallel between said electrodes across which arcs may burn at a relatively low arcing voltage even during high current interruptions,
- (c) means for forming parallel-connected arcs across said gaps during a circuit-interrupting operation,
- (d) said gaps being so disposed that the arcs burning thereacross extend generally circumferentially of a circle surrounding the kernel of the axially-directed current through the electrodes,
- (e) means for limiting the component of magnetic field that extends perpendicular to each of said arcs in said gaps to a low intensity that:
- (i) holds the arc voltage below 80 volts even when the interrupter is interrupting peak currents greater than 35,000 amperes, and
- (ii) is less than one half of $0.2I/r$, where the intensity is expressed in gilbers per centimeter, I is the total current flowing through the electrodes in amperes, and r is the radial distance in centimeters between the arc and the kernel of the axially-directed current through the electrodes,
- (f) and means affording free communication between said gaps for the vapors generated by arcing at said gaps.
10. The interrupter of claim 9 in which:
- (a) said means for forming arcs across said gaps comprises means for establishing an initial arc in a region outside of said gaps where the magnetic field component extending perpendicular to said initial arc is high compared to the magnetic field component extending perpendicular to an arc in one of said gaps, and
- (b) means is provided for affording free communication between the region of said initial arc and at least one of said gaps for vapors generated by said initial arc.
11. The interrupter of claim 9 in which:
- (a) means is provided for forming an initial arc between said electrodes in a region outside said gaps where the magnetic field component extending perpendicular to said initial high arc is high compared to the magnetic field component extending perpendicular to an arc in one of said gaps,
- (b) means is provided for affording free communication between the region of said initial arc and at least one of said gaps for vapors generated by said initial arc, and
- (c) means is provided for causing the current flowing to said initial arc to follow a path in the region of the initial arc so shaped that said latter current has a magnetic effect urging said initial arc in a direction generally toward said gaps.

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