

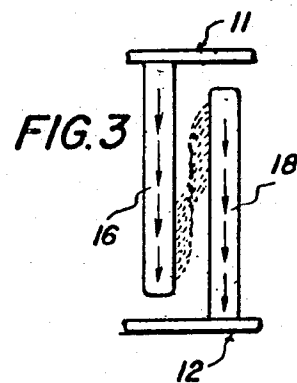
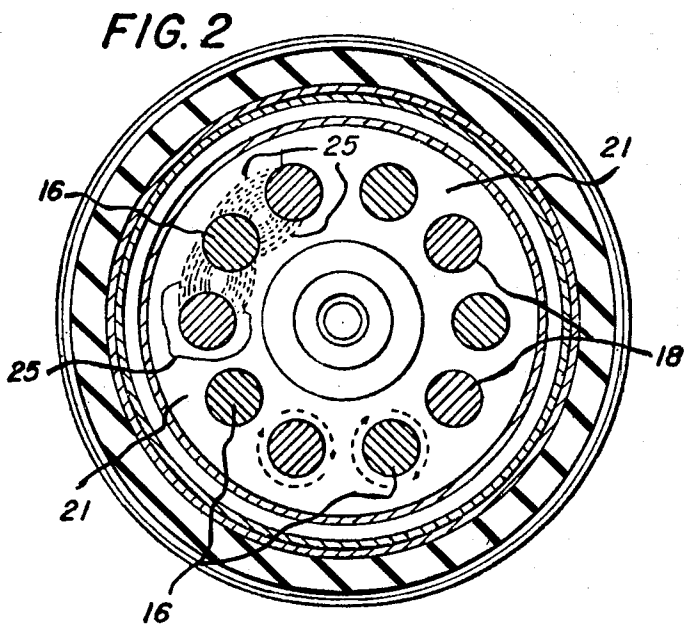
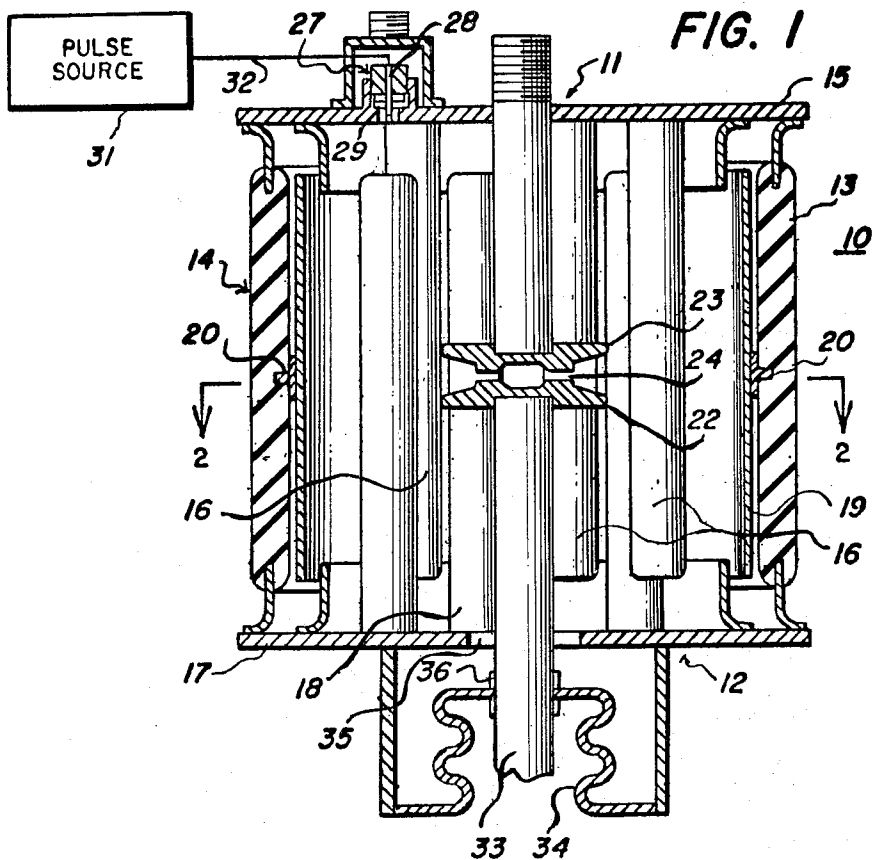
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PERIODIC ELECTRODE STRUCTURE FOR VACUUM GAP DEVICES

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3,679,474 PERIODIC ELECTRODE STRUCTURE FOR VACUUM GAP DEVICES

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Continuation-in-part of abandoned application Ser. No.
875,919, Nov. 12, 1969. This application Jan. 18, 1971,
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10 Claims

ABSTRACT OF THE DISCLOSURE

Discloses vacuum gap devices including triggerable gap and switch devices in which a pair of electrode assemblies, each having a plurality of electrode elements which are parallel and/or normal to the same plane are assembled with opposed electrode members interleaved to form a periodic ring shaped structure. A current interrupting arc is initiated by a pair of butt-type arc-electrodes located centrally of the rod array.

This application is a continuation-in-part of my co-pending application, S.N. 875,919, filed Nov. 12, 1969, now abandoned, and assigned to this assignee.

The present invention relates to vacuum gap devices adapted to operate at high currents without the formation of anode spots therein. More particularly, the present invention relates to such devices in which the formation of anode spots is avoided by the configuration and position of the electrodes such that essentially no magnetic field exists within the interelectrode gap. Specifically, a pair of primary arc-electrodes comprising a plurality of electrode members are generally assembled so that the individual electrode members interleave with one another to form a period structure which renders magnetic fields normal to the conduction paths within the interelectrode gaps a minimum to prevent the formation of anode spots.

In the development of vacuum switches and triggerable vacuum gap devices, a limiting factor to the amount of current which can be drawn by a given structure is the threshold current at which a destructive anode spot is formed. Formation of such anode spots results in erosion of the anode electrodes and melting thereof. Such erosion and melting adversely affect the surface of the device, making the breakdown voltage change from its original value, eventually leading to the failure of the device. It also adversely affects the switch recovery characteristics. This is because erosion of the electrodes leaves irregular surfaces, which irregular surfaces cause perturbations in the electric field, which facilitate the breakdown at lower voltages. In developing prior art vacuum gap devices, many attempts have been utilized in order to keep anode spots from causing such destructive erosion. Generally, these attempts have been along the lines of accepting the fact that anode spots are inevitable and constructing the electrodes of such a configuration and providing the interaction space with magnetic fields, either due to the action of the arc itself, or due to external influences, so that the interaction of the magnetic field with the electric arc causes the arc to move, generally by rotating around the periphery of disc-shaped electrodes. Although these techniques are useful and do in fact result in longer life than vacuum gap devices in which such attempts have not been made, much is left to be desired in order to prevent the formation of anode spots.

In my U.S. Patent 3,471,733, issued Oct. 7, 1969, I have set forth my discovery leading to a new approach in the attack on anode spots in vacuum gap devices. Briefly stated, I have found that it is not necessary to accept the

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fact that anode spots must be lived with. Rather, since the body force or force per unit volume of conducting fluid acting upon any conduction path between a pair of arc-electrodes in a vacuum gap device is governed by the formula

$$\vec{F} = \vec{J} \times \vec{B}$$

where F is the body force,

$$\vec{B}$$

is the magnetic field existing in the interelectrode gap, and

$$\vec{J}$$

is the current density between these electrodes, in accord with the general discovery set forth in my patent, I eliminate or minimize the body force by eliminating or minimizing the normal magnetic force in the interelectrode gap. In one embodiment of the invention set forth in my patent, I form an inner electrode from a re-entrant cylinder wherein the current path is "folded-back" upon itself, and form the other electrode from a concentric cylinder surrounding the first electrode. Current flow in the outer cylinder is longitudinal and thus, by Amperes law, current flow within the exterior cylinder results in no net magnetic field within the confines of the cylinder. In the innerelectrode, current in one direction within the re-entrant structure is substantially equal to current in the opposite direction in the other section thereof and, hence, the net magnetic field is essentially zero exterior of the re-entrant innerelectrode. Accordingly, the interelectrode gap, which is a cylindrical annulus between the two concentric cylindrical electrodes, is essentially magnetic field-free and essentially no body force acts upon the current paths between the concentric electrodes. The current paths are, therefore, not caused to bunch-up at one end of the device, thus causing the formation of destructive anode spots.

Although the class of devices described hereinbefore is a great advance upon the prior art and essentially opens a new field of development for vacuum gap devices, I have found that the precise geometry necessary to obtain a magnetic field-free region in the interelectrode space is difficult to achieve. Similarly, if and when the device does fail, the entire active portion must be replaced. It is desirable that replaceable electrode elements be incorporated therein in order to serve as a device without completely replacing the electrode structure.

In order to accomplish the foregoing, in my U.S. Patent 3,471,734, I disclose a structure for vacuum arc devices having a pair of arc-electrode assemblies each of which includes a plurality of cylindrical, rod-like members which interleave to form a periodic structure which maintains the minimum

$$\vec{J} \times \vec{B}$$

but provides greater flexibility and easier production capabilities.

While the type structure is a substantial improvement, it is not idealized for vacuum switch applications wherein a broad area of arc-electrode is required, wherein it is still essential to minimize the

$$\vec{J} \times \vec{B}$$

product, and wherein adequate means of interrupting a high current arc with a minimum of erosion is essential.

Accordingly, it is an object of the present invention to provide vacuum arc devices adapted to carry high current arcs without the formation of destructive anode

spots and to provide circuit making and breaking means for establishing such high current arcs.

Yet another object of the present invention is to provide vacuum arc devices adapted to establish and interrupt high current arcs and to provide arc-supporting means devoid of arc-bunching azimuthal magnetic fields.

Still another object of the present invention is to provide vacuum arc devices having arc electrode means including a plurality of cylindrical arcing members and juxtaposed arc-initiating means.

In accord with one embodiment of the present invention, I provide improved vacuum arc discharge device having high current thresholds for the formation of anode spots and juxtaposed means for establishing high current arcs and including a pair of primary arc-electrode assemblies, each of which includes a plurality of electrode members and which are assembled together with the individual electrode members interleaved or interdigitated together to form a ring-shaped structure of alternating, cylindrical rods providing a plurality of interelectrode gaps, each of which is substantially free from magnetic fields transverse to the path of current conduction between the individual electrode members. Such a structure facilitates the carrying of high currents between adjacent, opposite-poled electrode members, due to the large electrode area, without bunching thereof, with the resultant formation of destructive anode spots. In accord with another feature of the invention a pair of butt-type, high current carrying arc-initiating electrodes are located centrally of the ring array and adapted to initiate a high current arc by separation thereof, and to transfer the initiated arc rapidly to the ring array of cylindrical arc-electrode members whereat the arc may dwell without the formation of destructive anode spots.

The novel features believed characteristic of the present invention are set forth in the appended claims. The invention itself, however, together with further objects and advantages thereof, may best be understood with reference to the following description, taken in connection with the appended drawing, in which:

FIG. 1 is a vertical cross-sectional view, with parts broken away, of a vacuum switch constructed in accord with one embodiment of the present invention,

FIG. 2 is a horizontal section view taken along lines 2—2 in FIG. 1, and

FIG. 3 is a schematic representation of current and conduction paths between adjacent electrode members of the device of FIGS. 1 and 2.

In vacuum arc devices, the current threshold marking the onset of the formation of anode spots is a function of electrode geometry and electrode material. For a given material, therefore, the formation of anode spots is a function of electrode geometry. In the plane-parallel geometry, frequently utilized in switches in general and vacuum switches in particular, the threshold is relatively low, since a spot is formed at any point at which the current density becomes high, either due to surface irregularities or anchoring of the arc due to the interaction of electric currents and magnetic fields. One means of inhibiting the formation of anode spots is to use electrodes having a very large area so that the current paths between the arc-electrodes are diffused over a very large area to lower the current density and prevent the formation of anode spots. Yet another means utilized to avoid the formation of anode spots, or to facilitate the carrying of high currents without destructive action of anode spots, is to utilize electrode configuration and magnetic fields, either caused by the current conduction paths or an external magnetic field, to interact to cause the arc to move over the electrode surface, most generally to rotate about the periphery of a disc-shaped electrode. This tends to keep the burning and erosion at any given point of the anode to a minimum.

In accord with the invention set forth in my aforementioned U.S. Patent 3,471,733, realizing that the force

tending to cause conduction paths between a pair of oppositely-poled arc-electrodes to bunch together and form a high current density which results in the formation of an anode spot to be the result of the product of the current and the normal component of the magnetic field, I eliminate or reduce the normal magnetic field so as to reduce the magnitude of the vector product and, hence, the body force acting to propel the current conduction paths together, or to bunch or concentrate the arc discharge into a small region of the discharge volume. In accord with the configuration disclosed in that patent, concentric cylindrical conductors are utilized with the inner conductor being re-entrant in structure to cause a folding-back of current therein with a net zero contribution to the azimuthal magnetic field in the interelectrode gap.

In accord with the present invention, I find that it is not necessary to utilize a concentric configuration for the primary arc-electrodes, or even a large number of electrode members arranged in interleaved relationship to form a periodic electrode structure filling the arcing chamber in which magnetic fields transverse to the current conduction paths are minimized or eliminated, as is disclosed in my aforementioned U.S. Patent 3,471,734. Rather, I find it sufficient to provide a ring-shaped array of smooth surfaced cylindrical rod electrode elements alternately interleaved in opposite polarity. This facilitates the location of means for establishing a high-current arc and propagating the arc to the ring array structure of interleaved cylindrical rods, at which the arc is non-destructively extinguished.

FIG. 1 illustrates a vacuum switch device constructed in accord with the present invention. In FIG. 1, switch 10 includes an upper electrode assembly 11 and a lower electrode assembly 12 joined with an insulating cylindrical sidewall member 13 which is hermetically sealed to lower electrode assembly 12 and upper electrode assembly 11 to form an hermetically sealed envelope 14. Upper electrode assembly 11 includes a base plate or disc 15 and a plurality of downwardly-depending electrode members 16. Lower electrode assembly 12 includes a plurality of upwardly-depending electrode members 18 and a base plate or disc 17. Each of the individual, downwardly-depending electrode members 16 may include a central post and a concentric smooth surfaced cylindrical member which is connected to the central post at the inward end thereof by a disc member as is disclosed in my aforementioned U.S. Patent 3,471,734. Similarly, each of the upwardly-depending electrode members 18 may include a central post and a concentric cylindrical member which is joined to the central post at the inner end thereof by a disc member. Preferably, however, each of cylindrical electrode members 16 and 18 are solid smooth surfaced rod-like members, as is illustrated. Alternatively, rods 16 and 18 may be as illustrated, but hollow. The alternating ring-shaped structure caused by the alternation of downwardly-depending electrode members 16 and upwardly-depending electrode members 18 causes the creation of a plurality of interelectrode gaps 21. The active surfaces of the arc-electrode members are the smoothly curved surfaces of cylindrical members 16 and 18 of electrode assemblies 11 and 12, respectively.

The arc-electrode materials are prepared from a high purity, high vapor pressure material, as for example, copper or any of the materials set forth in Patent 2,975,256, to Lee et al., Patents 2,975,255 and 3,016,436 to Lafferty, and Patent 3,140,373 to Horn, and similar materials, alloys and intermetallic compounds which are operative to provide a copious quantity of metallic particles during arcing for the supplying of conduction carriers during operation of the device.

During operation, it is essential that none of the aforementioned vaporized metallic particles be deposited upon the insulator 13 separating the opposite electrode assemblies. Accordingly, shield member 19, in the form of a

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cylinder surrounding the arc-electrode structures and supported by flange 20, imbedded in sidewall member 13 serves to prevent deposition of electrically conductive species on insulation 13.

An arc initiating means is provided, in the form of massive butt-type arc-electrodes 22 and 23, defining a starter arcing gap 24 therebetween, centrally of the ring rod array. Arc-electrodes 22 and 23 are massive enough to carry temporarily, without destructive erosion the currents eventually distributed among gaps 21. Due to the substantially plane-parallel configuration of electrodes 22 and 23, the magnetic forces due to the initially struck arc therebetween acting upon the arc substantially, instantaneously propel the arc out into the ring array of alternating cylindrical rods so that the discharge is uniformly distributed among gaps 21.

I am aware that a U.S. Patent 3,321,598 shows a vacuum switch having an arrangement of interleaving arcuate segment primary electrodes surrounding a central pair or butt-type electrodes. It is essential, however, to the achievement of the advantages of my discoveries regarding the elimination of

$$\vec{J} \times \vec{B}$$

forces upon arcing currents to eliminate anode spots, that there be no sharp edges or corners upon which arcs may "hang up" and cause the formation of anode spots. Accordingly, without the smooth surfaced cylindrically shaped electrode members of my device the advantages of the present invention are not achieved.

Due to the cylindrical cross sections of the respective arc-electrode members 16 and 18, the active surface of each member is a cylinder so that, in the absence of points or corners, the entire surface is used and a very broad area of electrode surface carries arcing current, with arcing currents describing paths substantially as are identified by current paths 25 in FIG. 2. Should any other geometry arc-electrode member be utilized, the current carrying capacity of the device would be much lower, particularly if the arc is able to concentrate at a point or corner. Thus, for example, any sharp edges or discontinuities would "bunch" conduction paths and cause the formation of destructive anode spots.

In the case of a recloser switch, which is normally open and closes to short circuit a protected load, it is desirable to provide an instantaneous supply of conduction carriers to initiate conduction between the arc-electrode assemblies while the mechanical apparatus (not shown) is in operation to cause electrode 22 to abut electrode 23. Trigger assembly 27 serves this purpose. Trigger assembly 27 includes a trigger anode 28 and a trigger cathode 29 in electrical contact with arc-electrode assembly 11. Trigger electrode 28 may conveniently comprise a metallized ceramic cylinder with a scored gap therein with the metal on one side of the gap connected electrically to trigger cathode 29 and the metal on the other side of the gap connected to a pulse source 31 by trigger anode lead 32. Although a simplified trigger assembly is shown herein, it is to be understood that any suitable trigger assembly operative to inject a cloud of electron-ion plasma into the interaction space between the arc-electrode members is suitable. Some such triggers are illustrated, for example, Lafferty Patents 3,465,192 and 3,465,206.

In operation, when a pulse of electron-ion plasma is injected into the interaction space, simultaneously with the actuation of the recloser mechanism, the plurality of interelectrode gaps 21 between individual electrode members 16 and 18 become the site of a number of small arcs or conduction paths with the conduction paths spreading rapidly over the many broad areas presented by the closest surfaces of the individual electrode members. The conduction paths are limited to the interelectrode gaps 21 because these are the shortest distances between any points in the device 10 which are electrically at the potential of the primary arc-electrodes. Although

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FIG. 1 of the drawing is not meant to be exact scale, it is to scale in the respect that it clearly represents that the distance between the upwardly-depending electrode members 18 and the base plate 15 of upper arc-electrode assembly 11 is much greater than the interelectrode gaps 21. Similarly, the distance from downwardly-depending arc-electrodes 16 to the lower plate 17 of arc-electrode assembly 12 is much greater than distance of interelectrode gaps 21.

Once the device 10 has become conducting with a plurality of conduction paths between adjacent oppositely-poled individual electrode members, the principles enunciated hereinbefore of the substantial elimination of magnetic forces within the interaction space becomes apparent. The conduction paths in any individual arc-electrode member, as for example, downwardly-depending arc-electrode members 16, are downwardly, while in upwardly-depending electrode member 18 current conduction is downwardly. The substantially equal and parallel conduction paths and magnitude thereof causes a substantial cancellation of the azimuthal magnetic fields due to the conduction paths therein and the entire assembly between the individual arc-electrodes is substantially azimuthal field-free. Although shield member 19 surrounds the entire interaction space, since it is typically of stainless steel and conducts no current, there is no conduction of electric current therein and no effect upon the magnetic field, either favorable or unfavorable results from the presence of member 19. This arc is terminated when electrodes 22 and 23 come into contact.

In all embodiments of the present invention, whether switch or recloser, and in the substantial absence of magnetic field in the interaction space between the arc-electrode members 16 and 18, there is substantially no body force tending to bunch the numerous conduction paths between the individual electrode members and thereby anode spots are avoided and very high currents may be carried before what minimal field remains is effective to cause any bunching. Accordingly, a very great current conduction may be obtained with no destructive arcing or erosion of the arc-electrodes. In the event that destructive arcing does occur, however, it may occur between only a particular pair of electrodes. In accord with the invention, it is a simple matter to cause each of arc-electrode members 16 and 18 to be individually removable as for example, with a screw-thread from base members 15 and 17 to make it possible to disassemble the device, remove any damaged or eroded arc-electrode member and re-assemble the device, evacuate and re-seal. In devices in accord with the present invention, it is possible to switch currents of the order of one hundred thousand amperes (peak) at voltages of 15,000 to 30,000 volts in devices having a volume of approximately one cubic foot, with substantially no arcing or erosion of the electrode members.

Establishment of an arc between starter arc-electrode members 22 and 23 is accomplished by virtue of the mounting of arc-electrode 22 upon an actuating rod 33, which is reciprocably movable by means of a sylphon bellows 34 which is suitably fastened to the outer periphery of an aperture 35 in lower base plate 17 and similarly fastened in hermetic seal by flange 36 to actuating rod 33. Starter arc-electrodes are conveniently constructed of the same materials as arc-electrode members 16 and 18. To initiate an arc by starter electrodes 22 and 23 alone, a force is applied to actuating arm 33, withdrawing electrode 22 from electrode 23, causing an initial arc to be struck. Electrode 22 is completely withdrawn a sufficient distance from electrode 23 so that as the magnetic forces act upon the struck arc, the arc is preferentially caused to spread out into the spaces between oppositely-poled cylindrical electrode members 16 and 18 and, almost instantaneously, the arc is transferred to the individual gaps 21.

In FIG. 3, a schematic representation of current conduction paths between an upper electrode assembly 11

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and a lower electrode assembly 12 having only one individual downwardly-depending electrode member 16 and one upwardly-depending electrode member 18 is shown. Current paths within arc-electrode members 16 and 18 are represented by arrows. It is apparent, in view of the great area encompassed by the sheath over electrodes 16 and 18 that the principles of the present invention are realized almost ideally in that conduction paths are greatly spread out over the electrode surfaces with essentially no bunching. With the structure as illustrated in FIG. 1 and FIG. 2 of the drawing, the moderate azimuthal magnetic fields immediately surrounding the individual electrode members 16 and 18, respectively, tend to exert a moderate body force upon the conduction paths in the immediate vicinity of the electrodes. Since, however, these body forces acting upon the current paths are opposite in direction, the conduction paths are urged in opposite directions in the immediate vicinity of electrodes 16 and 18, causing the current paths to occupy the shaded area represented in FIG. 3.

In the devices described in my aforementioned patents, the force acting upon the current path between adjacent electrode members has been minimized by causing the magnetic field that is orthogonal to the current to be minimized or eliminated. Thus, the product

$$\vec{J} \times \vec{B}$$

approaches zero. In the present invention, essentially the same result will be obtained by allowing

$$\vec{B}$$

to exist, but by rendering

$$\vec{B} \text{ substantially parallel to } \vec{J}$$

Thus, for example, since

$$\vec{J} \times \vec{B}$$

is the vector product if the two vectors are parallel or substantially parallel, or even antiparallel, the product equals or approaches zero. In the devices of the present invention, such is the case. Turning for the moment to FIG. 2, it may readily be seen that any two adjacent electrode members are surrounded by a substantially equal magnetic field due to current flow in the same direction in the adjacent electrode members. Since, however, with respect to the current represented by current conduction paths 25, the radial components of the magnetic fields due to current conduction in respective electrode members substantially cancel in the intervening space between the electrodes and the azimuthal component of the magnetic fields due to current conduction in adjacent electrode members is additive. As a result of this characteristic of the magnetic field in the present invention, the resultant magnetic field (except in the immediate vicinity of each electrode member) is an azimuthal field which is substantially parallel with current conduction paths 25 between adjacent arc-electrodes. Accordingly, due to this configuration, the product

$$\vec{J} \times \vec{B}$$

approaches zero and substantially no body force (other than that which causes the schematic arc configuration illustrated in FIG. 3) is operative upon current conduction paths between the arc-electrode members. As a result, current conduction path bunching at the anode is avoided and destructive anode spots do not form. Accordingly, devices of the present invention are operative, with a relatively simple construction, to achieve substantially the same result as the more complicated structures of my aforementioned patents, and to permit the carrying of exceedingly large values of current within the device 10, without causing a high current density to exist at any place within the device to cause the formation of destructive anode spots.

Thus, the current threshold for the formation of anode spots is greatly increased and the current carrying capacity of the device is exceedingly high as compared with prior art devices.

Additionally, the utilization of the high current sustaining starter arc-electrodes 22 and 23 in close juxtaposition to members 16 and 18 of arc-electrode assemblies 11 and 12 (but at a greater distance than the interelectrode gaps 21) ideally enables the establishment of a high current arc and its rapid and non-destructive transfer to the equilibrium arc sustaining electrode structure, when it is desired to initiate an arcing condition by separation of a pair of normally-closed electrode assemblies.

Although the invention has been disclosed with respect to specific embodiments, numerous modifications and changes may be made. Thus, for example, electrode members of circular symmetry may be replaced with a plurality of elongated parallel electrode members which alternate and which may be folded or cylindrical vanes, as desired. Many other modifications and changes will occur to those skilled in the art.

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

1. A vacuum arc discharge device adapted to carry high currents without the formation of anode spots comprising:
 - (a) an hermetically sealed envelope evacuated to a pressure of 10^{-5} torr or less;
 - (b) a first primary arc-electrode assembly disposed within said envelope and including a first plurality of spaced substantially parallel cylindrical electrode members having smooth cylindrical arcing surfaces extending substantially normal to a first common base member;
 - (c) a second primary arc-electrode assembly within said envelope and including a second plurality of spaced substantially parallel cylindrical electrode members having smooth cylindrical arcing surfaces extending substantially normal to a second common base member and interleaved in alternating sequence between the spaced electrode members of said first arc-electrode assembly;
 - (d) said first and second spaced electrode members being positioned so as to form a ring of electrode members within said envelope, said members alternating in polarity about said ring and causing the vector product

$$\vec{J} \times \vec{B}$$

to be insignificantly small in the spacings between electrode members of first and second electrode assemblies where

J =current density in the arc discharges between any given pair of opposite electrode members and

B =magnetic field between any given pair of electrode members due to current paths within said electrode members when said device is in a current conduction condition;

- (e) means for causing an electric arc breakdown to be established between said primary arc-electrode assemblies; and
 - (f) means for connecting said arc-electrode assemblies in circuit with an electric load.
2. The device of claim 1 wherein said first electrode assembly includes an upper base member and a plurality of downwardly-depending smooth surfaced cylindrical electrode members and said second electrode assembly includes a base member and a plurality of upwardly-depending smooth surfaced cylindrical electrode members.
 3. The device of claim 2 wherein each of said electrode members is in the form of solid smooth surfaced cylindrical members projecting from said base member.
 4. The device of claim 2 wherein said periodic array constitutes a pattern in which each cylindrical electrode

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member of said first electrode assembly is laterally surrounded by a pair of cylindrical electrode members of said second electrode assembly.

5. The device of claim 2 wherein said device exhibits circular symmetry about a longitudinal axis.

6. The device of claim 2 wherein said device is a triggerable vacuum gap device and the means for supplying an electron-ion plasma therein is a trigger electrode assembly.

7. The device of claim 2 wherein the device is a vacuum switch and the means for supplying an electron-ion plasma therein is a starter electrode assembly adapted to establish a starter arc discharge therein.

8. The device of claim 7 wherein said starter electrode assembly constitutes a pair of arc-electrodes located at the approximate center of said ring.

9. The device of claim 8 wherein said starter electrodes are of a refractory metal.

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10. The device of claim 7 wherein said starter electrodes are supplemented by a trigger electrode assembly to facilitate recloser mode of operation.

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