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VACUUM GAP DISCHARGE DEVICE HAVING GROOVED ELECTRODES FOR THERMAL INSULATION

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Fig. 1.

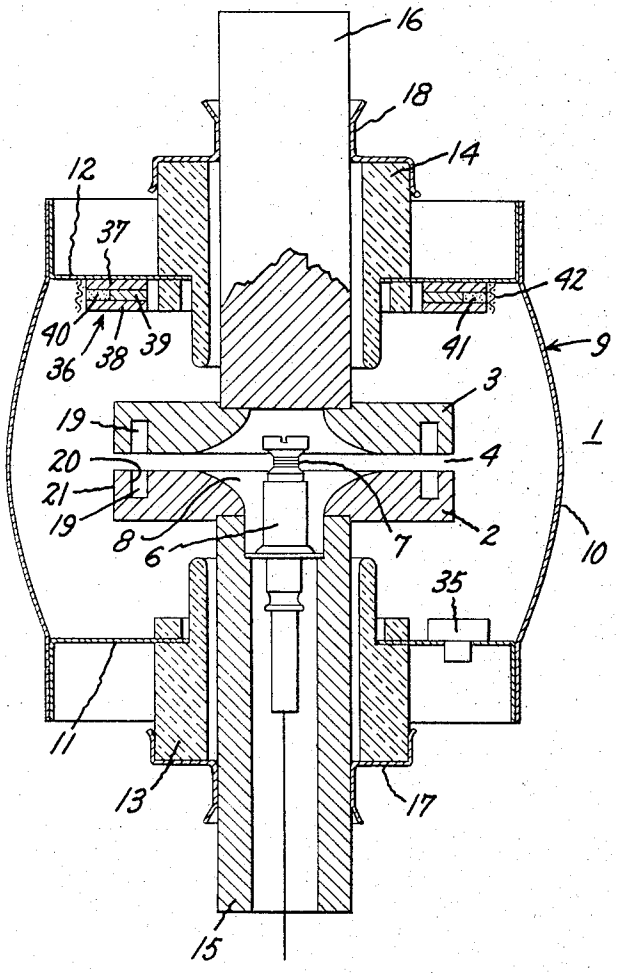
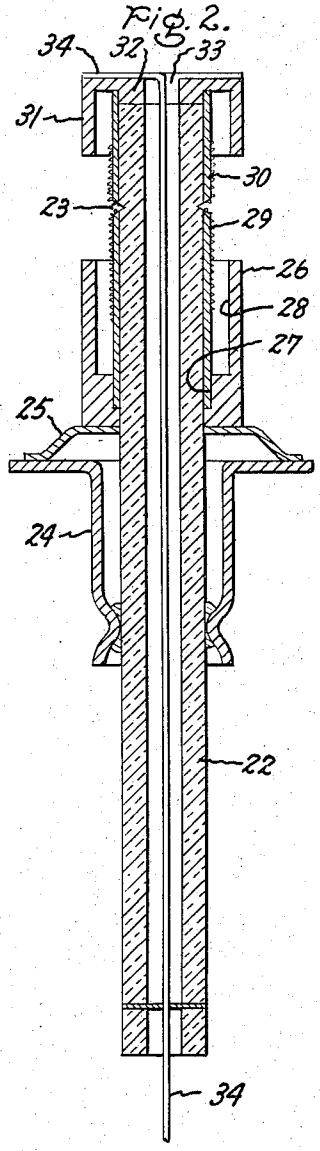


Fig. 2.



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VACUUM GAP DISCHARGE DEVICE HAVING GROOVED ELECTRODES FOR THERMAL INSULATION

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Continuation-in-part of application Ser. No. 422,373, Dec. 30, 1964. This application July 11, 1966, Ser. No. 564,132

13 Claims. (Cl. 313—217)

ABSTRACT OF THE DISCLOSURE

Vacuum arc devices including a pair of primary arc electrodes adapted to sustain an arc therebetween. Improved current carrying capacity results from arc dispersal means at the periphery of one arc electrode, including an annular slot at the electrode periphery defining a peripheral ridge which is uniformly heated to vapor emission temperature to avoid formation of anode spots.

The present invention is a continuation-in-part of my copending application, Ser. No. 422,373, filed Dec. 30, 1964 and assigned to the present assignee, now abandoned.

This invention relates to improved vacuum gap devices and particularly those of the triggered vacuum gap and triggered vacuum switch type and to improved electrode configuration therefor.

Vacuum switches and vacuum gaps, particularly triggered vacuum gaps have recently undergone great improvements. A number of such devices generally referred to as vacuum gap devices are presently of important commercial considerations. In most of these vacuum gap devices a limiting factor as to the current carrying capacity lies in the ability of the anode to withstand destructive melting caused by the formation of intense anode spots. Similar destructive melting also occurs at the cathode eletcrode, although the anode destruction is the most extensive.

Accordingly, it is an object of the present invention to provide improved vacuum gap devices having electrode configurations which facilitate the carrying of extremely high currents without destructive melting of the anodes thereof.

A further object of the invention is to provide triggerable vacuum switch and fixed vacuum gap devices in which the electrodes are adapted to carry high values of current between arc initiation and arc interruption without destructive melting thereof.

A further object of the present invention is to provide improved vacuum gap devices which are suitable for utilization over a greater number of circuit interruptions or arc estabilshments than devices of the prior art.

In accord with one feature of the present invention I provide a vacuum gap device including a pair of primary electrodes defining therebetween a vacum gap. These electrodes are located within an evacuable envelope which envelope is composed partially of metal and at least in part of a high voltage insulating substance so as to provide electrical isolation between the primary electrodes to prevent short circuiting of the gap defined thereby. In one embodiment of my invention the man gap electrodes are provided with an annular groove closely adjacent to the external periphery thereof, which groove provides a portion thereof which is, as far as thermal conduction characteristics are concerned, partially isolated from the remainder of the main electrode in order that the isolated portions thereof may achieve a higher temperature causing a substantially uniform emission of vapor therefrom and the prevention of destructive spots. In accord with a further feature of the present invention the electrodes of the vacuum devices thereof are so shaped as to provide a central portion at which the gap between the primary electrodes is larger than the gap at the periphery thereof so as to facilitate the location of the arc discharge between the peripheral portions of the electrodes at which the thermally isolated portions are located. In accord with a further feature of the present invention a trigger electrode is located within the central portion of at least one of the electrodes and is connected so as to cause the injection of a highly ionized gaseous plasma into the gap between the main electrodes to cause the breakdown thereof upon the initiation of a voltage pulse thereto.

The novel features believed characteristic of the present invetnion are set forth in the appened claims. The invention itself, together with further objects and advantages thereof may be more readily understood by a reference to the appended drawing in which:

FIGURE 1 is a vertical cross-sectional view of a fixed gap triggerable vacuum gap device constructed in accord with the present invention, and

FIGURE 2 is a vertical cross-sectional view of the trigger electrode utilized in the device of FIGURE 1.

The vacuum gap device of FIGURE 1 includes an envelope represented generally as **1** containing therein a pair of primary arc electrodes **2** and **3** defining therebetween a primary gap **4**. A trigger electrode **6** having a trigger gap **7** is concentrically located within a central aperture **8** of electrode **2** and extends to substantially to the center of the primary gap **4**.

Envelope **1** is comprised of a substantially cylindrical metallic member **9** having a central bulbous portion **10** which is symmetrical along the longitudinal axis thereof, a first flanged metallic end piece **11** having a central aperture therein and a second flanged metallic apertured end plate **12** also having a central aperture therein. A pair of substantially cylindrical, centrally apertured insulator bushings **13** and **14** each of which has a large outside diameter portion and a smaller outsider diameter portion connected by an annular shoulder serve as insulating members for the device and are assembled with the smaller outside diameter portion thereof extending inwardly with the annular shoulder resting against the planar exterior surface of apertured end plates **11** and **12** respectively. The central apertures within insulator bushings **13** and **14** are closed by the insertion therewithin of annular cylindrical electrode support members **15** and **16** respectively. The interior of cylindrical electrode support member **15** is hollow and is sealed to vaccum by the insertion therein and sealing thereto of trigger electrode assembly **6**. Each of the central cylindrical apertures in bushings **13** and **14** are slightly larger than the outside diameter of electrode support members **15** and **16** for added insulation properties and to provide an insulator surface not likely to be short circuited by condensed metal vapor. A vacuum seal is made between these members by the brazing thereto of annular seal members **17** and **18** respectively each of which has a larger diameter portion which fits tightly over the outside diameter of the respective insulator bushing and a smaller diameter portion which fits tightly over the exterior portion of the respective electrode support member.

The materials comprising the devices illustrated in FIGURE 1 are substantially as follows. Main envelope member **9** may be a metal which will withstand high temperatures and which possesses sufficient physical strength as to constitute the outside body of the device, as for example stainless steel. Flanged end plate members **11** and **12** and flange seal members **17** and **18** are

comprised of a material which makes good vaccum-tight seals to ceramic bushings **13** and **14** and to metallic members **9**, **15** and **16** respectively and may conveniently be a Fernico or Kovar alloy generally utilized in electric discharge devices for this purpose. Bushings **13** and **14** are comprised of a high temperature gas impermeable ceramic material, as for example high density alumina (94% or higher or Al_2O_3). Electrode support members **15** and **16** are preferably composed of a highly conductive substantially gas-free material, as for example OFHC copper Premium Grade. No special precautions need be taken to render this material gas-free, other than vacuum firing prior to assembly. Primary electrodes **2** and **3** are composed of highly purified copper or other high vapor pressure material, as for example any of the matrials set forth in Lee and Cobine Patent No. 2,975,256 issued Mar. 14, 1961. This material is rendered substantially free of all gases and gaseous-forming compounds by vacuum melting, as for example by repeated zone refining steps so as to reduce the concentration of gas and gas-forming impurities therein to a figure of less than one part in 10^6.

Electrodes **2** and **3** are preferably provided with at least one arc dispersion means **19** although only the anode need be so provided. Arc dispersion means **19**, in the illustrated embodiment comprises an annular slot which is cut from the arcing surface **8** of electrode **2**, for example, so as to provide a vertical surface **20** and a thermally substantially isolated annulus **21** on electrode **2**. The dimensions of arc dispersion slots **19** is related to the material from which the electrodes are formed and to the gap distance. In general the slot should be located far enough in from the periphery so that the peripheral isolated region so formed is raised to a vapor-emitting temperature without destructive "boiling" of vapor at too rapid a rate. The depth of the slot is not critical but is related to the thickness of the electrode body. Naturally, the slot depth should be sufficient to substantially increase the surface-to-volume ratio of the peripheral region and to so constrict the path of thermal conduction as to allow for the controlled heating of the peripheral region as described hereinbefore. For a given geometry, as the chosen electrode material, the width of the slot **19** varies indirectly with vapor pressure and directly with thermal conductivity of the material. As one example of dimensions, for a 2½" diameter, ½" thick electrode of copper, with a gap width of ⅛" operated on 60 c.p.s. alternating current voltage, slot **19** was ⅛" wide and ¼" deep and the width of the peripheral region **21** was ⅛". Arc dispersion means may take other forms. Thus, for example, a series of slots may be drilled in a circular pattern along a radius only slightly less than the radius of the electrodes. Preferably, such slots should be interconnected to provide for arc rotation and for a uniform dispersion of the arc. Alternatively, a plurality of annular slots could be cut at different radial distances from the center of the arc to create several peripheral vapor emitting ridges.

The trigger electrode assembly **6** of FIGURE 1 of the drawing is illustrated in greater detail in vertical cross section in FIGURE 2 of the drawing. In FIGURE 2 the trigger is composed of a hollow cylindrical metallized ceramic base member **22** which has a narrow circumferential groove **23** cut therein, which may be tapered as shown, near the inward extremity thereof. Means for sealing the trigger electrode in a vacuum-tight seal to the interior of electrode support member **15** are provided in the form of an annular flange member **24** having an extended shoulder and an apertured collar member **25** which rests thereupon and is sealed thereto. Both of these members are conveniently constructed of a metal suitable for making metal to ceramic seals, as for example one of the general class of metal alloys known as Fernicos. A first hollow cylindrical shield member **26** having a first counterbore **27** therein and a second counterbore **28** of greater diameter also therein rests upon collar member **25**. The smallest diameter of cylindrical member **26** makes electrical contact with metallized ceramic cylindrical member **22**. A first metallic sleeve member **29**, which is beveled at one end thereof to fit the bevel in the annular groove **23** in ceramic cylinder member **22**, slides over member **22** and is aligned with the inward or lower bevel of the annular groove therein. A second cylindrical sleeve **30**, which is likewise beveled at one of its ends to match the groove **23** in cylindrical member **22**, slides over ceramic member **22** and is aligned with the outward or upward bevel of groove **23** therein. A metallic cap and shield piece **31** having a re-entrant portion **32** and a central aperture **33** rests upon the upper end of ceramic cylindrical member **22** and within the interior end of second sleeve member **30**. A trigger lead wire **34** centers the central aperture within ceramic trigger support member **22** and is affixed to the re-entrant end cap **31** at the uppermost portion thereof. This lead may conveniently be of nickel or any other material conventionally utilized for providing lead wires in electric discharge devices. Members **24** and **25** are conveniently selected as a Fernico or equivalent. The remaining metallic members **26**, **29**, **30** and **31** are conveniently selected as a refractory metal, as for example, tungsten or molybdenum. Appropriate vacuum-tight seals are made to the mating surfaces members of all of the ceramic and metal parts by conventional, well-known techniques. When assembled, the trigger electrode assembly is lowered into the open end of electrode support member **15** and rests upon a counterbore shoulder therein where flange member **24** is sealed in a vacuum-tight seal thereto. Prior to final assembly the portions of metallic sleeve members **29** and **30** which are to be exposed between the upper portion of cylindrical shield member **26** and cylindrical end cap and shield member **31** are coated with a material, as for example a hydride of titanium, zirconium, hafnium, yttrium, erbium or other rare earth metals which hydrides serve as a source of ionizable gas which may be emitted upon the initiation of a voltage pulse between sleeve members **29** and **30**.

The device of the present invention may be fabricated in accord with standard ceramic and metal tube technology in which case the device is assembled and the various members thereof are sealed into assemblies and sub-assemblies and the device is finally sealed leaving only plug **35** unsealed. The device is then placed in an outgassing furnace and raised to a temperature of, for example, 800° C., and held at this temperature for one or two hours in order to cause outgassing and the removal of sorbed gases from all of the constituent parts thereof. After sufficient outgassing, and while the device is still at an elevated temperature an atmosphere of, for example, hydrogen is introduced through plug **35** and the device is sealed. Since, in the case of a titanium hydride coating upon metal sleeves **29** and **30**, a large fraction of the hydrogen has been evolved therefrom, hydrogen is taken up from the furnace atmosphere to recharge the trigger electrode and to cause the establishment of a vacuum within the sealed envelope. In order to enhance this operation a reservoir for an active gas, as for example hydrogen, may be provided in the form of reservoir **36** which comprises two larger metallic, preferably stainless steel annular washers **37** and **38** with an interposed smaller outside diameter washer **39** of the same material. The assembly of these three washers creates an annular cavity **40** which is filled with granular active gas absorbing material, as for example titanium **41**, the opening thereto being covered with a wire mesh **42** which may conveniently be 200 mesh stainless steel screen. Since, in the case of titanium hydride used as a gas reservoir, the titanium hydride of the reservoir is substantially exhausted of hydrogen by the outgassing process, after the device has been sealed by plug **35** and the device cools to room temperature substantially all of the remaining

hydrogen gas within the device is taken up by the titanium to form titanium hydride. Since the maximum concentration of hydrogen in the titanium hydride at room temperature is substantially represented by the formula $TiH_{1.73}$ a sufficient quantity of titanium is provided within reservoir **41** to ensure that not all of the hydrogen which could be absorbed thereby is present within the envelope prior to sealing. Thus, a hard vacuum of at least 10^{-5} millimeters of mercury is provided by the absorption of hydrogen by the trigger electrode and by the reservoir.

An alternative method for fabricating devices in accord with the present invention is substantially disclosed and claimed in my copending application Ser. No. 417,562 filed Dec. 11, 1964, now U.S. Patent No. 3,331,961 assigned to the assignee of the present invention. In accord with the method disclosed and claimed in my copending application, the materials are assembled unsealed and the charged material utilized for the trigger electrode and the reservoir are initially supplied within the device. The device is then placed in an atmosphere of the active gas contained within the reservoir, as for example, hydrogen in the case of titanium hydride, and the temperature is elevated to a temperature to sufficiently outgas the component parts of the device and to simultaneously cause pure hydrogen to be evolved from the trigger electrode and from the reservoir to further purge the device of all impurities other than pure active gas. The temperature of the device is then further raised to cause sealing of the ceramic and metal parts together after which the sealed device is allowed to cool to room temperature to provide the requisite vacuum of less than 10^{-5} millimeters of mercury.

The operation of a triggered vacuum gap in accord with the present invention and as illustrated on FIGURE 1 of the drawing is quite similar to that of the triggered gaps of the prior art as is disclosed with great particularity in my Patent No. 3,087,092, issued Apr. 23, 1963. Briefly stated, this action is substantially as follows. Electrodes **15** and **16** are connected to a source of high voltage, as for example, a primary power transmission line to be protected from overvoltages. A high electric field is therefore established within gap **4** between electrodes **2** and **3**. When, because of a high voltage transient which could damage the equipment to be protected, a preselected pulse of voltage is supplied between trigger lead **34** and electrode **2**. Since electrode **2** is connected to the lower sleeve **29** abutting the triggered gap and the trigger lead is connected to the upper sleeve **30** abutting the trigger gap, a transient high voltage is applied across the trigger gap. Due to the low breakdown potential required at the interface between metal and ceramic, a spark discharge is initiated between sleeves **29** and **30**. The heat of this discharge immediately causes the evolution of an active gas, as for example hydrogen from an active gas storing substance, as for example titanium hydride, which comprises the coating upon these two sleeves. As the hydrogen is evolved the hydrogen molecules are ionized, thus causing the arc discharge across the triggered gap to be intensified, causing the release and ionization of a large quantity of hydrogen gas. A pulse of a hydrogen ion-electron plasma is thus injected into the gap between the main electrodes **2** and **3** and the main arc is broken down within a matter of microseconds or less.

Since the initial breakdown between primary electrodes **2** and **3** occurs in the immediate vicinity of the trigger electrode where the path length between the two electrodes is long and since the vacuum arc is essentially vapor starved, the natural tendency of the arc is to conserve vapor causing a propultion of the arc out into the smaller gap-length region between the two electrodes. This operation so far is conventional.

In my experimental work I have determined that the prime cause of the failure of vacuum gap devices, as for example the triggered vacuum gap illustrated in FIGURE 1 of the drawing is the destructive melting of the anode electrode by virtue of the formation of anode spots. As used herein an anode spot is intended to indicate the footpoint of the arc between the primary electrodes where it is anchored to or terminates at the anode electrode.

Under normal operation of a vacuum arc discharge the anode electrode is surrounded by a space charge of negative charge carriers, namely electrons. Electrons which are attracted to the positive or anode electrode must fall through the potential represented by the space charge surrounding the anode. At the anode, all of the discharge current is carried by electrons impinging thereupon. This electron bombardment of the anode is primarily responsible for anode heating. Anode heating is produced both by the kinetic energy of the incident electrons corresponding to the anode voltage drop and by the heat of condensation of the electrons. As the arc current between the primary electrodes is increased the density of the space charge sheath surrounding the anode increases, thus increasing the anode potential drop. This increases the energy of electrons impinging upon the anode, causing its temperature to further increase.

As the current density is increased further, a point is eventually reached at which a given local area of the anode, randomly selected because of anode geometry and other considerations or by instabilities in the arc is sufficiently heated as to cause the release of metal vapor. This metal vapor is immediately ionized by the high velocity electrons striking the anode. This is because, in all but the very shortest of vacuum arcs the anode potential drop exceeds by several times the ionization potential of the metal vapor. The ions created by such ionization tend to neutralize the space charge in the localized area of the anode emitting metal vapor. This neutralization of the space charge causes the anode voltage drop at the localized area to decrease causing more electron current to flow to the anode in this area. A cyclic reaction thus takes place with a continued build-up of localized anode current, resulting in a hot spot at the localized portion and a constriction of the arc at the anode. This is known as an anode spot. The intense local heating produced by the anode spot causes destructive localizing melting of the anode. If the vacuum discharge device is operating on unidirectional current, the damage can be great upon the formation of the spot. Even if the device is operating on alternating current and only one-half cycle of time elapses between striking and re-striking of the arc, the anode spot formed within this time can cause destructive erosion of the anode electrode.

The utilization of the electrode structure of the present invention greatly diminishes or eliminates such anode spot formation. Thus, in accord with the present invention the anode is caused to emit vapor over an extended area in a controlled fashion. This is achieved by providing a large area of the anode electrode (or of both electrodes if there is some uncertainty as to the electrode which will be the anode upon striking of an arc) which so emits to prevent localized spot formation. In the illustrated embodiment of the invention shown in FIGURE 1 of the drawing, the entire peripheral region **21** of the electrode is caused to so emit. As is described hereinbefore, conservation of vapor principles tend to propagate the arc to the exterior portions of the electrodes. When the arc located between the peripheral regions of the main gap electrodes, peripheral region **21** is raised in temperature to a higher degree than the remainder of the electrode. This is due to two effects. Firstly, heating is increased because the surface-to-volume ratio of peripheral portion **21** is larger than the remaining portion of the electrodes since the impinging electrons may strike the grooved vertical surface, the top surface, and the vertical outside surface of the peripheral region of the electrode. Additionally, since the peripheral region of the anode electrode is connected to the main body of the electrode only by a restricted cross-sectional area under the peripheral slot, the conduction of

heat away from the peripheral portion of the electrode is less than would be in the absence of slot 19. Accordingly, peripheral region 21 becomes uniformly heated to a temperature to cause metallic vapors to be emitted at the edges of the outer ring uniformly around the electrode, thus preventing the formation of a single anode spot with destructive melting and destruction of the anode electrode. Further accentuation of this effect may be achieved by the location of a radial magnetic field normal to the longitudinal axis of the device of FIGURE 1 which tends to rotate the arc current conducting path circularly around the electrode, thus further reducing the probability of the formation of anode spots.

Although one embodiment, namely a peripheral groove, has been illustrated and discussed in detail it will be appreciated that other equivalent means to achieve the results contemplated by the present invention may be utilized. The necessary criterion to be met is that the outer periphery of the electrode be heated to a higher temperature than the remaining portion of the electrode. This is achieved by causing increased surface-to-volume ratio for that portion and by causing a restricted thermal conduction path between that portion of the electrode and the main portion of the electrode. As mentioned hereinbefore this may be achieved by other expedients than the cutting of a peripheral slot as is illustrated in FIGURE 1.

Although the vacuum gap device of the present invention has been illustrated and described with reference to the specific embodiment of a fixed gap triggerable device, the advantages of the present invention may be equally achieved by the incorporation of the disclosed electrode structure in a fixed gap device which is not triggerable or in a vacuum switch of the circuit interrupter or recloser type in which one electrode is fixed and the other is movable from a circuit closing position to a circuit breaking position and in such devices whether the discharge is triggerable or whether the interrupter is of the conventional vacuum type.

While the invention has been described in detail herein in accord with certain preferred embodiments thereof, many modifications and changes therein may be effected by those skilled in the art. Accordingly, it is the intention in the appended claims to cover all such modifications and changes as fall within the true spirit and scope of the invention.

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

1. A vacuum gap device comprising: an envelope evacuated to a vacuum of at least 10^{-5} mm. of mercury and having at least a portion thereof composed of a high voltage insulator; a pair of primary electrodes constituting an anode electrode and a cathode electrode disposed within said envelope and adapted to define therebetween a breakdown gap, at least said anode electrode having arc dispersion means at the periphery thereof sufficient to inhibit the formation of destructive anode spots, said peripheral region of said anode electrode being a portion of the arcing surface thereof, being substantially uniformly in poor thermal contact with the remainder of said electrode and having a high substantially uniform surface-to-volume ratio, such that said peripheral region under arcing conditions becomes uniformly heated to a temperature at which arc sustaining vapor is uniformly emitted; and means for connecting said electrodes in circuit with an electrical load.

2. The vacuum gap device of claim 1 wherein both electrodes are fixed to define a fixed dimension gap.

3. The vacuum gap device of claim 1 wherein at least one electrode is movable between circuit making position in contact with said other electrode and a circuit breaking position out of contact with said other electrode and defining a gap therewith.

4. A vacuum gap device comprising: an envelope evacuated to a vacuum of at least 10^{-5} millimeters of mercury and having at least a portion thereof composed of a high voltage insulator; a plurality of primary electrodes constituting an anode electrode and a cathode electrode disposed within said envelope and adapted to define therewith a breakdown gap, at least said anode electrode having arc-dispersion means at the periphery thereof sufficient to prohibit the formation of destructive anode spots, said peripheral region of said electrode being a portion of the arcing surface thereof, being in poor thermal contact with the remainder of said electrode and having a high surface-to-volume ratio, such that said peripheral region under arcing conditions becomes uniformly heated to a temperature at which arc-sustaining vapor is uniformly emitted therefrom; trigger means associated with one of said electrodes and comprising a trigger electrode having therein a secondary gap and having located immediately adjacent said gap a quantity of a material having chemically bound therein a quantity of an active ionizable gas which is thermally evolved therefrom upon the initiation of a spark breakdown across said trigger gap; means for connecting a primary voltage between said primary electrodes and means for delivering a pulsed voltage to said trigger electrode independent of the primary voltage to cause breakdown of the primary gap.

5. The vacuum device of claim 4 wherein both primary electrodes are fixed to define a fixed gap.

6. The vacuum device of claim 4 wherein one primary electrode is fixed and the other primary electrode is movable between a closed, contact-making position and an open contact breaking position.

7. The vacuum device of claim 4 wherein both primary electrodes are substantially circular discs with substantially flat arcing surfaces and the arc-dispersion means comprises a peripheral annular slot in the arcing surface of at least said anode electrode.

8. A vacuum gap device comprising: an envelope evacuated to a vacuum of at least 10^{-5} millimeters of mercury and having at least a portion thereof composed of a high voltage insulator; a pair of primary electrodes constituting an anode electrode and a cathode electrode disposed within said envelope and adapted to define therewith a breakdown gap, at least said anode electrode having an annular slot in the arcing surface thereof near the periphery thereof so as to define a peripheral surface arcing region of very small radial dimension as compared with the radial dimension of the entire electrode and having a high surface-to-volume ratio, said peripheral region under arcing conditions becoming uniformly heated to a temperature at which arc-sustaining vapor is uniformly emitted therefrom; means associated with one of said electrodes to inject a gaseous plasma into said primary gap upon receipt of a pulsed signal and comprising a trigger electrode having thereon a trigger gap, and a quantity of a hydride of an active metal immediately adjacent to such trigger gap so that hydrogen gas is thermally released therefrom upon the initiation of a spark breakdown across said trigger gap; and means for connecting said primary electrodes in circuit with an electrical load; and means for supplying a source of pulsed voltage to said trigger electrode to cause the breakdown of the primary gap.

9. The vacuum device of claim 8 wherein both primary electrodes are fixed to define a fixed gap.

10. The vacuum device of claim 8 wherein one primary electrode is fixed and the other primary electrode is movable between a closed, contact-making position and an open contact breaking position.

11. The vacuum arc device of claim 8 wherein the hydride utilized to store hydrogen is titanium hydride.

12. The vacuum arc device of claim 8 wherein the hydride utilized to store hydrogen is yttrium hydride.

13. A vacuum gap device comprising: an envelope evacuated to a vacuum of at least 10^{-5} mm. of mercury and having at least a portion thereof composed of a high voltage insulator; a pair of primary electrodes constituting an anode electrode and a cathode electrode having substantially planar arcing surfaces disposed in closed juxta-

position within said envelope to define therebetween a breakdown gap, at least said anode electrode having an annular slot in the arcing surface thereof at the periphery thereof, said slot isolating a peripheral surface arcing region of very small radial dimension as compared with the radial dimension of the entire electrode and having a high substantially uniform surface to volume surface ratio, said peripheral region under arcing conditions becoming uniformly heated to a temperature at which arc-sustaining vapor is uniformly emitted therefrom to prevent the formation of anode spots, and means for connecting said electrodes in circuit with an electrical load.

References Cited

UNITED STATES PATENTS

3,163,734 12/1964 Lee.

FOREIGN PATENTS

1,306,918 9/1962 France.

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