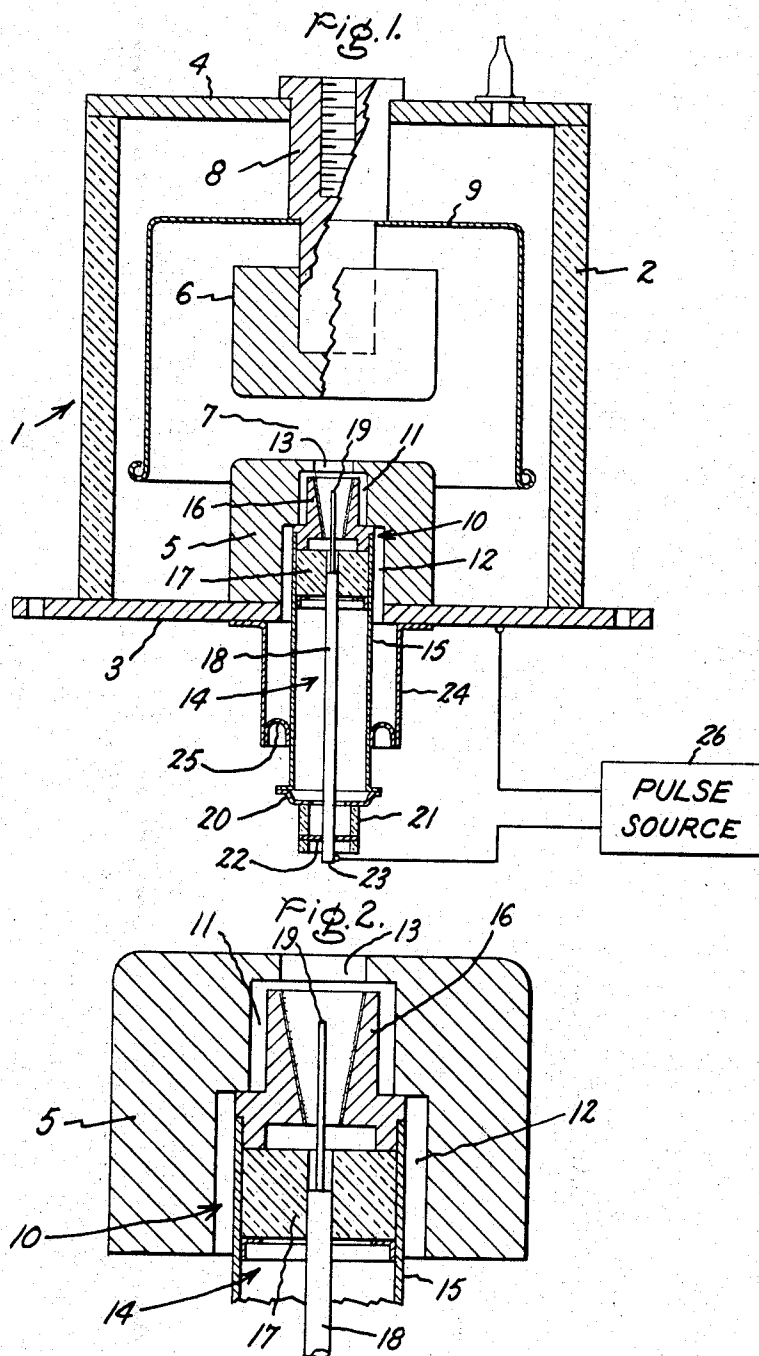


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TRIGGERED VACUUM GAP DEVICE HAVING
FIELD EMITTING TRIGGER ASSEMBLY
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TRIGGERED VACUUM GAP DEVICE HAVING FIELD EMITTING TRIGGER ASSEMBLY

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This application is a continuation-in-part of may co-
pending application, Ser. No. 297,925, filed July 26, 1963,
now Patent No. 3,290,542, and assigned to the present
assignee.

The present invention relates to improved vacuum gap
devices and particularly to such devices which exhibit a
unique characteristic of non-degradation of the trigger
gap thereof over long periods of use.

Vacuum switches and vacuum gaps with variable and
fixed gaps respectively and in various embodiments and
modifications have recently become of great commercial
significance. In accord with my issued U.S. Patent No.
3,087,092, entitled "Gas Generating Switching Tube",
issued April 23, 1963, one very substantial detriment to
the wide applicability of vacuum gap devices, namely the un-
predictability and unreliability of breakdown voltages and
the time of breakdown (or jitter) has been overcome.
This has been accomplished by the provision of a separate
trigger electrode assembly which injects a pulse of ion-
electron plasma into the primary gap to cause the break-
down thereof upon the provision of a triggering pulse to
a secondary or trigger gap.

While devices constructed in accord with my afore-
mentioned patent have overcome the greatest impediment
to wide usage of vacuum gaps, many of these devices
utilize a trigger gap which is, in essence, a pair of metal
ceramic interfaces separated by a ceramic gap as the trigger
gap thereof. Such a trigger gap is highly advantageous
in that the field configuration in the vicinity of a metal-
ceramic interface is highly favorable for low voltage
breakdown and such a gap may predictably and repetitively
be broken down with the application of a low voltage
thereto. Such a gap, however, is susceptible to deteriora-
tion with usage, in that metallic particles from the main
arc between the primary electrodes may become deposited
thereupon and lower the dielectric strength of the trigger
gap.

Accordingly it is an object of the present invention to
provide improved triggerable vacuum gap devices suitable
for continuous and long-life operation without any ap-
preciable deterioration of the trigger gaps thereof.

Another object of the present invention is to provide
triggerable vacuum gap devices having reliable and repeat-
able breakdown characteristics in response to a voltage
signal, which gaps do not include a trigger gap subject
to deterioration by the deposition of metallic particles
thereon.

Yet another object of the present invention is to pro-
vide triggerable vacuum gap devices having trigger gaps
which rely upon field emission for the provision of a
triggering pulse to breakdown the primary gap.

In accord with the present invention a triggerable vacu-
um gap device includes an evacuable envelope containing
therein a pair of arc-electrodes defining a vacuum gap.
At least one of the arc-electrodes contains a central
cavity connected with the arcing face thereof with an
aperture. Immediately within the aperture I provide a
trigger electrode assembly including a central trigger elec-
trode of small diameter and substantial length surrounded
coaxially with a tapering concentric electrode member
which terminates in a field concentrating ring surrounding
the trigger electrode at a distance far removed from the
aperture into the main gap. The application of a trigger-

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ing pulse between the central electrode and the surround-
ing trigger electrode causes field breakdown between the
aforementioned ring and the adjacent portion of the cen-
tral trigger electrode. Vacuum breakdown occurs, a
plasma is formed and a burst of plasma is injected through
the aperture into the main gap to cause the breakdown
thereof. This breakdown is repetitive and the gap may be
broken down under substantially identical conditions an
indefinite number of times. Additionally, since there is no
contaminable ceramic surface immediately adjacent the
trigger gap, deterioration thereof due to deposition of
metallic particles thereon is avoided, thus increasing the
useful life of the trigger gap and of the device under all
circumstances of use.

The novel features characteristic of the present inven-
tion are set forth in the appended claims. The invention
itself, however, together with further objects and advan-
tages thereof may be more readily understood by refer-
ence to the appended drawing in which:

FIGURE 1 is a vertical cross-sectional view of a
triggerable vacuum 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.

In FIGURE 1 of the drawing a vacuum gap device
having a pair of fixed electrodes constructed in accord
with the invention includes an evacuable envelope 1 in-
cluding an insulating cylindrical sidewall 2 and a pair of
apertured metal end closures 3 and 4. A pair of primary
arc-electrodes 5 and 6 are disposed within envelope 1 and
define therebetween a gap 7. Anode arc-electrode 6 is sus-
pended within envelope 1 by anode support member 8
which is suitably fastened in an hermetic seal to metallic
end wall plate 4. A suitable metallic shield member 9 is
also connected to anode support member 8 and suspended
therefrom so as to laterally encompass the primary gap 7.
Cathode arc-electrode 5 is in the form of a hollow cylind-
rical member having a cavity 10 along the axis thereof
which cavity is composed of a first, smaller-diameter, deep
counterbore 11 and a second, larger-diameter, shallow
counterbore 12. Cavity 10 is connected to the gap 7 be-
tween arc-electrodes 5 and 6 by means of a central aper-
ture 13 in the arcing face of arc-electrode 5. A trigger
electrode assembly 14 is disposed centrally within cavity
10 and is oriented so as to project an ionized electron-ion
plasma through aperture 13 into gap 7 to cause the device
to become conducting thereacross.

Trigger electrode assembly 14 comprises a suitable
metallic cylindrical member 15 which encloses at one
end thereof a generally cylindrical outer trigger electrode
member 16 having inverted frusto-conical bore therein
which is widest at the inwardly depending end and nar-
rowest at the outwardly depending end thereof. Also in-
cluded within cylindrical member 15 is an insulating
ceramic disc 17 located substantially outwardly from the
most constricted region of the frusto-conical interior sur-
face of trigger electrode member 16 and abutting against
an outwardly depending annular flanged portion thereof.
A metallic trigger electrode support member 18 extends
through a central aperture in disc 17 and supports an
inner, axially located trigger electrode member 19 which
passes concentrically into the frusto-conical cavity formed
within the outer trigger electrode member 16 and is ter-
minated slightly short of the most inwardly depending
surface thereof. The exterior outwardly depending end of
trigger electrode support member 18 extends through a
first, cupped and apertured seal member 20 which is
bonded in an hermetic seal to a hollow cylindrical ceramic
insulating member 21 and hermetically sealed through a
trigger electrode end plate 22 which is also hermetically
sealed to ceramic cylinder member 21. A protruding trig-
ger electrode lead 23 extends outwardly from the seal

assembly. Cylindrical trigger assembly support cylinder 15 is rigidly supported and hermetically sealed within the aperture in end wall plate 3 of envelope 1 by a pair of suitable sealing flanges which are annular in shape and are illustrated at 24 and 25.

Cylindrical sidewall member 2, apertured ceramic disc 17, and cylindrical seal disc 21 may all be fabricated from a suitable high temperature, gas-impervious ceramic material which is conventionally used in the fabrication of devices of this general class. Thus for example these materials may be fabricated from Coors-V-200 or American Lava-T-164 ceramics. Alternatively a suitable forsterite ceramic may be utilized. End wall members 3 and 4 may conveniently be fabricated from stainless steel, nickel, or titanium parts which are adaptable for sealing by hermetic seals to the chosen ceramic bodies. Primary electrodes 5 and 6 are fabricated from high purity, gas and gas-forming impurity-free copper, or other suitable high vapor pressure material suitable for vacuum switch and vacuum gap applications, and should be sufficiently pure as not to contain any more than 10^{-7} atomic parts of gas or gas-forming impurities. Similarly, this material must be sufficiently pure as to gas and gas-forming impurities so that under repeated arcing conditions quiescent pressure within the device after sealing does not rise above a value of 10^{-5} mm. of Hg. Such material may readily be formed by a suitable zone-refining process such as is described and claimed in the copending application, Ser. No. 146,245, filed Oct. 19, 1961 of M. H. Hebb and assigned to the assignee to the assignee of the present invention.

First trigger electrode 16 may conveniently be fabricated from molybdenum with the inner surface of the frusto-conical counterbore therein coated with a thickness of a few mils of titanium or titanium hydride, or any active gas storing substance which may take on an active gas, for example hydrogen, and maintain it under non-operating conditions so as to allow a hard vacuum of 10^{-5} mm. of Hg pressure or less to be established and maintained, but, when subjected to the high temperature of the footpoint of an electric arc, to evolve the active gas, as for example hydrogen. Once this gas is evolved, it is ionized to form a pulse of electron-ion plasma which is injected into the primary gap to cause the breakdown thereof. Centrally located trigger electrode 19 may conveniently comprise a tungsten or molybdenum or a tungsten-rhenium thoria alloy (73% tungsten, 25% rhenium, 2% thoria). Rhenium adds ductility to the tungsten and thoria lowers the work function to aid full emission. The electrode conveniently may be fabricated of approximately 10 mils diameter wire and may be supported upon a substantially thicker molybdenum support member 18. Seal flanges 20, 24, and 25 and end cap 22 may all conveniently be fabricated from Ceramaseal, Fernico, Kovar or other suitable materials well adapted for forming ceramic-to-metal seals.

Assuming that the device of FIGURE 1, which has only one trigger electrode assembly, is to be connected in a protective circuit across a uni-directional high voltage line, it is predictable that the arc-cathode will be arc-electrode 5 and only one trigger electrode need be provided and that is, therefore, located within cathode arc-electrode 5. If the device were to be utilized with an alternating current system, then a similar electrode assembly 11 would be also disposed concentrically within arc-electrode 6. For D.C. operation, the vacuum arc device is connected between the line voltage with the anode electrode 6 connected to the positive polarity through support member 8 and the cathode electrode 5 connected to the negative potential through end plate 3. A voltage pulse is supplied to trigger electrodes 16 and 19 from pulse source 26 through lead 23 and end plate 3.

The operation of the trigger gap is substantially as follows: With the high voltage connected between the arc-electrodes 5 and 6, a high intensity electric field exists within gap 7. Because of the high dielectric strength of the vacuum this high intensity electric field is insufficient to cause breakdown of the gap and the device remains non-

conductive. When a fault in a transmission line occurs or when it is desired to discharge a capacitor bank or for any other reason the device is to be activated, a pulse is applied to inner trigger electrode 19 which is negative with respect to outer trigger electrode 16. When this occurs, an initial breakdown occurs across the interior, smaller-diameter end of the truncated conical bore within electrode member 16 and the thoriated tungsten or tungsten alloy wire. The small diameter of the wire and the close spacing between the wire and the surrounding circular discontinuity in the first electrode member produces an electric field at the surface of the wire equal in magnitude to nearly 50 times the applied voltage pulse. Under these circumstances breakdown of a main gap voltage of approximately 30,000 volts applied to a $\frac{1}{8}$ inch gap between $\frac{3}{4}$ inch diameter electrodes may readily be achieved with a pulse voltage of the order of 7 kilovolts. The initiation of the first breakdown is facilitated by the use of a thoriated tungsten wire as the cathode of the trigger gap since this lowers the work function of the cathode and increases the field emission therefrom. A glow discharge is rapidly established between the trigger cathode 19 and the trigger anode 16. Since the trigger anode is coated with a material which stores an active gas such as hydrogen, which material may conveniently be titanium hydride, the heat of the footpoint of the initial arc immediately causes the liberation of hydrogen molecules which are rapidly ionized, to further increase the arc current and the temperature of the arc footpoint, the cumulative effect being the creation of a large cloud of hydrogen ion-electron plasma which is propagated by magnetic forces out of the trigger electrode, through aperture 13 in arc-electrode 5 and into the main or primary gap causing the immediate breakdown thereof and the establishment therein of a high current, high voltage electric arc.

A disadvantage with prior art devices has been associated with the use of a grooved surface coating of titanium or equivalent upon a ceramic insulating disc or cylinder. There is always some leakage resistance between the opposite electrodes of such a gap, which resistance may vary from 100 to 10,000 ohms. In general this resistance is caused by minute deposits of metallic particles which are propagated to the insulator of the gap from the main gap during arcing. Although this leakage does not affect the operation or performance of the trigger and does not lower the breakdown resistance of the main gap, it proves in some cases to be a limiting factor upon the type trigger circuits which may be utilized in conjunction with such devices, since the charge on a capacitor may not be retained when connected directly across such a high resistance leakage path. In accord with the present invention, however, I avoid this difficulty by providing a breakdown gap in the trigger electrode assembly which is over a space unoccupied by any physical substance and which is actually a vacuum gap also. Any metallic materials which are propagated down into this gap do not deposit upon an intervening ceramic or other insulating material but rather are usually deposited upon one or the other of the trigger electrodes, those few which do pass through the gap generally being deposited upon the inwardly depending end of trigger support member 18 or the immediately surrounding portions of insulating disc 17, which in no way affects the resistance between the trigger electrodes.

While the invention has been disclosed hereinbefore with respect to a single trigger electrode it has been mentioned that for alternating current operation a pair of trigger electrodes may be associated respectively one with each of the primary arc-electrodes. Under such circumstances a separate pulse source may be associated with each trigger electrode or a grounded source may be connected to both trigger electrodes and, with the line conductors which are connected to respective primary gaps having a particular relationship to ground potential an electric arc will occur within the trigger electrode which is associated with the most positive of the line conductors.

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Similarly this invention may be practiced with devices having movable primary arc-electrodes as well as fixed.

Furthermore, while the invention has been described hereinbefore with respect to certain embodiments and features thereof, many other modifications and changes will no doubt occur to those skilled in the art. Accordingly, it is intended by 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 field emission triggered vacuum gap device comprising:

an evacuable envelope at least one portion thereof is an insulating dielectric to provide at least two electrically insulated portions thereof;

a pair of primary arc-electrodes disposed within said envelope so as to define therebetween a primary gap,

at least one of said arc-electrodes having a longitudinal cavity therein and an aperture connecting said cavity with said primary gap;

a field emission trigger electrode assembly positioned within said cavity and positioned with respect to said aperture as to inject a highly ionized plasma into said main gap when a signal pulse is received,

said assembly including an elongated filamentary central field emitting trigger cathode and a concentric trigger anode having a hollow truncated conical bore therein terminating in a pointed annular discontinuity closely surrounding the trigger cathode at a point remote from the primary gap end of said trigger cathode and in concert therewith constituting a trigger gap,

the surface of said trigger anode being coated with an active gas storing substance which

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is capable of maintaining a vacuum of 10^{-5} mm. Hg or less at non-operating temperature conditions;

means for connecting a primary voltage between said arc-electrodes; and

means for supplying a voltage pulse between said trigger electrodes to cause breakdown across the vacuum gap therebetween, the generation of an electron-ion plasma and injection of said plasma into said primary gap to cause the breakdown thereof,

2. The device of claim 1 wherein each of said primary arc-electrodes has a cavity therein and a trigger electrode assembly located therein.

3. The device of claim 1 wherein both of arc-electrodes are fixed so as to define a fixed primary gap.

4. The device of claim 1 wherein at least one of said arc-electrodes is movable so as to define a variable primary gap.

5. The device of claim 1 wherein the arcing surface of said trigger anode is comprised of titanium as an active gas storing substance which emits active gas upon arcing of the trigger gap and is effective to reabsorb said active gas under non-arcing conditions and withstand a quiescent pressure of 10^{-5} mm. of mercury.

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