

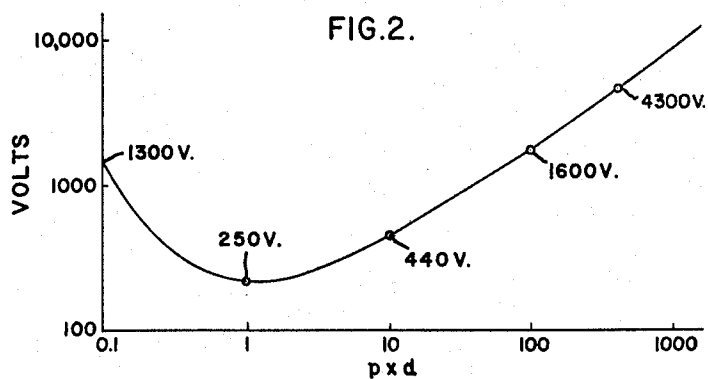
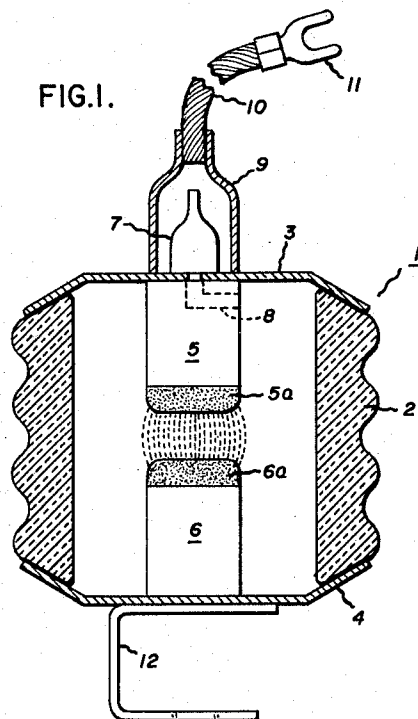
Jan. 21, 1964

P. C. GARDINER ET AL
GAS DISCHARGE GAP TUBE

3,119,040

Filed March 21, 1960

2 Sheets-Sheet 1



WHERE p IS IN mm OF Hg REPRESENTING PRESSURE
WHERE d IS IN cm REPRESENTING GAP DISTANCE

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2 Sheets-Sheet 2

FIG. 3.

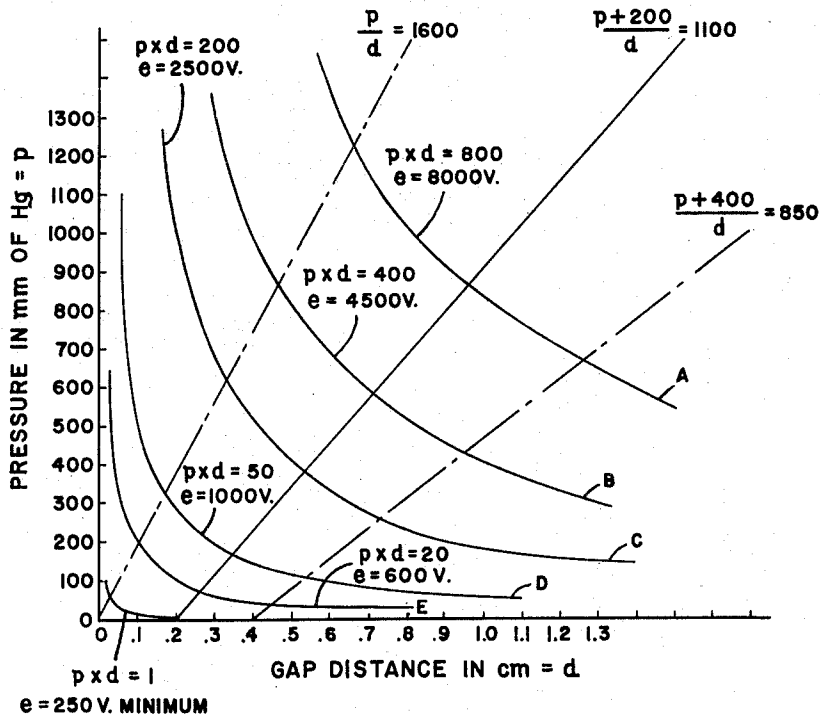


FIG. 4.

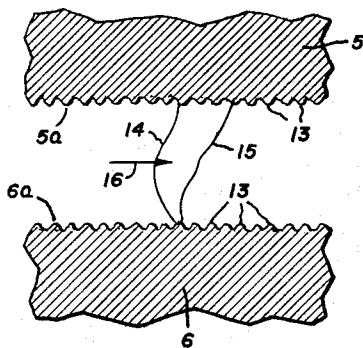
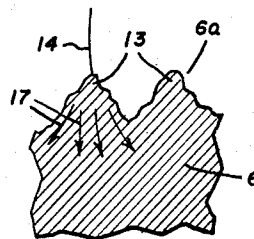


FIG. 5.



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1

3,119,040

GAS DISCHARGE GAP TUBE

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6 Claims. (Cl. 313-214)

This invention relates generally to electric discharge devices and pertains more particularly to a new and improved gap tube and a new and improved electrode structure for a gap tube.

Gap tubes have heretofore, been employed, for example, as protective devices for capacitors in power circuitry. When so employed, a gap tube is connected in parallel with the capacitor and protects it by breaking down or discharging when the capacitor voltage rises under fault conditions above a predetermined value. After the capacitor voltage returns to normal, the discharge in the gap tube is extinguished and the device stands ready to protect the capacitor against any subsequent fault overvoltage.

Long life, high reliability, and substantial uniformity in the breakdown voltage throughout an extended operational life are particularly desirable in gap tubes, especially where failure of such a device to protect adequately can result in considerable and costly damage, and where replacement of the device is both difficult and expensive. Additionally, it is desirable to obtain gap tubes for increased power handling capacity without foregoing any of the above-discussed desiderata and without resort to increased tube size.

In prior art devices, highly polished opposed metal electrode surfaces are utilized in efforts to obtain some of the above-noted desiderata. However, it has been found that, in devices including such polished surfaces, the arc tends to stick or hesitate at particular points on the electrode surfaces and for such durations as to cause substantial heating and pitting of the metal surface. The pitting is caused by vaporization of the metal. There is a natural tendency for the evaporated metal to condense on the relatively cooler side walls of the insulator separating the electrodes. Deposition of metal on the side walls adversely affects the surface conductivity of the insulator. Additionally, the presence of metal on the side walls enables spurious breakdowns or undesirable jumping of the arc to the side walls. Further, the pitting of the electrode surfaces has the undesirable effect of releasing occluded gases from the electrode material during operation of the device. All of these adverse effects usually result after only a few breakdown discharges and cause radical departure from the breakdown conditions in the device as originally designed. Additionally, the deposition of conductive material on the side walls and adverse effects thereof have been observed in prior art devices to become progressively worse with life and consequently such devices were not found reliable and adapted for substantial uniformity in breakdown voltage throughout a long operating life.

Further, in prior art devices of the above-described type substantial diffusion or radial extension of the discharge column between the opposed electrode surfaces has required that the devices be of such dimensions as to dispose the internal envelope walls sufficiently remote from the discharge column to minimize spurious discharges to the walls. Where condensed material tends to deposit on the envelope walls due to the evaporation of electrode material, even greater dimensioning has been required to dispose the walls sufficiently remote to minimize spurious discharges. Thus, for a given value of breakdown voltage the dimensions of the device have had to be increased to compensate for the undesirable effects of dep-

2

osition of conductive material from the pitted electrode surfaces, and for the substantial diffusion of the discharge column. Expressed in another manner, for given dimensions of a device envelope, power handling capacity has been reduced in prior devices due to, the deposition of conductive material from the pitted electrode surfaces on the wall portions of the device, and the substantial diffusion of the discharge column ordinarily encountered in prior art devices.

The present invention contemplates the provision of an improved gap tube adapted for affording all of the above-discussed desiderata and for overcoming the difficulties encountered with prior art devices by including a simplified ceramic and metal envelope construction, and an improved electrode construction. Additionally, the present invention contemplates the provision of a gap tube wherein the pressure of a filler gas, spacing of the opposed electrodes and dimensioning and positioning of the electrodes and envelope walls are all in predetermined selected relationships for affording orders of magnitude of increased power handling capacity and extended tube life.

Accordingly, the primary object of the present invention is to provide a new and improved gap tube adapted for increased operating life, greater reliability and greater uniformity of breakdown voltage throughout an extended operating life of the tube.

Another object of the invention is to provide a new and improved electrode construction for a gap tube adapted for minimizing pitting of the electrodes and deposition of evaporated electrode material on the internal walls of the device, thereby to minimize the adverse effects thereof on both the breakdown conditions of the tube during operation and the reliable life expectancy of the tube.

Another object of the invention is to provide a new and improved gap tube electrode adapted for causing the arc to move rapidly over substantially the whole active surfaces of the electrode, thereby to avoid pitting of the surfaces and provide for cooler operation of discrete areas thereof.

Another object of the invention is to provide a new and improved gap tube including improved means adapted for controlling the diffusion of the discharge column in a manner which enables increases in power handling capacities in order of magnitude and while enabling reduction in tube sizes for given values of gap breakdown voltages.

Another object of the invention is to provide a new and improved gap tube which is relatively simple and inexpensive from both the structural and manufacturing standpoints.

Further objects and advantages of the invention will become apparent as the following description proceeds and the features of novelty which characterize the invention will be pointed out with particularity in the claims annexed to and forming part of this specification.

In carrying out the objects of the invention there is provided a hollow ceramic cylinder having metal end caps hermetically bonded to the opposed ends thereof to provide an envelope assembly. Supported from the end caps and extending in coaxially spaced relation in the envelope are a pair of relatively massive solid cylindrical metal electrode members. The electrode members include opposed parallel, generally planar, transverse, active end surfaces defining a gap therebetween. The active surfaces comprise a myriad of substantially uniform and closely spaced protrusions which are substantially small relative to the electrode members and the gap between these members, but which are each substantially massive relative to the spaces between the protrusions. Additionally, the protrusions are integral portions of the electrode members proper. The active surfaces extend at least

partially over the side portions of the electrode members and are advantageously formed by fluid blasting with powdered alumina or a like abrasive material of predetermined mesh size. Further, the envelope contains a predetermined ionizable medium and the pressure of the medium and the distance of the gap are each preselected in providing a pressure-distance product appropriate for a device of a predetermined voltage breakdown characteristic.

For a better understanding of the invention reference may be had to the accompanying drawing in which:

FIGURE 1 is a sectional elevational view of a gap tube constructed in accordance with the present invention;

FIGURE 2 is a chart showing the breakdown voltages obtainable with opposed planar electrodes in argon;

FIGURE 3 is a chart illustrating the pressure and gap distance values at which prolonged tube life is obtainable according to the present invention;

FIGURE 4 is an enlarged fragmentary sectional view illustrating the manner in which the improved electrodes of the invention are effective for minimizing evaporation of the electrode material; and

FIGURE 5 is a fragmentary sectional view greatly enlarged and illustrating the manner in which the individual protrusions on the active electrode surfaces are effective for assisting in minimizing undesired metal evaporation and for affording greater power handling capacity for the device.

Referring to the drawing, there is illustrated in FIGURE 1 a gap tube constructed in accordance with the present invention and generally designated 1. The tube 1 comprises a hermetically sealed envelope including a cylindrical ceramic insulator or wall member 2 which can be advantageously formed of alumina. The inner wall of the insulator 2 defines a straight cylinder while the outer wall is annularly corrugated to increase the electrical creepage distance thereacross.

Sealed to the upper and lower ends of the insulator 2, by means of any suitable hard solder method, are upper and lower metal end caps 3 and 4, respectively. The end caps are shaped to define shallow cup-like members and can be advantageously formed of copper-clad chrome iron; and, as seen in FIGURE 1, the bonding is effected so that any sharp edges on the end caps are disposed exteriorly of the envelope.

Mounted on the end caps 3 and 4, as by welding, are upper and lower electrode members 5 and 6, respectively. The electrode members comprise solid cylindrical metal members and are massive relative to the other members of the structure. Additionally, the electrode members extend in the envelope in coaxial longitudinally spaced relation. Further, the electrode members include transverse inner ends which are parallel and are predeterminedly spaced for defining a discharge gap of predetermined length. Still further, the electrode members are formed of a material having a very low impurity content, high specific heat capacity, high magnetic permeability and, at least, a medium high melting point and a medium high thermal conductivity. The purpose for providing members having these properties and the particular material found highly advantageous in forming such members will be brought out in detail hereinafter.

The upper end cap 3 is fitted with an exhaust tubulation 7 and communication between the exhaust tubulation and the interior of the envelope is provided by a passage 8 extending from the side of the upper electrode 3 and through the electrode member and the upper end cap. Following exhaust of the device through the tubulation 7 the latter is pinched off and thereby sealed.

Provided for protecting the tubulation 7 against damage is a tubular member 9 brazed to the end cap 3 about the tubulation. Additionally, the member 9 serves as an electrical connection between the upper end of the gap and a flexible lead 10 provided with a connector lug 11.

Secured to the lower end cap 4, as by welding also, is a

member 12 constituting a combination mounting bracket and an electrical contact. The member 12 can be generally U-shaped with one side of the U welded to the end cap 4 and the opposite side formed with apertures for receiving screws for mounting purposes. With this construction the tube can be satisfactorily and easily mounted with the bracket 12 being effective for making satisfactory electrical contact with the lower end of the tube and minimizing transfer of shocks and vibration to the tube.

The tube 1 contains an atmosphere of inert gas which is preferably argon and can include a quantity of radioactive material for assisting in initiating breakdown. However, where shielding from cosmic radiation is not present this form of radiation can be relied upon for assisting in breakdown and the use of radioactive material can be avoided.

The argon is present in the tube at a predetermined pressure which is related to the design breakdown voltage, or voltage at which desired operational discharge will occur across the gap defined by the opposed ends of the electrode members 5 and 6.

In accordance with common practice, the design of a gap tube first involves reference to a chart of the type illustrated in FIGURE 2 which shows the breakdown voltage, or the prediction of starting voltage for ionization of argon in a device including opposed planar electrode surfaces. From this curve it is possible to predict the pressure-distance product required to effect breakdown at given desired operating voltages. Thus, for example, if one desired to construct a gap tube including an argon atmosphere and adapted for breaking down or discharging at 1600 volts, the product of the pressure of the argon and the distance of the discharge gap measured in centimeters should ideally equal a value of 100.

Heretofore, the above-discussed pressure-distance product requirement was well recognized. However, the product requirement has always been considered paramount and, accordingly, it has been the practice, in arriving at the desired product, first to select, for example, either the pressure arbitrarily as any desired multiplier value and then to adjust the value of the distance as a multiplicand, whereby the desired product would be obtained.

According to one feature of the present invention, tube life can be maximized or prolonged by unexpected orders of magnitude by preselecting both the gas pressure and gap distance in arriving at the desired breakdown product. More specifically, after the required product is arrived at by reference, for example, to the chart of FIGURE 2, pressure and gap distance, whereby prolonged tube life is obtainable, are selected to afford a relationship between

$$\frac{p}{d} = 1600 \text{ and } \frac{p+400}{d} = 850$$

where p = the pressure of argon in mm. of Hg and d = the gap distance in cm. For optimum tube life the relationship should closely approach

$$\frac{p+200}{d} = 1100$$

Still more specifically, and referring to FIGURE 3, one desirous of constructing a gap tube having a breakdown voltage of $e=8000$ volts, for example, can obtain prolonged life for such device by utilizing a pressure and a gap distance satisfying the above noted relationships. The 8000 volt breakdown is indicated by a curve designated A in FIGURE 3. The relationships

$$\frac{p}{d} = 1600 \text{ and } \frac{p+400}{d} = 850$$

are indicated in FIGURE 3 as dash line curves and the desired prolonged life will be obtainable with any values of p and d satisfying a relationship falling on the curve A.

5

between the two mentioned dash line curves. On the portions of the curve A outwardly of the dash line curves, tube life falls off by orders of magnitude. As indicated above optimum prolonged tube life is obtained as the relationship of p and d approaches the values indicated by the solid line representing the relationship

$$\frac{p+200}{d}=1100$$

The curves designated B to E are exemplary of pressure-distance products for use in obtaining devices having other desired breakdown voltages. With tubes constructed to operate at these breakdown voltages the pressure-distance values for prolonged tube life also fall between the relationships indicated in FIGURE 3 by the dash line curves and tube life is optimized generally along the solid line curve

$$\frac{p+200}{d}=1100$$

The curve E represents a range of pressure-distance resulting in close to the minimum breakdown value for argon. However, it will be understood from the foregoing that the above-discussed prolonged tube life is obtainable with E or any breakdown voltage thereabove and the curves A—D are only exemplary. It will also be understood from the foregoing that the medium utilized is preferably essentially argon and any atmosphere which might include argon and small amounts of other gases can be considered essentially argon and will be satisfactory for use in the presently disclosed device.

The active electrode surfaces defining the gap between the electrode members 5 and 6 are shown in FIGURE 1 as being cap-shaped and are designated 5a and 6a, respectively. Additionally, the surfaces 5a and 6a are constructed in a particular manner according to the present invention. Specifically, and as perhaps better seen in FIGURE 4, the active surfaces of the electrode members are predeterminedly textured or formed to provide a myriad of substantially uniform closely spaced protrusions 13. The protrusions 13 are substantially small relative to the electrode members proper. However, as shown in FIGURE 5, each protrusion is substantially massive relative to the spaces between the protrusions and extends substantially straight axially toward the opposed electrode. Additionally, the protrusions comprise integral portions of the electrode members proper and the base portions of the protrusions are substantially large, which features of the structure provide for optimum current flow and heat transfer through the protrusions to the bodies of the electrode members. Integral protrusions of approximately 1.0 to 50 mils height and having base widths of approximately 1.0 to 50 mils have been found advantageous for obtaining the objectives of the present invention.

In operation of the device, and during a discharge, the protrusions 13 are effective for causing the arc, designated for purposes of illustration by the lines 14 and 15 in FIGURE 4, to "run" or move rapidly completely over the active surfaces of the electrode members. This "running" effect is believed to be caused by the influence of induced transverse magnetic field components, such as indicated by the arrow 16. It is believed that the magnetic field components tend to bend the arc laterally away from the vertical position over the individual protrusion upon which it is anchored at a particular instant, and this is effective for causing the arc to "run" or jump to the next adjacent protrusion after only a relatively short dwell period on the preceding protrusion. Thus, the arc is caused to move rapidly from one protrusion to another without dwelling at any particular one long enough to generate enough heat to cause evaporation of the electrode material.

It will be understood from the foregoing that the spaces between the protrusions 13 must not be so great that the

6

magnetic field will be ineffective for influencing the arc to jump rapidly from one protrusion to the next adjacent one and so on. If the spaces between the protrusions are too great, the magnetic field will be insufficient for influencing the arc to bend toward and rapidly jump to the next protrusion and the arc will dwell an inordinate length of time on a particular protrusion and will move in a jumpy, jerky manner, in which case the arc will cause evaporation of the protrusion material and create the same type of problems encountered in the prior art with polished active electrode surfaces. Thus, prior art devices wherein, for example, the active surfaces have been knurled or otherwise roughened for endeavoring thereby to provide field concentrations to facilitate arc initiation and without appreciation of the present teaching that the protrusions must be predeterminedly dimensioned and spaced for causing the arc to move rapidly over the active surface, will be subjected to the same, if not greater, difficulties as encountered with polished active surfaces.

Contributing to avoidance of evaporation of the electrode material at the active surfaces of the electrode member is the integral construction of the protrusions, the high specific heat capacity of the material employed for the electrode members and the high magnetic permeability of the electrode material. As illustrated in FIGURE 5, the size and dimensions of the protrusions are such as to afford substantial heat transfer paths indicated by the arrows 17 from the discrete protrusions to the main body portions of the electrode members. Additionally, heat transfer from the protrusions to the bodies of the electrode members is maximized by the integral nature of the protrusions. It will be understood from the foregoing that the mere bonding of protruding conductive particles on the active surfaces of electrodes, as has been done in the prior art to provide field concentrations for facilitating initiation of an arc, will not afford the same kind of heat and current transfer as do the presently described integral portions. As pointed out above, the protrusions of the present invention are integral and include substantially large base portions which insure substantial direct heat flow paths to the electrode base portion. The avoidance of substantial heating of discrete areas of the active surfaces resulting from the running of the arc not only prevents the undesirable evaporation of the electrode material and all the incidental difficulties resulting therefrom, but also is effective for distributing the heat more uniformly over the entire active surface or, in other words, it reduces the average power density at the active electrode surfaces. This causes the active surfaces of the electrodes to run cooler during a discharge because more of the electrode body portion is thus adapted for conducting the heat outwardly toward the end caps. As a result of the cooler electrode operation and adaptation of the structure for greater current conduction, the tube is adapted for increases in current handling capacity of as much as 10 to 1 or 20 to 1.

In practice the desired texture of the active surfaces 5a and 6a has been obtained by blasting the electrode ends with powdered alumina having a mesh designation of approximately 25 to 150 mesh and with a pressure of approximately 100 lbs. per square inch. An 80 mesh powder has been found to provide particularly satisfactory results. In blasting the active surfaces other abrasive materials such as Carborundum may be effectively utilized in place of the alumina.

The provision of the opposed active surfaces textured in accordance with the present invention is also effective for substantially confining the arc to the opposed parallel active surface portions of the electrodes. This minimizes tendency toward spurious arcing to the side walls. Additionally, it permits the side walls to be moved inwardly to reduce the size of the tube or to locate the side walls at a distance from the electrode members calculated to yield the most consistent breakdown voltages and still

result in maintaining the arc substantially confined between the electrode members without spurious discharges to the side walls of the envelope and without the side walls becoming coated with evaporated electrode material. Also, it enables the electrode members 5 and 6 to be of greater diameter relative to the inside diameter of the insulator 2 without introducing problems regarding undesirable changes in breakdown conditions, spurious discharges to the envelope wall and deposits of conductive material on the wall. Increased diameter of the electrode members allows for increased active electrode surface areas and increased current and heat conductivity for increasing the power handling capacity of the gap tube. Further, increasing the diameter of the electrode members reduces the field concentrations about the electrode members with the desirable effect of minimizing tendency toward spurious arcing to the side portions of the electrode members.

It has also been found advantageous to round off the circumferential edges of the active surfaces of the electrode members and to extend the blasted or textured surface portions of the electrodes at least partially along the side walls of the electrode members to provide a textured skirt. The textured skirt portions are adapted for affording the desired protrusions and the beneficial effects thereof in respect to any arc occurring outwardly of the opposed planar active surface portions of the electrodes.

As indicated above, the electrode members 5 and 6 are advantageously formed of material having a very low impurity content, high specific heat capacity and at least a medium high melting point and thermal conductivity.

The low impurity content of the material insures against release into the atmosphere of the device of ingredients which would adversely affect operation. The high specific heat of the electrode material enables the electrodes to absorb substantial heat from the arc for conduction to the end caps and dissipation therefrom. This conduction is facilitated by the high conductivity of the material. The high thermal conductivity nature of the material also enhances the heat transfer from the discrete protrusions to the bodies of the electrode members 5 and 6. The electrode material preferably has at least a medium high melting point in order that each of the discrete protrusions 13 will be adapted for resisting the high temperature effects of the arc, or, in other words, the tendency for the arc heat to cause melting and evaporation of the material of which each protrusion is formed. In addition, it has been found that the magnetic permeability of the lower melting point materials is important. Higher permeability materials have a tendency to make the arc run easier. A low impurity content iron has been found particularly effective in affording all of the above-noted desired properties. Additionally, this material has been found particularly adaptable to the above-described process of forming the myriad of protrusions 13, namely, the blasting of the active surfaces of the electrodes with abrasive particles.

Control of the diffusion of the arc column so that the column will be sufficiently contracted to minimize any tendency toward contacting the tube walls and yet be of sufficient diameter to make full utilization of the opposed planar active electrode surfaces is attributable primarily to the density of the ionizable medium and the spacing between electrodes in the tube. That is, with the active electrode surfaces textured in the manner described above and illustrated in the drawing and with the pressure of the ionizable medium and the gap distance satisfying the above-discussed relationships the arc runs rapidly over the active surfaces and the column extends over substantially all of the opposed active surfaces without substantial diffusion of the column toward the envelope wall.

It has been found that when the value of the gap

and the gap distance do not satisfy the desired relationships shown in FIGURE 3, the arc column often constricts or is limited to restricted areas of the active electrode surfaces. This causes concentrated heating of the restricted areas of the electrode surfaces and the above-discussed undesired pitting of the electrode surfaces and evaporation of the electrode material. Additionally, the construction of the arc column reduces substantially the power handling capacity of the device.

On the other hand, it has also been found that when the desired pressure and distance relationships above-described are not satisfied the arc column will also sometimes tend to diffuse radially or expand substantially toward the side walls. As explained above, substantial radial diffusion tends to cause spurious arcing to the side walls and changes in the breakdown voltage due to release of impurities from the walls, and generally necessitates either reducing the size of the electrode surfaces relative to the diameter of the inner side wall of the envelope or enlargement of the envelope device to locate the side walls more remote from the electrode surfaces.

Thus, the present invention, in addition to avoiding evaporation of the electrode material and all of the above-mentioned undesirable effects thereof, is adapted for controlling the cross section of the arc column and enabling the envelope walls to be brought in closer to the electrode members for reducing the over-all size of the tube for any given breakdown voltage and power handling capacity. Additionally, since the present invention minimizes outward bowing or diffusion of the arc column, the diameters of the active surfaces thereon can be increased, thereby to increase the power handling capacity of a tube given dimensions.

While a specific arrangement of the invention has been shown and described it is not desired that the invention be limited to the particular form shown and described, and it is intended by the appended claims to cover all modifications within the spirit and scope of the invention.

What is claimed as new and desired to be secured by Letters Patent is:

1. A gap tube comprising an envelope containing an ionizable medium, a pair of electrode members mounted in mutually insulated relation in said envelope, said electrode members comprising solid blocks of metal including opposed active surfaces defining a discharge gap, and the active surface of at least one of said members comprising a myriad of integral substantially uniform and closely spaced protrusions effective for causing rapid movement of an arc in said gap over substantially the whole area of said active surface.

2. A gap tube according to claim 1, wherein said protrusions comprise upstanding portions on said active surface of approximately 1.0 to 50 mils height.

3. A gap tube according to claim 1, wherein said electrode members comprise coaxially aligned and axially spaced solid cylindrical blocks of a metal having a low impurity content, high specific heat, high magnetic permeability and at least a medium high melting point and a medium high thermal conductivity, the opposed end surfaces of said electrode members comprising substantially parallel planar active surfaces defining a discharge gap, and said planar active surfaces and the lateral surface portions of said electrode members contiguous with said planar surfaces are textured to include a myriad of integral substantially uniform and closely spaced protrusions of approximately 1.0 to 50 mils height.

4. A gap tube comprising an envelope containing an essentially argon atmosphere, a pair of electrode members mounted in mutually insulated relation in said envelope, said electrode members comprising solid blocks of metal including opposed active surfaces defining a discharge gap, the active surface of at least one of said members comprising a myriad of integral substantially uniform and closely spaced protrusions, and the pressure

9

of said atmosphere and the distance of said gap satisfying a predetermined relationship between

$$\frac{p}{d}=1600 \text{ and } \frac{p+400}{d}=850$$

wherein p equals pressure in mm. of Hg and d equals the distance of said gap in cm., said protrusions being effective for causing rapid movement of an arc in an arc column in said gap over substantially the whole of said active surfaces, and said predetermined relationship of said pressure and gap distance being effective for both avoiding constriction of said column to a limited area of said active surfaces and to minimize the diffusion of said column toward the walls of said envelope.

5. A gap tube according to claim 4, wherein said electrode members comprise cylindrical blocks of metal having a low impurity content, high specific heat, high magnetic permeability, and at least a minimum high melting point and minimum high thermal conductivity, and said active surfaces and the lateral surfaces of said electrode members contiguous with said planar areas being textured to include said myriad of integral substantially uniform and closely spaced protrusions.

6. A gap tube comprising an envelope including a cylindrical ceramic insulator, a metal end gap having the rim thereof sealed to the outer surface of each end of said ceramic insulator by a metallic bond, an essentially argon atmosphere contained in said envelope, a pair of solid cylindrical electrode members of substantially greater mass than said end caps bonded each to one of said end caps and extending in axially aligned relation in said insulator, said electrode members comprising a low impurity content iron and having axially

10

spaced substantially planar parallel active surface areas defining a discharge gap, said planar active areas and the lateral surfaces of said electrode members contiguous with said planar areas being textured to include a myriad of integral substantially uniform and closely spaced protrusions, said protrusions having heights of approximately 1.0 to 50 mils and bases of generally corresponding dimensions and effective for causing rapid movement of an arc in an arc column established in said gap upon discharge, whereby said column is caused to extend substantially the whole of said active areas, and said atmosphere and the distance of said gap satisfying a predetermined relationship between approximately

$$\frac{p}{d}=1600 \text{ and } \frac{p+400}{d}=850$$

wherein p equals pressure in mm. of Hg and d equals the distance of said gap in cm., which predetermined relationship is effective for both avoiding constriction of said column to insure extension thereof substantially the whole of said active areas and to minimize diffusion of said column outwardly toward the walls of said envelope.

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