June 16, 1959 V. L. HOLDAWAY 2,891,188

GASEOUS DISCHARGE DEVICE

Filed March 24, 1955

FIG. 1

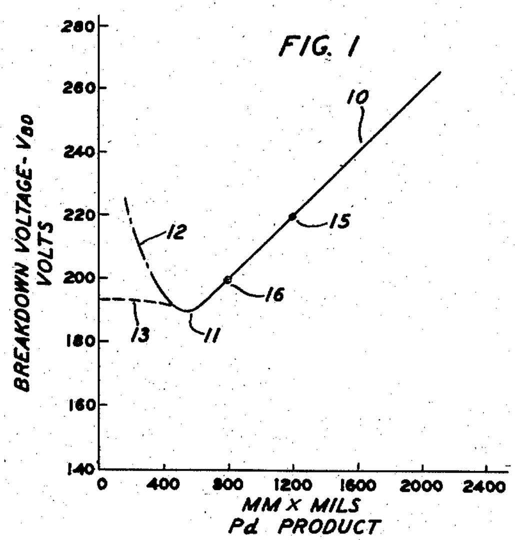
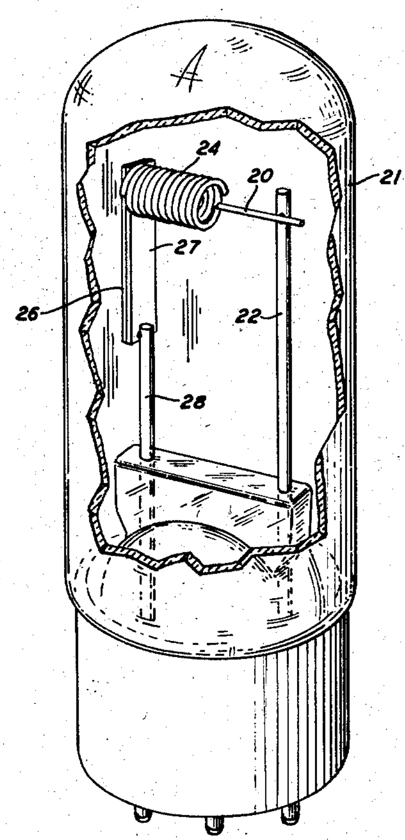


FIG. 2



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GASEOUS DISCHARGE DEVICE

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3 Claims. (Cl. 313—151)

This invention relates to gaseous discharge devices, and more particularly to such devices especially suitable for use in switching networks.

In gaseous discharge switching networks, of the type described in Bruce-Straube Patent 2,684,405, July 20, 1954, two desirable characteristics are a high breakdown voltage, so that the margin between a device's breakdown and sustaining voltages is high, and stability of breakdown voltage. In order to attain a constant breakdown voltage despite variations in spacing between different devices in the network and variations in the gas density in a single device due to operation thereof, it has been proposed to operate such devices at the Paschen minimum of the voltage breakdown-pressure times distance curve; the Paschen minimum, or the *pd* minimum of the Paschen curve as it is sometimes called, is the minimum breakdown voltage that can be applied to effect a discharge in the device. At the Paschen minimum the *pd* curve has a small slope so that slight variations in the gas density in the anode-to-cathode gap will not affect the value of breakdown voltage. Thus stability of breakdown voltage can be readily attained within satisfactory limits.

However, as stated above, this is the minimum breakdown voltage that can be applied to the device and accordingly the breakdown voltage stability has been attained by sacrificing another desirable characteristic for operation in gaseous discharge device switching networks, namely, a high breakdown voltage. Accordingly, it has been proposed also to operate the device with a larger *pd*, and specifically with a larger main gap spacing, in order to increase the breakdown voltage. However, at these other points on the *pd* curve, slight variations in spacing between devices or in the density in a given device, due to a prior discharge in the device, give rise to large variations in the breakdown potential requisite to fire the tube, as the slope of the curve is large at these other points.

It is possible to determine the initial spacing between the anode and cathode very accurately for a given desired breakdown voltage. This may be attained by utilizing a wire anode positioned with its tip or end opposite to and facing a hollow cathode, and ionically bombarding the end of the anode to etch it away while maintaining a large discharge between the cathode and an auxiliary aging anode in the device. This etching is periodically interrupted for measurement of the breakdown voltage of the main gap to determine if the anode-to-cathode spacing has been reduced to the desired distance. This process and an apparatus for automatically initiating and interrupting the etching discharge and measuring the main gap breakdown voltage are further described in Patent 2,825,618, of A. D. White, issued March 4, 1958.

The anode-to-cathode spacing may also be initially determined during the manufacture of the device in other ways, known in the art, such as by mechanical jigging and optical measurements. Advantageously, the anode-to-cathode spacing, the shape of the cathode, and the gas

pressure are chosen to attain a stable negative resistance characteristic at the current and frequency ranges at which it is intended to employ the device in a particular switching network, as further disclosed in Patent 2,804,565, of M. A. Townsend, issued August 27, 1957.

However, even though the initial spacings between the main anode and cathode of the various devices in the network be very accurately determined to attain the same breakdown voltage for all the devices, nevertheless various devices in the network may, at any given instant, have a lower breakdown voltage than other devices. This arises due to the localized heating of the cathode of the device by the discharge. Heating of the cathode in turn heats the gas immediately adjacent to it, and thus within the cathode-to-anode gap, thereby reducing the gas density. When the density of the gas in the gap is changed, the breakdown voltage of the gap varies in the same way as if instead of the density the distance between the electrodes had been changed, and in the same proportion.

Thus, heating of the gas in the gap by the discharge causes a reduction of the breakdown voltage required for that device. As this heating occurs while the device has a discharge sustaining in it, it has generally not been considered serious. However, in switching networks employing gaseous discharge devices, a device may be utilized in a subsequent connection or path through the network immediately upon extinction of a prior discharge in the device and before the gas has had an opportunity to cool and the breakdown voltage of the tube return to its original and higher value.

If a new connection is to be set up through a switching network after a prior connection has been interrupted but before the devices employed in that connection have had an opportunity to cool, these devices, having lower breakdown voltages, will be preferred also for the next connection. What will then occur is that a "rut" will exist in the network in which connections will always prefer to go through a few of the devices in the network, because of their lower breakdown potentials, rather than even through all of the devices on a statistical basis. This will cause the devices of the network not to be used equally, with the result that a few devices will be quickly burned out while the other devices are not employed.

A further serious difficulty that then arises when the breakdown voltage of devices employed immediately priorly on other paths is lower is the possibility that false paths may result from the degraded margins in the network. In order to assure against these false paths all components and voltages utilized in the network are maintained to close tolerances so that the maximum pile-up will not cause improper voltages to appear across devices, which voltages approach the breakdown voltage of a device not to be broken down in setting up a connection, such as a device having one terminal connected to an existing connection through the network. However, if the breakdown voltage of a device is decreased, as described above, and a maximum adverse culmination of tolerances occurs, false paths may result. This can be guarded against by increasing the margins, decreasing the allowable tolerances, and decreasing the number of stages, but, as is readily apparent, each of these would result in considerable sacrifice in economy and efficiency of operation of the network.

It is an object of this invention to provide an improved gaseous discharge device and specifically such an improved device for operation at other than the Paschen minimum.

It is a further object of this invention to maintain the breakdown voltage of a gaseous discharge device constant regardless of the prior operation of the device.

It is a still further object of this invention to prevent one or a number of discharge devices employed in a switching network being utilized excessively in connections set up through that network. Thus it is an object of this invention to enable connections through a switching network employing gaseous discharge devices to utilize the various devices available for any path between two points in that network evenly.

It is a still further object of this invention to provide a gaseous discharge device in which the breakdown voltage is independent of the previous conducting or nonconducting state of the device.

These and other objects of this invention are attained in one specific illustrative embodiment wherein a gaseous discharge device comprises a hollow cathode and an anode positioned opposite thereto and defining a gap therewith, the cathode, gap, and pressure being advantageously such that the device has a stable and usable negative resistance characteristic, as disclosed in the above-mentioned Townsend patent. The cathode is mounted on a bimetallic support which is constructed so that on heating of the cathode, by the discharge, the variations in the gas density in the cathode-to-anode gap will be compensated for by motion of the cathode away from the anode, thereby increasing the size of the gap. In this manner the breakdown voltage is maintained constant as the product *pd* remains constant.

The heating of the cathode and therefore the decrease in gas density at the cathode can be determined for a given discharge current and the increase in spacing required can then be calculated. Accordingly, the thermally responsive element supporting the cathode can readily be constructed to have a thermal characteristic so that it will provide precisely this amount of motion of the cathode away from the anode for this decrease in gas density at the cathode or may, if desired, be designed to overcompensate slightly.

It is a feature of this invention that the cathode of a gaseous discharge device be supported by a thermally responsive element so constructed that motion of the cathode directly compensates for variation in the gas density adjacent the cathode to prevent decrease in the breakdown voltage of the device due to decrease in the gas density adjacent the cathode.

It is another feature of this invention that the breakdown voltage of a gaseous discharge device operated at other than the *pd* minimum of the Paschen curve be maintained constant with change of density in the anode-to-cathode gap due to heating of the cathode by the discharge by mounting the cathode on a bimetallic support having a thermal characteristic such that the motion of the cathode with relation to the anode exactly compensates for the change in density in the anode-to-cathode gap.

A complete understanding of this invention and of these and other features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a Paschen curve of breakdown voltage as a function of the pressure-distance product for an exemplary discharge device; and

Fig. 2 is a perspective view of one illustrative embodiment of this invention, a portion of the envelope being broken away to show the internal elements more clearly.

Fig. 1 is a typical plot of voltage breakdown V_{BD} as a function of the pressure-distance product, *pd*. The solid portion **10** of the curve can be determined experimentally quite readily by maintaining the gas pressure constant and varying the spacing between the cathode and the anode. At some pressure and spacing corresponding to point **15** on Fig. 1, breakdown occurs when the applied voltage is high enough so that each electron crossing the gap produces sufficient ionizations and excitation in the gap to release another electron at the cathode.

As the anode is moved closer to the cathode, a given applied voltage produces a larger electric field and the efficiency of the ionization increases. The necessary voltage for breakdown consequently decreases. As the spacing is decreased further, a minimum breakdown voltage is realized at the point **11**, which is often referred to as the Paschen or *pd* minimum. At this point the spacing between the electrodes is still large enough to enable a sufficient number of ionizing collisions in the gap and the electric field at the cathode is high.

As the spacing is further decreased, the number of collisions an electron can make in passing from the cathode to the anode become low enough to outweigh the aiding effect of the higher field strength at the cathode, resulting in an increase in the breakdown voltage. This is indicated by the dashed portion **12** of the curve. This portion of the curve is difficult to find experimentally as the electrons will prefer to traverse a longer path from the cathode to the back of the anode or to the anode support wire, so that the actual distance *d* that is involved is not definite. It can be measured however by using geometries which restrict these longer paths. With usual geometries, the actual breakdown voltage at these low values of *pd* is indicated by the dotted portion **13** of the curve and does not rise as greatly as theory indicates (due to these longer paths around the anode).

The breakdown voltage is also dependent on the particular gas and the cathode material, as well as on the pressure-distance product. In the particular devices for which this curve was plotted, as described more fully below, a molybdenum cathode was employed and the device was filled with neon.

It can readily be seen from Fig. 1 that one method of obtaining fairly constant breakdown voltage is to operate the device at the *pd* minimum point **11**, as decrease in density, due to heating of the cathode, will cause the breakdown voltage to follow the dotted portion **13** of the curve. However, this approach to the problem of maintaining the breakdown voltage constant requires that the breakdown voltage be a minimum and this may be very undesirable. It is therefore greatly to be preferred that the device be operated at some point to the right of the *pd* minimum, such as the point **15**, with a breakdown voltage considerably higher than that at the Paschen minimum; in the embodiments for which this plot is descriptive the breakdown voltage at the Paschen minimum is 190 volts and the breakdown voltage desired at point **15** is 220 volts or an increase of 30 volts.

Now, however, a decrease in the gas density adjacent the cathode will in effect cause the *pd* product to decrease so that the breakdown voltage may be at a lower point on curve **10**, such as point **16**. Here the breakdown voltage is only 200 volts, a drop of 20 volts from the breakdown voltage of the tube when cold.

In accordance with this invention, a gaseous discharge device is provided which maintains the pressure-distance product constant so that the breakdown point of the device is always at the design point **15** regardless of the prior operate or non-operate condition of the device. One specific illustrative embodiment of this invention is depicted in Fig. 2 and comprises a wire anode **20** supported within a glass envelope **21** by a support lead **22**. The anode is positioned with its tip or end pointing towards a hollow cathode **24**, which may be a helically coiled cathode as depicted, though other types of hollow cathodes may advantageously be employed. The dimensions of cathode **24**, the spacing between the cathode and the anode, and the gas pressure may advantageously be such that the device has a stable negative resistance characteristic over a usable current and frequency range, as further taught in Patent 2,804,565, of M. A. Townsend, issued August 27, 1957. The various types of cathodes disclosed in this Townsend patent may also all be employed, but this invention is not to be considered as limited to these or any particular cathode configuration.

The base of the cathode is secured, as by welding, near one end of a bimetallic strip comprised of plates

26 and 27. If desired, one end of the cathode coil may depend from the cathode and be secured to the bimetallic strip. Heat conduction from the cathode to the bimetallic strip is improved however by assuring a good thermal path therebetween. The bimetallic strip is secured near its other end, as by welding, to a cathode support lead 28. The cathode 24 and support lead 28 may be secured to the same or opposite sides of the bimetallic strip. In accordance with an aspect of this invention, the two plates 26 and 27 which comprise the bimetallic strip or element are so arranged that heating of the plates, due to heating of the cathode 24, will cause the plates to bend, moving the cathode 24 farther away from the anode 20. In one specific illustrative embodiment, the plate 26 was a .010 x .050 x .187 inch molybdenum plate and plate 27 was a nickel plate with the same dimensions.

The operation of the bimetallic support to compensate for the change in density can readily be seen from consideration of a specific illustrative example. In this specific example the anode 20 was a .005 inch molybdenum wire mounted with its tip initially, i.e., in the cold condition, .012 inch from the hollow cathode 24, which was of molybdenum. The envelope was filled with neon at 100 millimeters of pressure. In the cold state the temperature of both the cathode 24 and the envelope 21 was 25° C.

In a gaseous discharge device of this type in accordance with the prior art and without a compensatory cathode mount, the device, immediately after operation at a discharge current of .010 ampere would have the following characteristics. The cathode temperature would be 250° C. and the average envelope temperature 75° C. causing the gas density at the cathode to decrease. The *pd* product under these conditions corresponds to the point 16 on curve 10 and a breakdown voltage of 200 volts.

In gaseous discharge devices in accordance with this invention, however, having compensatory cathode mounts the cathode is arranged to move away from the anode to increase the gap distance *d* an amount just sufficient to keep the *pd* product constant. In one specific embodiment in which the *pd* product remained constant, the bimetallic support provided a 6 mil movement when the tube had been operated at 0.010 ampere.

While a specific type of thermal compensating support using particular metals has been depicted and described, it is to be understood that various other types of such supports may be utilized. Further, the amount of motion required exactly to compensate for the change in density in the anode-to-cathode gap will of course depend on the specific device, the operating current, the original gas pressure, and the increase in temperature of the cathode due to the discharge.

In the above described embodiment, the bimetallic element has been arranged exactly to compensate for the change in density so that the breakdown voltage is maintained constant. In certain applications it may be desirable, however, slightly to overcompensate, thus giving an initial preference in the network to employing devices not immediately priorly employed in a connection through the network. Further, arranging the various devices so as to be slightly overcompensated will enable the design to be less critical. Conversely, in certain arrangements it may be satisfactory if the compensation afforded by the thermal mounting of the cathode be somewhat less than required for exact compensation.

In certain applications very adverse ambient temperature conditions may be encountered. If the ambient temperature increases appreciably, there will be motion of the cathode, because of its thermally responsive support, which is due to this ambient temperature increase and

not caused by a local temperature variation due to the glow discharge at the cathode. Variations in ambient temperature, however, do not affect the gas density and thus do not affect the breakdown voltage. Accordingly, if severe ambient temperature variations are to be encountered, the anode may be also supported by a thermally responsive element, identical with that supporting the cathode, so that the anode moves to follow the cathode and prevent ambient temperature changes affecting the desired breakdown voltage characteristic.

Accordingly, it is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A glow discharge device comprising an envelope, a gaseous filling in said envelope at a predetermined pressure, a hollow cathode within said envelope, a wire anode positioned with its end opposite to and directed towards the hollow portion of said hollow cathode and defining therewith a gap having an initial predetermined spacing, whereby said discharge device has initially a predetermined breakdown voltage, and means for maintaining said breakdown voltage constant with change in density of said gaseous filling in said gap due to heating of said cathode by a discharge, said means comprising a bimetallic support for said cathode having a thermal characteristic such that the increase of spacing of said gap from said initial predetermined spacing exactly compensates for the decrease in density of said gaseous filling in said gap from said predetermined filling.

2. A glow discharge device for operation in a region where the breakdown voltage changes with density comprising an envelope, a gaseous filling within said envelope, an anode, a hollow cathode opposite said anode and defining a gap therewith, said gap having a predetermined breakdown voltage, and means for preventing substantial decrease in said breakdown voltage on change in the gas density in said gap due to heating of said cathode by the glow discharge, said means comprising a bimetallic element supporting said cathode for motion towards and away from said anode and having a thermal characteristic such that said cathode moves away from said anode on heating of said cathode an amount compensating for the change in gas density in said gap on heating of said cathode.

3. A glow discharge device for operation at other than the pressure distance minimum of the Paschen curve comprising an envelope, a gaseous filling within said envelope, an anode, a cathode capable of maintaining a large glow discharge opposite said anode and defining a gap therewith, said gap having a predetermined breakdown voltage, and means for preventing said breakdown voltage decreasing on change in the gas density in said gap due to heating of said cathode by said glow discharge, said means comprising a bimetallic support for said cathode having a thermal characteristic such that the increase in the gap spacing on heating of said cathode is at least sufficient to prevent a decrease in the breakdown voltage of said gap.

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