Sept. 26, 1950 | H. FRIEDMAN | 2,523,287

VOLTAGE REGULATOR

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FIG. 1

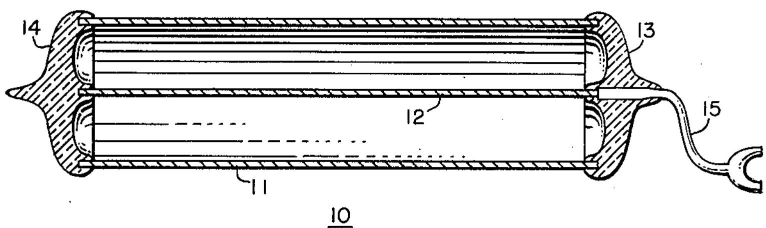

FIG. 2

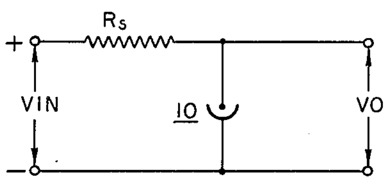

FIG. 3

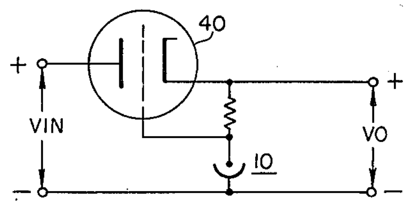

FIG. 4

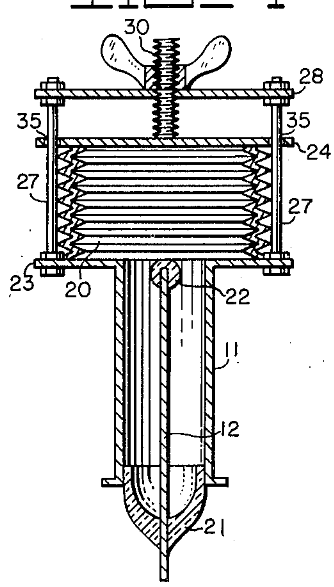

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FIG. 5

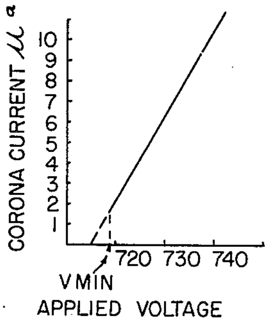


FIG. 6

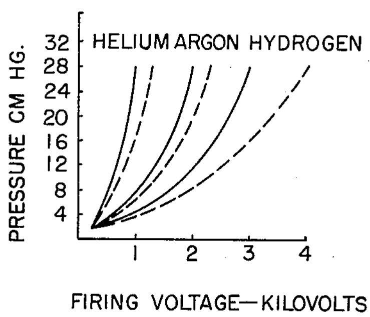


FIG. 7

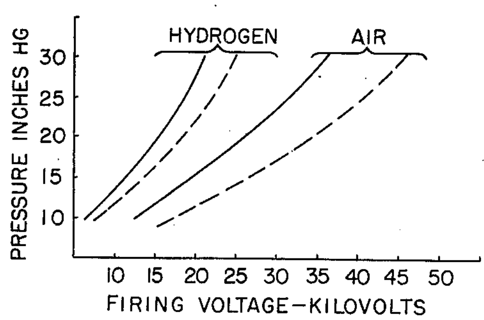
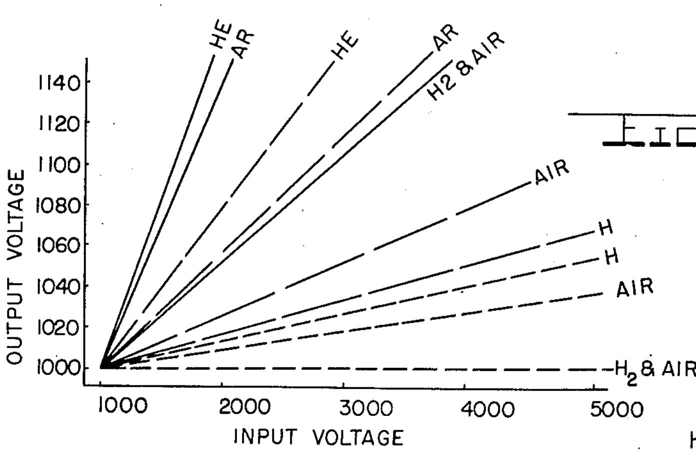


FIG. 8



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VOLTAGE REGULATOR

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5 Claims. (Cl. 250—27.5)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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This invention relates to voltage regulation in general and to a novel voltage regulator tube in particular.

With greater particularity, the present invention provides regulation of high voltages by means of a gas filled diode comprising a pair of cylindrical or generally cylindrical electrodes spatially arranged in coaxial relation and sealed at their adjacent ends to provide a gastight chamber. This chamber is filled with a diatomic or monatomic gas whichever is preferred. The pressure of the gas filling and the radial dimensions of the tube electrodes are predetermined in accordance with the magnitude of the voltage to be regulated.

In applications having low current consumption, the diode is used in connection with a simple series voltage dropping resistance element. In applications having high current consumption the tube is employed as a means for obtaining a reference potential for control of a series type hard tube regulator circuit. In either application the tube is designed to operate in a confined region of its voltage-current characteristic, known to the art as the "corona discharge region." Specifically this region is defined as that portion of the voltage-current characteristic where a self-sustaining discharge occurs.

It is accordingly an object of this invention to provide a new and simple gas tube for voltage regulation.

It is another object of this invention to provide regulation of voltages up to or exceeding 40 kilovolts in magnitude.

It is another object of this invention to provide a corona discharge voltage regulator tube.

Other and more specific objects of this invention will become apparent upon a careful consideration of the following detailed description when taken together with the accompanying drawings, in which:

Fig. 1 is a simplified longitudinal sectional view of one exemplary embodiment of the invention,

Figs. 2 and 3 illustrate, in circuit diagram form, two types of regulator circuits useable in practicing the teachings of this invention,

Fig. 4 is a simplified longitudinal sectional view of an alternate embodiment of this invention, and

Figs. 5 through 8 show a series of graphs useful in representing certain qualities and operational characteristics of the invention.

Referring now to Fig. 1 there is illustrated in cross section, a corona regulator tube 10 con-

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structed in accordance with the teachings of the invention. As exemplified, the tube comprises only two electrodes; an outer cathode cylinder 11 made from any suitable metal such as stainless steel, copper or etc., and an inner coaxial anode cylinder 12 also made of any suitable metal. The electrodes are sealed at their adjacent ends by means of glass insulating caps 13 and 14 or the like to form a gastight chamber between the electrodes. This chamber is filled to a predetermined pressure with any suitable gas later to be described. Attached to the anode cylinder 12 at one end thereof to provide an electrical connection thereto is a flexible lead 15.

As aforementioned, regulation of high voltages by the diode tube of the invention is accomplished by operating the tube in the corona discharge region of its voltage-current characteristic. A corona discharge is self-maintained by photoelectric ionization or electrons emitted at the cathode by photons or positive ion impact and its existence is evidenced by a luminous or positive ion sheath formed about the anode cylinder.

In the construction of the tube and for purposes of obtaining a suitable corona characteristic, there exists a certain well defined geometrical limit on the ratio of electrode radii. In particular this geometrical limit arises by virtue of the fact that when a corona discharge occurs the positive ion sheath formed about the anode cylinder increases the effective radius thereof. If this increase in radius increases the field intensity at the cathode then the tube will pass directly into a disruptive or glow discharge. If, however, the increase in anode radius decreases the field intensity at the cathode then the condition for a corona discharge is fulfilled. In general it has been ascertained that for the realization of a suitable corona discharge characteristic the ratio of cathode radius to anode radius must not be less than e, the Napierian logarithm base.

The voltage-current characteristic of a typical embodiment of this invention is illustrated in Fig. 5 to which reference is now had. For purposes of illustration the curve shown herein is directed to the corona characteristic of a specific diode filled with hydrogen gas and having a cathode radius of .5 centimeter and an anode radius of .005 centimeter. As will be noted from the curve slight changes in applied voltage produce large changes in current thus indicating that the tube possesses a positive resistance well suited for voltage regulator applications. The potential point denoted as V_{min} on the curve is indicative of the inception of corona discharge. Applied voltages below this value produce non-self-sustaining discharges which can only be maintained by the use of an external ionizing source. The reciprocal of the slope of this curve is representative of the corona resistance, R_c, of the tube. Accordingly, when the tube is used in the circuit of Fig. 2 then the voltage stabilization ratio, given by the ratio of ΔV_0 to ΔVin, or

$$\frac{\Delta V_0}{\Delta Vin}=\frac{R_c}{R_s+R_c}$$

where R_s is the series voltage dropping resistance. The corona resistance per unit length of the tube is dependent on pressure, and positive ion mobility of gas, and electrode dimensions. To minimize R_c, a gas should be selected which produces the required firing voltage at a relatively low pressure, and has a high positive ion mobility. For high voltage application, hydrogen offers what at present is deemed to be the best combination of mobility and starting voltage versus gas pressure characteristic. Air, however, is almost as effective because its higher starting voltage compensates to a great extent for the lower ionic mobility. Helium, neon and mixtures of rare gases with hydrogen are effective in the lower voltage ranges.

Neglecting space charge distortion, and assuming the anode radius r_a, small in comparison to cathode radius r_c then to a first approximation the corona resistance per unit length of tube is known to approximate

$$R_c=\frac{pr_c}{2KV}\log\frac{r_c}{r_a}$$

where p denotes gas pressure, K is the electron mean free path at unit pressure and V is the applied voltage. Accordingly, for a given cathode radius, r_c, the larger the anode r_a, the smaller the value of corona resistance R_c. It being understood, of course, that this condition prevails only so long as r_a is kept small in comparison to r_c, and does not exceed the herein above geometrical limit as to the ratio of these two values. Since R_c is representative of the corona resistance per unit length, it follows that increasing the length of the tube reduces the corona resistance. Alternatively, a number of short discharge tubes may be combined in parallel relation and enclosed in a single envelope.

The manner in which gas pressure and ratio of electrode radii effects the regulated voltage obtainable from a circuit such as that shown in Fig. 2 is illustrated in Fig. 6. In this figure, three sets of curves are drawn; one set for each of three different gases, helium, argon and hydrogen. The abscissa is plotted in terms of kilovolts of regulated potential and the ordinate in centimeters of gas pressure. The length of the tube and the cathode radius are fixed at 10 centimeters and one centimeter respectively. The series voltage dropping resistance R_s is fixed at 100 megohms. In each of the three sets of curves the solid curve is representative of an anode radius of .038 centimeter and the dotted curve is representative of an anode radius of .3175 centimeter. From this figure it is apparent that the corona firing voltage for a given tube not only varies with gas pressure, but also with the selection of gas. It is also apparent that the corona firing voltage can be altered to a certain extent by altering the ratio electrode radii.

A similar set of curves drawn to represent regulated voltage versus gas pressure for two gases,

hydrogen and air is shown in Fig. 7. In this case the cathode diameter and length was fixed at three inches and 20 inches respectively. The solid curve of each set is representative of an anode diameter of one quarter inch, and the dotted curve is representative of an anode diameter of $\frac{13}{32}''$. Again it is apparent that increasing the gas pressure increases the firing voltage. Also that the firing voltage for air at a given pressure is greater than hydrogen, and hence greater than argon and helium.

The manner in which the voltage regulation characteristic of the circuit of Fig. 2 varies with electrode dimensions and types of filling gas is shown in Fig. 8 to which reference is now had. Curves shown in this figure are plotted as output voltage versus input voltage for several different gases, hydrogen, argon, helium, and air, and anode radii. In the circuit, the series voltage dropping resistance was fixed at 10 megohms and the cathode radius fixed at .5 centimeter. The solid curves are representative of the voltage regulation characteristic with the anode radius fixed at .0025 centimeter and the type of filling gas changed as indicated. Similarly, the dashed curves are representative of the regulation characteristics obtainable using a larger anode radius of .0125 centimeter. And finally the dotted curves are representative of the voltage regulation characteristic obtainable using a still larger anode radius of .064 centimeter. As will be noted from this figure, the regulation improves with larger anode radius or larger ratios of anode radius to cathode radius—irrespective of the gas filling. Moreover, that the regulation obtainable with hydrogen or air is nearly the same. Air being favored at the higher voltages due to its higher breakdown potentials.

In a specific example a tube constructed according to the teachings of the invention, comprises a cathode electrode made of copper 2.54 centimeters in diameter and ten centimeters long. The anode consisted of a stainless steel tube 6.4 millimeters in diameter. The electrodes were sealed at their ends by hard glass end caps, and the filling gas was hydrogen. Changing the gas pressure shifted the regulated voltage between 360 volts at less than one centimeter pressure to 9000 volts at one atmosphere pressure. The lower voltage limit of this tube was reduced to approximately 250 volts by using helium. From the foregoing it becomes apparent that the firing potential or regulated voltage is in large a function of gas pressure. Thus by providing a tube with means, such as the Sylphon bellows **20** as shown in Fig. 4, for adjusting the gas pressure, the firing potential can be changed accordingly. In this embodiment the tube is closed at one end by a glass seal **21** and at the other end by a bellows **20**. As exemplified, the anode cylinder **12** is rigid and is terminated at its free end in a glass insulating bead **22**. The cathode cylinder **11** is flanged at one end **23** to receive the bellows **20**, the same being sealed thereto to provide a gastight connection. The other end of the bellows **20** is terminated in a gastight seal to end plate **24** which is carried by a plurality of guide rods **27**. Guide rods **27** are bolted or otherwise secured at one end to the flanged end **23** of the cathode cylinder and similarly secured to support **28** at their other end. The bellows end plate **24** is provided with a series of pilot holes **35** for slideably receiving the guide rods **27**. The longitudinal positioning of the bellows end plate **24** is controlled from a screw member **30** which is adapted to engage the threads of an internally threaded aperture cut in support 28. Turning screw 30 compresses or expands bellows 20 to thereby change the pressure of the gas in the tube and hence the firing voltage thereof.

The diode regulator tube provided by this invention is well suited for types of regulator circuits other than that shown in Fig. 2. For example, the diode may be employed as a means for obtaining a reference potential as illustrated in Fig. 3. In this application, a series hard tube 40 is used as a variable impedance and the diode 10 as a source of reference potential for the grid of the hard tube. Diode 10 operates to inversely vary the conductivity of the hard tube with variations in output voltage. This regulator circuit is particularly advantageous for high current loads. Other modifications and variations can of course be made in the present invention without exceeding the spirit thereof. Accordingly, although I have shown only certain and specific embodiments of the inventon it must be understood that I am fully aware that there are many other modifications possible thereof.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. A diode voltage stabilizing tube; comprising an outer cylindrical non-thermionic cathode electrode and an inner cylindrical anode electrode coaxially disposed within said outer electrode providing an annular space therebetween, the ratio of said cathode radius to said anode radius being only slightly greater than the Napierian logarithm base, a gaseous medium filling said space to a predetermined pressure operative to produce a self-sustaining corona discharge within the tube at a desired operating voltage.

2. A diode voltage stabilizing tube; comprising an outer cylindrical non-thermionic cathode electrode and an inner cylindrical anode electrode coaxially disposed within said outer electrode providing an annular space therebetween, the ratio of said cathode radius to said anode radius being only slightly greater than the Napierian logarithm base, a body of air filling said space to a pressure operative to produce a self-sustaining corona discharge at the desired operating voltage.

3. A diode voltage regulator tube comprising, a pair of spatially disposed non-thermionic electrodes one of which surrounds the other and has a radius of curvature approximately three times greater than the other, said one of said electrodes serving as the cathode of said tube and the other as the anode of the tube, and a gaseous

medium filling the space between said electrodes to a predetermined pressure, said pressure being characterized by the production of corona discharge between said electrodes at the desired operating voltage.

4. A diode voltage regulator tube comprising, a pair of non-thermionic cylindrical electrodes one coaxially surrounding the other and having a radius of curvature approximately three times greater than the other, insulating plugs sealing said electrodes together at their adjacent ends thereby providing a gastight chamber therebetween, and a gaseous medium filling said chamber to a predetermined pressure, said pressure being characterized by the production of a self-sustaining corona discharge between said electrodes at the desired operating voltage.

5. A diode voltage regulator tube comprising, a pair of spatially disposed non-thermionic cylindrical electrodes one of which has a radius of curvature approximately three times greater than the other, said one of said electrodes serving as the cathode of said tube and the other as the anode of the tube, and a body of air filling the space between said electrodes to a predetermined pressure, said pressure being characterized by the production of a self-sustaining corona discharge between said electrodes at the desired operating voltage.

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