Nov. 2, 1937. E. KOBEL 2,097,490

ELECTRON DISCHARGE DEVICE

Filed Dec. 21, 1933 3 Sheets-Sheet 1

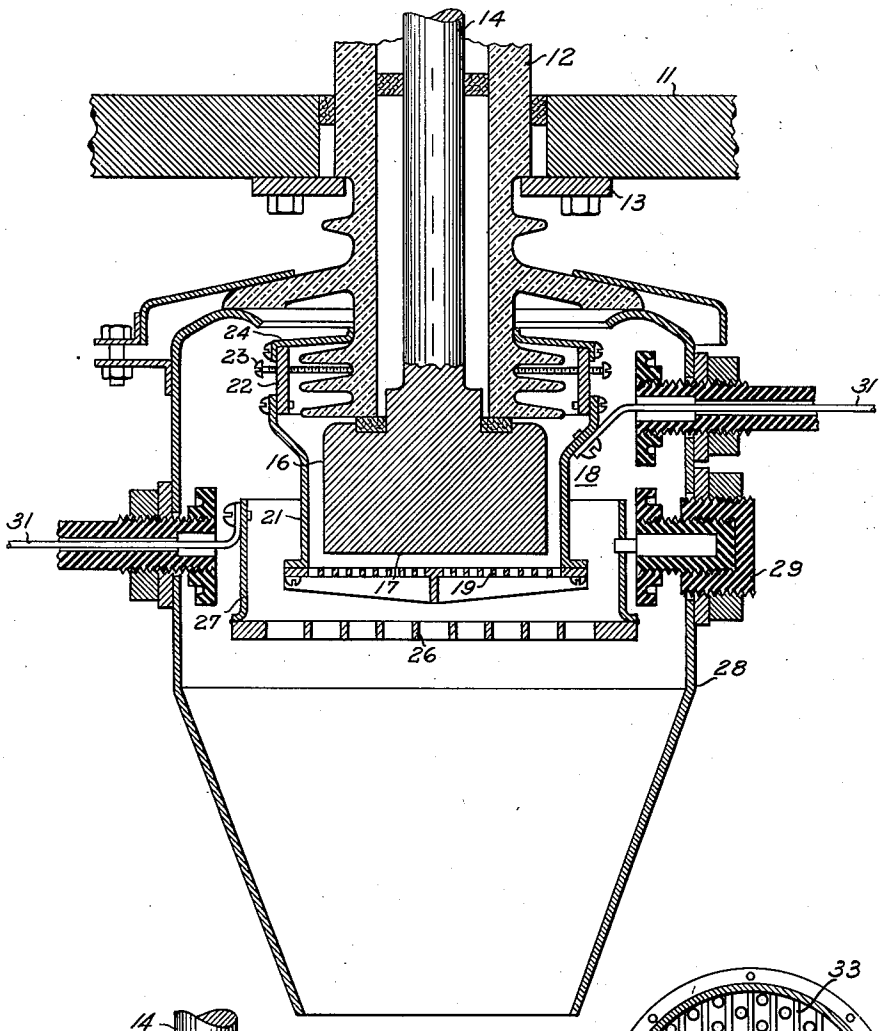

Fig. 1

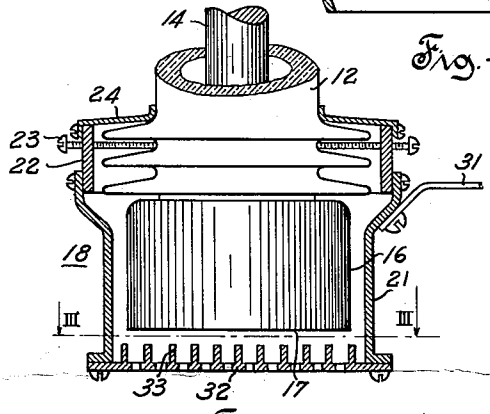

Fig. 2

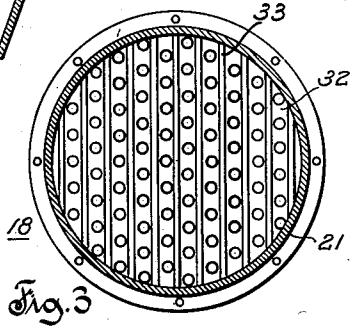

Fig. 3

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ELECTRON DISCHARGE DEVICE

Filed Dec. 21, 1933 3 Sheets-Sheet 2

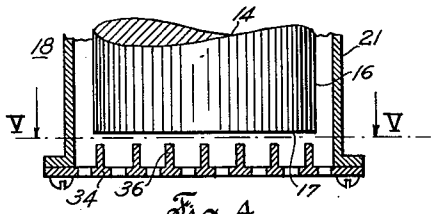

Fig. 4

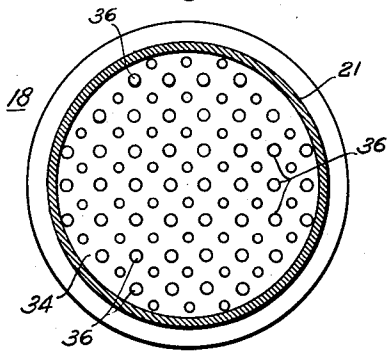

Fig. 5

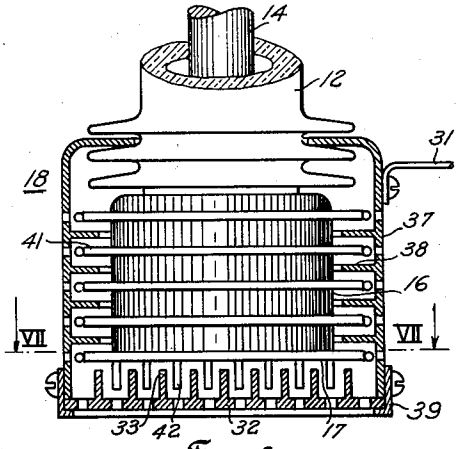

Fig. 6

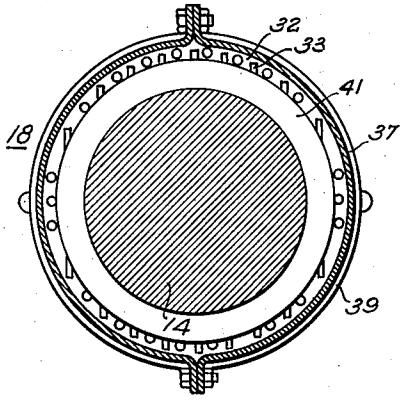

Fig. 7

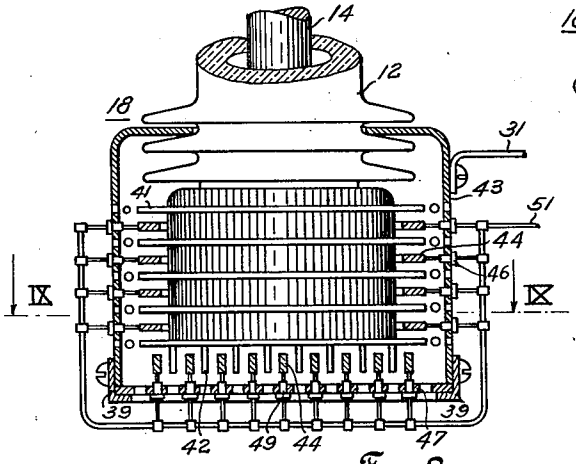

Fig. 8

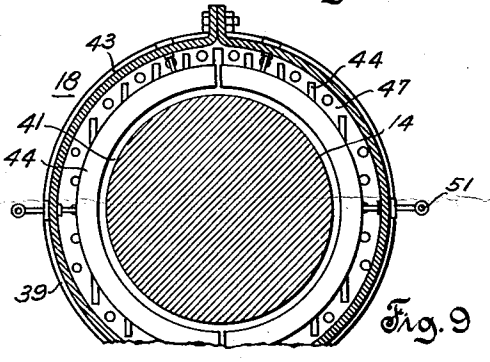

Fig. 9

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Nov. 2, 1937. E. KOBEL 2,097,490

ELECTRON DISCHARGE DEVICE

Filed Dec. 21, 1933 3 Sheets-Sheet 3

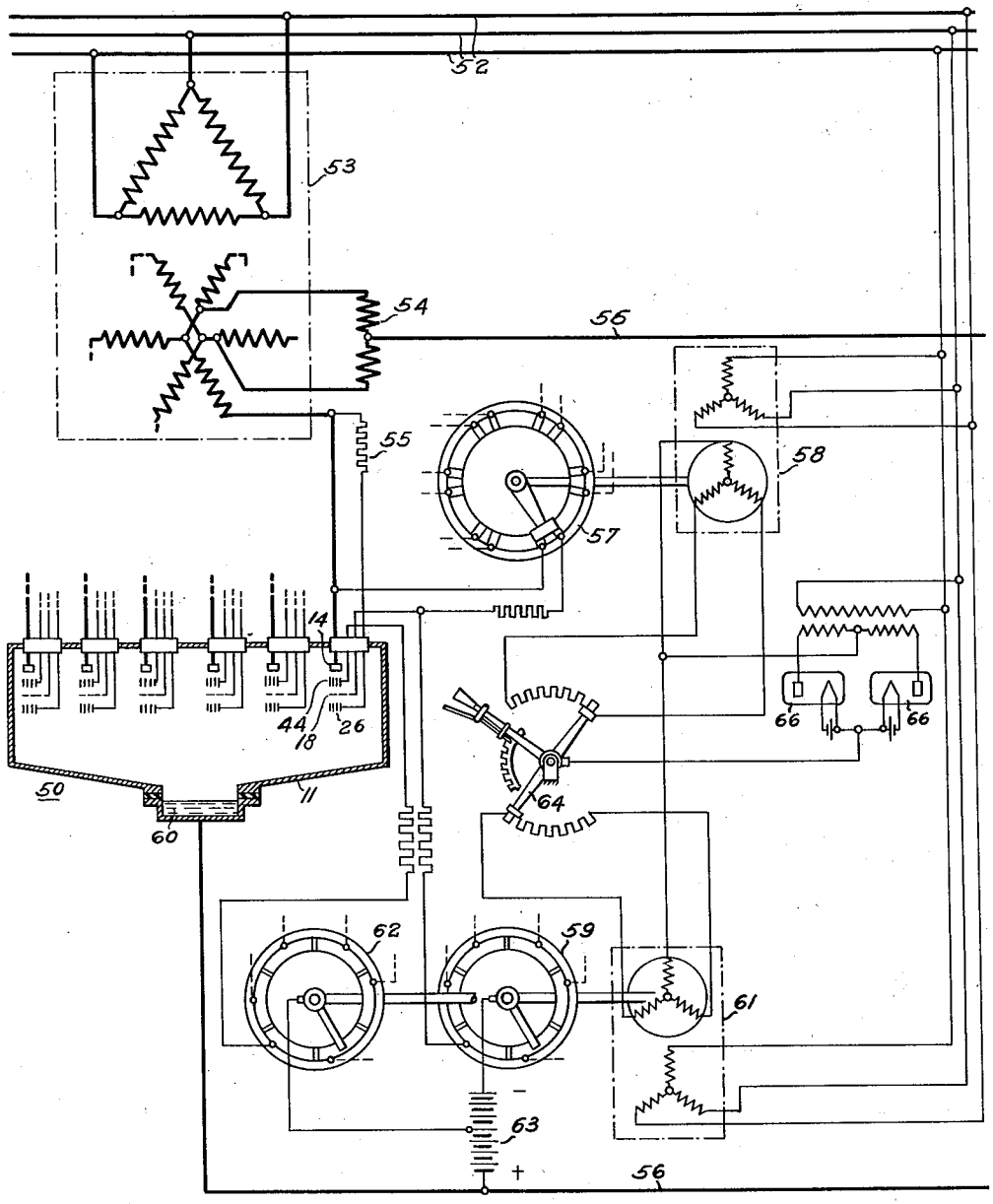

Fig. 10

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Patented Nov. 2, 1937 2,097,490

UNITED STATES PATENT OFFICE

2,097,490

ELECTRON DISCHARGE DEVICE

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Application December 21, 1933, Serial No. 703,349
In Germany December 24, 1932

8 Claims. (Cl. 250—27.5)

This invention relates generally to electron discharge devices and more particularly to means for controlling the discharge within an electric valve in which current is conducted through a gas or a vapor.

A large number of different kinds of electric valves of the vapor type are known in which current is conducted between one or more anodes and one or more cathodes through attenuated gas or vapor or sometimes through air at atmospheric pressure. It is generally considered that the flow of current is effected almost entirely by the flow of electrons between the cathode and the anode, such electrons being primarily produced at the cathode by the thermal emission of a filament maintained at incandescence or of an incandescent spot of a mercury pool, or by other processes in valves utilizing cold cathodes. The vapor contained within the valve is then ionized by collision of such electrons to an extent which results in the presence, within the discharge path, of positive ions in number substantially equal to the number of electrons, thereby causing the apparent neutrality of such space. The flow of current then occurs under a low anode to cathode voltage if the space charge of the electrons which tends to hinder such flow is substantially neutralized.

Such valves are frequently provided with control electrodes, but although the control electrodes known heretofore were operative to prevent and to release the flow of current through the valve in dependence upon the potential of such control electrodes, the flow of the current could not be interrupted thereby after being once established. Such result is due to the fact that when a control electrode is negatively energized with respect to the associated cathode, it becomes surrounded by a sheath of positive ions which completely absorbs the potential difference between the control electrode and the cathode. The grid therefore becomes incapable of controlling conditions within the valve outside of the ion sheath.

If, however, means are provided for removing the positive charges of the ions within the discharge path, over at least a portion of the length thereof, by neutralizing such charges at a rate greater than the rate of appearance thereof, it is possible to obtain within such space a purely electronic flow of current which can be controlled and interrupted by suitable discharge controlling means such as a control electrode. Such removal of ionic charges is preferably effected by means of a control electrode suitably arranged and of suitable dimensions.

The initiation of a discharge or arc from the anode may then require energization of the control electrode at a positive potential and this potential may advantageously be reduced if an auxiliary or excitation discharge is caused to occur through the space adjacent the control electrode. Such excitation discharge also provides ionized vapor in the space between the anode and the control electrode during operation of the anode, thereby neutralizing the electronic space charge in such space and decreasing the voltage drop of the discharge. When the flow of current through the anode is interrupted by the action of the control electrode, the magnetic energy stored in the anode circuit will cause appearance of a voltage surge at the anode which is preferably dissipated over a suitable discharge path.

It is, therefore, one of the objects of the present invention to provide an electron discharge device of the gas or vapor type in which current flowing from an anode to cathode can be interrupted as well as released by control means while the anode is positive with respect to the cathode.

Another object of the present invention is to provide an electron discharge device of the gas or vapor type in which the current flowing from an anode to a cathode can be interrupted by energizing a control electrode at a negative potential less than the potential which would produce backfiring of such electrode.

Another object of the present invention is to provide an electron discharge device of the gas or vapor type in which the flow of current through an anode is initiated and maintained by the ionizing action of an excitation discharge.

Another object of the present invention is to provide an electron discharge device of the gas or vapor type in which voltage surges appearing on the anode are diverted over a discharge path.

Another object of the present invention is to provide an electron discharge device of the gas or vapor type in which a portion of the discharge path may be deionized to permit control and interruption of the discharge.

Objects and advantages other than those above described will be apparent from the following description when read in connection with the accompanying drawings, in which:

Fig. 1 illustrates, in cross-section, an anode structure for an electron discharge device having a control electrode and an auxiliary elec-

trode constructed in accordance with the present invention;

Figs. 2 to 7 illustrate three modified embodiments of the control electrode utilized in the present invention;

Figs. 8 and 9 illustrate a portion of another embodiment of the present invention utilizing a separate deionizing electrode; and

Fig. 10 diagrammatically illustrates an example of one of the numerous possible connections of an electron discharge device constructed in accordance with the present invention and utilized as an alternating current rectifier.

Referring more particularly to the drawings by characters of reference, reference numeral 11 designates the casing wall of a discontinuously controllable electron discharge device such as an electric valve of the vapor type and having an aperture therethrough receiving the anode structure to be hereinafter described. An insulator bushing 12 extends through such aperture and is supported from wall 11 by suitable means such as a split collar 13 bolted on the wall. The joint between wall 11 and insulator 12 is sealed by any means known in the art whereby a gas tight joint may be obtained. Insulator 12 supports an anode 14 having a stem portion extending through the insulator and a head portion receiving the discharge. The head portion of the anode is pressed against the lower part of the insulator by suitable means (not shown) and the anode is sealed against the insulator in any suitable manner. It will be understood that anode 14 may be constituted of any suitable conductive materials and may be constructed with a plurality of separate portions of different materials. Anode 14 will generally present a cylindrical surface 16 and an end surface 17 although anodes of any other suitable shape and construction may be used.

Anode 14 is associated with a control electrode generally designated 18 having dimensions to be more particularly specified hereinafter. In the present embodiment, control electrode 18 is represented as comprising a perforated plate 19 provided with reinforcing ribs and supported from insulator 12 by an unperforated cylinder 21 and a ring 22 provided with set screws resting in corrugations of insulator 12. To force the discharge to pass only through the apertures of plate 19, ring 22 is sealed against insulator 12 by a sealing ring 24. The discharge also comes into contact with an auxiliary electrode 26 herein constituted by a plate having large perforations and reinforced by a ring 27. Electrode 26 is supported within a discharge guide 28 by means of suitable insulators 29. Electrodes 19 and 26 are connected with suitable energizing means through insulated leads 31. Guide 28 is preferably supported from insulator 12 in sealing engagement therewith to cause the discharge to occur only through the lower part of the guide.

In the modification illustrated in Figs. 2 and 3, plate 19 of control electrode 18 is replaced by a perforated plate 32 provided with a plurality of parallel fins 33 constituting collecting surfaces for the charges of positive ions present in the space between the anode 14 and control electrode 18.

In the embodiment illustrated in Figs. 4 and 5, plate 19 is replaced by a perforated plate 34 provided with a plurality of pins 36 having the same purpose as fins 33 in Figs. 2 and 3.

In the embodiment illustrated in Figs. 6 and 7, the control electrode 18 consists of finned plate 32 and of a cylindrical portion 37 made in two parts attached to plate 32 by means of a ring 39, and provided with a flange portion resting in a corrugation of insulator 12. Cylinder 37 is provided with a plurality of annular fins 38 having the same purpose as fins 33 of plate 32 and is preferably perforated in the same manner as the plate. Anode 14 may be provided with parallel fins 42 occupying the spaces between fins 33 and with annular fins 41 occupying the spaces between fins 38.

In the embodiment illustrated in Figs. 8 and 9 control electrode 18 comprises a cylindrical portion 43 and a plate 47 similar to cylinder 37 and plate 32 of the embodiment illustrated in Figs. 6 and 7 but not provided with interior fins. In the present embodiment such fins are replaced by a separate ion collecting electrode structure 44 comprising a plurality of annular members supported on cylinder 43 by means of insulators 46 and a plurality of rectilinear members supported in plate 47 by insulators 49. The electrode structure 44 is connected with a suitable energizing means to be described hereinafter by means of a lead 51, but is not of dimensions such as to thereby prevent initiation of the flow of current through the anode.

In each of the above described embodiments the control electrode utilized is of a type so arranged and so dimensioned as to permit not only blocking of the flow of current between anode 14 and the associated cathode (not shown) but also to permit instantaneous interruption of such flow of current upon negative energization of such control electrode by means of a suitable source. To obtain such interruption the positive charges of the ions present over a portion of the length of the discharge path, such as for instance in the space between the anode and the control electrode, must be largely eliminated. In other words, the ionic charges within such space must be removed at a rate greater than the rate of appearance of such charges as the result either of collisions of the electrons with vapor atoms therein or of wandering of ions from the space outside the control electrode through the openings thereof. Upon substantially complete removal of such charges the control electrode becomes operative to control or to completely interrupt the flow of electrons therethrough, the complete interruption being obtained by impressing a suitable negative potential on the control electrode to prevent any further transport of charges at the anode. To obtain such result without resorting to the use of a source of such high voltage as to introduce disturbances in the operation of the device, it is necessary to employ control electrodes having dimensions maintained within predetermined limitations. It is, however, not possible to define the permissible range for all dimensions of the control electrode because the dimensions of each portion thereof limit the permissible range of dimensions of all the other portions, and all such dimensions are dependent upon the nature of the vapor carrying the discharge, the temperature, the pressure and the degree of ionization thereof, as well as upon the potentials impressed between the control electrode and the cathode and between the anode and the cathode, and on the amount of current flowing therebetween. It has been found that the desired result is accomplished, in particular, by means of a control electrode having all the openings thereof, available for the passage of the discharge, so dimensioned that the ion sheaths formed about the several portions of the structure substantially fill all such openings when such

control electrode is unenergized or is energized at negative potentials of any magnitude with respect to the associated cathode. Irrespective of such condition, the openings of the control electrode should preferably be of dimensions less than twice the mean free path of the electrons in the device to substantially prevent ionization by collision within such openings and thus facilitate the deionizing action of the electrode. The total area of such openings must also be limited and should preferably not exceed 40% of the area of the anode carrying the discharge. The distance between the control electrode and the anode should be comparable with the mean free path of the electrons, but should not exceed fifty times the greatest dimension of such openings. The area of the control electrode in contact with the space contained between such electrode and the associated anode, plus the total area of the surfaces of such control electrode forming the openings thereof, which surfaces jointly operate to collect the charges of positive ions present in the space between the control electrode and the anode, should be greater to a variable extent than the total cross-section area of such openings. The lower limit of the ratio of such areas varies with the distance between the control electrode and the anode and should exceed the value 2.5 in a device utilizing mercury vapor when such distance is equal to the mean free path of the electrons. It will be understood that such dimensions are given only as an example of constructions which have been found successful by experiment but that such dimensions and the arrangement of the control electrode may be departed from to a considerable extent. With the above dimensions, it is possible to interrupt current through an anode by impressing on the control electrode a negative potential less than the amplitude of the positive potential of the anode immediately after interruption of the current therethrough.

The effectiveness of control electrode **18** may be impaired if the space adjacent such control electrode contains appreciable amounts of gases or vapors other than the operating vapor. It is, therefore, advantageous to make the control electrode of materials which do not easily adsorb gases or vapors and from which, therefore, gases or vapors are released in only inappreciable amounts at operating temperatures. Among the materials particularly suitable for the construction of the control electrode are metals or alloys such as nickel, nickel steel, chrome nickel steel, molybdenum, tungsten and tantalum. The control electrode is preferably made by casting or sintering such metals in vacuum and may be subsequently heat treated in vacuum to further decrease the foreign gas content of the material.

The method of operation and the scope of the present invention will be more clearly understood from a consideration of the application thereof in the system illustrated in Fig. 10, which corresponds to the embodiment of the invention as illustrated in Fig. 1 of the drawings of the Ernst Kobel copending application Serial No. 677,069, filed June 22, 1933, enitled "Electron discharge control device"; and which is per se claimed therein. In such figure a discharge device **50** is diagrammatically represented as being of the type having a mercury pool cathode **60** and as being provided with a plurality of anode structures similar to anode **14** with the associated control electrode **18**, and also provided with electrodes such as **26** and **44** if so desired. It is assumed that device **50** is utilized for rectifying current transmitted from an alternating current line **52** through a transformer **53** and an interphase transformer **54** to a direct current line **56** connected with cathode **60** and the interphase transformer **54**. Each anode **14** is connected with the associated electrode **26** through a resistor **55**, and is connected with the associated control electrode **18** through one of the segments of a distributor **57** having a brush driven by a synchronous motor **58** energized from line **52**. Each control electrode **18** is further connected with a source of negative potential with respect to cathode **60** such as battery **63** through one of the contacts of a distributor **59** driven by a synchronous motor **61** energized from line **52**. When electrodes such as **44** are utilized, each such electrode is connected with a suitable point of battery **63** either directly or through a distributor **62** operating in conjunction with distributor **59**. Synchronous motors **58** and **61** are each provided with a plurality of field windings receiving exciting current from line **52** through rectifying devices **66** and a regulating device **64** to adjust the moments of energization of the several electrodes of device **11** during the voltage cycle of line **52**.

In operation, assuming that line **52** is energized and that motors **58** and **61** have been brought to synchronous speed, anode **14** receives, from transformer **53**, an alternating voltage recurringly bringing such anode to a positive potential with respect to cathode **60**. Electrode **26** is then likewise brought to a positive potential and carries a current limited by resistor **55**, which ionizes the discharge path between anode **14** and cathode **60**. At a moment of the voltage cycle of line **52** depending upon the adjustment of regulator **64**, distributor **57** connects anode **14** with control electrode **18**. Such control electrode then also carries current and releases the flow of current between anode **14** and cathode **60** in the manner well known in the art. Such flow of current continues to occur until connection of electrode **44** and of control electrode **18** with battery **63** is effected through distributors **62** and **59**. Upon such connection and as a result of the construction and arrangement of control electrode **18** in the manner above specified, the charges of the ions present between control electrode **18** and anode **14** are removed at a rate greater than the rate of appearance of such ions within such space by collision or by wandering through the control electrode apertures. As a result of such removal, the space charge of the electrons between anode **14** and control electrode **18** is no longer entirely neutralized and the uncompensated fraction of such space charge causes the electrons originating at cathode **60** or in the adjacent space to reach anode **14** with greater difficulty and, therefore, in smaller number. The ions produced by collisions of such electrons with vapor atoms, therefore, also appear at a lesser rate whereas the capacity of the electrodes **18** and **44** to remove such ions remains undiminished, with the result that such ions are removed with increasing ease, and the resulting increasing impedance of the space confined between anode **14** and control electrode **18** causes the flow of electrons within such space to decrease to a value comparable with the flow of electrons in a valve of the vacuum type. Such flow of electrons may then be controlled by the action of control electrode **18** which repels such electrons as a result of the negative energization thereof and causes all transport of charges between anode **14** and cathode **60** to

cease. Such sequence of operation is repeated for each anode 14 during the voltage cycle of line 52 to cause a flow of substantially uniform current through cathode 60 and line 56.

It will be understood that devices constructed in accordance with the present invention may also be utilized for all the purposes for which devices both of the vapor and of the vacuum type are utilized at present. Although in the embodiments illustrated a portion of the space within the device is deionized by either the control electrode alone or the control electrode in conjunction with an auxiliary electrode, such deionization may be effected by the auxiliary electrode alone or by any other suitable means. When such space has been deionized, the control of the electronic discharge may also be effected by any suitable means other than the control electrode illustrated in the above described embodiments. If the control electrode is used, it has been found sufficient to deionize the space on one side only of such control electrode, but if so desired, the space on both sides of the control electrode may likewise be deionized by the provision of charge collecting surfaces or of equivalent means. It is, of course, necessary that the discharge path be deionized over the entire cross-sectional area thereof. In the embodiments illustrated, the control electrode completely encloses the anode head, but where a discharge guide such as guide 28 illustrated in Fig. 1 is provided, such discharge guide may cooperate with the control electrode in separating the space surrounding the anode head from the space between the control electrode and the cathode.

Although but a few embodiments of the present invention have been illustrated and described, it will be apparent to persons skilled in the art that various changes and modifications may be made therein without departing from the spirit of the invention or from the scope of the appended claims.

It is claimed and desired to secure by Letters Patent:

1. An electron discharge device of the vapor arcing type having an electron emitting cathode in contact with a body of ionizable vapor, an anode positioned to receive electrons from said cathode ionizing said vapor and constituting with said cathode spaced electrodes for the flow of current by way of arcs through said vapor, and means for controlling said flow of current by interruption of said arcs while the said anode is subjected to potential of sign and magnitude sufficient to maintain said arcs comprising a control electrode spaced from said anode by approximately the mean free path of said electrons and having apertures therethrough of a total cross-section area of approximately forty percent of the arcing surface of said anode, and having a total area in contact with the space contained between the control electrode and said anode, plus the total area of the surfaces forming said apertures, of not less than two and a half times the total cross-section area of said apertures.

2. An electron discharge device of the vapor arcing type having an electron emitting cathode in contact with a body of ionizable vapor, an anode positioned to receive electrons from said cathode ionizing said vapor and constituting with said cathode spaced electrodes for the flow of current by way of arcs through said vapor, and means for controlling said flow of current by interruption of said arcs while the said anode is subjected to potential of sign and magnitude sufficient to maintain said arcs comprising a control electrode spaced from said anode by approximately the mean free path of said electrons and having apertures therethrough of a total cross-section area of approximately forty percent of the arcing surface of said anode, and having a total area in contact with the space contained between the control electrode and said anode, plus the total area of the surfaces forming said apertures, of not less than two and a half times the total cross-section area of said apertures, and another electrode arranged in the path of said arcs between said control electrode and said cathode and connected with said anode.

3. In an electron discharge device of the vapor arcing type, the combination of a cathode, an anode constituting with said cathode spaced electrodes for the flow of current by way of arcs therebetween, and means for controlling said flow of current by interruption of said arcs during periods when said anode and cathode are subjected to potential differences sufficient to maintain said arcs comprising a control electrode having a surface thereof positioned from the arcing surface of said anode at a distance not greater than the length of the mean free path of electrons involved in sustaining said arcs and having apertures defined by opposite surfaces distant not more than twice the thickness of ion sheaths produced within said apertures when subjected to potential more negative than the potential of said cathode.

4. In an electron discharge device of the vapor arcing type, the combination of a cathode, an anode constituting with said cathode spaced electrodes for the flow of current by way of arcs therebetween, and means for controlling said flow of current by interruption of said arcs during periods when said anode and cathode are subjected to potential differences of sign and magnitude sufficient to maintain said arcs comprising a control electrode having a surface thereof positioned from the arcing surface of said anode a distance not greater than the length of the mean free path of the electrons involved in sustaining said arcs, and having a plurality of apertures constituting paths for the flow of said current of a total cross section area of approximately forty percent of the arcing surface of said anode.

5. In an electron discharge device of the vapor arcing type, the combination of a cathode, an anode constituting with said cathode spaced electrodes for the flow of current by way of arcs therebetween, and means for controlling said flow of current by interruption of said arcs during periods when said anode and cathode are subjected to potential differences sufficient to maintain said arcs comprising a control electrode positioned across the path of said arcs and having a plurality of apertures of a total cross section area of approximately forty percent of the arcing surface of said anode, and having a total area in contact with the space contained between the said control electrode and anode, plus the total area of the surfaces forming said apertures, of not less than two and one-half times the total cross section area of said apertures.

6. The combination with a cathode and an anode comprising elements of an electron discharge device of the vapor arcing type and constituting spaced electrodes for the flow of current by way of arcs therebetween, of means for controlling said flow of current by interruption of said arcs during periods when the said anode and cathode are subjected to potential of sign

and magnitude sufficient to maintain said arcs comprising a control electrode having a surface thereof positioned at a distance from the arcing surface of said anode not greater than the length of the mean free path of the electrons involved in sustaining said arcs and having a plurality of apertures forming paths for the flow of said current and of such cross section area that the distance between opposite surfaces defining the same is not greater than twice the thickness of ion sheaths produced therein when subjected to a potential more negative than the potential of said cathode, and means comprising an auxiliary electrode having connection with said anode and so positioned relative to said cathode as to constitute therewith spaced electrodes for the discharge of voltage surges occurring upon the said interruption of said arcs.

7. In an electron discharge device of the vapor arcing type, the combination with an electron emitting cathode supported in contact with a body of ionizable vapor, and an anode positioned to receive electrons from said cathode ionizing said vapor and constituting with said cathode spaced electrodes for the flow of current by way of arcs through said vapor, of means for controlling said flow of current by interruption of said arcs during periods when said anode is subjected to potential of sign and magnitude sufficient to maintain said arcs comprising a control electrode having a surface thereof positioned at such a distance from the arcing surface of said anode as to deionize the space therebetween when subjected to a potential more negative than the potential of said cathode, and having a plurality of apertures forming paths for the flow of said current of such cross section area that the distance between opposite surfaces defining the same is not greater than twice the thickness of ion sheaths produced therein when subjected to said potential, and means comprising an auxiliary electrode having apertures forming paths for said arcs positioned in the space between said control electrode and said cathode for deionizing the same upon being subjected to a potential of suitable sign and magnitude to thereby facilitate the said arc interruption action of said control electrode.

8. The combination in an electron discharge device comprising an evacuated chamber having a cathode of vaporizable material and an anode supported thereon and constituting with said cathode spaced electrodes for the flow of current by way of arcs therebetween, and a shield supported within said chamber about said anode and forming a guide for said arcs, of means for controlling said flow of current by controlling the initiation and interruption of said arcs during periods when said anode and cathode are subjected to potential differences of sign and magnitude sufficient to maintain said arcs comprising a control electrode supported within said shield with a surface thereof positioned from the arcing surface of said anode at a distance not greater than the length of the mean free path of electrons involved in sustaining said arcs and having apertures defined by opposite surfaces distant not more than twice the thickness of ion sheaths produced within said apertures when subjected to potential more negative than the potential of said cathode, and an auxiliary anode supported within said shield intermediate said cathode and control electrode and cooperating with the latter to intensify the ionization of the vapor within said shield when subjected to potential more positive than the potential of said cathode, to thereby facilitate the initiation of said arcs.

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