Sept. 24, 1946. C. M. SLACK ET AL 2,408,004

CONSTANT VOLTAGE FIELD EMISSION ARC DISCHARGE DEVICE

Filed Sept. 26, 1942 2 Sheets-Sheet 1

Fig. 1.

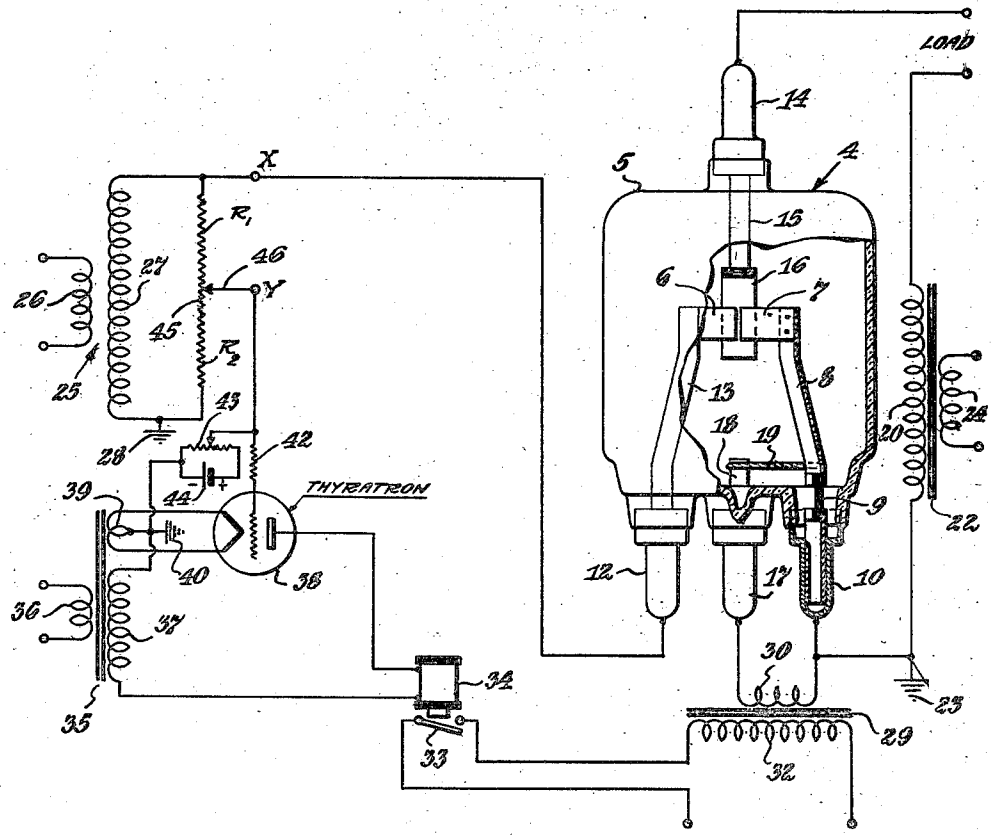


Fig. 2.

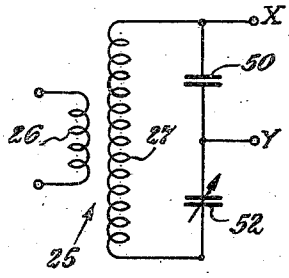
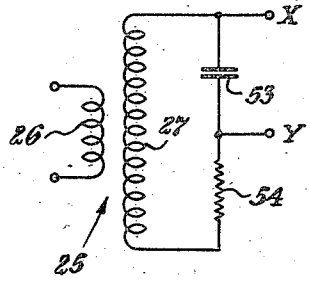


Fig. 3.



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Fig. 4.

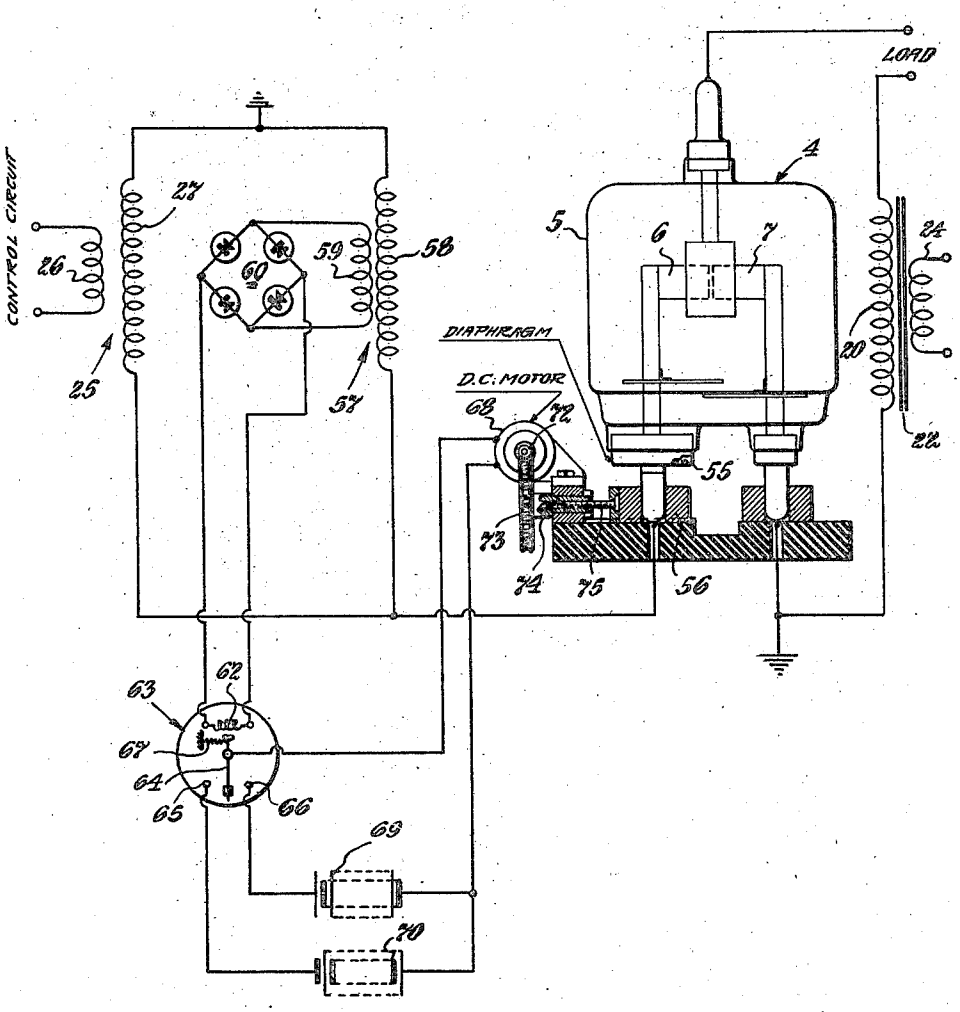
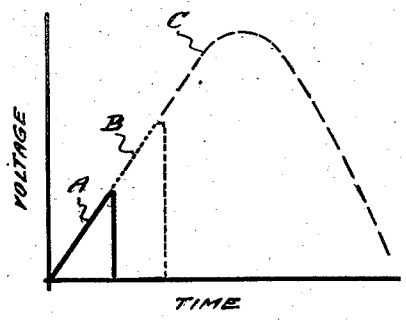


Fig. 5.



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CONSTANT VOLTAGE FIELD EMISSION ARC DISCHARGE DEVICE

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Application September 26, 1942, Serial No. 459,777

9 Claims. (Cl. 315—357)

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The present invention relates to discharge devices and more particularly to such devices wherein operation is initiated by a "field emission" arc discharge as an electron source.

A device of this character is fully shown and described in the copending application of Charles M. Slack et al., Serial No. 412,566, filed Sept. 27, 1941, and assigned to the same assignee as the present invention. As pointed out in this application, in the operation of devices of this character field emission of electrons occurs between a pair of "cold" electrodes due to the high potential gradient at the cathode. This electrostatic field pulls electrons from one of the electrodes which causes a minute arc discharge to form between the starting electrode and the cathode, apparently due to evolved metallic particles, and the positive ion bombardment caused by ionization of the evolved metal vapor resulting from the arc, forms a cathode spot and reduces the impedance of the device, and an electron discharge between the cathode and anode of the device almost instantaneously occurs following initiation of the arc discharge between the starting electrode and cathode.

It has been found that a certain amount of material will be lost from and transferred between the closely spaced electrodes between which the "field emission arc" is initiated. This loss and transfer of material is inherent in the operation of this "field emission arc" since, contrary to other high current sources in tubes, a device of this character does not depend upon the ionization of volume gases or vapor within the tube, but is dependent primarily on the positive ions which are the result of the vaporized material from one of the electrodes interacting with the field emission electrons. The positive ions are necessary to relieve space charge and to increase the field concentration at the cathode spot which in turn produces more field and Schotky electrons.

This loss of electrode material tends eventually to increase the electrode spacing, causing an increase in the voltage required to initiate the "field emission arc," finally leading to a condition where operation of the device becomes unsatisfactory because of the high initiating voltage involved, or the device may stop functioning altogether because of a lack of sufficient voltage. From such characteristics it follows that even though the spacing between the initiating electrodes may not be measured directly, nevertheless, this spacing is a function of the voltage required to initiate the "field emission arc" and is a definite factor in the useful life of the device.

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In the copending applications of Charles M. Slack et al., Ser. No. 459,775, and John H. Findlay et al., Serial No. 459,776, both filed concurrently herewith and assigned to the same assignee as the present invention, various structures are shown and claimed for maintaining the electrode spacing and hence the initiating voltage substantially constant during the useful life of the device. Although such structures operate satisfactorily, they are subject to the disadvantage that they are dependent on the human element by requiring manipulation by an operator.

It is accordingly an object of the present invention to provide a discharge device wherein operation is initiated by a "field emission arc" and the spacing between the ignition electrodes is automatically maintained substantially constant throughout the useful life of the device.

Another object of the present invention is the provision of a discharge device wherein operation is initiated by a "field emission arc" and the voltage required to initiate such arc discharge is automatically maintained substantially constant throughout the useful life of the device.

A further object of the present invention is the provision of a discharge device wherein operation is initiated by a "field emission arc" and the spacing between the ignition electrodes is automatically maintained substantially constant to thus maintain a constancy of the ignition voltage despite an inherent tendency for the spacing between the electrodes to increase due to loss of electrode material during the useful life of the device.

Still further objects of the present invention will become obvious to those skilled in the art by reference to the accompanying drawings wherein:

Fig. 1 is a schematic diagram of the automatic control arrangement of the present invention for maintaining the spacing between the ignition electrodes of a field emission discharge device constant and showing such device partially in cross section;

Fig. 2 is a schematic diagram showing a modification which a portion of the automatic control arrangement of Fig. 1 may take;

Fig. 3 is a view similar to Fig. 2 but showing a still further modification which a portion of the automatic control arrangement of Fig. 1 may take;

Fig. 4 is a schematic diagram of another automatic control arrangement for maintaining constancy of spacing between the ignition electrodes

and hence constancy of ignition voltage in accordance with the present invention, and

Fig. 5 is a graphic illustration of the voltage required to initiate a "field emission arc" with a given electrode spacing, together with the relationship of the ignition voltage for a somewhat greater spacing, as well as an electrode spacing too great for field emission to occur.

Referring now to the drawings in detail, the present invention as shown in Fig. 1 comprises a discharge device 4 having a vitreous envelope 5 provided with a pair of oppositely disposed ignition electrodes 6 and 7 of substantially rectangular configuration with their edges parallel to each other and spaced apart a distance of less than approximately .010 inch. The structural details of the device 4 are set forth in detail in the above noted concurrently filed application of Charles M. Slack et al., Serial No. 459,775, and reference may be had thereto, making further description herein superfluous.

It should suffice to say that the cathode electrode 7 is supported by a leading-in and supporting conductor 8 provided with a bimetallic portion or section 9 and secured by welding, soldering, or the like, to a terminal 10. A similar terminal 12 and leading-in and supporting conductor 13 is provided for the starting electrode 6 and a terminal 14 and leading-in conductor 15 for the anode 16, except that these latter conductors 13 and 15 are not provided with a bimetallic portion. For the purpose of passing a heating current through the bimetallic portion 9 a terminal 17 is provided which is connected to the electrode side of the leading-in and supporting conductor 8 by a short support or rod 18 and horizontally disposed conductor 19.

Although the discharge device 4 has a variety of usages, it is here shown as a control tube for supplying energy to a load. In such application the secondary winding 20 of a high tension transformer 22 has one end connected directly to the "load," as indicated by the legend, while its remaining end is connected to the terminal 10 and hence to the cathode 7 and also grounded at 23. Since the anode 16 is connected through its terminal 14 to the "load," energy from the secondary winding 20 is supplied as soon as the device 4 becomes conductive. The transformer 22 has its primary winding 24 connected to the customary domestic source of potential of 115–230 volts.

In order to cause the formation of a "field emission arc" between the ignition electrodes 6 and 7, an induction coil 25 is provided, the primary winding 26 of which may be connected to a suitable source for supplying an energy impulse thereto, such as that shown in the above-mentioned copending application of Charles M. Slack et al., Serial No. 412,566, filed Sept. 27, 1941. The secondary winding 27 of this induction coil 25 has one end connected to the terminal 12, and hence to the starting electrode 6, while its remaining end is grounded at 28; and since the cathode is grounded at 23 as before mentioned, the potential of this secondary winding, resulting from the impulse induced therein by energization of the primary winding 26, is impressed across the ignition electrodes 6 and 7.

A high potential gradient at the cathode 7 accordingly results, causing the formation of a "field emission arc" discharge between the ignition electrodes 6 and 7. Such arc in turn causes an electron discharge to occur almost instantaneously between the cathode 7 and anode 16, as hereinbefore mentioned, with the device 4 then becoming conductive, allowing energy from the transformer secondary 20 to be supplied to the "load." The ignition electrodes, as before mentioned, are subject to wear due to the evolution of metallic particles which tends to increase the spacing therebetween, as well as causing an increase in the voltage required to initiate the "field emission arc."

In order to maintain the electrode spacing and hence the ignition voltage constant, a source of heating current is provided for the bimetallic section 9 comprising a transformer 29 having its secondary winding 30 connected to the terminals 10 and 17 and thus through the rod 18 and conductor 19 to the bimetallic portion 9, while the primary winding 32 is arranged to be connected to a source of the customary domestic potential of 115–230 volts upon attraction of the armature 33 of a relay 34. For the purpose of energizing this relay 34 a further transformer 35 is provided which also has its primary winding 36 connected to the same domestic source as that of the primary windings 24 and 32.

The main secondary winding 37 of this transformer 35 has one of its ends connected to one end of the winding of the relay 34, while the remaining end of this relay winding is connected to the anode of a three-electrode control tube 38. The filamentary cathode of this control tube 38 receives heating current from a low voltage tertiary winding 39 of the transformer 35; and in order to complete the control circuit for the relay 34, the remaining end of the secondary winding 37 connects to the mid-point of the tertiary winding 39, the latter of which is grounded at 40. The relay 34 is thus energizable under the control of the tube 38 and the supply of heating current to the bimetallic portion 9 is accordingly controlled by the relay 34.

In order to make the control tube 38 conductive in accordance with variation in ignition voltage due to an increase in spacing between the ignition electrodes 6 and 7 of the discharge device 4, the grid electrode of the control tube 38 is connected through a resistance 42 to an adjustable resistance or rheostat 43, the latter of which is connected across a battery 44, with one side of both the rheostat 43 and battery 44 being connected to the filamentary cathode of the tube 38 at the mid-point of the tertiary winding 39 and hence to ground at 40. Such arrangement enables the battery 44 to normally apply a potential to the grid of the control tube 38 which is made negative with respect to the cathode through adjustment of the rheostat 43 to cause the tube to block the flow of energy in the filament-plate circuit, while the resistance 42 operates to limit the potential. A small direct current thus flows from the battery 44 through the rheostat 43.

A potentiometer 45 is connected across the secondary winding 27, and its adjustable arm 46 is connected to the adjustable arm of the rheostat 43 as well as to the grid of the control tube 38 through the resistance 42. The potentiometer 45 is thus divided by its adjustable arm 46 into what may be considered as two resistances R1 and R2 so that when initially set for a given ignition voltage for the electrodes 6 and 7 of the discharge device 4, a "bucking" current is caused to flow through the rheostat 43 of the same magnitude as the current supplied to the latter by

the battery 44, so that current flow through the rheostat 43 is neutralized.

It is a characteristic of discharge devices operable by "field emission" that the initial field emission from the initiating electrode is transformed almost instantaneously into a negative characteristic metallic arc, as hereinbefore mentioned, causing the voltage to fall quickly to a low value. Thus the spacing of any given electrode determines the maximum voltage independent of the maximum or peak voltage of the supply coil 27. This may be better appreciated by reference to Fig. 5 wherein the ordinate represents "voltage" and the abscissa "time." The curve A indicates the ignition voltage required to cause a "field emission arc" for a given electrode spacing, while the curve B represents the voltage for a somewhat greater electrode spacing. Curve C shows the form of voltage wave when the electrode spacing is too great for field emission to occur.

Accordingly, when the ignition voltage impressed across the electrodes 6 and 7 tends to rise due to wearing away of the electrodes with an increase in their spacing, the voltage on the potentiometer also varies, although independently of the voltage of the supply coil, causing a change in current flow through the rheostat 43 which unbalances the neutralized condition resulting from the direct current flow from the battery 44, and this in turn causes the potential of the grid to become less negative with respect to the cathode, thereby making the control tube 38 conductive.

Upon this control tube becoming conductive, energy then flows from the secondary winding 37 of the transformer 36, thus energizing the winding of the relay 34. The relay armature 33 is accordingly attracted completing a circuit from the source of domestic supply to the primary winding 32 of the transformer 29, with the result that a heating current is supplied by the secondary winding 39 to the bimetallic portion 9 of the leading-in conductor 8. Deflection of the latter follows, causing the electrode 7 to move closer to the starting electrode 6, lowering the voltage to which the potentiometer 45 can rise, thus again causing a reconditioning of the arrangement so that the negative bias is restored to the grid of the control tube 38 making it non-conductive. When this occurs, the winding of relay 34 is de-energized, allowing the armature to return to its normally open position, thus interrupting the circuit to the transformer 29 and hence the supply of heating current to the bimetallic portion 9.

The above described operation is intermittent and occurs each time the ignition voltage tends to rise above the value for which the electrodes 6 and 7 were initially set. Moreover, the voltage corresponding to the electrode spacing and at which the system functions may be set by altering the ratio between the sections R1 and R2 by adjustment of the arm of the potentiometer or the initial grid bias of the control tube 38 may be changed by adjustment of the rheostat 43. However, once set for a given electrode spacing and ignition voltage, the spacing of the ignition electrodes 6 and 7, together with the voltage required to initiate the "field emission arc," is automatically maintained constant during the useful life of the device.

In Figs. 2 and 3 a slight modification is shown for the potentiometer portion of the system. For example, in Fig. 2 a condenser 50 connected in series with a variable condenser 52 across the secondary winding 27 of the induction coil 25, may be employed in lieu of the potentiometer of Fig. 1 if desired, with such elements being connected to the circuit at the points designated x and y as shown in both Figs. 1 and 2. In the same manner a series connected capacitor 53 and resistance 54 as shown in Fig. 3 may be substituted in the arrangement as shown in Fig. 1, which would also be connected thereto at the points x and y. In both modifications, however, the operation is substantially the same in its effect on the conductivity of the control tube 38.

A still further modification is shown in Fig. 4 and wherein the discharge device 4 is constructed in the manner as shown and described in the copending application of Charles M. Slack et al., Ser. No. 459,776, filed concurrently herewith. Since reference may be had to such application for structural details of the device 4, it is believed unnecessary that they be set forth herein. Suffice it to say that one of the leading-in conductors is secured to a deflectable terminal or a diaphragm, such as shown at 55, which enables deflection of the leading-in and supporting conductor, together with the starting electrode 6 carried thereby, upon sliding movement of a terminal block 56 so as to decrease the spacing between the ignition electrodes 6 and 7 similar to that hereinbefore described with reference to Fig. 1.

In the same manner as shown in Fig. 1 the discharge device 4 of Fig. 4 controls the supply of energy from the high voltage transformer 22 to the "load" and the induction coil 25 also supplies the ignition voltage to the starting electrodes 6 and 7. Since the only difference in the modification of Fig. 4 resides in the apparatus for automatically controlling the electrode spacing, further description of Fig. 4 will be restricted to the latter. By reference to Fig. 4, it will be noted that a second induction coil 57 is provided, the primary winding 58 of which is connected across the secondary winding 27 and thus in electrical parallel with the ignition electrode circuit, as is the potentiometer 45 of Fig. 1.

The low potential secondary winding 59 of the induction coil 57 is connected to a full wave rectifier, shown generally at 60 and comprising the customary two pairs of oppositely connected rectifying valve tubes, and the direct current output side of such rectifier is connected to the magnetic coil 62 of a suitable switch 63. Although this switch may be of any appropriate type, it is shown as being provided with a spring biased rotatable arm 64 which is normally maintained in a central position between a pair of stationary contacts 65 and 66 against the tension of a spring 67, when a small D. C. magnetizing current flows through the winding 62.

Flow of current through this winding 62 is thus dependent upon the voltage impressed on the primary winding 58 of the induction coil 57, which latter is dependent upon the voltage of the secondary winding 27 of the first induction coil 25 supplying the ignition voltage to the electrodes 6 and 7. Again, as in the modification of Fig. 1, when the ignition electrodes 6 and 7 wear away, there is a tendency for the ignition voltage to rise, which thus increases the voltage supplied to the primary winding 58. This increased voltage causes an increase in the flow of D. C. current through the magnetic winding 62 of the switch 63, with the result that the rotatable arm 64 moves into contact with the stationary terminal 65, and when the current falls to a low value, the spring

67 causes the arm 64 to engage the stationary contact terminal 66.

As shown, the rotatable arm 64 is connected to a D. C. motor 68, while the contacts 65 and 66 are connected respectively to suitable D. C. sources of supply, such as batteries 69 and 70, with the opposite side of these batteries in turn connected to the D. C. motor 68. Accordingly, when the switch arm 64 engages the contact 65, an energizing circuit is completed from the batteries 70 to the D. C. motor. The motor 68 is provided with a worm 72 engageable with a worm gear 73, the latter of which is carried by a journalled shaft 74 engageable by a threaded shaft 75 loosely secured to the slideable block 56. Consequently, rotation of the motor upon closing of the energizing circuit will cause the sliding block 56 to move to the left, as shown in Fig. 4, deflecting the leading-in and supporting conductor carrying the starting electrode 6, thus decreasing the spacing between the ignition electrodes 6 and 7.

Reverse operation is effected by engagement of the rotatable switch arm 64 engaging the stationary contact terminal 66 which again closes an energizing circuit from the batteries 69 to the D. C. motor 68, thereby causing reverse rotation of the D. C. motor, together with the gears 72 and 73 and sliding movement of the block 56 to the right, as shown in Fig. 4.

It will be appreciated that, as in the modification of Fig. 1, the arrangement of Fig. 4 is intermittently operable in response to variations in ignition voltage caused by wearing away of the electrodes 6 and 7, so that again the spacing between the ignition electrodes 6 and 7 is automatically maintained constant, as is the ignition voltage, by energization of the motor and attendant mechanical operation to move the electrode 6 toward the electrode 7, thus decreasing the spacing.

It thus becomes obvious to those skilled in the art that a discharge device is herein shown and described wherein operation is initiated by field emission of electrons and the spacing between the ignition electrodes is automatically maintained substantially constant during the useful life of the device, despite the fact that such electrodes are subject to deterioration tending to increase their spacing, due to the evolution of metallic particles.

Moreover, since any tendency for the ignition electrode spacing to increase causes a corresponding increase in the ignition voltage, such variation in ignition voltage is employed to automatically readjust the electrode spacing, thereby maintaining the ignition voltage substantially constant.

Although several embodiments of the present invention have been shown and described, it is to be understood that other modifications of the same may be made without departing from the spirit and scope of the appended claims.

We claim:

1. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween during operation, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, and means automatically operable in response to the voltage across said pair of electrodes to cause controlled movement between the latter and maintain the spacing between said pair of electrodes substantially constant during the useful life of said device.

2. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween during operation, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, and means automatically operable in response to variations in ignition voltage between said pair of electrodes to cause relative movement therebetween and maintain the spacing between said pair of electrodes substantially constant despite deterioration of the latter during the useful life of said device.

3. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, means associated with said pair of electrodes to cause relative movement therebetween, and means electrically associated with said first mentioned means and automatically operable in response to an increase in voltage between said pair of electrodes to cause operation of said first mentioned means with attendant relative movement between said pair of electrodes to maintain the spacing therebetween substantially constant during the useful life of said device.

4. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, a deflectable support for one of the electrodes of said pair, and means associated with said pair of electrodes and automatically operable in response to an increase in voltage between said pair of electrodes to cause deflection of said support and movement of the electrode supported thereby toward the other electrode of said pair to maintain the spacing between said pair of electrodes substantially constant during the useful life of said device.

5. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required

to initiate the field emission arc discharge during operation of said device, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, a heat-responsive element in said device and operable upon heating to cause deflection of one of the electrodes of said pair, and means electrically associated with said pair of electrodes and automatically operable in response to an increase in ignition voltage to cause heating of said heat-responsive element with attendant deflection of one of said electrodes toward the other electrode of said pair to maintain the spacing therebetween substantially constant despite deterioration of said pair of electrodes during the useful life of said device.

6. A discharge device wherein operation is initiated by field emission of electrons comprising an envelope, a pair of oppositely disposed spaced electrodes in said envelope between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode in said envelope positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, means operable to cause relative movement between said pair of electrodes, an electrical circuit operable upon closure thereof to cause operation of said means, a second electrical circuit for supplying an ignition voltage to said pair of electrodes to initiate the field emission arc discharge therebetween including an element subject to variations in voltage corresponding to variations in ignition voltage caused by an increase in spacing between said pair of electrodes, and a third electrical circuit operable in response to voltage variations on the element of said second circuit to cause closure of said first mentioned circuit with attendant operation of said means and relative movement between said pair of electrodes to automatically maintain the spacing therebetween substantially constant despite deterioration of said pair of electrodes during the useful life of said device.

7. A discharge device wherein operation is initiated by field emission of electrons comprising an envelope, a pair of oppositely disposed spaced electrodes in said envelope between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode in said envelope positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, a heat-responsive element in said device and operable upon heating to cause deflection of one of the electrodes of said pair, an electrical circuit operable upon closure thereof to supply heating current to said heat-responsive element, a second electrical circuit for supplying an ignition voltage to said pair of electrodes to initiate the field emission arc discharge therebetween and including an element responsive to variations in ignition voltage caused by an increase in spacing between said pair of electrodes, and a third electrical circuit operable in response to variations in ignition voltage on the element of said second circuit to cause closure of the heating circuit for said heat-responsive element with attendant deflection of one electrode of said pair to automatically maintain the spacing between said pair of electrodes substantially constant despite deterioration thereof during the useful life of said device.

8. A discharge device wherein operation is initiated by field emission of electrons comprising a pair of oppositely disposed spaced electrodes between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, electrically operable means mechanically connected to one of the electrodes of said pair and operable when energized to cause deflection of said electrode, and means electrically associated with said pair of electrodes and automatically operable in response to an increase in ignition voltage to cause energization of said electrically operable means with attendant deflection of one of said electrodes to maintain the spacing therebetween substantially constant despite deterioration of said pair of electrodes during the useful life of said device.

9. A discharge device wherein operation is initiated by field emission of electrons comprising an envelope, a pair of oppositely disposed spaced electrodes in said envelope between which a field emission arc discharge occurs upon the application of a potential thereto and subject to deterioration tending to increase the gap therebetween and the voltage required to initiate the field emission arc discharge during operation of said device, an anode in said envelope positioned adjacent said pair of electrodes for supporting an electron discharge with one of the electrodes of said pair immediately following the field emission arc discharge between said pair of electrodes, an electric motor mechanically connected to one of the electrodes of said pair and operable when energized to cause deflection of said electrode, an electrical circuit operable upon closure thereof to cause rotation of said electric motor, a second electrical circuit for supplying an ignition voltage to said pair of electrodes to initiate the field emission arc discharge therebetween and including an element responsive to variations in voltage corresponding to variations in ignition voltage resulting from an increase in spacing between said pair of electrodes, and a third electrical circuit operable in response to variations in voltage on the element of said second circuit to cause closure of the circuit to said electric motor with attendant deflection of one electrode of said pair to automatically maintain the spacing between said pair of electrodes substantially constant despite deterioration thereof during the useful life of said device.

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