

Nov. 6, 1962

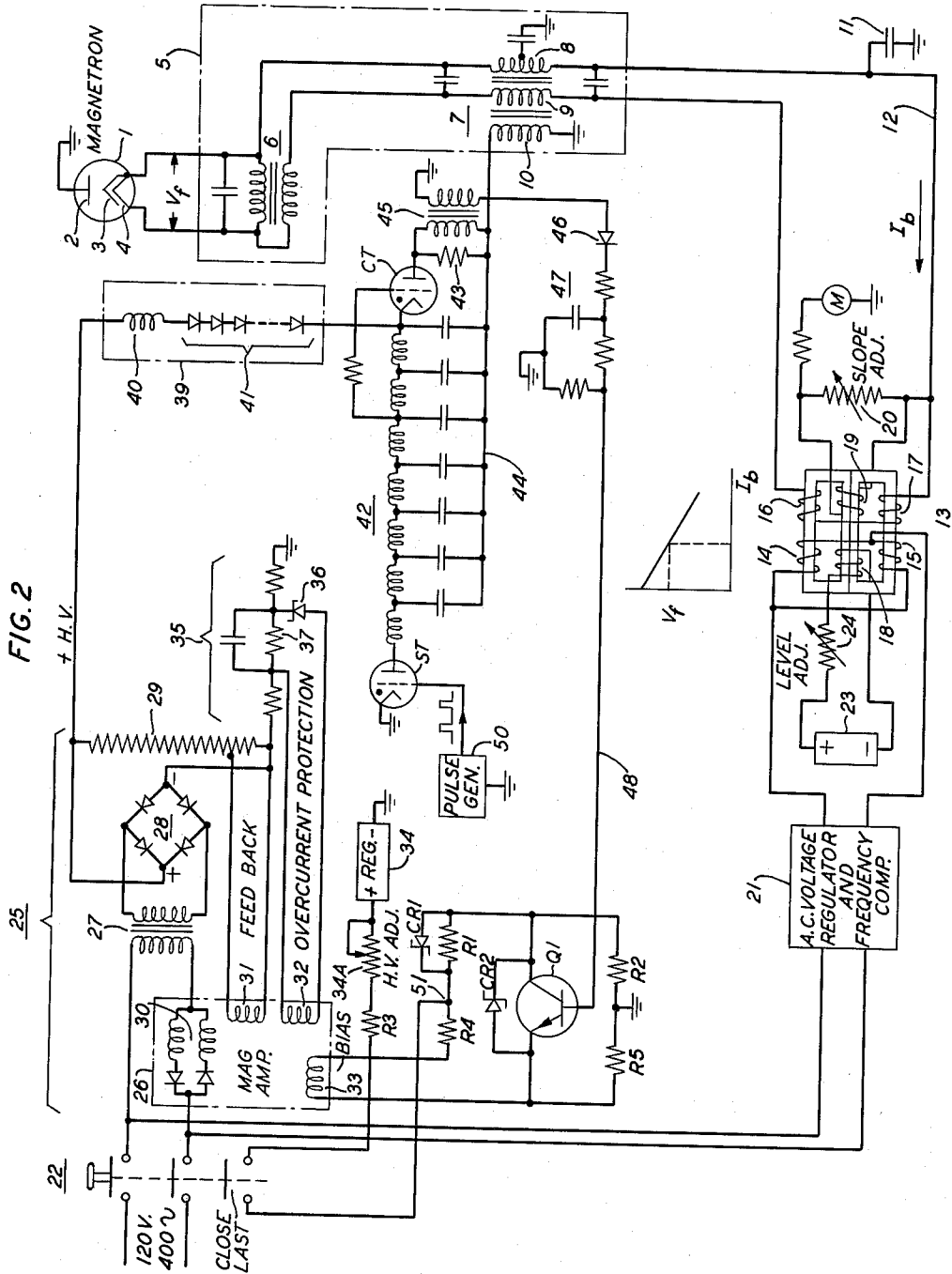
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3,063,012

AUTOMATIC MAGNETRON CONTROL CIRCUITS

Filed March 22, 1961

2 Sheets-Sheet 2



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3,063,012

AUTOMATIC MAGNETRON CONTROL CIRCUITS
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 Filed Mar. 22, 1961, Ser. No. 97,694
 8 Claims. (Cl. 328-8)

This invention relates to electron discharge device circuits and more particularly to an automatic control circuit for supplying anode and heater power to such devices.

Most failures in radar systems have been attributed to magnetron failure. It has been discovered that, in many instances, the cause for the apparent short life and unreliable performance of the magnetron was not the fault of the magnetron but rather the fault of its external circuitry. The performance characteristics of magnetrons have not been well understood by most field maintenance personnel so that in many instances perfectly good magnetrons have been replaced under the mistaken belief that the tube was at fault for the operation failure. It is a common mistake to assume that if a magnetron arcs complete operation failure is imminent. While field bulletins have attempted to correct this misunderstanding by specifying proper aging procedures, the instructions have not always been followed due to the length of time that it requires to properly age a tube after the cathode has cooled. The aging procedure specified in the field bulletins consists of slowly raising the anode potential to the threshold of arcing as indicated by the magnetron average current meter. After a brief period of operation at this level, the arcing threshold increases so that arcing stops. This is followed by again gradually increasing the anode potential to reach a new arcing threshold. This is continued until the anode potential is raised somewhat above the normal operating level after which it is slowly lowered to the normal level where it remains. Should the tube, for any reason, arc excessively under normal operating conditions, the anode potential must be quickly lowered to stop the arcing. However, this permits the cathode to cool and the above-described aging procedure must be repeated.

It is evident that the above-described aging procedure takes considerable time which possibly accounts for the fact that it is not always properly followed. It has been discovered that much of this time can be avoided if, by some means, the cathode temperature is kept constant in the presence of arcing. The control of the cathode temperature, however, must be very rapid and must be properly coordinated with the anode potential control. The temperature of the cathode is a function not only of the heater voltage but also of the average space current. Consequently, when arcing occurs and the anode voltage is lowered to stop the arcing, the space current also lowers to permit the cathode to cool. This immediately lowers the arcing threshold making it necessary to again lower the anode potential, thus departing still farther from the desired operating level. It has been discovered that if this cathode temperature is kept constant by an appropriate automatic control of the heater voltage the necessity for re-aging the tube is substantially eliminated. In order to successfully control the temperature of the cathode in the manner indicated, it is essential that the heater voltage be under control of the average space current.

It is, therefore, the object of this invention to automatically control the cathode temperature of an electron discharge device with changing average space current while simultaneously and automatically controlling the anode voltage in response to arc currents.

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The foregoing object is achieved by this invention by a circuit combination comprising an electric heater control circuit, the voltage whereof is made an inverse function of the average space current and means responsive to arcing currents in said cathode circuit for automatically lowering the anode potential in response to said currents.

The invention may be better understood by reference to the accompanying drawings, in which:

FIG. 1 is a block diagram illustrating the essential elements of the invention; and

FIG. 2 discloses a preferred embodiment of the invention as applied to an electron discharge device of the magnetron type.

The block diagram of FIG. 1 discloses an electron discharge device 1 having a grounded anode 2, a cathode 3 and a cathode heater 4. A coupling unit 5 serves the dual purpose of supplying the heater voltage V_f as well as the anode voltage for the anode-cathode space path circuit. Energy for the heater is supplied from a heater current regulator 13 which, in turn, is connected through an obvious path to the power source. A direct current meter M is connected in series with the anode-cathode space path to indicate the average space path current I_b . The space path circuit may be traced from the grounded anode through the cathode, the coupling unit 5, conductor 12, the heater current regulator 13 and back to ground through meter M. Rapid changes in space current are by-passed to ground through capacitor 11.

The heater voltage regulator 13 has a heater voltage V_f versus space current I_b characteristic of the type illustrated within block 13. From this characteristic, it is evident that the heater voltage will increase if the space current lowers. Thus, should the magnetron begin to arc and the anode voltage is lowered to reduce arcing by means hereinafter described, the space current also lowers, which would permit the cathode to cool below its normal temperature. The heater voltage regulator, however, acts to prevent any substantial change in cathode temperature by reason of its characteristic which increases the heater voltage V_f as the space current lowers. The slope of the curve defining this regulator characteristic may be established by observing the cathode temperature with an optical pyrometer while simultaneously changing the anode voltage, and thus the space current, and determining the filament voltage necessary to maintain a constant cathode temperature. While this characteristic is not strictly linear, it has been found that it is nearly so over practical operating ranges so that, if desired, a linear characteristic may be used.

The anode voltage for the space path is injected into the anode-cathode circuit by coupling unit 5 from a regulated power supply through an overload protection circuit 35. The regulated power supply is, in turn, supplied from the power source through an obvious path. The action of the overload protection circuit 35 is to automatically reduce the output voltage of the regulated power supply when the output current increases above a critical level.

When arcing occurs in tube 1, sudden increases in current appear in coupling unit 5. These increases in current are detected by the arc current detector which develops a control current in response to the arc current. This control current is fed back to the regulated power supply 25 to immediately lower the output voltage of this regulator and hence the anode voltage supplied to tube 1.

From the above description, it is evident that a close cooperative relationship exists between the two power supplies in such a way that arcing is quickly eliminated by a rapid and automatic reduction of the anode voltage, while at the same time the cathode temperature is auto-

matically maintained substantially constant by the action of the heater voltage regulator 13. The fact that the cathode temperature is maintained constant overcomes the de-aging difficulty described above.

FIG. 2 discloses an electron discharge device 1 which, for illustrative purposes, may be a magnetron having a grounded anode 2, an indirectly heated cathode 3 and heater filament 4. It is supplied with heater voltage V_f from a 400 cycle per second alternating current source through a coupling unit 5 and voltage regulators 13 and 21. Coupling unit 5 comprises a filament supply transformer 6 which lowers the supply voltage to the proper voltage for the heater and a pulse transformer 7 for injecting the high voltage pulse into the anode-cathode circuit of the magnetron. Transformer 7 comprises two secondaries 8 and 9 and one primary winding 10. The bifilar arrangement of secondary windings prevents transmission of the 400 cycle per second heating voltage into the primary winding 10 while at the same time permitting the injection of the high voltage pulse from primary 10 into the two secondaries. Further description of this transformer arrangement is unnecessary as it is quite conventional in magnetron circuits. The several capacitors shown associated with transformers 6 and 7 are for the purpose of by-passing the high frequency magnetron current in a manner well understood. The heater current is supplied to the filament transformer 6 (through the two windings 8 and 9) from the heater voltage regulator 13 which is shown as a magnetic amplifier having two secondaries 16 and 17. The primaries 14 and 15 of this magnetic amplifier are connected in parallel to the output circuit of a voltage regulator 21 which also contains a network to compensate for small frequency variations. This type of automatic voltage regulator circuitry is also conventional and requires no further description. The input circuit to this regulator 21 is connected to the upper two poles of the three-pole switch 22 and thus to the 120 volt, 400 cycle per second power supply.

The direct current component of the space current flows from cathode 3, through winding 8, conductor 12, through a bias winding 19 on magnetic amplifier 13 and to ground through the average current meter M. The alternating current components are by-passed to ground by way of capacitor 11. A second bias winding 18 on magnetic amplifier 13 is supplied with direct current from any convenient source 23 through a level adjusting means 24.

In order to maintain the cathode temperature constant, it is necessary that magnetic amplifier 13 increase the heater supply voltage as a function of the decreasing average current I_b flowing in conductor 12 which is indicated by meter M. The required heater voltage versus magnetron current characteristic is substantially of the type shown directly above magnetic amplifier 13. The dotted lines indicate the normal operating voltage and current. As the magnetron current increases due to arcing, the current in the bias winding 19 increases to cause the magnetic amplifier to lower the filament supply voltage V_f and when the bias current lowers as the anode voltage is lowered to stop arcing, V_f is increased. In order that the magnetic amplifier will change the voltage at the proper rate to maintain the cathode temperature constant, a slope adjusting rheostat 20 is connected across bias winding 19 and may be adjusted until the rate of voltage change with respect to changing current maintains a constant cathode temperature. It will, of course, be understood that the adjustment of the slope rheostat 20 must be done in cooperation with the level adjusting rheostat 24 to the end that both the proper operating level and the desired slope are reached.

The high voltage for the anode circuit is derived from the power source through an automatically regulated power supply schematically illustrated as power supply 25. This power supply comprises a suitable transformer

27, the primary of which is connected to the power source through the two upper poles of switch 22 and a magnetic amplifier 26. The secondary of transformer 27 is connected to a suitable full wave rectifier bridge 28 which is schematically illustrated as having four rectifier units. The output of this bridge is connected to a potential divider 29 so that a fraction of the output voltage may be connected to a feedback winding 31 for automatically regulating the output voltage through control of the voltage applied to the primary winding of transformer 27. The operation of such magnetic amplifiers is conventional and requires very little description. Briefly, however, the power windings 30 of the magnetic amplifier provide a variable loss depending upon the amount of bias current supplied by the three bias windings 31, 32 and 33. As the current increases in winding 31, for example, the loss in power winding 30 is caused to increase, thus tending to maintain the output voltage of rectifier 28 substantially constant.

Also connected in series with the high voltage output circuit of rectifier 28 is an over-current protection circuit 35 comprising three series-connected resistors connected between the negative terminal of the rectifier and ground. One of these resistors, resistor 37, is caused to maintain a voltage drop substantially proportional to the average current by reason of its parallel-connected capacitor. Should this current increase for any reason beyond a safe limit, the terminal voltage across resistor 37 will increase sufficiently to reach the avalanche breakdown point of diode 36, thus causing current to flow through bias winding 32 which quickly lowers the output voltage of rectifier 28. The output voltage of rectifier 28, under normal operating conditions, is under control of the current in bias winding 33. This output voltage is substantially a linear function of the current in winding 33 and increases with the current in this winding. Current is supplied to this winding from a voltage regulated source 34 through a rheostat 34A, a resistor R3, the lower pole of the three-pole switch 22, resistor R4, bias winding 33 and back to the regulated source 34 through resistor R5 and ground. To prevent undesirable high voltage transients which may cause insulation breakdown, the voltage is raised gradually by lowering the resistance of the high voltage adjusting rheostat 34A. To further prevent high voltage transients, it is desirable that the voltage be supplied to the primary of transformer 27 a short instant before any current is supplied to bias winding 33. To this end, the lower pole of switch 22 is adjusted to close a short instant after the two upper poles have closed. This time lag may be in the order of 25 milliseconds or more. The voltage is then gradually raised to the desired operating level by lowering the resistance of the high voltage adjusting rheostat 34A.

The high voltage pulses are applied to primary winding 10 of transformer 7 from a pulse forming network 42. This pulse forming network is of a conventional type and comprises a plurality of similar inductors and capacitors connected as a transmission line in the manner shown in the drawing. A thyatron switch ST is connected at the load end of the line, the load comprising that presented by the anode-cathode circuit through winding 10 of transformer 7. When switch tube ST is rendered conductive, winding 10 is connected across the left end of line 42 defining a path from the upper end of winding 10, conductor 44, the left end of line 42, the switch tube ST and back to the grounded end of winding 10. Switch tube ST is repeatedly fired through an obvious circuit path by a train of positive pulses applied to its grid from a pulse generator 50, the frequency of which is the desired pulse repetition frequency for the magnetron.

Line 42 is charged from the high voltage supply 25 by way of conductor 38, the choke-diode unit 39, the line 42 and to the grounded side of the power supply by way of winding 10 and the over-current protection network

35. The direct current resonant charging principle is employed so that line 42 charges to substantially twice the supply voltage of source 25. This action is provided by choke 40 and diodes 41 in cooperation with the capacitors in line 42. For convenience of description, all voltages in line 42 will be considered with reference to conductor 44.

Under normal operating conditions, the load presented by winding 10 substantially matches the characteristic impedance of line 42 so that, when switch tube ST fires, a negative-going pulse of approximately one-half the original line voltage travels to the far end of the line toward the clipper tube CT, leaving behind a net positive charge of one-half the original voltage. Under these conditions, clipper tube CT cannot fire because its cathode is positive with respect to its anode at the instant the wave reaches the far end of the line. The far end of the line is, therefore, effectively open and reflects back a pulse of the same magnitude and polarity, thus bringing the cathode potential to zero and causing this reflected wave to travel back to the load end, completely discharging the line, terminating the pulse and extinguishing the switch tube ST.

Under abnormal operating conditions, when the magnetron is arcing, its average space current increases to tend to saturate transformer 7 and cause it to present a low impedance load, approaching a short circuit, to line 42 through its winding 10. Under these conditions tube ST connects a strongly mismatched load to line 42 such that the negative-going pulse travelling toward the far end of the line is of a voltage only a little less than the original voltage of line 42 thus leaving behind on line 42 only a small positive voltage. When this pulse reaches the far end of the line, it again initially meets an open circuit condition so that the line starts to reflect a voltage of the same magnitude and polarity as that of the incident wave, thus resulting in a negative-going pulse developing at the far end of the line. This immediately starts conduction in the clipper tube CT by reason of its anode becoming positive with respect to its cathode, thereby presenting to the far end of the line the load resistor 43 which has a resistance equal to the characteristic impedance of line 42. The negative-going voltage pulse then reaches only one-half of the incident wave which now travels back to the load end of the line, leaving behind on line 42 a negative charge equal to the difference between the voltage of this pulse and the small positive voltage the first wave had left behind it on line 42. When this negative voltage pulse reaches the load end, switch tube ST immediately opens because the wave drives its anode negative. The reflected wave of equal amplitude then returns to the far end of the line where it is met by the characteristic impedance of resistor 43 and the charge is dissipated to zero.

From the above description, it will be evident that the conduction of clipper tube CT always follows arcing in the magnetron in response to an increase in the average magnetron current. It is convenient to use this voltage pulse across resistor 43 to reduce the high voltage applied to the magnetron anode circuit as this is the method which must be employed to overcome destructive arcing in the tube. This is conveniently accomplished by connecting a transformer 45 across resistor 43. The ungrounded side of its secondary is connected through a rectifier 46 and its output integrated in a conventional integrating circuit 47. A fraction of this voltage is applied to the base of transistor Q1 by way of conductor 48. The action of transistor Q1 is to shunt bias winding 33 in the magnetic amplifier 26, thereby quickly reducing the output voltage of high voltage power supply 25 and consequently the voltage charge on line 42. The manner by which transistor Q1 performs its function in the network with which it is associated requires some further description.

To avoid instability during the period that the power supply 25 is being turned on, it is necessary that tran-

sistor Q1 be disabled. The instability arises by reason of the fact that as the magnetron is being brought into its normal operating condition, its impedance differs from its normal operating impedance so that the arc detector circuit is operated as if arcs were present. This would cause transistor Q1 to prevent the high voltage circuit from ever building up to the required normal level. Disabling is accomplished by connecting the emitter and collector of the transistor in a substantially balanced bridge network comprising resistors R1, R2, R4 and R5. The resistance of coil 33 is neglected for present purposes. Resistors R1 and R4 are made large compared with resistors R2 and R5, respectively. As the current in the bias coil 33 is increased by adjusting rheostat 34A, the voltage drop across R1 reaches the breakdown level of diode CR1 shunted thereacross. This breakdown level occurs when the output voltage of high voltage supply 25 is a little below its normal operating level. When diode CR1 breaks down, the collector of transistor Q1 is effectively connected to junction 51 so that its potential differs therefrom only by the drop across the diode. The transistor now is enabled to operate so that as arcing currents cause pulses to develop across resistor 43, the integrated voltage from network 47 will turn transistor Q1 "ON" to shunt bias winding 33 and quickly lower the output voltage of power supply 25, thereby lowering the pulse voltage supplied to the anode-cathode circuit of the magnetron. Conversely, as the arcing currents disappear, the voltage from network 47 reduces to zero and transistor Q1 opens, restoring the normal operating voltage to the anode-cathode circuit of the magnetron.

While the circuit has been described with reference to a specific, preferred embodiment of the invention, it will be evident to those skilled in the art that other means may be provided for maintaining the heater temperature constant with changes in average space current and that other means also may be used to detect the presence of arcing currents and to derive therefrom a suitable control for reducing the output voltage of power supply 25. The invention is, therefore, not limited to the specific embodiment disclosed herein for purposes of illustrating the invention.

It is also evident that the invention is useful in controlling the aging of high voltage tubes other than magnetrons. In fact, the invention is useful in the manner described with any such device having an electrically heated thermionic electron emissive cathode.

What is claimed is:

1. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a second automatic regulator connected to supply regulated voltage to the anode-to-cathode space path of said device, a current-responsive control means in said second regulator for causing the output voltage of said regulators to vary as a function of the current in said control means, a detector means coupled to said heater supply circuit for detecting the presence of currents therein due to arcing in said space path and for deriving a control current therefrom, and a circuit means connecting said detector means to said current-control means to lower the second regulator output voltage in response to said control current.

2. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a voltage regulator connected to supply electric heating energy to the cathode of said

device, a control circuit in said regulator for controlling its output voltage as an inverse function of the current in said control circuit, a series circuit comprising said control circuit and the space path of said device so that the cathode temperature may be kept substantially constant with changes in space current, a second automatic regulator connected to supply regulated voltage to the anode-to-cathode space path of said device, a current responsive control means in said second regulator for causing the output voltage of said regulator to vary as a function of the current in said control means, a detector means coupled to said heater supply circuit for detecting the presence of currents therein due to arcing in said space path and for deriving a control current therefrom, and a circuit means connecting said detector means to said current-control means to lower the second regulator output voltage in response to said control current.

3. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a pulse generator having an output circuit and including a second voltage regulator, means coupling said generator output circuit in series with the space path of said device, a current-responsive control means in the second regulator for causing the amplitude of the pulses from said generator to vary as a function of the current in said control means, a detector connected to said coupling means for detecting an abnormal increase of current in the space path of said device and for deriving a control current therefrom, and a circuit means connecting said detector to said current-responsive control means to lower the voltage of said pulses in response to said control current.

4. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a pulse generator having an output circuit and including a second voltage regulator, means coupling said generator output circuit in series with the space path of said device, a current-responsive control means in the second regulator for causing the amplitude of the pulses from said generator to vary as a function of the current in said control means, a detector coupled to a circuit in series with the space path of said device for detecting abnormal increases of current therein and for deriving a control current therefrom, and a circuit means connecting said detector to said current-responsive control means to lower the voltage of said pulses in response to said control current.

5. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a second automatic regulator connected to supply a regulated voltage to the anode-to-cathode space path of said device, a current-responsive control means in said second regulator for causing the output voltage of said regulator to vary as a function of the current in said

control means, a detector means coupled to said heater supply circuit for detecting the presence of currents therein due to arcing in said space path and for deriving a control current therefrom, a source of current connected through resistive means to said current-responsive control means in said second regulator for establishing the normal anode-to-cathode space path voltage for said device, a current-controlled variable impedance means effectively connected across said current-responsive control means, and a circuit connecting said detector means to said variable impedance means to lower its impedance in response to the control current derived by said detector whereby said space path voltage is caused to lower in response to arcing in said space path.

6. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a voltage regulator connected to supply electric heating energy to the cathode of said device, a control circuit in said regulator for controlling its output voltage as an inverse function of the current in said control circuit, a series circuit comprising said control circuit and the space path of said device so that the cathode temperature may be kept substantially constant with changes in space current, a second automatic regulator connected to supply a regulated voltage to the anode-to-cathode space path of said device, a current-responsive control means in said second regulator for causing the output voltage of said regulator to vary as a function of the current in said control means, a detector means coupled to said heater supply circuit for detecting the presence of currents therein due to arcing in said space path and for deriving a control current therefrom, a source of current connected through resistive means to said current-responsive control means in said second regulator for establishing the normal anode-to-cathode space path voltage for said device, a current controlled variable impedance means effectively connected across said current-responsive control means, and a circuit connecting said detector means to said variable impedance means to lower its impedance in response to the control current derived by said detector whereby said space path voltage is caused to lower in response to arcing in said space path.

7. A control circuit for an electron discharge device having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a pulse generator having an output circuit and including a second voltage regulator, means coupling said generator output circuit in series with the space path of said device, a current-responsive control means in the second regulator for causing the amplitude of the pulses from said generator to vary as a function of the current in said control means, a detector connected to said coupling means for detecting an abnormal increase of current in the space path of said device and for deriving a control current therefrom, a source of current connected through resistive means to said current-responsive control means in said regulator for establishing the normal voltage of said pulses, a current-controlled variable impedance means effectively connected across said current-responsive control means, and a circuit connecting said detector to said variable impedance means to lower its impedance in response to the control current derived by said detector, whereby said pulse voltages are lowered in response to an abnormal increase of current in said space path.

8. A control circuit for an electron discharge device

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having an anode and an electrically heated cathode to automatically maintain the aged condition thereof in the presence of abnormal currents in its anode-cathode space path, said circuit comprising a heater supply circuit having an automatic regulator for maintaining the cathode temperature of said device substantially constant as the average current in said space path varies, means for connecting said supply circuit to the cathode heating means of said device, a pulse generator having an output circuit and including a second voltage regulator, means coupling said generator output circuit in series with the space path of said device, a current-responsive control means in the second regulator for causing the amplitude of the pulses from said generator to vary as a function of the current in said control means, a detector coupled to a circuit in

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series with the space path of said device for detecting abnormal increases of current therein and for deriving a control current therefrom, a source of current connected through resistive means to said current-responsive control means in said second regulator for establishing the normal voltage of said pulses, a current controlled variable impedance means effectively connected across said current-responsive control means, and a circuit connecting said detector to said variable impedance means to lower its impedance in response to the control current derived by said detector, whereby said pulse voltages are lowered in response to an abnormal increase of current in said space path.

No references cited.