

Feb. 4, 1941.

A. E. BOWEN

2,230,558

ELECTRON DISCHARGE APPARATUS

Filed July 26, 1938

2 Sheets-Sheet 1

FIG. 1

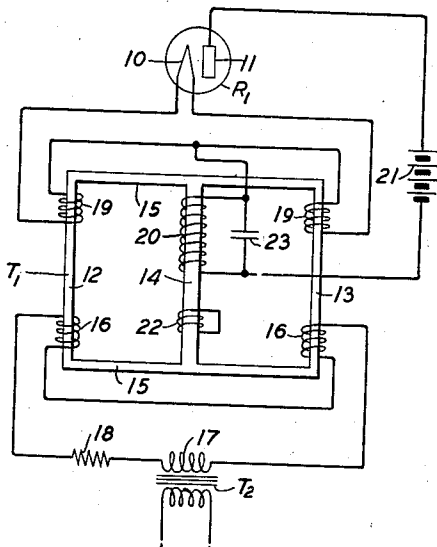


FIG. 2

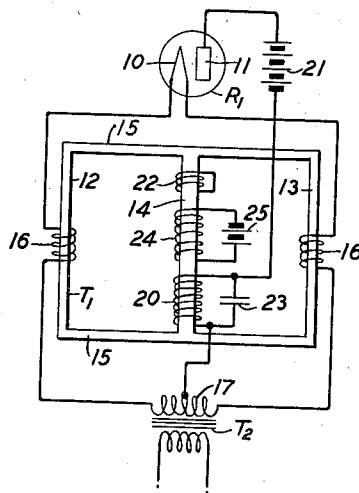


FIG. 3

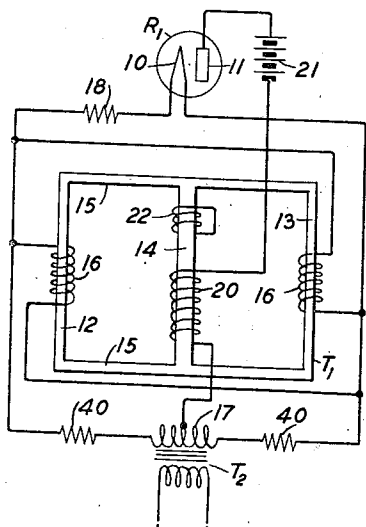
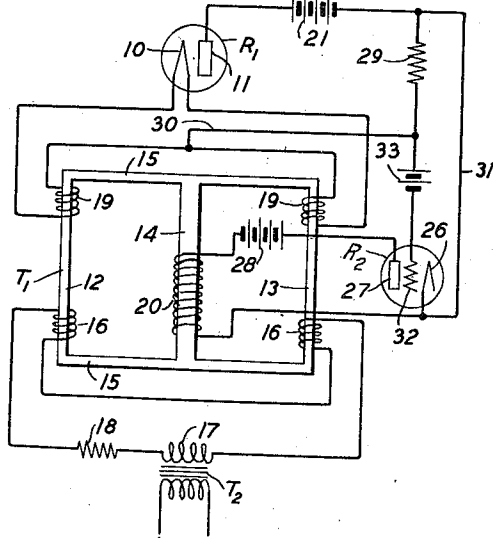


FIG. 4



INVENTOR
A. E. BOWEN
BY

Walter C. Kiesel
ATTORNEY

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A. E. BOWEN

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FIG. 6

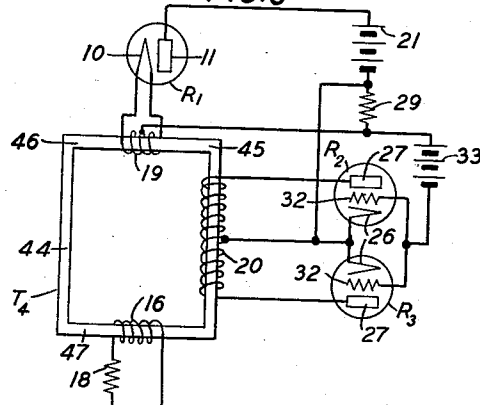
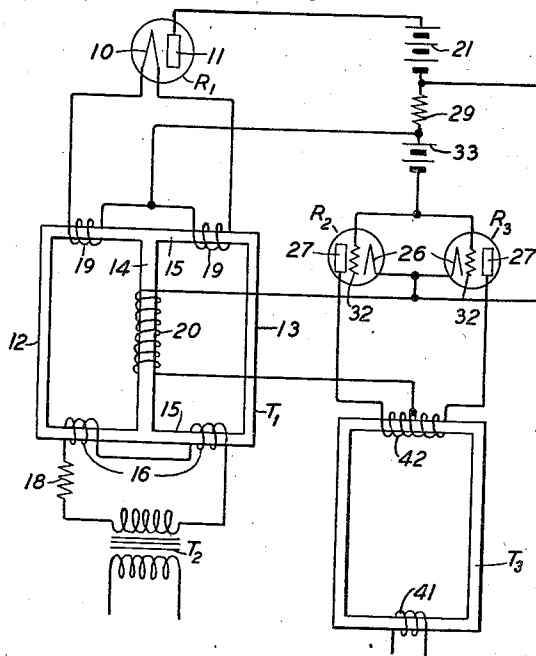


FIG. 5



INVENTOR
A.E. BOWEN
BY
Walter C. Kiesel
ATTORNEY

UNITED STATES PATENT OFFICE

2,230,558

ELECTRON DISCHARGE APPARATUS

Arnold E. Bowen, Red Bank, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

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9 Claims. (Cl. 250—27)

This invention relates to electron discharge apparatus and more particularly to apparatus for energizing thermionic cathodes in electron discharge devices of the magnetron type operable at extremely high frequencies.

Electron discharge devices of the magnetron type comprise in general, a thermionic cathode, an anode in cooperative relation with the cathode, and means for producing a magnetic field for controlling or determining the trajectories of the electrons emanating from the cathode. Some of the electrons emanating from the cathode flow to but do not reach or impinge upon the anode. These electrons derive energy from the anode or output circuit and return to the cathode, impinging thereon and expending this energy in heating the cathode. Consequently, material variations in the temperature of the cathode and, hence, in the magnitude of the emission therefrom are produced. An increase in the emission results in an increase in the anode current and also in the number of electrons returning to and bombarding the cathode. Consequently, a still greater heating of the cathode obtains together with an attendant increase in the anode current and bombarding electrons.

This repeating and cumulative action produces very unstable operating characteristics. Furthermore, the heating due to electron bombardment may become sufficiently great to destroy the cathode.

One object of this invention is to prevent overheating of thermionic cathodes in electron discharge devices.

Another object of this invention is to increase the stability of magnetrons, particularly at operation at very high frequencies.

A further object of this invention is to maintain the heating current supplied to the cathode of an electron discharge device at a substantially constant value or within a safe range of values.

In one illustrative embodiment of this invention, a supply or energizing circuit for the cathode of an electron discharge device comprises a transformer including a core having three legs connected at corresponding ends, and a pair of secondary windings on the outer legs and connected in series with each other and the cathode. The transformer is so constructed that when the cathode is being supplied at its normal rating, the core is operated below saturation. Under these conditions, a sinusoidally varying current in the primary winding produces a similarly varying current in the secondary windings in series with the cathode.

In accordance with one feature of this invention, means are provided for altering the flux through the portions of the core to which the secondary windings are coupled, in accordance with excessive increases in the anode current of the electron discharge device. More specifically, in accordance with one feature of this invention, means are provided in association with the anode circuit of the discharge device for introducing into the magnetic circuit of the transformer a magnetomotive force, in accordance with excessively high anode currents, sufficiently great when superimposed upon the force created by the primary winding to cause the core to be operated above the knee of its saturation curve. Hence, sinusoidal variations in the current in the primary winding of the transformer do not result in sinusoidal variations in the secondary current. The flux through the secondary windings, therefore, is smaller and the voltage induced in the secondary windings likewise is smaller. Consequently, the cathode heating current is reduced and deleterious heating of the cathode is thereby prevented.

In accordance with another feature of this invention, means are provided for preventing such reaction between the transformer and the anode circuit of the electron discharge device as would result in superimposing an alternating or variable potential upon the steady anode voltage.

The invention and the foregoing and other features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawings wherein Figs. 1 to 6 are circuit diagrams illustrating several typical embodiments of this invention.

Referring now to the drawings, the electron discharge apparatus illustrated in each of the figures comprises an electron discharge device R_1 , which may be of the magnetron type, having a cathode 10 and an anode 11. Suitable means, not shown, may be provided for producing the requisite magnetic field if the discharge device is of the magnetron type. The cathode 10 may be a filament, as shown, or may be of the indirectly heated equi-potential type.

The heating current for the cathode 10 is obtained from a system including a transformer T_1 having three legs 12, 13 and 14 which are connected at their ends by yokes 15. Wound about the legs 12 and 13 are a pair of identical primary windings 16 connected in series aiding so that the fluxes in the legs 12 and 13 are opposite in direction with respect to the same yoke 15. Energizing current may be supplied to the windings 16 by a

transformer T_2 having its secondary winding 17 in series with the windings 16. If desired, as shown in Figs. 1 and 4, a suitable resistor 18 may be connected in series with the windings 16 and 17. In general, this resistor should have a magnitude substantially equal to the resistance of the cathode circuit of the electron discharge device R_1 multiplied by the square of ratio of transformation of the transformer T_1 . Thus, for example, if the ratio of transformation is unity, the resistor 18 should have a value commensurate with the resistance of the cathode.

In the system illustrated in Fig. 1, two identical secondary windings 19 are wound upon the legs 12 and 13 and connected in series with one another and with the cathode 10 and poled as shown. Because of the symmetry of the magnetic circuit and the identity of the windings 16 and also the windings 19, the flux is confined to the legs 12 and 13 and yokes 15 and no flux is produced in the leg 14 by currents in the primary windings 16 or secondary windings 19.

The core of the transformer T_1 , and the windings 16 and 19 are such that the core material is operated at a point well under the saturation point when the cathode 10 is being supplied at its normal rating.

Wound upon the intermediate leg 14 of the core is an auxiliary or biasing winding 20 which is connected between the cathode 10 and anode 11 in series with a direct current source, such as a battery 21. The winding 20 has a large number of turns such that when a current somewhat greater than the normal anode current of the electron discharge device R_1 passes through this winding, the core of the transformer T_1 will be operating substantially at its saturation point.

When the electron discharge device R_1 is operated and the normal anode current is flowing, the sinusoidally varying current in the primary windings 16 produces a similarly varying flux in the legs 12 and 13 of the core and a sinusoidal voltage is induced in the secondary windings 19. If the anode current becomes unduly great, as a result of electron bombardment of the cathode 10 as described heretofore, the current flowing through the winding 20 produces a magnetomotive force sufficiently great, together with that produced by the windings 16, to raise the operating point of the core above the knee of the saturation curve thereof. Consequently, a sinusoidal variation in the current in the primary windings 16 no longer produces a corresponding change in the flux through the secondary windings 19. Hence, the alternating flux through these windings 19 is reduced and the voltage induced in these windings also is reduced. This reduction in voltage is accompanied by a corresponding reduction in the current supplied to the cathode 10 whereby the temperature of the cathode is reduced from the high point caused by electron bombardment. This action continues until a stable point is reached and the cathode heating current is reduced sufficiently to compensate for the heating by electron bombardment. Therefore, deleterious overheating of the cathode is prevented, destruction or impairment of the cathode is avoided and stable operation of the electron discharge device is assured.

The magnitude of the reduction in the current flowing through the secondary windings 19 will be dependent upon the magnitude of the current through the auxiliary or biasing winding 20. If the current through this winding becomes quite large the core of the transformer T_1 may be oper-

ating well above the knee of the saturation curve therefor so that the change in the flux through the windings 19, due to current in the primary windings 16 approaches zero. The voltages induced in the windings 16, and hence the cathode heating current, also approach zero.

It has been found that for an intermediate range of currents in the auxiliary or biasing winding 20, there is a tendency for some of the alternating flux to flow through the leg 14 of the core. Such alternating flux, because of the linkage of the winding 20 thereto, would result in the superimposing of a variable potential upon the steady potential produced by the source 21 in the anode circuit of the discharge device R_1 .

This undesirable effect may be prevented, in accordance with a feature of this invention, by providing a low resistance short-circuited loop 22 upon the leg 14. This loop may be a separate winding as shown or may be a metallic, e. g., copper, spool upon which the auxiliary or biasing winding 20 may be wound or mounted. The superimposing of an alternating voltage upon the anode circuit of the device R_1 by the winding 20 may be prevented further by a large capacitance condenser 23 connected directly across this winding.

Although the primary windings 16 have been illustrated as supplied from a transformer T_2 , they may be designed to handle whatever line voltage is available, in which case the transformer T_2 need not be employed. Also the transformer T_1 may be adapted for use with a variety of tubes having different ratings by providing one or more of the windings with taps. For example, the auxiliary or biasing winding 20 alone could be tapped. For tubes having a large normal anode current, a small number of the turns of the winding 20 would be included in the anode circuit of the tube. For tubes having smaller anode currents a greater number of the turns of the winding 20 would be employed.

An arrangement particularly suitable for low resistance cathode circuits is illustrated in Fig. 2 wherein elements corresponding to those of Fig. 1 are designated by the same reference numerals. A single pair of windings 16, in series with the secondary winding 17 of transformer T_2 , is provided upon the arms 12 and 13. These windings 16 are connected in series also with the cathode 10 and are so poled that they produce no flux in the intermediate leg 14 of the core of the transformer T_1 . Preferably they are so designed that when there is no steady flux in the legs 12 and 13, the inductive reactance of the windings is large in comparison with the resistance of the cathode circuit.

The auxiliary or biasing winding 20 is wound on or disposed about the intermediate leg 14 and connected in the cathode-anode circuit of the electron discharge device R_1 as shown, one end of the winding 20 being connected to the mid-point of the secondary winding 17 of transformer T_2 .

Also wound upon or disposed about the intermediate leg 14 is a second auxiliary or biasing winding 24, which preferably is identical with the winding 20 and which is supplied from a direct current source, such as a battery 25. The current passed through the winding 24 is such as to produce saturation of the legs 12 and 13 of the core of transformer T_1 . The two windings 20 and 24 are so poled that the flux produced by the passage of the anode current through the winding 20 opposes the steady flux produced by the winding 24.

When no current, or small current, is flowing through the winding 20, the reactance of the windings 16 is substantially negligible and the normal heating current is supplied to the cathode 10. However, when the anode current increases and the flux produced by the winding 20 increases accordingly, the steady flux in the legs 12 and 13 decreases inasmuch as, as noted above, the flux produced by the winding 20 is in opposition to that produced by the winding 24. This decrease in the steady flux through the legs 12 and 13 results in an increase in the reactance of the windings 16 offered to the flow of current in the cathode or heating circuit. Consequently, an increase in the anode current results in a decrease in the heating current for the cathode so that overheating of the cathode is prevented.

The value of the anode current at which regulation of the heating current for the cathode begins may be controlled by adjusting the relative value of the currents in the windings 20 and 24. For this purpose, for example, either of the windings 20 or 24, or both, may be provided with suitable taps allowing variation of the number of effective turns thereof.

An arrangement particularly suitable for use in systems wherein the filament circuit has a high resistance is illustrated in Fig. 3, wherein elements corresponding to those in Figs. 1 and 2 are designed by the same reference characters. As shown in the figure, the cathode 10 is directly in series with the secondary winding 17 of the transformer T₂ and resistances 18 and 40, the resistances 40 serving to limit the total current drawn from the transformer T₂ to a safe value. The windings 16 on the legs 12 and 13 are connected in parallel with each other and with the cathode 10 of the discharge device R₁ and are poled so that the fluxes produced thereby are in series aiding around the magnetic circuit defined by the legs 12 and 13 and the yokes 15. The windings 16, furthermore, are so designed with respect to the core that when the normal cathode voltage is impressed thereon, and with no steady flux in the core, the core material is operated well up towards the knee of its saturation curve at the maximum or peak values of the alternating flux. When current flows in the anode circuit of the discharge device R₁, the steady flux produced by the current in the auxiliary winding 20 raises the operating point of the core material toward the knee of the saturation curve and for portions of the cycle of the alternating potential supplied, the core material will be operating above the knee of the saturation curve.

When current is flowing in the anode circuit of the device R₁, the alternating current in one of the windings 16 will tend to cause an increase in the flux in the leg on which this one winding is mounted, during the positive half cycle, while during this half cycle, the current in the other winding 16 will tend to decrease the flux in the leg on which it is wound. Hence, during this positive half cycle, the impedance of the first winding is relatively small and acts as a partial short circuit across the cathode 10 so that the current supplied to the cathode is reduced. During the negative half cycle, the other winding 16 provides a low shunt impedance across the cathode 10.

The short-circuiting effect of the windings will be dependent upon the degree to which the core material is driven above the knee of its saturation curve by the alternating current supply and, hence, upon the magnitude of the steady or bias-

ing flux produced by the current flowing through the winding 20. This current, and hence the degree of regulation obtained, may be adjusted by varying the resistance 18. In general, the larger the magnitude of the resistance 18 is, the greater is the decrease in the power supplied to the cathode produced by a given anode current.

Although in the systems shown in Figs. 1, 2 and 3, the auxiliary winding 20 is shown as connected directly in the anode circuit of the electron discharge device, the current to this winding may be supplied in other ways, whereby very sensitive control of the filament power may be effected. For example, as shown in Fig. 4, which is generally similar to Fig. 1 and wherein corresponding elements are identified by the same reference characters, the winding 20 may be connected between the cathode 26 and anode 27 of an electron discharge device R₂, a suitable source, such as a battery 28 being provided as shown. The circuit between the cathode 10 and anode 11 of the discharge device R₁ may be completed through a suitable resistance 29 having one end connected to the cathode 10 through a conductor 30. The other end of the resistance 29 is connected to the cathode 26 by a conductor 31 and a circuit between the cathode 26 and the control electrode or grid 32 is completed through a biasing source, such as a battery 33. The potential upon the control electrode or grid 32 at any particular instant will be dependent, of course, upon the potential drop across the resistance 29. The negative grid bias provided by the battery 33 preferably is such that when the potential drop across the resistance 29 is zero, no anode current flows in the discharge device R₂.

When anode current flows in the discharge device R₁, the resultant potential drop across the resistance 29 causes a reduction in the bias upon the grid 32. When the reduction in the grid bias is sufficient to allow the flow of current through the discharge device R₂, current will flow through the auxiliary or biasing winding 20 whereby the current to the cathode 10 is regulated as described heretofore in the description of Fig. 1. The degree of regulation and the point at which control of the current through the cathode 10 begins will be dependent, of course, upon the characteristics of the discharge device R₂, and the magnitude of the resistance 29 and the grid bias provided by the source 33. These may be adjusted to effect any desired control or regulation.

Although a single discharge device R₂ has been shown in Fig. 4 in circuit with the auxiliary or biasing winding 20, an amplifier of two or more stages may be employed and extremely sensitive control of the power for the cathode 10 thereby obtained.

For example, as shown in Fig. 5, two space discharge devices R₂ and R₃ connected and operated in push-pull relation may be employed, each of these devices having a cathode 26, anode 27 and control grid 32. The potential for the anodes 27 may be obtained from a transformer T₃ having a primary winding 41 and a secondary winding 42 connected to the anodes. The auxiliary winding 20 is connected between the mid-point of the winding 42 and the mid-point of the connection between the cathodes 26.

The operation of the system shown in Fig. 5 will be clear, it is believed from the description hereinabove of Fig. 4. It may be noted, however, that the arrangement shown in Fig. 5 obviates the use of a separate direct current supply for the auxiliary winding 20.

It will be noted that in Figs. 4 and 5 a short-circuited winding, such as the winding 22 in Figs. 1 to 3, is not necessary inasmuch as the auxiliary winding 20 is not connected directly in the anode circuit of the discharge device R₁. Elimination of the winding 22 allows more rapid changes in the flux in the core of the transformer T₁. The arrangements shown in Figs. 4 and 5, therefore, are particularly suitable for regulation of the cathode power in electron discharge devices of low power capacity, wherein small cathodes with small thermal lags and small space currents are employed.

It will be understood that although Figs. 4 and 5 illustrate control, through the intermediary of one or more electron discharge devices, of the current through the auxiliary winding 20 in an arrangement similar to that shown in Fig. 1, similar control may be utilized in the systems shown in Figs. 2 and 3.

In the system illustrated in Fig. 6, the regulating transformer T₄ comprises a core including the four sections or legs 44 to 47 inclusive. The primary winding 16 is wound on the leg 47 and the secondary winding 19, in series with the cathode 10 of the discharge device R₁, is wound on the leg 46. The anode circuit of the device R₁ is completed through a source 21 and a series resistance 29 connected to the mid-point of the secondary winding 19. The center tapped auxiliary winding 20 is connected to the anodes 27 of the space discharge devices R₂ and R₃, connected in push-pull fashion, and supplies the anode potential, which may be several hundred volts, therefor.

The control electrodes or grids 32 of the devices R₂ and R₃ are biased by a source, such as a battery 33, connected to the cathodes 26 through the resistance 29 in the anode circuit of the discharge device R₁, so that when no current flows in this anode circuit, no current passes in the devices R₂ and R₃ and hence no load is placed on the auxiliary winding 20.

When current flows in the anode circuit of the device R₁, the bias upon the grids 32 will decrease because of the potential drop across the resistance 29. At a desired predetermined value of this current, which is determined by the resistance 29 and source 33, the devices R₂ and R₃ will become conductive and a load will be added to the auxiliary winding 20. This added load will result in an increase in the current in the primary winding 16 and, because of the resistance 18, the primary voltage will decrease. The decrease in the primary voltage will result in a decrease in the voltage induced in the secondary winding 19 and, hence, in a decrease in the power supplied to the cathode 10.

If the anode current of the device R₁ increases, the current in the devices R₂ and R₃ will increase and, as will be apparent from the preceding paragraph, the power supplied to the cathode 10 will be decreased. The value of this anode current at which regulation begins can be adjusted by varying the resistance 29 or the voltage of the source 33, or both.

Although several illustrative embodiments of this invention have been shown and described, it will be understood of course, that various modifications may be made therein without departing from the scope and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising an electronic device having a cathode and an elec-

trode in cooperative relation with said cathode, a circuit connected to said cathode and said electrode, a transformer including a core having three legs connected at their ends, similar windings on two of said legs and connected to each other and said electrode, means for energizing said transformer to produce in said two legs a flux less than the saturation value when the current supplied to said cathode through said windings is at the normal cathode rating, and means for increasing said flux above the saturation value in accordance with increases in the current in said circuit, said second means including an auxiliary winding on the other of said legs and connected to said circuit.

2. Electron discharge apparatus comprising an electronic device having a cathode and an electrode in cooperative relation with said cathode, a circuit connected between said cathode and said electrode, a transformer including a core having a pair of outer legs and an intermediate leg, said legs having corresponding ends thereof magnetically connected, a pair of windings on said outer legs, oppositely poled and connected in series with each other and said cathode, means for energizing said core, and means for changing the flux in said outer legs in accordance with increases in the current in said circuit to reduce the voltage induced in said windings, said second means including an auxiliary winding on said intermediate leg and in said circuit.

3. In combination, an electron discharge device having a cathode and an anode, an output circuit connected between said cathode and said anode and including a resistance, a transformer having a pair of outer legs and an intermediate leg connected at corresponding ends, a pair of windings on said outer legs and defining a series circuit with said cathode, means for energizing said transformer whereby a potential sufficient to supply said cathode with its normal rated current is produced in said windings, and means for reducing the potential of said windings and the current supplied to said cathode in accordance with increases in the current in said circuit, said second means including an auxiliary winding on said intermediate leg, a space discharge device, an output circuit for said space discharge device including said auxiliary winding, and an input circuit for said space discharge device including said resistance.

4. In combination, an electron discharge device having a cathode and an anode in cooperative relation with said cathode, means for heating said cathode including a transformer having a pair of windings in circuit with said cathode, said transformer having a pair of legs on which said windings are wound and having a third leg in shunt with said first legs, an auxiliary winding on said third leg, means for energizing said transformer to produce equal, oppositely directed, sinusoidally varying fluxes in said pair of legs with substantially zero flux in said third leg, said fluxes being below the saturation value of said pair of legs, and means for preventing excessive supply of current to said cathode through said windings, said second means comprising a circuit connected between said cathode and said anode including said auxiliary winding and a source of direct current potential.

5. In combination, an electron discharge device comprising a cathode and an electrode in cooperative relation with said electrode, a circuit connected between said cathode and said electrode, a transformer having a core including a

closed series magnetic branch and an auxiliary branch, means for energizing said transformer to produce an alternating flux of less than the saturation value in said series branch, a heater circuit for said cathode including a winding on said series branch, and means responsive to the flow of abnormal currents in said first circuit for applying a direct current magnetomotive force to said auxiliary branch sufficient to increase the flux in said series branch above the saturation value therefor.

6. The combination defined in claim 5 wherein said first circuit includes an impedance and said second means includes a space discharge device for controlling the magnitude of said magnetomotive force, said space discharge device having an input circuit including said impedance.

7. Electron discharge apparatus comprising an electron discharge device including a cathode and an electrode in cooperative relation with said cathode, a circuit connected between said cathode and said electrode, a transformer including a symmetrical core having a pair of outer legs and an intermediate leg connected at corresponding

ends by yokes, means for energizing said transformer to produce an alternating flux less than the saturation value in said outer legs, the flux in said outer legs being opposite in direction, windings on said outer legs in circuit with one another and said cathode for supplying heating current to said cathode, and means including a winding on said intermediate leg and coupled to said circuit for impressing a direct current magnetomotive force on said core sufficient when abnormal currents flow in said circuit to increase the flux in said outer legs above the saturation value.

8. Electron discharge apparatus in accordance with claim 2 comprising means for preventing reaction of said auxiliary winding upon said circuit to impose an alternating potential on said circuit.

9. Electron discharge apparatus in accordance with claim 2 comprising a short-circuited winding on said intermediate leg for preventing the superimposing of an alternating potential upon said circuit by said auxiliary winding.

ARNOLD E. BOWEN.