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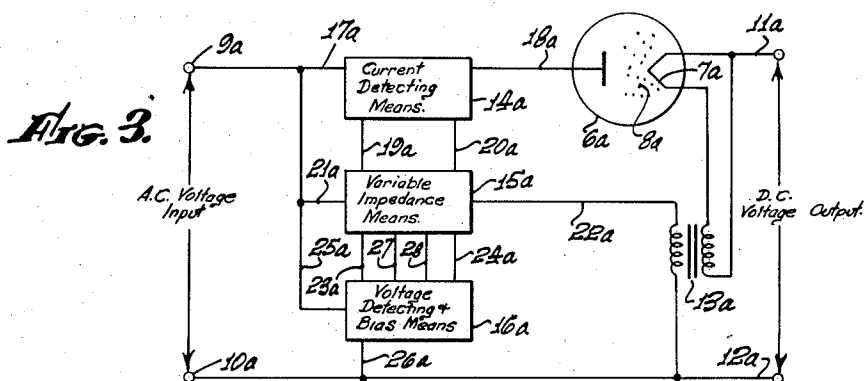
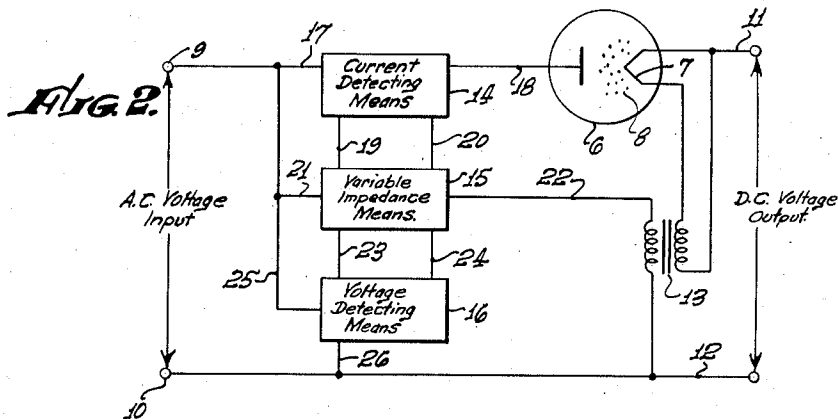
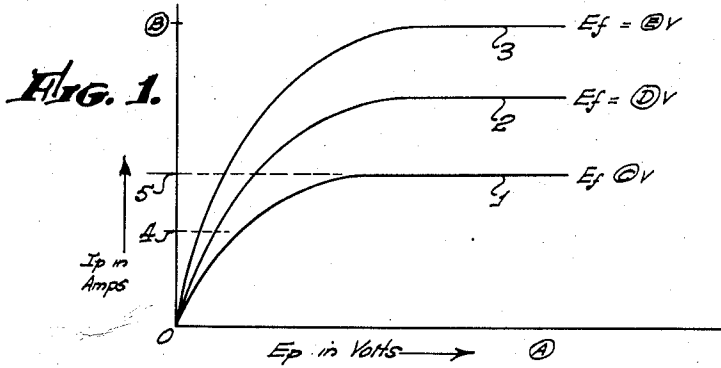
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2,964,692

SPACE CHARGE REGULATOR

Filed Aug. 19, 1957

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 4.

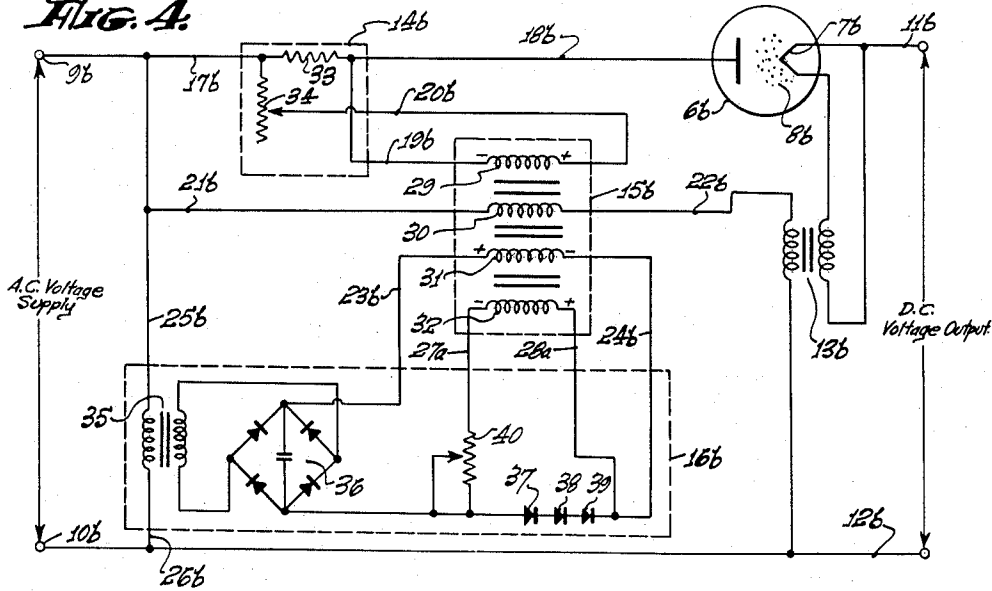
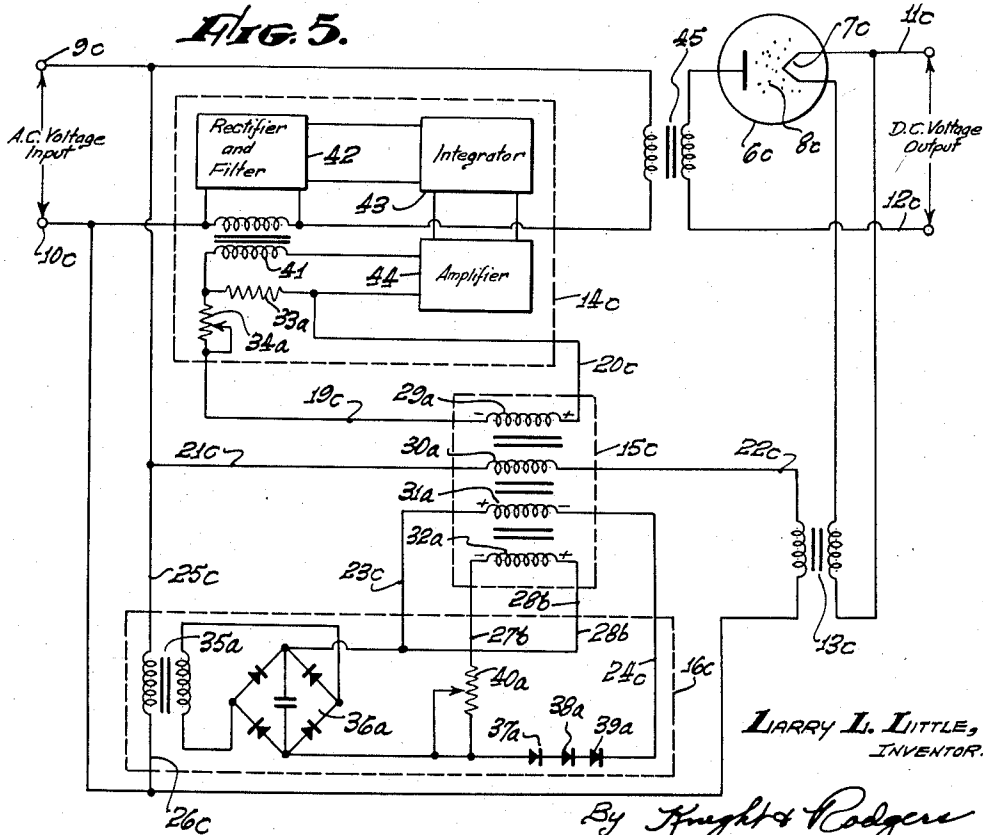


FIG. 5.



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1

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SPACE CHARGE REGULATOR

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2 Claims. (Cl. 321—42)

The present invention relates to a space charge regulator useful in prolonging the life of a vacuum tube, and in reducing the average filament power dissipated within a vacuum tube, without adversely effecting the operation of the tube. This action is attained in accordance with the invention by automatically maintaining the space charge of electrons within the vacuum tube at an optimum value in relation to the current flow through the tube.

In a vacuum tube of the thermionic emission type there is normally a space charge, or cloud, of electrons surrounding the emitting element. The space charge is formed by heating the emitting element to a high temperature, and thus causing electrons to leave the surface of the emitter due to an increase in their kinetic energy. The emitter may be heated directly, i.e. by applying a filament voltage directly to the emitter, or indirectly, i.e. by applying a filament voltage to a filament placed near the emitter. The size of the space charge depends on the material and temperature of the emitter. With a given emitter, an increase in temperature will increase the space charge, and a decrease in temperature will decrease the space charge. Normally the emitter is set at some predetermined temperature level by applying a fixed voltage to the tube filament.

When a positive potential is applied to some second element of the tube, electrons are attracted from the space charge to the second element, thus forming a current flow through the tube. The electrons which are drawn from the space charge as tube current are replaced by other electrons from the emitter; however, since there is a time lag between the escape of electrons as current flow and their replacement by emission, a flow of current tends to reduce the size of the space charge. In general, an increase in tube current reduces the space charge and a decrease in tube current increases the space charge.

The internal resistance of the vacuum tube to current flow depends on the relation between the space charge and the current flow. When the space charge is large compared to current, there are many free electrons available, and the tube resistance is relatively low. When the space charge is small compared to the current, the tube resistance is relatively high. And if the current is increased to the point where no space charge remains, i.e. the point where all emitted electrons are drawn off as current flow, a saturation level is reached where the tube resistance increases very rapidly, and little or no further increase in current is possible.

In many thermionic vacuum tube circuits it is undesirable to operate the tube in or near the region of saturation, and therefore in these circuits it has been customary to fix the emitter temperature at a level which will maintain an adequate space charge for the maximum current surge that the tube will normally handle, even though the maximum current surge may only be present during 10% of the tube operating time. This insures that the tube will not normally operate in its saturation

2

region. But it also results in excessive emitter temperature during the 90% of operating time when the current is at its average level, and this excessive emitter temperature significantly deteriorates the emitter, and also adds unnecessarily to the filament power dissipated within the tube. It has been found that an increase in the fixed emitter temperature which corresponds to a 5% increase in filament voltage will halve the life of a vacuum tube, and conversely that a decrease in fixed emitter temperature corresponding to a 5% decrease in filament voltage will double the life of a vacuum tube. In accordance with my invention, I have found that the emitter deterioration and excess filament power dissipation which accompanies a fixed emitter temperature can be avoided if the emitter temperature is automatically regulated to maintain the space charge at its optimum value in relation to tube current and to change the space charge to correspond to its optimum value in response to changes in tube current. Such regulation is particularly desirable in industrial applications, where vacuum tubes may be quite costly, or in aircraft applications, where a small increase in heat may require the addition of heavy air-conditioning equipment.

The relationships described above will be more clearly understood by reference to Fig. 1, which shows a set of characteristic curves for a diode thermionic emission vacuum tube. Curves 1, 2 and 3 show the relationship between plate voltage and plate current with different filament voltages applied to the filament, as noted. On each curve the lower portion is the area in which the space charge is large compared to the current, and it can be seen that in that area a small increase in plate voltage results in a relatively large increase in plate current, thereby indicating a low tube resistance. The upper portion of each curve is the area in which the space charge is large compared to the current, and it can be seen that in that area a large increase in plate voltage results in only a small increase in plate current, thereby indicating a high tube resistance. The horizontal portion of each curve is the saturation area, where a very large increase in plate voltage results in little or no increase in tube current, thus indicating an extremely high tube resistance. The spacing between the curves reflects the fact that a higher emitter temperature results in a larger space charge.

If the tube whose characteristics are shown in Fig. 1 is used in a circuit with a steady current flow corresponding to the height of line 4, the filament may be operated at its lowest voltage, since this current level falls in the optimum region on curve 1. However, if occasional current surges are expected corresponding to the height of line 5, the filament voltage must be raised to avoid entering the saturation region of curve 1. According to the past practice of setting a fixed filament voltage, this requires that the tube be operated on curve 2 all of the time, even though operation on curve 1 might be acceptable 90% of the time. Under these conditions the filament voltage will be at least 10% high during 90% of the tube operating time, and the resulting filament deterioration will more than halve tube life. Also, the filament power dissipation within the tube will be about 10% higher than necessary during 90% of the tube operating time.

Thus it becomes one general object of my invention to provide a method and means whereby a thermionic vacuum tube may be operated under widely varying current conditions without unnecessary emitter deterioration or filament power dissipation.

A second general object of my invention is to provide a method and means whereby a thermionic vacuum tube may be operated under widely varying current conditions without entering its saturation region and

without unnecessary emitter deterioration or filament power dissipation.

Another object of my invention is to provide a space charge regulator for a thermionic vacuum tube which automatically regulates the space charge within the vacuum tube in accordance with the current flow through the vacuum tube.

A further object of my invention is to provide a device of that character which is easily adaptable to a variety of thermionic vacuum tube circuits. An additional object of my invention is to provide a device as described above which is simple to manufacture, and reliable in operation.

Other objects and advantages of my invention will be apparent to those skilled in the art from the following description and annexed drawings, in which:

Fig. 1 is a set of characteristic curves for a diode thermionic emission vacuum tube.

Fig. 2 is a block diagram of one general embodiment of my invention as used with a half wave rectifier circuit.

Fig. 3 is a block diagram of a second general embodiment of my invention as used with a half wave rectifier circuit.

Fig. 4 is a schematic diagram of one specific embodiment of my invention as used with a half wave rectifier circuit.

Fig. 5 is a schematic diagram of the specific embodiment shown in Fig. 4 as used with a half wave rectifier circuit having a voltage regulator.

In accordance with the general method of my invention, I have discovered that the life of a thermionic vacuum tube can be substantially increased by automatically maintaining the space charge within the tube at an optimum level in relation to the current through the tube, and I have provided means for effecting this automatic control by automatically maintaining the filament voltage applied to the tube at a level related to the current flow through the tube.

Fig. 2 shows one general embodiment of my invention as used with a half wave rectifier circuit. The rectifier circuit comprises diode 6 having a directly heated cathode (or filament) 7 and a space charge of electrons 8 surrounding the filament. An A.C. input voltage is applied to the rectifier circuit between terminals 9 and 10, and a D.C. output voltage is taken from the circuit between conductors 11 and 12. The tube filament is heated by a filament voltage applied through a filament transformer 13 from the A.C. input voltage to the rectifier. The operation of the rectifier circuit will not be described further, since it is well known to those skilled in the art.

My invention comprises a variable impedance means connected in series with the filament voltage source, current detecting means connected to detect the current flow through the tube and to control the variable impedance means in accordance with tube current, and voltage detecting means connected to detect the filament source voltage and to control the variable impedance means in accordance with the filament source voltage. Both detecting means are required because there are two ways in which the space charge can be altered from its optimum value in relation to tube current: one way is by a variation in tube current while filament voltage remains constant, and the other way is by a variation in filament voltage while the tube current remains constant.

When the filament voltage input remains constant and the tube current increases, the increase in tube current is detected by the current detecting means and utilized to decrease the impedance of the variable impedance means in series with the filament transformer. The decrease in impedance of the variable impedance element raises the amount of voltage appearing across the transformer primary, consequently increasing the voltage applied to the filament, and thus increasing the space charge to correspond with the increase in current. When the

tube decreases, an inverse action takes place which decreases the space charge to correspond to the decrease in current.

When the tube current remains constant and the A.C. input voltage increases, the increase in voltage is detected by the voltage detecting means and utilized to raise the impedance of the variable impedance means such that the increase in voltage is dropped across the variable impedance, and the voltage appearing across the transformer primary is held constant, thus leaving the space charge unaffected by the increase in filament source voltage and maintaining the space charge at its optimum value in relation to the tube current. When the A.C. input voltage decreases, an inverse action occurs which maintains the space charge unaffected by a decrease in the filament source voltage thus maintaining the space charge at its optimum value in relation to tube current. In this manner my invention acts to maintain the space charge at its optimum value in relation to tube current in spite of fluctuations in the filament voltage source, and it also acts to change the space charge to its optimum value in relation to tube current in response to fluctuations in the tube current.

Fig. 3 shows a second general embodiment of my invention in which bias means have been added to the voltage detecting means to adapt the invention to different initial impedance conditions of the variable impedance means. The bias means act to set the initial impedance of the variable impedance means according to a manual control. Except for the addition of the bias means and bias conductors 27 and 28, this embodiment is identical in function with the embodiment described in the preceding paragraphs. The reference numbers in Fig. 3 correspond in function to the same numbers in Fig. 2.

Fig. 4 shows a specific embodiment of my invention which is of the general type shown in Fig. 3. The reference numbers in this drawing also correspond in function to the same numbers in Figs. 2 and 3. The variable impedance means 15b consists of a saturable reactor with an A.C. impedance winding 30 and three D.C. control windings 29, 31 and 32. The impedance of winding 30 is controlled by the total magnetic field existing in the reactor core, which in turn depends on the current flow and number of turns in the control windings. Winding 30 is connected in series between the A.C. filament source voltage input and the primary of filament transformer 13b, so that the proportion of the A.C. filament input voltage which appears across the transformer primary depends on the impedance of winding 30, in accordance with well known laws of series circuits. When the impedance of winding 30 increases, the voltage applied to the transformer is decreased, and when the impedance of winding 30 decreases, the voltage applied to the transformer is increased.

The total magnetic field in the reactor core is proportional to the algebraic sum of the ampere-turns in the three control windings, and the direction of the magnetic field corresponds to the dominant direction of current flow. The direction of current flow through the control windings is indicated by the polarities marked on Fig. 4 near the ends of the windings. Normally the sum of the ampere-turns in the aiding windings 29 and 32 is significantly greater than the ampere-turns of the bucking winding 31, so that the direction of the total magnetic field corresponds to the current flow through windings 29 and 32, and the opposing magnetic field generated by the current flow through winding 31 serves only to cancel a portion of the total field. The arrangement of control current polarities as described above is critical in this particular embodiment of the invention, because it is necessary that an increase in current through winding 29 act to increase the total magnetic field while an increase in current through winding 31 decreases the total field. By connecting winding 32 to aid winding 29 the direction of

5

the total magnetic field will be dominated by the polarity of winding 29, and the necessary action of the invention will be obtained even if the current through winding 31 is greater than the current through winding 29, provided that the difference is not greater than the current through winding 32. The direction of the total magnetic field in relation to the A.C. winding 30 is immaterial, so long as the three control windings are related as described above.

It should be particularly noted that in this embodiment the action of the invention will be reversed if the total magnetic field ever takes its direction from the current flow through winding 31, so that it is necessary to make the current flow through winding 32 large enough to counter act the normal surges of current through winding 31, to maintain the direction of the total field in accordance with the current flow through winding 29.

Although the impedance of the A.C. winding 30 depends on the algebraic sum of the control ampere-turns, as described above, it will be convenient to describe the action of the control windings one at a time, assuming for purposes of explanation that the current in the other two windings remains constant.

The current through control winding 29 is controlled by the voltage output from the current detecting means 14b, which comprises a resistor 33 in series with the tube current, and an adjustable resistor 34 in series with the control winding 29. The variable resistor 34 is used to set the sensitivity of the current detecting means, i.e. to set the amount of voltage output variation at conductors 20b and 19b which will result from a given change in the tube current. When the tube current increases, the voltage drop across the output conductors 19b and 20b increases and consequently the current flow through winding 29 increases, increasing the total magnetic field in the reactor core, and decreasing the impedance of winding 30. The decrease in impedance of winding 30 causes an increase in the voltage applied to the transformer primary, thus increasing the voltage applied to the filament 7b, and thereby increasing the space charge to correspond with the increase in tube current. When the tube current decreases, an inverse action takes place which lowers the filament voltage, and decreases the space charge to correspond to the decrease in tube current.

The current flow through windings 31 and 32 are controlled by the voltage detection and bias means 16b, which comprises a transformer 35, rectifier 36, variable resistor 40, and voltage regulators 37, 38 and 39. The D.C. voltage output from the rectifier 36 corresponds to the A.C. voltage input to the transformer 35, which is connected to the filament voltage source. When the A.C. voltage of the filament voltage source increases, the D.C. voltage output from rectifier 36 increases, and the current flow through winding 31 increases. Since the magnetic field of winding 31 is in opposition to the total magnetic field in the reactor core, this results in a decrease in the total magnetic field, and consequently an increase in the impedance of winding 30. The increase in the impedance of winding 30 absorbs the increase in the filament voltage source, thus holding the voltage input to the filament transformer constant, and maintaining the space charge at its optimum value in relation to the tube current. When the A.C. voltage of the filament source decreases an inverse action takes place which decreases the impedance of winding 30, thus increasing the proportion of the filament source voltage applied to the filament transformer, and similarly maintaining the space charge at its optimum value in relation to tube current.

The current flow through winding 32 is controlled by the voltage drop across voltage regulators 37, 38 and 39 and the setting of variable series resistor 40. The voltage regulators 37, 38 and 39 are constant voltage devices which maintain the same voltage drop over a wide variation of current, therefore the voltage drop across the voltage regulators is not effected by a variation in voltage from the rectifier 36 or a variation in current through the

6

winding 31. Thus the current flow through winding 32 is varied solely by the setting of series variable resistor 40, which is the bias control of the bias means. By means of resistor 40 the initial value of the total magnetic field can be set at any desired level, thus setting the initial impedance of winding 30 at any desired level. However, as noted before, the bias current level must be set to a minimum level which will prevent the total magnetic field from taking its direction from the current through winding 31, so that the operation of the invention will not be reversed.

Since the total magnetic field in the core is a result of the currents through all three windings, the impedance of winding 30 will simultaneously be controlled by the bias setting, any variations in filament source voltage, and any variations in tube current, to automatically maintain the space charge at its optimum value in relation to the tube current, thus increasing tube life, and decreasing average filament power dissipation within the tube.

The specific embodiment of my invention described above is shown in Fig. 5 as it is used with a half wave rectifier having a voltage regulator circuit. The voltage regulator circuit of the rectifier consists of a saturable reactor 41, a rectifier and filter 42, an integrator 43 and an amplifier 44. The voltage regulator circuit is adapted to produce an increase in the current output from amplifier 44 corresponding to an increase in current through the tube. This in turn causes an increase in the voltage drop across resistor 33; which causes an increase in the filament voltage in a manner identical to the invention described in connection with Fig. 4. The arrangement shown in Fig. 5 has the advantage of detecting current at a low voltage point.

The bias control winding connection is slightly altered in the circuit of Fig. 5 from the configuration shown in Fig. 4. Conductor 28b has been connected to conductor 23c, rather than to conductor 24c as shown in Fig. 4. This altered connection has the advantage of avoiding a back-flow of bias current through the voltage detecting winding 31a and since the impedance of the rectifier 36a and bias control 40a are relatively high compared to the resistance of winding 32a, any voltage variations introduced into the bias winding by this altered connection are negligible.

Except for the two changes noted above, the operation of the invention in Fig. 5 is identical with the invention described in connection with Fig. 4.

The foregoing description and annexed drawings are set forth solely for purposes of disclosure, and should not be construed as limitations on my invention. My invention has many practical embodiments not here disclosed, limited only by the scope of the following claims.

I claim:

1. A space charge regulator for use in a circuit including a source of alternating current and a vacuum tube having a cathode and an anode, comprising:

A source of current for heating the cathode including a transformer having a secondary winding connected to the cathode to supply heating current thereto, and a primary winding;

A saturable reactor having a main winding and a plurality of control windings;

Circuit elements connecting the main winding serially with the primary winding of the transformer and with the source of alternating current;

Current detecting means connected to one of said control windings of the saturable reactor and to the source of alternating current, said current detecting means being adapted to produce an output voltage related to the current flow through the vacuum tube;

Voltage detecting means connected to said current source and to a second one of said control windings of the saturable reactor, said voltage detecting means being adapted to produce an output voltage related to the voltage from the alternating current source;

And bias means having a manual control and connected to a third one of said control windings and to said voltage detecting means, and adapted to produce an output voltage corresponding to the setting of the manual control;

Said voltage detecting means and said bias means comprising a transformer, the primary winding of said transformer being connected to said cathode voltage source, a rectifier circuit having its input terminals connected to the secondary winding of said transformer, said rectifier circuit having a first and a second D.C. output terminal;

A constant voltage element connected in series with the second one of said control windings across said D.C. output terminals, and bias means including said third

one of the control windings connected across said D.C. output terminals.

2. A device as defined in claim 1 wherein said bias means includes a manually adjustable variable resistor connected in series with the third one of the control windings.

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