Dec. 20, 1927. 1,653,102

W. K. KEARSLEY, JR

ELECTRON DISCHARGE APPARATUS

Filed Sept. 2, 1924 2 Sheets-Sheet 1

Fig. 1.

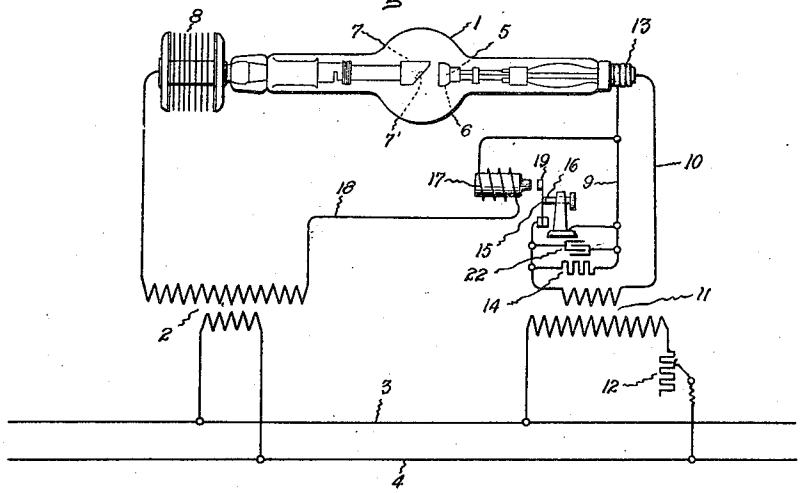


Fig. 2.

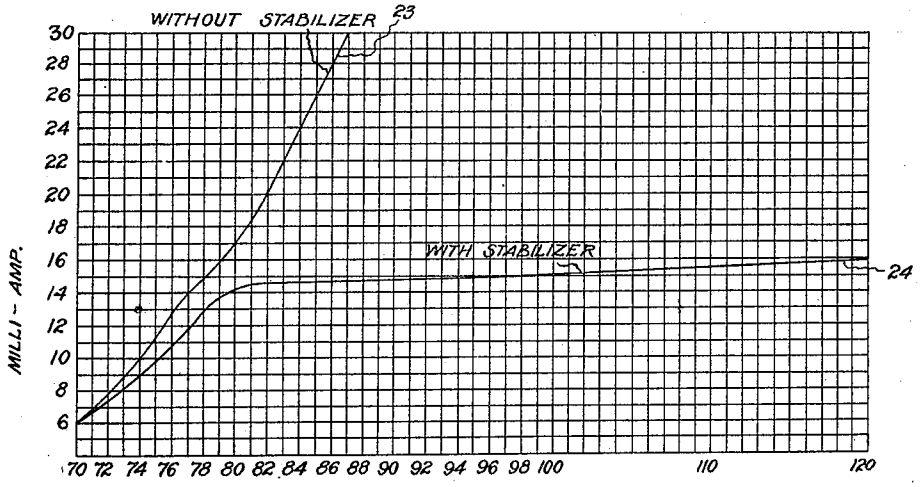


Fig. 3.

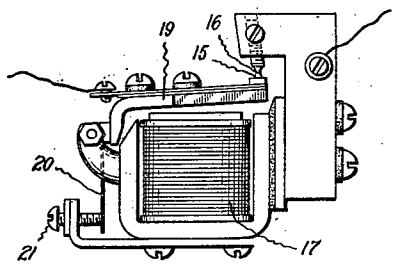
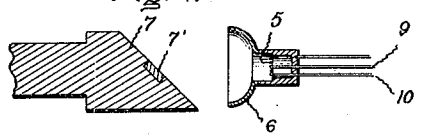


Fig. 4.



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Fig. 5.

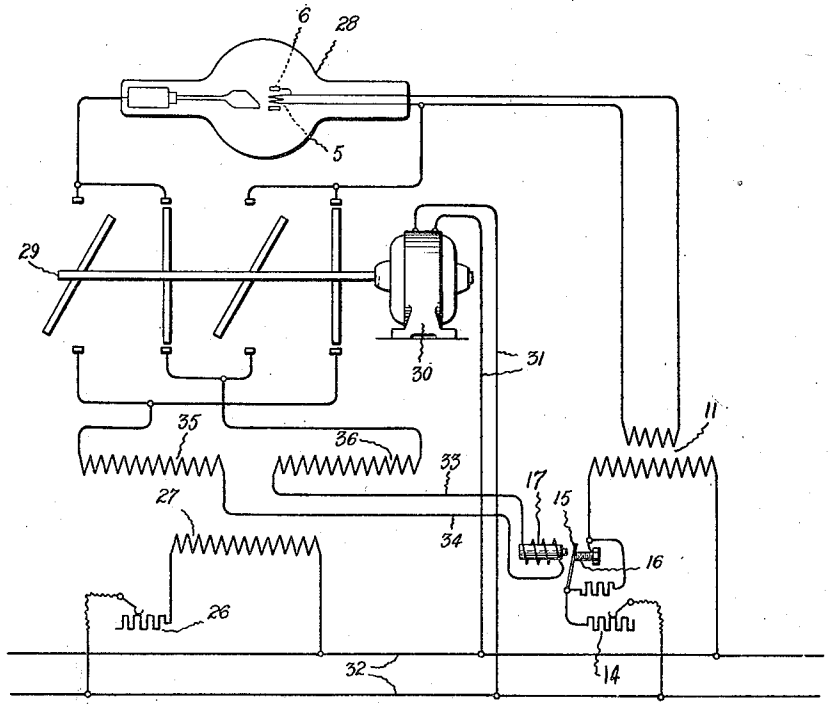
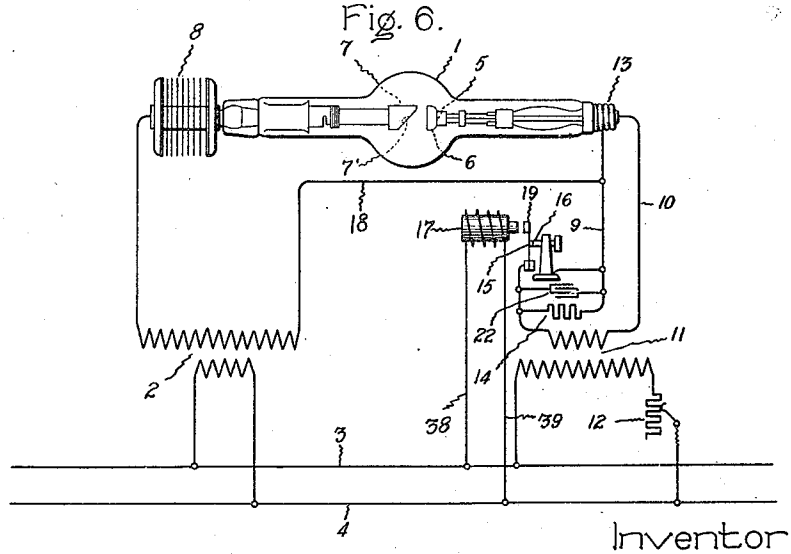


Fig. 6.



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UNITED STATES PATENT OFFICE.

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ELECTRON-DISCHARGE APPARATUS.

Application filed September 2, 1924. Serial No. 735,266.

This application is a continuation in part of my prior application filed October 22, 1920, Serial No. 418,642.

The present invention relates to devices, such for example as X-ray tubes, which operate by the production of an electron discharge, and particularly to an electron discharge produced independently of gaseous ionization. It is the object of my invention to provide a method and means for automatically regulating the electron emission of the cathode of a thermionic device to give a desired operating characteristic.

My invention is particularly applicable to the operation of an X-ray tube of the incandescent cathode type, and is embodied in an apparatus whereby a constant X-ray output may be secured even though the source of cathode heating current varies in voltage.

The novel features of my invention will be pointed out with greater particularity in the appended claims. For a better understanding of my invention, reference may be had to the following description taken in connection with the accompanying drawings in which Fig. 1 is a diagram of an X-ray system embodying my invention; Fig. 2 is a graph of electrical characteristics of a device equipped with a stabilizer, as compared with the same device not so equipped; Fig. 3 is a detail view of a vibrator used in my new apparatus; Fig. 4 is a detail view of X-ray tube electrodes, and Figs. 5 and 6 illustrate modified systems embodying my invention.

In the system shown in Fig. 1, an X-ray tube 1 of the type now known as the self-rectifying Coolidge tube, is shown connected to the high tension secondary winding of the transformer 2, having the low tension primary circuit connected to a suitable source of current represented by mains 3, 4, carrying alternating current. The X-ray tube 1 contains a cathode shown in detail in Fig. 4 consisting of a heated filament 5 surrounded by a focusing device 6 and an anode 7 consisting preferably of a rod of copper containing an inset 7′ of refractory metal, preferably tungsten. The anode is preferably in good thermal relation to a radiator 8, but auxiliary devices such as this radiator, are merely shown in the drawing as illustrating one complete embodiment of my invention. My invention is not confined in its function to an X-ray tube, but is applicable to other forms of electron discharge devices, differing in function and structural details from an X-ray tube.

The cathode 5 of the X-ray tube is connected by the conductors 9, 10 to the secondary winding of a transformer 11, the primary of which is connected in series with a suitable adjustable resistance 12 to the supply mains 3, 4. A resistance 14 is included in the auxiliary heating circuit 9, 10 in series with the secondary winding of the transformer 11. In a shunt circuit to the resistance 14 are vibrating or make-and-break contacts 15, 16, one at least of which is adjustable.

These contacts 15, 16 are caused to open and close at a rapid rate during the operation of the tube, the relative durations of periods of "make" as compared with the periods of "break" being determined by the strength of the current flowing through an electromagnet 17, the winding of which is included in the circuit 18 carrying the current flowing from cathode to anode through the X-ray tube. One embodiment of a vibrator magnet is shown in Fig. 3. In the apparatus illustrated in this figure the vibrating armature 19 of the magnet opposes in its downward motion a spring 20, the tension of which may be adjusted by a screw 21. Preferably the vibrator is adjusted to operate substantially in synchronism with the alternating current supply. A condenser 22 may be provided connected across the contacts 15, 16 to reduce sparking.

Before describing the operation or function of the apparatus illustrated by Fig. 1, attention is directed to the graph shown in Fig. 2. In a system similar to the system shown in Fig. 1 but in which the resistance 14 and the shunt connected vibrating contacts 15, 16 are omitted, and in which the cathode of an electron discharge device is heated without any regulation by current from a transformer supplied from a source varying in potential, the load current flowing from cathode to anode through the electron discharge device varies with the variations of potential of the cathode heating current at a rate indicated by the curve 23. The voltage across the terminals of the primary winding of the filament heating transformer have been plotted in Fig. 2 as abscissæ through a range of voltages from 70 to 87 volts, the corresponding current values be-

tween the cathode and the anode being plotted as ordinates over a range from 4 to 30 milliamperes. It will be noted that as the voltage of the filament heating transformer increases through this range, the space current transmitted by the device very rapidly increases. For example, for an increase of from 82 to 87 volts, that is, an increase of about 5.1% the space current increases from 20 to 30 milliamperes, an increase of about 50%.

When a system such as above described having no regulator is connected to an ordinary commercial transmission line, incidental voltage variations in these lines, especially when commercial devices such as elevator motors, are supplied by the same lines, is sufficient to produce such wide variations in output of an electron device, such as an X-ray tube, as to make it difficult to determine a proper X-ray exposure.

When, in accordance with my invention, a device having a cathode which emits electrons independently of ionization effects and from which hence a saturation current may be obtained, such for example as a hot cathode X-ray tube, is supplied with a stabilizer responsive in its operation to the load current passing through the device, the transmitted current becomes substantially constant with wide variations of voltage. As shown, for example in the curve 24, an increase of voltage from 82 to 87 volts produces no appreciable change of current, and in fact, even an extreme increase of line voltage to 120 volts causes an increase of current of only slightly more than one milliampere or an increase of about 10% of current change with a voltage change of 46%. In commercial operation the filament heating transformer of an X-ray tube probably would not be subjected in its primary voltage to this wide variation. In practice, therefore, over an operating range of say, 10 volts, the current through the tube is maintained substantially constant. This action occurs by reason of the variations in magnetic attraction of the core of the stabilizer magnet 17 upon the armature 19 of the vibrator, as already indicated. The magnet 17 for any particular current setting varies the effective length of the cyclic impulses of the current fed to the cathode, the impulses of current depending in duration on the conditions governing electron emission, thus heating the cathode to the temperature required to maintain the desired current value. By "effective length" of current impulses, I mean the length of the current wave before it is reduced to a low value, as when a resistance is inserted in the circuit. For example, if the current has a tendency to increase the time required for the magnet 17 to build up to a strength required to open the contacts 15, 16 each wave of current is reduced. Hence, the contacts 15, 16 are open longer and the resistance 14 is included in series with the circuit 9, 10 for relatively longer periods, thereby weakening the cathode heating current sufficiently to oppose any further increase of the cathode temperature. Similarly, a slight decrease of current will result in weakening the magnet 17, thereby increasing the relative durations of the periods of closure of the short-circuiting contacts and thereby strengthening the cathode heating current. As the electron emissivity of the cathode varies at a rapid rate directly with the temperature, this control of cathode temperature by the vibrating stabilizer in the cathode heating circuit controls the electron emission and hence the current-carrying capacity of the X-ray tube. The stabilizer consequently maintains the current reaching the anode at a predetermined value, as the described X-ray tube is operated at voltages at which substantially all of the electrons emitted from the cathode are utilized to carry current (see Physical Review, Vol. II, 409–430, 1913). With the ordinary commercial voltage variations, as above noted, this substantial constancy of anode current results in a substantially constant output of X-ray. It follows that by the operation of this current-responsive regulator the generation or emission of the electron by the cathode is maintained at a predetermined value regardless of any changes which may occur in the electron emissivity of the cathode.

In some cases my invention may be used advantageously in an X-ray apparatus which has a resistance in series with the primary of the high voltage transformer in order to limit the current which may be drawn from this transformer. For example, in X-ray devices operating at exceedingly high voltages, say, for therapeutic purposes, such a resistance can be used to limit the current to a value not fatal to life. My invention in such a system can be used to give a substantially constant current through the X-ray tube instead of a variable current as would otherwise be the case.

In Fig. 5 I have illustrated an X-ray system suitable for operation with a regulable resistance 26 in series with the primary winding of a high potential transformer 27. The X-ray tube 28 in this case is connected to the secondary windings of the transformer 27 in series with a mechanical rectifier 29 driven by a synchronous electric motor 30. Conveniently this motor is supplied with current by the conductors 31 connected to the supply mains 32 in common with the X-ray transformer 27. The cathode 5 of the X-ray tube is supplied with a heating current by a transformer 11 in the primary winding of which are vibrating contacts 15, 16, controlled by a magnet 17 connected by the con-

ductors 33, 34, in series with the secondary coils 35, 36, of the X-ray transformer. A resistance 14 preferably is connected across the contacts 15, 16.

The system shown in Fig. 5 is closely similar to the system shown in Fig. 1 except that the use of a resistance in the primary of the main transformer 27 renders the use of a special rectifier in series with the X-ray tube desirable in order to protect the tube from high potential during the periods of polarity reversal when a rectifying direct connected X-ray tube, as shown in Fig. 1, is not taking current.

In both the systems described, that is the systems shown in Fig. 1 and also in Fig. 5, the regulator maintains in response to space current flowing through the X-ray tube, an X-ray output which is constant in quantity. In these systems the energy input to the cathode is regulated to maintain a constant emission of electrons regardless not only of voltage variations of the cathode heating source but also of variations of conditions in the X-ray tube which affect the emissivity of the cathode, such for example, as the evolution of a small amount of gas from the interior parts of the X-ray tube. Even a small amount of water vapor which may be evolved from the glass envelope may lower the electron emissivity of the cathode by a "poisoning effect". By varying the temperature of the cathode the action of the regulator will compensate for such tube changes and will maintain a substantially constant electron emission.

It is not necessary in all cases to make the regulator responsive to changes of conditions within the X-ray tube. In the case of a very carefully exhausted X-ray tube, constancy of electron emission at the cathode and hence of quantity X-ray output, which is sufficient for some purposes, may be maintained by keeping the temperature of the cathode substantially constant, regardless of line voltage changes. In that case the actuating coil of the regulator may be connected directly to the heating source for the cathode of the X-ray tube. Such an arrangement is illustrated by Fig. 6, in which the actuating coil 17 is connected by the conductors 38, 39 to the respective supply lines 3, 4. The parts and electric connections otherwise correspond to the apparatus described in connection with Fig. 1. An X-ray tube such as shown in Fig. 5 may be used. Fluctuations of supply voltage will advance or retard the instant the circuit is broken each half wave, thus increasing or decreasing as required the doles of current received by the cathode. For example, should the supply voltage rise, the coil 37 will cause the contact 16 to open sooner, thus decreasing the periods during which the heating current is flowing. By reason of the increased voltage the current rises at a faster rate and hence energy delivered during these shorter periods remains unchanged. By reason of the heat storage capacity of the cathode, this intermittent heat input will produce continuously a substantially constant cathode temperature. Conversely, a fall of voltage of the supply circuit will cause the periods of cathode excitation to increase but without substantially altering the cathode temperature and hence the electron emission. As already stated, constancy of vacuum and other tube conditions are assumed to secure a constant quantity of X-ray output from the apparatus illustrated by Fig. 6.

It is obvious that various modifications, such for example as the above described, may be made without departing from the spirit of my invention.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. An X-ray apparatus comprising the combination of an X-ray tube having main electrodes including a cathode which is heated by passage of current therethrough, a main operating circuit connected to the main electrodes of said tube, an independent heating circuit connected to said cathode, a source of alternating current subject to voltage variation for supplying both circuits, and means responsive to load current in said main circuit for reducing the current in said heating circuit during each half wave for periods of such length that the load current is maintained substantially constant.

2. The combination of an electron discharge tube having a cathode adapted to be heated by passage of current, an alternating current supply means for heating said cathode, and a vibrating regulator responsive to load current in said tube and constructed to operate in synchronism with the current in said supply circuit for regulating the heating current to maintain the load current at a predetermined value.

3. The combination of an X-ray tube having a cathode adapted to be independently heated, a source of alternating current subject to variations of voltage connected to operate said tube, means for deriving current from said source to heat said cathode, and means responsive to current through said tube for decreasing the heating current for said cathode to a low value during each cyclic change of current for a period of such length that the current through said tube is maintained substantially constant.

4. An X-ray apparatus comprising the combination of an X-ray tube having a cathode operable at incandescence, a main supply circuit for said tube, a heating circuit for said cathode, a resistance in said heating circuit, a circuit containing make and break contacts connected in shunt to said resistance, and means responsive to an electrical condi-

tion of the current in said main circuit for varying the relative duration of the periods of make and break of said contacts to control the heating current for said cathode.

5. An X-ray apparatus comprising an X-ray tube having a cathode adapted to be independently heated and an anode, means for heating said cathode, a main operating circuit connected to the electrodes of said X-ray tube, and a vibrating regulator arranged to maintain the electron emission of said cathode at a predetermined relation to an electrical characteristic of said main circuit.

6. An X-ray apparatus comprising a source of alternating current subject to variations of voltage, an X-ray tube operatively connected thereto, said tube having a cathode supplied with heating current from said source and means responsive to load current in said tube and operating in synchronism with said source for controlling the cathode heating current.

7. An X-ray apparatus comprising an X-ray tube having an incandescible cathode and an anode, a main supply circuit connected to said electrodes, a circuit for supplying heating energy to said cathode, vibrating contacts in said heating circuit, and electromagnetic means responsive to current in said main circuit for regulating the relative duration of the periods of make and break of said contacts thereby preventing departures of current in said main circuit from a predetermined value.

8. An X-ray apparatus adapted for operation from a source of alternating current of fluctuating voltage comprising the combination of an X-ray tube of the Coolidge type operating substantially independently of impact ionization, a main step-up transformer having a secondary winding connected to the main electrodes of said tube, an auxiliary transformer having a winding connected to supply heating current to the cathode of said tube, a resistance in circuit with said winding, electric make and break contacts connected in shunt to said resistance, and electromagnetic means in circuit with said X-ray tube for operating said contacts in synchronism with the alternations of supply current, the relative duration of the periods of make and break being determined by the current value in said tube circuit.

9. An X-ray apparatus adapted for operation from a source of variable voltage comprising an X-ray device having an electrode capable of emitting electrons when heated, a main load circuit, a heating circuit for said electrode, a resistance in said heating circuit and electromagnetic means responsive to the current in said main circuit having contacts arranged to insert and withdraw said resistance intermittently, and means for controlling the relative duration of the periods of insertion and withdrawal to maintain the load current at a predetermined value.

10. An X-ray apparatus comprising an X-ray tube having a cathode adapted to be heated by passage of current and operating without substantial gas ionization, a source of alternating current subject to variations of voltage, means for supplying said tube with both load current and cathode heating current from said source, and an electromagnetic regulator responsive to load current having make and break contacts in circuit with said cathode and being constructed to operate synchronously with the periodicity of said source, to control the heating current supplied to said cathode at a value required to produce a constant X-ray output.

11. An X-ray apparatus adapted for operation from a source of alternating current of variable voltage comprising the combination of an X-ray tube having a cathode adapted to emit electrons when heated by passage of current, means for deriving energy from the supply source to operate said tube, separate means for deriving energy from the supply source to heat said cathode, and means operated by current from said source for intermittently reducing said cathode current synchronously with the alternations of said source for periods varying in duration in such measure that the quantity of X-ray output remains substantially constant when the voltage of said source varies.

12. The combination of an electron discharge device which is constructed and evacuated to be capable of operation substantially independently of positive ionization, and having a cathode adapted to generate electrons independently of a load current in said device, means for energizing said cathode with alternating current, and means responsive to a load current in said device for varying the effective duration of the cyclic impulses of said alternating circuit in such measure that the load current is maintained substantially constant.

13. An X-ray apparatus adapted for operation from an alternating current supply source of variable voltage comprising the combination of an X-ray tube provided with a cathode adapted to emit electrons when heated by passage of current, a main circuit connected to the electrodes of said tube, a heating circuit for said cathode connected to derive current from said source, and arranged for operation at voltages at which current in the main circuit is limited by electron emission of the cathode, and regulating means responsive to current in said load circuit for decreasing the cathode heating current during each wave of current flowing therein for periods of such duration that the cathode temperature and current in the main circuit will remain substantially constant.

14. An X-ray apparatus adapted for operation from a source of alternating current subject to variations of voltage comprising an X-ray tube of the Coolidge type having a cathode operable at incandescence, a high potential transformer connected to said source for supplying said tube with current, an auxiliary heating circuit for said cathode, means for deriving energy from said source to supply said auxiliary circuit, a resistance in said auxiliary circuit and means responsive to the current in said tube circuit for inserting and withdrawing said resistance during each impulse of alternating current in the heating circuit for periods of such length that said load current remains substantially constant.

15. An X-ray apparatus comprising an X-ray tube having an electrode adapted to be heated by passage of current, a heating circuit connected to said electrode, alternating current supply means subject to voltage variations for said heating circuit, and electromagnetic means responsive to a load current in said tube and operating in synchronism with said heating current for varying the effective resistance of said heating circuit during each wave of heating current for periods of such duration that the electron emission in said X-ray tube and consequently the output of X-rays are maintained substantially constant.

16. The method of operating an electrical discharge device which consists in supplying energy to the cathode of said device at a rate which if continued would generate a greater supply of current carriers than is required to maintain a desired current through said device at a given voltage and intermittently reducing the supply of energy to said cathode below the value required to maintain the desired current, said reductions occurring during time intervals of the order of frequency per second of commercial alternating current and varying the duration of said intervals of energy reduction in such measure that a load current of desired value can be maintained at a chosen impressed voltage.

17. The method of operating a thermionic discharge device which is subject to changes of operating conditions which consists in supplying to the cathode of said device a heating current of materially higher value than is required to give a desired electron emission, intermittently reducing said current at intervals recurring per second with a frequency of the order of cyclic changes of commercial alternating current and varying the relative duration of the intervals of reduced current in such measure that the load current in said device is maintained at a substantially predetermined value.

18. The method of operating a thermionic discharge device which is subject to changes of operating conditions which consist in supplying to the cathode of said device a cyclic current of higher value than required to heat said cathode to a temperature giving desired electron emission, materially reducing said current during each cycle, and varying the duration of the intervals of reduced current relative to intervals of unreduced current in such measure that the electron emission of said cathode is maintained at a predetermined value.

19. The combination of an electron discharge device having a cathode adapted to be heated by passage of current, means for supplying a heating current to said cathode, means responsive to space current in said tube for reducing the heating current to a low value at rapidly recurring intervals of such variable duration relative to the periods of high current that a substantially uniform electron emission is obtained from said cathode.

20. The combination of a thermionic X-ray device, a supply circuit therefor, means for supplying a heating current to said cathode, means for materially reducing said current at intervals recurring with a frequency of the order of commercial alternating current and means responsive to a space current in said device for varying the duration of said intervals of reduced heating current relative to the unreduced heating current to produce a desired electron emission by said cathode, whereby the X-ray output is maintained substantially constant.

21. An X-ray apparatus comprising the combination of an X-ray tube which is operable independently of positive ionization and is provided with a cathode rendered active by passage of current, means for supplying a cyclic heating current to said cathode, and means for regulating the effective value of said heating current in such measure during the periods when said X-ray apparatus is conducting current that a constant current carrying capacity is maintained in the X-ray tube when changes occur in the electron emissivity of said cathode or in the voltage of the cathode heating current.

22. In a system of the class described, an X-ray tube of the hot cathode type with a secondary of a step-up transformer divided into two coils, a relay in said system with its magnet connected to said coils, a transformer for generating a hot cathode current and suitable connections including a resistance so that when the system is in use the resistance will be thrown in and out of circuit according to the action of the relay magnet.

In witness whereof, I have hereunto set my hand this 29th day of August, 1924.

WILLIAM K. KEARSLEY, JR.