June 7, 1927. 1,631,625

W. D. COOLIDGE

REGULATING METHOD AND APPARATUS

Filed Jan. 30, 1923 2 Sheets-Sheet 1

Fig. 1.

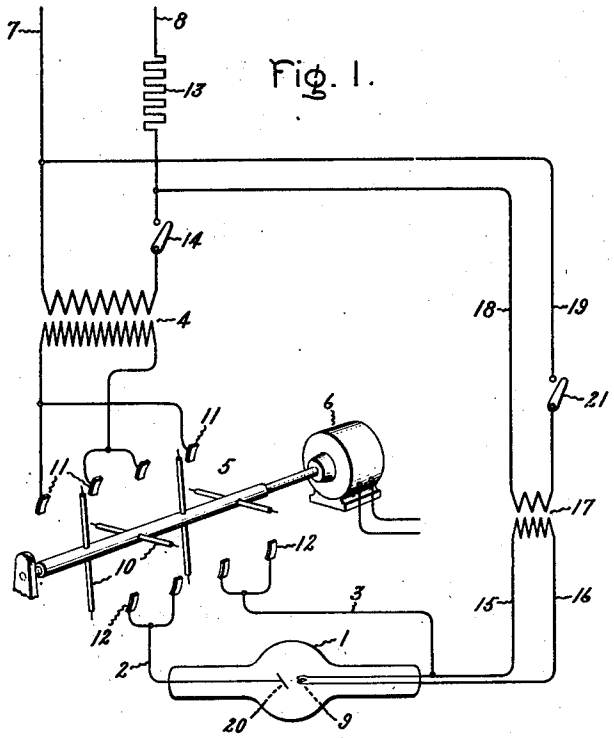


Fig. 2.

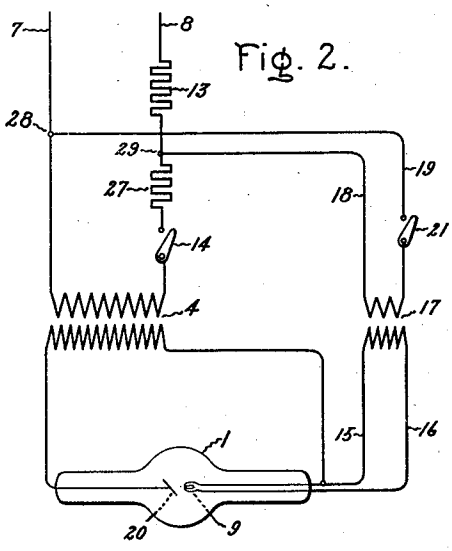
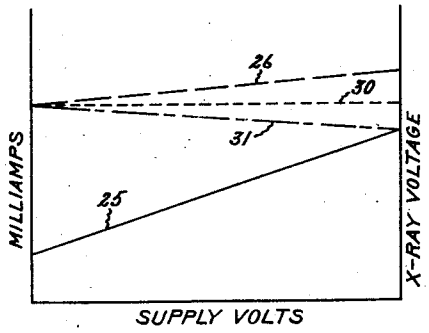


Fig. 4.



Inventor:
William D. Coolidge,
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His Attorney

June 7, 1927.

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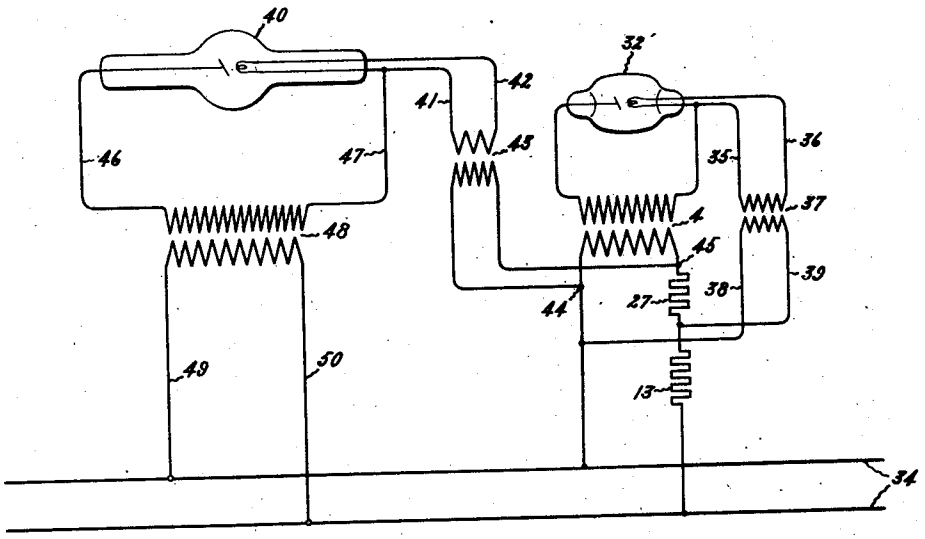
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REGULATING METHOD AND APPARATUS

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2 Sheets-Sheet 2

Fig. 3.



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Patented June 7, 1927.

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UNITED STATES PATENT OFFICE.

WILLIAM D. COOLIDGE, OF SCHENECTADY, NEW YORK, ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

REGULATING METHOD AND APPARATUS.

Application filed January 30, 1923. Serial No. 615,952.

The present invention relates to the regulation of electric distribution systems through the intermediary of electronic discharge. In its broad aspects my invention provides a method and apparatus for regulating either voltage or current in a circuit of variable characteristics.

In particular I have described herein my invention as applied to X-ray apparatus. In accordance with my invention, I have described a system whereby substantially constant potential is maintained at the terminals of an X-ray tube when the supply voltage varies, thereby producing X-rays of constant penetrability. Another embodiment of my invention described herein is adapted to maintain substantially constant current value in a circuit of variable supply characteristics. Other broad embodiments of generic features of my invention are described in another application filed concurrently herewith.

In accordance with my invention the current in a circuit supplied with a means for consuming voltage, as for example, an impedance device, is varied by an electron discharge in response to incipient variations of the condition to be controlled, for instance, the voltage at chosen points. As the responsiveness of the electron discharge is without lag and is made so magnified that a given departure of the controlled condition will produce a many fold increase of current, better regulation is afforded than could be obtained in the absence of said electron device. In the specific embodiment herein described, variations in supply voltage are absorbed both by the electron discharge and by the impedance device thereby controlling the voltage at chosen points where regulation is desired.

In an X-ray apparatus the voltage may be maintained substantially constant at the terminal of an X-ray tube by the controlled variation of current through the X-ray tube itself, thereby producing a corresponding variable drop of voltage in an external impedance which absorbs voltage variations in the circuit.

In accordance with a further development of my invention, the current of substantially constant voltage which is derived by the intermediary of an electron discharge as above described, is utilized to energize the cathode of a second electron discharge, thereby maintaining substantially constant the current in the circuit of the second electron discharge in so far as this would be affected by change of supply voltage. In one embodiment of my invention the second electron discharge device is constituted by an X-ray tube, thus providing means for generating a substantially constant X-ray output with a supply current of variable characteristics.

As a consequence of my invention, I have provided a method and apparatus which is free from moving parts and of extreme simplicity for controlling a circuit condition, such as voltage or amperage.

The accompanying drawing illustrates diagrammatically in Fig. 1 an embodiment of my invention whereby a controlled slightly rising potential may be maintained; Fig. 2 illustrates a modification for obtaining a current of constant or decreasing potential; Fig. 3 shows a constant current system; Fig. 4 is a diagram of electrical characteristics of the devices shown in Figs. 1 and 2.

Referring to Fig. 1, the X-ray tube 1 is connected by the conductors 2, 3 to the secondary of a transformer 4, through the intermediary of a mechanical selector or rectifier 5, driven by a motor 6. The primary of the transformer 4 is connected to a source of current of variable potential, represented by the conductors 7, 8. The drawing shows a rectifier of the well-known mechanical selector type, although other suitable high voltage rectifiers may be used. The provision of a rectifier avoids the impressment of a high voltage on the X-ray tube during the half-wave intervals when it is not carrying current, that is, when the incandescent cathode 9 is positive in potential. When the selector arms 10 are synchronously driven with the alternating current supply, rectified current impulses are delivered to the X-ray tube by a reversal of the circuit connections 11, 12, at proper intervals, as is well understood.

The primary circuit of the transformer 4 contains an impedance device 13, as for example, a resistance or inductance, and a switch 14.

The cathode 9 of the X-ray tube which preferably consists of tungsten, is connected by the conductors 15, 16 to the secondary

of a transformer 17. The primary of the transformer 17 is connected by the conductors 18, 19 to points on the supply conductors where the potential is equal to the difference between the impressed potential and the voltage drop in the impedance device 13. For convenience, the conductor 18 is connected to the low voltage side, namely, to the conductor 8, at a point between the impedance 13 and the primary of the transformer 4, the conductor 19 being connected to the opposite conductor 7.

The anode 20 of the X-ray tube usually consists of tungsten, although other refractory materials can be used. The envelope and parts of the X-ray tube are thoroughly freed from gas and the space within the tube is evacuated to a pressure so low that ionization of gas by electron impact is substantially negligible during operation.

When the switches 14 and 21 are closed, current passes through the X-ray device which varies, as explained below, to cause the impedance device 13 to absorb the differences between the controlled voltage and the supply voltage The electron emission of the cathode 9 and the voltage impressed across the X-ray device are so related that substantially the available electron supply is utilized at all times. In other words, electron current is operated at the saturation value of electron emission. Hence the current varies with the cathode temperature in accordance with Richardson's equation

$$I = a\sqrt{T}\, e^{\frac{-b}{T}}$$

(I being current, T absolute temperature of the cathode, a and b constants and e the base of natural system of logarithms which is 2.718). A rise of cathode temperature increases the current value at a much greater rate than a change of the heating current. For example, a 10% increase of heating current may increase the electron current through the tube as much as 300%. As the heating current varies with the voltage in the cathode or heating circuit, this relation permits small voltage changes to produce much larger current changes in the impedance. That is, an increase of voltage in the supply conductors 7, 8 is accompanied by an increase of current, which is sufficient to very largely absorb the increase of voltage in the impedance 13.

In the embodiment of my invention shown in Fig. 1, the variations of voltage in the supply current cannot be entirely absorbed as there must be some increase in the voltage at the points of connection of conductors 18, 19 in order to produce an increase of current through the electron discharge tube 1. However, a variation of voltage of 10% will result in an increase of current sufficiently large to absorb about 8% of the voltage so that as a result the voltage at the primary of the transformer 4 will vary only 2%, which for practical purposes in ordinary X-ray work may be considered as constant voltage. In place of the impedance device 13, I may use a ballast resistance, such as iron wire resistor in hydrogen. In this case slow changes of voltage are largely absorbed by the ballast but rapid changes are regulated by the changes in heating current of the cathode of the X-ray tube.

Fig. 4 illustrates the relation between the milliamperage through the X-ray tube and the rise of voltage at the terminals of the supply transformer by a graph in which the abscissæ are represented as supply volts, that is, represent the voltage values of the source, and the two ordinates represent respectively the current through the tube for the full line 25 and the voltage at the terminals of the X-ray tube for the dash line 26. It will be observed that as the supply voltage increases the voltage at the terminals of the X-ray tube, which is proportional to the voltage upon the primary of the supply transformer, rises slightly as indicated by the line 26, while the current, as indicated by the full line 25, increases at a more rapid rate.

In the absence of the impedance device 13 used in accordance with my invention, a corresponding increase of supply voltage would be accompanied by a very much greater increase of current through the tube and a corresponding abrupt fall of voltage at the terminals of the X-ray tube.

Should it be desired for any reason to maintain a constant or decreasing voltage at the terminals of the X-ray tube 1, a second impedance device is inserted in the supply circuit, as represented in Fig. 2, by the resistance 27. In this figure the rectifier 5 has been omitted in the diagram for the sake of simplicity. In fact, the system is operative as illustrated, as an X-ray tube may be used which is constructed to rectify its own current. When a rise of voltage occurs at the points 28, 29 by the method described in connection with Fig. 1, the current through the impedance device 27 must correspondingly rise. The impedance value of the device 27 is so chosen that a rise of current therein produces sufficient voltage drop to cause the voltage at the terminals of the primary of the transformer 4 to have the desired constant or dropping characteristic, as indicated respectively by the dotted curve 30 or the dot and dash curve 31.

The desired regulation of current through an impedance device to control voltage at given points in a circuit can be produced by an electron discharge tube without the generation of X-rays. In Fig. 3 is illustrated a system in which the electron discharge device 32 is not represented by an X-ray tube, but rather is constructed to operate with a

low voltage drop while still operating at the saturation value. The cathode is heated by a current varying with the variations of voltage of the main supply line 34 in the same manner as in the X-ray tube. For this purpose the impedance devices 13 and 27 are provided in the primary circuit of the transformer 4. The cathode conductors 35, 36 are connected to the secondary of a transformer 37, having its primary connected by the conductors 38, 39 to the points of controlled potential. An electron device 40 represented by an X-ray tube has the cathode heating circuit 41, 42 supplied by a transformer 43, the primary of which is connected across the points of constant potential 44, 45. The cathode of the tube 40 therefore, is heated to a substantially constant temperature irrespective of variations of supply voltage. The main terminals of the X-ray tube are connected by conductors 46, 47 to the usual high voltage transformer 48 which in turn is connected by conductors 49, 50 to the supply lines 34.

Except for internal changes, such as "poisoning" of the cathode by gas, the electron current through the X-ray tube 40 is substantially constant, in the described system even when the voltage of the supply system 34 is variable. The cathode of the X-ray tube here represents a load device for utilizing current at a controlled voltage. In my co-pending application, Serial No. 615,953, filed of even date, I have described and claimed an X-ray system in which constant current is maintained by a different system of connection which takes care not only of line voltage changes but also of internal changes in the X-ray or other electronic device.

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

1. An apparatus for maintaining substantially constant voltage at chosen points in a circuit subject to voltage variations comprising a voltage-consuming device, an electron discharge device having substantially constant vacuum conditions, connections for supplying current from said circuit to said device in series with said voltage-consuming device, means for varying the current drawn by said discharge device in such measure when voltage variations occur in said circuit that the voltage drop in said voltage consuming device will vary in magnified measure with said voltage variations and a second voltage-consuming device in said circuit between a point of connection of said voltage-consuming device and a point at which constant voltage is desired.

2. An electrical discharge apparatus comprising an electric supply circuit, an electron discharge device, exhausted to a pressure so low that the operation of said device is substantially unaccompanied by positive ionization, operatively connected to said supply circuit, means for generating electrons at the cathode of said tube, a resistance device in said supply circuit and means for regulating the electron emission of said cathode directly in response to the difference between the voltage in said supply circuit and the drop of voltage in resistance and a second resistance in said supply circuit proportioned and connected to modify the voltage impressed on said discharge device.

3. An X-ray outfit comprising current supply means of variable voltage, a thermionic device connected to derive a space current from said supply means, a resistance device in circuit with said tube, an electrical circuit for heating the cathode of said tube by current varying in voltage proportionately to the differences between the supply voltage and the drop of voltage in said resistance device, a second resistance between said tube and said heating circuit, and circuit connections for heating the cathode of an X-ray tube by current derived from said supply circuit traversing both said resistances.

4. An X-ray system comprising a supply circuit of variable voltage, a resistance device therein, an X-ray tube having an incandescent cathode and being adapted to conduct current without substantial gas ionization operatively connected to derive current from said circuit, means for heating the cathode of said tube by current derived from said supply circuit in a series with said resistance and a second resistance in said supply circuit located between a point of connection of said heating means and said X-ray tube.

5. An electron discharge apparatus comprising a supply circuit of variable voltage, an incandescent cathode tube, operable independently of gas ionization connected thereto, a resistance device in said circuit, electrical circuit means for heating the cathode of said tube by current having a voltage proportional to the difference between the voltage of said supply circuit and the drop of voltage in said resistance device and a second resistance device in said supply circuit connected to consume voltage in said supply circuit without affecting the cathode heating current.

6. The combination of a source of current of variable potential, an electron discharge device operatively connected to said source, an impedance device in circuit with said discharge device, means for maintaining the current carrying capacity of said electron device at a value proportional to the difference between the voltage of said source and the drop of voltage in said impedance device, and a second impedance device con-

nected to consume voltage in said supply circuit without affecting the current-carrying capacity of said electron device.

7. An X-ray apparatus comprising an X-ray tube in which the residual gas pressure is so low that gas ionization is negligible, a supply circuit for said tube, an impedance device in said circuit, means for varying the electron emission at the cathode of said tube at such rate in response to a variation of voltage in said supply circuit, that the voltage drop in said impedance approximates the departure of voltage in said supply circuit from a predetermined value, and a second impedance device connected in series with said first impedance device and arranged to cooperate therewith to produce a desired regulation of voltage at the terminals of said X-ray tube.

In witness whereof, I have hereunto set my hand this 29th day of January, 1923.

WILLIAM D. COOLIDGE.