

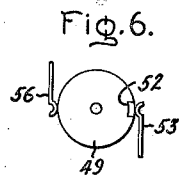
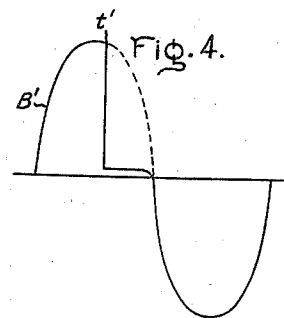
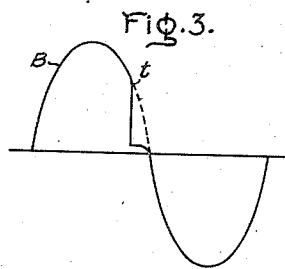
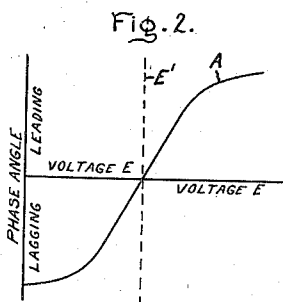
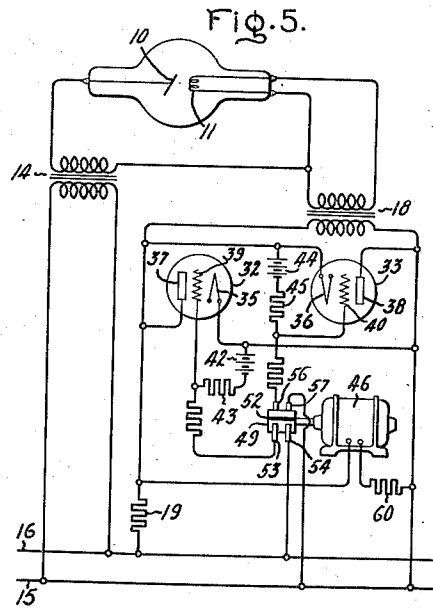
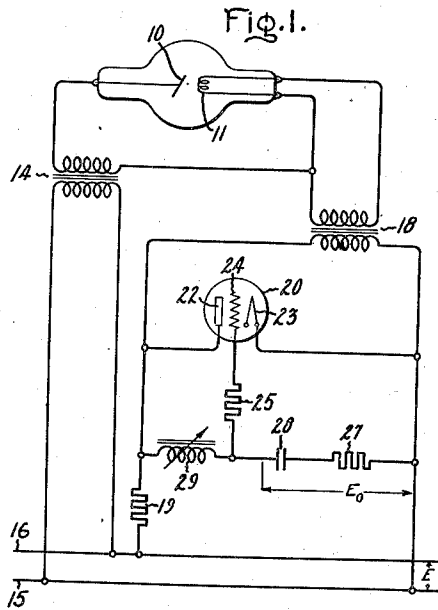
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X-RAY APPARATUS

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X-RAY APPARATUS

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17 Claims. (Cl. 250—103)

The present invention relates to electrical discharge apparatus, and more particularly to means for regulating the current supply of a separately heated cathode.

5 In the use of discharge devices of the type employed in the generation of X-rays it is desired to maintain the space current through the device substantially constant in order that no change in radiation shall occur during a particular operation. In the past it has been necessary to provide for continuously varying the cathode heating current in order to offset unstable discharge characteristics resulting from uncontrollable changes in the residual gas content
10 of the discharge envelope. As a result of substantial improvements in manufacturing technique, however, the quality of X-ray tubes now available is such that the desired condition of constant space current is sufficiently fulfilled if the heating current supplied to the cathode is held at a constant average value.

It is an object of the present invention to provide simple and reliable means whereby the average value of cathode heating current may be maintained substantially constant irrespective of variations in the magnitude of the supply potential. In one embodiment of the invention this is accomplished by modifying the instantaneous value of the current during a certain period of each current cycle and by varying the period of current modification in such a way as to offset changes in supply potential. An additional feature of the invention comprises the provision of novel regulating means for producing the desired
35 modification of the heating current.

The features of novelty which I desire to protect herein will be pointed out with particularity in the appended claims. The invention itself, together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the drawing, in which Fig. 1 illustrates a particular embodiment of the invention; Figs. 2, 3 and 4 are graphical illustrations useful in explaining the invention; Fig. 5 is a diagrammatic illustration of an alternative modification, and Fig. 6 is a detail view of a particular element used in the construction of Fig. 5.

Referring particularly to Fig. 1, I have shown
50 in schematic outline an X-ray tube comprising an anode or target 10 and a separately heated cathode 11. A discharge potential is impressed between these electrodes by connection to the high voltage secondary of a step-up transformer 14, which transformer is in turn supplied with

energy from lines 15 and 16 connecting with a suitable source of alternating potential (not shown).

It is well known that the intensity of radiations from a hot cathode X-ray tube is extremely
5 sensitive to variations in cathode temperature. For example, a variation of a few per cent in the temperature of the cathode may result in a variation on the order of 100 per cent in the X-ray output of the tube. For this reason it is important that the heating current supplied to the cathode be maintained constant within narrow limits.

The control circuit illustrated in Fig. 1 provides means whereby the effect on the cathode
15 temperature of variations in supply potential may be substantially eliminated. For this purpose I provide in circuit with the primary of a heating current transformer 18 compensating means responsive to variations in the potential of the supply source connected to the lines 15 and 16. More specifically, this means comprises an intermittently conducting device which in the case illustrated includes a discontinuously controlled discharge tube 20 so connected as to short circuit
25 the primary of transformer 18 during its conducting periods. By a discontinuously controlled discharge tube I intend to designate a tube which is capable of being rendered initially conductive by the action of a control element but
30 whose conductivity can be terminated only by cessation or reversal of the discharge voltage. The particular device shown in the drawing comprises an anode 22, a cathode 23, and a control element or grid 24, these elements being surrounded by a readily ionizable medium, for example, argon.

The anode and cathode elements of the device 20 are connected directly across the primary of the transformer 18 while the control
40 grid 24 is connected through a resistor 25 to a voltage responsive means adapted to vary the periods of conductivity of the device in accordance with variations in the supply potential. This means, in the present instance, comprises a
45 non-linear circuit combining a resistor 27, a capacitor 28, and an adjustable self-saturable reactor 29. The latter device may suitably comprise an iron core reactance, such a reactance being inherently non-linear in its response characteristic because of the saturability of its magnetic circuit. The control element 24 is so connected that the voltage E_0 impressed between it and the cathode 23 is that appearing across the capacitor 28 and the resistor 27.
55

As a result of the non-linear characteristics of the circuit shown the phase of the voltage E_0 will change appreciably with variations in magnitude of the voltage E of the supply source.

Thus, assuming initial equality between the impedance of the reactor 29 and that of the capacitor 28, the voltage E_0 may change from a lagging phase with respect to the voltage E to a condition of being substantially in phase with such voltage when the inductor 29 is completely saturated so that its reactance has dropped to an extremely low value. Since the degree of saturation of the reactor 29 is a function of the average magnitude of the supply potential E , the adjustment may be such that for a given range of supply potential variations, the relative phase of the voltage E_0 will be shifted in a compensatory fashion. The nature of the relationship which may be obtained with appropriately chosen circuit constants is indicated in Fig. 2, in which curve A shows the variations of phase angle between E and E_0 with varying magnitudes of E . It will be noted that as the supply potential E tends to depart from a median value E' , which may be specified as normal line voltage, the phase angle changes in corresponding fashion. More specifically, as the supply voltage increases or decreases the voltage E_0 advances or is retarded in phase so that the tube 20 is caused to become conductive at an appropriately modified instant of time. It will be understood from a consideration of curve A that the circuit here employed is of such character as to be smoothly responsive to the variations in potential. In this respect it distinguishes from those non-linear circuits which are so adjusted as to give a discontinuous response, that is to say, which transfer abruptly from one operating condition to a widely different operating condition in response to a slight change in the control factor.

The ultimate effect obtained is illustrated in Figs. 3 and 4, which represent the instantaneous variations of the heating current (which is not necessarily in phase with the supply voltage) for different conditions of operation of the control circuit. Curve B of Fig. 3, for example, may be assumed to depict the current passing through cathode 11 for a value of supply voltage which may be assumed to be the normal value. The dotted portion of the curve to the right of the datum line t indicates a period of conductivity of the device 20 and represents an appreciable diminution in the average cathode current value as a result of the temporary short circuit obtaining.

In curve B' of Fig. 4 there is assumed to be an increase in supply potential above the normal value and a resultant increase in the maximum instantaneous value of the heating current. It will be seen, however, that the moment of operation of the device 20 has been advanced to a new point t' , this advance being an incident of the shift in phase angle of the control voltage E_0 produced by increasing saturation of the inductor 29. By comparison of Figs. 3 and 4 it will be seen that whereas the maximum instantaneous value attained by the heating current is increased in accordance with the assumed increase in potential, the average value as represented by the area under the full line portion of the curve is about the same as in the case previously considered. In view of the relatively high thermal capacity of a cathode of the type under consideration, the variations in instantaneous current will be of too short duration to be followed by

the cathode emission characteristic which will consequently be held at a substantially constant value. It will be understood, of course, that a decrease in line voltage is compensated by a corresponding decrease in the length of the short-circuiting operation of the device 20.

While I have shown the control electrode 24 as being connected to a point intermediate between the condenser 28 and the inductor 29, it will be understood that substantially similar operation may be obtained by a connection in which only the voltage of the resistor 27 is impressed between the cathode 23 and the control member. Various other equivalent connections will occur to those skilled in the art and do not constitute departures from the present invention. Regulation of the average value of cathode heating current may be obtained by adjusting the value of the reactance 29 within desired limits.

In Fig. 5 I have shown an alternative modification of the invention which may, in some cases, be preferred to that previously described. As in the arrangement of Fig. 1, the filament 11 is supplied with heating current through a transformer 18 and a current limiting resistor 19 from an alternating supply source connected to lines 15 and 16. In this case, however, modification of the instantaneous value of heating current is accomplished by a pair of intermittently conducting devices 32 and 33 so connected as to be conductive during alternate half cycles of potential variation. These devices are in the form of discontinuously controlled discharge tubes and respectively comprise cathodes 35 and 36, anodes 37 and 38, and control elements or grids 39 and 40. The control grid 39 is supplied with a suitable biasing potential by means of a battery 42 in combination with an associated resistor 43, while similar elements 44 and 45 are provided in connection with the control grid of the tube 33.

The supply of control potential to each of the control elements is governed in the present case by a synchronous motor 10 which may comprise any of the known types of synchronous electrodynamic machines as, for example, a motor having a separate direct current excitation, or a motor whose excitation depends upon the effect of armature reaction. It is well known that the torque angle of such a machine, that is, the angle of lag between the field structure and the axis of magnetomotive force produced by the supply potential is proportional to the load imposed on the machine and inversely proportional to the magnitude of the supply voltage. Consequently, if the load is substantially constant as it is in the present case, the torque angle will be directly responsive to variations in voltage. This relationship is utilized for control purposes by employing a commutator arranged to rotate with the shaft of the motor, such a commutator being shown as comprising a cylinder 49 of insulating material and a conducting bar 52 set into the cylinder. It will be clear that when the bar 42 is rotated to such a position as to make contact with brushes 53 and 54 and to complete a circuit between them, a control impulse of voltage will be impressed on the control element 39. If this potential is in the proper direction to favor initiation of a discharge, the tube 32 will be rendered conductive and the heating current temporarily decreased in the manner previously explained. A half cycle later the contact bar 52 will have been rotated sufficiently to make contact with the brushes 56 and 57 and the dis-

charge tube 33 will be rendered conductive and effective to short circuit the cathode heater for the second time.

Assuming now an increase in supply potential the torque angle (angle of lag) of the machine rotor load will be proportionately decreased. As a result the position of the contact bar 52 will be advanced with relation to the cycle of voltage variation and the tubes 32 and 33 will be energized earlier than with the lower voltage previously assumed. In this way a regulatory action may be obtained which will serve to maintain the average value of heating current substantially constant in spite of variations in the supply potential. The use of two short-circuiting devices operative on alternative half cycles permits a greater regulatory effect for a given change in torque angle than would be possible with only one such device.

If it is desired to use a system such as that just described in connection with a source of potential supply which is variable in frequency as well as in voltage, provisions should be made for rendering the control device substantially insensitive to frequency changes. Since a change in the frequency of the potential impressed across a synchronous motor tends to vary the current through the motor and thereby to change the torque angle, frequency insensitivity may be accomplished by the use of means for imparting to the motor circuit a substantially constant current characteristic. One such means may comprise, for example, a ballast resistance 60 connected in series with the motor 46. If this resistance is of sufficient size so that the voltage drop across it is great in comparison with the drop across the motor 46, then variations in frequency will be ineffective to change appreciably the current flow through the motor or to affect the torque angle of the motor.

While I have shown particular embodiments of my invention, it will be understood by those skilled in the art that many modifications may be made without departing from the invention, and I aim by the appended claims to cover all such modifications as fall within the true spirit and scope of the invention.

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

1. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to the cathode, an intermittently conductive device adapted to be rendered conductive during controllable periods of each cycle of alternation of said potential and effective during its conductive periods to modify the flow of heating current to said cathode, a control element operable, when energized by a control potential, to render said device conductive, and means for impressing on said control element an alternating control potential derived from said supply source, said last-named means being responsive to variations in magnitude of the supply source potential to produce compensatory variations in the phase relation between said supply source potential and said control potential.

2. In combination, a discharge tube of the type which includes an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to said cathode, a device operable for controllable periods to modify the instantaneous flow of heating current to the cathode, and means

connected between said device and said supply source for controlling the operation of the device, said means including a non-linear circuit responsive to variations in the magnitude of said alternating potential to produce compensatory variations in the period of operation of said device.

3. In combination, a discharge tube of the type which includes an anode and a separately heated cathode, means for energizing the tube, a source of cyclically varying potential for supplying heating current to said cathode, means including a discontinuously controlled discharge device operable during its conductive periods to modify the instantaneous flow of current to the cathode, a control element for rendering said device initially conductive, and means responsive to variations in the magnitude of said supply potential to produce a compensatory variation in the periods of conductivity of said device thereby to maintain the average value of heating current substantially constant, said last-named means including a non-linear circuit comprising a non-linear reactance, and capacitance and resistance elements serially connected across said supply source and a conductor connecting said control element to a point intermediate between said reactance and said capacitance element.

4. In combination, a current-consuming device, a source of alternating potential for supplying current to the device, and means for maintaining the average value of current substantially constant irrespective of variations in magnitude of the supply potential, said means comprising a device operable during controllable periods to modify the instantaneous flow of current to the current-consuming device, an electro-dynamic machine adapted to be operated synchronously from said supply source and having its torque angle variable with the potential of said source, and means dependent on the torque angle of said machine for controlling the operation of said controllable device.

5. In combination, a current-consuming device, a source of alternating potential for supplying current to the device, and means for maintaining the average value of current substantially constant irrespective of variations in magnitude of the supply potential, said means comprising an intermittently conducting device adapted during its periods of conductivity to modify the instantaneous flow of current to the current-consuming device, a rotary synchronous machine arranged to be driven from said supply source and having its torque angle variable with the potential of the source, a control element rotatable with the rotor of said machine, and means associated with said control element and dependent on the torque angle of said machine for controlling the periods of conductivity of said intermittently conducting device.

6. In combination with an X-ray tube comprising an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to said cathode, and means for maintaining the average value of said current substantially constant irrespective of variations in the magnitude of said supply potential, said means comprising at least one discontinuously controllable discharge device adapted during its conductive periods to modify the instantaneous flow of heating current, a control element operable to initiate a discharge through said device, a rotary synchronous machine operated from said supply source and having its torque angle variable

with the potential of the source, a contactor cyclically opened and closed by the machine at times determined by the torque angle thereof, and means dependent on the time of closure of said contactor for controlling the periods of conductivity of said discharge device.

7. In combination, a current consuming element, a source of alternating potential for supplying current to the element, and means for maintaining the average value of current substantially constant irrespective of variations in magnitude or frequency of the supply potential, said means comprising a device operable during controllable periods to modify the instantaneous flow of current to the current consuming element, a synchronous motor connected to said supply source and having its torque angle variable with the potential of the source, means dependent on the torque angle of said motor for controlling the operation of said device, and means for rendering the torque angle of the motor substantially independent of the frequency of the supply potential.

8. In combination, a current consuming element, a source of alternating potential for supplying current to the element, and means for maintaining the average value of current substantially constant irrespective of variations in magnitude or frequency of the supply potential, said means comprising a device operable during controllable periods to modify the instantaneous flow of current to the current-consuming element, a synchronous motor connected to said supply source and having its torque angle variable with the potential of the source, means dependent on the torque angle of said motor for controlling the operation of said device, and means including a ballast resistance in series with the motor for rendering its torque angle substantially independent of variations in the frequency of the supply potential.

9. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the discharge tube, a source of alternating potential for supplying heating current to the cathode, a device adapted cyclically to modify the conductivity of the supply circuit in time with the variations of a control potential applied to the device, means for applying to the device an alternating control potential of the same periodicity as the supply potential, and means responsive to variations in magnitude of the supply potential for producing compensatory variations in the phase relation between the supply potential and the control potential, thereby to obtain a desired regulation of the heating current.

10. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to the cathode, and means in circuit with the supply source for maintaining the average value of said current substantially constant irrespective of variations in the magnitude of the supply potential, said means including a device which is operable responsively to a control potential of the same periodicity as the supply potential and which is effective to modify the heating current to the cathode for a fraction of each cycle of the supply potential determinable by the phase relation between the control potential and the supply potential, means for applying such a control potential to the device, and means responsive to variations in magnitude of the sup-

ply potential to produce compensatory variations in the phase relation between the supply potential and the control potential.

11. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to the cathode, means including a discontinuously controlled discharge device operable during its conductive periods to modify the instantaneous flow of current to the cathode, a control electrode forming a component part of said discharge device and effective when energized by a control potential to render the device initially conductive, means for impressing on said control electrode an alternating control potential of the same periodicity as the supply potential, and means responsive to variations in magnitude of the water supply potential to produce compensatory variations in the phase relation between said supply potential and said control potential.

12. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to the cathode, means including a discontinuously controlled discharge device operable during its conductive periods to modify the instantaneous flow of current to the cathode, a control electrode forming a component part of said discharge device and effective when properly biased by a control potential to render the device initially conductive, means for impressing on said control electrode an alternating control potential derived from the supply source, and means including a non-linear resonant circuit responsive to variations in magnitude of the supply source potential for producing compensatory variations in the phase relation between said supply source potential and said control potential.

13. In combination with an electrical discharge tube including an anode and a separately heated cathode, means for energizing the tube, a source of alternating potential for supplying heating current to the cathode, a discontinuously controlled discharge device connected in shunt to said supply source, a control electrode forming a component part of the discharge device and effective when properly biased by a control potential to render the device initially conductive, means for impressing on said control electrode an alternating control potential derived from the supply source, and means responsive to variations in magnitude of the supply source potential to produce compensatory variations in the phase relation between said supply source potential and said control potential.

14. In combination, a load device, a source of alternating potential for supplying current to the device and means in circuit with the supply source for obtaining a desired regulation of said current irrespective of variations in the magnitude of the supply potential, said means including a device which is operable responsively to a control potential of the same periodicity as the supply potential and which, when so operated, is effective to modify the current flow to the load device for a fraction of each cycle of the supply potential determinable by the phase relation between the control potential and the supply potential, and means for applying such a control potential to the said current-modifying device, said last-named means including a non-linear resonant circuit having its circuit elements so cor-

related as to be smoothly responsive to variations in magnitude of the supply potential for automatically producing compensatory variations in the phase relation between the supply potential and the control potential.

15. In combination, a load device, a source of alternating potential for supplying current to the device, and means in circuit with said source for obtaining a desired regulation of said current irrespective of variations in the magnitude of the supply potential, said means including a discontinuously controlled discharge device operable during its conductive periods to modify the instantaneous flow of current to the load device, a control electrode forming a component part of said discharge device and effective when energized by a control potential to render the device initially conductive, means for impressing on said control electrode an alternating control potential of the same periodicity as the supply potential, and a non-linear resonant circuit having its circuit elements so correlated as to be smoothly responsive to variations in magnitude of the supply potential for automatically producing compensatory variations in the phase relation between the supply potential and the control potential.

16. In combination, a load device, a source of alternating potential for energizing the device,

and means for maintaining a desired relation between the energization of the load device and the magnitude of the potential of said source, said means comprising a device operable during controllable periods to modify the instantaneous flow of current to the load device, a synchronous motor driven by said source and having its torque angle variable with the magnitude of the source potential, and means dependent on the torque angle of said motor for controlling the operation of said controllable device.

17. In combination, a load device, a source of alternating potential for energizing the device, and means for maintaining a desired relation between the energization of the load device and the magnitude of the potential of said source, said means comprising a discharge device which is conductive during controllable periods and which is effective while conductive to modify the instantaneous flow of current to the load device, a control electrode effective when energized to render the discharge device conductive, a synchronous motor driven by said source and having its torque angle variable with the magnitude of the source potential, and means dependent on the torque angle of said motor for controlling the energization of said electrode.

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