May 30, 1939. C. G. SUITS 2,160,605

REGULATING SYSTEM

Filed Dec. 18, 1936 2 Sheets-Sheet 1

Fig. 1.

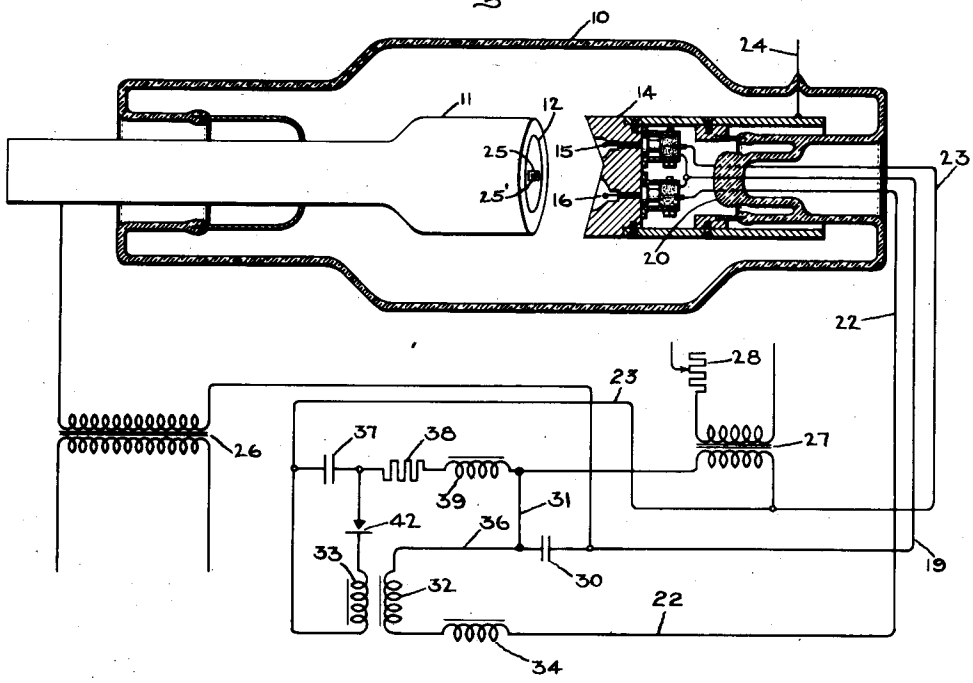


Fig. 2.

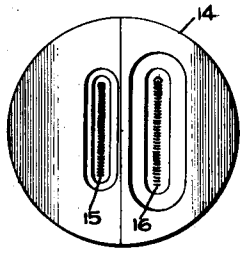


Fig. 3.

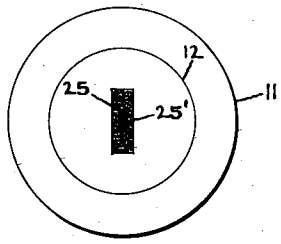
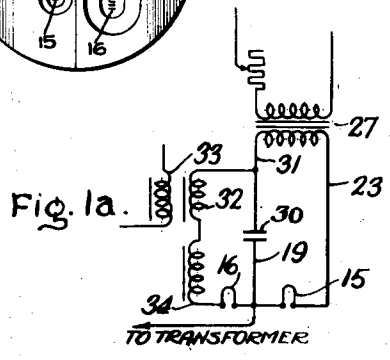


Fig. 1a.



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May 30, 1939. C. G. SUITS 2,160,605

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Filed Dec. 18, 1936 2 Sheets-Sheet 2

Fig. 4.

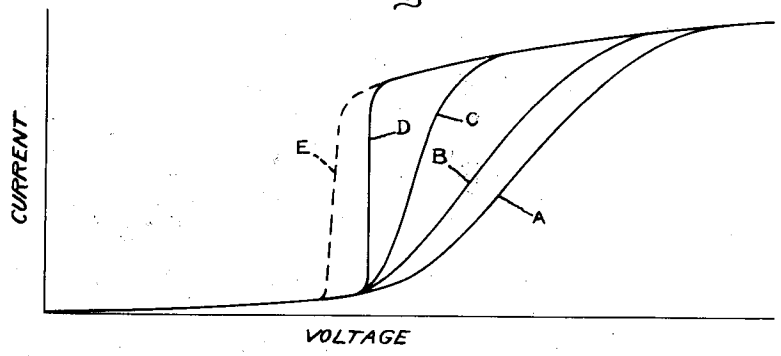


Fig. 5.

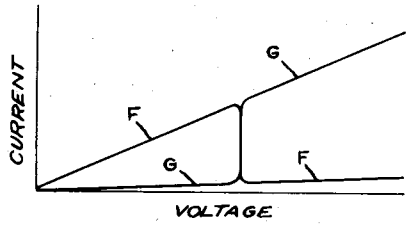


Fig. 6.

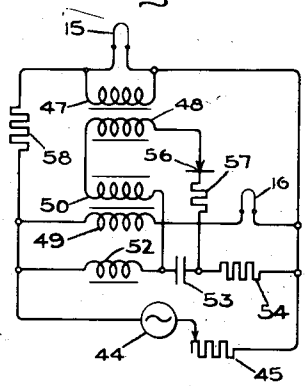
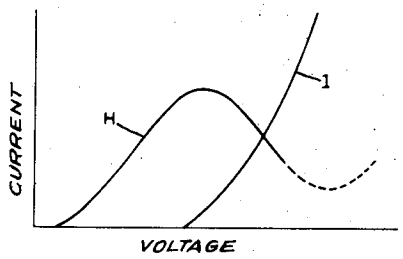


Fig. 7.



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REGULATING SYSTEM

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Application December 18, 1936, Serial No. 116,602

13 Claims. (Cl. 250—103)

The present invention relates to regulating systems and more particularly to control circuits useful in the operation of X-ray devices having a plurality of independently operable cathode elements.

It is common in radiographic X-ray tubes to provide two or more alternatively usable electron emissive filaments adapted to produce a corresponding number of different sized focal spots on a cooperating target surface. The small spot results in radiographs of better definition while the larger spot permits greater total X-ray output and shorter intervals of exposure. Typical cathode constructions for this purpose are described and claimed, for example, in G. C. Kucher patent, 1,610,863, granted December 14, 1926 and assigned to the same assignee as the present invention.

In operating a multifilament X-ray tube, care must be taken not to raise the temperature and emissivity of the filament associated with the smaller focal spot above a point at which burning of the target face will result. It is therefore incumbent upon the operator to bear constantly in mind the necessity of switching from the smaller to the larger focal spot when higher values of total X-ray output are desired. It is an object of the present invention to provide improved means for automatically selecting the proper cathode filament in accordance with the particular amount of X-radiation desired without the necessity of a manual change-over operation. According to particular embodiments of the invention, the automatic transition from one filament to another may be accomplished either gradually or abruptly as the potential of the heating current source is varied by the operator.

The invention includes the provision of certain circuit arrangements which may be useful in the regulation of other independently operable devices than those particularly referred to in the foregoing. While these circuits are described in the following only in connection with a specific use, it is not intended to exclude other equivalent uses from the scope of the present disclosure.

The features of novelty which I desire to protect herein are 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 specification taken in connection with the drawings, in which Fig. 1 represents the combination of an X-ray tube and circuit suitably embodying the invention; Fig. 1*a* is a simplified representation of a portion of the circuit of Fig. 1; Fig. 2 shows the detailed appearance of the active face of the cathode; Fig. 3 shows the surface of the anode target; Figs. 4 and 5 are graphical representations useful in explaining the invention; Fig. 6 illustrates a modified embodiment of the invention, and Fig. 7 is a graphical representation useful in explaining the operation of the circuit of Fig. 6.

Referring particularly to Fig. 1, I have shown in section an X-ray tube comprising an envelope **10** and cooperating discharge electrodes enclosed therein. The anode, which may be of conventional design, comprises a relatively massive metal body **11** supported at one end of the envelope **10** and provided with a target surface which may suitably comprise a tungsten plate **12** set into the anode face. The cathode, which is positioned in opposed relation to the target surface, includes a pair of independently operable filaments **15** and **16** suitably arranged in parallel recesses formed in the face of a metallic focusing body **14**. As will be more readily apparent from Fig. 2, these filaments are of different lengths and are disposed in mutually inwardly inclined faces of the focusing body **14** so that electrons emitted from them are directed toward a common focal region of the target **12**.

At one end the filaments **15** and **16** are both electrically connected to a common lead-in conductor **19** which is sealed through a press **20** provided for that purpose at the cathode end of the X-ray tube. The other ends of the filaments are provided respectively with separate lead-in conductors **22** and **23** by means of which they may be independently energized by connection to an external source of potential. The focusing body **14** is also provided with a lead-in conductor **24** in order that it may be biased to a proper potential to produce the desired focusing of the electrons emitted by the filaments, Fig. 3 shows overlapping focal regions or spots **25** and **25'** which may be formed by the impingement of focused electrons on the surface of the target **12**.

In the operation of the device a discharge potential is impressed between the anode **11** and the cathode structure by means of the secondary of a high potential transformer **26**, and a common source of alternating current supply is provided for the two cathode filaments by means of a heating transformer **27**. The potential developed by the heating transformer secondary may be varied at the will of the operator by means such as an adjustable resistance **28** connected in the transformer primary.

The relative amounts of energy supplied to the

two filaments are determined by variable impedance means connected in circuit with the filaments. In the arrangement of Fig. 1 the filament 15, which is adapted to produce the smaller of the two focal spots, is connected across the secondary of the transformer 27 in series with a parallel circuit which includes capacitive and inductive branches. A simplified representation of this portion of the circuit connections is shown in Fig. 1a, in which parts corresponding to those illustrated in Fig. 1 are similarly numbered.

The capacitive branch of the parallel circuit includes the condenser 30 and is connected to the filament 15 and the power source by a circuit which may be traced from one side of the transformer winding through the lead-in conductor 23, filament 15, lead-in conductor 19, condenser 30 and the conductor 31 back to the transformer 27. The inductive branch, which is connected in shunt across the condenser 30, includes the filament 16 and a constant inductance 34 in series with variable impedance means. Such means may comprise, for example, a saturable reactor having an alternating current winding 32 and a saturating winding 33 by means of which the impedance of the winding 32 may be varied. It is contemplated that the inductance 34 shall have such a value that when the saturable reactor is saturated the capacitive and inductive branches will be in a condition of parallel resonance.

A consideration of the circuit connections described in the foregoing (which connections actually constitute the energizing system for the cathode filaments) will show that these filaments are adapted to be separately and alternately energized. Thus, when the saturable reactor is in its unsaturated condition the impedance of the winding 32 is extremely high and little or no current will be permitted to flow through the filament 16. At the same time, a considerable current will be flowing in the circuit which includes the filament 15 and the condenser 30. If, however, the reactor impedance is substantially reduced by an increase in current through the saturating winding 33, the current through the filament 16 will rise to a relatively high value, being limited chiefly by the inductance 34. Furthermore, under the condition of parallel resonance assumed to exist with the reactor saturated, the current taken by the condenser 30 will be equal in magnitude and opposite in phase to that taken by the inductance 34 so that the resultant current flowing through the filament 15 will be reduced to a low value. It will thus be seen that when the filament 16 is receiving a maximum of heating current, the filament 15 will be receiving a minimum of heating current and that the reverse is also true.

In accordance with the present invention, means are provided whereby the transition from one filament to another will occur automatically in accordance with variations of the potential of the transformer 27 as controlled by the resistance 28. Such means may suitably comprise a device having a non-linear response characteristic operating in connection with the saturating winding 33. By a device having a non-linear response characteristic, I intend to designate a device in which the effect produced by a change in condition (such as a change in the impressed potential) is disproportionate to the magnitude of the change, at least within a certain range of operation of the device. The particular such arrangement which I have illustrated comprises a series non-linear circuit including a condenser 37, resistance 38 and non-linear inductance 39. Such an inductance may consist, for example, of an inductive winding having a closed magnetic circuit of such nature as to be self-saturating during a portion of the operating range of the inductance. The characteristics of such non-linear circuits are fully described in my patent, 1,921,786, granted August 8, 1933, but may be briefly summarized as follows:

As the alternating potential impressed across a series non-linear circuit, such as that illustrated, is increased, the current also increases linearly up to a point at which the non-linear inductance approaches resonance with the capacitance of the circuit. At this point, if the saturation characteristic of the inductance is properly chosen, the current may rise suddenly to a value several times in excess of its former value. The abruptness of this effect will depend in part upon the resistance of the non-linear circuit and in general will decrease for increasing values of resistance. Thus, in Fig. 4, I have illustrated the relation of current and voltage in a series non-linear circuit for various values of resistance on the circuit. For higher values of resistance such as are assumed to exist in connection with curves A, B, and C of Fig. 4, the change from a low to a high value of current is gradual and at extremely high resistance values approaches a linear relationship. For one particular value of resistance, however, the change may be made a sharp and reproducible one depending upon a very slight variation in voltage in either direction. This condition is represented by curve D which shows that the transition from low to high current values may occur so abruptly as to constitute a type of relay action. For still lower values of resistance, it may happen that the return to low current values will take place at a different voltage from that pertaining to the original transition to high current values. This is indicated, for example, by the disparity between curves D and E of which the latter represents the current variation which might result with decreasing voltages when using a circuit resistance slightly lower than that required to produce curve D.

In connection with the particular embodiment of the invention under consideration, it is contemplated to use a non-linear circuit having a single valued characteristic such as that indicated by curve D of Fig. 4. Under these conditions, when a critical value of supply potential is exceeded, the current through the non-linear circuit will increase abruptly to a high value thus correspondingly raising the voltage drop across the condenser 37. This increased voltage drop, acting through a rectifying device 42 and the saturating winding 33 will at once reduce the impedance 32 to a low value. As previously explained, such a change will be attended by an abrupt increase in the heating current flow through the filament 16 and equally abrupt decrease in the current supplied to the filament 15. The nature of this change is illustrated diagrammatically in Fig. 5 in which curve F represents the variations in current flow through the filament 15 and curve G represents corresponding variations in current through the filament 16.

The result of an arrangement such as that which I have described is that the operator may safely adjust the control resistance 28 to a value calculated to give the total desired X-ray output without having to worry about changing from one filament to another. It will be apparent from the foregoing explanation that the change

to the filament which pertains to the larger focal spot may be accomplished automatically by the described circuit in any case where the energy input to the tube exceeds a predetermined safe value.

In certain cases it is desirable to make a gradual transition from one filament to another rather than an abrupt transition as described above. In Fig. 6 I have illustrated an alternative embodiment of the invention whereby this result may be accomplished automatically in such a way as to avoid all danger of burning the target surface. In the illustrated arrangement, the filament 15 corresponds to the filament previously described for producing the smaller focal spot of an X-ray tube while filament 16 may be considered a filament adapted for producing a larger focal spot. As in the previously described arrangement, these filaments are supplied with heating current from a common alternating current supply source 44 in series with a regulating resistance 45.

Filament 15 is shunted with a variable impedance comprising in the case illustrated the alternating current winding 47 of a saturable reactor which also includes a saturating winding 48. A similar impedance means including windings 49 and 50 is employed in series relation with the filament 16. Control is accomplished by means of a non-linear circuit comprising a non-linear inductance 52, a condenser 53 and a resistance 54. To obtain the more gradual transition desired in this application, the resistance 54 is of relatively high value so that the characteristics of the circuit correspond, for example, to curve A of Fig. 4. Under these conditions the saturating windings 48 and 50, which are connected across the condenser 53 in series with a rectifier 56 and a stabilizing or ballasting resistor 57, will be only slightly energized as long as the voltage remains below that required to saturate the inductance 52 and will be energized to a gradually increasing extent as the voltage is raised above this value. The ultimate result in terms of current flow through the cathode filaments is indicated in Fig. 7 in which curve H represents the variations in current through the filament 15 while curve I shows corresponding variations of the current through the filament 16. Resistance 58 connected in series with the filament 15 insures that the source 44 shall not be short-circuited when the saturation of the winding 47 is complete.

It will be apparent upon consideration of Fig. 7 that I have provided an improved method of operation of a multi-filament X-ray tube in which one filament alone may be operated up to a predetermined value of supply potential and both filaments may be operated simultaneously for higher values of potential, the conditions of operation being such that the total input to the smaller focal spot never exceeds a safe value. This may be true even though the two focal spots are superimposed or fall upon overlapping regions of the target since the combined input of the two filaments to the region of the smaller focal spot may be limited in such a way as not to exceed a predetermined value.

While I have described my invention particularly in connection with an X-ray tube, it will be understood that its various embodiments may be useful in connection with the operation of other independently operable translating devices which are desired to be energized alternatively. An example of such an alternative application may comprise a theater lighting system in which it is desired to shift from one group of lighting devices to another in response to an increase in the intensity of illumination required. It should also be pointed out that the circuits which are described above may be used interchangeably and that many other circuits of generally similar character may be substituted for those illustrated without departing from the invention. I therefore aim in the appended claims to cover all such alternative modifications as come within the spirit and scope of the foregoing disclosure.

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

1. In an X-ray apparatus, a target, means including a first cathode filament for producing a small focal spot on said target, means including a second cathode filament operable independently of the first for producing a larger focal spot on the target, a common source of potential connected in circuit with both of said filaments, a saturable reactor in series with said second filament, a condenser in series with said first filament, inductance means including said saturable reactor in parallel with the condenser and in series with said first filament, said inductance means being adapted to be resonant with the condenser during periods of saturation of the reactor and means for saturating said reactor in accordance with a rise in said potential above a predetermined value.

2. In an X-ray apparatus, a target, means including a first cathode filament for producing a small focal spot on said target, means including a second cathode filament operable independently of the first for producing a larger focal spot on the target, a common source of potential connected in circuit with both of said filaments, a variable impedance in parallel with said first filament, another variable impedance in series with said second filament, and means for simultaneously increasing the value of one impedance and decreasing the value of the other impedance in accordance with variations in potential of said source.

3. In an X-ray apparatus, a target, means including a first cathode filament for producing a small focal spot on said target, means including a second cathode filament operable independently of the first for producing a larger focal spot on the target, a common source of alternating potential connected in circuit with both of said filaments, a saturable reactor in parallel with said first filament, another saturable reactor in series with said second filament, and means for simultaneously varying the saturation of both of said reactors in accordance with variations in potential of said source.

4. In an X-ray apparatus, a target, means including a first cathode filament for producing a small focal spot on said target, means including a second cathode filament operable independently of the first for producing a larger focal spot on the target, a common source of potential connected in circuit with both of said filaments, a saturable reactor in parallel with said first filament, another saturable reactor in series with said second filament, and means operable within a predetermined potential range for simultaneously varying the saturation of said reactors in accordance with variations in the potential of said source, said means including a device having a non-linear response characteristic within said predetermined potential range.

5. The combination of a plurality of independ-

ently operable electrical translating devices, means including a common source of alternating potential for supplying electrical energy to said devices, means for varying at will the potential of said source and means for controlling the relative amounts of energy supplied to the various devices in accordance with such variations in potential, said means including saturable reactance means in series with certain of the devices and in parallel with certain others of the devices and means responsive to the potential of said source for varying the saturation of said means.

6. The combination of a pair of independently operable electrical translating devices, a common source of alternating potential for supplying energy to both of said devices, means for varying at will the potential of said source, and means for controlling the relative amounts of energy supplied to the devices in accordance with such variations in potential, said means including a first saturable reactor in series with one of the devices, a second saturable reactor in parallel with the other device, and a non-linear circuit responsive to the potential of said source for simultaneously varying the saturation of said first and second reactors.

7. In combination, a pair of independently operable electrical translating devices, a common source of alternating potential for supplying energy to said devices, means for varying at will the potential of said source, and means for controlling the relative amounts of energy supplied to the devices in accordance with variations in potential of the source, said means comprising a parallel circuit having inductive and capacitive branches in series with one of the devices, the other device being included in the inductive branch, means including a saturable reactor in said inductive branch effective during saturation of the reactor to produce resonance of said parallel circuit, and means for varying the saturation of said reactor in accordance with variations in the potential of said source.

8. In combination, a pair of independently operable electrical translating devices, a common source of alternating potential for supplying energy to both of said devices, and means for controlling the relative amounts of energy supplied to the devices in accordance with variations in the potential of said source, said means comprising a parallel circuit having inductive and capacitive branches in series with one of the devices, the other device being included in the inductive branch, means including a saturable reactor in said inductive branch effective during saturation of the reactor to produce resonance of said parallel circuit, and means including a non-linear circuit responsive to variations in the potential of said source for varying the saturation of said reactor.

9. In combination, a pair of electric translating devices, a common source of potential variable above and below a predetermined value for supplying energy to said pair of devices, saturable reactance means in circuit-controlling relation with said translating devices for concurrently and inversely varying the energization of the respective translating devices in accordance with the condition of saturation of the said means, and means responsive to the departure of the potential of said source from said predetermined value for varying the saturation of said saturable reactance means.

10. In combination, a pair of electric translating devices, a common source of potential variable above and below a predetermined value for supplying energy to said pair of devices, saturable reactance means in circuit-controlling relation with said translating devices for concurrently and inversely varying the energization of the respective translating devices in accordance with the condition of saturation of the said means, a single direct current circuit for varying the saturation of said saturable reactance means, and means responsive to the potential of said source for varying the current in said direct current circuit.

11. In combination, a pair of electric translating devices, a common source of potential variable above and below a predetermined value for supplying energy to said pair of devices, saturable reactance means in circuit-controlling relation with said translating devices for concurrently and inversely varying the energization of the respective translating devices in accordance with the condition of saturation of the said means, a single direct current circuit for varying the saturation of said saturable reactance means, and a non-linear resonant circuit connected to vary the energization of said direct current circuit in response to variations in the potential of said source.

12. In combination, an X-ray tube having a target, a first filament for producing a small focal spot on the surface of the target and a second filament for producing a larger focal spot on the target surface in a region overlying the first spot, means including a source of potential for simultaneously energizing both filaments, means for varying the potential of the source, thereby to vary the discharge current supplied by the filaments, and means in circuit-controlling relation with the said filaments for preventing the energy input to the said small focal spot from becoming excessive for any condition of operation, the said last-named means including means automatically responsive to variations in the potential of the said source for gradually and simultaneously decreasing the energization of the first filament and increasing the energization of the second filament in substantially inverse ratio as the discharge current through the tube is progressively increased.

13. In combination, an X-ray tube having a target, a first filament for producing a small focal spot on the surface of the target and a second filament for producing a larger focal spot on the target surface in a region overlying the first spot, a source of potential for supplying heating current to both the said filaments, means for varying the potential of the source, thereby to vary the discharge current through the tube, and means automatically effective in response to such variations gradually and simultaneously to increase the energization of said second filament and to decrease the energization of the first filament in approximaely inverse ratio as the discharge current is progressively raised above a predetermined value, the said last-named means being operative to cause the exclusive energization of the first filament for discharge currents below the said predetermined value.

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