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SELF-REGULATING X-RAY TUBE

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Fig. 1.

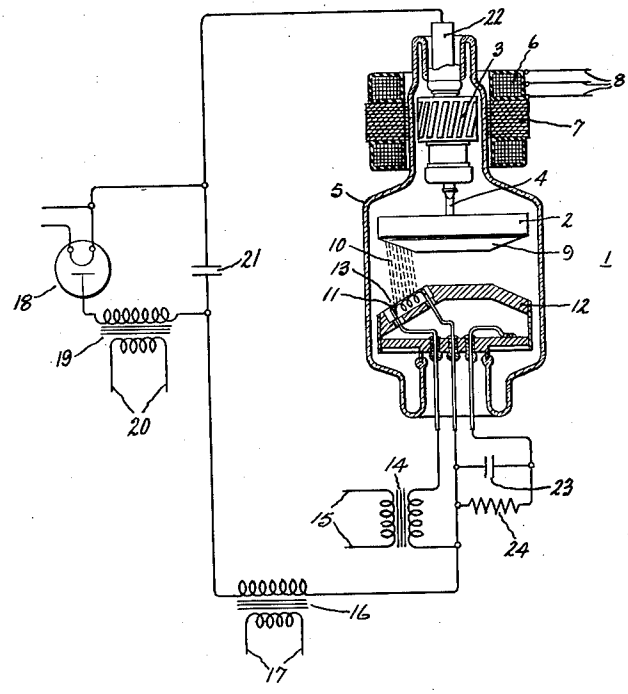
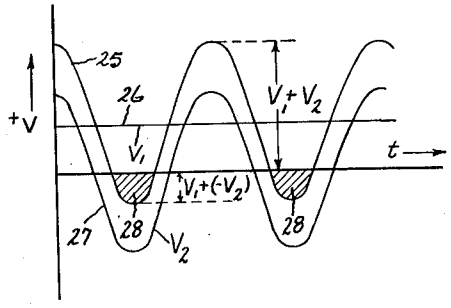


Fig. 2.



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SELF-REGULATING X-RAY TUBE

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8 Claims. (Cl. 250—93)

The present invention relates to optimum temperature regulation of electron discharge devices, and, more particularly, to arrangements for automatically regulating the temperature rise of anodes of X-ray tubes

One of the major difficulties encountered in the operation of X-ray tubes is that of deterioration of tube structure, particularly the anode, occasioned by excessive temperatures experienced when the tubes have been operated too long with high potentials impressed thereacross. Those versed in the art appreciate that optimum X-ray emission for many purposes may be achieved only when the electron beam is of great concentration and accelerated by very large potentials, and yet such tube operation may be attended by the generation of heat in amounts not only requiring forced cooling of the tube structure but reduction of the operating voltage as well if the tube is not to be damaged. Conventionally, the anode may be constructed of materials which efficiently dissipate the generated heat, either by radiation or conduction or by air or liquid cooling; and many tubes are of the rotating-anode type wherein the anode target area for the electron beam is continuously changing to limit the anode temperature rise. However, none of these expedients is effective to accomplish a regulation of the tube such that it may safely withstand the highest operating potentials, draw the largest currents, and generate the maximum output of most penetrating X-rays at all times when the anode temperature continuously increases during extended operating intervals. In accordance with the instant invention, anode temperature increases are limited to safe values by automatic control of the electron emission from the filament structure, whereby the electron beam impinging upon the anode surfaces is incapable of generating abnormal heating, and, further, the maximum electron flow and output of radiation are always maintained consistent with whatever anode heating may be experienced at any time. Optimum utilization of the tube is thus enabled.

It is, therefore, one object of this invention to provide a self-regulating electron discharge circuit wherein electron flow is limited to the maximum permissible for any anode heating conditions.

Further, it is an object to provide an X-ray tube arrangement wherein the electron flow is automatically and electronically controlled in accordance with the heating of the X-ray tube anode.

In addition, it is an object to provide an X-ray system wherein the X-ray tube current flow is simply and automatically regulated in accordance with electron emission from the tube anode to afford a maximum output of radiation for any heated condition of the anode.

By way of a summary account of but one aspect of this invention, there is provided an X-ray tube to which a D. C. voltage and superimposed A. C. voltage are applied, the respective voltages being proportioned such that the anode is made negative in relation to the filament during a small portion of each A. C. cycle. Electron emission from the heated anode, during that portion of each cycle when reverse potential is applied, is caused to impinge upon the focusing electrode in the tube and thereby charge a capacitance coupled with the focusing electrode. Upon return of the anode-filament circuit voltage to the proper polarity, the charge maintained on the focusing electrode by the capacitance opposes electron flow to the anode, to an extent dependent upon the magnitude of the charge. Because higher anode temperatures result in greater emission of electrons from the anode and a consequent more negative charge on the capacitance, the forward tube current is reduced accordingly and is in proportion to the heating of the anode.

Although the features of this invention which are believed to be novel are set forth in the appended claims, the details of the invention itself and further objects and advantages thereof may be readily comprehended by reference to the following description taken in connection with the accompanying drawing, wherein:

Fig. 1 is a partly pictorial and schematic representation of an X-ray tube and circuit therefor as taught by this invention; and

Fig. 2 is a plot of the potentials applied to the X-ray tube of Fig. 1.

Referring generally to the arrangement depicted in Fig. 1, it is noted that the X-ray tube **1**, a rotating-anode device, is characterized by having its filament-anode circuit coupled serially with both a unidirectional and a periodically-varying potential source and by having a concentration electrode biasing circuit. Considering the structural details, tube anode **2** and the electrical motor rotor **3** which continuously rotates the anode through shaft **4** are sealed within the evacuated glass tube envelope **5**, the rotor being driven by the external electric motor stator unit comprised of stator windings **6** and lamination stack **7**. An external electrical power source excites the stator windings through input terminals **8**. Anode **2** possesses an electron bombardment or target surface **9**, commonly made of a heavy metal such as tungsten, upon which impinges the highly concentrated electron beam **10** from the electron emitter in the form of a filament **11** to occasion the high frequency radiation termed Röntgen rays. Proper focusing of the electron beam upon the anode surface is accomplished by a concentration or focusing electrode **12** which contains a shaped recess **13** in which the filament **11** is mounted, the focusing control being established both by the shaping of the recess and the electrical charge of the electrode. The filament and concentration electrode are also enclosed within envelope **5**, with electrical coupling leads being brought through the envelope for the anode, filament and concentration electrode.

Heating supply power for filament **11** is obtained from the filament transformer **14** deriving its excitation from electrical source terminals **15**. An alternating potential supply for the anode-filament circuit is serially impressed by a transformer **16** which is coupled with electrical supply terminals **17**. As was stated earlier herein, the anode-filament circuit includes not only the foregoing A. C. supply, but a serially-coupled unidirectional potential supply, and, accordingly, the latter has been represented by the kenotron rectifier tube **18**, transformer **19** excited from A. C. supply terminals **20** and coupled in series with the rectifier, and the capacitor **21** paralleled with the series combination of rectifier **18** and transformer **19**. The rectified voltage appearing across capacitor **21** is applied between anode terminals **22** and filament **11** in series with the A. C. output of transformer **16**.

Biasing of concentration electrode **12** in the sense and to the extent required for automatic temperature-regulated operation of the X-ray tube **1** is achieved by the parallel combination of capacitance **23** and resistance

24 coupled between filament 11 and concentration electrode 12.

The mode of operation of this arrangement is dependent upon the characteristic anode-filament electrical power supply, and that supply, 25, and its D. C. and A. C. components, 26 and 27 respectively, are plotted in Fig. 2 with reference to a time abscissa and a voltage ordinate. The D. C. rectifier output 26 and voltage V_1 and the A. C. supply output 27 and voltage V_2 are relatively proportioned such that their combined voltages are slightly negative for only a small portion of each cyclic variation of the combined output. Cross-hatched portions 28 of the cycles of illustrated combined voltage 25 represent the negative impulses applied between the anode and filament, it being understood that the tube produces X radiation only when conducting in the forward direction as a result of the anode's being sufficiently positive in relation to the filament. The negative impulse applied during each cycle of anode circuit voltage causes the concentration or cathode element 12 and the filament 11 to become positive in relation to the anode 2, whereupon any electrons emitted by anode 2 because of its heating are attracted to element 12 and charge it negatively. Electron emission from the anode varies in accordance with its temperature, and the capacitance 23 coupled with element 12 is thus charged to an extent governed by the anode temperature. During the positive remainder of the anode circuit voltage cycle, the capacitance 23 maintains element 12 negative in relation to filament 11, thereby suppressing electron emission and the focusing of the electron beam. These reductions result in decreased heating of the anode. Resistance 24 shunted across capacitance 23 permits the charge thereon to leak gradually such that the charge on element 12 varies with the electron emission and temperature of the anode. In this manner, the element 12 operates automatically to limit the filament electron emission to values which will prevent an excessive build-up of temperature. When the anode is cold, the opposition to electron flow by element 12 is essentially absent, and, as the anode heat increases, the anode electron emission increases, thereby raising the negative charge upon element 12 such that filament emission is reduced. Cooling of the anode results in a lessened electron emission from it, whereupon the charge upon capacitance 23 decreases, because of leakage through resistance 24, and maintains a substantially stable charge at some reduced value. By proportioning the D. C. and A. C. supplies appropriately, the inverse voltage interval and amplitude may be adjusted to permit operation which yields maximum radiation for any anode temperatures which may be experienced and which prohibits the anode temperature from exceeding a predetermined safe limit. Time response of the control arrangement is adjustable with values of the capacitance 23 and resistance 24.

Although a preferred embodiment of this invention has been described in detail, it will occur to those skilled in the art that various modifications and substitutions may be employed to realize an automatic temperature-regulated X-ray or other tube system in accordance with these teachings. By way of example, it is not essential that the electron discharge device possess a rotating anode structure, rather, it is expressly intended that a stationary anode construction may be employed with the same attendant advantages. Likewise, the illustrated focusing electrode structure may be replaced, in another tube, by any suitable grid arrangement or element controlling the electron beam output from a filament, cathode or other electron emitter. The capacitance charging and discharging circuitry may be modified to suit particular requirements and may include variable resistance or capacitance elements to change the characteristics of that circuitry and, thereby, the operation of the tube.

It should thus be apparent that the specific embodiment of this invention disclosed herein is of a descriptive rather than a limiting nature and the various changes, combinations, substitutions or modifications may be employed without departing in spirit or scope from this invention in its broader aspects.

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

1. A temperature-regulation system comprising an electron discharge device including an anode, an electron emitter, and an electron beam control element disposed to intercept electrons emitted by said anode due to heating thereof, a source of periodically varying potential, means applying said potential between said anode and emitter of said discharge device, said potential being of amplitudes periodically causing said emitter to emit electrons and said anode to attract said electrons, means coupling said control element with said emitter and during operation of said device maintaining said control element negatively charged with respect to said emitter in proportion to the anode-emitted electrons intercepted by said control element.

2. A temperature regulation system comprising an electron discharge device including an anode, an electron emitter, and an electron beam control element disposed to intercept electrons emitted by said anode due to heating thereof and to control the electron beam from said emitter, a source of periodically varying potential, means applying said potential between said anode and emitter, said potential causing said anode to become alternately positive and negative in relation to said emitter, and capacitance means coupling said emitter with said control electrode, whereby said control electrode being negatively charged during operation of said device by anode-emitted electrons in proportion to the emission of said anode when said anode is negative with respect to said emitter, whereby said control electrode is effective to limit electron emission from said emitter when said anode becomes positive during the next portion of potential variation.

3. An X-ray generator temperature regulation system comprising an X-ray tube having an anode, an electron emitter, and a control electrode, a source of periodically varying potential coupled across said anode and emitter, said potential rendering said anode alternatively positive and negative in relation to said emitter, and capacitance means coupling said control electrode with said emitter.

4. An X-ray generator temperature regulation system comprising an X-ray tube having an anode, an electron emitter, and an electron beam control electrode disposed to be charged by electrons emitted by said anode due to heating thereof and to control electron flow from said anode, a source of periodically varying potential coupled across said anode and emitter, said potential rendering said anode alternately positive and negative in relation to said emitter and control electrode, and capacitance means coupling said control electrode with said emitter and during operation of said device maintaining said electrode negatively charged by and in proportion to anode-emitted electrons, whereby said electrode limits electron emission from said emitter in accordance with electron emission from said anode due to heating thereof.

5. An X-ray generator temperature regulation system as set forth in claim 4 wherein said potential source produces a cyclically varying potential which is of alternate positive and negative polarity, the potentials of negative polarity being of relatively small amplitude and short duration.

6. An X-ray generator temperature regulation system as set forth in claim 4 wherein said potential source comprises serially-coupled alternating and unidirectional electrical sources, said potential varying cyclically and being negative for a portion of each cycle of variation.

7. An X-ray generator temperature regulation system as set forth in claim 4 wherein said capacitance means comprises a capacitance and a resistance coupled thereacross, said resistance permitting a gradual leakage of the charge on said capacitor.

8. An X-ray generator temperature regulation system

as set forth in claim 4 wherein said emitter comprises a filament and wherein said control electrode comprises a focusing electrode.

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