April 29, 1941. R. D. EATON 2,240,037

METHOD AND APPARATUS FOR PRODUCING X-RAY FLASHES

Filed Oct. 8, 1938 3 Sheets-Sheet 1

Fig. 11

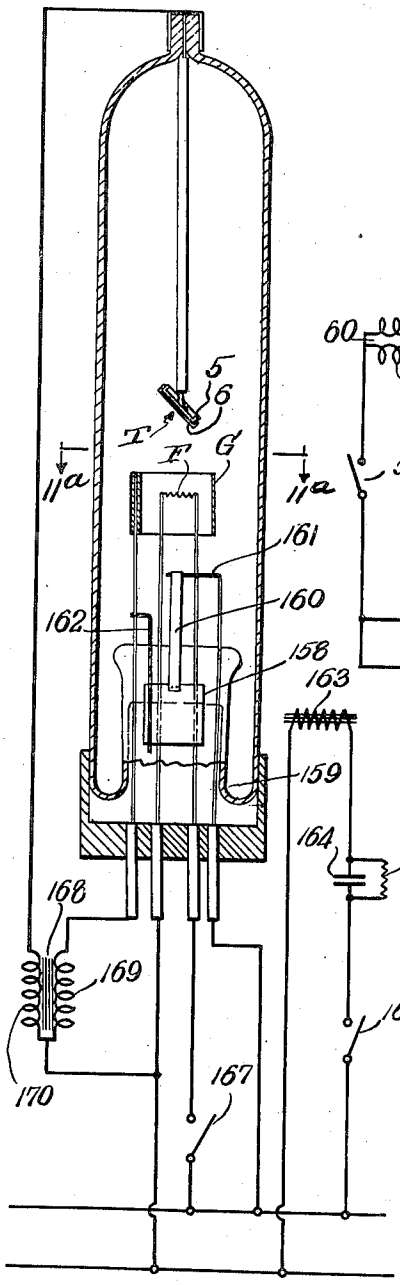


Fig. 7

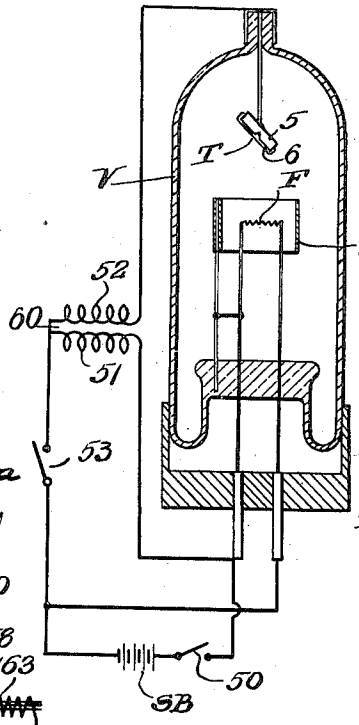


Fig. 1

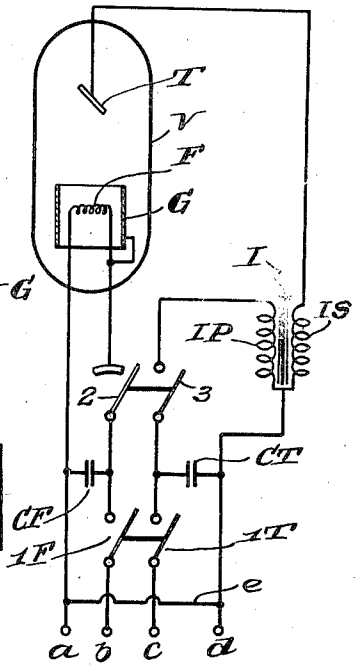
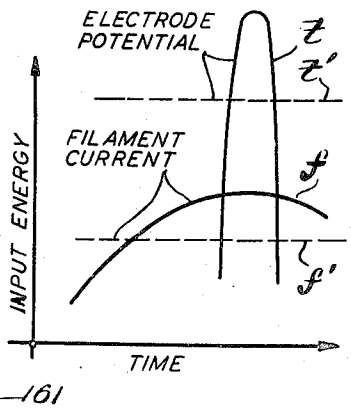


Fig. 2



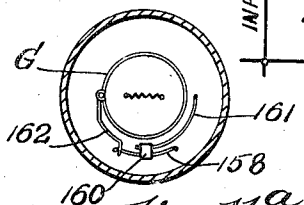


Fig. 11a

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METHOD AND APPARATUS FOR PRODUCING X-RAY FLASHES

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Fig. 3

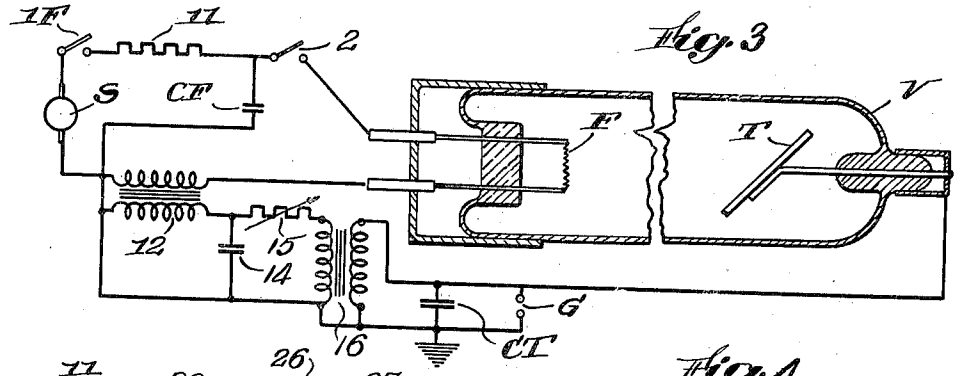


Fig. 4

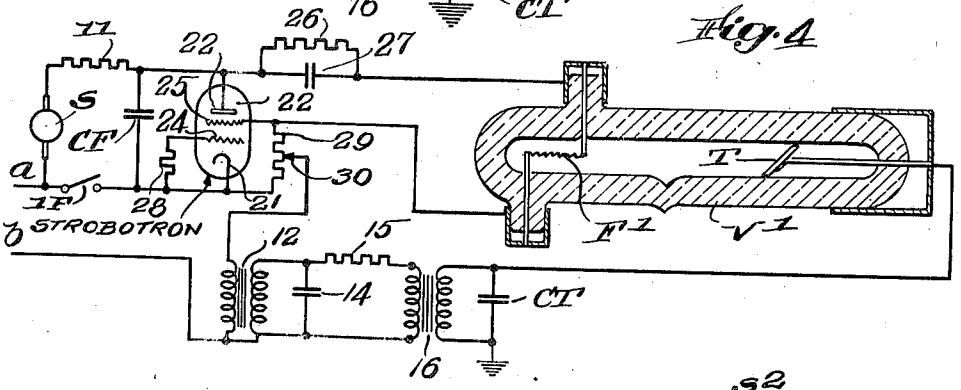


Fig. 6

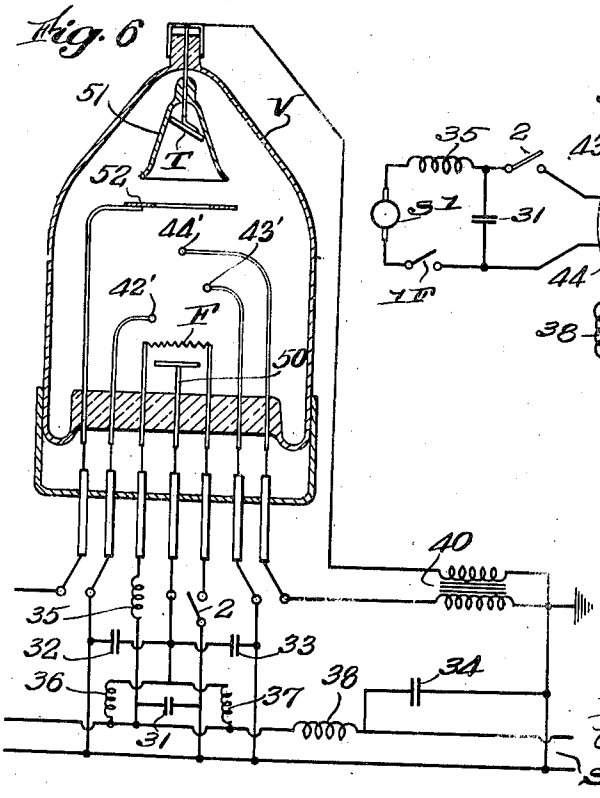
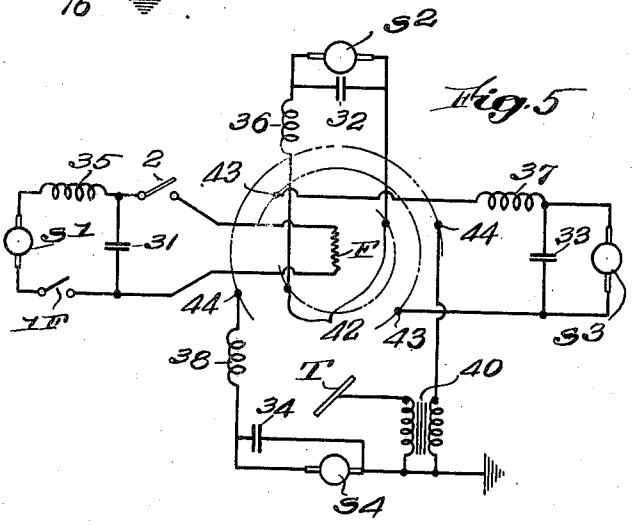


Fig. 5



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METHOD AND APPARATUS FOR PRODUCING X-RAY FLASHES

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Fig. 8

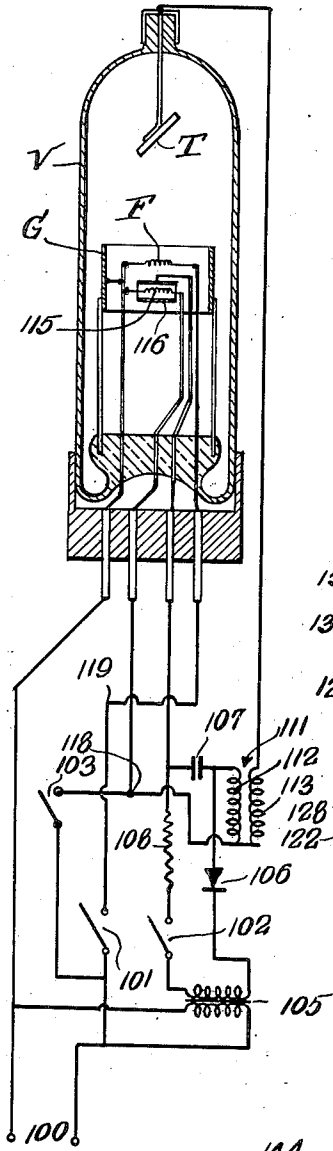


Fig. 9

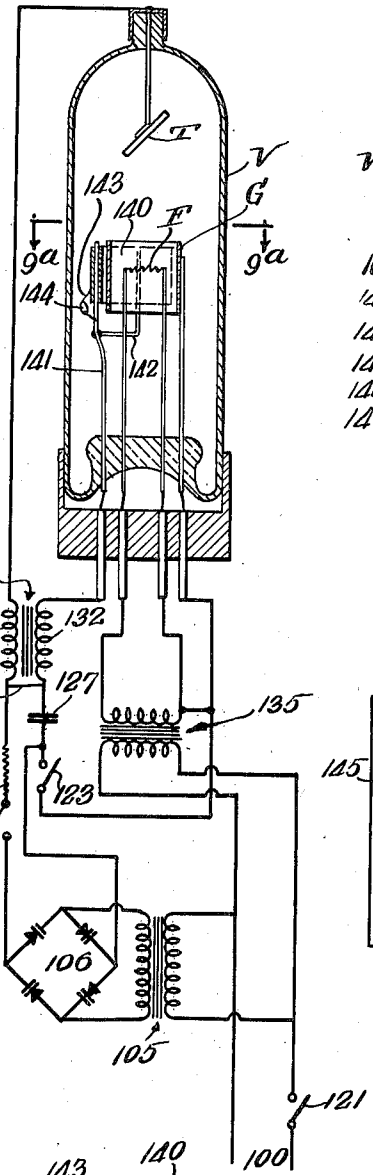
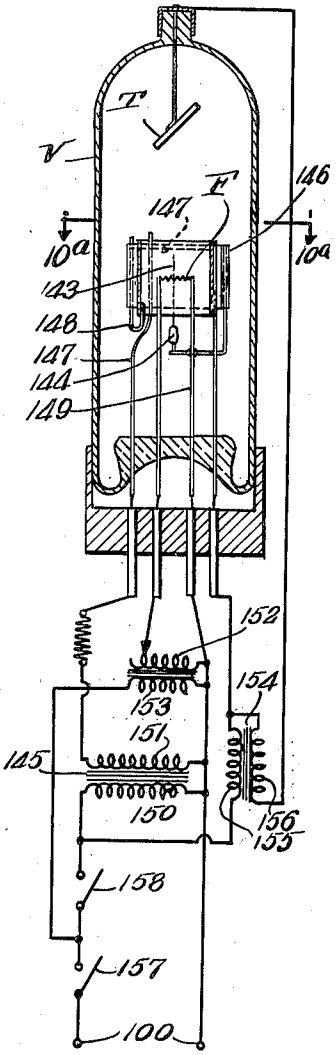


Fig. 10



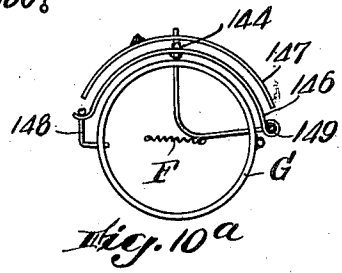


Fig. 10a

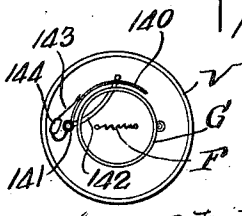


Fig. 9a

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UNITED STATES PATENT OFFICE

2,240,037

METHOD AND APPARATUS FOR PRODUCING X-RAY FLASHES

Roland D. Eaton, Boston, Mass., assignor to X-Ray Flash Lamp Corporation, Newton, Mass., a corporation of Massachusetts

Application October 8, 1938, Serial No. 233,990

11 Claims. (Cl. 250—98)

Roentgen apparatus now in use does not lend itself well to instantaneous exposures because the conventional X-ray tube is not able to furnish the energy necessary for short time exposures or, for carrying off the heat developed by the large amount of energy consumed during lengthy periods of operation, requires provisions which are so complicated and expensive that such tubes are not very well suited for extensive use. Also, it is often desirable to have inexpensive X-ray apparatus for infrequent use but still able to furnish high-grade X-ray records. Still further, emergency conditions often require high power X-ray equipment having as little as possible auxiliary equipment.

After extensive experimentation I have succeeded in providing a method of making X-ray records, and X-ray equipment which overcome the above disadvantages. My new method is based on the idea that very high energies can be utilized in an X-ray tube during a short period of time if no value is placed on the preservation of the tube itself. On the other hand, due to this fact that each tube is used only once, and that high energy is applied only during a very short period of time, the tube can be constructed in the simplest manner and therefore very cheaply, so that it becomes economical to use such tubes not only for short time exposures for which equipment is now hardly available, but also for the above-mentioned infrequent and emergency uses, and indeed for general purposes.

It is, therefore, one of the main objects of the present invention to provide a method, and apparatus for carrying out that method, for the purpose of making X-ray exposures of short duration but high intensity, without being forced to provide for the disposal of great amounts of energy not actually used for making the X-ray exposure.

In one aspect my invention is based, as mentioned above, on the idea of using and constructing Roentgen apparatus on the single use flash principle. In another aspect, my invention is concerned with the problem of supplying to an X-ray tube of the simplest possible form a surge of energy applied to the electron emitting cathode or the electrode gap, which will produce, during a very short period of time, an X-ray beam furnishing records of excellent quality.

Among the various features of my invention may be mentioned provisions for creating surges of electric current or potential, or both, and for applying such potentials to filament and electron path at suitable times and time relations, and in suitable form. Other features are the provision of switching means especially suitable for purposes of my invention, and the provision of means for coupling filament heating and electrode circuits in such a manner that the application of energy to these elements is correlated to furnish optimum efficiency. In still another aspect, the invention provides X-ray tube structures, and X-ray energizing circuits which promote the above main object.

These and other objects, features and aspects of my invention will be apparent from the following detailed description of several practical concrete embodiments explaining the genus of the invention by way of example. This description refers to drawings, in which:

Fig. 1 is a simplified circuit diagram, and Fig. 2 a diagram indicating the energy input-time relation respectively, these figures explaining the principle of the invention;

Figs. 3 and 4 show longitudinal sections through X-ray tubes, and the corresponding circuits;

Fig. 5 is a simplified circuit diagram of one modification of the invention;

Figs. 6 to 11 are longitudinal sections through X-ray tubes according to the invention; and

Figs. 9^a, 10^a and 11^a are sections on lines 9—9, 10—10 and 11—11, of Figs. 9, 10 and 11 respectively.

With reference to Figs. 1 and 2, the general principle of my invention will first be described. In Fig. 1, a highly evacuated vessel V contains a filamentary cathode F, a target anode T, and a focusing element G. Filament F is supplied with current from terminals *a*, *b* through a circuit containing condenser CF, switch 1F between supply and condenser terminals and switch 2 between condenser and filament terminals. The cathode-anode circuit is supplied from terminals *c*, *d* through a circuit including condenser CT, primary IP of transformer I, and switch 1T between condenser and transformer primary. The transformer secondary IS is connected to terminal *d* and target T and, as indicated at *e*, anode and cathode circuits are suitably correlated to establish an electric potential between filament and target.

As indicated in Fig. 1, switches 1F and 1T may be correlated for simultaneous operation. As likewise indicated, switches 2 and 3 may be so related that 2 closes prior to 3 and is maintained closed while contact is established at 3.

For operating this circuit, switches 1F and 1T are first closed, charging condensers CF and CT, whereupon they may again be opened. Switch 2

is then closed, causing condenser DF to discharge through filament F a surge of high current energy. Practically at the same time, switch 3 closes and a high potential energy surge is discharged from condenser CT through the cathode-anode circuit. The filament current and the anode-cathode potential should be essentially in phase; the relation of these discharges is indicated in Fig. 2. These discharges cause cathode F to emit a high energy electron beam striking target T, which again causes the emission of X-rays in well known manner. It will be evident that tubes of this type are made for selected useful emission values furnishing with given photographic emulsion material satisfactory exposures of a given object. The tube will thereby be put out of commision which, however, is of no consequence since it is of cheap construction, as will appear hereinafter more in detail; moreover, the destruction of the tube at a certain emission value prevents overloading of the tube which might result in overexposure or damage to a patient at an undesirable emission value.

Instead of applying surges to both filament and target, it is for most practical purposes satisfactory either to apply a constant potential to the target and to flash the filament, evaporating it in that process, this modification being indicated at *t'* and *f* of Fig. 2,—or to apply constant heating energy to the filament and a momentary surge to the target, as indicated by *f'* and *t* of Fig. 2. Always, target voltage and filament current should be as far as possible in phase.

Although an arrangement according to Fig. 1 was found satisfactory for certain purposes, special tube constructions, surge circuits and switch constructions have been found preferable in most instances, and such especially practical constructions will now be described more in detail.

The arrangement shown in Fig. 3 is similar to that of Fig. 1, with a somewhat different correlation of filament and target circuits. V is again an evacuated vessel containing filament F and target T. The circuit may be supplied from a current source indicated as S, furnishing, for example, direct current of 2000 volts. Filament condenser CF (about 280 mf.) can be charged through switch 1F and resistance 11 (about 5000 ohms). A transformer 12 steps up the surge voltage, a condenser 14 by-passes part of the surge which may be the high frequency component, and a variable resistance 15 of about 5 ohms controls the current input into the high tension transformer 16 which may deliver about 50,000 volts to target T. A gap G may be provided for approximately measuring the high voltage. It will be evident that the circuit intermediate filament and target provides for time control of the surges, correlating the beginning of the discharge through the filament to the peak of the discharge through the target. Condenser CF is first charged by closing switch 1F, whereupon switch CF may again be opened. Switch 2 is then closed, causing a discharge current, as indicated at *f* of Fig. 2; a discharge voltage corresponding to *t* follows in the appropriate time phase which can be controlled by means of the elements of the intermediate circuit.

It will be evident that the above conditions are satisfactory for furnishing a comparatively powerful instantaneous X-ray discharge. Although the discharges will destroy the filament, and in most instances admit air through the vessel which is caused to crack, the tube can be of such simple construction that its price is practically negligible and not much higher than that of the conventional "photo flash" tube. Target T may be a thin sheet 6 of molybdenum clamped onto a nickel support 5, and filament F a coiled tungsten wire of the commercial type such as used in incandescent lamps. As shown in Figs. 7 and 11, the molybdenum sheet may be 0.005'' thick, and the tungsten wire of 237 mg. per 200 cm. gage.

Instead of controlling the time relation with a circuit as shown in Fig. 3, a Strobotron tube (as for example described in "Electrical Engineering," 1936, page 794) may be used as indicated in Fig. 4. In this figure, elements corresponding to those of Fig. 3 have corresponding reference characters respectively. A current source S is again provided and, in addition, alternating current is supplied at *a* and *b*, for example standard 110 volt, 60 cycle current. The Strobotron is indicated at 22, having cathode 21, anode 22, control electrodes 24 and 25 and electrode resistances 28 and 29. A condenser 27 with parallel resistance 26 is provided in order to correct the phase displacement between target voltage and filament current. Through the adjustable contact 30 of resistor 29, transformer 12 is provided with a controlled amount of current as well as with a synchronizing pulse of 60 cycles.

In a practical embodiment, the circuit elements may have the following dimensions. Condenser CF may have 2 to 30 mf., condenser 27 about 0.01 mf., condenser 14 about mf., condenser CT about .0001 mf., resistance 11 about 2000 ohms, resistance 28 about 10,000 ohms, resistance 26 about 500,000 ohms, resistance 29 about 100,000 ohms, transformer 12 about 0.5 kva. with a 2 to 1 ratio, and transformer 16 about 1 kva. with a 600 to 1 ratio. In operating a circuit of this type, it is only necessary to close switch 1F, the Strobotron connecting the target circuit at the correct time in order to provide time relations as indicated in Fig. 2.

The tube V' shown in Fig. 4 has the special characteristic of providing an interior space only wide enough to accommodate target T and a filament F' which is arranged longitudinally of the vessel. This construction provides in a simple manner concentration of the electron beam; it may, however, be replaced by one of the electron beam focusing devices, as for example shown in figures referred to hereinafter.

I found that the effectivity of my arrangement can be improved by adding booster terminals or electrodes which apply high potentials to the vapor of the heated filament; in this manner, the input energy can be increased considerably without essentially prolonging the time period of the X-ray emission. Figs. 5 and 6 show an arrangement of this type, and in addition modified provisions for initiating the anode-cathode surge.

Fig. 5 indicates only the elements necessary for an explanation of the principle of this circuit. F is again the cathode, and T the anode. S1, S2, S3, S4 are suitable current sources supplying the four circuits now to be described.

Source S1 charges through switch 1F a condenser 31 which discharges through switch 2 into filament F. Sources S2 and S3, respectively, charge condensers 32 and 33 which discharge through inductances 36 and 37 into booster gaps 42 and 43. Source S4 charges condenser 34 which, through coil 38, transformer 40 and gap 44 discharges across cathode F and anode T. The gaps 42, 43, 44 are formed by auxiliary electrodes which may be arranged as indicated in

Fig. 6, presently to be described. These electrodes are adjacent the filament; gaps 42 and 43 apply a high potential to the vapor as it emerges from the evaporating filament, moving away from the filament zone and establishing ionized paths for these discharges which supply additional energy to the cathode and therefore increase the electron discharge. When the vapor has reached gap 44, the target circuit is closed and a surge across T and F initiated, again according to the scheme of Fig. 2.

Fig. 6 shows a practical embodiment of the arrangement shown schematically in Fig. 5. In Fig. 6, one auxiliary terminal or electrode of each pair is replaced by a common electrode 50; the complementary auxiliary electrodes are indicated at 42', 43' and 44'. A glass funnel 51 is provided in order to concentrate the electrons upon the target. An annular electrode 52, carrying bias potential, constitutes an electrode for focusing the electron beam to a small spot on target T.

The circuit of Fig. 6 is quite similar to that of Fig. 5, corresponding elements being identified with similar numerals; condensers 31, 32 and 33 have about 50 mf. each, and the secondary of transformer 40 supplies about 2000 volts. Gaps 50—42, 42—43 and 43—44 measure about 0.030", 0.025" and 0.020", respectively.

For operating the arrangement according to Fig. 6, it is only necessary to close switch 2, whereupon the filament will begin to evaporate, the two booster circuits will consecutively become effective and finally trigger electrode 44 will close the target circuit, as soon as the vapor ionizes the gap between 50 and 44'.

Fig. 7 shows a modification especially suitable for portable equipment, utilizing a storage battery as power source. Battery SB is, by means of switch 50, connected in parallel to the primary 51 of transformer 60 through switch 53, one side of transformer secondary 52 being connected to the filament circuit and the other to the target. Transformer 60 is of the ironless or Tesla type. I found as satisfactory a battery of 24 volts and a transformer having a heavy primary winding able to withstand a surge of approximately 2000 amps. which will flow therein upon closing of switch 53; for a very short instant, the transformer has to carry a load of about 50 kw.

In operating a system according to Fig. 7, the filament is first heated by closing switch 50; switch 53 is then closed, whereupon transformer 60 will discharge through the anode-cathode circuit. It will be evident that this process of producing X-ray emission is represented by a combination of curves *f'* and *t* of Fig. 2, there being no surge applied to the filament.

The above described practical arrangements are using, for the control of the timing of filament and target discharge, respectively, either external circuit arrangements (Figs. 3 and 4), or manually operated switches (Figs. 1 and 7), or auxiliary electrodes within the tube (Fig. 6). In certain instances, such arrangements are either still not quite as simple as desirable, or they need such skill in operation which can not always be found in all practical situations; the type of arrangements now to be described, utilizing flash X-ray tubes with internal switching devices, is often preferable.

In Fig. 8, a current source, for example standard 110 volt, 60 cycle alternating current, supplies filament F through switch 101. Connected in parallel to the filament circuit is a transformer 105 whose secondary supplies a potential of about 2000 volts to the target circuit comprising switch 102, rectifier element 106 (for example an Ignitron or mercury vapor rectifier), condenser 107 of about 240 mf. and resistor 108 of about 5000 ohms. In parallel to condenser 107 is the anode circuit proper, comprising a transformer 111, for example a low impedance Tesla transformer with 1:600 ratio of primary winding 112 and secondary winding 113, respectively. Secondary 113 is connected to target T and primary 112 in parallel to condenser 107, in a circuit containing also a switch constituted by trigger filament 115 and trigger sleeve 116 surrounding filament 115. The other side of filament 115 is connected to filament F, completing the tube circuit. This arrangement operates as follows.

Switch 101 is first closed, bringing filament F to the required temperature (*f'* of Fig. 2). Switch 102 is then closed, which causes condenser 107 to be charged. Thereupon switch 103 is closed which supplies trigger filament 115 with current and causes it to emit electrons, establishing a current path to sleeve 116 and permitting the discharge of condenser 107 through the anode-cathode circuit. It is easy with conventional means to dimension trigger arrangement 115—116 in such a manner that the current path bridging condenser 107 will be established during the peak amplitude of the alternating current supplying condenser 107, so that a surge wave of optimum voltage amplitude is discharged through the target (corresponding to *t* of Fig. 2) causing optimum electron flow and optimum X-ray emission.

Instead of using a special trigger filament, the filament proper F can be used for closing the target circuit, in which case points 118 and 119 are directly connected and contact element 116 placed adjacent to F. The normal electron emission of F will then be arranged not to close the target circuit, but to reach a maximum (*f* of Fig. 2) at the time when the surge between anode and cathode is a maximum (*t* of Fig. 2).

In still another modification of Fig. 8, an auxiliary grid can be introduced, directly supplied with the transient target potential and closing the target circuit at the optimum time. Such a grid can be arranged to constitute a focusing cylinder which will inherently have its optimum effectiveness at the time of the surge peak.

Again, a tube according to Fig. 8 will be suited for single use only, since the surge discharge, causing the required momentary but high intensity X-ray emission, will destroy at least the trigger arrangement and most likely also otherwise introduce gas into the tube.

Instead of the trigger electrode arrangement of Fig. 8, an actual switch may be arranged within the tube, and I found the arrangements now to be described especially efficient while their construction is so simple that the increase in price of the tube due to such constructions is practically insignificant.

Figs. 9, 9a, 10 and 10a show types of tubes utilizing an internal switch operated by an electric field.

In Figs. 9 and 9a contact element 140 is rotatably mounted on rod 141 which also carries a stop 142 welded thereto. Contact element 140 is a simple metal sheet, curved to the shape of focusing cylinder G and at one edge bent in the form of a hinge around rod 141. A spring 143 tends normally to separate cylinder G and leaf 140. I prefer to insert a glass bead insulator 144 into spring 143, in order to prevent the spring

from functioning as a high resistance. Transients travel through a continuous high resistance rather than a contact resistance. In the present instance, the spring and the points where it is welded to 140 and 141, respectively, form such a high resistance as compared to the resistance of the hinge where 140 and 141 come into contact. Consequently, the current might flow mainly through the energy consuming spring instead of the contacts.

The current may again be furnished by a 110 volt 60 cycle source 109. In an actually used embodiment, filament F is supplied through switch 121 and transformer 135 having a secondary voltage of about 7.5 volts and rated about 20 W. The target circuit receives direct current of about 2000 volts by means of transformer 105 and a conventional rectifier bridge 106 which feeds through switch 122 and resistor 128 (about 3000 ohms) into condenser 127. One side of condenser 127 is connected to the common terminal 126 of auto transformer 131 having a ratio of about 600:1 and a rating of ½ to 1 kva. The other side of condenser 127 is connected, through switch 123, to cylinder G and the secondary of transformer 135 feeding into filament F. The primary 132 of transformer 131 leads from 128 to contact leaf 140, and the secondary 133 to target T. This system is operated in the following manner.

Filament F is first supplied with current by closing switch 121. Switch 122 is then closed, which causes condenser 127 to be charged. Switch 122 is then opened and 123 closed, which establishes an electric field between contacts G and 140, pulling them together and shunting condenser 127 directly across transformer 131 which now discharges through the anode-cathode circuit, flashing the tube.

In order to obtain maximum energy input, it may be preferably to employ an internal switch closing at the peak of the potential supplied by the target transformer 131. Such an arrangement will now be explained with reference to Figs. 10 and 10a.

In Fig. 10 the internal switch is so constructed that it vibrates at a resonance frequency of about 60 cycles. This switch is similar to that shown in Figs. 9 and 9a except that the spring 143 with insulator 144 is heavier and holds the switch contact plate 146, on filament post 149, away from both guide plate 147 and contact rod 148. This plate or vane 146 is caused to oscillate at 60 cycles by an electrostatic field furnished by a 2000 volt transformer 145 between plates 146 and 147. A contact 148 on focusing cylinder G is not allowed to touch vane 146, except when the latter is pulled over toward 147 at 2000 volts. Contacts of the internal switch are made between the filament post 149, carrying plate 146, and stop 148 on G. Since vane 146 oscillates at 60 cycles, the two voltages will be in phase so that contact is made at the peak represented by the greatest swing of the switch when it strikes contact 148.

The filament transformer has a secondary 152 and a primary 153, and electrode transformer 145 has a primary 150 and a secondary 151 supplying about 2000 volts. Transformer 154 with primary 155 and secondary 156 corresponds to 131 of Fig. 9. Switch 157 is provided for connecting the filament alone, whereas 158 controls the anode-cathode circuit. The circuit may be supplied, at 109, from a 110 volt, 60 cycle line.

In operation, switch 157 is first closed causing transformer 152, 153 to be activated, lighting filament F but not burning it out. Closing switch 158 causes the vane 146 to resonate at its natural period of 60 cycles/sec. and strike contact 148. This connects the primary 155 across the 110 volt line. The contact is made at 148 on the peak of the amplitude of the switch, and this automatically places the target voltage in phase with the filament current, as shown in Fig. 2.

Another internal switch, but operated magnetically instead of statically, is shown in Figs. 11 and 11a. A cylindrically shaped vane or plate 158 conforming to the cylindrical shape of the stem 159 is suspended by spring 160 welded onto a stem wire 161. This vane is made in such a way that it will resonate mechanically at 60 cycles. This vane is constructed to make contact with a wire 162 welded onto the support of the focusing cylinder G. An iron core coil 163 is placed against or near the outside glass wall of the tube. In series with this coil is placed condenser 164 with a leak resistor 165. The purpose of this condenser is to bring the current in phase with the voltage, since, normally, the voltage lags 90° behind the current, so that, if the condenser were not present, the voltage operating the switch would be zero when the switch is making contact. The purpose of the leak resistance 165 is to allow enough current to flow around condenser 164 to operate the magnetic field of the coil. This does not change the phase if the resistor is large enough.

In operation, switches 166 and 167 are closed, which causes spring 160 and vane 158 to oscillate at 60 cycles, building up amplitude until contact is made at 162. This sets off peak voltage discharges from the 110 volt line into primary 169 and through high voltage winding 170 into target T, flashing the tube.

With the above described equipment I have been able to make clear X-ray exposures showing sharp detail, these flash exposures being of very short duration, corresponding to conventional photographic exposures of $\frac{1}{100}$ second to $\frac{1}{1000}$ and less, depending upon the circuit, tube, energy input and phase relation used. As will be evident from the description, the tubes are very simple and do not involve any expensive material and manufacturing processes, nor complicated cooling and mounting equipment; therefore, their use as "flash X-ray tubes", either for single exposures or in apparatus for making X-ray motion pictures is practical and fills a recognized demand in the medical and technical arts. The circuits involved are likewise simple and not dependent on any unusual current sources, so that the equipment can be used without difficulty in most situations.

It should be understood that the present disclosure is for the purpose of illustration only and that this invention includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. X-ray apparatus comprising a substantially evacuated tube having electrode means constituting a cathode, electrode means constituting a target anode, said electrode means being constructed to dissipate energy substantially only within said tube, means for supplying electric energy to said cathode for heating it, means for supplying an electric potential between said electrode means for propelling electrons from the cathode to the anode, and booster circuit means including gap electrode means adjacent said cathode, a condenser in series with said gap electrode means and means for charging said con-

denser, the heated cathode rendering said gap conductive for a discharge of said condenser, thereby increasing said energy input.

2. X-ray apparatus comprising a substantially evacuated tube having electrode means constituting a cathode, electrode means constituting a target anode, said electrode means being constructed to dissipate energy substantially only within said tube, a circuit for supplying an electric potential to said cathode for heating it, a second circuit for supplying an electric potential between said electrode means for propelling electrons from the cathode to the anode, and means including a switch normally disconnecting said anode from said second circuit, located within said tube and actuated by means of one of said supply circuits, for suddenly applying to said electrode means a potential sufficiently high to cause instantaneous X-ray emission and to destroy the tube.

3. X-ray apparatus comprising a substantially evacuated tube having electrode means constituting a cathode, electrode means constituting a target anode, said electrode means being constructed to dissipate energy substantially only within said tube, means for supplying electric energy to said cathode for heating it, surge supply means for suddenly applying to said electrode means a surge potential sufficiently high to cause instantaneous X-ray emission and to destroy the tube, switch means within said tube normally disconnecting said electrode means from said surge means, and means for closing said switch means to apply said surge potential to said electrodes.

4. X-ray flash apparatus dimensioned for a predetermined useful emission above a certain ineffective value and below a certain undesirable value, comprising a substantially evacuated tube having a solid cathode and a target anode, a circuit for applying to said cathode a potential for heating it, a circuit for applying a potential between said cathode and said anode for propelling electrons toward said anode, and means for supplying said potentials to said circuits with at least one potential having a peak value high enough momentarily to effect said useful emission but substantially to destroy said tube before said undesirable value is reached.

5. The method of providing X-ray flash emissions of predetermined useful value above a certain ineffective value and below a certain undesirable value, comprising momentarily applying to an X-ray tube having no special provisions for dissipating energy the cathode heating and anode circuit potentials with at least one of said potentials at a value high enough to effect said useful emission above said ineffective value, and rising said potential to destroy said tube before said undesirable value is reached.

6. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit normally open terminals located adjacent to each other within said vessel, and means to connect said terminals for the flow therethrough of current in said circuit.

7. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit two contact elements movable relatively to each other and located adjacent to each other within said vessel, and means to contact said elements for the flow therethrough of current in said circuit.

8. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit normally open terminals located adjacent to each other within said vessel, one of said terminals being a filament, and means for heating said filament causing it to emit electrons and hence to connect said terminals for the flow therethrough of current in said circuit.

9. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit two contact elements movable relatively to each other and located adjacent to each other within said vessel, and means for applying an electric field to said elements, said field controlling the relative position of said elements for the flow therethrough of current in said circuit.

10. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit two contact elements movable relatively to each other and located adjacent to each other within said vessel, and means for oscillating one of said elements to contact said elements for the flow therethrough of current in said circuit.

11. Electron discharge apparatus comprising a vessel with electrode means including cathode and anode, a circuit for supplying potentials to said electrode means, in said circuit two contact elements movable relatively to each other and located adjacent to each other within said vessel at least one of said elements being of magnetic material, and means for establishing a magnetic field containing said magnetic element, said field controlling the relative position of said elements for the flow therethrough of current in said circuit.

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