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X-RAY APPARATUS

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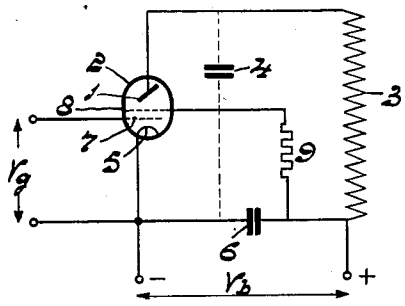


Fig. 1

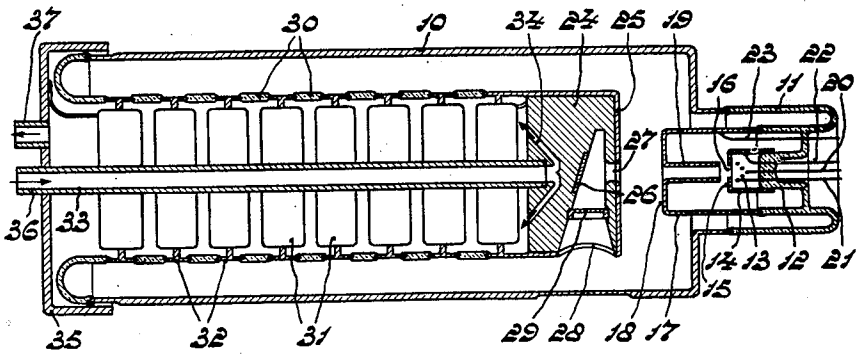


Fig. 2

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X-RAY APPARATUS

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6 Claims. (Cl. 250—99)

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The invention relates to X-ray apparatus and more particularly to an X-ray tube and associated circuits which are adapted to operate on pulsed direct current potentials.

The production of X-rays with pulsed direct-current potentials has the advantage that the voltage permissible between the anode and the cathode of the X-ray tube is higher than with direct-current or alternating-current potentials. Moreover, the instantaneous value of the current strength can be materially higher which permits the production of transient flashes of hard X-rays and X-rays of very high intensity.

The oldest known devices which produced X-rays operated with an inductance coil in which the anode and the cathode of the tube were connected to the ends of the coil and direct-current was passed through a small number of turns of the coil or a winding coupled with the coil which was periodically interrupted. The voltage thus produced across the X-ray tube varied in the manner similar to that of a damped oscillation, so that not only the voltage peak for producing the X-rays but also high voltages of opposite polarity occurred which restricted the highest value of the effective permissible voltage. The secondary voltage moreover exhibited a fairly large degree of irregular fluctuations with the result that the ray emission became nonreproducible.

In another device voltage pulses were taken from a capacitor which was periodically discharged across the X-ray tube which required a separate high-voltage generator for supplying the charging voltage to the capacitor.

As an alternative, the required voltage pulse was also obtained with a surge voltage generator, but such a system is both involved and costly.

The present invention relates to a device of very simple construction for producing X-rays with a pulsed direct-current voltage thus ensuring satisfactory reproducibility of the quality of radiation. According to the invention, the apparatus comprises an X-ray tube which includes a control-electrode and at least one screen electrode and is connected in series with a choke to a direct-current source, the screen electrode also being connected to the source. The voltage which is available at the source is too low for the production of X-rays, so that provision is made for separate means to cause the control-electrode periodically to assume alternately a potential at which the current across the X-ray tube is interrupted, but no longer than is required to increase the additional voltage across

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the tube which is thus produced to a value at which X-rays of the required wavelength are emitted and a higher potential at which the current is allowed to pass through the tube.

The total energy incorporated in the inductance at the instant when the anode current across the X-ray tube is cut off is preferably consumed in a single discharge in the X-ray tube thus avoiding the occurence of a counter voltage. For this purpose the vale of the negative voltage supplied to the control-electrode may decrease in accordance with a characteristic to be indicated more fully below.

The high voltage is produced across the inductance because of the interruption of the direct-current which passes through the coil. For controlling this current to obtain high voltages it has been known to utilize an electric discharge tube comprising a control-grid which is periodically supplied with a negative voltage and to use the pulsatory voltage produced for the supply of an X-ray tube connected in parallel with the coil. A triode for controlling the current supply has been suggested for constituting the X-ray tube in a circuit arrangement comprising an inductance for the supply of the voltage pulses, the negative grid voltage being obtained from the anode supply voltage by employing feedback between anode circuit and grid circuit. Emission of X-rays is obtained during the occurrence of the pulsatory voltage, since, in spite of the negative voltage, the control-grid allows the passage of electrons. If allowance is made for the fact that the effective X-ray emission does not occur until the anode supply voltage approaches its maximum value and if the transmissibility of the control-grid is adjusted to pass electrons only in the range of the highest voltage, the ray emission will again be interrupted at such an instant that only part of the energy in the inductance has been conducted away, so that in this arrangement high voltage will occur in the opposite direction. This disadvantage is not inherent in the device according to the invention.

The invention will now be described in detail with reference to the accompanying drawing in which:

Figure 1 shows schematically the circuit arrangement of the apparatus according to the invention; and

Figure 2 shows one embodiment of the X-ray apparatus according to the invention.

In Figure 1 the voltage V^b of the supply source of direct-current, which may be of the order of

0.5 kv. to 20 kv., is supplied to the anode 1 of an electric discharge tube 2 through choke 3. The latter has an inductance L and in addition a slight capacity c, represented by capacitor 4 and in which are also incorporated the tube capacitance and any additional stray capacitances. The cathode 5 of the discharge tube 2 is connected through a smoothing capacitor 6 to the voltage supply conductor. A negative voltage V^g is periodically applied in a conventional manner between the cathode 5 and the control-electrode 7 of the discharge tube 2, and the current flowing in the X-ray tube in consequence of the application of this supply voltage is thus interrupted.

For the period of time the discharge tube 2 is conductive, current flows through the tube. When the conductivity of the tube is abruptly interrupted at the instant t_0, the current can no longer flow nor can it suddenly become zero, since the choke is included in the anode circuit of the tube. The current will consequently charge the capacitor 4. If the supply current is designated i, the magnetic energy of $\frac{1}{2}L.i^2$ available in the coil at the instant of interruption is converted into electric energy $\frac{1}{2}CV^2$. The value of the voltage V is a maximum, when the current i has become zero, where $\frac{1}{2}L.i^2=\frac{1}{2}CV^2_{max}$ or

$$V_{max}=i\sqrt{L/C}$$

With a suitable choice of the circuit constants, i. e., conductance and capacity, this voltage may assume a very high value. If the resistance of the coil is neglected, and if $i=1$ amp., $L=2$ henries and $C=50\mu\mu F$, the maximum voltage $V_{max}=200$ kv.

This voltage first occurs as a positive anode voltage across the discharge tube 2 and this tube is thus also capable of operating as an X-ray tube.

The instant when the discharge current, at which X-radiation is produced, begins to flow, is determined by the period of time, in which, after the control-electrode has become negative, the voltage to be used for this purpose has become ineffective. This must be when the anode voltage approaches its maximum value. If t_1 is assumed as the moment the anode has become a maximum after the interruption of the current at the instant t_0, the high voltage across the tube at which emission of rays takes place, lasts longer when the instant the tube becomes conductive is prior to t_1 rather than when it coincides therewith or is subsequent thereto. In the first case the charging current still flows into the capacitor 4 at this instant. In the latter case, the capacitor is already being discharged through the coil. Consequently the shape and value of the voltage pulse vary with the instant the tube 2 becomes conductive. A favorable effect is obtained if the interruption of the current is of the order of from ⅛ to ¼ of the period of the oscillatory time of the LC-circuit.

Use may be made of means for extending the period of time during which a high anode voltage is available, for example, by slowly causing the tube to become conductive. In this case, instead of rectangular voltage, a voltage slowly decreasing from the maximum negative voltage is applied to the control-electrode.

Due to provision of a screen electrode 8 in the X-ray tube, the control-voltage may be comparatively low and in addition the control can be made substantially independent of the anode voltage occurring. The screen electrode 8 is connected to the supply voltage, for example, through a resistance 9.

After the interruption of the supply current an oscillating voltage would occur across the choke if the variation of the voltage across the control-electrode were not such that the energy in the choke is withdrawn through the tube. The variation of the voltage at the control-electrode should preferably be such that this energy has been withdrawn at the instant the anode voltage has become ineffective. In this case a counter voltage does not occur across the tube and the advantage of the improved possibility of subjecting the tube to voltage pulses is utilized to the fullest extent.

The time of discharge of the capacitor 4 is of the order of C.V/I, where I designates the discharge current, which in view of the emissive power of the cathode may have the same value as the supply current i available at the supply voltage V_b. Between two discharges the current must increase from zero to i. When neglecting the voltage across the tube,

$$L\frac{di}{dt} \text{ becomes} = V_b$$

at which after t seconds$=Li/V_b$ the current has increased from zero to i.

The following calculation shows that in this manner a reasonable power can be converted into X-rays. If the condition is to be satisfied that the power should be 3 kw. at 300 kv. of pulsatory voltage, $\frac{1}{2}nCV^2$ must be 3 kw. in the case of n pulses per second. If C is assumed to be $50\mu\mu F$, it follows that $n=1333$ c./sec.

If the tube current i is assumed to be 1 amp., it follows from $\frac{1}{2}nLi^2=3$ kw. that $L=4.5$ henries. In order that the current may increase from 0 to 1 amp. for $1/n$th second, it follows from $nLi=V_b$ that $V_b=6000$ volts.

An erroneous assumption has been made, since the time t in which the current increases is assumed to be equal to the time interval between two successive pulses. The duration of the pulse $(1/n-t)$ is negligible with respect to the time t, so that this simplification does not give rise to any substantial difference in result.

Figure 2 shows that the outer wall 10 of the X-ray tube is made almost completely of metal. Sealed to the metal part is a glass wall part 11, which comprises a re-entrant portion. The re-entrant portions comprise a glass foot 12, to which the cathode 13 is secured. The foot also supports a control-electrode 14 which is formed as a cylindrical tube provided at one end with a diaphragm 15 in which an aperture 16 is provided to allow the passage of the electron beam. Secured to the re-entrant part by sealing is a cylindrical electrode 17, at the other end of which an apertured plate 18 is provided to which a cylindrical tube 19 is secured, which extends towards the cathode. This electrode acts as a screening cylinder between the anode and the cathode and its function is to reduce the sensitiveness of the cathode emission relative to anode voltage variations.

The current is supplied to the cathode by two connecting wires 20 and 21 sealed in the foot 12. A third wire 22 for supplying voltage to the control-electrode 14 is provided internally while the connection to the screening cylinder 17 is effected by a connecting wire 23.

The anode 24 of the tube is of usual form with a screening hood 25 to suppress secondary emis-

sion. It has a bevelled front surface in which is housed the anode disc 26, onto which the electron beam is focussed. The screening hood 25 has an aperture 27 for the passage of the beam and an exit orifice 28 of the X-rays which is closed by a disc 29 of a metal, usually beryllium, which readily allows the passage of X-rays.

The anode 24 is secured in a vacuum-tight manner to a re-entrant part 30 of the tube wall. This wall part defines a cylindrical space which offers accommodation for the choke of the circuit-arrangement shown in Fig. 1, the coil being built up of a number of parts 31, each of which is separately manufactured and surrounded by a layer of insulating material. These parts are connected in series, one end of the choke being conductively connected to the anode and the other to the metal outer wall of the tube. The wall portion between the anode and the tube end must be sufficiently insulated to withstand the voltage occurring across the coil and hence be made wholly or in part of insulating material, for example glass or porcelain. It may be subdivided by metal rings 32, each of which is connected to a separate coil part, so that the voltage occurring across the choke provides a compulsory voltage distribution to the re-entrant part of the tube wall.

Internally within the coil provision is made of a pipe 33 of insulating material for supplying a cooling liquid to the anode. This liquid flows through channels 34 provided in the anode into the coil chamber and may also be used to conduct away the heat produced in the coils. The liquid must be a satisfactory insulator, preferably oil.

The outer wall of the tube may be connected to earth potential, so that parts at a high voltage are completely protected during operation of the tube. This avoids the need for an envelope of oil or compressed gas. Connected intermediate the tube wall and the cathode is the supply source, which supplies a comparatively low voltage, for example, 6000 volts.

Provided on the side remote from the cathode is a lid 35 for closing the coil chamber, this lid being provided with coupling means 36 and 37 for supplying and discharging the cooling liquid.

While the invention has thus been described in specific embodiments and applications thereof, other modifications of the invention will be readily apparent to those skilled in the art without departing from the spirit and scope of the invention.

What we claim is:

1. X-ray apparatus comprising an X-ray tube including a cathode, a control electrode, a screen electrode, and an anode, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied between the anode and cathode, an anode supply circuit connecting the anode to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor in series with the anode and the source in the anode supply circuit, said inductor having an inductance value at which a potential is developed thereacross when current flowing through the X-ray tube is interrupted which is sufficient to generate X-radiation of a desired wave-length, and input means to apply a cyclically recurring control voltage to the control electrode, said cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube and having a duration at which the inductor is capable of developing the required voltage thereacross.

2. X-ray apparatus comprising an X-ray tube including a cathode, a control electrode, a screen electrode, and an anode, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied between the anode and cathode, an anode supply circuit connecting the anode to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor in series with the anode and the source in the anode supply circuit, said inductor having an inductance value at which a potential is developed thereacross when current flowing through the X-ray tube is interrupted which is sufficient to generate X-radiation of a desired wave-length, and input means to apply a cyclically recurring control voltage to the control electrode, said cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube, a duration at which the inductor is capable of developing the required voltage thereacross, and a value which decreases in a manner such that the energy in the inductor at the instant the current flowing through the X-ray tube is interrupted is dissipated in the X-ray tube until the anode voltage has decreased to the voltage of said source.

3. X-ray apparatus comprising an X-ray tube comprising an envelope having a reentrant electrically insulated wall portion and including a cathode, a control electrode, a screen electrode, and an anode in close proximity to the reentrant metal wall portion, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied between the anode and cathode, an anode supply circuit connecting the anode through the metal wall portion to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor mounted within the reentrant wall portion and having one terminal thereof connected to the anode and another terminal connected to the metal wall portion whereby said anode is connected in series with said inductor to said source, said inductor having an inductance value at which a potential is developed thereacross when current flowing therethrough is interrupted which is sufficient to generate X-radiation of a desired wave-length, and input means to apply a cyclically recurring control voltage to the control electrode, said cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube and having a duration at which the inductor is capable of developing the required voltage thereacross.

4. X-ray apparatus comprising an X-ray tube comprising an envelope having a reentrant electrically insulated wall portion, and including a cathode, a control electrode, a screen electrode, and an anode, in close proximity to the reentrant metal wall portion, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied be-

tween the anode and cathode, an anode supply circuit connecting the anode through the metal wall portion to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor comprising a plurality of wound sections each electrically insulated from each other, said inductor being mounted in said reentrant wall and having one terminal connected to the anode and another terminal connected to the metal wall portion whereby said anode is connected in series with said inductor to said source, said inductor having an inductance value at which a potential is developed thereacross when current flowing therethrough is interrupted which is sufficient to generate X-radiation of a desired wave-length, and input means to apply a cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube and having a duration at which the inductor is capable of developing the required voltage thereacross.

5. X-ray apparatus comprising an X-ray tube comprising an envelope having a reentrant electrically insulated wall portion and including a cathode, a control electrode, a screen electrode, and an anode in close proximity to the reentrant metal wall portion, and insulated therefrom, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied between the anode and cathode, an anode supply circuit connecting the anode through the metal wall portion to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor comprising a plurality of wound sections each electrically insulated from each other, said inductor being mounted within said reentrant wall portion and having one terminal connected to the anode and another terminal connected to the metal wall portion whereby said anode is connected in series with said inductor to said source, said inductor having an inductance value at which a potential is developed thereacross when current flowing therethrough is interrupted which is sufficient to generate X-radiation of a desired wave-length, and input means to apply a cyclically recurring control voltage to the control electrode, said cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube and having a duration at which the inductor is capable of developing the required voltage thereacross.

6. X-ray apparatus comprising an X-ray tube comprising an envelope having a reentrant electrically insulated wall portion and including a cathode, a control electrode, a screen electrode, and a water-cooled anode electrically insulated from said metal wall portion, a source of direct-current voltage having a potential which is insufficient to generate X-radiation when applied between the anode and cathode, an anode supply circuit connecting the anode through the metal wall portion to one terminal of the source having a positive potential, circuit means connecting the cathode to another terminal of the source having a negative potential with respect to said first terminal, circuit means connecting the screen electrode to the positive terminal of the source, an inductor comprising a plurality of wound sections each electrically insulated from one another, said inductor being mounted within said reentrant wall portion and having one terminal connected to the anode and one terminal connected to the metal wall portion whereby said anode is connected in series with said inductor to said source, said inductor having an inductance value at which a potential is developed thereacross when current flowing therethrough is interrupted which is sufficient to generate X-radiation of a desired wavelength, and input means to apply a cyclically recurring control voltage to the control electrode, said cyclically recurring voltage having a potential sufficient to interrupt current flow through the tube and having a duration at which the inductor is capable of developing the required voltage thereacross.

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