Dec. 17, 1935. A. BOUWERS 2,024,333

X-RAY INSTALLATION

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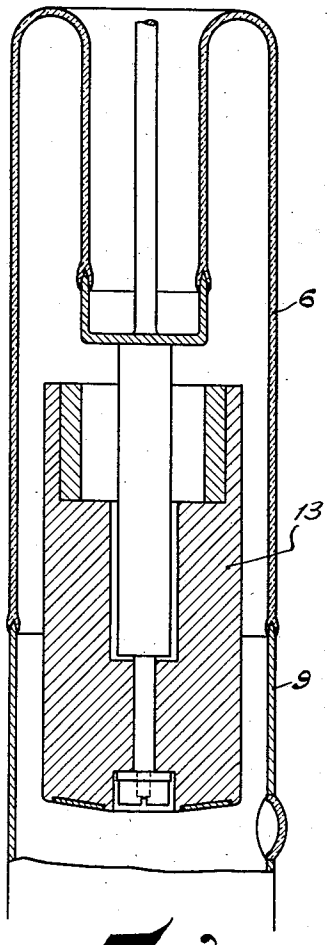


Fig. 2.

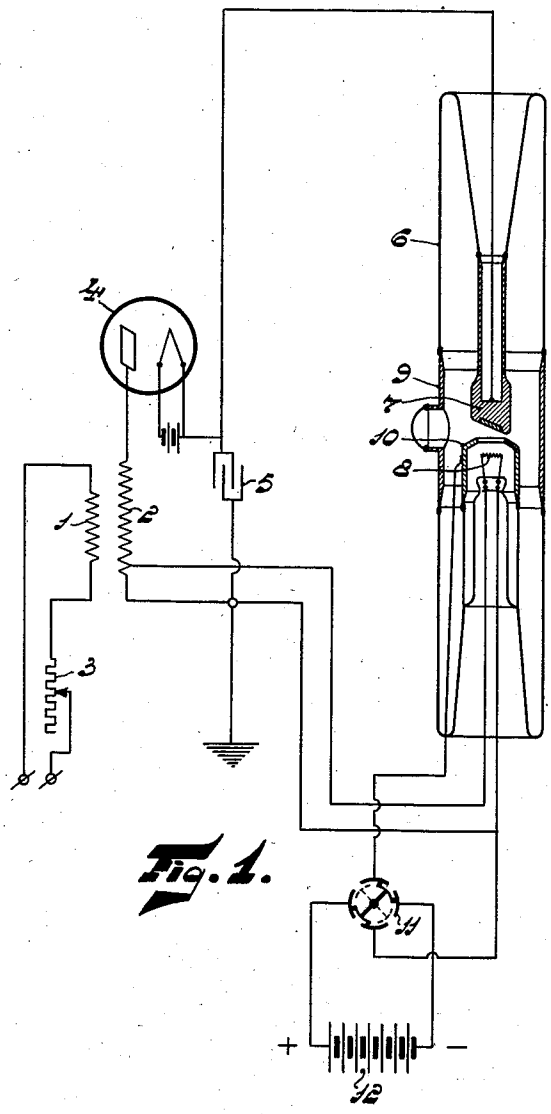


Fig. 1.

Inventor:-
Albert Bouwers
by E. F. Wunderlich
Atty.

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X-RAY INSTALLATION

Albert Bouwers, Eindhoven, Netherlands, assignor to N. V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands

Application April 2, 1932, Serial No. 602,851
In the Netherlands March 26, 1927

6 Claims. (Cl. 250—34)

This application is a continuation in part of my copending application for X-ray Installation, Serial Number 384,400 filed August 8, 1929, now Patent No. 1,954,612, dated April 10, 1934, which in turn is a continuation-in-part of my copending application Serial No. 257,044, filed February 25, 1928, now Patent No. 1,901,865, dated March 21, 1933. It relates to X-ray installations, and more particularly concerns an apparatus which, while adapted to momentarily energize an X-ray tube, preferably of the rotating anticathode type, at a high current intensity, nevertheless can be charged over a charging circuit adapted to be plugged in on ordinary house mains.

Considerable difficulty has been experienced in providing a satisfactory apparatus for use by the ordinary practicing physician, either in his own office, or at the home of a patient, in the photography of moving parts of the body, such as the heart or lungs.

This is due to the fact that a very intense discharge is necessary during a very short time interval. For instance, such currents may be of the order of magnitude of 0.500 ampere during 0.05 second. This differs materially from the requirements of the ordinary installation, wherein a less intense current continues over a comparatively long time interval, say 1 to 10 seconds or thereabouts, despite the fact that the product of current in amperes and the time in seconds is approximately the same in both instances. Prior to my invention such short exposures could be obtained, if at all, only with extreme difficulty, by the use of very large and expensive transformers and other equipment.

One object of my invention is to devise a simple, small, and inexpensive apparatus wherein the desired intense current can be discharged at any desired moment through the X-ray tube, during a very small time interval. To accomplish this end I employ the idea of charging a condenser to the voltage which it is desired to impress across the tube, the said condenser being of sufficient capacity to store the required number of coulombs or ampere-seconds, and by its discharge to momentarily and intensely energize the X-ray tube. In order not to produce an unduly great drain on the house mains, I bring the condenser to its full charge and its full voltage only over a plurality of cycles of the charging current. In other words, I add successive increments of charge to my condenser during that portion of each consecutive cycle which is in the desired direction, so that both the voltage and the charge increase in step-like manner in the condenser until the latter is brought to its full charge, the voltage of the condenser at full charge corresponding to the peak value of the voltage in the charging circuit. This I obtain in any desired manner, as by providing a small transformer, the primary of which is connected to the main, and the secondary of which is connected through a suitable rectifier, preferably of the thermionic type, to the condenser.

The limiting of the current is obtained in any of a plurality of different ways, for instance, by providing a resistance inserted in the primary circuit of the transformer. Another means for limiting the current may be provided if a hot cathode, high vacuum rectifier is used. In this last mentioned case the inherent characteristics of the tube are such that no current larger than the saturation current can flow through the tube, the saturation current being readily controlled by adjustment of the filament current.

A discharge circuit is provided for the condenser, which in the preferred instance comprises a filamentary cathode X-ray tube adapted to operate on heavy instantaneous current and preferably of the rotating anti-cathode type as disclosed in my copending application, Serial No. 186,522 filed April 25, 1927, now Patent No. 1,893,759 and having a grid or other means disposed in the discharge path for controlling the flow of electrons from the cathode or the anode.

The control member is normally maintained at a potential no higher than the most negative part of the cathode. This is accomplished in any desired manner, for instance by inserting a battery in the connection between filament and grid. During normal operation of the installation, the filament of the X-ray tube is continuously maintained at its normal emitting temperature, despite the fact that no circuit is completed through the tube. The electrodes of the tube are connected across the condenser. After the condenser has been brought to its full charge, suitable means are operated for changing the potential on the control member from a value which is negative with respect to the filament, to a value which is positive with respect thereto. As a result of the immediate supply of the necessary quantity carrier electrons by the filament, the saturation current of the tube will immediately flow, so that the discharge of the condenser through the voltage range at which X-rays of the desired hardness are produced will be in the order of magnitude of say, only $\frac{1}{20}$ of a second.

Certain attempts have been made to utilize

condenser discharge for energizing X-ray tubes, which, however, have been uniformly unsuccessful, while the present installation has proved uniformly successful.

An object of my invention, therefore, is to produce a new form of X-ray apparatus for use in the so-called "instantaneous" photography.

Another object of my invention is to produce a new X-ray apparatus for use in instantaneous photography, which is adapted for connection to the ordinary house mains.

Another object of my invention is to produce a new X-ray apparatus in which a current storage means of large capacity is charged from the ordinary house mains by apparatus of small size, after which the storage means is employed to momentarily energize an X-ray tube, at high current intensity.

Another object of my invention is to produce a new X-ray apparatus in which a current storage means of large capacity is charged from the ordinary house mains by apparatus of small size, after which the storage means is employed to momentarily energize an X-ray tube which is provided with an anticathode adapted to operate at high instantaneous currents, and which anticathode is preferably rotatable.

Another object of my invention is to produce an X-ray apparatus in which a storage condenser of large capacity is charged from the ordinary house mains over a plurality of cycles of the charging current by apparatus of low rating, after which the storage condenser is discharged in a very small period of time, at a high, uniform current intensity, over an X-ray tube.

Another object of my invention is to produce an X-ray installation in which a storage condenser of large capacity is brought to its full charge over the ordinary house mains, only over a plurality of cycles, and in which means are provided in the discharge circuit for constantly maintaining the filament of an X-ray tube at its normal emitting temperature; the condenser, after it is brought to its full charge, being discharged at will at any desired moment through the X-ray tube over a small time interval and at a current intensity substantially equal to the saturation current from the filament.

Still another object is to produce an X-ray apparatus including a storage condenser of high capacity, a charging circuit therefor, comprising a rectifier and a transformer of small capacity adapted to be connected to the ordinary house mains of the usual frequencies, the condenser being brought to its full charge only over a plurality of cycles, and an X-ray tube in the discharge circuit of the condenser, having a filament normally maintained at its full emitting temperature, means being provided, operable at the will of the operator, for causing the discharge of the condenser through the X-ray tube during a small time interval and at high current intensity.

Other objects and advantages of my invention will more fully appear hereinafter.

In order that a better understanding of my invention may be had the following explanation is given, merely by way of example, in connection with the accompanying drawing, wherein is shown in Fig. 1, a schematic arrangement of one form of my invention, while in Fig. 2 is illustrated in fragmentary section the anode portion of a rotating anticathode type of tube which is adapted for use in connection with my invention.

Considering the charging circuit as shown in Fig. 1, the primary of the charging transformer is shown at 1. This is adapted to be connected through the intermediary of the variable resistance 3 to the ordinary house mains, which for example, may be wired for the passage of a 127 volt, 60 cycle current at no more than say approximately 15 amperes, a value which is obviously high. The secondary 2 of the transformer and the ohmic value of the resistance 3, taken in view of the capacity 5, is insufficient to bring the condenser to its full charge during a single cycle of the charging current. However, by using a transformer of such low capacity, no undue drain is placed on the current mains, and after the passage of a plurality of cycles of the charging current, the condenser 5 is eventually brought to its full charge. Taking one particular example of such charging circuit, merely by way of example, the following calculations can be made:

Assume that a current of 15 amperes flows through the primary circuit, and that a potential difference of 125 volts at 60 cycles is impressed across the primary of the transformer. Then a peak voltage of 100,000 volts, or effective voltage of approximately 70,000 is produced across the transformer secondary. The condenser is assumed to be of 0.25 microfarad. The ratio of transformation between the primary and the secondary of the transformer is therefore calculated to be 1/560. Therefore the maximum current in the secondary is equal to the current in the primary divided by the transformation ratio, that is,

$$\frac{i_1}{560}=\frac{15}{560}=26.8 \text{ milliamperes}$$

The value thus obtained is the average over a complete cycle. In view of the fact that the current is rectified, it flows only during one half cycle so that the maximum current value is $2\times(2)^{\frac{1}{2}}\times 26.8$ miliamperes=76 milliamperes. The average loading current is of course less than 76 milliamperes, but this value will be employed throughout the following calculations in order to impart an idea of the order of magnitude.

The charge in coulombs that is placed on the condenser during one half cycle is smaller than

$$\frac{1}{2n}\times 0.076$$

wherein n is equal to the number of cycles per second. Numerically, therefore, this value becomes

$$\frac{1}{120}\times 0.076=0.00063$$

coulombs. This value in practice will be found to be too high, due to the fact that the average charging time is shorter than ½ cycle because it is only during a part of the charging period that the voltage of the transformer is higher than that of the charge of the condenser. The charge when the condenser is fully charged has a value of 0.025 coulomb, so that the shortest possible charging time is

$$\frac{0.025}{0.00063}=40 \text{ cycles}$$

That is, the condenser may be brought to its full charge only over a period of ⅔ second, and for the reason pointed out above, in actual practice, the charging period will be several times longer.

After the first charging cycle has elapsed, the voltage of the charge placed on the condenser

will be approximately 2500 volts, this value being ascertained from the equation

$$V=\frac{Q}{C}$$

where V is the potential in volts, Q is the quantity of electricity in coulombs, placed on the condenser during the time interval under consideration, and C is the capacity in farads.

In successive charging cycles both the potential and the charge on the condenser is increased, until finally the condenser is brought to its full charge at a potential substantially equal to that across the transformer secondary.

The condenser 5 has a filamentary X-ray tube of suitable type placed in its discharge circuit, the tube illustrated in the drawings being provided with a filamentary cathode 8, and an anode 7. The tube envelope, while it may be of any desired construction, is shown as comprising two insulated portions 6 joined through the intermediary of a central metallic sleeve 9, having an X-ray transparent window of desired construction. About the cathode 8 is placed a control member of desired contour, the control member in the present instance comprising a focusing device 10. In desired manner, the focusing member 10 is adapted to normally receive a potential more negative than that of the point of lowest potential of the cathode 8. This desired negative potential may be placed on the focusing member 10 by connecting it to the ground, the corresponding most negative portion of the cathode 8 also being grounded.

As shown, the X-ray tube is permanently connected directly across the condenser 5, and through a suitable circuit the filament 8 is constantly maintained at its normal full emitting temperature.

Any suitable means, such as the manually operated switch 11, is adapted to interrupt the connection of the control member 10 to the ground, and to impress on said member a potential greater than that of the most positive portion of the cathode 8. This desired potential may be impressed, for instance, by means of the battery 12. With the connection shown, a circuit between the control member 10 and the filament 8 may be traced as follows:

From the right hand end of the filament 8 the circuit is traced through the lowermost switch segment, and thence to the plus pole of the battery 12. From the battery 12 the negative lead extends to the right hand switch segment and thence to the uppermost segment, thereby impressing a potential on the control member which is negative with respect to the filament.

Upon manual rotation of the commutator rotor through 90 degrees the circuit relations will be reversed and a potential will be impressed on the control member which is positive with respect to the filament.

At this point, inasmuch as the condenser 5 has previously been brought to its full charge, and since the cathode 8 has already been brought to its normal electron emitting temperature, the condenser will immediately discharge across the tube at a current intensity limited only by the saturation current of the tube.

In actual practice the discharge of the condenser across the tube through the voltage range at which X-rays of the desired hardness are produced is approximately in the order of $\frac{1}{20}$ of second, the current being of the order of say, 0.5 ampere.

In an actual numerical example, for instance, employing a condenser of 0.25 microfarad capacity at a potential of 100,000 volts, and assuming a tube adapted to carry a current of 0.5 ampere during the time mentioned, as can be done, for instance, by the use of a rotatable anti-cathode such as shown at 13 in Fig. 2, (assuming that

$$V=\frac{Q}{C}$$

where V is in volts, Q is the charge in coulombs and C is the capacity in farads), and also assuming that $Q=Q_0-i\,t$, where Q is the charge on the condenser in coulumbs at any moment during the discharge, Q_0 is the initial charge on the condenser, i is the saturation current in amperes, and t is the time in seconds since the beginning of the discharge, then when the condenser is completely discharged the time of the discharge will be found to be represented as follows:

$$t=\frac{VC}{i}$$

Solving this, t is found to equal

$$\frac{100{,}000\times 0.25\times 10^{-6}}{0.5}, \text{ or } t=0.05 \text{ second}$$

It is to be recalled that the time thus calculated is the time of substantially complete discharge. However, in actual practice under the conditions assumed, no X-rays of wave lengths useful for the intended purpose are produced when the voltage drops below 40,000 volts, so that the time of discharge is only 0.6 × the time of complete discharge, that is, $0.6\times 0.05=0.03$ second, or approximately 1/30 of a second, it being obvious from the foregoing that the voltage drop is a linear function of the time, since the current is a constant, equal to the saturation current. This conclusion follows more directly when it is considered that since the discharge current is constant in value, equal to the saturation current of the tube, the drain of charge from the condenser is at a constant rate, as a consequence of which the voltage drop across the tube is seen to be a linear function of the elapsed time of the discharge.

It is obvious from the foregoing that my invention is susceptible to numerous adaptations and modifications and it is intended that the application be limited only by the scope of the appended claims.

What I claim is:

1. An X-ray installation for making short X-ray exposures, comprising a transformer, a storage condenser, and a rectifying discharge tube having an incandescable cathode, said condenser and rectifying tube being connected in series with the secondary of said transformer, said transformer substantially fully charging said condenser only over a plurality of cycles, an X-ray tube connected across said condenser and comprising main electrodes and an auxiliary electrode, and means connected between said auxiliary electrode and one of said main electrodes for impressing on the auxiliary electrode a low potential for preventing the passage of current across said tube, and a higher potential for causing the discharge of the condenser.

2. An X-ray installation for making short X-ray exposures, comprising a transformer, a storage condenser, and a rectifier said condenser and rectifier being connected in series with the secondary of said transformer, said transformer substantially fully charging said condenser only

over a plurality of cycles, an X-ray tube connected across said condenser, and comprising a cathode, an anticathode, and an auxiliary electrode, and means connected between said auxiliary electrode and the cathode of the X-ray tube for impressing on the auxiliary electrode a potential lower than that of the cathode for preventing the passage of current across the tube, and a higher potential than that of the cathode for causing the discharge of the condenser.

3. An X-ray installation for making short X-ray exposures, comprising a transformer, a storage condenser, and a rectifier, said condenser and rectifier being connected in series with the secondary of said transformer, said transformer substantially fully charging said condenser only over a plurality of cycles, an X-ray tube connected across said condenser and comprising a cathode, an anticathode and a focusing device for directing the cathode rays on a limited surface of the anticathode, and means connected between said focussing device and the cathode of the X-ray tube for impressing on said device a low potential for preventing the passage of current across said tube, and a higher potential for causing the discharge of the condenser.

4. An X-ray installation, comprising a storage condenser of large capacity, means adapted to be supplied by the ordinary house mains connected to said condenser and comprising a step-up transformer for bringing the condenser to its full voltage and its full charge only over a plurality of cycles of the charging current, a filamentary type X-ray tube having a control electrode therein, and a rotatable anticathode, said anticathode being adapted to operate at high, instantaneous current, said tube being connected across said condenser, means for constantly maintaining the filament of the X-ray tube at its normal, full emitting temperature, and means interconnecting said control electrode and the filament of the X-ray tube for changing at will the bias on the control electrode, for causing an inertialess discharge at any desired moment of the condenser across the tube during a small time interval and at a current intensity substantially equal to the saturation current from the filament.

5. An X-ray installation, comprising a storage condenser of large capacity, means adapted to be supplied by the ordinary house mains connected to said condenser and comprising a step-up transformer for bringing the condenser to its full voltage and its full charge only over a plurality of cycles of the charging current, a filamentary type X-ray tube having a control electrode therein, and a rotatable anticathode, said anticathode being adapted to operate at high, instantaneous current, said tube being connected across said condenser, means for constantly maintaining the filament of the X-ray tube at its normal, full emitting temperature, and means interconnecting said control electrode and the filament of the X-ray tube for changing at will the bias on the control electrode, and for causing an inertialess discharge at any desired moment of the condenser across the tube during a small time interval and at a high current intensity.

6. An X-ray installation for making short X-ray exposures comprising a transformer having a secondary winding, a storage condenser, and a rectifying discharge tube, said rectifying discharge tube and condenser being connected in series with said secondary winding, said transformer substantially fully charging said condenser only over a plurality of cycles, an X-ray tube connected across said condenser and comprising a filamentary cathode, an anticathode, and an auxiliary electrode, and means connected between said auxiliary electrode and said filamentary cathode for impressing on said auxiliary electrode a potential which is not higher than the potential of the portion of the cathode having the lowest potential for preventing the passage of current across the tube, and a potential which is not lower than the potential of the portion of the cathode having the highest potential for causing the discharge of the condenser.

ALBERT BOUWERS.