Sept. 14, 1926. 1,599,989

H. v. DECHEND

RÖNTGEN TUBE AND SYSTEM AND METHOD FOR OPERATING THE SAME

Filed August 27, 1921

Fig. 1

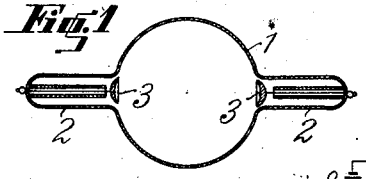


Fig. 2

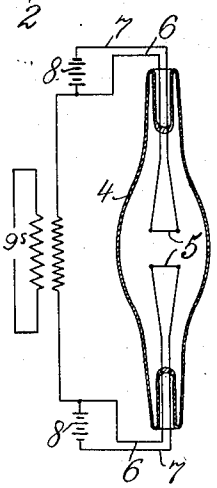


Fig. 3

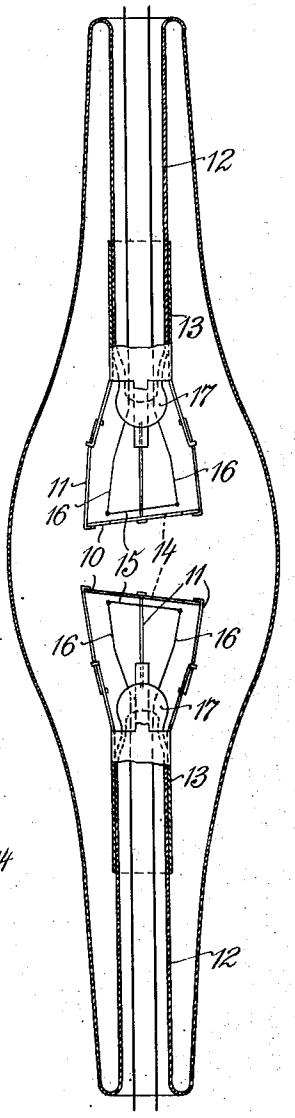


Fig. 5

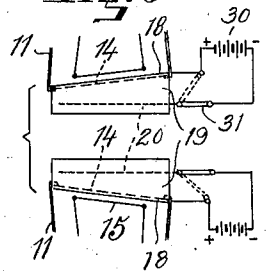


Fig. 6

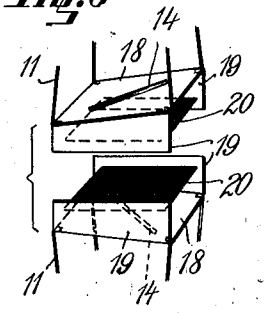


Fig. 4

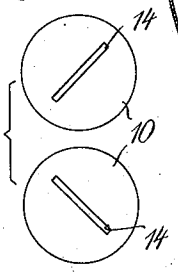
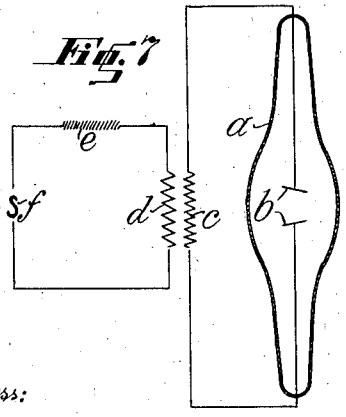


Fig. 7



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UNITED STATES PATENT OFFICE.

HERMANN v. DECHEND, OF HAMBURG, GERMANY.

RÖNTGEN TUBE AND SYSTEM AND METHOD FOR OPERATING THE SAME.

Application filed August 27, 1921, Serial No. 495,909, and in Germany April 19, 1920.

(GRANTED UNDER THE PROVISIONS OF THE ACT OF MARCH 3, 1921, 41 STAT. L., 1313.)

My invention relates to improvements in Röntgen-tubes and the system and method for operating the same, and one of the objects of the improvements is to provide a Röntgen-tube which can be operated by means of alternating current so applied to the tube as to flow first through the tube in one direction and then in the opposite direction, the flow in each direction being effective in producing X-rays. With this object in view my invention consists in the matters to be described hereinafter and particularly pointed out in the appended claims.

For the purpose of explaining the invention several examples embodying the same have been shown in the accompanying drawings, in which the same letters of reference have been used in all the views to indicate corresponding parts. In said drawings,

Fig. 1 is a section of a Röntgen-tube filled with gas.

Fig. 2 is a sectional view showing a Röntgen-tube having an incandescent cathode and the electrical connection of the tube,

Fig. 3 is a sectional view showing a modification of the Röntgen-tube having an incandescent cathode,

Fig. 4 is a detail view showing the disk shaped slotted electrodes of the tube shown in Fig. 3.

Figs. 5 and 6 are respectively a front view and a perspective view of a modified form of the electrodes of the Röntgen-tube shown in Fig. 3, and

Fig. 7 is a diagram showing a preferred system for operating Röntgen-tubes having incandescent cathodes.

As is known in the art, the Röntgen-tubes now in use are unsymmetrical so far as their electrodes are concerned, the cathode and the anticathode being entirely different from each other as regards their construction and the material composing them, and each electrode having a function peculiar to itself. For example, in Röntgen-tubes now in use the cathode is built up from an aluminum plate ordinarily in the form of a concave mirror, and the anti-cathode consists of a tubular body made of copper and equipped with cooling means and closed at the end directed towards the cathode by a plate made from platinum, tungsten, or the like. In Röntgen tubes having incandescent cathodes instead of the aluminum cathode a wire is provided which is made from a metal having a high melting point, such for example as tungsten, tantalum, and the like, said wire being ordinarily surrounded by a suitable collector. In any case one of the electrodes has the function to generate the cathode rays, while the object of the other electrode is to collect the cathode rays and thereby to cause the emission of Röntgen rays.

Therefore, as a general rule Röntgen-tubes of the types now in use can be operated only by currents which flow in one direction, and the direction of the current is such that the electrode from which the electrons are emitted is the cathode. Therefore, for operating Röntgen systems of the class now in use special means such as induction coils, rectifiers, etc., are indispensable for generating high voltage, uni-directional currents.

My improved Röntgen-tube can be operated by means of alternating current (as distinguished from alternating voltage), so that the operation does not depend any more on the generation of uni-directional currents. Therefore, my improved Röntgen tube is provided at least with two electrodes which are similar as to their construction and to the material from which they are made, and each of which can operate as a cathode as well as an anticathode. During the impulses of one polarity of the alternating current supplied to the tube one of the electrodes acts as a cathode and the other one as an anticathode, and during the impulses of the opposite polarity conditions are reversed. Accordingly in my improved Röntgen tube the Röntgen rays are emitted from two points. For this reason the tube is not suitable for diagnostical purposes depending on a source of rays which as far as possible resembles a point, while for other purposes, for example in therapeutics, this feature is not objectionable.

In the example shown in Fig. 1, the glass bulb 1 is formed with two tubular extensions, and in said extensions electrodes 3 are disposed which consist for example of aluminum and which are in the form of concave mirrors opposed to each other. The curvature of the concave surfaces of the electrodes is such, that the cathode rays emanating from each of the electrodes are concentrated on the opposite electrode. The electrodes 3 are each connected with

one of the terminals of a high-voltage transformer. The Röntgen rays which are thus generated at both electrodes have a high intensity only if the electrodes are made from a metal having a high atomic weight, such for instance as platinum, tungsten, and the like. However, experience has shown that with increasing atomic weight the disintegration of the cathode is increased, so that a tube of this construction has a short life, or, if the cathode is made from a metal of a low atomic weight such as aluminum the radiation is low. Therefore a tube of the construction shown in Fig. 1, in which in addition both electrodes must be provided with effective cooling means, can be used only for certain purposes, in which cases however it is distinguished from known types by its simple construction and the simple electrical system required for operating the same.

My invention is more successfully used in tubes having a pure electron discharge such as are illustrated by way of example in Fig. 2. In this example a tube 4 is used in which the vacuum is as high as possible and which is equipped with two incandescent wires 5 made from a metal of a high atomic weight and located opposite each other and having their electrical conductors 6 and 7 connected to heating batteries 8. The material of which the wires 5 are made, must have a melting point higher than the temperature at which a pure electron discharge takes place. The incandescent wires 5 are connected to a high-voltage transformer 9 for alternating current. During the positive impulses of the alternating current one of the incandescent wires 5 has the function of the cathode and the other one that of the anti-cathode, and during the negative impulses conditions are reversed. Both wires emit Röntgen rays.

In Fig. 3 I have shown a preferred construction of a Röntgen tube having an incandescent cathode. As shown the electrodes 10 are in the form of circular disks made from tungsten, tantalum, or the like, and they are mounted on wires 11 secured to a metallic sleeve 13 fixed to a tubular part 12 of the glass bulb. The material of which the electrodes 10 are made, is of the same character as that of the wires 5 and, as explained above, has a melting point above the temperature at which a pure electron discharge takes place. Each of the disks 10 is formed with a slot 14, as is shown in Fig. 4, and at the rear of said slots there are incandescent wires 15 which are carried by wires 16 supplying electric energy thereto. The wires 16 are spaced a suitable distance apart and extend gas-tight through the inner end walls of the tubular parts 12.

The object of the incandescent wires 15 is to start the operation of the tube. The electrons emanating from one of the incandescent wires are thrown through the adjacent slot 14 and on the opposite electrode disk 10, where they generate the Röntgen rays and heat the disk. During each phase the electrons emanating from one or the other of the incandescent wires 15 are thrown on the opposite disk 10. By disposing the slots 14 at an angle to each other or arranging them out of registry, the incandescent wires 15 are prevented from heating each other. After the electrode disks 10 have been heated to the desired temperature the incandescent wires 15 can be disconnected from their source of electric energy, whereupon the temperature of the disks required for the emission of electrons is maintained exclusively by the action of the electrons and the high-voltage alternating current supplied to the tube.

The surface of the electrodes can be materially reduced without reducing the effect of the tube by increasing the temperature at which the energy set free at the disks and the radiation of the heat are at an equilibrium.

To effect this the emission of electrons can intentionally be reduced, for example by preventing the electric flux from meeting the glowing surface. For this purpose I provide a wire net or the like in front of the disk, and in some cases I provide means for generating a counter-field between the net or screen and the electrode disk in order to increase the desired effect. Thereby the lines of force can be weakened or screened in any desired degree. Most of the electrons coming from the other electrode pass through the netting and get to the disk from which the electrons are to be emitted without heating the net to glowing temperature. Such means for generating a counter-field may be constructed, for instance, in the manner indicated in Fig. 5, where the wire nets 20 are connected with the negative poles of storage batteries or other sources of electricity designated by 30, while the electrodes 18, 19 are connected with the positive poles of said sources of electric current. Switches such as I have indicated at 31 permit the battery circuits to be opened or closed as desired. It will be noted, however, that when these circuits are opened, each of the wire nets 20 remains in electrical connection with the respective companion electrode 18, 19.

This effect can be increased in the manner shown in Figs. 5 and 6, in which each of the electrodes is in the form of a frame open at two sides and consisting of a bottom 18 providing the plate-like electrode and side members 19 having the screening wire net 20 secured thereto. The projecting side members 19 take up most of the lines of force. Therefore the intensity of the field on the

plate electrodes 18 is reduced, and the nets 20 can be made with comparatively wide meshes without losing in efficiency.

By disposing the plate electrodes 10 and 18 emitting the Röntgen rays at suitable angles a comparatively wide cone of radiation is obtained.

In Röntgen tubes of the class described for operation by alternating current and provided with incandescent electrodes, and in which, by the impact of the electrons against the incandescent electrodes, the latter heat each other to the temperature necessary for the emission of electrons, special means must be provided to insure stability of the operation. The mutual bombardment of the wires by electrons requires a high supply of energy. Therefore, the heating battery connected to the incandescent wires, which in Fig. 2 have been indicated by the numeral 5 and in Fig. 3 by the numeral 15, must be switched off as soon as the operating current producing the Röntgen rays becomes effective, or at least the heating current must be weakened by switching in resistances. Notwithstanding this the apparatus remains unstable, because the electric energy set free at the electrodes is not completely removed from the electrodes in the form of radiation. For example, if the initial temperature of the electrodes is so high that there is already a certain emission i of electrons, and the electrodes are connected to one of the terminals of a transformer which is directly connected to the net and which always has an effective voltage E_o, there is an equilibrium between the radiation Q and the energy set free by the electrons impinging on the electrodes, if

$$Q=\frac{E_o \cdot i}{2}$$

The values i and Q are functions of the temperature, according to the following equations:

$$Q=\alpha T^n, i=a \cdot T^{\frac{1}{2}} \cdot e^{-\frac{b}{T}}.$$

In these equations α, n, a and b are constants depending on the material, e is the base of the natural logarithms. The values Q and i are expressed with reference to a unit of one square centimeter. With increasing temperature the value Q is increased at a much smaller rate than the value i. This is the reason why with a constant voltage E_o the system can not be stable. For example, any increase of the temperature causes a considerable increase of the current supply. Therefore as E_o remains constant, this also increases the effect which is transformed into heat at the electrodes. However, this increase of the effect is connected with a smaller increase of the radiation of the electrodes. Therefore, the surplus of the supplied energy over the radiation must necessarily heat the electrodes and again increase the emission of electrons and the effect. Therefore, the electrodes are destroyed by melting within a short period of time.

When however the energy supplied to the electrodes is less than the heat radiated, so that the temperature is reduced, such reduction of temperature will increase automatically until no current passes through the tube.

If the conditions for stability in the system are shown in a diagram, stability prevails if the curve showing the radiation as a function of the temperature ascends more rapidly than the curve representing the effect set free at the electrodes as a function of the temperature. If this is the case, with any increase of the temperature beyond the point of the equilibrium the radiation is larger than the energy supplied to the system. Therefore the electrodes are cooled, or in other words, the increase of the temperature is retarded. If, however, in case of a reduction of the temperature the supplied energy is larger than the radiation, the heating of the electrodes is increased.

To express the condition of the stability in analytical terms, we have the following equation:

$$\frac{dQ}{dT}>\frac{\frac{dEi}{2}}{dT}$$

This condition can prevail, if a resistance is connected in the circuit of the tube. If the value of the resistance is R, the loss of voltage caused thereby is R. i. The voltage of the generator supplying the current may be constant and equal to E_o. Therefore, the voltage at the electrodes is $E=E_o-Ri$.

Therefore we have the following equation:

$$\frac{Ei}{2}=\frac{E_o i}{2}-\frac{Ri^2}{2},$$

and the condition of stability is:

$$\frac{dQ}{dT}>\frac{E_o}{2}\cdot\frac{di}{dT}-Ri\cdot\frac{di}{dT}$$

Therefore, dividing by

$$\frac{di}{dT},$$

we have:

$$\frac{\frac{dQ}{dT}}{\frac{di}{dT}}>\frac{E_o}{2}-Ri.$$

The first member of this equation can be found by calculation from the relation between Q and i stated above. When entering numerical values into the equation, it is found that the value of the fraction is between zero and several hundreds. As the

numerator and the denominator are both positive, the value is necessarily positive, and it can be neglected as against E_o. Therefore, the want of equality is at the most increased.

Therefore, the condition which is sufficient to produce stability is:

$$Ri > \frac{E_o}{2},$$

or in other words, it is sufficient to connect in the circuit of the tube a resistance which causes a loss of voltage which with the desired intensity of the working current is higher than one half of the voltage of the generator.

In the practice of the invention I prefer to connect the resistance to the primary of the transformer supplying energy to the tube, rather than connecting the same to the high voltage coil. It will readily be understood that a resistance connected to the primary is equivalent to a resistance connected to the secondary and to the tube as far as stabilizing action is concerned.

Accordingly, my improved system for operating the tubes comprises a stabilizing resistance either included in the high voltage circuit and in series with the tube, or in the circuit of the primary of the transformer, said resistance causing such a reduction of the voltage that the above formula

$$\frac{\frac{dQ}{dT}}{\frac{di}{dT}} > \frac{E_o}{2} - Ri$$

is satisfied.

In the system shown in Fig. 7 including a Röntgen tube having incandescent cathodes, the stabilizing resistance is connected to the primary. In said figure, *a* indicates the glass bulb of the Röntgen tube, and *b* are the opposed electrode plates adapted to be heated to incandescence. Both plates are directly connected to the terminals of the secondary *c*. The circuit of the primary *d* includes the resistance *e* and an alternating current generator *f*.

At first the voltage of the tube is increased by reducing the resistance *e*, which reduction, however, should not go beyond a certain limit, as follows from the theoretical explanations given above. If this limit is attained, a further increase of the voltage of the tube must be brought about by increasing the voltage of the generator *f* and simultaneously increasing the resistance *e*. This increase must always be made in such a way that the condition of the stability is fulfilled.

It is not necessary that the resistance *e* be an ohmic resistance, it may be an inductive resistance. Instead of the generator *f* a transformer may be provided the primary of which is connected to an alternating current generator or to the mains and which has a variable ratio of transformation.

Preferably the generator *f* or the transformer provided in lieu thereof and the resistance *e* are regulated by positively connecting the switching devices with one another, and so arranging the said devices that it is impossible to raise the voltage without simultaneously raising the resistance according to the condition of the stability.

Special means must be provided if tubes of the construction indicated in Fig. 3 are used in which the electrodes must first be heated by electrons from subsidiary sources of electrons striking against the same in order to be conductive. In some cases, and more particularly while the necessary incandescence is not yet attained, there is a voltage between the electrodes which largely exceeds that of the regular operation, whereby the insulation of the tube and the transformer is endangered. Therefore, at the beginning of the operation and while the electrodes are being heated, the stabilizing resistance is entirely or in part switched out of the circuit and the voltage of the generator is reduced, the resistance being switched into the circuit when the electrodes begin to emit electrons in a sufficient degree.

I claim:

1. A device of the character described, comprising an exhausted tube, a pair of electrodes mounted therein and each serving alternately as a cathode and an anti-cathode, mechanism for subjecting said electrodes to the action of alternating currents of a voltage high enough to produce Röntgen rays penetrating through said tube to the outside thereof and thus exposing each electrode to bombardment by electrons from the other electrode, in order that each electrode be heated by the bombardment, and means for heating each electrode at the start.

2. A device of the character described, comprising an exhausted tube, a pair of electrodes made substantially alike as to structure and as to the material of which they are composed, mechanism for subjecting said electrodes to the action of alternating currents of a voltage high enough to produce Röntgen rays penetrating through said tube to the outside thereof so as to expose each electrode to bombardment by electrons from the other electrode, so that each electrode is continuously heated by the bombardment, and means for heating each electrode at the start.

3. A device of the character described comprising an exhausted tube, a pair of electrodes mounted therein and each having a function as a cathode and as an anti-cathode, mechanism for energizing said electrodes by means of alternating currents of high voltage so as to cause each electrode to be heated by

bombardment of electrons from the other electrode, and a screening member of foraminous form disposed intermediate the electrodes in order to restrict the quantity of electrons passing from each electrode to the other.

4. A device of the character described, comprising an exhausted tube, a pair of electrodes mounted therein and each having a function as a cathode and as an anti-cathode, mechanism for subjecting said electrodes to the action of alternating currents of high voltage so as to cause each electrode to be heated by the bombardment of electrons from the other electrode, a screening member having a general foraminous form and disposed intermediate the electrodes in order to restrict the quantity of electrons passing from each electrode to the other, and means for heating each electrode at the start.

5. A device of the character described, comprising an exhausted tube, a pair of electrodes mounted therein and each having a function as a cathode and as an anti-cathode, means for subjecting said electrodes to the action of alternating currents of high voltage in order to cause each electrode to be heated by bombardment of electrons from the other electrode, a screening member of foraminous form disposed intermediate the electrodes in order to restrict the quantity of electrons passing from one electrode to the other, and means for producing a counter-field in order to further restrict the quantity of said electrons.

6. A device of the character described, comprising an exhausted tube, an electrode mounted therein and having a function as a cathode, another electrode mounted within said tube and having a function as an anti-cathode, means for heating to incandescence said electrode serving as a cathode, a screening member of foraminous form disposed intermediate the electrodes, and a similar screening member interposed between the first-named screening member and one of said electrodes.

7. A device of the character described, comprising an exhausted tube, a pair of electrodes mounted therein and each having the form of a plate provided with an opening, there being a clear direct passage between said electrodes for the travel of electrons from one to the other, a pair of other electrodes located within said tube and disposed in proximity to said openings, mechanism connected with said last-mentioned electrodes for heating them to incandescence, and means for subjecting said first mentioned pair of electrodes to the action of alternating current.

8. A system of producing Röntgen rays, comprising a Röntgen tube provided with a pair of electrodes made from the same material and having the same construction, a supply of alternating electric energy connected with said electrodes, and a resistance connected with said supply and having such dimension as to reduce the voltage in such a degree, that the effect set free at the electrodes is increased with rising temperature of the electrodes at a smaller ratio than the loss of energy caused by radiation and dissipation of heat from the electrodes.

9. A device of the character described comprising an exhausted tube, a pair of electrodes located within said tube and provided with openings, the opening in one of said electrodes being out of registry with the opening in the other electrode, means for connecting said electrodes with a source of alternating current, a pair of other electrodes mounted within said tube and each located adjacent one of said openings, and means for heating said last-mentioned electrodes to incandescence.

10. A device of the character described, comprising an exhausted tube and a pair of electrodes, substantially alike as to structure and as to material, the latter having a melting point higher than the temperature at which a pure electron discharge takes place, said tube and said electrodes being constructed to admit of operation at voltages high enough to produce Röntgen rays penetrating through said tube to the outside thereof.

11. A device of the character described, comprising an exhausted tube, a pair of electrodes located within said tube and provided with openings, the opening in one of said electrodes being located in a direction at an angle to the direction of the opening in the other electrode, and a pair of other electrodes each adapted to be heated to incandescence, mounted within said tube and each located adjacent to one of said openings.

In testimony whereof I hereunto affix my signature.

HERMANN v. DECHEND.