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Historical X-Ray Tubes

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ABSTRACT

The classes of the simplest x-ray tube are considered. The main differences and schemes of an electron x-ray tube from an ion one are given. The emission and anode characteristics of the electron tube are shown.

An x-ray tube is an electrovacuum device in which high voltage electrical energy is converted into x-ray energy. To obtain x-rays, a beam of electrons is given a high speed, and then they are suddenly stopped, forcing them to hit some obstacle; at the moment of impact, the kinetic energy of the movement of electrons will turn into thermal energy and partially into the energy of x-rays.

The simplest x-ray tube is a spherical glass bulb with two cylindrical necks, into which two metal electrodes are soldered—the anode and cathode of the tube. A high vacuum of air is created inside the flask and a source of free electrons is located. If the electrodes of the tube are connected to a high voltage source of the order of tens or hundreds of thousands of volts, then the electrons will begin to move with great acceleration from the cathode to the anode and, hitting the latter, will create x-rays.

According to the nature of the electron source in the X-ray tube and the magnitude of the vacuum inside its bulb, X-ray tubes are divided into two classes.

Tubes belonging to the first class are called gas or ion tubes (Fig. 1).

The magnitude of the current flowing through such a tube depends both on the magnitude of the voltage applied to the tube and on the state of its vacuum. Since during the operation of the tube the state of its vacuum changes, and its regulation is difficult, the operating mode of the tube changes all the time.

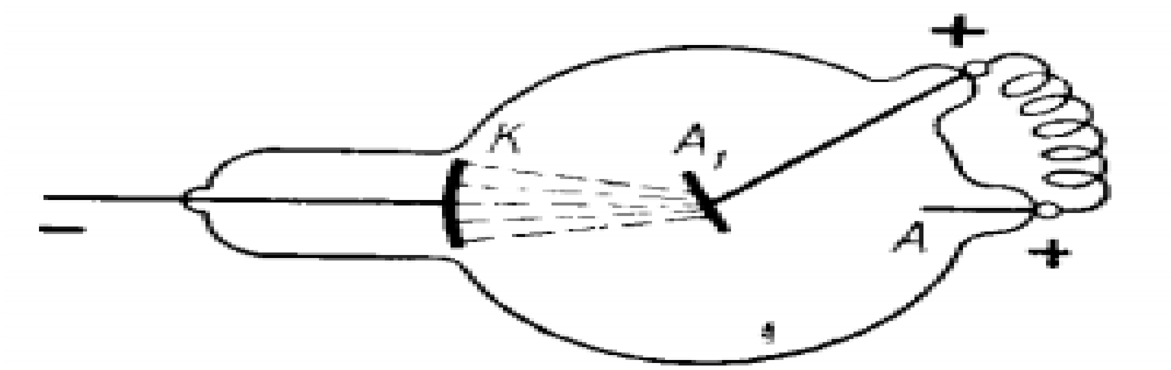

Fig. 1. Diagram of an ion x-ray tube. A - anode; A; - anticathode; K-cathode.

Historically, they are the oldest. These tubes contain a small amount of air. Its pressure is about 1/800,000 of atmospheric pressure. If the electrodes of such a tube are connected to a high-voltage direct current source, then neutral air molecules, due to the splitting off of electrons from them, will begin to transform into positive ions, which, moving quickly towards the cathode and bombarding its aluminum cup, will separate from it a large number of free electrons. The latter, in turn, will be transferred at high speed to the anticathode, where X-rays will be created as a result of shock deceleration.

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This tube, in which it was impossible to independently regulate the current flowing through it and the magnitude of the high voltage applied to it, the tube, moreover, still unstable in operation, was replaced by a tube of a different class - an electron tube, or, as it is called named after the inventor, the Coolidge pipe.

The main difference between an electron x-ray tube and an ion one is that the source of electrons in it is a specially heated filament placed in the tube as its cathode (Fig. 2).

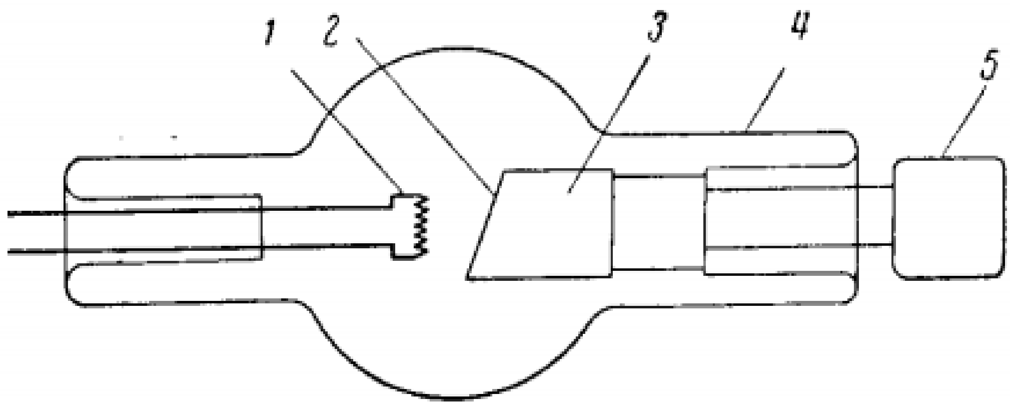

Fig. 2. Scheme of an electron x-ray tube. 1 - cathode filament; 2 - anode mirror; 3 - anode; 4 - glass flask; 5 - radiator.

In addition, such a rarefaction is created in it, which is only possible with the modern level of vacuum technology (the residual air pressure in it is about 10^{-6}—10^{-7} mm Hg). If a current source is connected to the filament, for example, a special transformer (filament transformer), and a current of such magnitude is passed through it so that it glows like a light bulb filament, then the filament will continuously emit electrons that accumulate around it in the form of a cloud. If you connect the anode of the tube to the positive pole of the current source, and the cathode to the negative, then an electric field is formed between them, in which electrons, like negatively charged particles, begin to move towards the anode. If the polarity on the tube is reversed, then the electrons will remain near the filament.

Due to the fact that the forces of the electric field act continuously on the electrons, the movement of the electrons will occur with acceleration. Just as a stone, subjected to the forces of the earth's gravitational field, falls down with a certain acceleration and reaches its highest speed, approaching the surface of the earth, so the electrons seem to "fall" from the cathode to the anode of the x-ray tube. Their speed will be greatest when they approach the anode. As the electrons move, they acquire kinetic energy proportional to their mass and the square of their speed. The value of this energy can be expressed in ergs, but in physics and X-ray technology it is customary to express it with a special unit of energy - electron volts (eV).

One electron volt is the energy that an electron receives when it passes through a potential difference of 1 volt.

The energy of electrons upon impact with the anode, expressed in electron volts, will be numerically equal to the magnitude of the voltage applied to the tube. For example, if a voltage of 100,000 V is applied to the tube, then the energy of the electrons will be equal to 100,000 eV.

When electrons collide with the anode, most of the energy accumulated by them is converted into heat, which is released at the anode, and only a very small part, about 1%, is converted into X-ray energy. Each electron “knocks out” one “portion”, one photon of X-ray energy from the anode. The greater the voltage across the tube, the greater the kinetic energy of each electron just before it stops. Accordingly, the energy of each X-ray photon will also be the greater, the higher the voltage on the tube.

The greater the number of electrons transferred every second from the cathode to the anode, the greater the number of ejected X-ray photons, and hence the energy of the entire radiation, and at the same time the amount of heat released at the anode.

Thus, the energy of X-rays and the amount of heat released in the tube depend on the voltage on the tube and the number of electrons transferred, i.e., on the magnitude of the current flowing through the tube, the so-called anode current of the tube.

Characteristics of the electron tube. To illustrate the operation of x-ray tubes, some of their electrical properties are depicted in the form of curves, the so-called characteristics. Of great practical interest are, first of all, two characteristics: emission and anode.

The emission characteristic shows the dependence of the number of electrons emitted by the filament on its temperature when a voltage is applied to the tube at which all the electrons are transferred from the cathode to the anode. The curve has the form shown in Fig. 3(a); it shows that the emission of electrons begins only at a temperature of about 2000; it increases slowly at first, and then quite rapidly, even with slight changes in temperature.

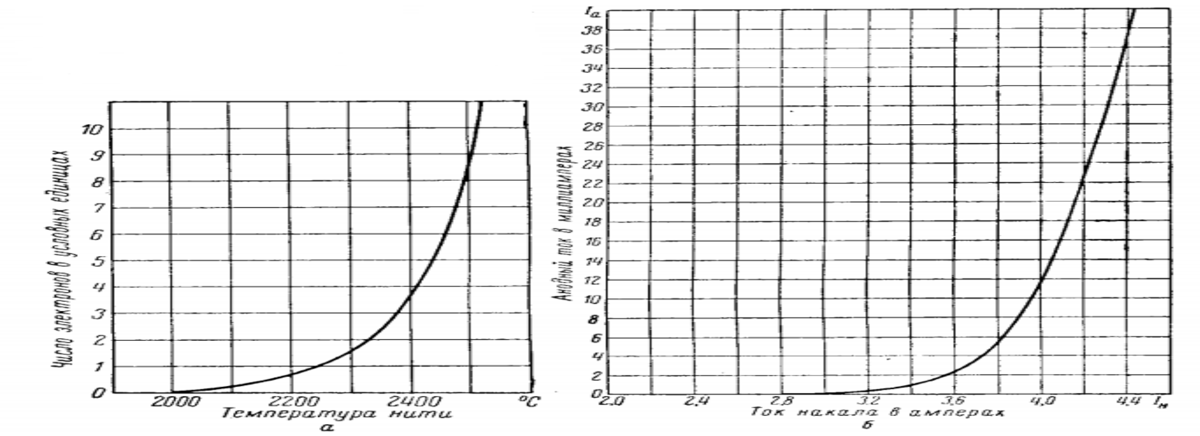

Fig. 3. Emission characteristic of the X-ray filament tube. a - dependence of the number of emitted electrons on the temperature of the filament and filament; b — dependence of the anode current of the tube on the filament current.

Since there is a proportional relationship between the anode current of the tube and the number of electrons transferred, and since the temperature of the filament depends on the magnitude of the current flowing through it, it is more convenient to depict the emission characteristic as a dependence of the anode current of the tube on the filament current. On fig. 3 (b) shows such dependence for the X-ray tube (at voltage of 80 kV).

It can be seen from the curve that the anode current begins to appear only when the filament current becomes more than 3 a. With a further increase in the filament current, the anode current increases at first rather smoothly, and then very quickly. For example, change in the filament current by 0.2 A at the beginning of the curve from 3.4 to 3.6 A causes an increase in the anode current from only 1 to 2.4 mA. Changing the same filament current by the same 0.2 A from 4.2 to 4.4 A leads to a significant increase in the anode current from 23 to 37 mA. It follows that the regulation of the filament current must be done with great smoothness and very carefully, especially when the filament current and the corresponding anode current reach their maximum permissible values. If you carelessly adjust the heat, it is very easy to overload the tube and disable it.

In contrast to the emission characteristic, the anode characteristic shows the dependence of the anode current of the tube on the magnitude of the voltage applied to it at a given glow of its filament.

Conclusions: The simplest X-ray tube consists of a glass bulb with two cylindrical necks. It is shown that in gas or ion X-ray tubes the current value depends on the voltage value and during operation the state of its vacuum changes, and its regulation is difficult, while the operating mode changes all the time. In an electron x-ray tube, a specially heated filament serves as a source of electrons.

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