

Measuring equipment for controlling the anode current during training and testing of the X-ray tubes

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Abstract. In this paper the features of controlling of the anode current of the X-ray tubes during their training and testing are described. Requirements for developing of the control and measuring equipment are given. In detail are shown the approaches to the development of two types of microammeters with optical signal transmission: analog, with compensation of the nonlinearity of the transfer characteristics with the use of the optical negative feedback, and digital, in which the values of anodic current are transferred using a microcontroller.

1. Introduction

Training and testing of the X-ray tubes are very important stages of their production, and allow achieving a significant increase in the quality of manufactured products [1]. The main aims and objectives of the training of the X-ray tubes are:

- electric polishing of the electrodes surfaces due to the evaporation of micro edges (enhancement of the electric strength);
- cleaning of the surfaces by electron-ion bombardment from the products of the cathode evaporation (reduction of the leakage current);
- removal of gas atoms from the surface layers of the electrodes and their absorption by the getter (stabilization of the vacuum condition during operation).

During training of the X-ray tubes it is necessary to control the current value in the X-ray tube circuit from a few μA to tens of mA at a potential of 160 kV with respect to the ground. Training is conducted in the two consecutive stages. During the first phase a high voltage is applied to the X-ray tube with a cold cathode. With the control of the leakage current the training continues for as long as this current is not reduced or at least becomes stable. The current at this stage may be in the range of 1...50 μA . Supply voltage can be accompanied by the electric breakdowns that need to be counted.

In the second phase, training is conducted with a gradual increase in the filament current, and consequently the anode current of the X-ray tube. Nominal anode current usually does not exceed 50 mA, however, during breakdowns a measurement device must be able to withstand current up to several amperes. Thus, the scale of measurement of the microammeter should be no less than 5 decades. The device should count the number of discharges occurring in the X-ray tube at both stages of training and maintain its performance when exposed to X-ray radiation up to 200 keV.

For many years for measuring current and voltage in the test process units pointer instruments were used (figure 1), however, this measurement method is only possible for static tests. Generally, measuring instruments are placed inside the test chamber where they are exposed to strong

electromagnetic fields and X-rays. The installation of the necessary current values or its measurement is associated to the operator with certain difficulties, since it is necessary to observe the readings at a considerable distance from them through a protective window made of lead glass.

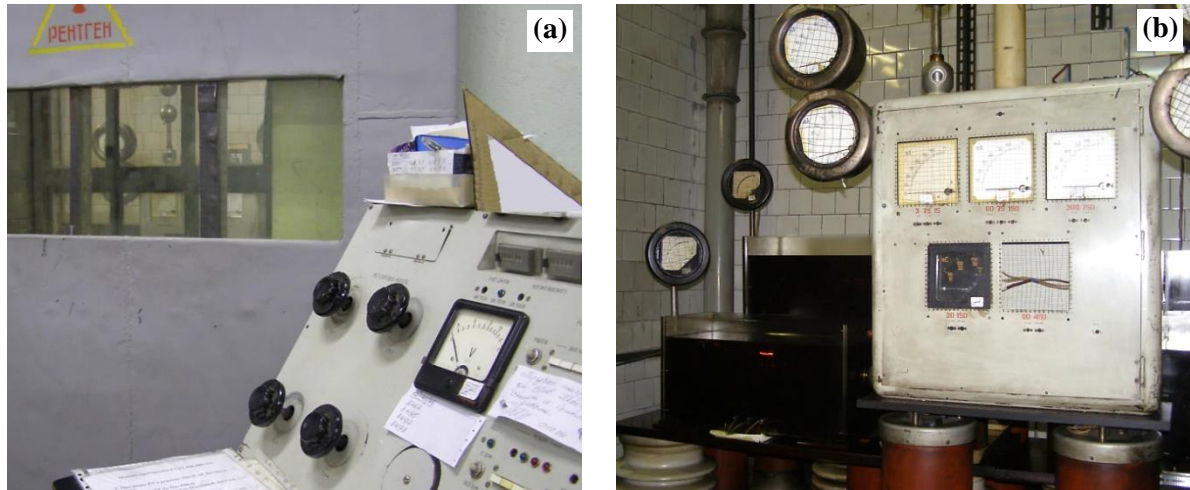


Figure 1. Control panel (operator's workstation) (a) and the location of the pointer-type ammeters in the training chamber (b).

As was mentioned earlier, during training and testing of the X-ray tubes, both the leakage currents of a few microamperes and operating currents, reaching tens of milliamps, are subject to control. This fact forces to install into the high-voltage circuit multiple meters with different measuring ranges, each of which is connected to the measuring circuit with a relay, insulated for a full voltage.

The problem is further complicated if tests are carried out for the pulsed X-ray tubes. The duration of the current pulses in these devices can vary from a few hundredths of second to a few seconds. Even the most modern analog ammeters do not permit the necessary measurements. Meanwhile, the production of the pulsed X-ray tubes has been increasing steadily. The advantages of pulse mode are undeniable both from the standpoint of radiation safety for personnel and the metrology characteristics of medical and translucent X-ray devices.

Based on the X-ray production situation, the task of developing new instruments to measure direct and pulse current in the high-voltage circuits arose. It is necessary to seek a solution based on the fact that modern technologies require information in a digital form. This opens up opportunities for processing and documentation of measurement results and creates more favorable conditions for the work of the operator [2].

2. Development of the control and measurement equipment

The current in the high-voltage circuit can be controlled by measuring the voltage drop across the shunt, which is connected directly into the high-voltage circuit, with the subsequent transfer of the signal proportional to the current to the operator panel. The conversion of the voltage drop on the shunt into the signal transmitted to the remote operator can be implemented by means of the conventional analog and digital circuits under the high-voltage circuit potential, using an independent low-voltage power source. There can be distinguished three different types of transmission channels that provide a reliable electrical insulation at a voltage of X-ray devices in the hundreds of kilovolts:

- radio channel;
- direct optical channel;
- fiber optic channel.

Data transmission over the radio channel provides a number of significant advantages; however, in the conditions of the test plant, when operating high-voltage X-ray units, intensive noise is inevitable in almost all the wavelengths range, the result is a huge technical challenge to provide a reliable radio

channel. The connection between the two units of the ammeter can be carried out by a direct optical channel, for example, in the infrared range. However, a special chamber, which houses the X-ray device, has only a small window of leaded glass, which greatly complicates the solution of the problem in this way.

Let us consider fiber optic as a communication means for transmitting data from the high-voltage unit to the operator panel. Fiber optic cable can be easily output from a high-voltage chamber, in which the X-ray device is placed. Usually a cable length of 10 m is sufficient; with such a small length damping in fiber optic communication lines will be very small – if a loss factor is taken equal to 10 dB/km, the intensity of the light flux at the output of the line is only 1.2 % less than at the entrance. Additionally, the signal propagating through the fiber is not susceptible to electromagnetic interference, which is very important in the operation of the device in proximity to X-ray installations.

The simplest converter of the current into an optical signal with a subsequent inverse transformation of the optical signal into the current or voltage is a volstron – device in which the emitter and the photodetector are nondetachably connected to each other with a fiber optic cable. The simplest volstron optocoupler consists of a light-emitting diode and a photodiode, separated by an optical fiber and has a significant nonlinearity of the transfer characteristics. One of the most effective and meanwhile simple means of linearizing the transfer characteristics of the volstron is the introduction of a negative feedback circuit.

To create thermostable volstron should be used such light-emitting diodes, the energy characteristics of which are minimally dependent on temperature. The second and main component of the optical system is the photodetector. After selecting the light-emitting diode it is required to coordinate its emission spectrum with the spectral sensitivity of the photodetector. The third component – fiber optic line (including optical connectors) must provide signal transmission with minimal losses and have high stability of parameters.

On the basis of selection of the optical elements, it is possible to proceed directly to creating a circuit of linear converter of the voltage into the proportional optical signal. It is known that the power to the light-emitting diode from the output of the amplifier covered by the feedback through the optical channel using the photodiode operating in the current source regime, allows to convert an input voltage into the proportional radiation flux with an error of a fraction of a percent and keep its temperature stability, provided that the optical components are stably optically aligned. This principle is used in the presented circuit of the voltage-to-voltage converter with optical isolation (figure 2).

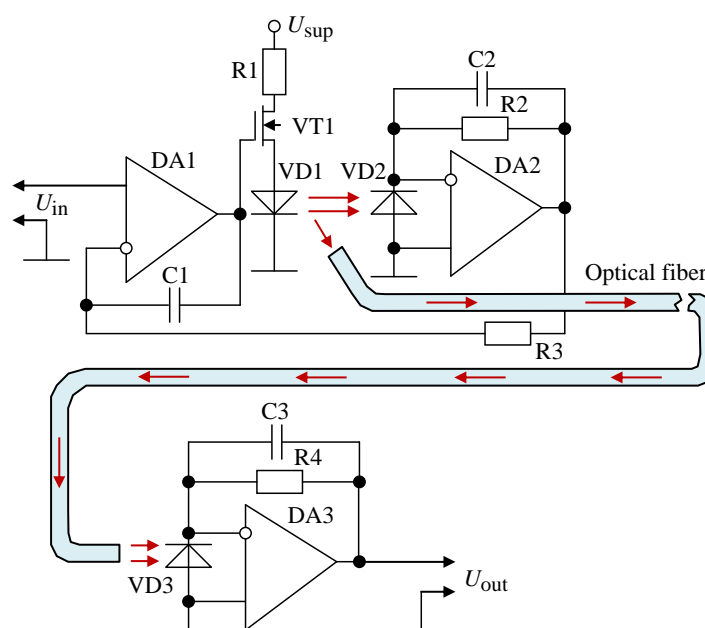


Figure 2. Linear voltage-to-voltage converter with optical isolation.

First, the input voltage U_{in} is converted into a current of the light-emitting diode VD1. Used in the circuit of the voltage-to-voltage converter a low-power operational amplifier has insufficient current output for direct control of VD1. To increase the current a field effect transistor VT1 is additionally applied. Feedback at the operational amplifier DA1 is supplied via resistor R3 from the operational amplifier DA2, which amplifies the signal from the photodiode VD2.

Thus, the input voltage is linearly transformed into a luminous flux generated by the light-emitting diode VD1. Part of the VD1 radiation is supplied via optical fiber to the receiving photodiode VD3. Since the photoelectric converter DA3 has a high linearity of conversion in not less than 4–5 decades, the output voltage U_{out} is linearly dependent on the input voltage, proportional to the measured current. Output voltage from the VD3 is passed through another amplifier to the microcontroller where it is processed and then the digital measurement result is displayed.

Although linearity of voltron converter fully meets the needs of production, its dynamical range does not exceed three decades. When training some X-ray tubes it is necessary to control the values of current from a few μA to tens of mA. Thus, the scale of measurement of the microammeter should be no less than 5 decades. Measurement of currents in units of microamps requires using at the input of transducer a precision operational amplifier with automatic zero point correction and offset voltage not more than units of microvolts. The task of transmitting signals proportional to the current from the measuring shunt to the input of the conversion and information processing device over a wide dynamic range from 0.5 mA to 50 mA, requires placement of the devices for conversion of the current into a digital code under the high voltage.

To convert the voltage drop at the shunt in the current circuit into a digital code and transmit it according to a specific protocol to an operator's console an analog-to-digital converter and a microcontroller must be placed in the high-voltage unit (figure 3).

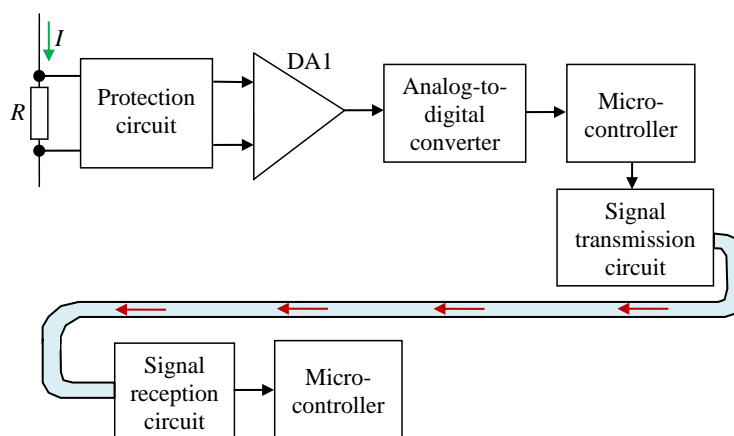


Figure 3. Structural scheme of a digital high-voltage ammeter.

The advantages of measuring current using such high-voltage blocks are obvious:

- the use of multi-bit analog-to-digital converters with internal programmable gain allows measurement over a very wide dynamic range – up to 5 orders of magnitude;
- the presence of a microcontroller makes it possible to transfer data using any protocol that allows to calculate and send a data checksum that virtually eliminates the possibility of undetected errors in the transmission.

At the same time, such device would also possess significant drawbacks:

- high energy consumption – in addition to powering up the microcontroller and analog-to-digital converter even the transmission of a zero level data consumes energy. Considering that the devices must be supplied from batteries, this will significantly reduce the working time;
- in the absence of grounding powerful electromagnetic interference when operating X-ray equipment may adversely affect both the conversion accuracy of the analog-to-digital converter and the operation of the microcontroller;

- there is a possibility of loss of communication with the conversion device under irradiation of a high flux X-ray radiation.

Microchips of ultrahigh degree of integration have a high sensitivity to exposure to X-rays and for this reason the developed device requires the use of a protective case that reduces radiation exposure of a measuring circuit to a safe level.

The current converter must operate in the conditions where depending on the type of the X-ray tube, the maximum energy of quanta does not exceed 320 keV. Protection may represent a screen of iron and lead, which is simultaneously the housing of the device. The case is a metal shell of stainless steel with a wall thickness of 0.5 mm, in which the batteries and a lead box containing a printed board with microchips are placed. The box is made of lead plates 5 mm thick due to the calculation results. Figure 4 shows the measuring blocks of two digital microammeters placed in the test chamber in close proximity to X-ray tubes.

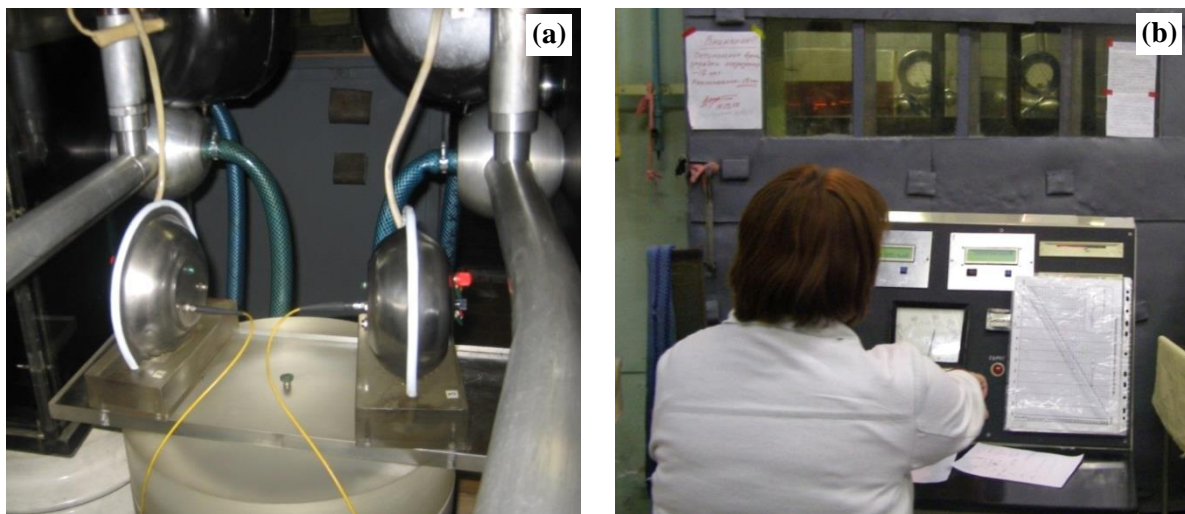


Figure 4. Measuring units of the digital microammeters in the test chamber (a) and the information processing units on the operator panel (b).

With the help of the developed device operator during the training and testing can detect the change in the leakage current and determine how many breakdowns in the X-ray tube occurs at certain stages of the training. This information allows making a conclusion on whether to send the X-ray tube for additional pumping or not. Ultimately, the application of the developed device allows improving the quality of the products. At the end of training depending on the results of measurement of the leakage current and the number of breakdowns, it is possible to classify the X-ray tube according to quality categories and make a prediction of the possible service life.

3. Conclusions

Using the solutions proposed in this work have been manufactured and delivered to the company two types of experimental models of electronic microammeters for the divisions of training and testing of the X-ray tubes, which are already several years successfully used in workshop conditions.

The developed equipment is capable of measuring pulsed and continuous anode current in the circuits, located under the high voltage, with wide dynamic range and leakage current of the X-ray tube, simultaneously counting the number of electric breakdowns and showing information to the operator in a digital form.

References

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