Control unit for a high voltage installation of X-ray microtomograph

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Abstract. A control and indication unit for current operating parameters has been developed for the Spellman XRF-160 high-voltage generator with an output voltage of up to 160 kV, used as part of a high-voltage X-ray microtomograph installation. Thanks to the use of isolating amplifiers in the unit, galvanic separation of the circuits for the formation of control and indication signals with executive circuits of the high-voltage generator is implemented. This makes it possible to virtually eliminate the possibility of the formation of stray ground loops and the flow of dangerous pulsed currents from electrostatic and corona discharges of a high-voltage source in the sensitive circuits of the tomography recording camera and Ethernet communication with the control computer and, as a result, radically increase the reliability of the device. The unit supports the operation of the XRF-160 generator in the modes of stabilization of the output voltage or stabilization of the emission current of the X-ray tube and provides adjustment and indication of the main parameters of the high-voltage installation - the maximum permissible and operating filament current of the cathode, high voltage and emission current of the tube. The unit is assembled in a typical 19-inch case.

1. Introduction
High-voltage power supplies for x-ray sources are one of the main devices of any x-ray apparatus, including tomographs. The main purpose of these installations is to ensure the stability of the high voltage and emission current of X-ray sources, and, accordingly, the size and spatial position of the X-ray focal spot for a sufficiently long experiment. The composition of high-voltage installations is determined by the nomenclature and type of x-ray sources (tubes) used in the tomograph. So, in a new experimental industrial microtomograph [1], an original tube [2] is used, designed for a maximum voltage of up to 80 kV at a power of up to 100 W, and a BS-16 microfocus tube [3] manufactured by Svetlana-Roentgen NPO (S.-Petersburg), designed for voltages up to 150 kV with power up to 10 watts. To power the first tube, an original high-voltage source [4] is used with direct USB connection to the control computer. The practice of its use has shown that at voltages on the tube above 40-50 kV, electrostatic and corona discharges begin to occur in the system, the frequency and intensity of which depends on the voltage and other, often not controlled, conditions (humidity, limited volume of the X-ray protective chamber, etc.). These discharges lead to a decrease in the quality of images (distortion, noise), to the failure of their registration, to “freeze” of the control computer. To power the BS-16 tube, a block with a voltage of 150 kV is required, and here these phenomena can cause catastrophic failures in the camera and computer circuits.
The fact is that in electronic systems with a direct connection between the control and executive circuits, especially in the presence of electromagnetic interference (EMI) and electrostatic discharges (ESD), it is almost impossible to avoid the appearance of spurious ground loops [5], through which pulsed currents capable of cause dangerous overvoltage in the sensitive input circuits of the computer (USB or Ethernet inputs) and, especially, cameras [6], leading to their failure. To eliminate these negative phenomena, it is necessary to use the galvanic separation of control and executive circuits of the electronic system.

2. Development of a control unit for a high-voltage generator

To power the BS-16 microfocus tube, the microtomograph uses the XRF-160 high-voltage generator of one of the world's leading manufacturers of high-voltage equipment from Spellman, USA [7]. The output voltage of this generator can reach 160 kV at a load (emission) current of up to 1000 µA. At the same time, it provides the possibility of supplying the glow of the cathode of the x-ray tube with direct current up to 5 A at a voltage at the cathode output (cathode + cable) of up to 7 V. The generator uses the advanced method of resonant power conversion [8], which provides switching of power switches at zero voltage or zero current, which leads to a drastic decrease in power dissipation on the keys and, correspondingly, to an increase in efficiency of generator. An important advantage of this generator is the lack of a direct communication controller with the control computer, which allows its analog control to be implemented with galvanic separation of the control and executive circuits.

Schematic diagram of the control unit of the high-voltage generator XRF-160 is shown in figure 1. In the diagram, there are 4 main functional modules: a power module, a setting module, a measuring module, and an indication module. The power supply module includes AC input circuits of ~ 220 V, a TV1 transformer and two identical ± 15 V power supplies implemented on typical integrated voltage stabilizers L7815 (+15 V) and L7915 (-15 V). The use of two separate sources is due to the need for a complete galvanic separation of the circuits of the control unit and the high-voltage generator. The power supply of the control unit circuits is marked with the letter L, and the power supply of the circuits associated with the high-voltage generator is marked with the letter H. The GNDL and GNDH ground circuits are respectively separated. In accordance with the requirements of the operating instructions for the XRF-160 unit [9], control signals for the filament current, high voltage, and emission current are generated by changing the +10 V reference voltage. For its formation, the precision integrated reference voltage source REF01 [10] is included in the power module.

Galvanic separation of control and executive circuits is ensured by using precision isolating amplifiers ISO124 [11]. The control signals from the setting module are transmitted to the high-voltage generator through isolation amplifiers U1-U3, and the indication signals of the parameters are transmitted in the opposite direction to the measuring module through amplifiers U4-U6.

A feature of the XRF-160 generator is that the control signals for all parameters of the generator are regulated by changing the reference voltage in the range of 0-10 V. In this case, the filament current varies in the range 0-5 A, the high voltage in the range 0-160 kV and the emission current 0-1000 µA. In the same way, only in the opposite direction do the measurement signals of the operating parameters coming from the XRF block change, i.e. and control signals and measurement signals of the operating parameters do not reflect the actual values of the generator parameters. This makes practical work on the tomograph very difficult. Therefore, the circuit of the control unit includes dividers and measuring instruments (display module), which allow you to control the actual values of the filament current, high voltage and emission current.

Murata digital 3.5-digit LCD voltmeters are used as measuring instruments [12]. The signals of the measured values of the current parameters of the high-voltage generator through isolation amplifiers U4-U6 are fed to voltage dividers R14-R20 and then to voltmeters PV2-PV4. The dividers are designed in such a way that the measuring signals 0-10 V of each parameter are displayed on voltmeters in the form of real values: the filament current in A, the high voltage in kV and the emission current in µA. The position of the decimal point of each voltmeter is determined by a specific switching circuit.
The XRF-160 high-voltage generator can operate in two modes - high-voltage stabilization or stabilization of the tube cathode emission current. In the first of them, two parameters are regulated - the filament current and high voltage, and the emission current of the x-ray tube is set independently. The disadvantage of this mode, especially in conditions of a long experiment, is the need for periodic adjustment of parameters in order to maintain a stable emission current. In the second mode, the adjustable parameters are the high voltage and emission current of the tube, and the filament current of the cathode is set automatically to maintain the required emission. This mode is best suited for continuous tomography. However, in this case there is a danger of a significant increase in the filament current upon switching on, which can lead to destruction of the cathode [13]. Therefore, in this mode, the third adjustable parameter is introduced - the filament limit current. To set the parameters, the signals of the adjustment potentiometers R10-R12 through the buffer amplifiers of the DA1 microcircuit, the voltage dividers R1-R5 and R7-R9 and the switch SA3 are fed to the voltmeter of the PV1 installation.
module for monitoring. After the external blocking (INTLK) and the high voltage (HV ON) are turned on, the parameter setting signals are transmitted through isolation amplifiers U1-U3 to the high-voltage generator circuit. The fourth amplifier of the DA1 chip is used to generate a supply voltage of digital voltmeters +5 V.

Structurally, the control and display unit is assembled in a typical 19-inch case, the electronic components are located on the printed circuit board, the controls and displays on the front panel. A photo of the control unit along with the controlled generator XRF-160 is shown in figure 2.

![Figure 2. Control unit and XRF-160 high voltage generator.](image)

3. Conclusion
A control and indication unit for the XRF-160 high-voltage generator has been developed, providing galvanic isolation of the control and executive circuits of the high-voltage X-ray microtomograph installation. The unit avoids the formation of spurious ground loops and protects the sensitive circuit of the tomography registration system (camera and computer) from EMI and ESD.

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