Intense Pulsed X-ray Source for High-Speed Radiography

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Abstract – The paper describes the design of a pulsed x-ray source for high-speed radiography. The high-voltage pulse is produced using the circuit of a line pulse transformer that charges a 1.2 nF capacitor to a voltage of 600–700 kV in 120 ns. The capacitor is connected in parallel to a backward x-ray diode. The anode is a ∅2 mm needle and the cathode is a ∅16 mm cylinder. The diode current is 3.5 kA and the FWHM is 115 ns. The x-ray doze at distance of 1 m is 15 mR and the radiation pulsewidth is 60 ns.

1. High-voltage tests of the generator

Figure 1 shows the design of the high-voltage pulse generator. Four HCEIcap50-0.1 capacitors are discharged into 16 stages of the line transformer. The transformer load is a high-voltage coaxial capacitor with glycerin insulation. The capacitor is connected in parallel to a backward x-ray diode (load). Outside the bushing insulator of the diode, directly on its surface, an inductance is wound for electric field distribution over the insulator surface. Table shows the electric field strength at different generator elements.

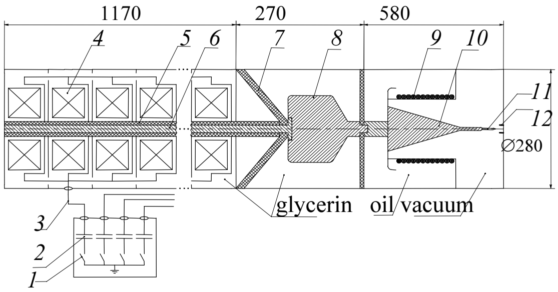

Fig.1. Electric field strength at different generator elements: *1* – HCEIcap50-0.1 capacitor (E = 200 kV/mm, DC voltage); *2* – high voltage pulsed oil-filled cables (E = 21 kV/mm, pulse 200 ns); *3* – insulation of the secondary winding (E = 100 kV/mm, pulse 200 ns); *4* – capacitor with glycerin insulation (E = 21 kV/mm, pulse 200 ns); *5* – surface strength in vacuum (E = 3 kV/mm, pulse 200 ns)

Table. Electric field strength at different pulse facilities

Device	Voltage, kV	Time, μs	D/d, mm	E, kV/cm
Highvoltage pulsed oil-filled cables	100	100	14/6	393
MIG generator	2600	1.5	180/76	794
Pulse transformer of the x-ray source	720	0.1	40/18	1000

A fundamentally new result is that the electric field strength in the insulation of the secondary winding reaches 1 MV/cm.

The generator provides a reasonably high reproducibility of electrical pulses at a fixed discharge voltage and constant load. By now, 70 startups of the generator at full voltage (720 kV) have been realized.

2. X-ray generation

An accelerating tube for X-ray generation with the required parameters was designed and tested. The accelerating tube consists of a case, a polyethylene insulator, an electrode for leveling the potential, electrodes, a vacuum chamber, and a target unit.

The operating mode was adjusted by varying the diode voltage and the acceleration gap width, while holding the geometry of the anode-cathode unit unchanged (Fig. 2).

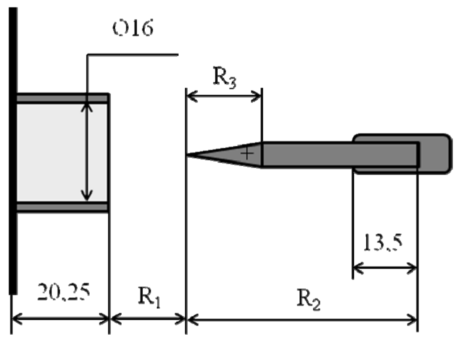

Fig. 2. Design of the cathode-anode unit. R_1 = 9.25 mm, R_2 = 47 mm, R_3 = 5.5 mm

The anode was a ∅2 mm tungsten rode tapered off by grinding over ~ 5 mm to a diameter of < 1 mm. The cathode was a hollow cylinder with a wall thickness of 1 mm and an emitting edge diameter of 16 mm. The gap between the emitting edge plane and the anode was ~ 10÷12 mm. The voltage across the tube is measured by a capacitive divider (located on the case of the accelerating tube) and the load currents by Rogowski coils. The vacuum chamber was pumped down to a pressure of $(2÷4) \cdot 10^{-4}$ torr by an oil-vapor pump. In preliminary experiments, about 230 startups of the facility prototype were realized. The voltage across the acceleration gap was 600–750 kV, the diode current was 2÷3.5 kA, the diode impedance 250÷300 Ω, the radiation doze 1 m away from the anode was up to 20–30 mR, the FWHM of X-ray power was 60–65 ns, and the spot size < 2 mm. The results roughly agree with known findings (e.g., Skandyflash) on voltage, current, dose and FWHM of X-ray power scaling. Figure 3 shows typical oscillograms for the cathode-anode unit.

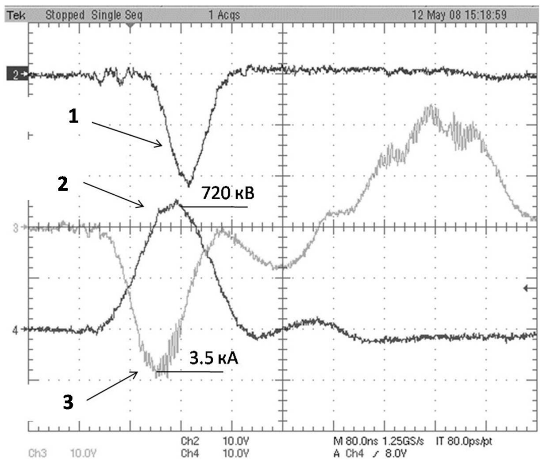

Fig. 3. Oscillograms: 1 – signal from SKD1-0.1; 2 – load voltage; 3 – load current

In this mode, experiments were performed to determine the transmission power of the facility. The arrangement of the test objects is shown in Fig. 4.

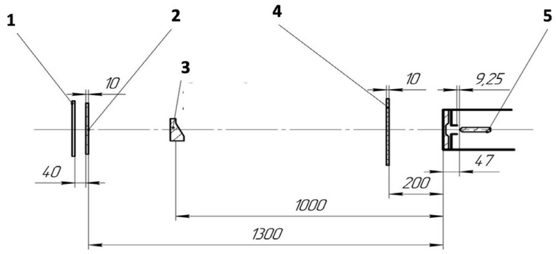

Fig. 4. Arrangement of the test objects: 1 – photoplate (x-ray plate); 2 – duralumin plate; 3 – object; 4 – glass textolite; 5 – anode

At 1 m from the anode, there was a step steel wedge with steps of width 2 mm and height 1 mm. The wedge thickness was varied from 5 to 15 mm. A cassette with x-ray film was 0.3 m from the wedge (1.3 m from the source). Near the wedge, small metal (lead, steel, copper) objects were located to determine the resolving power of the facility. Images were taken using RF-3 and AGFA films in a cassette with intensifying screens. All wedge steps are clearly visible on the RF-3 film at a radiation doze of ~ 3.6 mR (~ 6 mR at 1 m from the anode). On the film, one can also distinguish steel balls up to a diameter of 0.5 mm located in the wedge plane. For determination of the source dimension, an obscurogram (a camera obscura image) of the anode edge was taken. A magnified image of the edge is shown in Fig. 5.

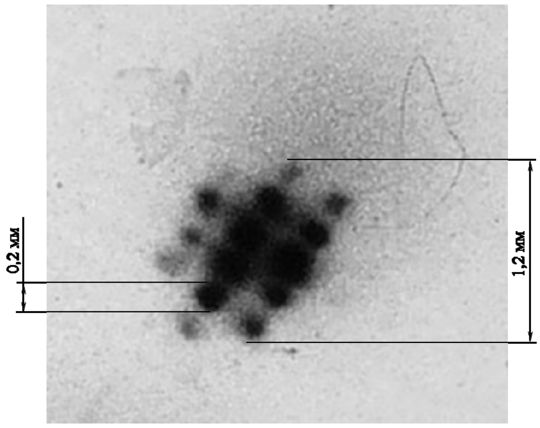

Fig. 5. Obscurogram of the anode

It is seen that the radiation source is the multitude of individual sources of characteristic diameter 0.2 mm uniformly distributed within a ∅1.2 mm circle.

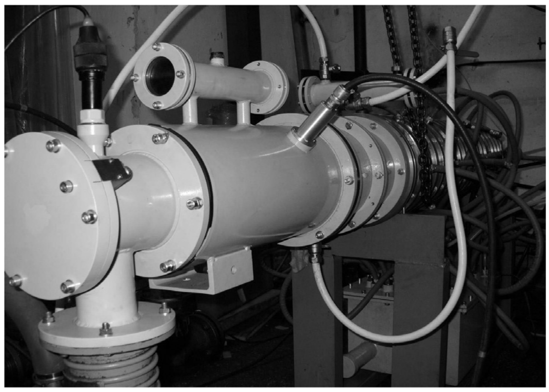

Fig. 6. Photo of the x-ray source

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