Intense Source of Pulsed X-Rays for High Speed Radiography

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Abstract – At the department of High Energy Densities (HCEI, SB RAS) the four-frame X-ray machine, made of four time-based pulsed X-ray sources, was developed. The sources were designed for the output voltage of 600÷700 kV and the output peak current of 1,5÷2 kA. As an X-ray tube the inversed diode with the ~2mm focal spot size was used. The pulse width was ~65 ns, dose per pulse at 1 m from the tube window was ~25 mR. The computer monitoring of the machine was applied.

1. Introduction

To develop a high-voltage pulse generator a Tesla coil with high coupling coefficient was offered. A coupling in the transformer was provided due to an open-loop iron-core system. Such scheme of the transformer ensures compactness and simplicity of manufacture of the accelerator.

For the filming of the stop-actions it is necessary to have a small size of a focal spot of an X-ray source. To create such source sharp focal tubes with the inversed cathode are used. That tube construction allows to get X-ray source with focal spot size in several millimeters.

2. The transformer

The Tesla coil with a high coupling coefficient possesses series of advantages. At first, at the given quality-factor of circuits an active losses are decreased, at second, the number of field oscillations in a time is decreased (the operation of the transformer becomes unipolar, that reduces the probability of a high-voltage insulation breakdown because of the voltage reverse). At high coupling coefficients the Tesla coil quite similar to a pulse transformer, however the system of two inductively coupled circuits in case too has a resonance properties which are appeared at a detuning of the circuits [1].

Usually the Tesla coil is used to charge a pulse-forming line, which is discharged on load through a switch, and the pulse duration in this case depends on a linear dimension of a line. To obtain electric pulse duration of 70 nanoseconds in an oil-filled line more than 10m length is required. Therefore we had to refuse to use of a pulse-forming line. In our case the pulse with required duration is formed in a primary circuit of the transformer. It let us to reduce facility dimensions and avoid of using an intermediate switch. The external view of the generator is shown in fig.1.

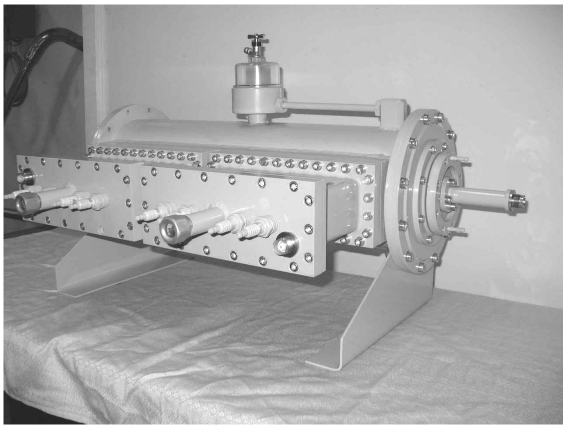

Fig.1. The external view of the generator

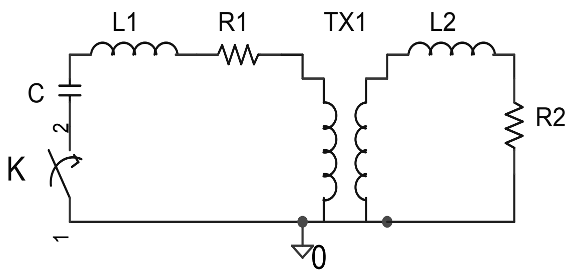

Fig.2. The electric circuit of the generator:
C=200nF, L1=27nH, R1=10mOhm – capacitance, inductance and active resistance of the primary circuits; L2=100nH, R2=300 Ohm – load inductance and resistance; TX1 – Tesla coil.

The electric circuit of the generator is shown in fig.2. The capacitance C is made of two plane capacitors HCEIcap 50-0.1, the external view of the capacitors is shown in fig.3. These capacitors are developed and made in the HCEI, SB RAS. An operation voltage of the capacitor is 50 kV, capacitance is 100 nF and inductance is 10 nH. The overall dimensions of the capacitor are 150 x 210 x 60 mm. The capacitor consists of four serial and 38 parallel sections. This is done in order to decrease the current loads on a section and output contacts. When the maximal achieved current through the capacitor is 120 kA, the current through any section does not exceed 3 kA. To decrease edge effects in the capacitor, the insulation in the region of the sharp edge was divided into thin layers by means of capacitor plates displaced with respect to each other to a given value [2]. The sections have combined paper-mylar insulation impregnated with a castor oil.

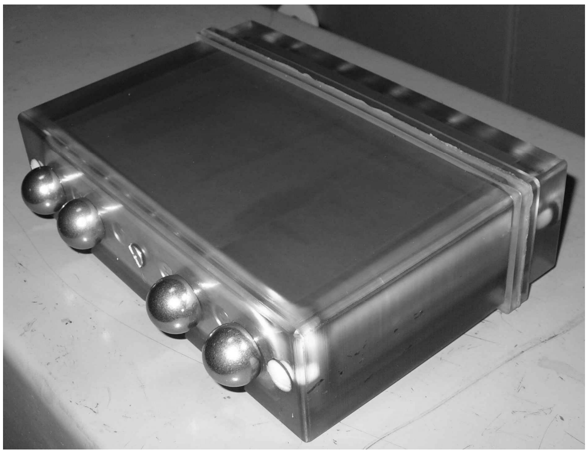

Fig.3. External view of the capacitor HCEIcap 50-0.1

Each capacitor is discharged through the separate switch, with a field distortion, on a primary turn of the transformer (fig. 4.). The primary turn was made of the copper bus by width of 0.3 mm. The inductance of

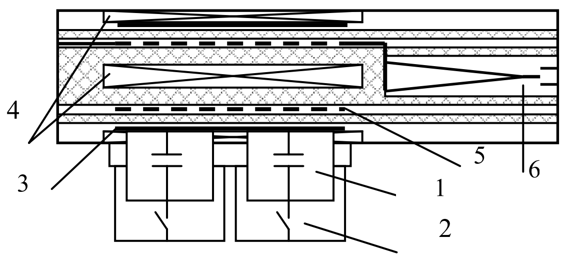

Fig.4. Construction of the generator:
1 –capacitor; 2 – switch; 3 – primary turn; 4 – open-loop magnetic path; 5 –secondary winding; 6 – accelerating tube.

the primary turn is 48 nH. The transformer core consisted of two magnetic paths: the one was placed in the centre, and another on the interior surface of the transformer case. The magnetic paths were performed with the cross-section of 16 cm^2, and were made of the electrical steel bands with the thickness of 50 μm. The steel grade was E3425. Polypropylene film with the 10 μm thickness as an insulation between the steel bands was used. As a secondary winding of the transformer the cylindrical solenoid coil with an inductance of 28μH was used. The winding of the solenoid coil contained 30 turns, made of the copper bus in width of 10 mm.

3. An accelerating tube

The accelerating tube used in experiments consisted of the stacked insulator, vacuum chamber and the electronic diode. The stacked insulator has been done from the insulator rings made from plexiglas and gradient rings from duralumin. The total height of the insulator rings was 200 mm. The vacuum surface of the insulator ring had special form to increase the total vacuum height of insulator. Inside of the stacked insulator a conical part of positive electrode with a length of 216 mm and with initial and final diameters of 44 and 10 mm respectively was placed. In a vacuum chamber the cylindrical part of the electrode with a diameter of 10 mm, a length of 133 mm was placed. An inner diameter of the negative cylindrical electrode, with a length of 130 mm, was 70 mm. Sharpened edge of a disk hole with diameter of 34 mm was used as an emitting edge of a disk cathode. The anode was a tungsten rod with a diameter of 2 mm with the pointed end. The anode-cathode gap in the given series of experiments was 16 mm between the anode surface and the cathode emission edge.

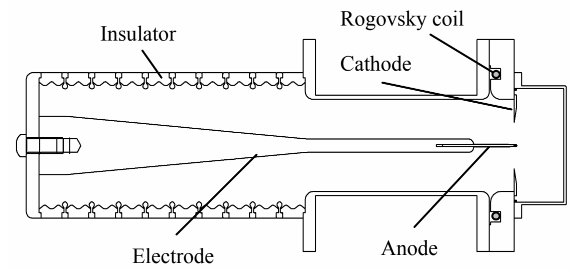

Fig.5. Construction of the X-ray tube.

The chamber was pumped off by the oil- diffusion pump up to vacuum not worse than 2·10-4 torr.

4. Tests

The transformer tests were carried out with resistive load. The value of the load was varied from 100 up to 400 Ohm. The current and voltage signals for the load resistances of 100 and 300 Ohm are shown in fig.5. The peak current in the primary circuit was 75 kA for the R≈100 Ohm and 70 kA for the R≈300 Ohm. As can be seen from the signal, the load peak current was ~ 2.5 kA for the R≈100 Ohm, and a peak voltage was ~ 270 kV. The load current is precisely in 30 times less then the primary current (the number of turns of the solenoid coil is N=30). It is proved that the transformer has sufficiently high coupling coefficient. At the R≈300 Ohm the load current is ~ 1.35 kA, and the voltage is 410 kV. The difference between primary and adjusted from load currents is about 30 kA. This difference current is a consequence of increasing of the load resistance value, therefore some part of the current (~30 kA) was lost on magnetizing inductance of the magnetic path. Lμ.

The X-ray tube was tested separately on the "Peskar" generator. For measurement of currents in the experiments the current transformers were used.

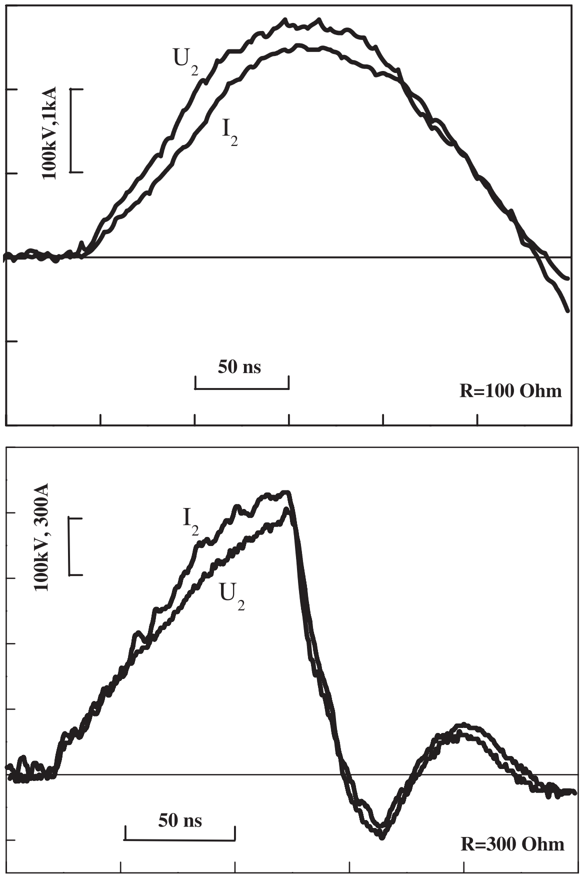

Fig.5. Oscillograms of the current and voltage at the load equivalent of 100 and 300 Ohm.

The voltage was defined by means of a liquid active divider, and an X-ray dose was measured using a LiF detectors. The sizes of the radiation source were defined using the pinhole camera. During the experiments for the given configuration of the accelerating tube the following parameters in maximum radiating power were obtained: the accelerating tube voltage is 635 ÷ 720 kV; the electron beam current is 1,5 ÷ 1,9 kA; the pulse duration of the radiating power on half-height is 60-65ns (fig.6.); the diameter of the radiation source is 2 mm; the X-ray dose at a distance of 72 mm from the anode is 3,9 ÷ 5,2 R, that corresponds to an X-ray dose of 20-28 mR at a distance of 1m from the anode.

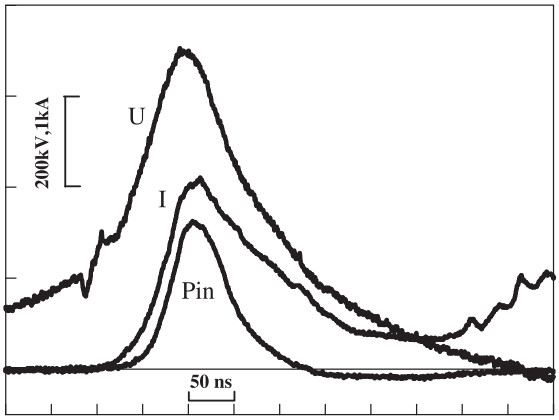

Fig.6. Oscillograms of the current, voltage and a Pin diode of X-ray tube.

5. Conclusion

The X-ray source for high-speed radiography of the stop-actions is developed and made, and also the X-ray tube with the voltage of 600 – 700 kV and an electron beam current of 1.5 – 2 kA is developed. An X-ray dose of 20– 28 mR at a distance of 1 m from the anode is obtained. As a primary storage a special developed low inductance pulse capacitors HCEIcap 50-0,1 with a voltage of 50 kV, and a 100 nF capacitance were used. The dimensions of the source are ø230x750 mm.

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References

[1] S.D.Korovin, *The Tesla coil in the high current pulsed periodical accelerators*, Tomsk, 1988, pp.10-13.

[2] A.V.Saushkin, N.V.Zharova, A.A.Kim, N.A.Ratakhin, and V.F.Fedushchak. Instruments and Experimental Techniques No. 4, 2006.