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X-RAY RADIATION SOURCE BASED ON PLASMA FILLED DIODE

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The paper gives the results of studies on a plasma X-ray source, which enables one obtain 2.5 krad of a radiation dose per pulse over an area of 100 cm² in the quantum energy range from 20 to 500 keV. Pulse duration is 100 ns. Spectral radiation distribution under various operation conditions of plasma a diode are obtained. A Marx generator served as an initial energy source of 120 kJ and discharge time of $T/4=10^{-6}$ s. A short electromagnetic pulse (10^{-7} s) was shaped using plasma erosion opening switches.

1. The most easy and reliable method to sharpen an electromagnetic pulse is to use plasma erosion opening switches (PEOS). This method does not require a "fast operating" capacitor bank [1]. In this method the energy stored in a "slow operating" capacitor bank is converted into a magnetic inductance energy, which is switched to a load. When an inductive storage circuit of breaks, a short electromagnetic pulse is generated which is delivered into a load. PEOS operation is based on the property of a high-current discharge in a plasma to increase resistance sharply, when the current reaches a critical current [2]. Because of the fact that power increase is followed by significant voltage increase, the generators based on PEOS have found wide application in accelerator engineering aimed at generating electron beams and X-ray bremsstrahlung pulses. The work presents the results of studies on the "PLASMA X-RAY" pulse generator. The parameters of the generator are: V=1 MV, I=250 kA, W=120 kJ.

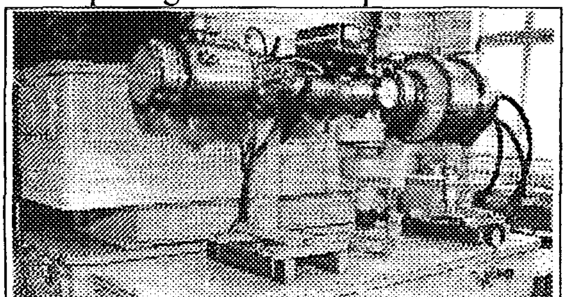


Fig.1. The general view of the radiation source.

2. The radiation source is shown in Fig.2. Three Marx generators served as initial energy storage connected in parallel. The total capacity of the generators is 0.96 μF, inductance is 0.25μH. The stored energy with 100 kV of the charging voltage is 120 kJ [3]. The output voltage of five cascades generator is 500 kV. When a circuit of an inductive storage breaks, a pulse of 1 MV amplitude is generated. The output of Marx generator is connected to a collector 2 of inductive storage using transmission line. The transmission line included three KVI-500 cables, its total inductance is 0.25 μH. The inductance of a transmission line up to PEOS is 0.72 μH. Time for discharge current in line is 6 μs, the current amplitude is 400 kA. With nine cables the period for discharge current is 4 μs. The vacuum portion of a storage is separated from a collector by a polyethylene insulator 3 with a diameter of 45 cm. Six coaxial plasma guns 4 of a surface-erosion type are located at a distance of 120 cm from an insulator. The radial velocity and the density of plasma created by this gun are 7cm/μs and 10^{13} cm^{-3} respectively. The discharge current amplitude in gun's circuit is 20 kA. The vacuum line is a coaxial one. It consists of a number of sections 5, connected by adapting rings 6, where inductive current probes 7 are located. The external coaxial diameter is 214 mm, internal one is 80 mm. At the end of the line a target 8 and a voltage divider 9 are located. To prevent the insulator from being illuminated by PEOS plasma and to protect it from target evaporation products it is shielded by a dielectric disk 10 and a set of metal washers 11.

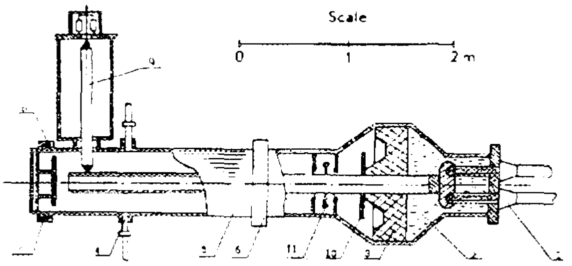


Fig.2. Structural design of the radiation source.

The facility operates the following way. After the Marx generator and capacitor bank, which powers plasma guns, have been charged, the capacitor bank is triggered and plasma is injected into the gap of the vacuum inductive storage line. After a delay time t_d, which is necessary to fill a gap with plasma and create the necessary density, the Marx generator fires and the inductive storage contour is closed via PEOS. When the critical current is reached, a sharp increase of plasma resistance takes place and the energy is transferred into a load. The source can work in regime one pulse per minute.

3. In the first experiments we used a vacuum diode as a load. The distance from a PEOS to diode is 90 cm, a cathode radius r_k is 20 mm, the cathode-anode gap changes from 5 to 30 mm. Voltage on a diode measured by a resistive voltage divider is 1.4 MV. The maximum beam current does not exceed 50 kA. The beam is formed by hollow cathode, the structure of wich has been retained. In order to measure X-ray radiation, thermoluminescent dosimeters (TLD) were used. They were located at the distance of 50 mm from a tantalum target with the thickness of 100 μm. The maximum X-ray dose reached 3 krad per pulse. X-ray pulse duration recorded by p-i-n diodes is 100 ns. The average quantum energy in the radiation spectrum of a vacuum diode is 400 keV. At the absence PEOS the voltage on the vacuum diode is 500 kV, current is 25 kA and X-ray dose is 300 rad.

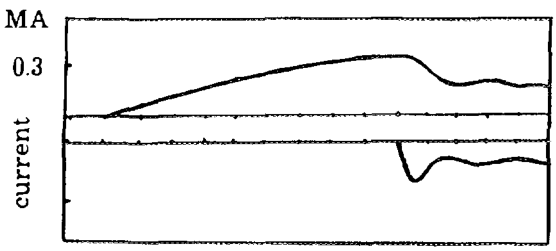
An erosion track, left on the center electrode of the vacuum inductive storage section when plasma is shifted by the effect of the force $\vec{F} = [\vec{j} \times \vec{B}]$, had the length about 70 cm. This value agrees with the calculated value, when PEOS critical current I_c is 300 kA given by [2]

$$I_c = \sqrt{M_i/Zm_e}\, n_i ZeV_F 2\pi r_k l, \text{ here} \qquad (1)$$

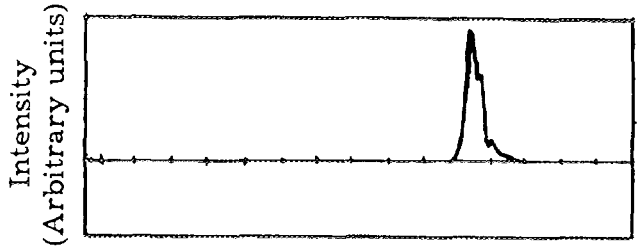
M_i, m_e-ion and electron mass, Z- ion charge, n_i-plasma density, V_F-flow velocity, $2\pi r_k l$- switch area. The ion species is composed mostly of doubly ionized carbon ions C^{++} and its velocity was defined in preliminary experiments $V_F \approx 6 \cdot 10^6$ cm/s. From (1) can be obtained the value of entire plasma mass per length unit $m_p = M_i n_i 2\pi r_k l$. We solved the plasma motion equation under the force $\vec{F} = [\vec{j} \times \vec{B}]$ and the shift length $L_{shift} \approx 70$ cm was obtained. It is consistent with observed value.

In the following experiments one portion of an inductive storage was disassembled and the distance from the PEOS to a load was reduced to 45 cm. During the time required to power the inductive storage (1.4 μs) plasma reached the load, filled the interelectrode gap and plasma diode was formed.

In this case diode current increased and reached the value 70-80% of storage current (Fig. 3). The presence of hard X-ray bremsstrahlung confirms that there is an electron beam in plasma. Cathode diameter change did not significantly effect the diode current. At the same time the change of the gap length between a cathode and anode leads to current and X-ray yield. Table 1 gives the results of the experiments for two values of the cathode-anode gap with various delay times and voltages of PEOS powering.



1. - current line;
2. - current load.



Signal from p-i-n-diode X-ray detector.
Marks - 100 nsec.

Fig. 3

In all pulses, when time delay or PEOS voltage increases, the moment of current transfer into a load is shifted to later times. When $t_d \approx 9.5$ μs and $V_{PEOS} \approx 80$ kV the current transfer moment comes far beyond maximum of the storage current. It is associated with plasma density increase and hence PEOS critical current. As storage current does not increase any more, the moment of transfer comes only when plasma disperses. In doing so X-ray dose drops sharply. The maximum X-ray dose, measured using TLD at the distance of 50 mm from a target, reached 2.5 krad.

Gap (cathode-anode), mm	8	8	27	27
U_{PEOS}, kV	60	60	80	80
Time delay t_d, μs	4.5	6.0	4.5	6.0
Storage current, kA	225	290	275	310
Load current, kA	205	220	205	255
Time of current transfer, μs	1.1	1.3	1.4	1.7
Radiation energy, J	90	270	230	55

To define spectral X-ray composition we used TLD spectrometer, comprising seven detectors based on aluminum phosphate glass with copper filters of various thickness. Detectors were located in an aluminum casing of the spectrometer at a radius of 45 mm. The spectrometer was calibrated by choosing a spectrum and comparing an absorption line, obtained on the basis of this spectrum, with the experimental curve. Fig. 4 gives spectral X-ray distributions with various time delay. Energy estimation in the range from 50 to 500 keV is 90 J for t_d=4.5 μs and 270 J for t_d=6 μs. In other case, when the plasma is injected to a gap of a diode, the radiation energy (5 keV) is 1 kJ.

4. When measuring the soft X-radiation, we used one Marx generator and slightly changed the target design. The hollow cylindrical anode was attached to the metal hollow cone connected to the reverse current conductor. In the end of the line the dielectric flange was installed. The hole in the anode was shielded by the tantalum foil with the thickness of 20 μm.

In the first pulse the line current amplitude reached 160 kA, while that of the load current-140 kA. In further pulses the foil evaporated, the hole was formed and with its increase the load current was rising. In Fig. 5 the set of oscillograms is given as to three sequential pulses, as well as the signal from the X-ray detector with the titanium filter (30 μm). In distinction from Fig. 3 the above mentioned signal duration is 200 ns and the long attenuation is observed. In this case the load current was increased more than twice and the line current at that moment rose insignificantly 10-15% of its amplitude.

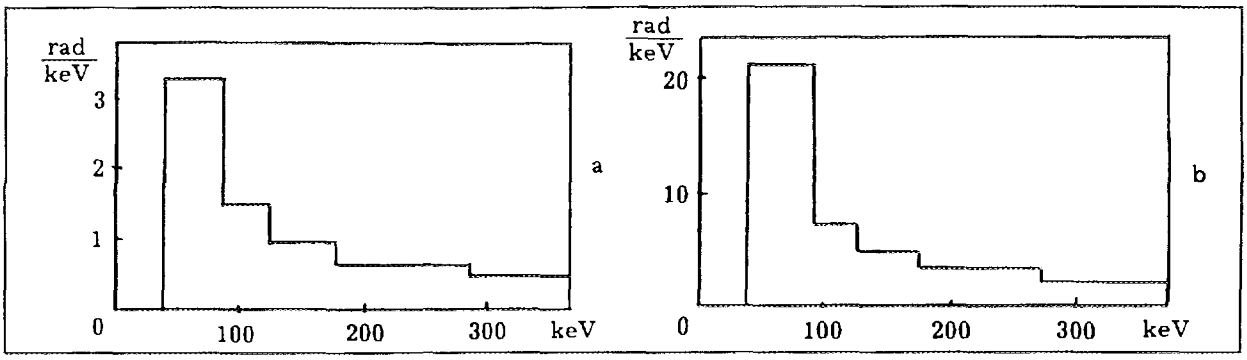


Fig. 4. Spectral X-ray distribution with various time-delays:
a - t_d=4.5 μs, V_{PEOS}=60 kV; b - t_d=6 μs, V_{PEOS}=60 kV.

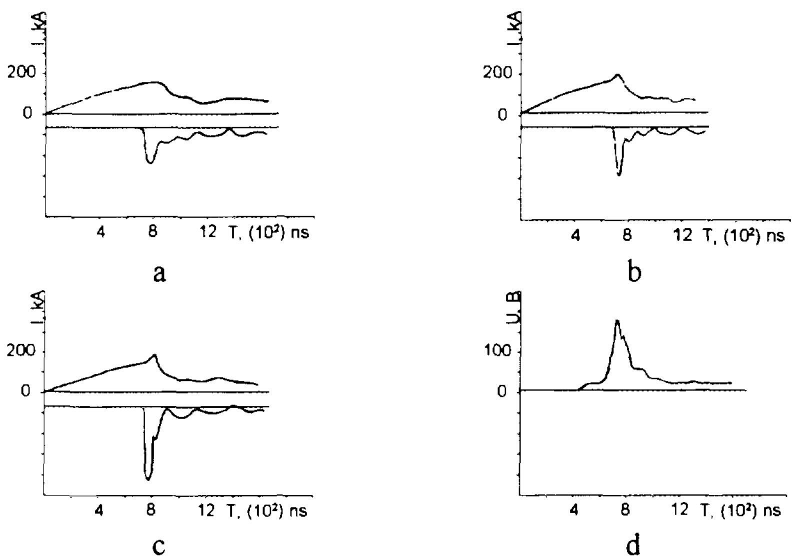


Fig. 5 Current pulses (a, b, c) and X-Ray pulse (d).

We believe that the load current increase is assotiated with the magnetic field topology change and formation in plasma of metastable current layer accumulating excessive magnetic field energy. In the course of this layer explosive damaging the magnetic fluxes are compressed in the contours, resulting in the current increase there. The line circuit inductance is much higher than that of the load circuit and changes rather slightly. So, the line current changes insignificantly. Formation and disintegration of such current layers in plasma are described in the article by A. G. Frank [4].

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