

High-intensity pulsed beam source with tunable operation mode

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Abstract. The report presents the design of an electron and an ion pulsed accelerator. The powerful high-voltage pulse generator of the accelerator and the vacuum bushing insulator is able to change the polarity of the output voltage. The low-inductance matching transformer provides an increase in the DFL output impedance by 4 times. The generator based on a high voltage pulse transformer and a pseudo spark switch is applied for DFL charging. The high-impedance magnetically insulated focusing diode with Br magnetic field and the "passive" anode was used to realize the ion beam generation mode. The plasma is formed on the surface of the anode caused by an electrical breakdown at the voltage edge pulse; as a result, the carbon ion and proton beam is generated. This beam has the following parameters: the current density is about 400 A/cm² (in focus): the applied voltage is up to 450 kV. The accelerator is designed for the research on the interaction of the charged particle pulsed beams with materials and for the development of technological processes of a material modification.

1. Introduction

Pulsed nanosecond electron and ion beams are widely used in applied researches of radiations and a plasma chemistry, a materials science, a medicine, a biology [1-2].

The most widespread and well-known electron and ion beam sources are the nanosecond pulsed high-voltage linear accelerators based on the generators with pulse-forming lines with distributed parameters [2- 5].

The main goal of the pulse-forming line is storing the energy rather slowly in order to transfer it rapidly to the load. A high-pressure gas spark gap is used as a switch in such devices. It is preferred to use the pulse-forming line with deionized water in the accelerators with pulse duration lower than 1 μs and the stored energy over 100 J. It allows designing the generators of a relatively small weight and size. To provide matching of the generator and the diode impedance, the high-voltage transformer is used after the pulse-forming line [5]. To charge the pulse-forming line, Marx generators are mainly used [2, 4-5]. A disadvantage of the Marx scheme is that a large number of spark gaps is required with synchronous triggering. In a frequency mode, it could lead to an instability of the output parameters of the accelerator.



In this paper, we consider the high-voltage pulsed accelerator of electrons and ions based on the high-voltage generator with a double pulse-forming line (DFL). To improve the DFL charging stability, the generator with a pulsed transformer and the thyatron (a pseudo spark switch) were used. The design of the accelerator is able to change the polarity of the output voltage without changes in the design.

2. The high-voltage pulsed accelerator

Figure 1 shows the electrical circuit of the accelerator.

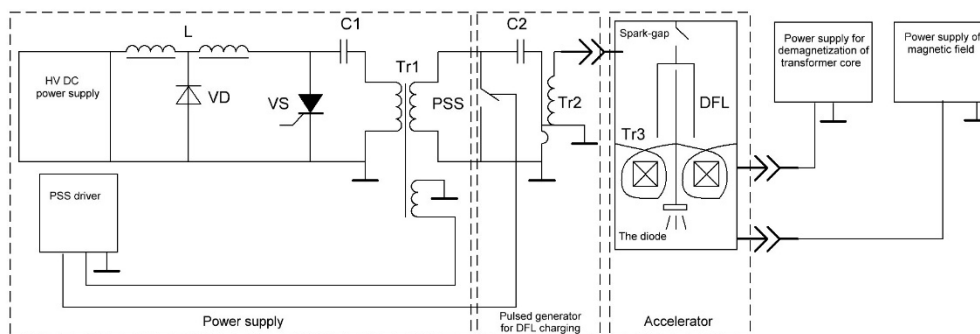


Figure 1. The electrical circuit of the accelerator. L, VD – diode and throttle of protective circuit, C1- power supply capacitance storage, VS- thyristor, Tr1 –pulsed transformer (2kV/40kV), PSS – pseudo spark switch (thyatron), C2 – pulsed generator capacitance storage, Tr2 - pulsed transformer (40kV/250kV), DFL – double forming line, Tr3 -matching pulsed transformer (250kV/500kV)

The HV DC is used as a charging unit. The capacitive storage C1 is charged to the required voltage through the primary winding of the pulsed transformer Tr1. During this charging, the ferromagnetic core of Tr1 is demagnetized by the charging current. Then, a control unit of the HV DC power supply triggers the thyristor VS, and the storage C1 discharges to the primary winding of the transformer Tr1.

The voltage induced across the secondary winding of the transformer Tr1 charges the capacitance storage C2. When the voltage is maximized at the storage C2, the PSS driver triggers the thyatron PSS, and the storage C2 discharges to the primary winding of the transformer Tr2. The induced voltage charges the DFL capacitance to the voltage when the gas spark gap is triggered. The DFL is discharged to the matching transformer Tr3. The core of Tr3 was preliminary demagnetized using the pulse from the special power supply. The high-voltage pulse from the secondary winding Tr3 is applied to the high-voltage output where an ion or electron diode is installed.

The two-winding throttle L and the diode VD provide a protection of the HV DC power supply output circuit against a reverse current. The power supply of magnetic field supports the required current in ion diode coils.

Figure 2 shows the design of the accelerator. The accelerator facility consists of four units (Fig.1): a power supply, a pulsed generator for DFL charging, an accelerator, and a diode system. In Figure 2, the pulsed generator for DFL charging and the accelerator are presented.

The generator based on the pulsed transformer [6] is applied as a pulsed generator for DFL charging. The thyatron PSS, the capacitance storage C2, and the pulsed transformer are located in an oil-filled tank. The thyatron TDI4-100k /45PD is produced by Pulsed Technologies Ltd. The pulsed generator can provide a charging voltage from 150 to 250 kV at 10 pps at the DFL.

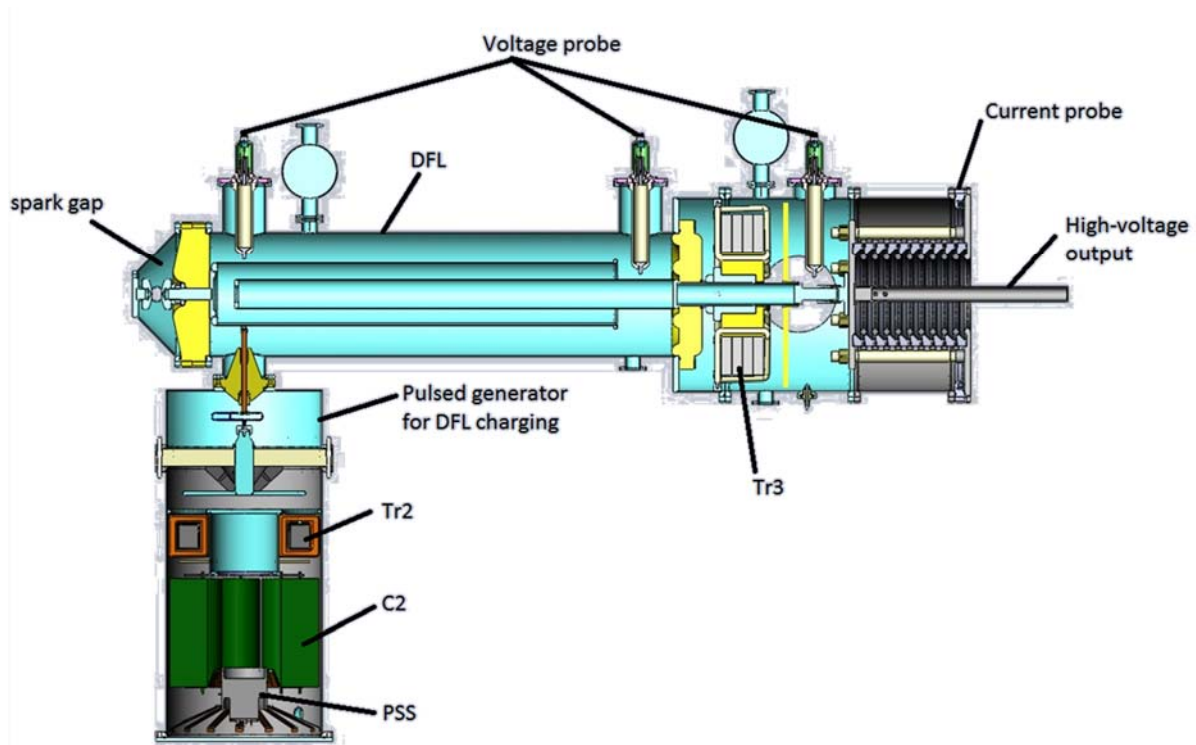


Figure 2. Design of the accelerator. PSS – pseudo spark switch (thyatron), C2 – pulsed generator capacitance storage, Tr2 - pulsed transformer (40kV/250kV), DFL – double forming line, Tr3 - matching pulsed transformer (250kV/500kV)

DFL electrodes are made of stainless steel. Deionized water is used as the dielectric. Two organic glass insulators limit the DFL volume. The accelerator is equipped with a water preparation system based on demineralization of water by an ion exchange method and a water tank. Two voltage probes are located on the DFL to measure the charging voltage and the voltage before the pulsed transformer Tr3.

The two-electrode gas spark gap switch is used. The spark gap is equipped with a gas circulation system to operate in the frequency mode.

The matching pulsed transformer Tr3 is located at the end of the DFL in an oil-filled volume. The magnetic core of the matching pulsed transformer is made of 50NP permalloy. The primary winding is the end of the DFL inner electrode. The secondary winding is realized in a form of twelve parallel-connected cables (RC-50-13-17) without armor [5]. The current and voltage probes are located after matching the transformer on the high-voltage output to measure the output accelerating parameters. The vacuum gradient insulator divides the oil and the vacuum volume.

The vacuum chamber for the ion mode is equipped with a turntable for samples.

3. Experimental results

Experiment was carried out in the electron mode. A material of the cathode is graphite. A diameter of the cathode is 45 mm. An anode-cathode distance is 20 mm. The 30- μ m titanium foil was used as the anode. Figure 3 shows a typical waveform of the beam current and the accelerating voltage.

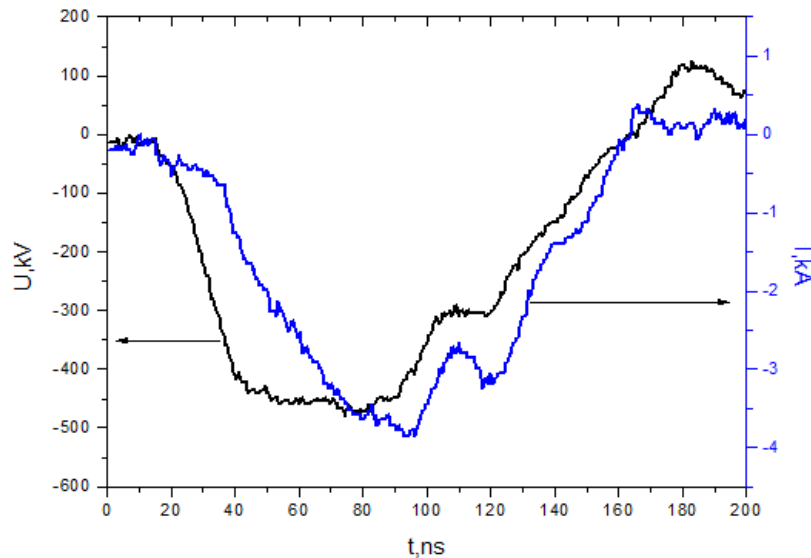


Figure 3. Typical waveforms of beam current and accelerating voltage

The accelerating voltage is 450kV. The output current is 3.7kA. The diode described in [7] was used as ion diode. The anode-cathode distance is 5mm. An emission surface of the anode was polyethylene. The magnetic field at the surface of the anode is provided by a special power supply and amounted to 0.8T. The power supply for the magnetic field is synchronized with the accelerator. When a high-voltage pulse is applied to the anode, the current in diode coils is maximum.

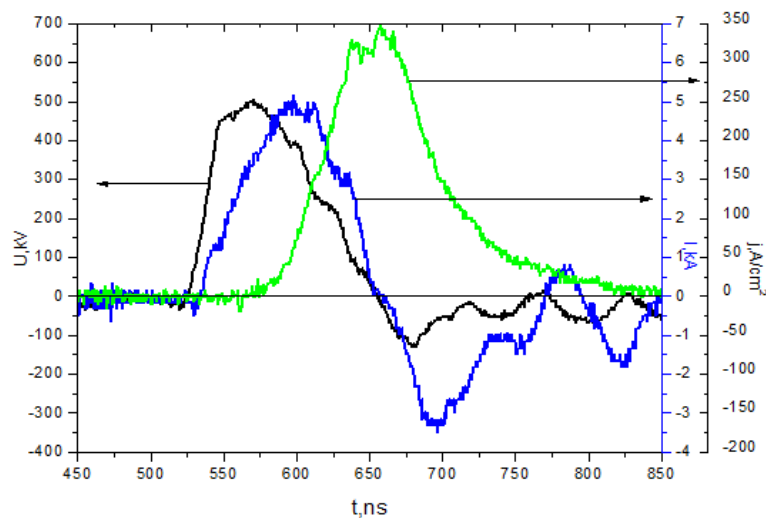


Figure 4. Typical waveforms of accelerating voltage, diode total current, and current density.

The current density of the ion diode was measured using a Faraday cup with magnetic insulation of electrons (0.4T). Figure 4 shows the typical waveforms of the accelerating voltage, the diode total current, and the current density.

4. Summary

The high-intensity pulsed beam source with a tunable operation mode was developed as a research facility for investigation of the interaction of charged particle pulsed beams with materials and for development of the technological processes of a material modification. The replacement of the Marx generator to the pulsed generator with pulsed transformer for DFL charging improved the stability of

the DFL charging voltage. A stability of the output parameters in the frequency mode is determined by the spark gap.

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