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Testing of the water supplying system for the cathode of a vacuum electron diode

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Abstract. An increase in the number of examples of the use of pulsed electron accelerators as sources of ionizing radiation stimulates the development of accelerator technology. One of the nodes that require the attention of researchers and developers of high-power pulsed accelerators is the electron emitter, the cathode. Research in this direction is being carried out both to improve the emission characteristics and to increase the lifetime and operational characteristics of the assembly. One of the original developments is the use of a liquid injected into the accelerating gap as a substance for plasma formation. This work is devoted to testing the system of external liquid supply to the cathode of a vacuum electron diode. The change in the vacuum conditions in the diode during the injection of water is studied. The system is tested when a high voltage pulse is applied to the cathode. The values of water flow rates at which frostbite occurs by the injection system are established. Based on the research results, conclusions were made about the required characteristics of the liquid during injection into the accelerating gap of the vacuum electron diode of a pulsed submicrosecond accelerator.

Keywords: pulsed electron accelerator, vacuum electron diode, cathode

1. Introduction

Well-known examples of the use of pulsed electron accelerators as sources of ionizing radiation for practical applications stimulates the development of accelerator technology [1, 2]. Directions of practical use associated with long-term operation of the accelerator with a high pulse repetition rate require a long service life with stable parameters from the accelerator nodes [3, 4]. It should be noted that the pulsed nature of the generation of an electron beam with a pulse duration of less than 1 μs and an energy per pulse of the order of 10 J/pulse corresponds to the order of pulse power ~10^7 W/s or higher. To ensure the emissivity at such a pulsed emitter power, as a rule, cathodes based on explosive electron emission are used [5]. Research and development of cathodes is carried out both to improve the emission characteristics and to increase the service life and performance of the assembly. With an increase in the number of pulses, the emissivity of the gap decreases, as a result, an increase in the impedance of the electron diode and a change in the operating mode of the accelerating voltage pulse generator. The reason for this is, as a rule, a change in the morphology and properties of the material of the cathode emitting surface [6–8]. One of the original ways to ensure the emissivity of the cathode is the use of a consumable for plasma formation, for example, liquid metal [9] or distilled water [10] stored in the cathode tank. The present work is testing a method for supplying liquid to the cathode of a vacuum electron diode from a container outside a high-voltage installation.

2. Experimental setup

For external cathode power supply (Fig.1), a simple scheme for regulating the liquid supply capacity (Fig.2) controlled by pressure in the supply receiver was developed and implemented. The device is described in more detail in [11]. The cathode power supply scheme makes it possible to control the rate of liquid supply to the cathode by regulating the pressure in the supply receiver (pressure difference in the vacuum chamber and the supply receiver). The circuit proved to work at atmospheric pressure, providing the required flow rate of 1.5 μg/s at an overpressure of 0.4 bar in the supply receiver. The liquid flow rate at the adjusted pressure difference is determined by the change in the liquid level (scale) in the receiver in a channel of known diameter.

When testing the external water supply system as part of electron accelerators, water was supplied to the cathode through a tubular channel with a diameter of 0.5 mm and a length of 2.6 m from the water supply control device. The water supply tube is made in the form of an Archimedes spiral, which acts as a choke that separates the potential part of the generator from the grounded case when an accelerating voltage pulse with duration of less than 1 μs is generated.

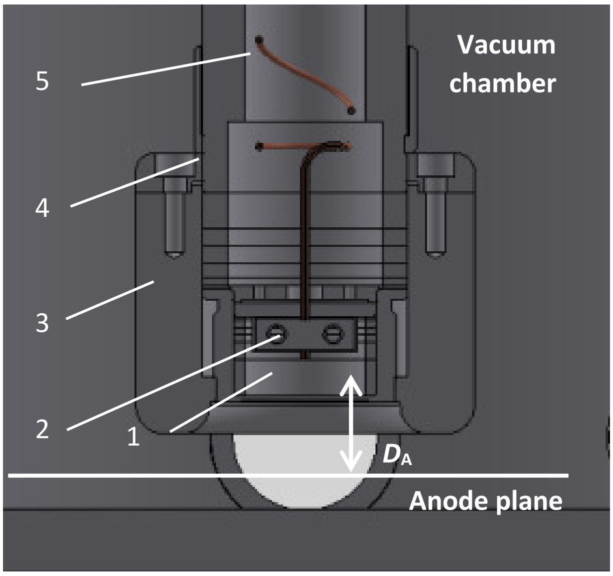

Fig.1. Water injection system: cathode mesh (*1*), pin water injector (*2*), cathode case with shielding electrode function (*3*), cathode-holder out of accelerating voltage pulse generator (*4*), supplying water pipe to cathode (*5*).

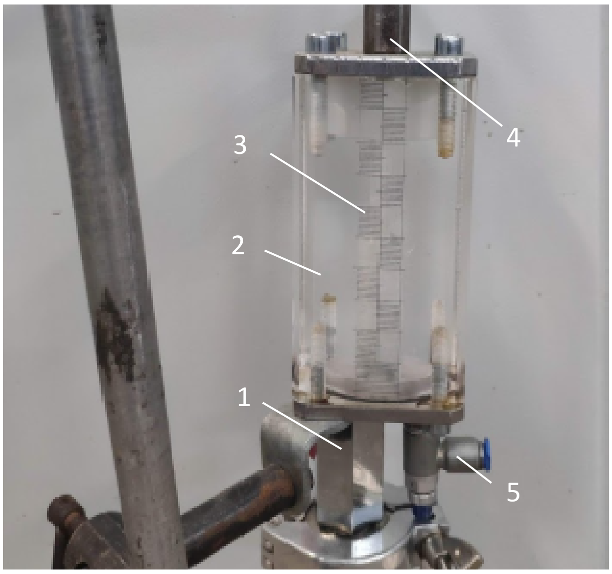

Fig.2. Outer water supplying system: water pipe connection valve (*1*), receiver case (*2*), liquid level scale in the supply receiver (*3*), pump and pressure-vacuum meter connector (*4*), liquid supply-drain valve (*5*).

Experiments as part of the accelerator were carried out on two experimental stands: on the basis of a forming line, which provides a voltage rise rate of about $5 \cdot 10^{12}$ V/s [12]; based on pulse transformer ($2 \cdot 10^{12}$ V/s) [13]. To measure the diode parameters, we used the developed complex diagnostic device [14] and current and voltage sensors of the accelerator diode. The pressure of the residual atmosphere in the vacuum chamber was provided by the operation of evacuation systems based on cryogenic high-vacuum pumps [15]. The current pressure was monitored according to the readings of a wide-range pressure sensor [16].

3. Test results and discussion

3.1. Blumlein line accelerator

The implemented liquid supply scheme (Fig.2) provides a flow rate in the range of 0.2–5 g/min at a pressure in the receiver of 50–760 Torr according to the readings of the pressure and vacuum meter. This range exceeds the values obtained experimentally ~1.5 mg/s [10] by approximately 1.5–2 times. Similarly to the previously tested prototype [10], the cathode system was initially tested without water supply. Typical voltage and current waveforms are shown in Fig.3.

An analysis of the current and voltage curves of the diode shows the oscillations with a period close to twice the electric length of the forming line, which indicates the presence of a sufficient gap in the accelerating gap of the diode for about 500 ns. The beam current signal behind the anode with a similar period of maxima indicates the processes of plasma formation and electron emission from the surface of the cathode grid.

The supply of water to the accelerating gap at a flow rate of ~3 mg/s, the minimum for the tested configuration, led to an increase in pressure in the vacuum chamber from $2 \cdot 10^{-6}$ Torr to $1 \cdot 10^{-3}$ Torr. It should be taken into account that the vacuum sensor is remote from the area of injection and acceleration to ensure the operability of the device, respectively, the local pressure in the area of injection is higher. The pressure of $1 \cdot 10^{-3}$ Torr corresponds to the maximum pressure of the residual atmosphere, which ensures the electrical strength of the high-voltage vacuum insulator of the accelerator, so the experiment with high-voltage pulses was carried out. Characteristic waveforms of signals from voltage and current sensors are shown in Fig.4.

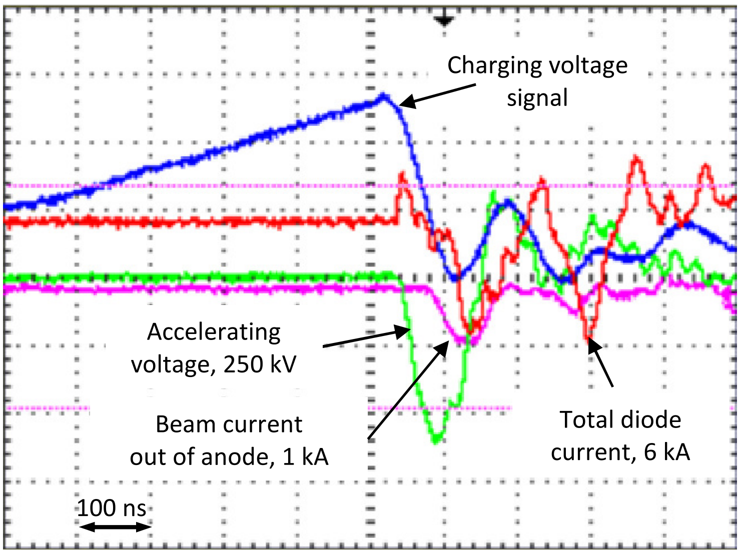

Fig.3. Diode voltage and current signals of Blumlein line accelerator without water supply.

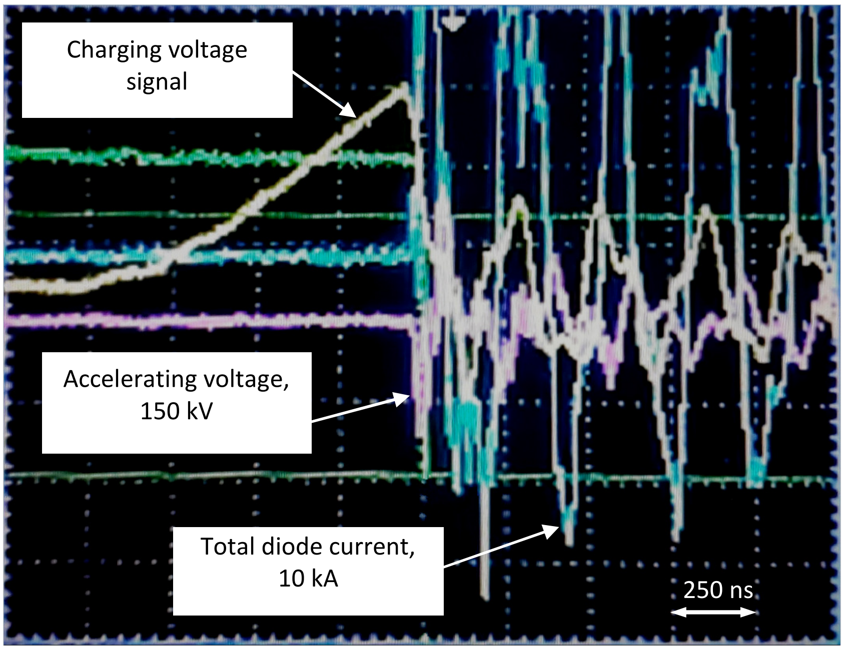

Fig.4. Diode voltage and current signals of Blumlein line accelerator with water supply of the cathode.

A high-amplitude periodic signal from the diode current sensor (Rogowski coil), coupled with a decrease in the signal from the diode voltage sensor, indicates the shorting of the accelerating gap during the action of the voltage pulse. A reliable value of the current behind the anode was not recorded, since the experiment with the critical operating modes of the diode (short-circuiting of the accelerating gap) ended with the failure of the recording device. Inspection of the cathode system immediately after the experiment established the presence of ice in the injection region.

3.2. Transformer based accelerator

Further studies were carried out using an accelerator based on a pulse transformer. The results without water supply to the cathode duplicate the results obtained earlier when testing the prototype [10], when the waveforms of the current and voltage sensors illustrate the operation of a generator based on a pulse transformer for a capacitive load of a vacuum electron diode. The diode current illustrated charge and discharge process of the constructive capacitance of the diode assembly.

The supply of water (~3–5 mg/s) led to an increase in pressure in the vacuum chamber from $5{\cdot}10^{-6}$ Torr to $6{\cdot}10^{-3}$ Torr, which is close to the critical values for maintaining the electrical strength of the high-voltage diode insulator. The higher pressure is due to the lower capacity of the vacuum system (ISO200 vs. ISO250 in Blumlein line accelerator).

When a high voltage pulse was applied to the cathode, a signal of the beam electron current (Fig.5) was recorded at the negative half-waves of voltage and current, and the radiation of the injection region into the accelerating gap in the optical range (Fig.6).

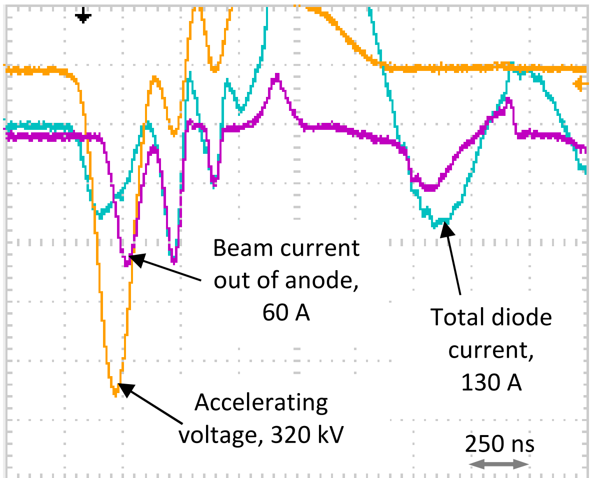

Fig.5. Diode voltage and current signals of transformer-based accelerator with water supply of the cathode.

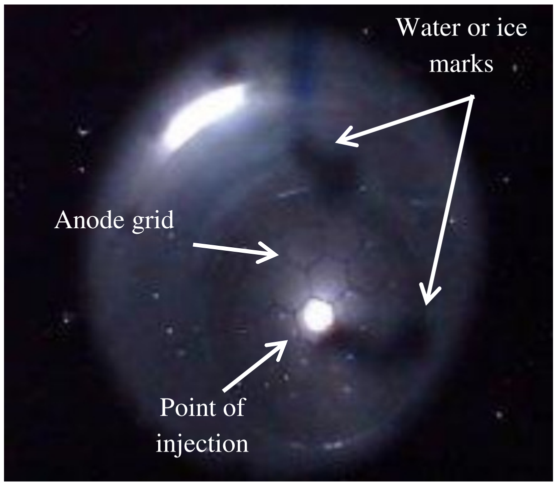

Fig.6. Cathode area image when electron beam pulse has been registered for transformer-based accelerator.

An increase in the amplitude and oscillations of the diode current on the afterpulse indicates a reduction in the accelerating gap after the action of the main voltage pulse. At the same time, the output current signal, which coincides in duration and polarity with the total diode current, confirms the existence of an accelerating gap 700 ns after the application of the voltage pulse (Fig.5). Note the delay of the beam current signal behind the anode by ~150 ns from the first diode current pulse and the coincidence of fronts and extrema for subsequent peaks. The presence of the diode current in the absence of current output from the anode is explained by the process of charging the constructive capacitance of the vacuum diode.

The experiment was carried out at a repetition rate of 1 pulse per second. After 10^3 pulses of the beam current, the registration of the electron current stopped (Fig.7). After the end of the experiment, the fact of injector icing was confirmed (Fig.8) similarly to the results of experiments on the accelerator with the Blumlein line.

In the area of observation of the device for recording the optical image of the cathode surface, traces of the liquid injected into the accelerating gap were found (Fig.6). This observation indicates an insufficient evaporation rate at such a flow rate and accumulation of liquid in a vacuum volume. To restore the efficiency of a vacuum system based on a cryogenic pump, it was necessary to carry out a long regeneration procedure with heating and evacuation of the gas absorber.

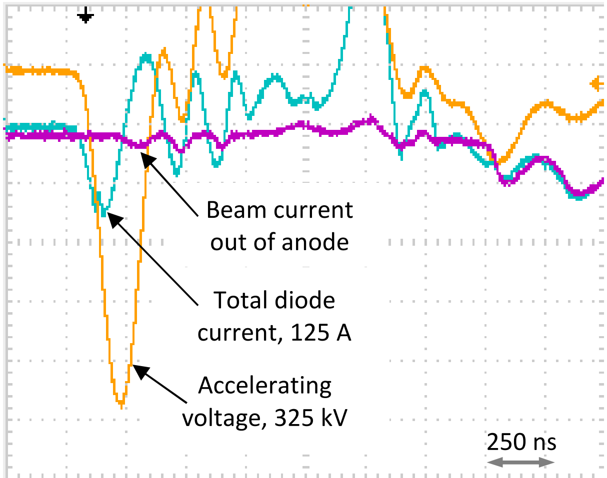

Fig.7. Diode voltage and current signals of transformer-based accelerator with water supply of the cathode after 10^3 pulses of beam current.

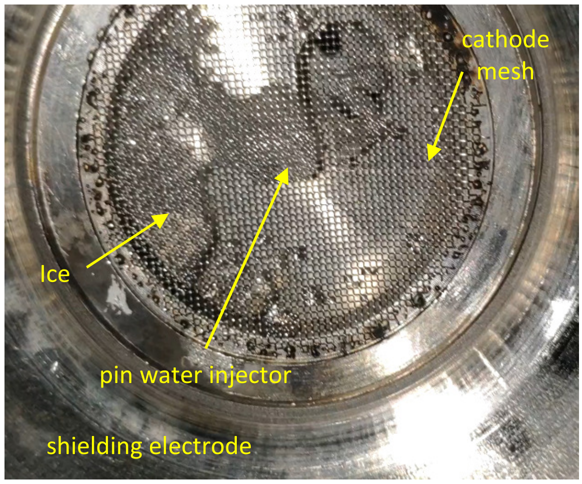

Fig.8. Water supplied cathode view after electron beam experiments with transformer-based accelerator.

Thus, the minimum liquid flow rate provided by the external supply system based on a long tube of ~3 mg/s made it possible to generate an electron beam during 10^3 pulses. Reduction of the voltage pulse duration from ~500 ns to 130 ns at voltage rise rates of $2{\cdot}10^{12}$ V/s and $5{\cdot}10^{12}$ V/s, respectively, led to shorting of the accelerating gap without registration of the beam current brought out beyond the anode. The number of pulses was limited by icing of the point liquid injector on the cathode, followed by a change in the operating mode of the diode. The data obtained indicate the need to reduce the minimum flow rate of the liquid and take measures to prevent icing of the cathode assembly. In addition, the modes of substance injection into a vacuum volume used are highly loaded for pumping systems based on cryogenic pumps and require a revision of the approach to building vacuum accelerator systems.

4. Conclusion

As a result of the work, test data for the system with external liquid supply to the cathode of a vacuum electron diode were presented. The change in the vacuum conditions from 10^{-6} Torr to 10^{-3} Torr in the diode during the injection of water was monitored for water supply of 3 mg/s. The system was tested when a high voltage pulse is applied to the cathode from Blumlein line generator and transformer based one separately. Both experiments resulted with icing of the pin water injector and keeping of the short circuit mode from pulse to pulse. Nonetheless, electron beam current has been demonstrated out of anode grid in experiments with transformer-based accelerator for more than 10^3 pulses. Thus, the direction for future developments of liquid supplied cathode was established.

Acknowledgement

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