Stabilization of the pulse current in the electron accelerator with a grid plasma emitter

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Stabilization of the pulse current in the electron accelerator with a grid plasma emitter

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Abstract. The experiments carried out in this work were aimed at increasing the work stability of the electron accelerator with a grid plasma cathode with the output of a large cross section beam into the ambient atmosphere. The instability of the beam current is related to its uncontrolled growth during the pulse at a constant value of the discharge current. Such an increase in the beam current can be due to several reasons. Namely: ionization of the working and desorbed gases in the accelerating gap and a change in the potential distribution in it, which leads to an increase in the electric field in the gap, and, accordingly, to changes in the parameters of the emission plasma, and as a result, to the violation of the layer stabilization of the grid plasma cathode. It is shown that an increase in the beam current can be compensated by a corresponding decrease in the concentration of the emission plasma during the beam current pulse. The flat top of the beam current pulse makes it easier to set up a scientific experiment and can be very important in various technological processes.

1. Introduction

When designing and creating electron accelerators for both scientific and technological purposes, one of the main problems that substantially determines its technical and technological capabilities is the development of power supply systems and control of the electron source [1]. The literature analysis shows that traditional electron accelerators based on thermal cathodes, in addition to low energy efficiency associated with significant electric power costs for heating the cathode [2]. The complexity of operation at relatively high beam current densities and low cathode lifetime, have such a significant drawback as high inertia, i.e. inability to work on the duration of the current pulse of the microsecond range due to the inertia of heating the cathode. Most often, such a problem is solved by introducing additional control electrodes into the design of the electron accelerator, which, however, leads to a complication in the design of the accelerator as well as in its power supply and control circuits.

Electron accelerators based on explosive electron emission (EEE) [3] have a relatively small operating lifetime (10⁷ imp.), the ability to achieve high beam current densities (≥1 kA/cm²) at a relatively high inhomogeneity of the current density distribution over the beam cross section (±20%) and the complexity of realizing the beam pulse duration exceeding tens of microseconds [4-6]. In addition, such electron accelerators are distinguished by changing the parameters of the generated beam from pulse to pulse during resource tests, since it is very difficult to achieve a stable value of the electric field strength needed to initiate the EEE at each individual point [4]. From the point of view of
controlling such electron accelerators, their main disadvantage is the interdependence of the main beam parameters and the complexity of controlling these parameters.

Electron accelerators with plasma cathodes and layer stabilization of the emission-plasma boundary occupy a separate place [7-13], which allows to provide a wide range of tuning of the generated beam parameters, since changing the plasma parameters changes the position of the plasma boundary slightly. The control of the beam current in such systems, characterized by a minimum inertia, can be carried out either by a controlled change in the near-wall layer [14] or by changing the concentration of the emission plasma, i.e. by controlling the magnitude of the discharge current in the plasma cathode [15].

However, since an intense gas desorption occurs in such systems, the ionization of this gas in the accelerating gap, the increase in the electric field intensity in it, the violation of the layer stabilization of the emission-plasma boundary, and other processes destabilizing the operation of the electron accelerator, most often lead to the breakdown of the high-voltage accelerating gap [15-17]. In this paper we investigate the possibility of introducing feedback into the discharge power supply to stabilize the beam current in the pulse duration by "instantaneous" correction of the discharge current shape.

2. Experimental procedure and results discussion
The experiments were performed using an electron accelerator with a multi-aperture grid plasma cathode based on a low-pressure arc discharge with the output of a generated large cross section beam into the ambient atmosphere [18]. A simplified scheme of the electron accelerator, which makes it possible to form a beam with a cross section of 750×150 mm$^2$ in the pulse-periodic mode, is shown in figure 1.

![Figure 1](image_url)

*Figure 1. Electron accelerator with grid plasma emitter: 1 – plasma cathode; 2 – cathode; 3 – igniter electrode; 4 – emission grid; 5 – mask; 6 – hollow anode; 7 – support grid; 8 – output foil; 9 - discharge power supply; 10 – igniter power supply; 11 – high-voltage capacitor bank; 12 – collector.*

The plasma cathode in such an accelerator is a hollow half-cylinder of stainless steel with two cathode units [19]. On the ends of cathode are fixed on the basis of a low-pressure arc with the initiation of a cathode spot by electrical breakdown in a gas with the aid of a power supply generating pulses with an amplitude of up to 5 kV, current $\approx$2 A, duration 5 microseconds. Initiation of the cathode spot leads to ignition of the main discharge between the cathodes and the inner surface of the semicylinder that is a common hollow anode for two cathode units. The space of the plasma cathode is filled with an emission plasma, the boundary of which is stabilized by a fine-mesh metal grid with a cell size (0.4×0.4 mm) with overall dimensions (750×150) mm, on which a stainless steel
mask 5 with a thickness of 200 μm is laid. The mask divides the emission surface into 344 macrocells \( \Phi 12 \) mm, which are separate emission structures of the plasma cathode. Under the action of a constant accelerating voltage of up to \( U_0 \leq 200 \) kV applied between the cathode and the output foil window, electrons are taken from the plasma surface area of these emission structures. Their accelerates and release into the ambient atmosphere or high-pressure gas through the output foil 8 laid on the support grid 7, in which 344 holes of \( \Phi 15 \) mm (coaxial with holes in the mask) are made.

Constant accelerating voltage is provided by a high-voltage capacitor bank with a total capacitance of \( C=0.26 \) μF, which has a maximum voltage change per maximum beam current pulse, not more than 5%.

The power supply source of the discharge is constructed according to the scheme “flyback two transistor” (figure 2). When the transistors of the single-cycle inverter \( I \) are opened, the rectified voltage is applied from the filter capacitance \( F \) to the two two-winding chokes \( L \) (in figure 2, for simplicity, only one choke is shown), wound with a transformation ratio of \( n=2 \). This makes it possible to achieve a voltage gap near \( U=300 \) V between cathode 2 and hollow anode 6 (see figure 1). Each choke is designed so that the amplitude of the discharge current decreases by no more than 50% for a pulse duration \( t=100 \) μs. It can be seen from figure 1 and 2 that the choke current is the discharge current \( I_d \) (the current sensor is installed in the anode circuit of the discharge power supply). Using the data from the current sensor in the accelerating gap \( I_0 \), which is set on the positive input of the high-voltage capacitor bank, it is possible to determine the part of the current \( I_{HA} \) closing through the emission grid 4 and the hollow anode 6, which is the difference of the currents \( I_{HA}=I_d-I_0 \). This statement is based on the analysis of the oscillogram shown in figure 3, from which it can be seen that in an unstable operating mode with increasing current \( I_0 \) a proportional increase in the beam current \( I_b \) outputed into the atmosphere takes place. Such a proportional change of the two signals allows us to conclude that the number of accelerated ions increases insignificantly, which is one of the terms in the common current in the accelerating gap \( I_0 \). Most likely, this increase in current in the accelerating gap is associated with an increase in the coefficient of electron extraction from the plasma emitter into the accelerating gap.

![Figure 2. Block diagram of the discharge power supply: TVHV – high-voltage dividing transformer; R - rectifier; F – filter; I – inverter; L – choke; D – load when the discharge current is closed through the hollow anode; B – load, when the discharge current closes through the accelerating gap (electron beam). Dotted lines marked the connection on the fiber.](image)

It should be noted that usually such increase is limited by electrical breakdown of the high-voltage accelerating gap.

Since the arc discharge voltage depends weak on the discharge current, it follows from the mathematical model of the choke that the beam current has a practically linear character of the time variation. It can be seen from the oscillogram shown in figure 4 that the decrease of the discharge current in time with a speed of \( \approx 0.5 \) A/μs leads to compensation of the current \( I_0 \) growth, which eventually has a quasi-constant flat top, and the beam current pulse itself is rectangular.
Figure 3. The oscillogram of the current in the accelerating gap $I_0$ and the beam current $I_b$ outputed into the atmosphere at an accelerating voltage of 200 kV in experiments without a mask 5 (see figure 1). Scale: horizontal 10 $\mu$s/div., vertical for $I_0$–2 A/div., for $I_b$–0,5 A/div.

Figure 4. Correction of current in the accelerating gap $I_0$ by reducing the discharge current $I_d$ during the beam current pulse in experiments with mask 6 (see figure 1). Scale: horizontal 20 $\mu$s/div., Vertical 10 A/div.

3. Conclusion

The possibility of compensation of uncontrolled current growth in the accelerating gap, and, consequently, of the beam current in the atmosphere during the pulse is demonstrated experimentally. Compensation is achieved by reducing the plasma density in time by using a discharge power supply with a falling vertex. Since in practice the shape of the beam current can be either growing or falling, the discharge current must be monitored by introducing a negative current feedback in the accelerating gap. Simultaneously with the stabilization of the beam current, this solution makes it possible to increase the electrical strength of the high-voltage accelerating gap. It is associated with a decrease in the probability of formation in the accelerating gap processes destabilizing the work of the electron accelerator, for example, such as desorption of gas from electrodes by electron bombardment, violation of electron optics and stabilization of the emission plasma boundary, etc.

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