Increasing the operation stability of the electron accelerator based on ion-electron emission

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Abstract. This paper presents the results of studying the stability of the plasma emitter of an electron accelerator based on ion-electron emission during the transition from self-sustained continuous to self-sustained frequency (up to 50 kHz) repetitively pulsed generation of an auxiliary glow discharge with a hollow cathode with an area of 20.8×10^3 cm^2. The experimental dependences of the probability of the appearance of cathode spots on the walls of a hollow cathode per unit time on the operating modes of the plasma emitter (pressure and type of working gas, amplitude of the auxiliary discharge current) are presented.

1. Introduction

Accelerator technology is a topical area for studying fundamental physical processes, as well as new possible applications in the applied field, since charged particle beams have properties that are unique in nature, which makes it possible to obtain various radiation effects. One of the areas of accelerator technology is the generation of large cross-section electron beams (LCB). These beams are characterized by a cross-sectional area of ~ 100 and even ~ 1000 cm^2 and are often extracted through a thin metal foil into the atmosphere or other extravacuum space, where the accelerated electrons interact with matter. LCB are capable of providing high productivity due to a large processing area and can have a relatively small inhomogeneity of the current density over the cross section, which in certain cases is an important aspect [1]. Currently, several types of electron accelerators are known, differing both in the principle of operation and in the parameters of the generated electron beams [2-4]. These differences concern not only the range of beam parameters, but also the nature of its generation (direct, pulsed, or pulse-periodic method of beam generation). Whatever the method for generating an electron beam, all this variety of accelerators continues to develop intensively, applying more and more new technical solutions for this.

In electron accelerators based on ion-electron emission and non-self-sustaining high-voltage glow discharge (HVGD), the stability of operation is determined by the probability of HVGD transition to the arc form. The transition of the HVGD to the arc form of discharge burning can be due to several reasons, namely, the exacerbation of the electric field at the cathode of the HVGD (due to the presence of micropoints or charge accumulation on any dielectric inclusions), violation of gas conditions (uncontrolled increase in the pressure of the working gas) disruption of the plasma emitter [5]. In the latter case, when an auxiliary glow discharge (AGD) is used to generate emission plasma, the
instabilities can be associated with the appearance of cathode spots on the walls of a hollow cathode and the transition of a glow discharge into an arc [6], which leads to a local increase in the concentration of emission plasma, disruption of ion-electronic optics, an increase in the density of the ion current at the cathode of the HVGD, when a certain value of which is exceeded, an electrical breakdown of the high-voltage accelerating gap occurs. Since the plasma emitter in an electron accelerator with a non-self-sustained HVGD largely determines the stability of the accelerator as a whole, in this work, we experimentally investigated the quantitative dependences of the probability of the appearance of cathode spots on the operating modes of the plasma emitter (direct and pulse-periodic).

2. Experimental technique
The work was carried out on a wide-aperture electron accelerator based on ion-electron emission with a non-self-sustained HVGD and extraction of the generated beam into the atmosphere [7].

![Schematic Diagram of an Electron Accelerator](image)

Figure 1. Schematic diagram of an electron accelerator.

The design of the accelerator (figure 1) includes two main areas: the area of generation of an AGD to create anode plasma and the area of combustion of the main non-self-sustained high-voltage glow discharge. The boundary between these regions is established by means of an anode grid, the configuration of the holes in which repeats the configuration of the holes in the support grid of the outlet foil window. The role of the AGD is performed by an independent glow discharge, in which two tungsten wires are the anode and the walls of the vacuum chamber as the cathode. The working gas helium is admitted into the combustion region of the AGD between the wire anodes. The boundary of the AGD plasma in such a system is not stabilized, but mobile, and its position depends on the conditions of electron beam generation [5]. Ions are extracted from the boundary of the emission plasma through holes in the anode lattice, are accelerated in the accelerating gap, and bombard the high-voltage cathode of the main discharge, which leads to ion-electron emission. Some of the ions are neutralized in the high-voltage gap, and the bombardment of the cathode in this case is carried out by neutrals having a wide energy spectrum [8]. As a result of such bombardment, electrons arise, which are also accelerated in the accelerating gap and, passing through the holes of the anode and support grids, are released into the atmosphere through a thin metal foil.

3. Main results
In order to evaluate the stability of the plasma emitter, and, consequently, of the electron accelerator as a whole, the deterioration of which is associated with the appearance of cathode spots on the surface of
the hollow cathode, it was decided to investigate the dependence of the number of cathode spots on the operating modes of the plasma emitter, namely, pressure and type gas in the working area of the AGD generation. The total number of cathode spots in the plasma emitter, as well as the degree of their growth per unit time, determine the stability of the operation of the electron accelerator as a whole. Figure 2 shows a schematic diagram of the experiment. In order to increase the cathode spot current, in view of the need to improve the registration properties of the cathode spot fixation circuit, an external capacitance $C_{out}$ with a nominal value of 7 nF was introduced into the anode-cathode circuit, parallel to the discharge power supply, which makes it possible to increase the duration of the arc current, as well as a small resistance $R_m$, rated to 20 ohms in order to limit the discharge current of the capacitor $C_{out}$. Registration of the appearance of cathode spots was carried out using an oscilloscope, as well as with the help of an "arc counter" built into the discharge power supply, which is triggered at an instantaneous value of the discharge current of 12 A. Nitrogen was used as a working gas in this experiment.

Since helium is the working gas for this system, the study of dependences on it is essential to determine the stability of the operation. When carrying out the experiment according to the scheme shown in figure 2, it was not possible to register the cathode spots within 15 minutes of the AGD source operation. In order to fix the cathode spots and determine the probability of their formation from the modes of combustion of the AGD, the studies were carried out using nitrogen and argon as working gases.

Figure 3 shows a comparison of the frequency pulse-periodic and continuous modes of generation of an AGD at the same average current of 150 mA. First, for two modes, the dependencies were built with the electrode system, which was out of work for 1 day. Then dependencies were built after 1 hour of waiting (second in figure 3). When comparing the graphs (circle and square) at direct current (DC), a significant decrease in the number of cathode spots is observed. We can say that the blue graph is a continuation of the green one, since they were made at the same currents, and this dependence is due to the effect of training the electrode system (reduction of adsorbed gas and dielectric inclusions on the walls of the hollow cathode). The same situation is observed in the pulse-frequency mode (triangle and rhombus in figure 3). When comparing the continuous mode and the pulse-frequency mode, it can be seen that in the latter, the number of cathode spots in the given time is less, while the angle of inclination after waiting 1 day is also smaller. This behavior of the system in the pulse-frequency mode is probably due to two reasons: 1) at the same average current in the pulse-frequency mode, the amplitude value is higher depending on the selected pulse filling factor, therefore, at the moment of pulse generation, the plasma concentration is higher, which in turn changes the size of the near-cathode layer and increases the flow of ions to the cathode surface, capable of etching dielectric inclusions; 2) at the moment of the pause between the discharge current pulses, the flow of electrons to the walls of the vacuum chamber, which at this moment are not the cathode, to some extent compensates for the accumulated positive charge on the dielectric inclusions, which also reduces the likelihood of the appearance of a cathode spot during discharge generation.
Figure 3. Dependence of the number of cathode spots on the operation time of the accelerator at continuous \((I_d = 30 \text{ mA})\) and pulse periodic \((f = 20 \text{ kHz}, \ D = 50\%)\) operating modes when using nitrogen as a working gas \((p = 0.4 \text{ Pa})\).

In order to assess the degree of influence of the working gas on the occurrence of cathode spots, as well as to estimate the number of cathode spots when working on reaction and inert gases, the working gas was changed to argon (figure 4). The obtained dependences fully confirm the results obtained when working on nitrogen, namely, the effect of training the accelerator over time, as well as the predominance of the pulse-frequency mode over the mode of operation on direct current.

Figure 4. Dependence of the number of cathode spots on time at continuous and pulse-periodic \((f = 20 \text{ kHz}, \ D = 50\%)\) operating modes when operating on argon \((p = 0.55 \text{ Pa})\).
Figure 5 shows the dependence of the number of cathode spots on the operating time of the system at different pressures and modes, but with the same discharge burning current $I_d = 80$ mA, from which it can be seen that when operating in the same mode with the same current, the number of cathode spots decreases when the pressure rises.

![Graph showing the dependence of the number of cathode spots on the operating time at different pressures in the system when operating in continuous and pulse-periodic ($f = 10$ kHz, $D = 80\%$) modes (work gas is nitrogen).](image)

**Figure 5.** Dependence of the number of cathode spots on the operating time at different pressures in the system when operating in continuous and pulse-periodic ($f = 10$ kHz, $D = 80\%$) modes (work gas is nitrogen).

4. **Conclusion**

1. An experimental assessment of the probability of the appearance of cathode spots was carried out during the operation of the plasma emitter of the accelerator in both continuous and pulse-periodic modes, which showed the advantage of the pulse-periodic mode of operation over the continuous one, which consists in reducing the number of cathode spots per unit time and accelerating the training process.

2. Assessment of the influence of the working pressure on the stability of the system operation showed that it plays a significant role in the appearance of cathode spots on the cathode surface - with an increase in the working gas pressure, the number of cathode spots decreases. In the course of experiments and calculations, the advantage was given to helium, due to its higher etching coefficient and dielectric strength. The working pressure range for the stable operation of the plasma emitter of the electron accelerator on helium is $(0.7\div1.2)$ Pa below which the AGD behaves less stable, and above which the dielectric strength of the high-voltage accelerating gap decreases with the impossibility of keeping the voltage above 160 kV.

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