Study of Electron Beam Emitter Based on a High Current Arc Plasma Source [1]

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Abstract – Experiments have been performed on the use of high-current arc plasma generator for a dense long-pulsed electron beam production. In the starting experiments the electron beam was obtained in a single-aperture two-electrode optical system with accelerating voltage up to 30 keV, beam current density up to 70 A/cm² and a pulse duration (defined by the power supply unit) of 0.25 ms.

1. Introduction

At present, the efforts are undertaken at BINP to develop an electron beam with particles energy above 100 keV, beam current in the range of kiloamperes and a pulse duration of 100 µs or more. The beam with such parameters is of interest for plasma heating in multimirror trap GOL-3 [1] and possible other applications.

An elaborated technique of powerful electron beams production with an explosive emission cathodes is inappropriate in the case of long pulsed beams due to limitations set by accelerating gap shortening with an explosive plasma. The plasma electron emitter on a base of high-current arc discharge seems a promising solution of the problem.

Solid experience is accumulated at BINP for development and use of high-current arc plasma generators. A number of the versions of such generators with cold and heated cathodes, pulse duration from 0.1 ms to 2 s and discharge current up to 1 kA are used for various purposes, especially for a high perveance proton beams production [2-3].

In the presented experiments we employed a high-current arc generator with cold cathode as a plasma source for electron beam extraction.

The first-stage task for the experiments was the determination of maximum current density which can be obtained from the plasma emitter in the simple single-aperture accelerating system with the duration of electron beam no less than 100 µs.

2. Experimental Device

A schematic layout of the electron beam source is shown in Figure 1. Main elements of the source are held on a ceramic insulator. The arc ignites between a cold aluminium cathode and copper anode. A stack of
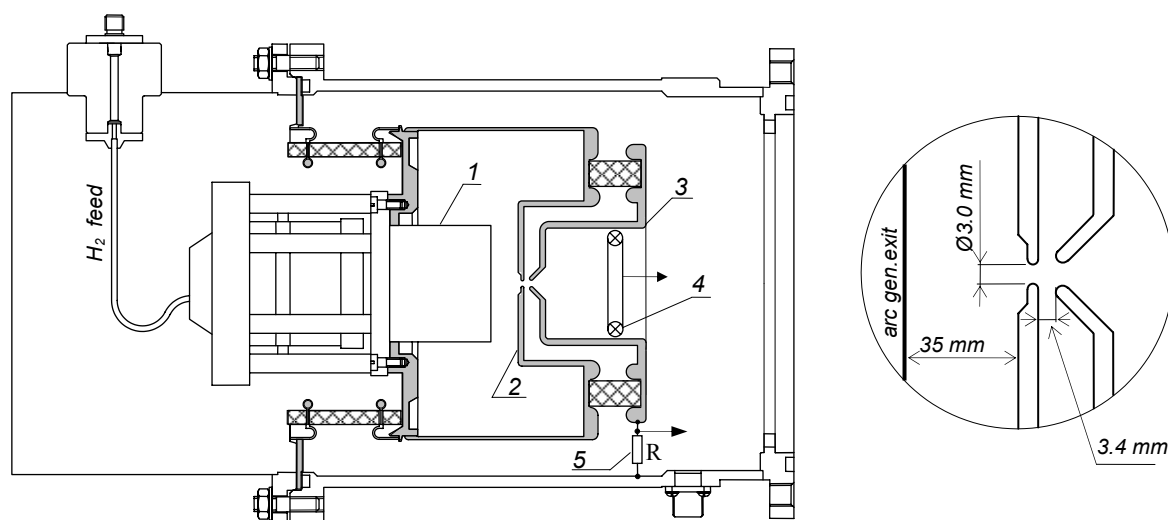

Fig. 1. Schematic of the electron beam source. *1*– arc plasma generator; *2* – plasma electrode (connected to the arc anode); *3* – electron beam extractor (grounded electrode); *4* –beam current measuring coil; *5* – current to the extractor measuring shunt

isolated metallic washers with inner diameter of 5−12 mm forms the discharge channel. Working gas (H_2 in our experiments) is puffed through a hole in the cathode with a pulsed electromagnetic valve. The arc discharge is maintained by *LC* pulse forming network, and the discharge current can be applied up to 600 A. The duration of discharge defined by the power supply was 0.25 ms. The plasma comes out from the anode orifice of 1 cm diameter with the density of $n_e \geq 10^{14} cm^{-3}$ and the electron temperature $T_e \approx 5{-}10$ eV. The plasma density and temperature are controlled by the discharge current and the gas supply rate. To increase the plasma outcome the magnetic insulation of anode region is provided by a special coil. The more detailed description of the arc plasma generator can be found in papers [4-6].

As the first step two-electrode system was used for the electron beam extraction and acceleration. Both the plasma and the beam extracting electrodes were made from stainless steel. Detailed geometry of the extraction system is depicted in the insert in Fig.1. The distance between the arc anode orifice and plasma electrode can be varied thus changing the plasma density at the electrode. In the present experiments this distance was set to be 3.5 cm. A 0.25 ms rectangular voltage pulse up to 30 kV from high-voltage modulator is delivered to the arc anode which, in turn, is connected with the plasma electrode. An extracting (accelerating) electrode is grounded through the low-ohmic shunt to allow measuring of the beam current precipitation on the electrode. The current of the beam electrons is measured by a Rogowski coil placed behind the opening in the extracting electrode. The net current from the HV modulator is also measured by a coil.

The beam source is encased in a stainless-steel housing and attached by a flange to the vacuum vessel which is pumped out with a turbovac down to a residual pressure of $6 \cdot 10^{-4}$ Pa.

3. Results and Discussion

In the experiments, for the given modulator pulse voltage the beam current is adjusted via arc discharge current, magnetic insulation field strength and gas supply rate. The arc is ignited with a delay relative to the voltage front, in the opposite case accelerating gap shortens immediately.

Waveforms for a typical shot are shown in Figure 2. The net current measured in high-voltage circuit is equal to the sum of the passed beam current and the current on accelerating electrode with a good accuracy. During the pulse the electrode current does not exceed 5% of the beam current. The maximum beam current obtained in the experiments for 29 kV accelerating voltage was ≈ 5 A, which corresponds to emitted current density of ≈ 70 A/cm^2. The

parameters of electron beam were confirmed also by the calorimetric measurements. Duration of the beam was determined solely by the power supply system.

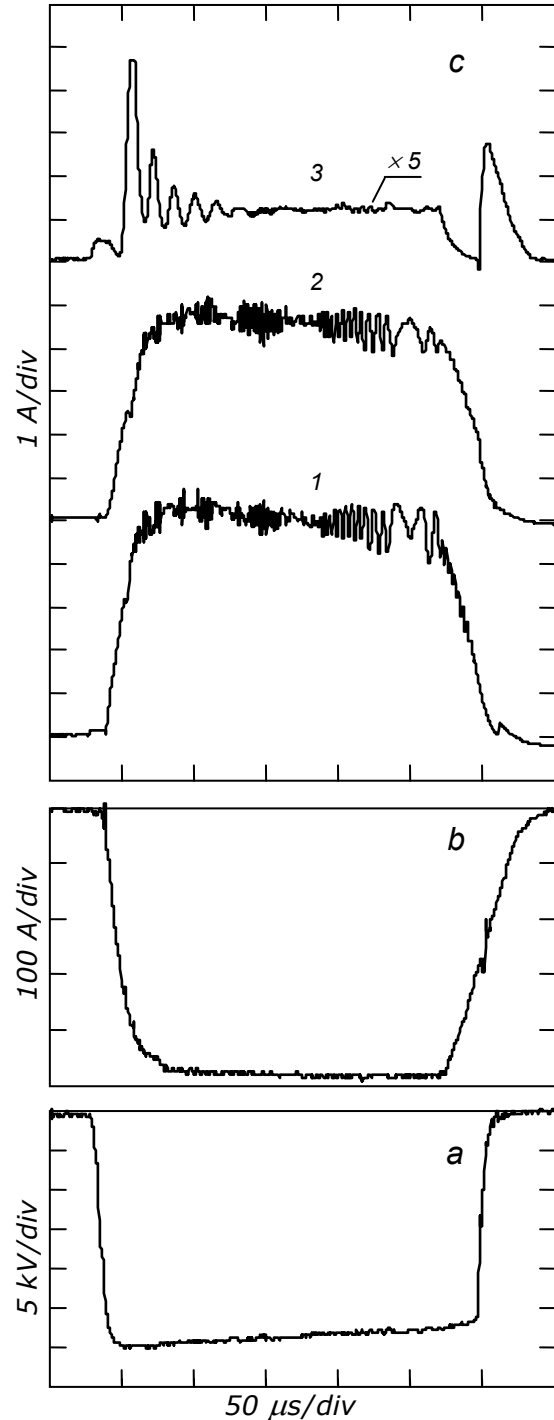The ray-tracing code PBGUNS Ver. 5.04 [7] was used to compute a perveance of the employed

Fig. 2. Waveforms for a typical shot: *a)* high-voltage modulator pulse, *b)* arc current, *c) 1* – net HV modulator current, *2* – electron beam current, *3* – current to extracting electrode (multiplied by 5)

accelerating gap, taking into account the position and shape of plasma emissive boundary. Numerical calculations give the value of limiting current ≈ 5.6 A that can be passed through the accelerating electrode aperture at 29 kV. As is evident, this value is close to that found in the experiment. This circumstance makes it possible to assume that the emitted current density of 70 A/cm^2 obtained in the experiment can be increased with appropriate design of the electrode system.

5. Acknowledgements

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