Application of a Plasma Anode in the Electron Beam Source with an Explosive Emission Cathode and Electron Beam Output into the Atmosphere

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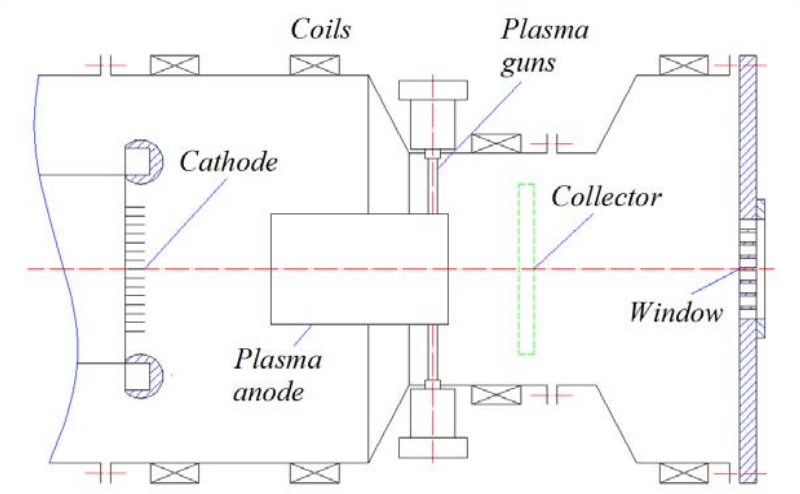
The task of the work was to develop an electron beam source with an explosive-emission cathode and a plasma anode for obtaining electron beams with an electron energy of up to 200 keV, a current of up to 2-3 kA, a duration of 5 μs of a rectangular cross-section up to 200 cm^2 with an energy of up to ~ 1 kJ and their output through a foil window into the atmosphere.

The use of a plasma anode with a guiding magnetic field, in comparison with traditional vacuum diodes, makes it possible to increase the current and duration of the beam, facilitates the realization of modes with quasi-constant values of the accelerating voltage and current, and provides the possibility of adjusting the beam current without changing the accelerating voltage.

To date, a laboratory model of an electron beam source with a plasma anode and a foil window has been developed and manufactured. Preliminary results have been obtained on the generation, transportation in an electron beam source with a plasma anode, and the extraction of circular and rectangular electron beams into the atmosphere in the presence of an external magnetic field and power supply of the source from a Marx generator based on artificial long lines with matched loads.

Electron beam source device and experimental technique



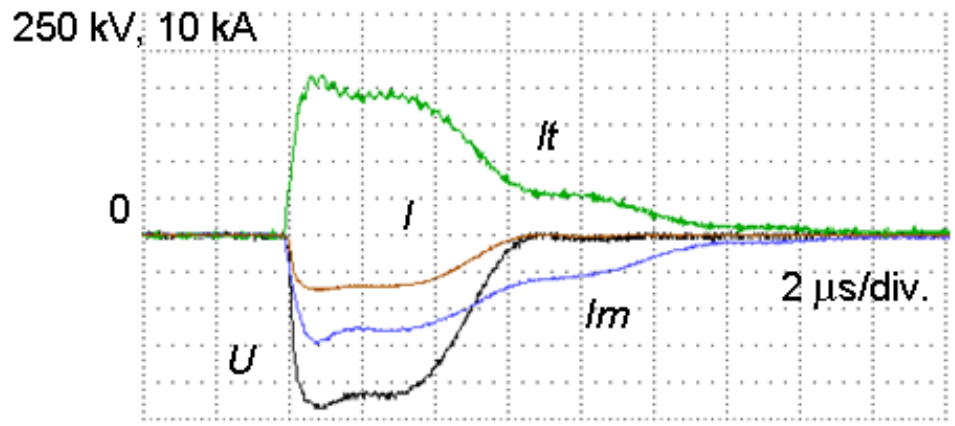
To obtain the beams of circular or rectangular cross-section, we used round and rectangular multipoint cathodes. The plasma anode was formed by filling with plasma from 4-8 plasma guns a metal cylinder 100 mm in diameter or a piece of rectangular pipe with a cross-section of 90×180 mm^2 and lengths of 180-150 mm, serving as an anode. A magnetic field of 300-700 G was used, which was close to uniform or growing towards the anode. The beam current was measured using collectors with diameter of 97-180 mm and a rectangular collector with dimensions of 110×220 mm^2.

Imprints, or autographs of the beam were obtained using viniproz, the sheets of which were mounted on a collector 180 mm in diameter and rectangular collector and covered with 20 μm thick aluminum foil. The collector 97 mm in diameter is equipped with a thermistor and at the same time was used as a calorimeter with a receiving surface area of 74 cm^2. The values of the energy entering the collectors were calculated from the waveforms of the voltage and current of the beam. The total energy supplied to the electron beam source was also calculated from waveforms of the generator voltage and current. The output window with dimensions 115×225 mm^2 was covered with an AMG-2n aluminum-magnesium foil 30 μm thick. Geometric transparency of the grid is 80%, edge height is 10 mm. The structure of the extracted beam was recorded using viniproz; energy measurements were performed using a set of TPI-2m calorimeters with a total receiving surface area of 120×240 mm^2.

Marx generator

In the experiments, a previously developed Marx generator with stages on the base of artificial long lines with matched loads was used. The generator provides near-rectangular voltage pulses without reflections at a constant arbitrary resistive operating load.

The operation of the generator at a constant resistive load (R = 75 Ω), not equal to the matched one, is illustrated by the waveforms below. It can be seen that there are no reflected pulses at the operating load.



Line parameters:

Number of links: 6

C = 0.19 μF

L= 3.4 μH

ρ = 4.3 Ω

τ = 5 μs

Matched loads:

Rm = 4.2 Ω

Generator parameters:

Number of stages: 6

Wave impedance:

ρ = 25 Ω

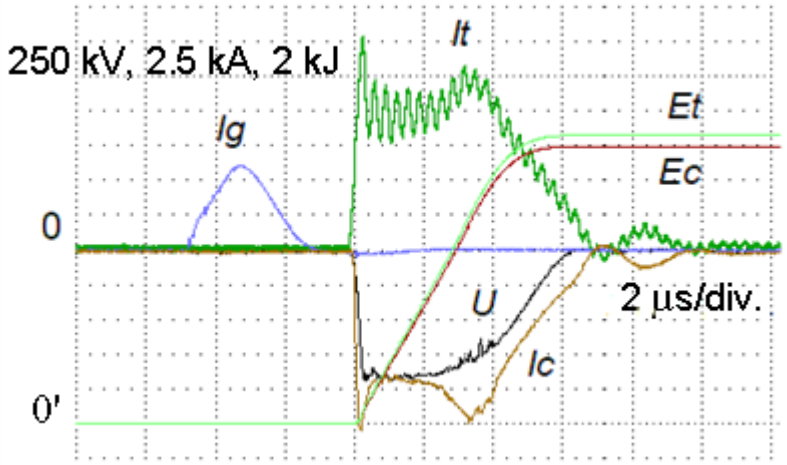
Operating loads:

R = 25-80 Ω

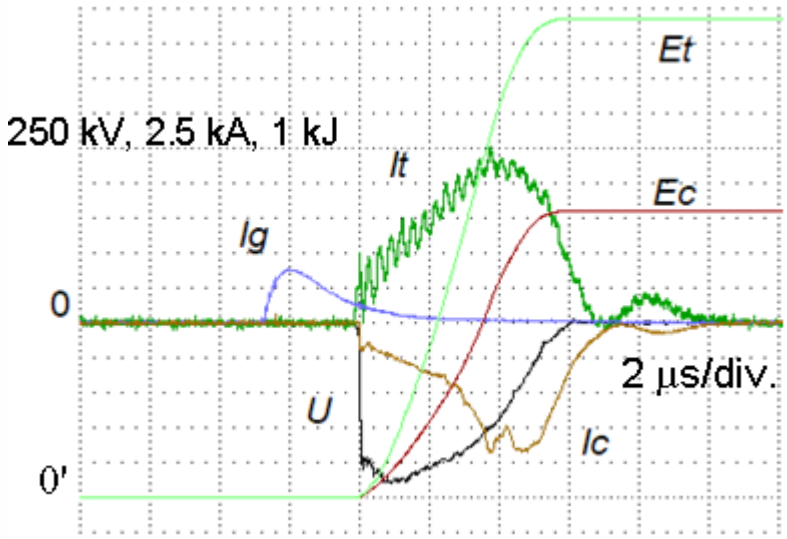
Output voltage is ~ 200 kV

Waveforms of the voltage across the operating load (U), the currents of the operating (I) and matched (Im) loads, and the total current (It) at the generator discharge to the working load of 75 Ω. The charging voltage Uch = 50 kV.

Beam parameters



***a*) Round cathode diode**



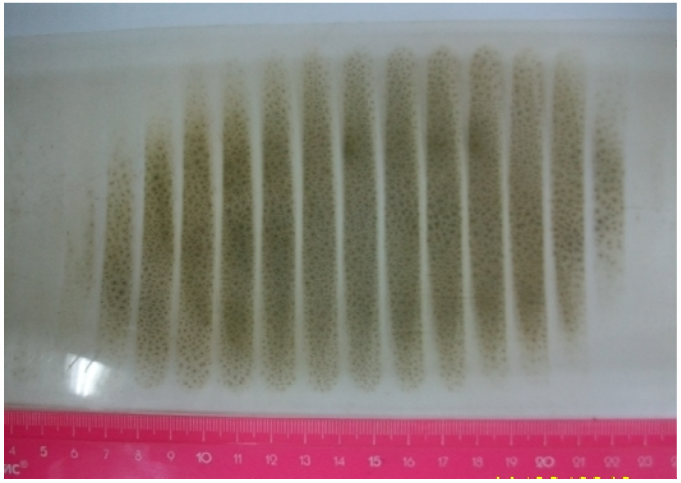
***b*) Diode with rectangular cathode**

Waveforms of the diode voltage (*U*), total diode current (*It*), the plasma guns current (*Ig*), and the beam current (*Ic*), entering the collector 180 mm in diameter (*a*) and rectangular collector (*b*). Calculated from waveforms the time dependences of the beam energy (*Ec*) entering the collector and the total energy (*Et*) entering the electron beam source. For convenience, the graphs of the dependences *Ec*(*t*) and *Et*(*t*) are shifted downward from the zero line. Generator charging voltage *Uch* = 45 kV.

The modes of operation of an electron beam source with a quasi-constant accelerating voltage of ~ 200-220 kV and a 5 μs duration of the beam are realized without breakdowns formation of the interelectrode gap.
The energy values of the electron beam arriving at the collector 97 mm diameter, recorded with a thermistor, reach 600-700 J / pulse, while they are ~ 0.6-0.7 of the values calculated from the waveforms. The values of the beam energy entering the collector 180 mm, taking into account the date of the temperature measurements, are ~ 1 kJ / pulse.
A decrease in the energy of a rectangular beam may be due to its rotation.

Autographs of the rectangular beam

a

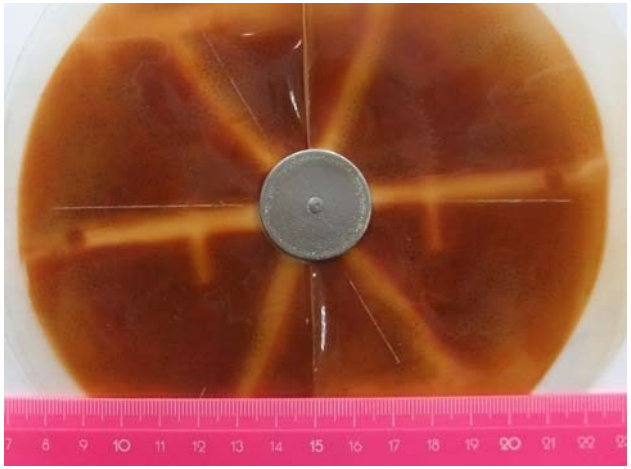


b

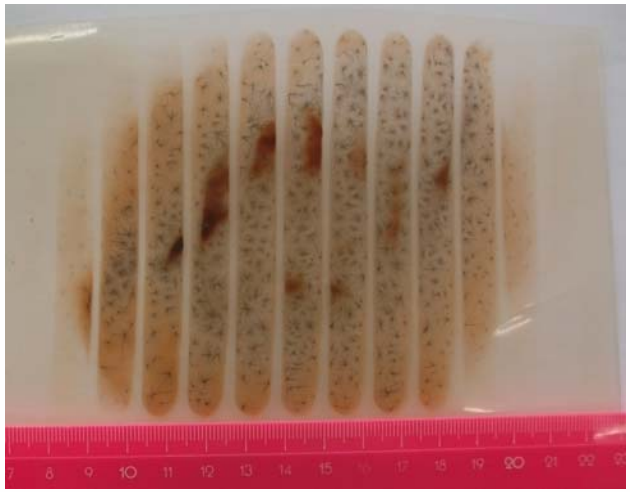
Autographs of the beam emitted from a horizontally mounted rectangular cathode on a viniproz sheet placed behind the plasma anode 5 cm from the plasma guns (*a*) and the beam emitted from a cathode rotated around the axis of the beam counterclockwise by 20° on a viniproz sheet installed behind the output foil (*b*). Preliminary turn of the cathode was used to improve the matching of the beam cross section with the aperture of the output window. The superimposed external magnetic field is directed from the anode to the cathode. The number of successive pulses of the electron beam is 5.

The maximum values of the beam energy extracted through the foil window and recorded with TPI-2m calorimeters are ~ 150-200 J / pulse.

Autographs of the beam from the cylindrical cathode



a



b

Autograph of the beam on the sheet of viniproz, placed on the collector 7-8 cm from the axes of the plasma guns (*a*). The print shows a shadow from the flag strip, set horizontally 16 mm from the collector surface. Autograph of the extracted beam on the viniproz sheet installed behind the foil (*b*). The direction of the external magnetic field is from the cathode to the anode. A counterclockwise rotation of the beam is visible. It is possible to decrease the angle of rotation by adjusting the magnetic field distribution in the electron beam source.

The maximum values of the beam energy extracted through the foil window into the atmosphere are ~ 250-270 J / pulse.

Conclusion

In the electron beam source with the explosive-emission cathode and plasma anode powered by Marx generator based on artificial long lines with matched loads at the accelerating voltage of up to 200-220 kV, electron beams with current of up to 2.5-3 kA, pulse duration of 5 μs, and cross-section of 100-200 cm^2 without formation of breakdowns in the interelectrode gap were obtained. The energy values of the electron beam, determined by the heating of the collector with a receiving surface area of 74 cm^2 using a thermistor, reach ~ 600-700 J / pulse and are 0.6-0.7 of the energy values calculated from the waveforms of the voltage and current of the beam. The energy of the electron beam entering the collector with large diameter of 180 mm, calculated from waveforms taking into account the temperature measurement date, reaches ~ 1 kJ / pulse. The maximum energy of the beam extracted through the foil into the atmosphere, recorded with calorimeters, is ~ 250-270 J / pulse.

Acknowledgment

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