PLASMA ELECTRONICS

EXPERIMENTAL INVESTIGATIONS OF INTERACTION OF SUPERCRITICAL ELECTRON BEAMS WITH PLASMA

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The first section of the collective ions acceleration based on simultaneous temporal and spatial modulation of relativistic electron beam (REB) was studied experimentally. The virtual cathode was originated in the electrodynamic structure consisting of two tubes with different diameters (jump of electrodynamics) by REB, produced in magnetically insulated diode. At plasma assistance the low-frequency oscillations of REB current and the low-frequency microwave radiation were obtained due to the virtual cathode periodical relaxation in the processes of charge compensation by ionized residual gas.
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1. INTRODUCTION

The structures with virtual cathode can be successful applied in collective accelerators of charged particles [1, 2]. They are an integral part of two-section collective ion accelerator based on simultaneous space and time modulation of relativistic electron beam [3,4]. In such accelerator the ions are accelerated by a field of space charge slow wave generated by a temporally modulated intensive electron flow, which is propagating in spatially periodic structure. The mechanisms of the low frequency excitation by ions moving in electron beams of the current above the space charge limiting one were studied in [5,6].
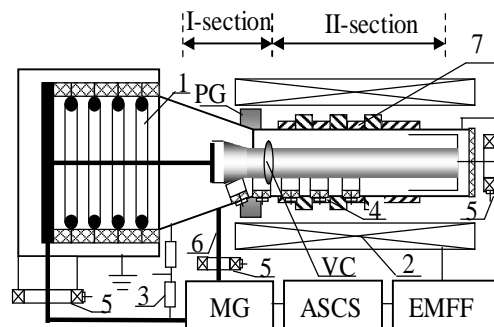
This work is a part of efforts aimed researches of a capability for creation of two-sectioned ion accelerator [1]. The essence of approach for the solution of this problem concludes to using of space charge fields in REB for the acceleration of intense ion beams. In the base of conception the collective ion acceleration by a synchronous slow space charge wave, that originates from simultaneous temporal and spatial modulation of REB. The temporary modulation arises during relaxation of virtual cathode at the plasma presence and spatial one is caused by the spatially - periodic magnetic field.

The basis of this article is experimental researches of the first section of collective ion accelerator. The conditions of formation of a virtual cathode in cylindrical electrodynamic structures are studied. The capability of low frequency modulation of REB by charge compensation of virtual cathode space charge by ionized residual gas in system is realized.

2. EXPERIMENTAL SETUP

In the vacuum structures with supercritical electron currents (above the space charge limiting current) a virtual cathode (VC) should arise. The problem of our research is to form VC in the anode tube (drift tube) of the magnetically insulated diode. It was achieved by making a jump of tube diameter. The arrangement for this experiment was performed in the first section of two-section collective ion accelerator [1]. The experimental setup of it is represented in Fig. 1.

In Fig. 1 the structure of the high-current REB accelerator is also shown. It is capable to generate the electron beam with energy up to 300 keV and current up to 4 kA at impulse duration of microsecond range. The Marx generator (MG) total energy is equal 0.9 kJ when each stage is charged by voltage of 30 kV.

Fig. 1. Collective accelerator of ions
MG – Marx generator; ASCS – accelerator starting and control system; EMFF – external magnetic field formation; VC – virtual cathode; PG – plasma gun.

The MG high-voltage pulse is applied to the magnetically - insulated diode (1). The cylindrical cathode was made from stainless steel. Its diameter was 31 mm and width of the emission edge was 0.1 mm.

The value of electron beam current is determined by diameter of input cylindrical anode, the diameter of which was equal 41, 46, and 50 mm and are provided with follow-up used constructers in the injection region of the beam. As it will be shown below the jump of electrodynamic structure is necessary for the virtual cathode formation. The inner diameter of the transport electron cylindrical liner (drift tube) is equal 50 mm.

The electron beam is conveyed by a longitudinal external magnetic field of the solenoid (2) with induction up to 1.33 T. In the cathode region the value of magnetic field was ~60 % from the value inside the solenoid. Such configuration of magnetic field forms the electron beam with diameter of 32 mm and wall thickness of 3 mm.

In Fig. 2 the cross-sectional portrait of electron beam is shown in the collector region after REB transporting by the homogeneous longitudinal magnetic field.

Fig. 2. *Portrait of electron beam*

High-voltage dividers (resistive (3) and capacitive (4)), magnetic sensors of currents (5) used on back current-conductor (6) of MG and together with Faraday cup which is as a current collector were used for the control and the measurements of parameters of the high-current electron accelerator. The periodic magnetic field is formed by means of alternating aluminum and iron rings (7), which was placed on the exterior of transport electron beam liner. The radial thickness of aluminum rings is equal 1 cm, and iron is 0.5 cm. The spatial period formed by rings on the second section of ion acceleration is equal 4 cm and the overall length of the structure has the value of 4÷5 periods. The external periodic magnetic field is necessary for ion acceleration in the second section by slow space charge wave of modulated REB.

In Fig. 3 the oscillograms of the main parameters of the high-current REB accelerator are shown. The peak values of the oscillograms correspond to following values: the input current of the magnetically - insulated diode is 4.4 kA, and the collector REB current is 3.4 kA, and diode voltage is 280 kV.
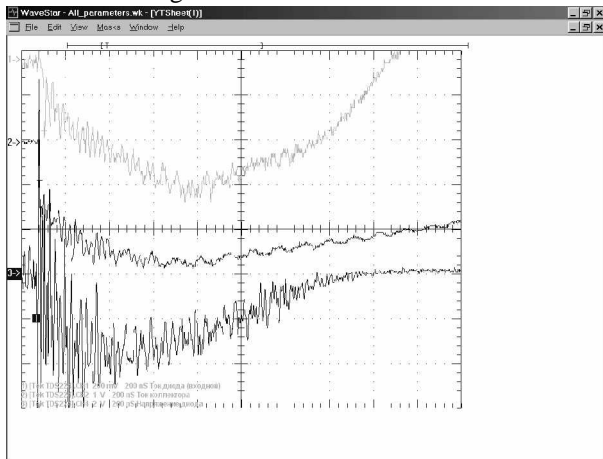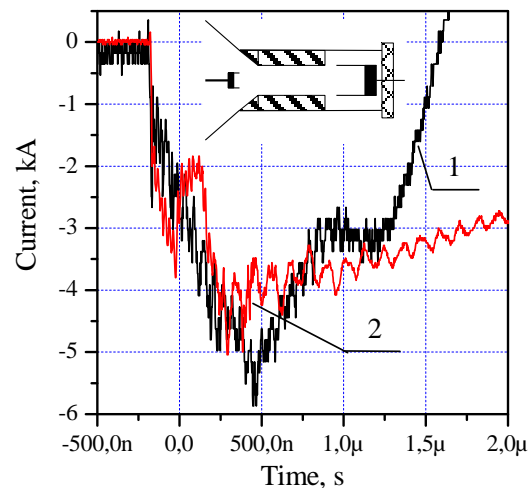

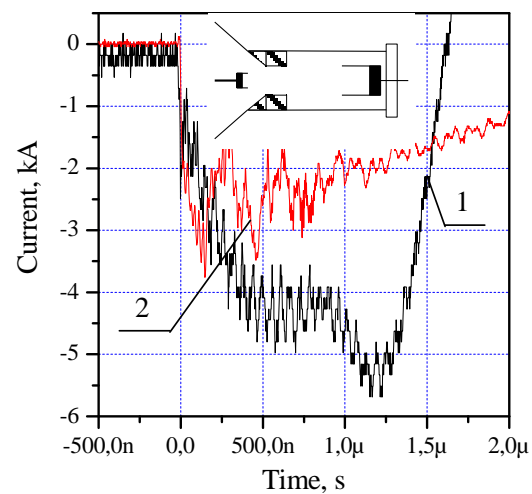Fig. 3. *Input (1), and collector (2) currents and diode voltage (3)*

3.VIRTUAL CATHODE FORMATION

The conditions of virtual cathode formation in the diode with magnetic insulation were studied using the cylindrical electrodynamic structures. Structures of two types: a circular tube of diameter 41 mm and waveguide with jumping namely "diode anodic unit of diameter 41 mm - cylindrical drift liner of greater diameter 50 mm" - were investigated experimentally.

In Fig. 4 the oscillograms of the diode input current and the REB current on the collector (Faraday cup) are shown. As it is seen from Fig. 4, a in the first case the REB current injected from the cylindrical cathode is transported without losses to the collector placed at the end of the drift liner and in the homogeneous magnetic field of induction 0.88 T. In the electrodynamic structure with jumping the REB current on the collector is much less than the diode input current and corresponds to value of a space charge limiting vacuum current in the drift liner (Fig. 4, b). It proves the possibility of the virtual cathode formation in the structure with jumping.

a)

b)

Fig. 4. *Current oscillograms*
1 – input diode current; 2 – collector current of REB
a) -tube diameter 41 mm; b) -jump of electrodynamic structure from 41 mm to 50 mm

4. PLASMA VIRCATOR

In case, when injected electron beam current exceeds the value of space charge limiting vacuum current in the given geometry, REB is locked in the drift liner under operating of a sagging space charge potential. The accumulated electrons form such potential distribution, that it can be looks like a virtual cathode. In Fig. 5 the oscillogram of input diode current (1) and the time

characteristic curve of the limiting vacuum current (2) during accelerator operation pulse are shown. From the Fig. 5 follows that in the transportation liner of electron beam the VC should be formed at beginning of the pulse.

In the structure with supercritical electron beams the oscillations of electrons between the cathode and virtual cathode forms a power microwave radiation (so-called, vircator-generator). In our case the frequency of these oscillations has a value of several GHz. At plasma assistance the low frequency modulation should take place in the system with virtual cathode. As a result of volume charge compensation the potential well disappears in the system, and accelerated ions in the well escape the region of virtual cathode. Thus, the system is returned in the initial state and the process is repeated periodically. As a result the high frequency oscillations of virtual cathode become modulated. Besides the relaxing potential well of virtual cathode modulates the REB current and accelerates plasma ions up to energies determined by the well depth.
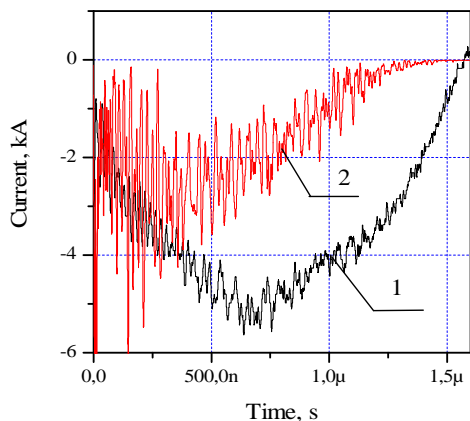

Fig. 5. Input diode current (1) and limited current (2) of electron beam

In Fig. 6 the oscillogram of the detected microwave radiation of vircator is shown. In our experiments the low frequency modulation of plasma vircator microwave radiation can be explained by charge compensation of virtual cathode space charge by ionized residual gas at pressure 2×10^{-4} Torr. The modulating frequency of microwave radiation has value ~40 MHz. It is necessary to notice, that the collector current of REB has the same value of modulating frequency (Fig. 3).
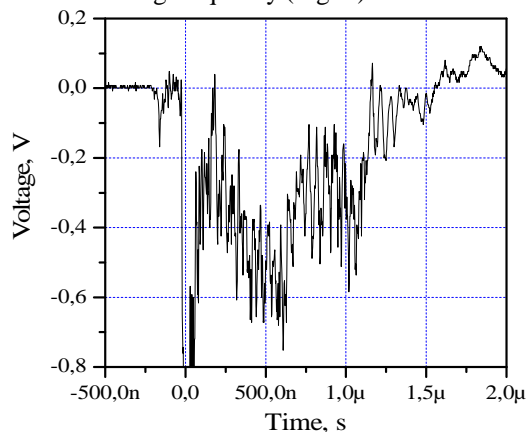

Fig. 6. Microwave radiation pulse

5. CONCLUSION

In this paper, the first section of the collective ions accelerator (Fig. 1) based on temporary and spatial modulation of the dense relativistic electron beam was experimentally investigated. The input current of the magnetically - insulated diode was obtained 4.4 kA from Marx generator with energy of 0.9 kJ. The transportation of electron beam with pick current of about 4.4 kA was realized along all drift liner with diameter of 41 mm. The virtual cathode was formed in the electrodynamic structure, which had the jumping of diameter from 41 mm to 50 mm. High microwave radiation generated of the virtual cathode was obtained.

In the condition of plasma assistance the low frequency oscillation of electron beam and low frequency microwave radiation were obtained by charge compensation of virtual cathode space charge by ionized residual gas. In the plasma vircator the plasma assistance leads to virtual cathode disappearance due to compensation its space charge by ions and to its subsequent relaxation restoration at plasma disappearance. Hence, there is an opportunity of low-frequency modulation, determined by the ion time of flight. This modulation is necessary to create the slow wave space charge in the second section. The further acceleration of ions will be occurred in a slow wave of a temporary-modulated electron beam at its subsequent spatial modulation by an external magnetic field.

The obtained research results confirms the possibility to realize the idea of collective acceleration of ions by a synchronous slow space charge wave generated by simultaneous temporal and spatial modulation of REB.

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