COMPUTER SIMULATION OF LOW-ENERGY HIGH-CURRENT ELECTRON BEAM DYNAMICS IN A LONG PLASMA-FILLED DIODE

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Results of computer simulation of low-energy high-current electron beam dynamics in a low-impedance system consisting of a diode with a long plasma anode, just siding with an explosive emission cathode and an auxiliary thermionic cathode are presented. Plasma anode plays simultaneously a role of the transport channel providing charge neutralization of high-current beam and is created by means of the residual gas ionisation by low-current, low-voltage electron beam emitted from the auxiliary cathode in an external longitudinal magnetic field. The main peculiarities of the beam-plasma system are discussed: 1) the formation of the beam of currents exceeding the limiting Alven's ones; 2) the formation of paramagnetic states of the beam under condition of beam charge density close to the plasma density. These peculiarities complicate beam-plasma interaction significantly due to sharp non-uniform distribution of the beam current density, significant transverse motion of the beam electrons and redistribution of ion plasma density under the influence of high-current electron beam fields. Computer simulation was performed using electromagnetic PIC code KARAT.

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1. INTRODUCTION

The main idea of low-energy high-current beam generation is based on the origin of a thin double-layer between a cathode and adjoined anode plasma just after the beginning of accelerating voltage pulse. Plasma-filled diodes with explosive cathodes are used for these purposes to generate electron beams for surface modification [1-3]. The full voltage is localised across this layer making possible the beginning of the explosive emission from a cathode surface. The plasma serves as the "liquid" anode preventing the system from collapse of the impedance. From another side it forms the channel to guide high-current beam from the cathode to a target making sure charge neutralisation of the beam and its transportation. We use a residual gas ionisation by additional pulsed low-energy, low-current electron beam to create well-defined plasma anode in a longitudinal magnetic field [2, 3, 7, 8].

2. CONDITIONS OF COMPUTER SIMULATION

Results of computer simulation of plasma anode formation in the residual gas by an auxiliary electron beam and the first experiments on the generation of high-current beams were described in [2, 3]. Additional experimental results and the results of computer simulation of the generation of low-energy high current beams under different condition are described in [8].

Diameter of the explosive emission cathode was chosen equals to 1 cm. At initial time the plasma column of the same diameter along the system fills completely space in longitudinal direction between explosive emission cathode and anode placed instead of auxiliary gun. The density of plasma is homogeneously distributed along longitudinal *z* and radial *r* co-ordinates and was varied from 1×10^{13} cm^{-3} up to 7×10^{13} cm^{-3}. Initial temperature of the plasma was changed from several to tens electronvolts. Applied voltage has the given form. It rose up to 20 kV for different time (1…10 ns) and was constant further. Output of electrons was permitted from the field-emission cathode and surfaces into plasma if accelerating field exceeds a given value. Calculations were performed for hydrogen, nitrogen and xenon plasmas for different values of external longitudinal magnetic field and for different length of the plasma diode.

3. GENERAL PECULIARITIES OF THE BEAM-PLASMA SYSTEM

Generation and transportation of low-energy high-current beams in such system is conditioned by several peculiarities. First of all, if the emission of the beam from the cathode is space charge limited, beam currents exceed Alven's limiting current for all considered condition, if the plasma density is high enough. It manifests the prevalence of transverse dynamics of beam electrons. The second peculiarity of the system is comparable density of the generated electron beam and the plasma. It means low average and large local electric fields. The last signifies the necessity to take into consideration the motion of plasma ions. Moreover beam electrons will force out plasma electrons to the chamber walls for a short time. As the result the exotic media will be formed consisting of low plasma ions and fast beam electrons. In the absence of current neutralisation by plasma electrons the beam has to be pinched to high local densities to the axis of the system. The density of plasma ions will follow the electron density with a time delay and pre-axis ion pivot will be formed. Pinching of electron beam will create high fast alternating electromagnetic fields. Therefore a modification of energy spectrum of beam electrons and stochastically accelerated plasma ions must be observed. The departure of plasma ions from the space between electrodes to walls will limit the duration of electron beam, i.e. as heavier ions of the residual gas as longer the duration of beam current pulse. Beam current depends on plasma density also and increases linearly with growth of residual gas pressure in noted above region. It is obviously that the

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behaviour and the main characteristics of the beam will depend on the external magnetic field. If to recollect about different time scales and multistage of processes, then the system as a whole can be characterised as multi-component one with alternating number of particles and can't be described by regular theoretical methods.

3.1. PINCHED AND ANNULAR STATES OF THE SYSTEM

Calculations were carried out for different levels of external magnetic field: 0, 500 and 5000 Gs. The behaviour of the beam does not differ significantly for the first two cases and for diodes of different length excepting the duration of the beam current. In small magnetic fields pinched state of the beam-plasma system is formed very likes to Bennett's pinch. Beam electrons force plasma electrons out to electrodes in longitudinal direction, beam electrons are pinched to the axis of the system by self magnetic field exceeding significantly external one, and near axis ion pivot is formed.

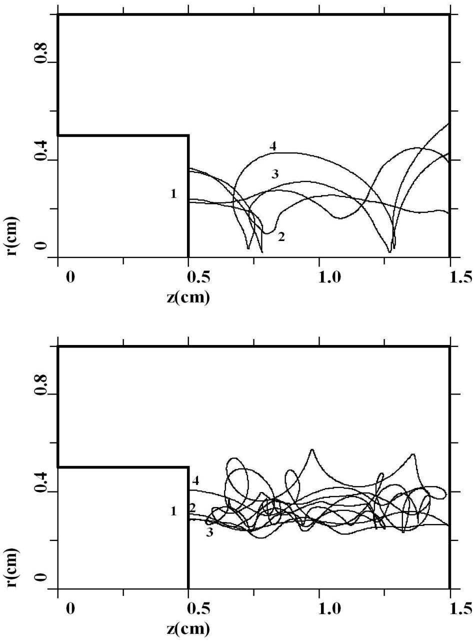

Fig.1. Trajectories of several beam electrons for different external magnetic field

Such metastable state of beam-plasma system exists for tens nanoseconds depending on the length of the system and ion mass. Further it goes to annular configuration of plasma ions and electron beam.

If external magnetic field is high enough to prevent beam electrons from focusing to the axis of the system then pinched state is not reached at all. Plasma ions leave pre-axis area under influence of self space charge and annular distributions of beam electrons and plasma ions are formed. Such state slowly expanding in radial direction with decreasing beam current can exist for tens nanoseconds.

Corresponding trajectories of several beam electrons emitted from the cathode for different values of external magnetic field (500 Gs and 5 kGs from the top to the bottom) are shown in Fig.1 for 2-ns time interval.

3.2. BEAMS PARAMAGNETIC STATES

Usually, charged beam in an external magnetic field behaves as a diamagnetic and forces the magnetic field out of its volume. In [4, 5] it was shown that for some systems, e.g. for inverted coaxial magnetic isolation diodes, it is possible to realise conditions under which the magnetic field is forced inside the volume occupied by the beam and is increased considerable as compared as external field. About similar situation could be realised in the beam-plasma system under consideration. In this case the role of the internal electrode plays near axis ion pivot. The reasons of the creation just of paramagnetic state of the beam are not clear enough. It can be assumed that just fast forced escape of plasma electrons to the electrodes and exceeding of Alven's limit by beam current play the main role. As the result a "clear" system consisting of slow plasma ions and fast beam electrons is formed. This system has many commons with so-called coupling state in moving quasi-neutral medium [6] and can be considered as polarised one.

The degree of magnetic field amplification depends on the value of the external magnetic field, plasma density, and rise time of the applied voltage and transverse dimensions of the system. In high external magnetic field the amplification is smaller. In low magnetic fields the amplification of the field can exceed 40. No special attempts were done to find conditions of maximum amplification. Below several results are given for short systems to be sure in the accuracy of the calculations. Fig.2 shows typical behaviour of beam current on the time. Beam current on the collector decreases rapidly because of fast escape of plasma ions to electrodes in the system with small longitudinal dimension (see Fig.1). The form and the duration of the current not strongly depend on magnetic field. Beam current duration increases with increasing of the distance between electrodes. Symbols *i, e* and *b* sign accordingly plasma ions, plasma electrons and beam electrons.

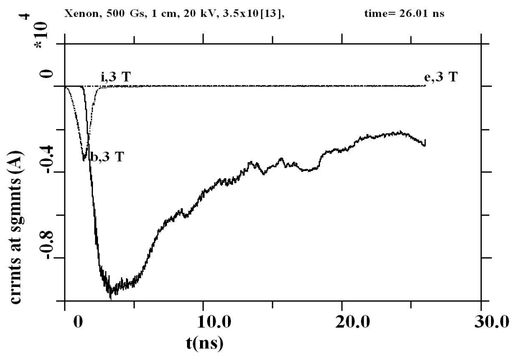

Fig.2. Typical beam current on the collector placed at 1 cm from the cathode for magnetic field 500 Gs

Dynamics of alternating part of longitudinal magnetic field near the axis in the centre of the system and longitudinal and radial distributions of complete longitudinal field at the moment are shown in Fig.3. For the case of B = 5 kGs magnetic field on the axis exceeds 12 kGs.

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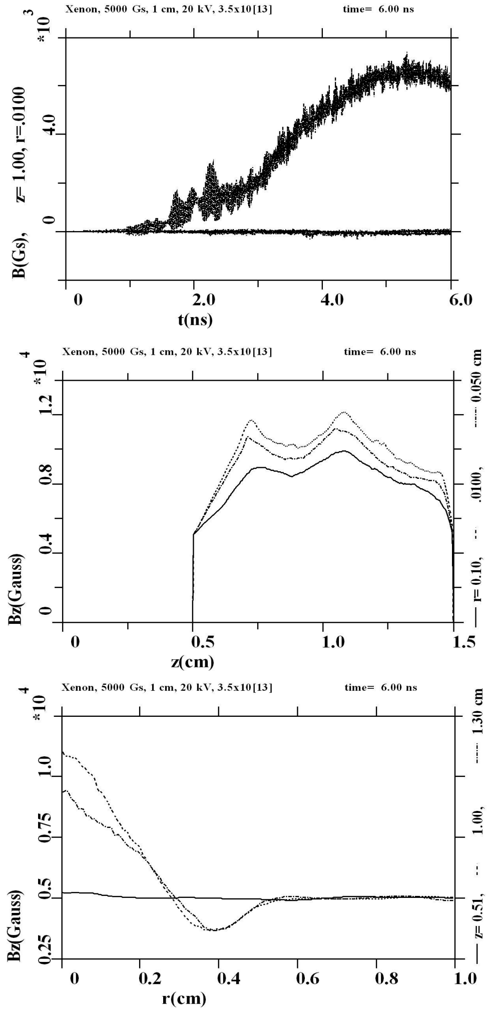

Fig.3. Dynamics and distributions of longitudinal magnetic field

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ДИНАМИКИ НИЗКОЭНЕРГЕТИЧНЫХ СИЛЬНОТОЧНЫХ ЭЛЕКТРОННЫХ ПУЧКОВ В ДЛИННОМ ПЛАЗМЕННОМ ДИОДЕ

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Приведены результаты численного моделирования динамики низкоэнергетичных сильноточных электронных пучков в низкоимпедансной плазменной системе, состоящей из диода с длинным плазменным анодом, вплотную прилегающим к взрывоэмиссионному катоду, и вспомогательного термокатода. Плазменный анод одновременно играет роль канала для транспортировки пучка и создается посредством ионизации остаточного газа слаботочным низковольтным пучком от термокатода во внешнем продольном магнитном поле. Рассмотрены основные особенности подобной пучково-плазменной системы: 1) формирование пучков с токами, превосходящими предельный ток Альфвена; 2) формирование парамагнитных состояний пучков в условиях, когда плотность заряда пучка сравнима с плотностью плазмы. Работа выполнена при поддержке РФФИ по гранту 05-02-16442.

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ДИНАМІКИ НИЗЬКОЕНЕРГЕТИЧНИХ ПОТУЖНОСТРУМОВИХ ЕЛЕКТРОННИХ ПУЧКІВ У ДОВГОМУ ПЛАЗМОВОМУ ДІОДІ

А.В. Агафонов, В.П. Тараканов

Наведено результати чисельного моделювання динаміки низькоенергетичних потужнострумових електронних пучків у низькоімпедансній плазмовій системі, що складається з діоду з довгим плазмовим анодом, що впритул прилягає до вибухоемісійного катоду, і допоміжного термокатоду. Плазмовий анод одночасно відіграє роль каналу для транспортування пучку і створюється за допомогою іонізації залишкового газу слабкострумовим низьковольтним пучком від термокатоду в зовнішнім поздовжнім магнітному полі. Розглянуто основні особливості подібної пучково-плазмової системи: 1) формування пучків зі струмами, що перевершують граничний струм Альфвена; 2) формування парамагнітних станів пучків в умовах, коли щільність заряду пучка порівнянна із щільністю плазми. Робота виконана за підтримкою РФФД по гранту 05-02-16442.