PARAMAGNETIC STATES OF HIGH-CURRENT ELECTRON BEAMS IN A BEAM-PLASMA SYSTEM

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Results of computer simulation of low-energy high-current electron beam generation in a low-impedance system show that high-current beams shape in paramagnetic states. Low-impedance system consists of a diode with a long plasma anode, just siding with an explosive emission cathode and an auxiliary thermionic cathode. The long plasma anode plays simultaneously the role of the transport channel providing charge neutralisation of high-current beam. Usually, a beam in an external magnetic field behaves as a diamagnetic and forces the magnetic field out of its volume. Earlier it was shown that for some systems it is possible to realise conditions under which the magnetic field is increased inside the volume occupied by the beam. It is accompanied by considerable increase of the magnetic field as compared as external field. The behaviour of beam-plasma system is discussed under different conditions. Computer simulation was performed using PIC code KARAT. Work supported by RFBR under grant 05-02-16442.

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1. INTRODUCTION

Plasma-filled diodes with explosive cathodes are used for the generation of high-current low-energy electron beams for surface modification [1 - 3]. The main idea of 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. 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 collapses of impedance from one side and as the channel to guide a high-current beam from another side making sure charge neutralisation of the beam and its transport to a target. In our experiments to create well-defined plasma channel we use a residual gas ionisation by additional pulsed low-energy, low-current electron beam guided by longitudinal magnetic field [2 – 3].

2. SOME PECUILARITIES OF BEAM-PLASMA DYNAMICS

Generation and transportation of low-energy high-current beams in such system is conditioned by several peculiarities: exceeding Alfven’s limiting current, prevalence of transverse dynamics of beam electrons, different time scales and multistage of processes, and comparable density of the plasma and generated electron beam. Behaviour and the main characteristics of the beam depend on the external magnetic field. 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.

Results of computer simulation of plasma anode formation in residual gas by an auxiliary electron beam and the generation of high-current beams was described in [3]. 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, 5, 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 two different length of the plasma diode (2 and 10 cm).

2.1. INFLUENCE OF EXTERNAL MAGNETIC FIELD

Calculations were carried out for different levels of external magnetic field: 0, 500 and 5000 Gs. The behavior 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. Such metastable state of beam-plasma system exists for 10…20 nanoseconds and further it goes to annular configuration of plasma ions and electron beam and emission of electrons from central area of the cathode is depressed. Fig. 1 shows radial distributions of beam electrons and plasma ions densities in pinched state for short diode and for external magnetic field B = 0 and initial plasma density is $7\text{x}10^{13}$ cm^{-3} (pressure of xenon $2\text{x}10^{-3}$ Tor). A half of the beam current reaches the anode electrode out of the marked area of the collector of 1 cm diameter.

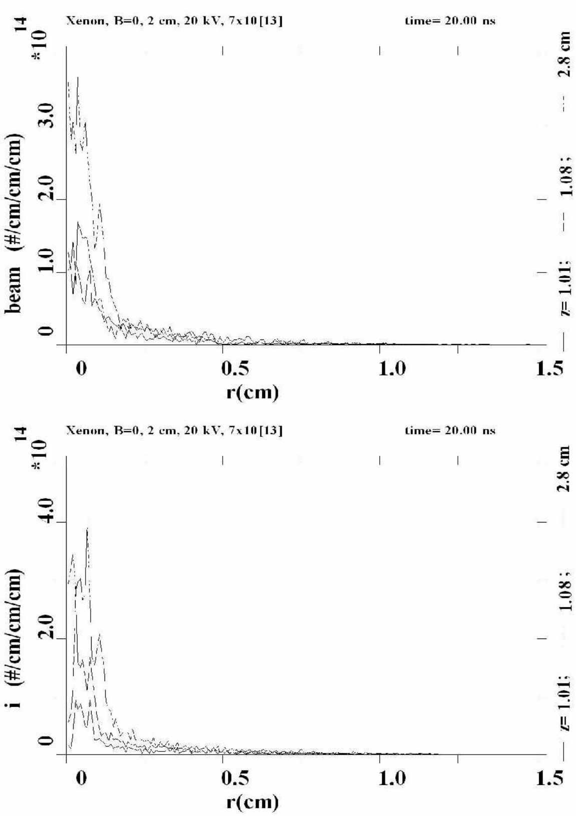

Fig.1. Radial distributions of beam electrons (upper part) and plasma ions (bottom part) in pinched state of beam-plasma system at different position along the system

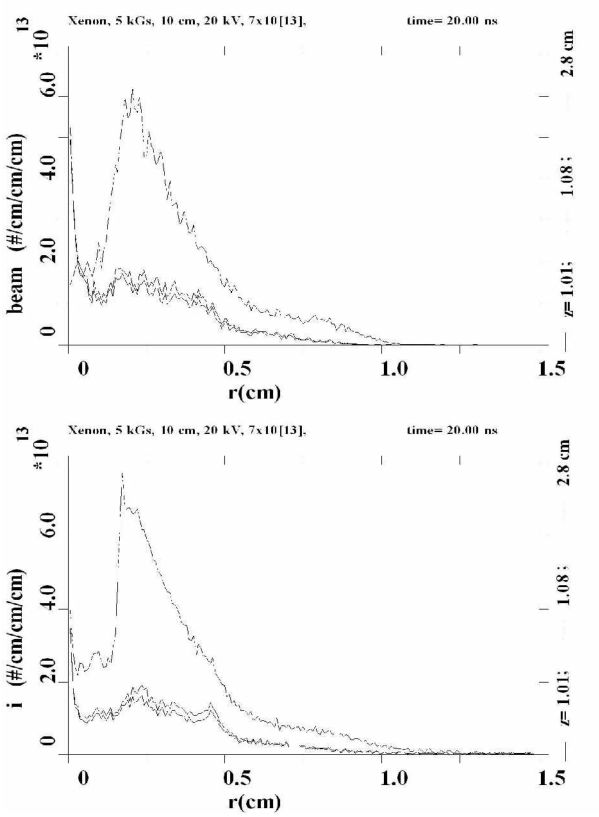

Fig.3. Radial distributions of beam electrons (upper part) and plasma ions (bottom part) in annular state of beam-plasma system at different position along the system

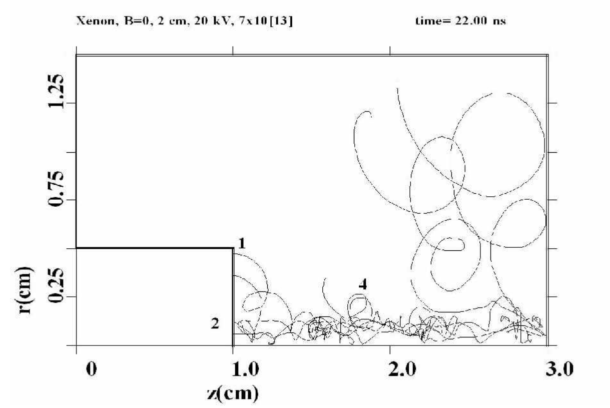

Fig.2. Trajectories of several beam electrons in pinched state

Corresponding trajectories of several beam electrons emitted from the field-emission cathode are shown in Fig. 2 for 2 ns time interval. The current of the beam at the moment is about 10 kA.

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. Radial densities distributions of beam electrons and plasma ions for B = 5 kGs are shown in Fig. 3. Results are given for long diode and initial plasma density of $7x10^{13}$ cm^{-3}.

2.2. PARAMAGNETIC STATES OF THE BEAMS

Usually, a 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 out inside the volume occupied by the beam and is increased considerable as compared as external field. About similar situation is 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 the main role plays fast forced escape of plasma electrons to the electrodes and exceeding of Alfven's limit. 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, rise time of applied voltage and transverse dimensions of the system. In high external magnetic field the amplification is small. Fig. 4 shows longitudinal distribution of complete longitudinal field at different radii. Naturally, the field reaches its maximum value on the axis of the system. For the case of external field B = 5 kGs magnetic field on the axis exceeds 12 kGs.

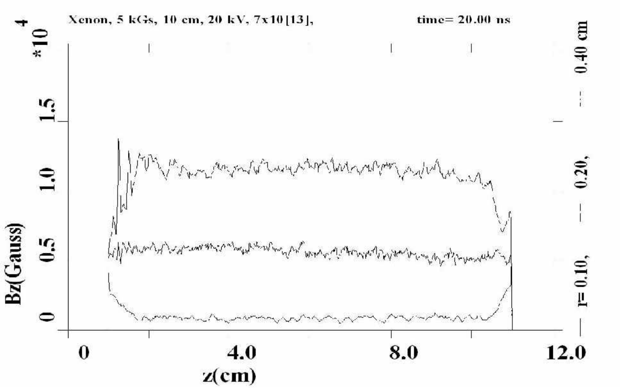

Fig.4. Longitudinal distributions of complete magnetic field at different radii for the B = 5 kGs

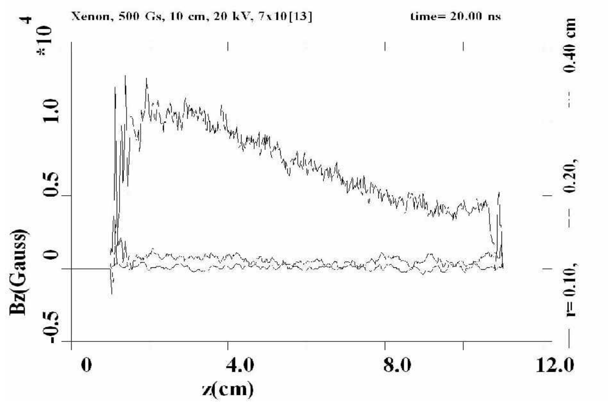

Fig.5. Longitudinal distributions of magnetic field at different radii for the B = 500 Gs

In low magnetic fields the amplification of the field can exceed 20. No special attempts to find conditions of maximum amplification were done. The example of field amplification for low magnetic field is shown in Fig. 5.

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ПАРАМАГНИТНЫЕ СОСТОЯНИЯ СИЛЬНОТОЧНЫХ ЭЛЕКТРОННЫХ ПУЧКОВ В ПУЧКОВО-ПЛАЗМЕННОЙ СИСТЕМЕ

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В процессе численного моделирования генерации и транспортировки низкоэнергичных сильноточных электронных пучков в низкоимпедансной плазменной системе показано, что электронные пучки формируются в парамагнитном состоянии. Низкоимпедансная система включает в себя диод с протяженным плазменным анодом, вплотную прилегающим к взрывоэмиссионному катоду, и вспомогательный термокатод для создания протяженного плазменного анода. Обычно, во внешнем магнитном поле пучок ведет себя как диамагнетик, вытесняя магнитное поле наружу из своего объема. Ранее было показано, что в некоторых системах можно реализовать вытеснение магнитного поля не наружу, а внутрь объема, занятого пучком, что сопровождается существенным увеличением поля по сравнению с внешним. Приведены результаты расчета динамики пучка и плазмы при различных условиях. Численное моделирование проведено с помощью электромагнитного PIC кода КАРАТ. Работа выполнена при поддержке РФФИ по гранту 05-02-16442.

ПАРАМАГНІТНІ СТАНИ ПОТУЖНОСТРУМОВИХ ЕЛЕКТРОННИХ ПУЧКІВ У ПУЧКОВО-ПЛАЗМОВІЙ СИСТЕМІ

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У процесі чисельного моделювання генерації і транспортування низькоенергійних потужнострумових електронних пучків у низькоімпедансній плазмовій системі показано, що електронні пучки формуються в парамагнітному стані. Низькоімпедансна система містить у собі діод із протяжним плазмовим анодом, що впритул прилягає до вибухоемісійного катода, і допоміжний термокатод для створення протяжного плазмового анода. Звичайно, у зовнішньому магнітному полі пучок поводиться як діамагнетик, витісняючи магнітне поле назовні зі свого обсягу. Раніше було показано, що в деяких системах можна реалізувати витиснення магнітного поля не назовні, а усередину обсягу, зайнятого пучком, що супроводжується істотним збільшенням поля в порівнянні з зовнішнім. Приведено результати розрахунку динаміки пучка і плазми при різних умовах. Чисельне моделювання проведене за допомогою електромагнітного PIC коду КАРАТ. Робота виконана за підтримкою РФФІ по гранту 05-02-16442.