DYNAMICS OF THE ELECTRON BUNCH, INJECTED INTO HOMOGENEOUS PLASMA: 2D ELECTROMAGNETIC PIC SIMULATION

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Dynamics of electron bunch in homogeneous plasma was studied via electromagnetic PIC method in the cylindrical geometry using PIC method. Electrostatic wake wave propagated behind the bunch in plasma as predicted by the theory. Magnetostatic field exists around the bunch. On the vacuum-plasma edge the surface electromagnetic wave is observed. It exists due to the motion of distorted plasma electrons on the boundary.

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1. INTRODUCTION

Theoretical studies of plasma usually deal with one or several specific effects thus the general picture of the phenomena frequently remains unclear. It was shown that different types of electrostatic waves could be excited simultaneously in plasma by injected charged particles [1]. Taking into account electromagnetic effects makes the interaction even more complicated because of surface and volume electromagnetic waves. Analytical description of all these waves interacting nonlinearly with injected bunch or beam is very complicated.

Computer simulation is the alternative research method in plasma science. Computer models could be tuned closely to the conditions of the real experiments. In numerical experiments it's possible to study all processes and characteristics of the plasma simultaneously.

In this paper we present computer simulation of the electrons' bunch interaction with the bounded homogeneous plasma in cylindrical geometry. Bunch is injected from vacuum into plasma with the sharp boundary. 2.5D electromagnetic relativistic PIC code was used for simulations [2].

2. SIMULATION MODEL

Beam-plasma system was simulated in 2.5D cylindrical geometry. In this model the space grid has two dimensions, large particle has the shape of ring, which can move along z-axis and its radius can increase or decrease. Particles can also rotate around the system axis, i.e. they can have an azimuthal velocity component. Three components of electric and magnetic fields can be taken unto account. It is possible to simulate the propagation of electromagnetic waves of both E- and H-types [3].

Simulation volume has a shape of cylindrical resonator with radius of 0.1 m and length of 0.8 m. Electromagnetic absorbing layers are imposed on both sides of the resonator.

The system is partly filled with homogeneous plasma. Plasma consists of electrons and hydrogen ions with near zero temperature. The plasma density is $3\cdot10^{8}cm^{-3}$.

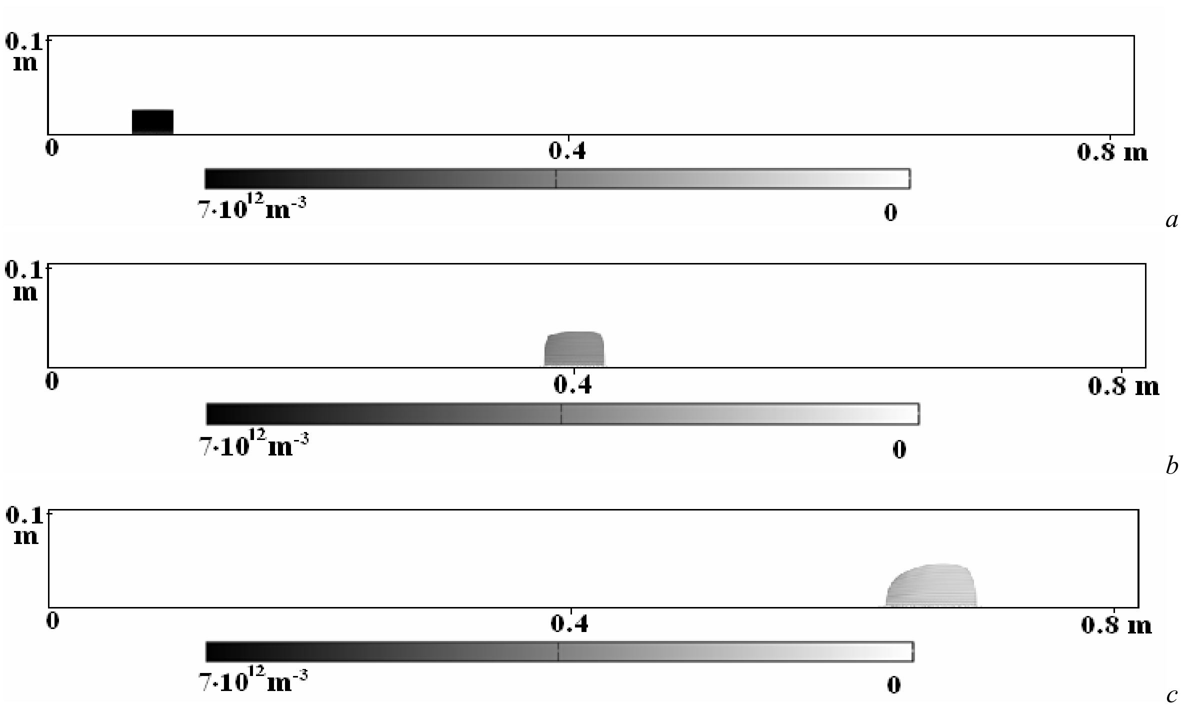

Fig1. Spatial distribution of the beam charge density for the time points 2ns (a), 13ns (b) and 24ns (c)

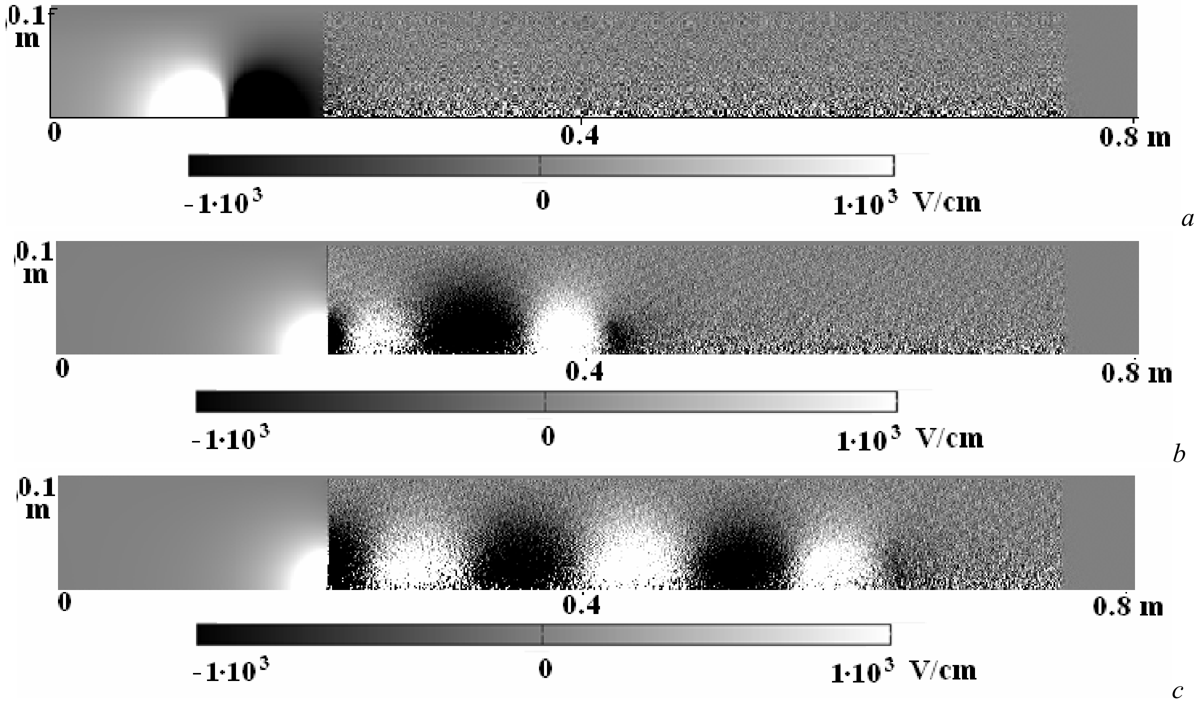

Fig.2. Spatial distribution of z component of electric field for the time points 2ns (a), 13ns (b) and 24ns (c)

Electron bunch with initially rectangular density profile is injected into vacuum from the left boundary of the system. At some distance from injector it crosses the sharp vacuum-plasma boundary. Initial beam velocity is $3 \cdot 10^7$m/s, initial density is $5 \cdot 10^6$ cm^{-3}, length and radius are 3cm and 2cm, respectively.

3. DYNAMICS OF THE BUNCH INJECTED INTO THE PLASMA

Bunch charge densities at three different time points are shown on Fig. 1: in vacuum near injector (a) and in plasma (b),(c).

One can see from comparing Fig. 1, a and Fig. 1, c that electron beam is expanded both in transversal and longitudinal directions. This effect is caused by the influence of the bunch space charge. Furthermore, the shape of the bunch changes during its motion in plasma. The front part of the bunch becomes wider in radial direction and less dense. In the contrast the rear part expands slower and becomes denser. It could be explained by interaction with the excited wake wave [4,5] which consumes energy of injected electrons, and they are decelerated. Different transversal motion of the bunch electrons could be explained by their different phases relatively to the wake wave [6].

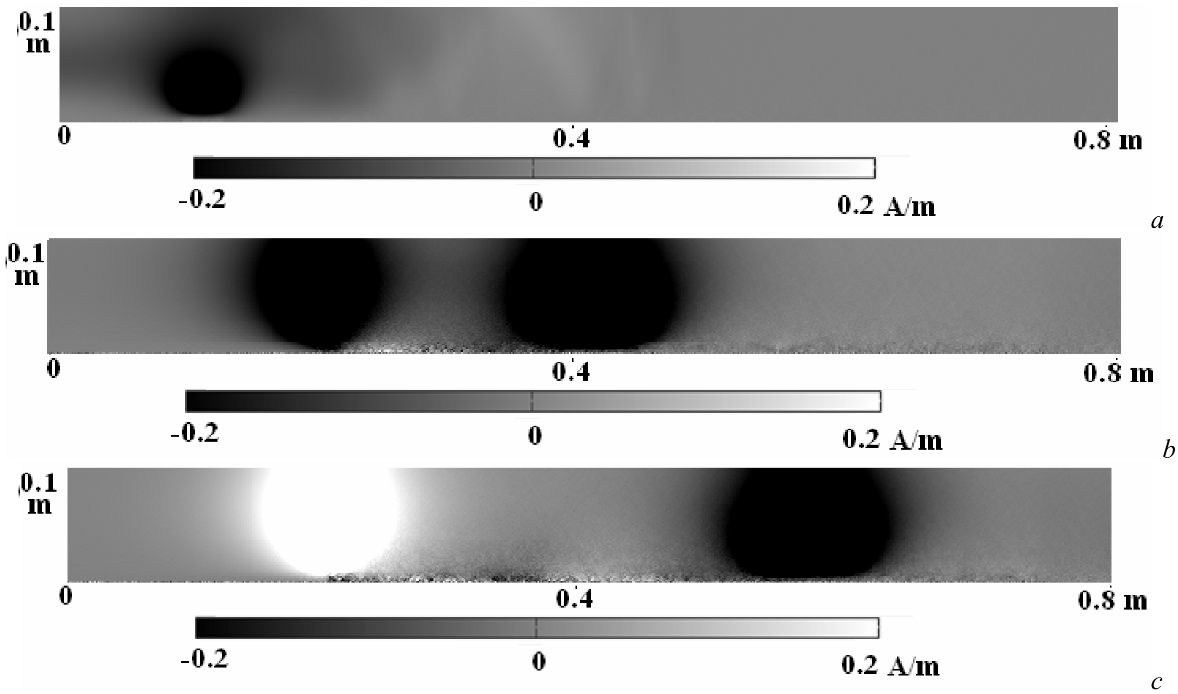

Fig.3. Spatial distribution of φ component of magnetic field for the time points 2ns (a), 13ns (b) and 24ns (c)

4. ELECTROMAGNETIC FIELD GENERATED BY THE BUNCH

Longitudinal component of the electric field at different time points are shown on Fig. 2, a-c. Azimuthal component of the magnetic field is shown on Fig. 3, a-c.

The electron bunch excites the electrostatic wave during its motion in the plasma. One can see from Fig.3 that magnetic field exists inside the plasma only around the bunch and it has the magnetostatic nature.

Magnetic field of substantial amplitude exists also on the plasma-vacuum border. In contrast to the field around the bunch it has an oscillating nature. Alternating electric field on the edge is also observed and could be interpreted as the surface wave excited by the bunch. The electromagnetic field exists because of the oscillation of electrons distorted from the equilibrium state by the injected bunch. This field cannot propagate leftwards because of the critical frequency of the waveguide which is higher than plasma frequency:

$$f_{crit} = c/\lambda_{crit} = c\nu_{01}/(2\pi R) = 1.20 \text{ GHz},$$

$$f_{pl} = (e^2 n/\varepsilon_0 m_e) = 0.98 \text{ GHz},$$

where R is the waveguide radius, and n is the plasma density.

5. CONCLUSIONS

Behavior of the electron bunch injected into homogeneous plasma was studied via electromagnetic PIC method in the cylindrical geometry. It was observed that the shape of the bunch changes differently for its front and rear parts. Front part expands in transverse direction faster than rear part.

Electrostatic wake wave propagated behind the bunch in plasma as predicted by the theory. Magnetostatic field exists around the bunch.

On the vacuum-plasma edge the surface electromagnetic wave is observed. It exists due to the motion of distorted plasma electrons on the boundary.

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ДИНАМИКА ЭЛЕКТРОННОГО СГУСТКА, ИНЖЕКТИРОВАННОГО В ОДНОРОДНУЮ ПЛАЗМУ: 2.5D-ЭЛЕКТРОМАГНИТНОЕ МОДЕЛИРОВАНИЕ PIC-МЕТОДОМ

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С помощью 2.5D-электромагнитного кода было проведено моделирование прохождения сгустком резкой границы плазма-вакуум и его дальнейшего движения в однородной плазме. Рассматриваются эффекты, которые возникают в такой системе. Это – возбуждение передним фронтом электронного сгустка кильватерной волны в плазме, а также электромагнитной волны на границе плазма-вакуум.

ДИНАМІКА ЕЛЕКТРОННОГО ЗГУСТКУ, ІНЖЕКТОВАНОГО В ОДНОРІДНУ ПЛАЗМУ: 2.5D-ЕЛЕКТРОМАГНІТНЕ МОДЕЛЮВАННЯ PIC-МЕТОДОМ

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За допомогою 2.5D-електромагнітного коду було проведено моделювання проходження згустком різкої межі плазма-вакуум і його подальшого руху в однорідній плазмі. Розглядаються ефекти, які виникають у такій системі. Це – збудження переднім фронтом електронного згустку кільватерної хвилі у плазмі, а також електромагнітної хвилі на межі плазма-вакуум.