FORMATION OF PLASMA ELECTRONS' FLOWS IN THE HOMOGENEOUS BEAM-PLASMA SYSTEM

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1D simulation of the beam-plasma interaction demonstrates formation of quasi-periodical flows of background plasma electrons. Flows directed along the electron beam velocity have larger velocities comparing with the flows directed in the opposite side. This effect is associated with plasma electrons' acceleration under the pressure of the inhomogeneous HF electric field excited during the development of the beam-plasma instability. At the same time, accelerated electrons moving parallel to the beam's direction can interact with the excited Langmuir wave via mechanism of Landau damping.
PACS: 52.35.Hr, 52.35.Mw, 52.40.Mj, 52.65.Rr

1. INTRODUCTION

Interaction of electron beams with plasma is one of the most interesting problems of plasma physics. Interest to this problem is caused by the possibility to use electron beams as a probes for diagnostics of magnetic and electric fields in plasmas, including HF fields, and by various instabilities excited in beam-plasma systems, that sometimes can result in the beam-plasma discharge ignition [1]. However, these processes don't represent all the variety of effects that take place during the beam-plasma interaction. In particular, some kinetic effects that take place in beam-plasma systems are usually left out of scope of the investigations.

In our previous works [2-3] longitudinal acceleration of plasma electrons due to the impulse, transmitted by the electron beam, was studied both theoretically and by means of the computer simulation. However, for the case of collisionless plasma without magnetic field interaction between electron beam and plasma electrons can be realized only through the electric fields of the charged particles. Strong electric HF field exited by the electron beam during its motion in plasma demonstrates the most essential influence on plasma electrons. Electron beams' energy and impulse transmission to plasma electrons can take place only by the intermediation of this field.

The aim of this work is to study numerically the time evolution of the plasma electrons' velocity distribution function in homogeneous beam-plasma system to find out the flows of plasma electrons, and their correlation with evolution of spatial distribution of the electric field and plasma density profile.

2. MODEL DESCRIPTION AND SIMULATION PARAMETERS

In order to study the plasma electrons' flow, one-dimensional computer simulation using modified PDP1 code [4] was carried out. In 1D space homogeneous plasma was located between conductive walls. In the initial time point the monoenergetic electron beam was injected into plasma, and the sign of its velocity was considered as positive. The initial plasma electrons' distribution function was considered as maxwellian.

Simulation was carried out for five different electron beams' current densities in order to compare plasma electrons' flows for these cases. Electron beams' current densities and corresponding beams densities j_b, used for the simulation, are presented in the table:

Electron beams' current density, A/m^2	Electron beams' density, m$^{-3}\times10^{13}$
3	0.11
5	0,2
15	0.6
24	0.95
50	2

Though results for various simulation parameters are similar, in this article we present the simulation results only for the case of j_b=24 A/m^2. Common simulation parameters were: plasma density – 2×10^{15} m^{-3} (corresponding plasma period is 2,49 ns); simulation range – 50 cm; plasma electrons' thermal velocity – 2×10^6 m/s; electron beams' velocity – 3×10^7 m/s.

3. SIMULATION RESULTS

Fig. 1 represents the time evolution of the plasma electrons' velocity distribution function in logarithmic scale. In the initial time points plasma electrons' distribution function is nearly maxwellian: magnitude of the HF electric field, exited by the electron beam, is not enough for plasma electrons' flows formation.

At the time point near 200 ns magnitude of the electric field reaches its maximum (Fig. 2), and from that time point one can observe a pronounced oscillations on plasma electrons' velocity distribution function. On the late stages of the beam-plasma interaction (after the time point 300ns) the oscillations disappear.

As one can see, period of the oscillations of the plasma electrons' distribution function is about 10^2 ns (see Fig. 1). This period is much more then plasma period, which is equal to the period of HF electric field exited by the electron beam as a result of beam-plasma instability. Consequently, the electrons' velocity oscillations are not caused directly by this field.

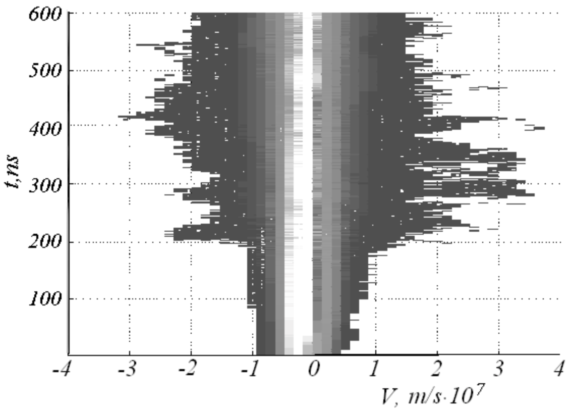

Fig. 1. Time evolution of plasma electrons' velocity distribution function

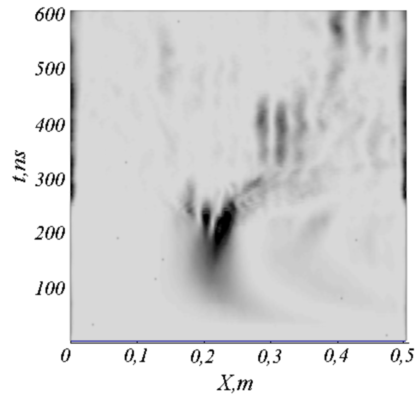

Fig. 2. Space-time distribution of the intensity of the HF electric field exited by the electron beam in plasma. Dark areas correspond to higher electric fields' magnitudes

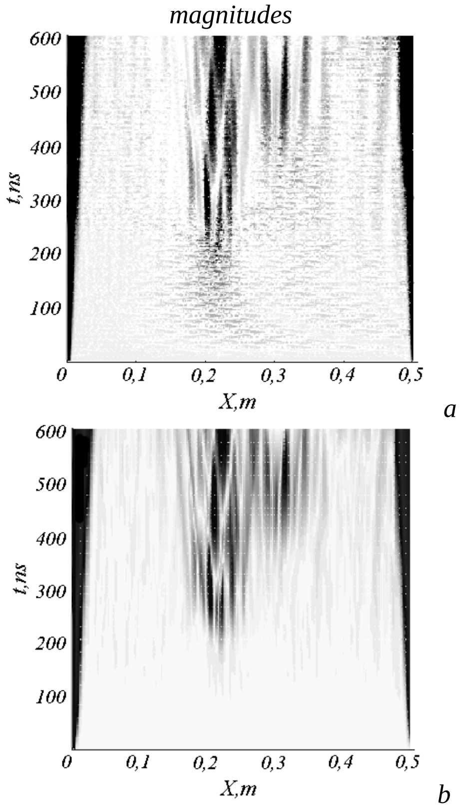

Fig. 3. Space-time distribution of the plasma density profile. a –plasma electrons profile; b- plasma ions profile

Figs. 3 a,b represent the space-time distribution of the plasma electrons' density profile and plasma ions' density profile correspondingly. Deformations on these profiles are caused by space-inhomogeneous electric field, exited by the electron beam (see Fig. 2). Deformation of electrons' density profile starts earlier then ions' profile deformation, since HF electric field directly interacts with plasma electrons (see Fig. 3 a,b).

One can see from the simulation results that formation of quasi-periodical structures on the plasma density profile results to decrease of the electric field exited by the electron beam in plasma (see Fig. 2).

Regarding to Figs. 3 a,b, one can see that quasi-periodical perturbations on plasma electrons' and ions' density profiles almost coincide with each other. So these perturbations can be identified as ion-acoustic waves. Excitation of these waves can be associated with the l-s decay of the Langmuir wave, excited by the electron beam due to the resonant beam-plasma instability. After the time point t = 270 ns one can observe the sudden decrease of the electric fields' magnitude (Fig. 2), and beam-plasma instability breakdown takes place. At the same time the essential deformation of plasma density profile is observed (see Figs. 3 a,b). During the time period between 300…450 ns the next areas of intensive electric field appear in 30…35 cm from beams' injector (see Fig. 2). After the time point t = 450 ns the second beam-plasma instability breakdown occurs, and the next ion-acoustic perturbations arise on this place (see Figs. 3 a,b). One can mention that initial plasma density perturbations remain visible. The same scenario takes place in the time interval 500…600 ns.

4. NATURE OF THE ELECTRON FLOWS IN THE BACKGROUND PLASMA

As it was mentioned before, period of oscillations of the plasma electrons distribution function is much longer then period of the electron plasma oscillations. Hence, it can be assumed that spikes on distribution function are caused by the plasma density cavities formation.

In our previous works [2, 3] formation of plasma electrons' flows was connected with the Landau damping of electric fields' wave, exited by the electron beam, on plasma electrons. However, the estimations show that relative part of resonant plasma electrons for initial maxwellian distribution is about 10^{-17} from the total plasma electrons' number. Also, simulation shown that oscillations on plasma electrons' distribution function are not the consequence of the bounce-oscillation of plasma electrons in the potential well: the estimated period of bounce oscillations is substantially less than period of the plasma electrons' distribution function oscillations (see Fig. 1).

Thus, appearance of oscillations of the plasma electrons' distribution function can be preliminarily associated with the formation of periodical density cavities on the plasma density profile. The moment of oscillations' appearance coincides with the moment of visible deformation of electrons' density profile (see Figs. 1-3, a). Period of the distribution function oscillations and lifetime of the electric field splashes are of the same order of magnitude.

Fig. 1 demonstrates the predominantly widening of plasma electrons' distribution function in the direction of positive velocities after the time point t = 250 ns. In this case the distribution function is essentially non-maxwellian, and its' "tail" reaches the velocities that are close to the electron beams' velocity, i.e. 3×10^7m/s, in order of magnitude. Hence, number of plasma electrons, that can interact effectively with the Langmuir wave excited by the electron beam, increases. Consequently acceleration of plasma electrons predominantly in the direction of the beam propagation is a result of Langmuir wave Landau damping.

5. CONCLUSIONS

Oscillations of the plasma electrons' distribution function and corresponding plasma electrons' flows directed parallel to the electron beam have larger velocities than electrons' flows anti-parallel to the beam. Initial appearance of the background plasma electrons' flows can be associated with the plasma density cavities formation caused by HF electric field excited by the electron beam. On the next stage of interaction plasma electrons with the velocities of the order of electron beam velocity can be trapped by the Langmuir wave excited in plasma and get the additional acceleration due to the mechanism of Landau damping.

All the interactions mentioned in this work provide the transmission of electrons beam's impulse to background plasma electrons.

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Article received 13.09.10

ФОРМИРОВАНИЕ ПОТОКОВ ЭЛЕКТРОНОВ ПЛАЗМЫ В ОДНОРОДНОЙ ПУЧКОВО-ПЛАЗМЕННОЙ СИСТЕМЕ

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Компьютерное моделирование пучково-плазменного взаимодействия в одномерной системе показало возникновение квазипериодических потоков электронов фоновой плазмы. Потоки, направленные вдоль распространения электронного пучка, имели большие скорости по сравнению с потоками, направленными в противоположную сторону. Этот эффект связан с ускорением плазменных электронов под воздействием высокочастотного давления неоднородного электрического поля, возбужденного во время развития пучково-плазменной неустойчивости. При этом ускоренные электроны, направленные параллельно пучку, взаимодействуют с возбужденной ленгмюровской волной по механизму Ландау.

ФОРМУВАННЯ ПОТОКІВ ПЛАЗМОВИХ ЕЛЕКТРОНІВ В ОДНОРІДНІЙ ПУЧКОВО-ПЛАЗМОВІЙ СИСТЕМІ

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Комп'ютерне моделювання пучково-плазмової взаємодії в одновимірній системі показало виникнення квазіперіодичних потоків електронів фонової плазми. Потоки, направлені вздовж напрямку поширення електронного пучка, мали більші швидкості у порівнянні із потоками, спрямованими в зворотному напрямкі. Цей ефект пов'язаний із прискоренням плазмових електронів під дією високочастотного тиску неоднорідного електричного поля, збудженого під час розвитку плазмово-пучкової нестійкості. При цьому прискорені електрони, спрямовані паралельно до напряму руху пучка, взаємодіють із збудженою ленгмюрівською хвилею за механізмом Ландау.