

# FORMATION OF ELECTRONS' AND IONS' FLOWS IN THE BACKGROUND PLASMA AT THE INITIAL STAGE OF THE BEAM-PLASMA INSTABILITY

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Formation of the flow of the background plasma electrons moving to the electron beam injector at the initial stage of the beam-plasma instability development in the region of maximum HF electric field intensity is demonstrated via 1D computer simulation. Effect is caused by the plasma density profile deformation due to the pressure of the inhomogeneous HF electric field.

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## INTRODUCTION

Interaction of electron beams with plasma is an important problem of plasma physics. Most analytical studies of the beam-plasma instability paid the primary attention to instability mechanisms at the linear stage of the beam-plasma interaction [1]. Non-linear effects play an essential role in the beam-plasma interaction [2, 3]. These effects mainly demonstrate themselves in the electron beam [4]. Background plasma nonlinearities were also studied. These nonlinearities were observed in numerous experiments. Among the plasma nonlinearities one can mention, for instance, modular instability of the Langmuir waves, excited in plasma by the electron beam, and the following deformation of plasma density profile with the consequent collapse of cavities [5]. Kinetic effects, which accompany the development of beam-plasma instability, for instance, plateau formation on beam-plasma systems' distribution function [6], were also studied. However, kinetic effects in the background plasma, which take place during the development of beam-plasma instability, are not entirely studied till now.

Beam-plasma interaction can result to the formation of plasma electrons' flows. In [7] this effect was observed when deformation of plasma density profile started.

The aim of the present work is to study the formation of the background plasma charged particles' (both electrons and ions) flows at the initial stage of the beam-plasma instability via computer simulation. We consider the initial stage as the time period during which the significant deformation of ions' density profile is not observed; in other words, redistribution of plasma density doesn't lead to reverse influence on the HF-field distribution in plasma.

## 1. MODEL DESCRIPTION AND SIMULATION PARAMETERS

To study the formation of the plasma particles' flows, 1D computer simulation using modified package PDP1 [8] was carried out. In 1D space plasma was located between two conductive walls. At the initial time point injection of the monoenergetic electron beam into plasma started from the left wall (injector) of the simulation space, i.e. the initial-boundary problem was solved. Beam electrons were absorbed by the right wall (collector). Velocity distribution function of plasma

electrons was initially maxwellian. Simulation was carried out for several beams' current densities ( $j_b=1.5 \text{ mA/cm}^2$ ,  $2.4 \text{ mA/cm}^2$ ,  $5 \text{ mA/cm}^2$ ,  $10 \text{ mA/cm}^2$ ) for the beam velocity  $V_b=3\cdot 10^9 \text{ cm/s}$  and three different beams' velocities ( $V_b=1\cdot 10^9 \text{ cm/s}$ ,  $3\cdot 10^9 \text{ cm/s}$ ,  $5\cdot 10^9 \text{ cm/s}$ ) for the current density  $2.4 \text{ mA/cm}^2$ . Other simulation parameters: plasma density –  $n_{e,i}=2\cdot 10^9 \text{ cm}^{-3}$  (corresponding electron plasma period –  $T_p=2,49 \text{ ns}$ ); distance between injector and collector –  $L=50 \text{ cm}$ ; thermal velocities of plasma electrons and ions –  $V_{Te}=2\cdot 10^8 \text{ cm/s}$  and  $V_{Ti}=1\cdot 10^6 \text{ cm/s}$ , respectively.

## 2. RESULTS AND DISCUSSION

We will discuss the simulation results for the beam current density  $2.4 \text{ mA/cm}^2$  and velocity  $V_b=3\cdot 10^9 \text{ cm/s}$ , which are typical for the whole array of the data obtained.

Fig. 1, a-b presents instantaneous space distributions of plasma electrons' and ions' averaged velocities, correspondingly, for the time point  $t=60T_p$ . These distributions were obtained via averaging over plasma period the velocities of particles located in the small space interval  $\Delta x$ .

At the initial stage of the beam-plasma instability plasma electrons are accelerated primarily in the direction of injector. At the same time, plasma ions are accelerated both to injector and to collector (see Fig. 1,a-b).

Fig. 2 demonstrates space distributions of plasma electrons' averaged velocities, moving only to the right (Fig. 2,a) and only to the left (see Fig. 2,b). Plasma electrons' averaged velocities distribution, presented on Fig. 1,a, is the sum of the distributions presented on Fig. 2.

To find out the cause of the plasma electrons' flow formation (see Fig. 1,a), we considered an instantaneous space distribution of electric field, excited by the electron beam, averaged over the plasma period, for the time point  $t=60T_p$  (Fig. 3,a). This distribution corresponds to the slow (in the time scale of plasma period) component of averaged electric field. Area of the negative field is located near the injector, while the positive field area with the larger strength value is located near the collector (see Fig. 3,a). Under the influence of negative field, plasma electrons are accelerated to the collector, then they appear in the area of larger positive field, and finally they start to move to the beams' injector.

Otherwise, negative field accelerates ions to the injector, and positive field – to the collector. Thus, electrons of the background plasma are accelerated to the injector, while ions are accelerated both to injector,

and (primarily) to the collector. The proposed mechanism of the electron flow formation is confirmed by the quasi-stationary potential distribution (see Fig. 3,b).

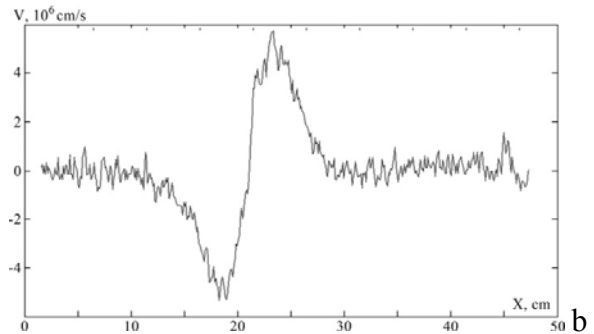
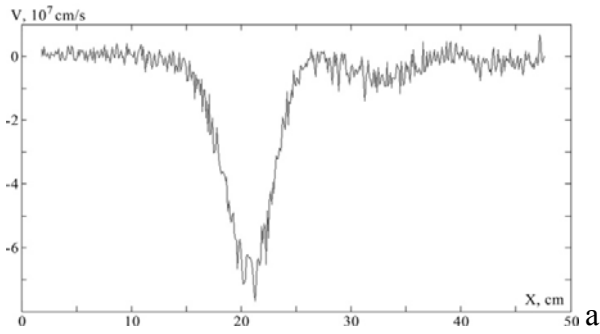


Fig. 1. Instantaneous space distributions of plasma electrons (a) and ions (b) velocity, averaged over the plasma period, for the time point  $t=60T_p$

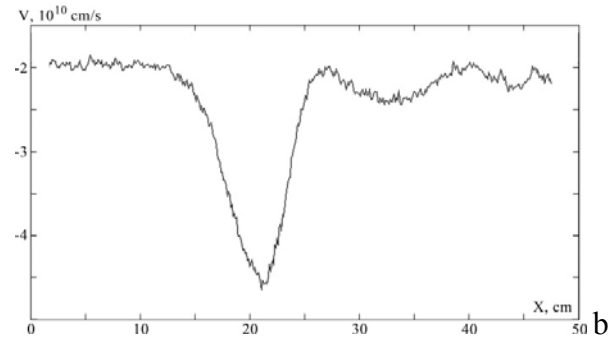
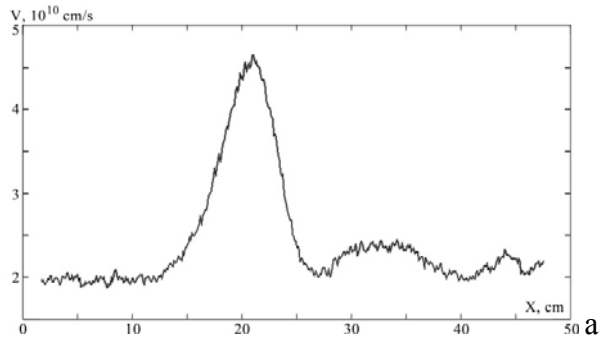


Fig. 2. Instantaneous space distributions of plasma electrons moving only to the right (a) and only to the left (b), for the time point  $t=60T_p$

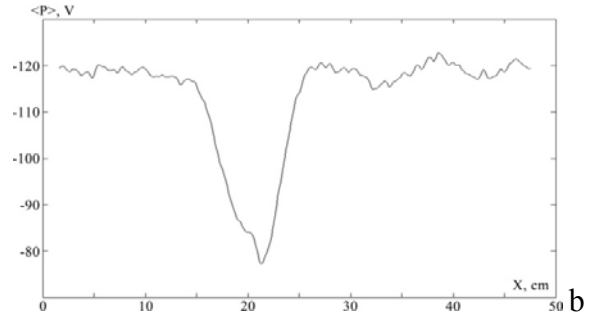
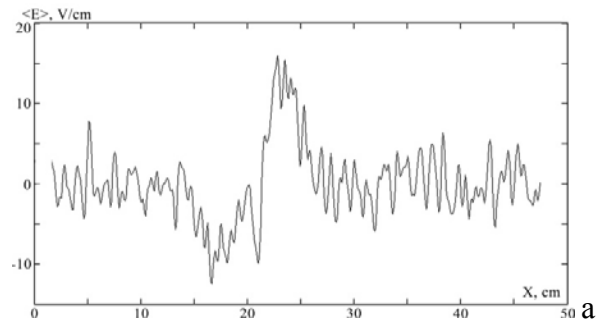


Fig. 3. Instantaneous space distribution of the electric field averaged over the plasma period for the time point  $t=60T_p$  (a); –instantaneous space distribution of averaged potential for the time point  $t=60T_p$  (b)

We can also mention that oscillations in this potential well just correspond to plasma electrons' flows to the left and to the right, presented on Fig. 2,a-b.

The spatial distribution of the quasi-stationary electric field allows to explain the formation of particles' flows in the background plasma (at least, at the qualitative level). Thereby, the electron beam, which is decelerated by the exited HF-electric field, indirectly transfers its impulse exactly to plasma ions. The quasi-stationary electric field formation is a result of plasma electrical neutrality perturbation owing to the plasma electrons' extrusion from the area of intensive HF electric field (ponderomotive force) [10]. Instantaneous spatial distribution of HF electric fields' intensity, averaged over the plasma period, for the time point  $t=60T_p$  is presented on Fig. 4,a. Present mechanism is a first stage of background plasma striction nonlinearity development under the influence of inhomogeneous HF electric field, exited by the electron beam. At the next

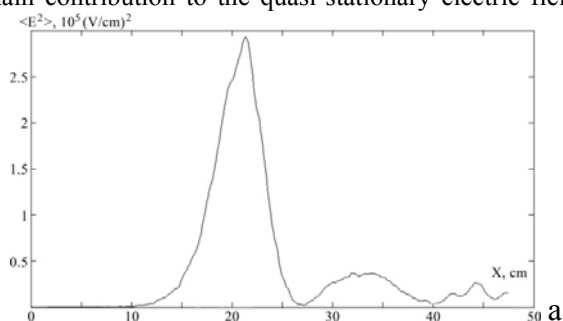
stage quasi-stationary electric field results to redistribution of the plasma ions' density, so quasi-neutrality perturbation is compensated. As it is clear from Fig. 4,a, HF electric fields' intensity gradient is larger from the side of collector comparing to its' gradient from the side of injector. Thus, the magnitude of corresponding electric field has to be larger, which is in good accordance with Fig. 4,a.

Fig. 4,b demonstrates an instantaneous spatial distribution of the striction electric field intensity, averaged over the plasma period, for the time point  $t=60T_p$ . This field is related with the HF electric fields' intensity gradient by the expression:

$$E_{str} = \frac{e}{4m\omega_p^2} \frac{d}{dx} \langle E^2 \rangle,$$

where  $\omega_p = 2\pi/T_p$  is the electron plasma frequency,  $\langle E^2 \rangle$  is the HF electric field intensity, averaged over the

plasma period. Comparison of Figs. 3,a and 4,b demonstrates that exactly the striction field makes the main contribution to the quasi-stationary electric field.



So asymmetry of the HF field intensity distribution results to the formation of the background plasma electrons' flow directed to the electron beam injector.

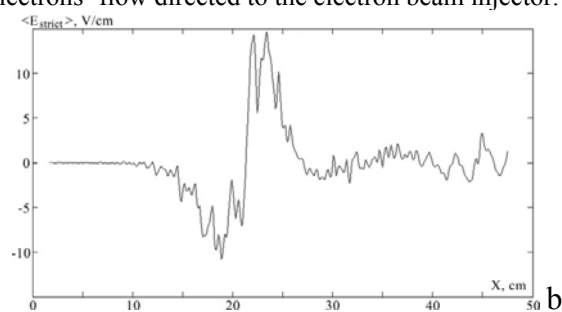


Fig. 4. Instantaneous spatial distribution of HF electric fields' intensity, averaged over plasma period for the time point  $t=60T_p$  (a); – instantaneous spatial distribution of striction field, caused by the gradient of HF electric fields' intensity for the time point  $t=60T_p$  (b)

## CONCLUSIONS

1. At the initial stages of the beam-plasma instability the flow of plasma electrons appears in the area of the intensive HF electric field. This flow is formed as the sum of two opposite flows, which appear due to the plasma electrons' oscillations in the potential well. The result flow is directed to the beams' injector (oppositely to the direction of the beam motion). In the same region the flows of plasma ions appear with both directions. Moreover, the ions' flow, directed along the electron beams' propagation direction, is more intensive.

2. The cause of plasma particles' flows formation is the quasi-stationary electric field, which change its' direction in space. Area of the negative field is located near the injector, while region of positive field is located further from the injector, and its' absolute value is larger.

3. Calculation shows that the cause of quasi-stationary electric field formation is plasma electrons' extrusion from the region of intensive HF electric field. Peculiarities of the quasi-stationary field space distribution are defined by the distribution of HF field intensity.

4. The results obtained are valid for the beams with the transversal length that is large in the scale of the

inversed spatial increment of the beam-plasma instability.

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## ФОРМИРОВАНИЕ ПОТОКОВ ЭЛЕКТРОНОВ И ИОНОВ В ФОНОВОЙ ПЛАЗМЕ НА НАЧАЛЬНОЙ СТАДИИ РАЗВИТИЯ ПУЧКОВО-ПЛАЗМЕННОЙ НЕУСТОЙЧИВОСТИ

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С помощью компьютерного моделирования показано, что на начальной стадии развития плазменно-пучковой неустойчивости в области, где достигается максимум интенсивности высокочастотного электрического поля, формируется поток электронов фоновой плазмы, направленный навстречу электронному пучку. Возникновение этого потока связано с начальным этапом деформации профиля концентрации плазмы под воздействием давления неоднородного ВЧ-электрического поля.

## ФОРМУВАННЯ ПОТОКІВ ЕЛЕКТРОНІВ ТА ІОНІВ У ФОНОВІЙ ПЛАЗМІ НА ПОЧАТКОВІЙ СТАДІЇ РОЗВИТКУ ПУЧКОВО-ПЛАЗМОВОЇ НЕСТІЙКОСТІ

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Шляхом комп'ютерного моделювання показано, що на початковій стадії розвитку плазмово-пучкової нестійкості в області, де досягається максимум інтенсивності високочастотного електричного поля, формується потік електронів фонові плазми, спрямований назустріч електронному пучку. Виникнення цього потоку пов'язане із початковим етапом деформації профілю концентрації плазми під дією тиску неоднорідного ВЧ-електричного поля.