INTERACTION OF THE MODULATED ELECTRON BEAM WITH PLASMA: KINETIC EFFECTS

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Evolution of the velocity distribution functions of plasma and beam electrons during modulated electron beam propagation in homogeneous and inhomogeneous plasma was studied numerically. Velocity distribution function of plasma electrons at the late time moments strongly differs from initially Maxwellian one. In the regions of strong electric field plasma electrons' bunches are formed. Comparison of distribution functions of beam electrons for modulated and non-modulated beams shows that deep initial modulation suppresses resonant instability development. In the inhomogeneous plasma acceleration of electrons in the plasma resonance point can be observed.

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1. INTRODUCTION

Problems of the modulated electron beam interaction with homogeneous and inhomogeneous plasma are of interest in various branches of plasma electronics such as electron beams' using as emitters of the electromagnetic waves in ionosphere, transillumination of the plasma barriers for electromagnetic waves using electron beams etc.

In our previous works [1,2] interaction of modulated electron beams with plasma was studied via computer simulation using modified package PDP1. Discussion of kinetic effects during the interaction of the modulated electron beam with homogeneous and inhomogeneous plasma is presented in this report.

2. MODIFICATION OF THE VELOCITY DISTRIBUTION FUNCTIONS DURING MODULATED ELECTRON BEAM PROPAGATION IN HOMOGENEOUS PLASMA

Simulation was carried out via particle-in-cell method using modified program package PDP1. 1D model was treated. Initially homogeneous background plasma layer was located between two plane conductive electrodes. Electron beam was injected from left electrode and moved to right one. The plasma particles were absorbed by electrodes.

Plasma was formed by hydrogen ions, and it was completely ionized. Simulation parameters corresponded approximately to the conditions of laboratory experiment [3]. The beam density was modulated harmonically with the initial depth 0.3. Simulation was carried out during the time interval of $5\cdot10^{-8}$ s that contained approximately 200 electron plasma periods or 5 ion plasma periods. During this time electron beam reached the opposite electrode, and approximately stationary processes were settled.

Possibility to save coordinates and velocities of large particles was used to obtain the velocity distribution function.

Fig. 1 presents velocity distribution functions of plasma electrons for different time moments (a,b) and space-time distribution of electric field (c). The darker areas correspond to the larger number of particles and field strength. Velocity distribution functions of plasma electrons at the late moments of time strongly differ from initially Maxwellian one (compare Fig. 1 a,b). In the regions of strong electric field plasma electrons' bunches are formed (Fig. 1b). One can see that regions of plasma electrons' bunch formation coincide with maximums of electric field (for $t=4.5\cdot10^{-9}$ s – 0.06-0.08m, 0.11-0.12m, 0.19–0.2m). After the start of injection maximum of the

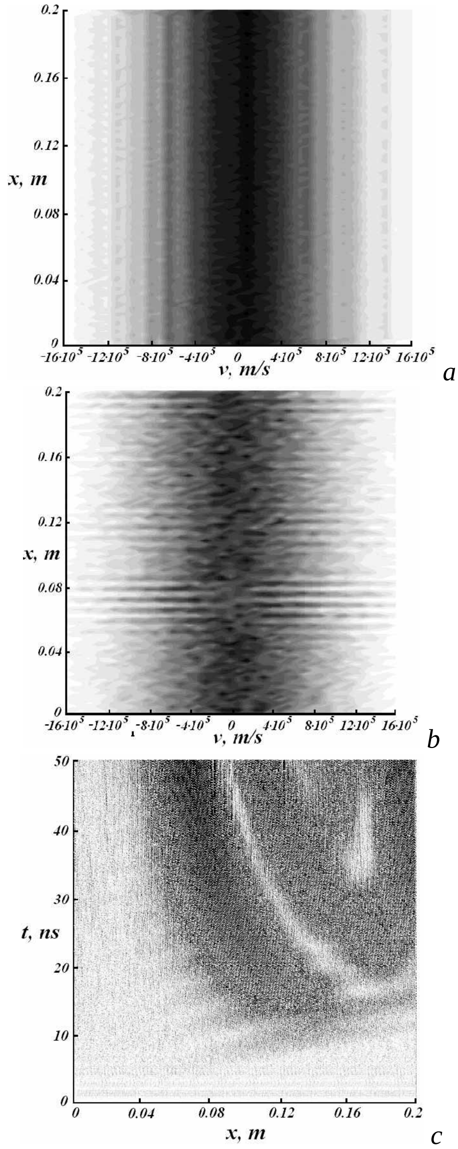
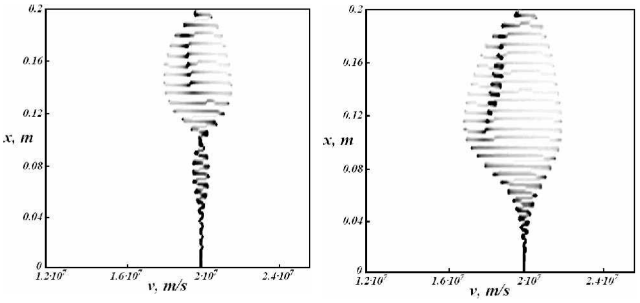


Fig. 1. Velocity distribution functions of plasma electrons for different time moments (a) $t=2.5\cdot10^{-9}$; b) $t=4.5\cdot10^{-9}$) and electric field strength (c)

electric field moves to the injector, and energy exchange between the electric field and the beam electrons occurs.

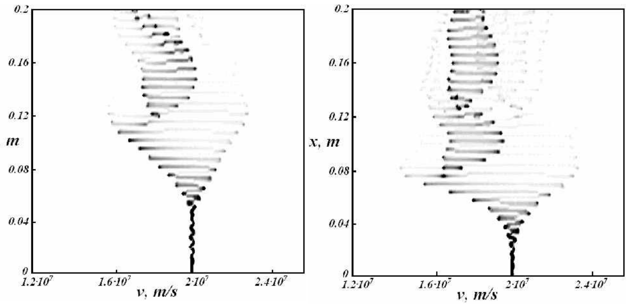
Figs. 2-4 show velocity distribution functions of beam electrons for modulated and non-modulated electron beam for different time moments (dark parts correspond to larger electron densities). In x-v plane these figures present phase portraits of electron beam. At Fig. 2 a,b one can see that most part of the beam electrons is decelerated. Appearance of secondary bunches can be connected with front reversal in the phase space. Comparison of pictures for modulated and non-modulated beams shows that sufficiently large initial modulation depth suppresses resonant instability development [4]. From Fig. 4 a,b one can see that distances between injector and region where resonant instability becomes significant for modulated and non-modulated beams are strongly different (0.04 - 0.05 and 0.02 - 0.25 m).

For the late moments of time the point where resonant instability becomes significant moves to injector both for modulated and non-modulated beams (Fig. 2-4). This effect is connected with the motion of the electric field maximum to injector (Fig. 1 c).



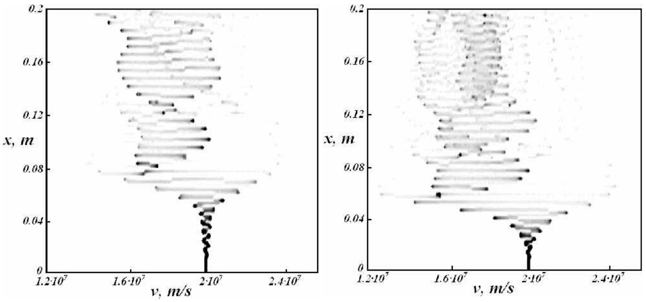
a b

Fig. 2. Velocity distribution functions of beam electrons for modulated (a) and non-modulated (b), electron beam at the time moment $t=10^{-8}$s



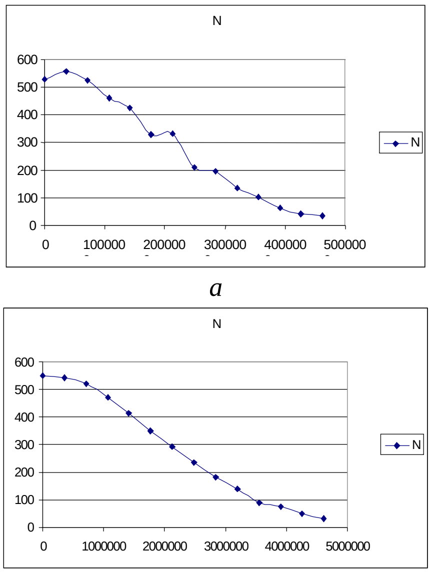
a b

Fig. 3. Velocity distribution functions of beam electrons for modulated (a) and non-modulated (b), electron beam at the time moment $t=2{\cdot}10^{-8}$s



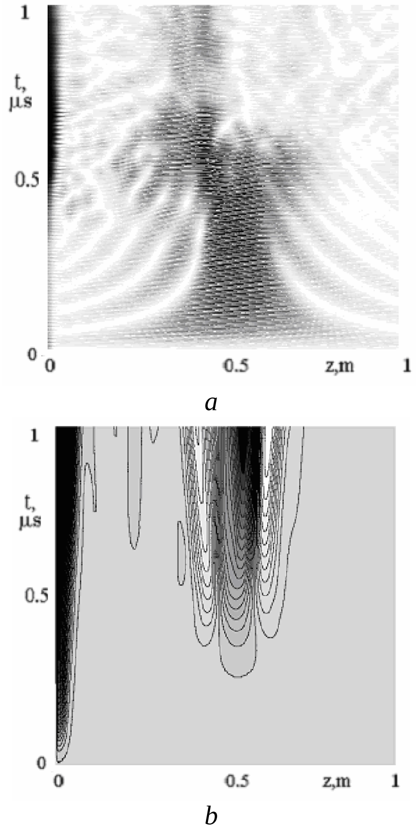
a b

Fig. 4. Velocity distribution functions of beam electrons for modulated (a) and non-modulated (b), electron beam at the time moment $t=4{\cdot}10^{-8}$s



b

Fig. 5. The instant distribution functions of the electrons of the plasma: a) for the moment of time $t=0{,}3\mu s$; b) for the moment of time $t=0{,}9\ \mu s$



b

Fig. 6. Space-time distribution of the absolute value of electric field (a) and ion density perturbation (b)

3. ELECTRONS' ACCELERATION IN THE LOCAL PLASMA RESONANCE REGION

During the study of inhomogeneous plasma dynamics in the homogeneous pumping electric field the effect of plasma electrons' acceleration in local plasma resonance region was found out [5]. It was shown that electrons accelerated in such a way move in the direction of plasma density decreasing in the weakly inhomogeneous plasma.

The model studied in this section differs from the previous one. The difference is that now plasma density grows linearly from left electrode to the right one. Plasma resonance point where modulation frequency of the beam coincides with the local Langmuir frequency is situated in the center of simulation interval.

The instant distribution functions of the plasma electrons during it's interaction with modulated electron beam is shown on Fig. 5 a,b. Space-time distribution of the absolute value of electric field (dark color corresponds intensive field regions) and ion density (dark color corresponds cavities in density profile) is shown on Fig. 6 a,b, respectively. In the moment of time t=0,5μs the density cavity is formed.

Fig. 5 a corresponds to the moment of time when the electric oscillations in LPRR have been already excited (see Fig. 6 a) but plasma density profile was not yet perturbed (see Fig. 6,b). The local peak on the distribution function can be associated with the electrons accelerated in LPRR.

Fig.5 b corresponds to the late moment of time when the density cavity has been already formed in LPRR, and the electric field in this region has been decreased (see Fig.6 a,b). So there is no more electron acceleration in LPRR. Consequently there is no perturbations on the distribution function.

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ВЗАИМОДЕЙСТВИЕ МОДУЛИРОВАННОГО ЭЛЕКТРОННОГО ПУЧКА С ПЛАЗМОЙ: КИНЕТИЧЕСКИЕ ЭФФЕКТЫ

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Численно исследована эволюция функции распределения электронов плазмы и пучка по скоростям при распространении модулированного электронного пучка в однородной и неоднородной плазме. Функция распределения для электронов плазмы в поздние моменты времени существенно отличается от начальной максвелловской. В областях сильного электрического поля образуются сгустки электронов плазмы. Сравнение функций распределения электронов пучка для модулированных и немодулированных пучков показывает, что глубокая начальная модуляция подавляет развитие резонансной неустойчивости. В неоднородной плазме может наблюдаться ускорение электронов в точке локального плазменного резонанса.

ВЗАЄМОДІЯ МОДУЛЬОВАНОГО ЕЛЕКТРОННОГО ПУЧКА З ПЛАЗМОЮ: КІНЕТИЧНІ ЕФЕКТИ

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Числовими методами досліджена еволюція функції розподілу електронів плазми та пучка за швидкостями при поширенні модульованого електронного пучка в однорідній і неоднорідній плазмі. Функція розподілу для електронів плазми в пізні моменти часу суттєво відрізняється від початкової максвеллівської. В областях сильного електричного поля утворюються згустки електронів плазми. Порівняння функцій розподілу електронів пучка для модульованих і немодульованих пучків показує, що глибока початкова модуляція придушує розвиток резонансної нестійкості. В неоднорідній плазмі може спостерігатися прискорення електронів у точці локального плазмового резонансу.