EVOLUTION OF THE MODULATED ELECTRON BEAM IN THE INHOMOGENEOUS PLASMA WITH LINEAR DENSITY PROFILE

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Evolution of the density profile of the modulated electron beam moving through the plasma with linear density profile is studied via computer simulation. Increase of the beam current and decrease of its velocity results to the substantial inharmonicity of the beam density profile. The deformation of this profile depends on the beam velocity direction.

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1. INTRODUCTION

Transformation of the beam modes into the Langmuir waves takes place mainly in the local plasma resonance region (LPRR) of the inhomogeneous plasma [1-3]. Maximum of electric field amplitude excited by the modulated electron beam is also localized in LPRR. This maximum results to the deformation of the plasma density profile (see, e.g., [4]). Analytic calculations [1-3] were carried out for harmonic current of the beam. But during the beam motion through plasma beam-plasma instability occurs. It results to the density and velocity modulation of the beam. In the nonlinear stage of the beam-plasma instability the overtaking of the particles occur, and the alternative current of the beam becomes substantially inharmonic [5].

In the beam-plasma amplifiers the input and output signals must have the same frequency. The nonlinear stage of the beam-plasma instability results to the appearance of higher harmonics in the output signal. This effect is undesirable.

The problem of the beam-plasma instability evolution in the inhomogeneous plasma was previously discussed in [6-7]. In this work evolution of the density modulated electron beam moving in the inhomogeneous plasma is studied. The conditions of harmonicity of the beam current in the LPRR are found.

Computer simulation using the modified package PDP1 [8] was carried out. In this package plasma forms the plane layer between two electrodes. Stationary plasma density changed linearly from $1\cdot10^{14}m^{-3}$ near the left electrode to $3\cdot10^{14}m^{-3}$ near the right electrode. LPRR was in the middle of the simulation region. The cases of beam injection from left and right electrode were treated.

2. THE BEAM MOVING INTO DENSE PLASMA

Spatial dependencies of the beam electrons' density and velocity as well as the beam current spectrum in LPRR are plotted on Fig.1 for $V=7\cdot10^7$m/s, j_m=1A/m^2. The beam density profile remains quasi-harmonic in the whole simulation region, but the alternative current amplitude decreases slowly. The amplitude of the second harmonic is about 5% from the amplitude of the first one (Fig.1c). Velocity modulation appears in the initially monokinetic beam. The bunches with higher density have smaller velocities (Fig.1b). It results to the steepening of the trailing front of the bunch.

These effects can be simply interpreted qualitatively. The beam moves initially in the subcritical plasma, where ε>0, so the electrons in the bunch repulse one another. It results to the bunch swelling and decrease of the density in its center.

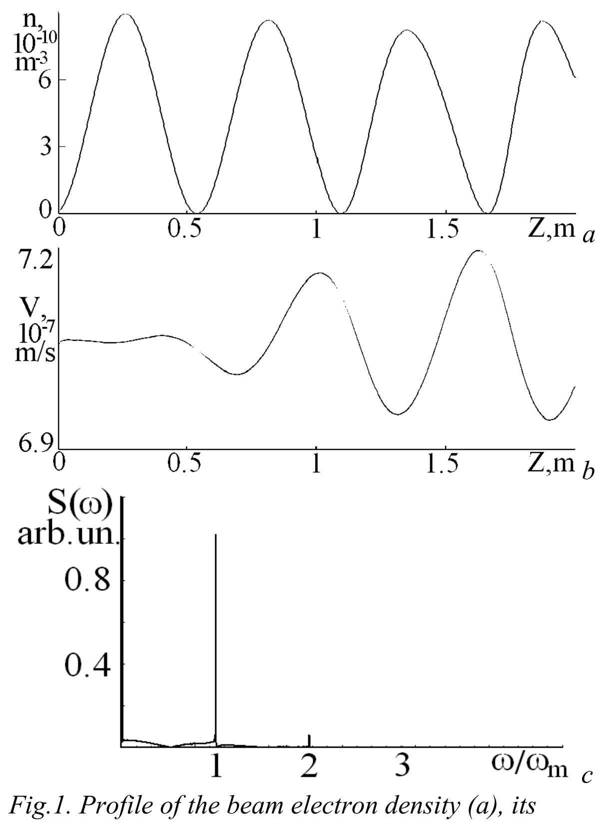

Fig.1. Profile of the beam electron density (a), its phase trajectory (b) and beam current spectrum in LPRR (c) for $V=7\cdot10^7$m/s, j_m=1A/m^2

Fig.2 demonstrates the simulation results for $V=7\cdot10^7$m/s, j=5A/m^2. The beam electrons' density profile near LPRR (z=1m) becomes substantially inharmonic for this case. All the processes described above also take place. But for the forth bunch the wave in the phase space has almost overturned (Fig.2b). It results to the increase of its amplitude and significant profile deformation (Fig.1a).

Harmonics up to the forth one appear in the spectrum (Fig.2c).

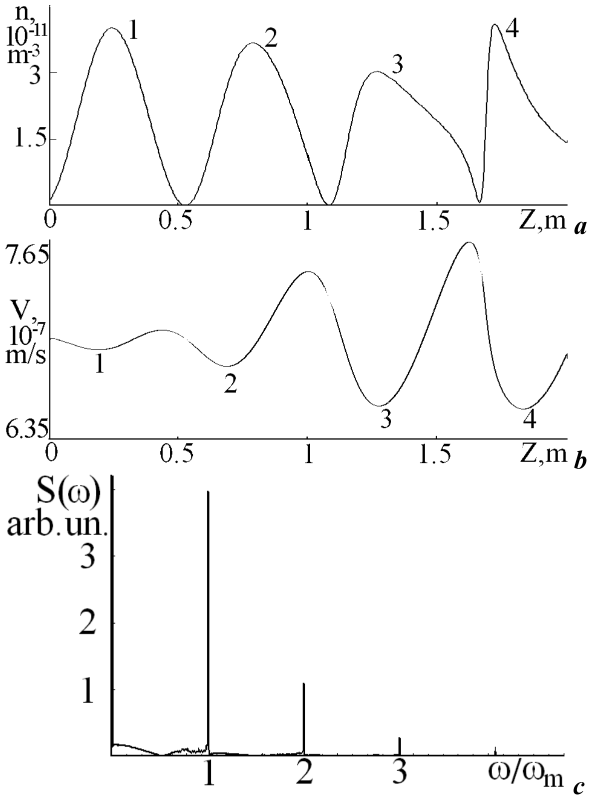

Fig.2. Profile of the beam electron density (a), its phase trajectory (b) and beam current spectrum in LPRR (c) for $V=7\cdot10^7$m/s, $j_m=5$A/m^2

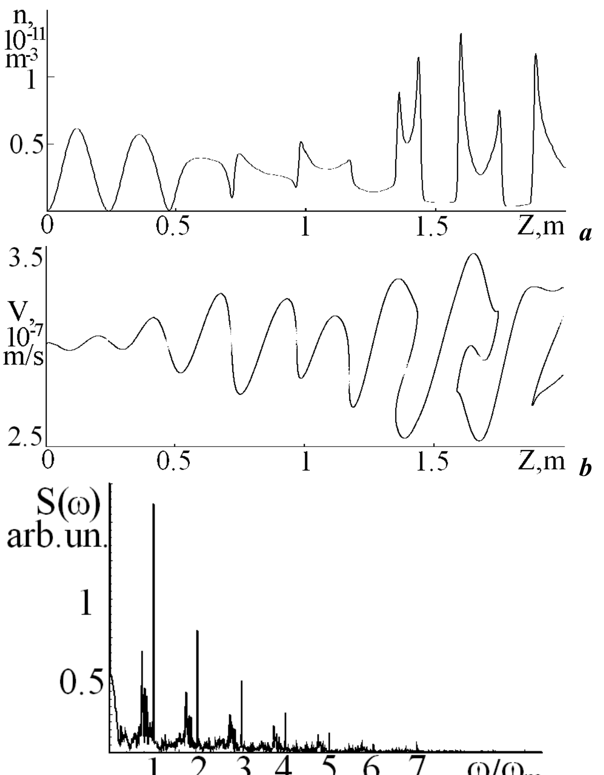

Fig.3. Profile of the beam electron density (a), its phase trajectory (b) and beam current spectrum in LPRR (c) for $V=3\cdot10^7$m/s, $j_m=3$A/m^2

Simulation results for $V=3\cdot10^7$m/s, $j=3$A/m^2 are plotted on Fig.3. Here the time of the beam-plasma interaction is increased. Consequently the particles' overtaking (Fig.3b) and bunch front overturn occurred before the beam reached LPRR. Due to the overturn the beam density profile has a form of separate narrow peaks of the large magnitude (Fig.3a). The harmonics of the downshifted frequency appear in the spectrum additionally to the higher harmonics of the modulation frequency (Fig.3c). The spectral lines are widened, and the spectrum becomes continuos.

3. THE BEAM MOVING INTO LOW-DENSITY PLASMA

Spatial dependencies of the beam density and velocity as well as beam current spectrum in LPRR for $V=7\cdot10^7$m/s, $j=1$A/m^2 are given on Fig.4. The processes that take place are similar to the described above. But now the beam electron bunches' density increases gradually, and bunches converge. During the beam motion the velocity modulation density initially increases, and somewhat decreases near the right electrode (Fig.4b). Now the beam initially moves in the supercritical plasma ($\varepsilon<0$), so the electrons in the bunch attract to one another. The forefront of the beam is decelerated, and the trailing front is accelerated (Fig.4b). When the beam gets the subcritical plasma, electrons start repulsing, and the velocity modulation depth decreases. The second harmonic with the small magnitude appears in the beam spectrum (Fig.4c). The beam profile remains quasi-harmonic.

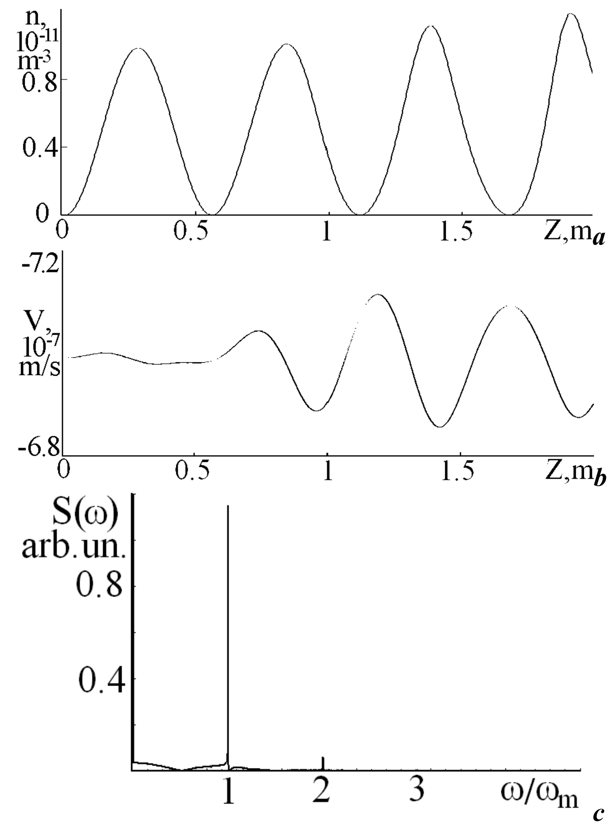

Fig.4. Profile of the beam electron density (a), its phase trajectory (b) and beam current spectrum in

LPRR (c) for $V=7\cdot10^7$m/s, j_m=1A/m^2

$V=1\cdot10^7$m/s, j_m=5A/m^2

For $V=7\cdot10^7$m/s, $j=5$A/m^2 the beam density profile near LPRR becomes substantially inharmonic (Fig.5a). The second, third and forth harmonics appear in the spectrum (Fig.5c). Magnitude of the second harmonic is about 30% of the magnitude of the first one. The overtaking of the wave front in the phase space takes place for the lust bunch (Fig.5a). It results to the strong increase of the bunch magnitude and deformation of its profile (Fig.5c).

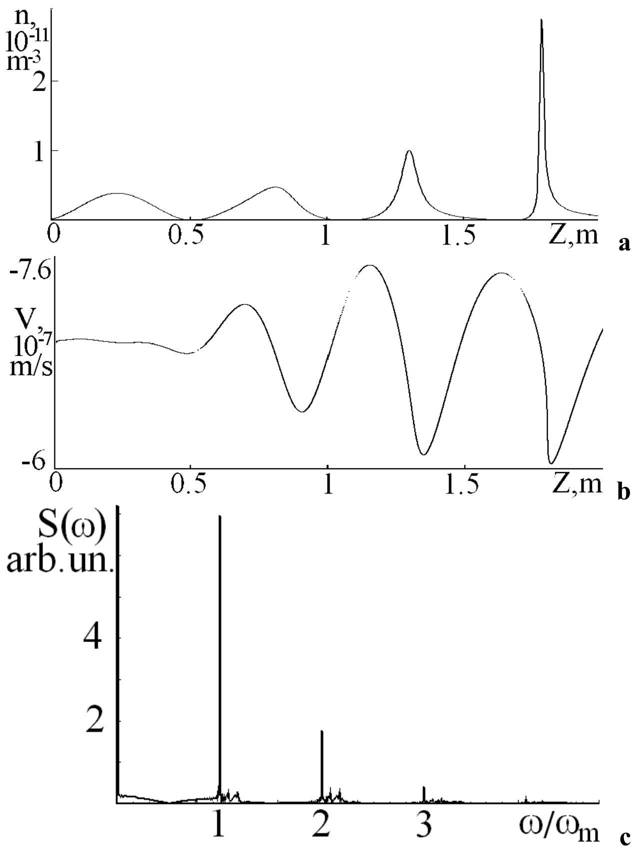

Fig.5. Profile of the beam electron density (a), its phase trajectory (b) and beam current spectrum in LPRR (c) for

4. CONCLUSIONS

1. Higher harmonics of the significant magnitude appear in the spectrum of the modulated electron beam current when the current density is increased or the beam velocity is decreased.

2. The beam density profile in the LPRR depends substantially from the beam velocity direction. When the beam initially moves in the subcritical plasma, bunches are widened. If it moves initially in the supercritical plasma, bunches converge.

5. REFERENCES

1. N.S.Erokhin, S.S.Moiseev. Transformation of waves in inhomogeneous unstable plasma // *ZhETF. (65).* 1973, №4, p.1431-1447. (In Russian)
2. K.P.Shamrai. Transformation and amplification of waves in a non-uniform plasma involving monoenergetic electron beam // *J. Plasma Phys. (31).* 1984, №2, p.301-311.
3. I.O.Anisimov, O.A.Borisov. Electrical field excitation in non-uniform plasma by the modulated electron beam // *Physica Scripta (62).* 2000, №5, p.375-380.
4. A.N.Kondratenko. On the possibility to control beam-plasma instability on the emission stage of this evolution // *UPhZh. (26).* 1981, № 4, p. 678-680 (In Russian).
5. E.V.Mishin, Yu.Ya.Ruzhin. V.A.Telegin. *Interaction electron stream with ionosphere plasma.* Moscow: "Gidrometeoizdat", 1989. (In Russian).
6. K.Yu.Blioh, On the influence of the plasma inhomogeneity upon the beam instability development // *Radio physics & radio astronomy (3).* 1998. №1, p.49-60. (In Russian)
7. I.O.Anisimov, D.V.Sasyuk, T.V.Siversky. Modified package PDP1 for beam-plasma systems' simulation // *Dynamical System Modelling and Stability Investigation. Thesis of Conf. Reports.* Kyiv, 2003, p.257.

ЭВОЛЮЦИЯ МОДУЛИРОВАННОГО ЭЛЕКТРОННОГО ПУЧКА В НЕОДНОРОДНОЙ ПЛАЗМЕ С ЛИНЕЙНЫМ ПРОФИЛЕМ

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В работе исследуется эволюция профиля плотности модулированного электронного пучка во время его движения через неоднородную плазму с линейным профилем. Показано, что при увеличении плотности тока пучка и времени взаимодействия пучка с плазмой профиль пучка становится существенно несинусоидальным. Также показано, что направление движение пучка влияет на характер деформации его начального профиля.

ЕВОЛЮЦІЯ МОДУЛЬОВАНОГО ЕЛЕКТРОННОГО ПУЧКА В НЕОДНОРІДНІЙ ПЛАЗМІ З ЛІНІЙНИМ ПРОФІЛЕМ

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В роботі досліджується еволюція профілю густини модульованого електронного пучка під час його руху крізь неоднорідну плазму з лінійним профілем. Показано, що зі збільшенням густини струму пучка та часу взаємодії пучка із плазмою профіль пучка стає істотно несинусоідальним. Також показано, що напрямок руху пучка впливає на характер деформації його початкового профілю.