Dynamics of cylindrical charged bunches in homogeneous plasmas

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1. Introduction

Dynamics of electron beams and bunches in plasma take one of the leading places in plasma electronics. Charged particles' acceleration by a powerful wake wave fields excited in plasma by relativistic electron bunches [1], inhomogeneous plasma diagnostics using transition radiation of electron bunches and beams [2] are actual problems in this field. Simulation of the electron bunch dynamics in homogeneous plasma in 1D geometry was carried out in [3]. It was shown if bunch duration is proportional to the period of Langmuir oscillations then initial bunch density profile is strongly deformed in longitudinal direction. This effect is caused by the influence of wakewave electric field excited by the bunch space charge. But influence of the magnetic field and radial bunch dynamics are not taken into account in 1D electrostatic model. Plasma simulation results obtained by 2.5D electromagnetic code [4] are presented at this paper.

2. Simulation model

Beam-plasma system was simulated in 2.5D cylindrical geometry. Simulation volume has a shape of cylindrical resonator with radius of 0.2 m and length of 1.5 m. The system is filled with homogeneous non-isothermal plasma. Plasma consists of electrons with temperature 1eV and hydrogen ions with temperature 0.1eV. The plasma density is $5\cdot10^{8}cm^{-3}$. Electron bunch of cylindrical shape with sharp forefront is injected into plasma. Initial bunch velocity is $3\cdot10^{7}$m/s, initial density is $8\cdot10^{6}$ cm^{-3}, radius is 2cm. Initial duration of electron bunch is equal to 4 periods of Langmuir plasma oscillations.

3. Results and discussion

Sharp forefront of the bunch excites wake field. Bunch electrons gather in maxima of the excited wake wave and move out of minima (compare beam density and E_z on Fig.1 a). This leads to the formation of series of microbunches with spatial periodicity of Langmuir wave length. After that the wake wave amplitude continues to grow due to resonant excitation by every separate microbunch.

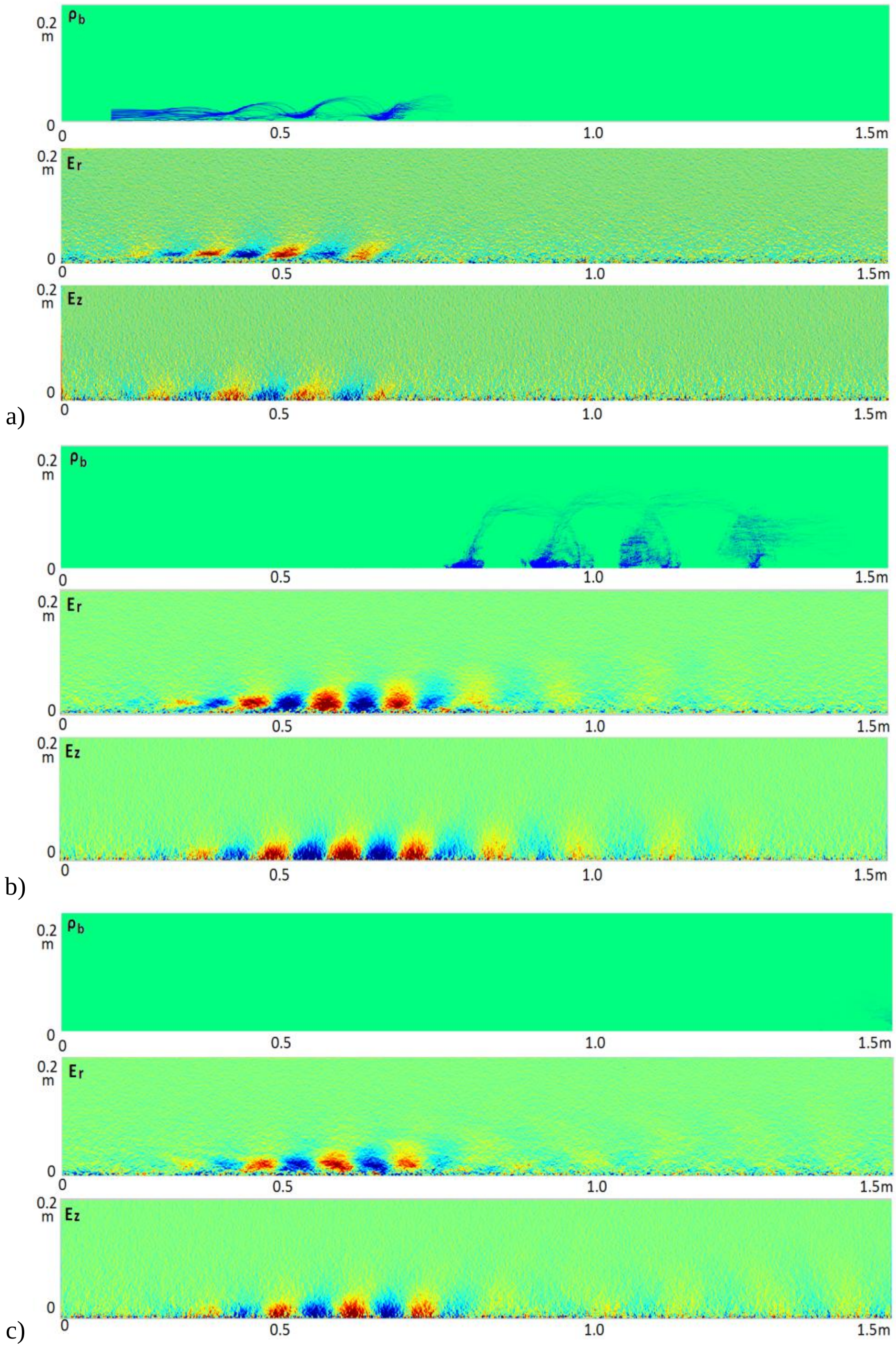

Fig.1. Spatial distribution of charge density of a bunch ρ_b and electric field components E_r, E_z at $2.1\cdot10^{-8}$s (a), $4.3\cdot10^{-8}$s (b) and $9.5\cdot10^{-8}$s (c) time moments.

One can see on Fig. 1b that trailing microbunches are more focused than leading ones. In other words the emittance of each subsequent microbunch decreases with number of microbunches. It happens because the amplitude of the excited wake wave grows from the forefront of the bunch to its back front. Strong wake field of convex shape gathers focuses last microbunches while weak field of leading bunches cannot compensate repulsing forces.

The dependency of maximum electric field in the system on time is shown on Fig. 2. One can see that strong electric field exists in plasma even after all microbunches leaves the system. This field is primarily located in the near-injector region (Fig. 1c). Space-time distribution of the longitudinal electric field component near the system axis is shown on Fig. 3. One can see that electric field has a form of Langmuir wave moving rightwards. The

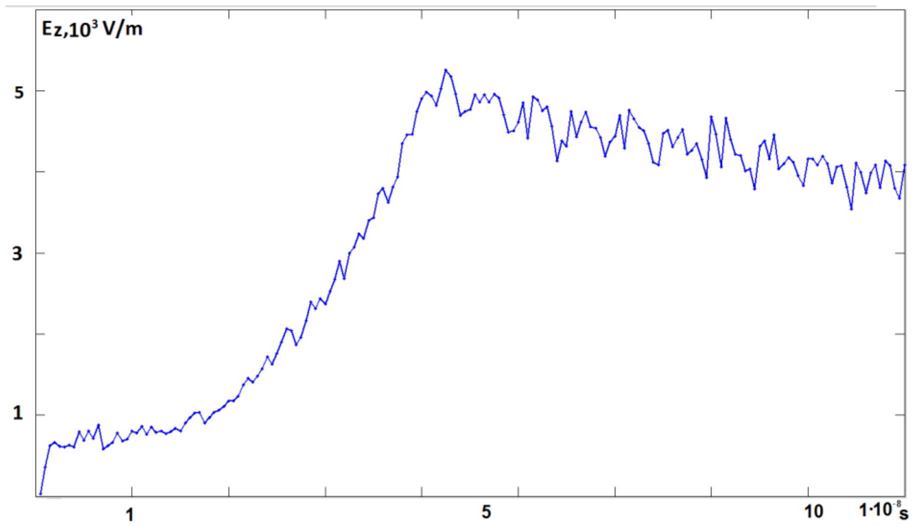

Fig.2 Dependency of the maximum wake wave amplitude on time

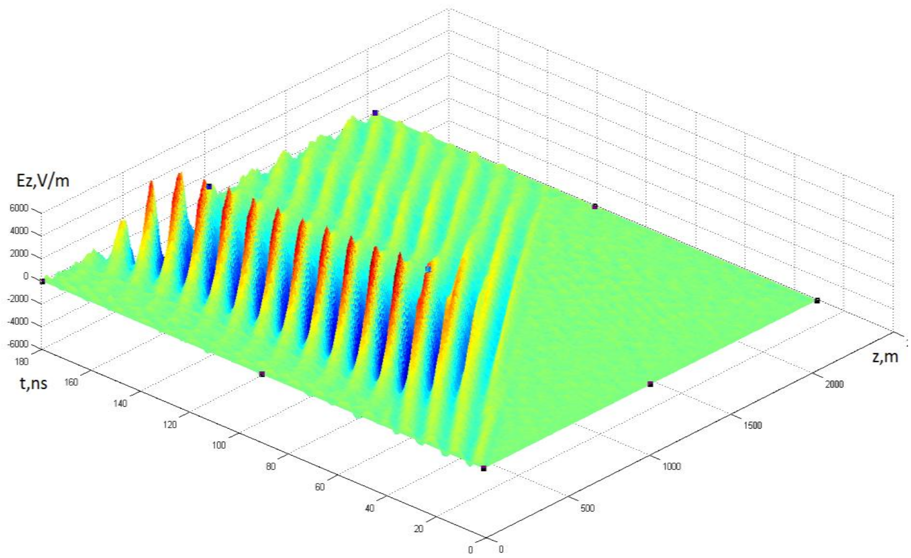

Fig.3 Space-time distribution of the E_z electric field component near the system axis

envelope of the wave is similar to NSE soliton. Nonlinear effects are possible in the system due to the fulfillment of condition (1):

$$\frac{\varepsilon_0 E^2}{2} \approx n k_b T_e \qquad (1)$$

which means that kinetic pressure is the same order of magnitude as the density of energy of electric field.

4. Conclusions

Bunch dynamics injected into the plasma was simulated using 2.5D relativistic electromagnetic PIC code. Strong non-linear effects were observed. The initial bunch decays into the series of microbunches under the influence of excited wake wave.

Strong electric field exists in plasma even after the bunch leaves the system. It’s localized in the near-injector region and has a form of Langmuir wave with envelope similar to that of NSE soliton.

References

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