EXCITATION OF THE WAKE WAVE FIELD IN PLASMA BY THE LONG CYLINDRICAL CHARGED BUNCH

Yu.M. Tolochkevich, T.E. Litoshenko, I.O. Anisimov

Taras Shevchenko Kiev National University, Kiev, Ukraine,
E-mail: yura.tolochkevich@gmail.com; taras.litoshenko@gmail.com; ioa@univ.kiev.ua

Results of analytic study and computer simulation of the wake waves excitation by cylindrical charged bunches are presented. Analytic solution was obtained for cold plasma in the given current approximation. Simulation was carried out for proton and electron bunches in electron-proton plasma using PIC method. For the proton bunch analytic results and simulation data are similar. The case of electron bunch differs strongly due to the formation of the microbunches' sequence and further resonant excitation of the wake wave field.

PACS: 52.35, 52.40 Mj

Problem of the waves' excitation in plasma by electron bunches is of significant interest because of its possible application for the creation of the compact high-energy electron accelerators [1]. However, the dynamics of electron bunches in the excited wake wave fields is also interesting for the possibility of diagnostics of the inhomogeneous plasma [2, 3]. The main aim of this work is the study of wake wave excitation by cylindrical electron bunch in the homogeneous plasma. Wake field is calculated in the approximation of a given current for cold plasma in Section 1. In Section 2 excitation of the wake wave is studied by PIC 2.5 simulation of the ion bunch injection into plasma. Finally, in Section 3 computer simulation of the electron bunch dynamics was carried out.

1. ANALYTIC CALCULATION

Full analytic solution is only possible in the given current approximation for cold plasma (for the warm plasma solution can be obtained in the far radiation zone). Bunch and plasma parameters are presented in Table.

Bunch and plasma parameters

System length, z	150 sm
Radius of the system, r	20 sm
Plasma Density	$5\cdot10^{8}$ sm^{-3}
Bunch density	$8\cdot10^{6}$ sm^{-3}
Initial bunch velocity	$3\cdot10^{9}$ sm/s
Radius of the bunch	2 sm
Bunch duration	$2.0\cdot10^{-8}$ s = 4 T langm

Wake wave field in the cold plasma is given by the following expression (see also Fig. 1):

$$n_1(r,\xi) = -\frac{n_B(r)}{2\pi}\exp\left(\frac{\nu\xi}{2v_0}\right)\left\{\exp\left(\frac{\nu L}{4v_0}\right)\cos\left[\frac{\omega_p(r)}{v_0}(\xi+L/2)+\varphi\right]\theta\left(-\xi-\frac{L}{2}\right)-\right.$$
$$\left.-\exp\left(-\frac{\nu L}{4v_0}\right)\cos\left[\frac{\omega_p(r)}{v_0}(\xi-L/2)+\varphi\right]\theta\left(-\xi+\frac{L}{2}\right)\right\},\qquad \varphi = arctg\frac{\nu}{2\omega_p}.$$

One can see from Fig.1 that for the selected parameters wake wave is strongly decreases behind bunch, because it is excited by leading and rear fronts that are in antiphase. Wake wave is excited only is a region of the bunch motion because the model of cold plasma was used.

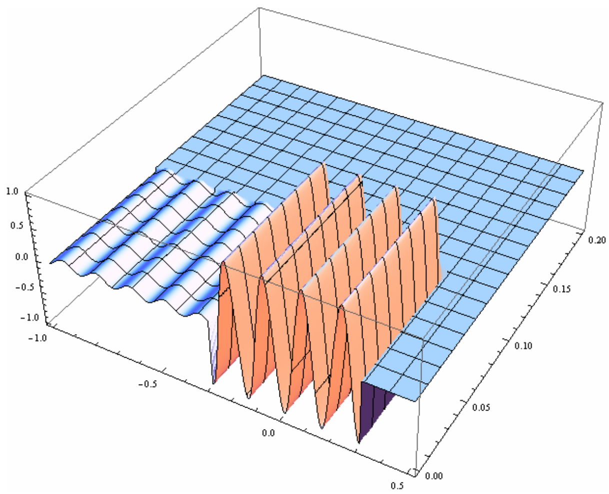

Fig. 1. Plasma density excitation by the charged bunch (analytic solution for cold plasma)

2. SIMULATION OF THE PROTON BUNCH IN PLASMA

Simulation of the proton bunch propagation was studied by 2.5D PIC simulation [4]. Parameters were chosen similar to Section 1. Plasma electron and ion temperatures are 1 and 0.1 eV, respectively. Results of simulation are in good agreement with analytic calculation in the given current approximation, because during the bunch motion through plasma its charge distribution hasn't been changed significantly.

3. SIMULATION OF THE ELECTRON BUNCH IN PLASMA

The main difference between simulation results for ion and electron bunches is the strong redistribution of the electron bunch density due to the initial wake wave excited by the sharp forefront of the bunch. Electrons of the bunch move in the field of this wave that leads to the microbunches' formation (Fig. 3) [5-6]. Bunch electrons are collected in the maxima of the excited wave potential and move out of the minima (compare beam density and E_r on Fig. 2). When microbunches are formed the wake wave is resonantly excited by their sequence, and its amplitude increases significantly (Fig. 4). Radial electric field exists in the restricted region. The bunch is stratified into separate layers inside this region. Layers located near the system axis are captured by the strong longitudinal field. Other electrons are pushed to the borders of the system, i.e. to the region where electric field disappears (Fig. 3).

CONCLUSIONS

Oscillations are excited only in a region of the bunch motion for the cold plasma model. Taking into account plasma temperature leads to a leakage of the oscillations from this area. Simulation results for the proton bunch are in good agreement with the calculation in the approximation of the given current bunch when wake wave field excited only by leading and rear fronts. Electron bunch is decomposed into a sequence of the microbunches in a wake wave field excited by leading front. This sequence excites wake wave field resonantly, and its amplitude increases significantly exceeding the level of the heating nonlinearity by a factor of 10^2 (compare with [7]).

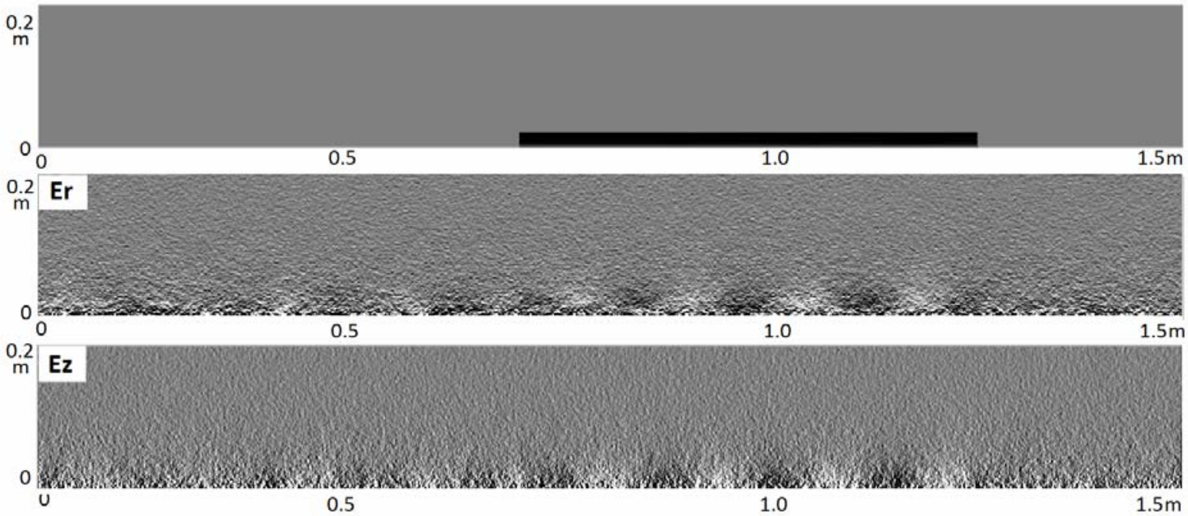

Fig. 2. Proton bunch charge density, E_r end E_z electric field components at the time moment $4.3\cdot10^{-8}$ s

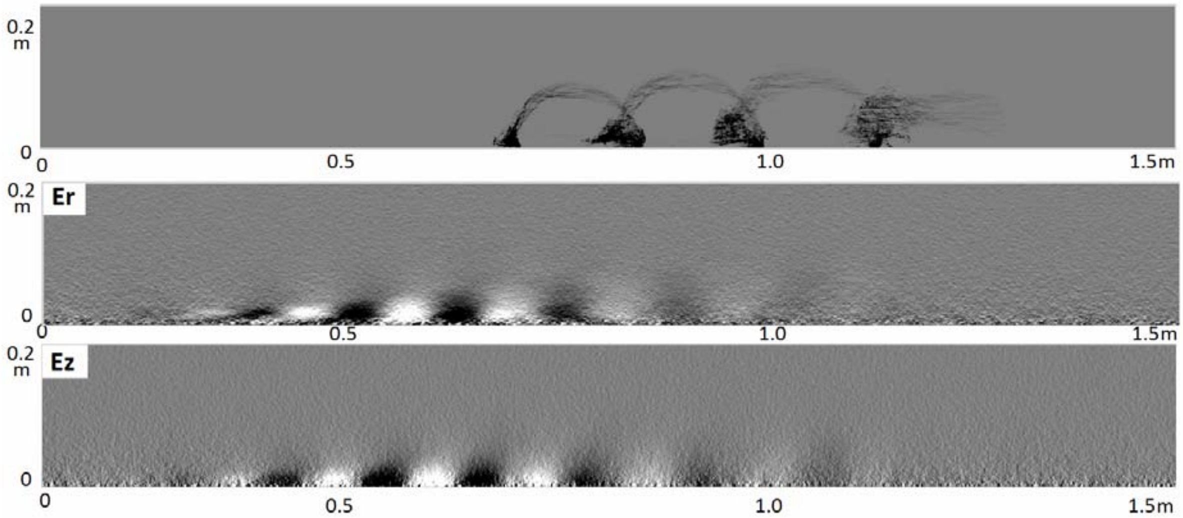

Fig. 3. Electron Bunch charge density, E_r end E_z electric field components at the time moment $4.3\cdot10^{-8}$ s

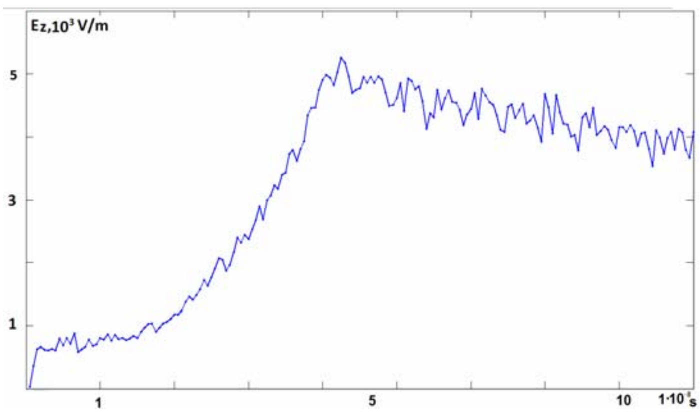

Fig. 4. Dependence of the maximum wakewave amplitude on time

REFERENCES

1. C.G. Geddes, D.L. Bruhwiler, and et al. // *J. Phys: Conference Series.* 2008, v. 125, p. 012002.
2. I.O. Anisimov, K.I. Lyubich // *J. Plasma Phys*. 2001, v. 66, Part. 3, p. 157-165.
3. I.O. Anisimov, Yu.M. Tolochkevich // *Ukr. J. Phys*. 2009, v. 54, №5, p. 454-460.
4. Yu.M. Tolochkevych, T.E. Litoshenko, I.O. Anisimov // *PAST. Ser. "Plasma electronics and new acceleration methods"*. 2010, №4, p. 47-50.
5. V.A. Balakirev, I.V. Karas', G.V. Sotnikov // PAST. Ser. "Plasma physics". 2000, №10, p. 948-951.
6. K.V. Lotov, V.I. Maslov, I.N. Onishchenko, E.N. Svistun // *PAST. Ser. "Plasma physics"*. 2010, №2, p. 122-124.
7. V.A. Balakirev, V.I. Karas', I.V. Karas'// *PAST. Ser. "Plasma physics"*. 2002, №2, p. 144-160.

Article received 20.09.12

ВОЗБУЖДЕНИЕ КИЛЬВАТЕРНЫХ ПОЛЕЙ В ПЛАЗМЕ ДЛИННЫМ ЗАРЯЖЕННЫМ ЦИЛИНДРИЧЕСКИМ СГУСТКОМ

Ю.М. Толочкевич, Т.Е. Литошенко, И.А. Анисимов

Представлены результаты аналитического расчета и компьютерного моделирования возбуждения кильватерных волн цилиндрическим электронным сгустком в однородной плазме. Аналитическое решение получено для холодной плазмы в приближении заданного тока. Моделирование выполнено для протонного и электронного сгустков в электронно-протонной плазме методом крупных частиц в ячейках. Для протонного сгустка результаты аналитического расчета и моделирования близки. Случай электронного сгустка сильно отличается вследствие формирования последовательности микросгустков и последующего резонансного возбуждения кильватерной волны.

ЗБУДЖЕННЯ КІЛЬВАТЕРНИХ ПОЛІВ У ПЛАЗМІ ДОВГИМ ЗАРЯДЖЕНИМ ЦИЛІНДРИЧНИМ ЗГУСТКОМ

Ю.М. Толочкевич, Т.Є. Літошенко, І.О. Анісімов

Подані результати аналітичного розрахунку і комп'ютерного моделювання збудження кільватерних хвиль циліндричним електронним згустком в однорідній плазмі. Аналітичний розв'язок отримано для холодної плазми в наближенні заданого струму. Моделювання виконане для протонного та електронного згустків в електронно-протонній плазмі методом макрочастинок у комірках. Для протонного згустку результати аналітичного розрахунку та моделювання подібні. Випадок електронного згустку сильно відрізняється через формування послідовності мікрозгустків та подальше резонансне збудження кільватерної хвилі.