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IDENTICAL DECELERATING WAKEFIELDS FOR DRIVER-BUNCHES AND IDENTICAL ACCELERATING WAKEFIELDS FOR WITNESS-BUNCHES FOR THEIR PERIODIC SEQUENCE

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Acceleration by the wakefield in the plasma can provide compact sources of relativistic electron beams of high brightness. Free electron lasers and particle colliders, using plasma wakefield accelerators, require high efficiency and beams with low energy spread. Achieving both conditions can be ensured by the formation of identical fields for all accelerating bunches and identical fields for all decelerating bunches by controlled selection of bunch currents and their spatial distribution for a given plasma wave. We demonstrate such optimal bunch currents and their spatial distribution in the linear regime in a plasma accelerator with wakefield excited by electron bunches injected from the RF accelerator with high quality.

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INTRODUCTION

Advanced plasma wakefield accelerators can support accelerating gradients to 100 GV/m [1-3]. Traditional conventional accelerators can support accelerating gradient no more than 100 MV/m [4]. Advanced plasma wakefield experiments [3] have demonstrated perspective of this method of electron acceleration to many GeV energy. This is why the plasma wakefield are developed (see [5-37]).

But characteristics of accelerated electron beam in plasma wakefield are not sufficiently applicable. Therefore advanced way to essentially improve the accelerated electron bunch quality is the usage of electron bunches, produced by traditional well-developed RF accelerators.

Applications (particle collider and FEL) of plasma-wakefield accelerators require small emittance and high efficiency. These demand plateau formation on both the accelerating field for witness-bunch and the decelerating fields for driver-bunches by controlled bunch loading of the excited plasma wave with controlled current shaping [29, 30, 38, 39]. It has been proposed to use the beam loading effect (see [29, 30]) to compensate the energy spread of an electron beam in plasma wakefield accelerators.

In this paper, we report on numerical simulation of wakefield excitation by short-train of resonant driver-bunches and following pairs of witness-driver-bunches. We consider the plateau formation by driver-bunches on decelerating field and the plateau formation by witness-bunches on accelerating field. The plateau formation is important to improve electron bunches quality. Combining the previous results [40] we found optimal conditions for creation of a sequence of witness-driver-bunches pairs after the short-train of resonant driver-bunches with plateau on corresponding wakefield.

We present results of numerical simulation of plasma wakefield excitation by short-train of resonant driver-bunches and following witness-driver-bunches pairs, the plateau formation by driver-bunches on decelerating field and the plateau formation by witness-bunches on accelerating field. The numerical simulation has performed with 2.5D code LCODE [41, 42], which considers the electrons of the beam as ensembles of macroparticles, and the electrons of the plasma as a cold electron fluid. We demonstrate such optimal bunch currents and their spatial distribution in the linear regime in a plasma accelerator with wakefield excited by electron bunches injected from the RF accelerator with high quality.

We consider the bunch, where electrons are distributed according to Gaussian in the transverse direction along the radius. We use the cylindrical coordinate system (r, z) and draw longitudinal electric and azimuthal magnetic fields at some z as a function of the dimensionless time $\tau=\omega_p t$ or $\xi=V_b t-z$, where V_b is the bunch velocity. Time is normalized on electron plasma frequency ω_{pe}^{-1}, distance – on c/ω_{pe}, bunch current I_b – on $I_{cr}=\pi mc^3/4e$, fields – on $mc\omega_{pe}/e$. e, m are the charge and mass of the electron, c is the light velocity.

1. PLATEAU FORMATION ON THE DISTRIBUTION OF A DECELERATING WAKEFIELD BY AN ELECTRON DRIVER-BUNCH AND ON THE DISTRIBUTION OF AN ACCELERATING WAKEFIELD BY AN ELECTRON WITNESS-BUNCH, ACCELERATED IN PLASMA

To begin with, we consider wakefield excitation in plasma by short-train of resonant driver-bunches and following witness-bunch and plateau formation by driver-bunches on the decelerating wakefield and by witness-bunch on the accelerating wakefield $E_z(\xi)$ (Fig. 1).

As we can see, after the witness-bunch the wakefield returns to its state before the fifth driver-bunch. This fact opens an opportunity to create infinite sequence that consists of driver-witness-bunches pairs with plateau on corresponding wakefield.

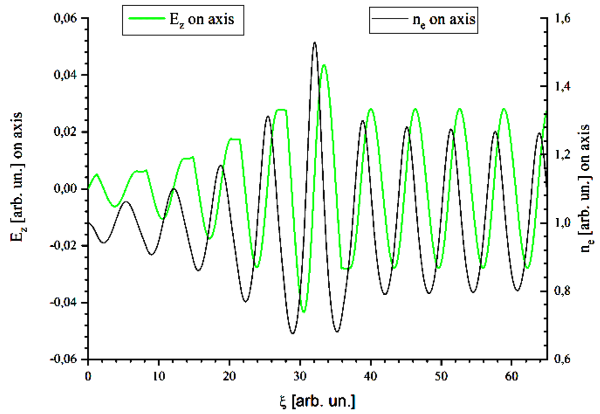

Fig. 1. The on-axis wakefield excitation E_z by short-train of resonant driver-bunches and acceleration of following witness-bunch, and plateau formation on $E_z(\xi)$ by short-train of resonant driver-bunches and following witness-bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. The length of bunches is equal to 0.19 of wavelength. The radius of bunches is equal to 0.3. The maximum current of bunch-driver is equal to $I_b=1.18\cdot10^{-2}$. The maximum current of bunch-witness is equal to $I_b=1.14\cdot10^{-2}$. The relativistic factor of bunches is equal to 1000

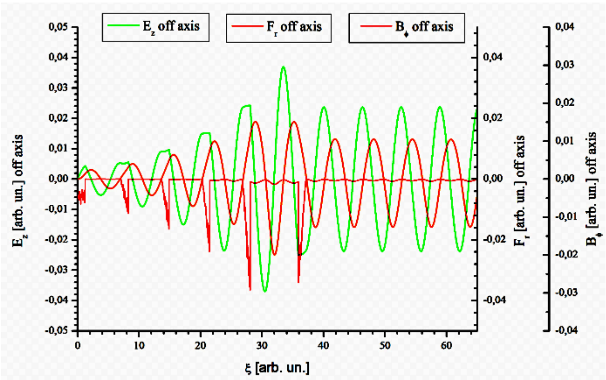

Fig. 2. The off-axis wakefield excitation E_z by short-train of resonant driver-bunches and acceleration of following witness-bunch, and plateau formation on $E_z(\xi)$ by short-train of resonant driver-bunches and following witness-bunch. The off-axis focusing force F_r is shown by orange. The off-axis azimuthal magnetic field B_ϕ is shown by red as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 1

As seen on the figure (Fig. 2) all electron driver- and witness-bunches are fully in focusing but inhomogeneous fields. The greater its charge along the bunch, both for driver-bunches and for witness-bunch, the stronger the focusing force. Since the velocity of bunches approximately equals to light velocity, the azimuthal magnetic field distribution shows the spatial distribution of bunches' charge densities/currents. As we can see, all electron bunches except the first one have triangle form.

2. INVESTIGATION OF THE PLATEAU FORMATION IN A PLASMA BY AN ELECTRON WITNESS-BUNCHES ON THE DISTRIBUTION OF AN ACCELERATING WAKEFIELD AND BY AN ELECTRON DRIVER-BUNCHES ON THE DISTRIBUTION OF A DECELERATING WAKEFIELD EXCITED BY INFINITE PERIODIC TRAIN OF PAIRS DRIVER AND WITNESS-BUNCHES

Now, we consider the wakefield excitation by short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs and plateau formation by short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs on the corresponding wakefield $E_z(\xi)$ (Fig. 3).

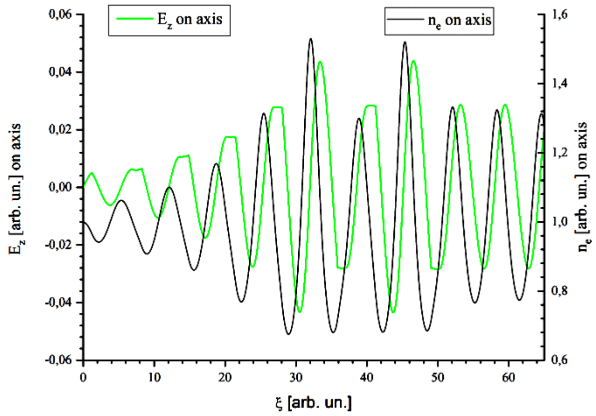

Fig. 3. The on-axis wakefield excitation E_z by short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs, and plateau formation on $E_z(\xi)$ by short-train of resonant driver-bunches and following sequence of witness- and driver-bunches. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 1

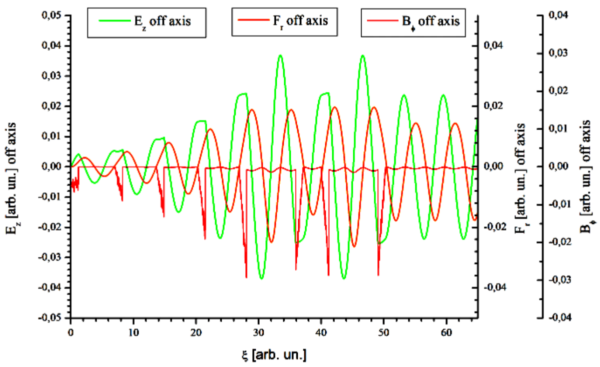

Fig. 4. The off-axis wakefield excitation E_z by short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs, and plateau formation on $E_z(\xi)$ by short-train of resonant driver-bunches and following sequence of witness- and driver-bunches. The off-axis focusing force F_r is shown by orange. The off-axis azimuthal magnetic field B_ξ is shown by red as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 1

In this case, after the last driver-bunch field returns to its state before the fifth driver-bunch. This fact proves initial prediction about possibility of creation of infinite sequence that consists of pairs of driver-witness-bunches with plateau on corresponding wakefield.

Fig. 4 gives us the same information as a Fig. 2 in previous section.

In Fig. 5 one can see spatial distribution of density of this short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs. In Fig. 6 one can see spatial distribution of plasma electron density, perturbed by this short-train of resonant driver-bunches and following sequence of witness-driver-bunch pairs.

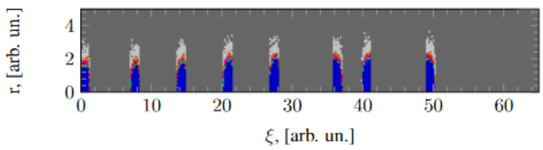

Fig. 5. The beam electron density as a function of the coordinate ξ along the plasma and the coordinate r *in the radial direction*

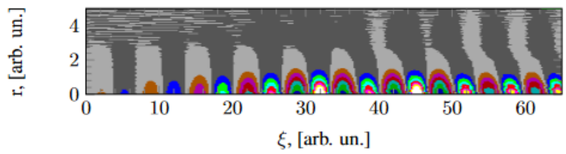

Fig. 6. The plasma electron density as a function of the coordinate ξ along the plasma and the coordinate r *in the radial direction*

3. CONCLUSIONS

Such parameters of the infinite periodic train of driver – witness pairs have been obtained under which identical accelerating wakefield for accelerated bunches is formed, and identical decelerating wakefield for all bunches, which excite wakefield, is formed by controlled selection for an excited plasma wave bunch currents and their spatial distribution. We demonstrate such optimal bunch currents and their spatial distribution in the linear regime in a plasma accelerator with wakefield excited by electron bunches injected from the RF accelerator with high quality.

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ОДНАКОВІ ГАЛЬМУЮЧІ КІЛЬВАТЕРНІ ПОЛЯ ДЛЯ ЗГУСТКІВ, ЩО ЗБУДЖУЮТЬ ПОЛЕ, ТА ОДНАКОВІ ПРИСКОРЮЮЧІ КІЛЬВАТЕРНІ ПОЛЯ ДЛЯ ЗГУСТКІВ, ЩО ПРИСКОРЮЮТЬСЯ, ДЛЯ ЇХ ПЕРІОДИЧНОГО ЛАНЦЮЖКА

І.В. Демиденко, В.І. Маслов

Прискорення кільватерним полем у плазмі може забезпечити компактні джерела релятивістських електронних пучків високої яскравості. Лазери на вільних електронах та колайдери частинок, де використовуються плазмові кільватерні прискорювачі, вимагають високої ефективності і пучків з низьким розкидом по енергії. Досягнення обох умов може бути забезпечене формуванням однакових полів для всіх згустків, що прискорюються, та однакових полів для всіх згустків, що гальмуються, шляхом контрольованого підбору для даної плазмової хвилі струмів згустків та їх просторового розподілу. Ми демонструємо такі оптимальні струми згустків та їх просторовий розподіл у лінійному режимі у плазмовому прискорювачі зі збудженням полів електронними згустками, які інжектуються з ВЧ-прискорювача при високій їх якості.