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PLATEAU FORMATION ON ACCELERATING WAKEFIELD FOR ELECTRON-WITNESS-BUNCH AND ON DECELERATING WAKEFIELD FOR DRIVER-BUNCHES IN A PLASMA

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Plasma wakefield acceleration promises compact sources of high-brightness relativistic electron and positron beams. Applications (particle colliders and free-electron lasers) of plasma wakefield accelerators demand low energy spread beams and high-efficiency operation. Achieving both requires plateau formation on both the accelerating field for witness-bunch and the decelerating fields for driver-bunches by controlled beam loading of the plasma wave with careful tailored current profiles. We demonstrate by numerical simulation by 2.5D PIC code LCODE such optimal beam loading in a linear and blowout electron-driven plasma accelerator with RF generated low and high beam charge and high beam quality.

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INTRODUCTION

Plasma wakefield accelerators have the ability to sustain accelerating gradients to 100 GV/m [1 - 3]. In conventional accelerators, due to breakdown which occurs on the walls of the accelerating structure at high electric fields, accelerating gradients are currently limited to approximately 100 MV/m [4] due to breakdown. Successful experiments on electron-bunch-driven wakefield acceleration have demonstrated acceleration of GeV-class electrons [3] and have therefore confirmed the relevance of this acceleration method. Plasma wakefield acceleration promises compact sources of high-brightness relativistic electron beams. Because the plasma accelerators provide large accelerating gradients the plasma (see [5 - 45]) accelerators are intensively investigated.

However, the quality of electron bunch produced in plasma accelerators is not yet sufficient for the realization applications. Precise control over the injected electron bunch properties is a key problem for plasma wakefield accelerators. One promising strategy towards the improvement of final quality of the accelerated electron bunch is the use of an electron beam from a conventional electron linac. Well-developed technologies of radiofrequency linacs allow electron bunches of good quality: small size and small energy spread to be provided.

Applications (particle colliders and free-electron lasers) of plasma wakefield accelerators demand low energy spread beams and high-efficiency operation. Achieving both requires plateau formation on both the accelerating field for witness-bunch and the decelerating fields for driver-bunches by controlled beam loading of the plasma wave with careful tailored current profiles [32, 33, 46]. It has been proposed in [47] to use the beam loading effect (see [32, 33]) to compensate the energy spread of an electron beam in plasma wakefield accelerators.

In this paper, we report on numerical investigations on optimization of the self-consistent distribution of an accelerating wakefield of plateau type, which can lead to minimizing the witness-bunch quality degradation during acceleration by a plasma wakefield, excited by an electron driver-bunches and formation a plateau on decelerating wakefield in areas of driver-bunches to increase efficiency of plasma wakefield accelerator with external injection. Analyzing the dependence of distribution of an accelerating and decelerating wakefield on witness-bunch density and driver-bunch density, we have demonstrated a mechanism to compensate the energy spread and to ensure the same deceleration of all electrons of each bunch.

We present results of numerical simulation of plasma wakefield excitation by driver-bunches and this wakefield modification, leading to plateau formation, by witness-bunch in its area and by driver-bunches in their areas. The numerical simulation has performed with 2.5D code LCODE [48, 49], which considers the electrons of the beam as ensembles of macroparticles, and the electrons of the plasma as a cold electron fluid. We demonstrate by numerical simulation optimal beam loading in a plasma accelerator with RF generated low and high beam charge and high beam quality.

We consider the bunch, electrons in which are distributed according to Gaussian in the transverse direction along the radius. We use the cylindrical coordinate system (r, z) and draw the plasma and beam densities and longitudinal electric field at some z as a function of the dimensionless time $\tau=\omega_p t$ or $\xi=V_b t-z$, 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. INVESTIGATION OF THE PLATEAU FORMATION ON THE DISTRIBUTION OF AN ACCELERATING WAKEFIELD IN A PLASMA BY AN ELECTRON WITNESS-BUNCH

To begin with, we consider the wakefield excitation in plasma in blowout regime by short electron bunch and plateau formation by accelerated bunch on the special distribution of an accelerating wakefield $E_z(\xi)$ (Fig. 1). One can see that accelerated bunch of a certain charge leads to the formation of a plateau on $E_z(\xi)$ at some depth inside the bubble.

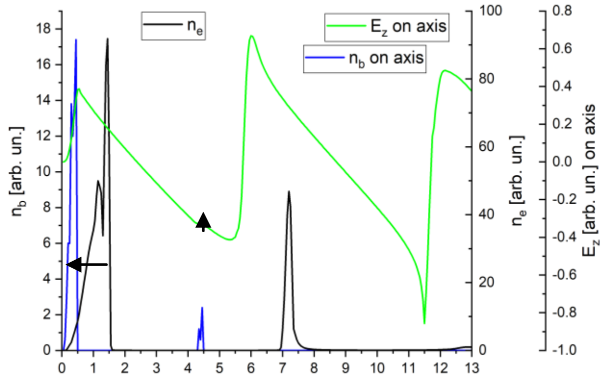

Fig. 1. The on-axis wakefield excitation E_z by short bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness. Densities of bunches n_b on the axis are shown by blue. Plasma electron density n_e is shown to be black as a function of the coordinate ξ along the plasma. The length of driver-bunch is equal to 0.08 of bubble length. The length of witness-bunch is equal to 0.04 of bubble length. The radius of bunches is equal to 0.3. The maximum current of bunch-driver is equal to I_b=0.72. The maximum current of bunch-witness is equal to I_b=0.06. The relativistic factor of bunches is equal to 1000. The arrow shows the plateau

In this case, the witness-bunch is in an almost uniform focusing field (Fig. 2).

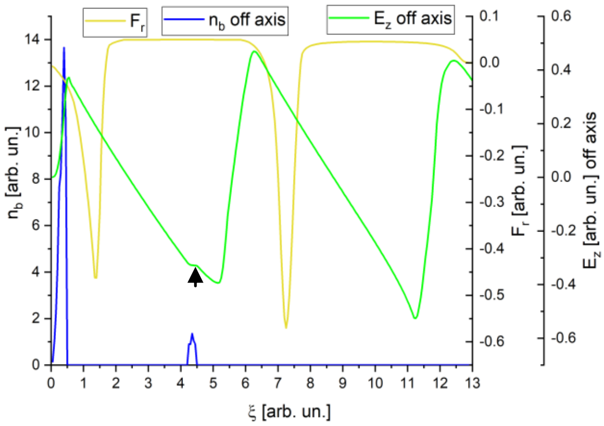

Fig. 2. The off-axis wakefield excitation E_z by short bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness. The off-axis densities of bunches n_b are shown by blue. The off-axis wake focusing force F_r is shown to be yellow as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 1. The arrow shows the plateau

2. INVESTIGATION OF THE PLATEAU FORMATION IN A PLASMA BY AN ELECTRON WITNESS-BUNCH ON THE DISTRIBUTION OF AN ACCELERATING WAKEFIELD, EXCITED BY SHORT TRAIN OF RESONANT DRIVER-BUNCHES

Now we simulate the plateau formation on the distribution of an accelerating wakefield in a plasma by an electron witness-bunch in the case of wakefield excitation by short train of resonant electron driver-bunches (Fig. 3).

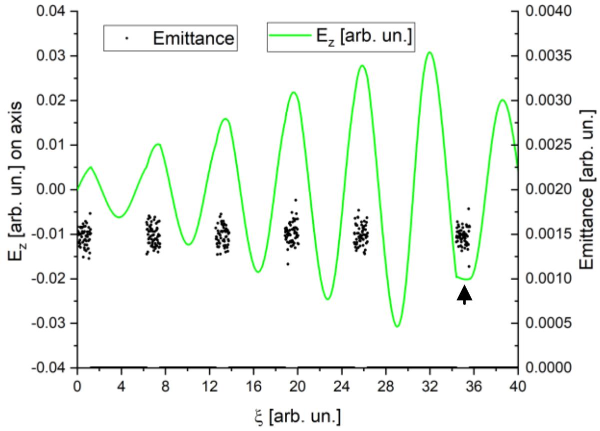

Fig. 3. The on-axis wakefield excitation E_z by short train of resonant electron driver-bunches and plateau formation on $E_z(\xi)$ by witness-bunch. Transversal emittance of bunches is shown to be black. The length of bunches is equal to 0.19 of bubble length. The radius of bunches is equal to 0.3. The maximum current of bunch-driver is equal to $I_b=2\cdot10^{-3}$. The maximum current of bunch-witness is equal to $I_b=8\cdot10^{-3}$. The arrow shows the plateau

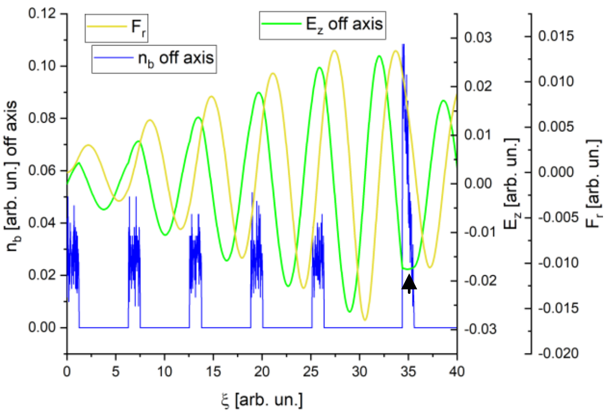

Fig. 4. The off-axis wakefield excitation E_z by short train of driver-bunches and plateau formation on $E_z(\xi)$ by witness-bunch. The off-axis densities of bunches n_b are shown by blue. The off-axis wake focusing force F_r is shown to be yellow as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 3. The arrow shows the plateau

In this case, the whitness-bunch is entirely in the focusing field (Fig. 4), in contrast to the Gaussian bunch, which would be partially focused and partially defocused.

3. INVESTIGATION OF THE PLATEAU FORMATION ON THE DISTRIBUTION OF A DECELERATING WAKEFIELD IN A PLASMA BY AN ELECTRON DRIVER-BUNCHES

Now we simulate the plateau formation on the distribution of a decelerating wakefield, excited by short train of resonant electron driver-bunches in a plasma (Fig. 5).

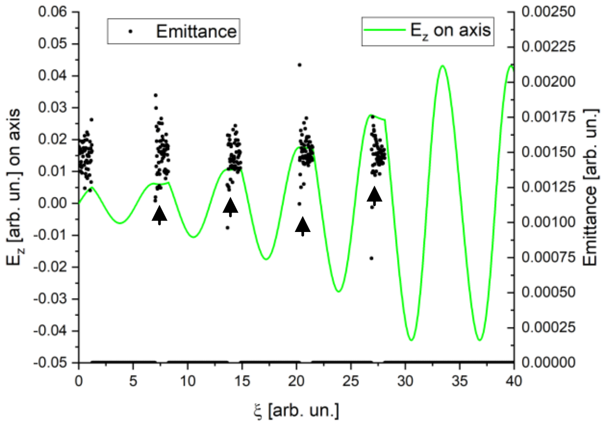

Fig. 5. The on-axis wakefield excitation E_z by short train of resonant electron driver-bunches and plateau formation on $E_z(\xi)$ by driver-bunches. Transversal emittance of bunches is shown to be black. The length of bunches is equal to 0.19 of bubble length. The radius of bunches is equal to 0.3. The maximum current of bunch-driver is equal to I_b=1.2·10^{-2}. The arrows show the plateaus

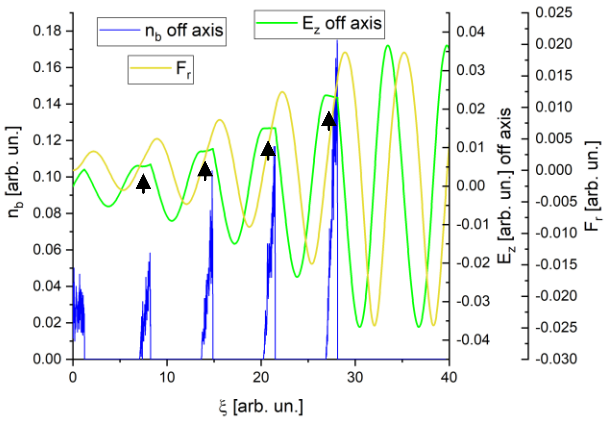

Fig. 6. The off-axis wakefield excitation E_z by short bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness. The off-axis densities of bunches n_b are shown by blue. The off-axis wake focusing force is shown to be yellow F_r as a function of the coordinate ξ along the plasma. The parameters are identical to Fig. 5. The arrows show the plateau

In this case, the driver-bunches are entirely in the focusing field (Fig. 6), in contrast to the Gaussian bunches, which would be partially focused and partially defocused.

CONCLUSIONS

The evolution of the distribution of accelerating and decelerating wakefields of plateau types has been investigated during wakefield excitation and electron acceleration by wakefield in linear and blowout regimes. The plasma wakefield is excited by an electron-bunch or by a short train of electron-bunches. The investigation has performed, using 2.5D PIC simulations by code LCODE. The final quality of the accelerated bunch strongly depends on the distribution of an accelerating wakefield. The part of energy, transferred to wakefield by driver-bunches, also strongly depends on the distribution of an decelerating wakefield. The investigations presented here show that the accelerated and decelerated bunch densities and their shapes can support plateau type distribution of accelerating and decelerating wakefields during acceleration in linear and blowout regimes. This can lead to energy spread of accelerated bunch decrease and to increase of part of energy, transferred to the wakefield by driver-bunches.

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ФОРМИРОВАНИЕ ПЛАТО НА УСКОРЯЮЩЕМ КИЛЬВАТЕРНОМ ПОЛЕ ДЛЯ УСКОРЯЕМЫХ СГУСТКОВ ЭЛЕКТРОНОВ И НА ТОРМОЗЯЩЕМ КИЛЬВАТЕРНОМ ПОЛЕ ДЛЯ СГУСТКОВ, ВОЗБУЖДАЮЩИХ ПОЛЕ

В.И. Маслов, Р.Т. Овсянников, Д.С. Бондарь, И.П. Левчук, И.Н. Онищенко

Ускорение кильватерным полем в плазме может обеспечить компактные источники релятивистских электронных и позитронных пучков высокой яркости. Использование (коллайдеры частиц и лазеры на свободных электронах) плазменных кильватерных ускорителей требует высокой эффективности и пучков с малым разбросом по энергии. Достижения того и другого требуют формирования плато как на ускоряющем поле для ускоряемого сгустка, так и на тормозящем поле для сгустков, которые возбуждает поле, путем контролируемой нагрузки пучком плазменной волны с тщательно подобранным профилем тока. Мы демонстрируем численным моделированием 2,5D PIC-кодом LCODE такую оптимальную нагрузку пучком в линейном и нелинейном режимах в плазменном ускорителе с возбуждением электронами, которые инжектируются с ВЧ-ускорителя, при небольшом и большом зарядах пучков и высоком их качестве.

ФОРМУВАННЯ ПЛАТО НА ПРИСКОРЮЮЧОМУ КІЛЬВАТЕРНОМУ ПОЛІ ДЛЯ ЗГУСТКІВ ЕЛЕКТРОНІВ, ЩО ПРИСКОРЮЮТЬСЯ, І НА ГАЛЬМУЮЧОМУ КІЛЬВАТЕРНОМУ ПОЛІ ДЛЯ ЗГУСТКІВ, ЩО ЗБУДЖУЮТЬ ПОЛЕ

В.І. Маслов, Р.Т. Овсянніков, Д.С. Бондарь, І.П. Левчук, І.М. Оніщенко

Прискорення кільватерним полем у плазмі може забезпечити компактні джерела релятивістських електронних і позитронних пучків високої яскравості. Використання (колайдери частинок і лазери на вільних електронах) плазмових кільватерних прискорювачів вимагають високої ефективності і пучків з низьким розкидом по енергії. Досягнення того і іншого вимагають формування плато як на прискорюючому полі для згустку, що прискорюється, так і на гальмуючому полі для згустків, що збуджують поле, шляхом контрольованого навантаження пучком плазмової хвилі з ретельно підібраним профілем струму. Ми демонструємо чисельним моделюванням 2,5D PIC-кодом LCODE таке оптимальне навантаження пучком у лінійному і нелінійному режимах у плазмовому прискорювачі зі збудженням електронами, які інжектуються з ВЧ-прискорювача, при невеликому і великому зарядах пучків і високій їх якості.