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OPTIMAL FIELD SHAPE, ACCELERETING POSITRON BUNCH IN PLASMA WAKEFIELD*

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Abstract

The quality of the electron or positron beam, accelerated in plasma accelerators, is still insufficient for applications. Accurate control over the properties of the electron or positron beam is a key issue for wakefield plasma accelerators. The effect of the presence of a witness-beam (the effect of the spatial charge distribution of the witness-beam) (see [1-5]) to compensate the energy spread of positron beam in plasma wakefield accelerators has been studied. This paper presents the results of a numerical simulation on the optimization of the parameters of the driver-bunch and witness-bunch for the formation of a self-consistent longitudinal distribution of the accelerating plateau-type field, which leads to the same value of the wakefield for the whole bunch of accelerated particles and minimizing bunch degradation during acceleration by an ion-driver-bunch [6] with external injection of witness-bunch into the plasma wakefield accelerator. The dependence of the longitudinal distribution of the accelerating wakefield on the density and shape of the accelerated bunch in the blowout regime was investigated. Plateau formation and energy spread compensation were observed.

INTRODUCTION

At the moment, the technology of wakefield accelerators is in great demand, due to the fact that conventional accelerators have already reached the limit of possible values of the energy of accelerated beams. This limit is associated with the existence of a design limit on the value of the accelerating gradient for the material of the accelerator. Accordingly, the only way to increase the energy of the accelerated beam is to increase the size of the accelerator, or else a new approach can be applied. However, the concept of a wakefield accelerator is far from being a finished device. There are many problems that need to be addressed.

One of such important problems is the control over the beam parameters, and in particular, the presence of defocusing, due to the appearance of dynamic electromagnetic fields. A possible solution to this problem is the acceleration of a bunch from a linear conventional accelerator by a wakefield accelerator (linear accelerator technologies are quite well developed and allow precision control of the bunch parameters). However, there still remains the problem of finding such a distribution of charges in the bunch so that in the wakefield accelerator, this bunch would create such a self-consistent accelerating field that would have the same value throughout the bunch. The search for such distributions is simplified if we consider the bunch-driver and bunch-witness systems.

In this work, we will try to find the longest witness-bunches for driver-bunches of various configurations. This problem is extremely important for positron bunches; therefore, it is for them that we will carry out numerical simulations.

We present results of numerical simulation of plasma wakefield excitation in blowout regime by a driver-bunch and of wakefield modification by witness-bunch, made with 2.5D code LCODE [7] that treats plasma electrons and bunches as ensembles of macro-particles. 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, distance, bunch current I_b, fields are normalized to electron plasma frequency ω_{pe}, c/ω_{pe}, $I_{cr} = \pi mc^3/4e$, $mc\omega_{pe}/e$. e, m are the charge and mass of the electron, c is the light velocity.

INVESTIGATION OF ACCELERATED POSITRON BUNCHES OF THE LONGEST LENGTH, WHICH FORM A SELF-CONSISTENT ACCELERATING FIELD OF THE PLATEAU TYPE

The description of the results obtained should begin with a description of the method for obtaining bunches that excite an accelerating wakefield of the plateau type of the longest length. All constructions of bunches were based on the assumption that a sufficiently small section of a bunch, independently of other sections, creates a self-consistent field in its region. At the same time, neighboring small areas of the bunch have little or no effect on the regions of other areas of the bunch. Thus, this assumption makes it possible to break the bunch into small sections, on which it is possible to independently select the required values of the charge density.

Figures 1 and 2 show small positron witness-bunches with large and small transformer ratios, respectively (the transformer ratio is the ratio of the maximum accelerating field in the witness-bunch to the maximum decelerating field in the driver-bunch region). It can be seen that for a very long driver, it is possible to achieve not only a self-consistent field distribution of plateau-type in the witness-bunch region, but also a very large transformer ratio, which, in fact, is responsible for the degree of acceleration.

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Figures 3 and 4 show the simulation results for positron witness-bunches of maximum length for driver-bunches of various lengths. It is seen that in both cases the witness-bunches occupy a rather large area. However, the transformer ratio does not reach unity.

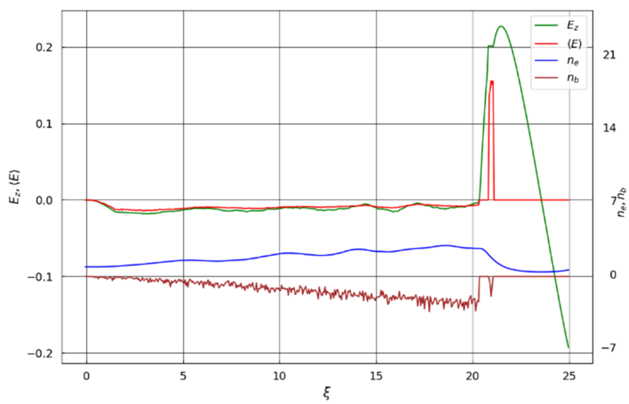

Figure 1: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field $\langle E \rangle = \int E_z n_b r dr / \int n_b r dr$ is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of bunch-driver is equal to 3.8 of wave length. The maximum current of bunch-driver is equal to $I_b = 2.04$ kA. The maximum current of bunch-witness is equal to $I_b = 1.326$ kA.

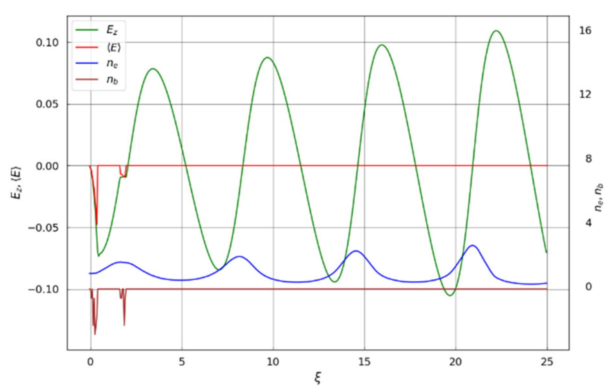

Figure 2: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by the second bunch, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.09 of nonlinear wavelength. The maximum current of bunch-driver is equal to $I_b = 2$ kA. The maximum current of the second bunch is equal to $I_b = 1.6$ kA.

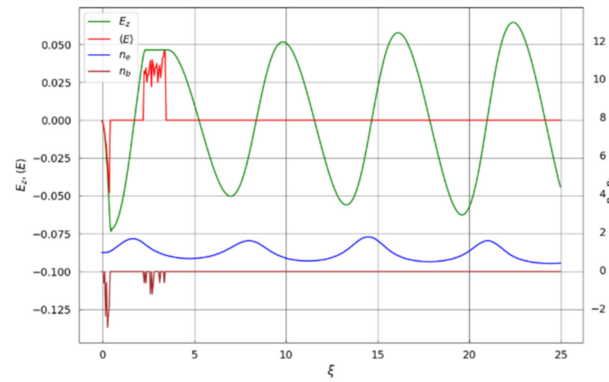

Figure 3: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.09 of nonlinear wavelength. The maximum current of bunch-driver is equal to $I_b = 2$ kA. The maximum current of bunch-witness is equal to $I_b = 0.4$ kA.

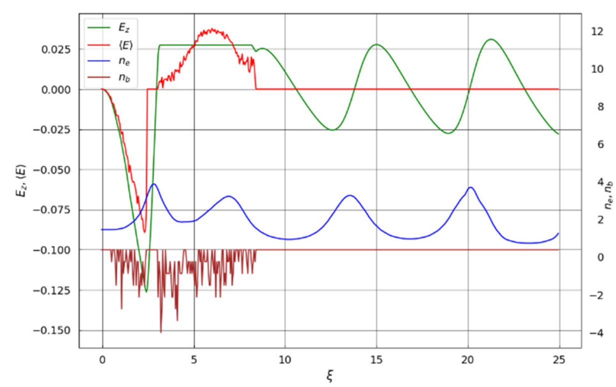

Figure 4: The on-axis wakefield excitation E_z by bunch-driver and plateau formation on $E_z(\xi)$ by bunch-witness, $\xi = z - V_b t$. Densities of bunches n_b on the axis are shown by brown. Average field <E> is shown by red. Plasma electron density is shown to be blue as a function of the coordinate ξ along the plasma. The length of uniform bunch-driver is equal to 0.3 of nonlinear wavelength. The maximum current of bunch-driver is equal to $I_b = 1$ kA. The maximum current of bunch-witness is equal to $I_b = 1.19$ kA.

CONCLUSION

As a result of numerical modeling, it can be argued that there is a possibility of obtaining positron accelerated bunches that form a self-consistent accelerating wakefield distribution, such as a plateau, for drivers of different lengths, with different transformer ratios, while the lengths of the witness-bunches can also vary within wide limits. The data obtained allow us to assert that with the help of the proposed method, constructing bunches from constituent elements, it is possible to obtain a bunch of maximum length, which forms a plateau-type field distribution, while with a high transformer ratio.

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