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REGULARIZATION OF WAKEFIELD IN A WEAKLY NONLINEAR REGIME

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In blowout regime of wakefield excitation, strong chaotization of wake occurs. However, for electron-positron colliders and X-ray microscopes, a weakly nonlinear regime is proposed with the formation of a regular short chain of bubbles. To increase the efficiency of the wakefield accelerator, it is necessary that not separate bunches participate. In this paper in 2D plane geometry, the dependence of the number of formed bubbles and their regularization on the degree of wake non-linearity and parameters: driver current, ion mobility, transverse plasma size and profile – is studied. We will show that in a weakly nonlinear regime the regular chain of bubbles becomes longer.

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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 gigaelektronvolt energy. This is why the plasma wakefield are developed (see [5 - 35]).

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.

In this paper, we report on numerical simulation regularization of wakefield in weakly non-linear regime and influence on it by different parameters.

We present results of numerical simulation of plasma wakefield excitation and its regularization. The numerical simulation has performed with 2.5D code LCODE, which considers the beam electrons as well as plasma electrons as ensembles of macroparticles. We demonstrate influence of currents and spatial distribution of bunches and influence of plasma parameters on wakefield regularization in the weakly non-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. We use the plane coordinate system (x, z) and draw longitudinal electric field 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. INFLUENCE OF WITNESS-DRIVER-BUNCES PAIR ON REGULARIZATION OF WAKEFIELD

Firstly, let us discuss how parameters of bunches influence on regularization of wakefield. Now we will simulate the wakefield excitation in homogeneous plasma with immobile ions. Below you can see the wakefield excitation by single electron bunch (Fig. 1).

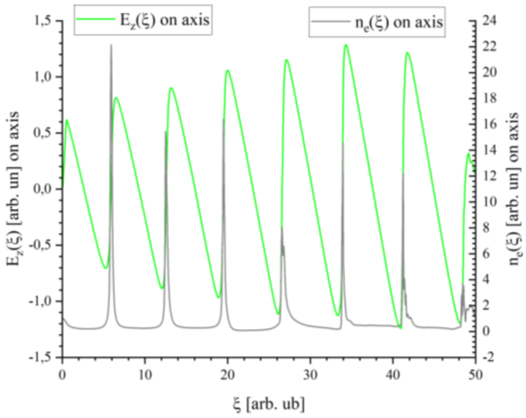

Fig. 1. The on-axis wakefield excitation E_z by single electron bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. The length of bunch is equal to 0.19 of wavelength. The radius of bunch is equal to 0.3. The current of bunch equals 0.3. The relativistic factor of bunch is equal to 1000

As we can see after the seventh wave length the field is not regular. In the Fig. 2 you can see the plasma electron density's distribution, corresponding to Fig. 1.

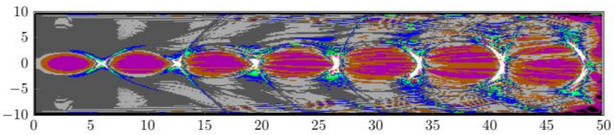

Fig. 2. Spatial distribution of plasma electron density

Now let us add witness-driver-bunches pair, which does not change the amplitude of wakefield. In this case regularization of wakefield is better (Fig. 3).

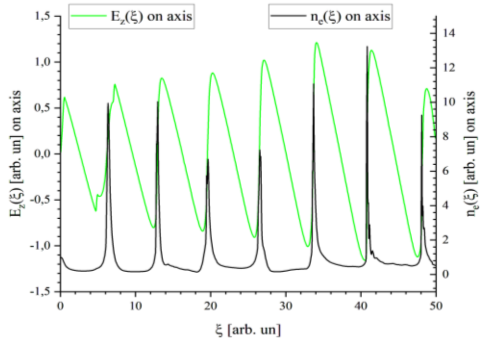

Fig. 3. The on-axis wakefield excitation E_z by driver bunch and following witness-driver-bunches pair. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. The length of bunches is equal to 0.19 of wavelength. The radius of bunches is equal to 0.3. The current of all bunches equal 0.3. The relativistic factor of bunches is equal to 1000

Below you can see spatial distribution of plasma electrons (Fig. 4), corresponding to Fig. 3.

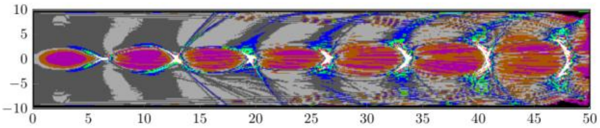

Fig. 4. Spatial distribution of plasma electron density

As we can see from Figs. 1 and 3 this pair makes wakefield more regular.

2. INFLUENCE OF ION MOBILITY ON REGULARIZATION OF WAKEFIELD

Now let us consider how ion mobility effects on regularization of the wakefield. As a parameter of ion mobility, we consider ratio of ions' mass to the electron mass. Here we are going to consider ions of hydrogen and argon. For hydrogen this ratio equals 1836 and for argon 73440. For convenience this ration we are going to call as parameter of mobility.

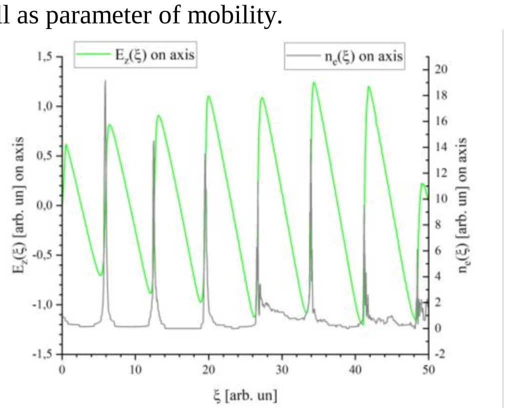

Fig. 5. The on-axis wakefield excitation E_z by single electron bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. Parameters of bunch are equivalent to Fig. 1. Parameter of mobility is equal to 1836

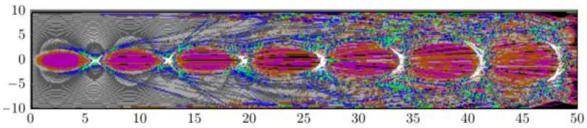

Fig. 6. Spatial distribution of plasma electron density. Parameter of mobility is equal to 1836

From comparison Figs. 4 and 6 one can see that in the case of immobile ions the wake is more regular. As we see, in case of light ions we have only four stable bubbles (Figs. 5 and 6).

Now let us consider heavier ions. In comparison with hydrogen ions, we can see (Fig. 7) that the fifth bubble became more regular and the boundary of the seventh bubble became more clearly.

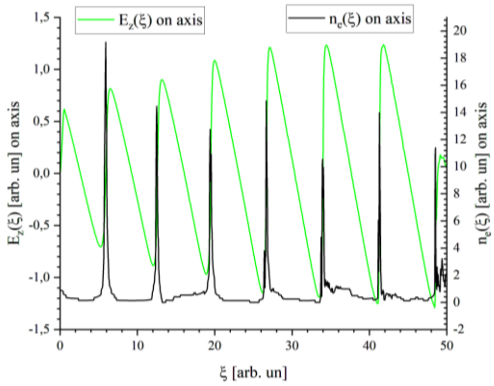

Fig. 7. The on-axis wakefield excitation E_z by single electron bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. Parameters of bunch are equivalent to Fig. 1. Parameter of mobility is equal to 73440

Below you can see spatial distribution of plasma electrons (Fig. 8), corresponding to Fig. 7.

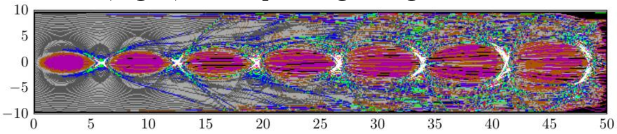

Fig. 8. Spatial distribution of plasma electron density. Parameter of mobility is equal to 73440

3. INFLUENCE OF PLASMA PROFILE ON REGULARIZATION OF WAKEFIELD

Now let us discuss how the plasma profile influence on the wakefield regularization. Earlier we considered case of plasma channel with radius higher than radius of the bunch. Now let us consider the case of homogeneous distributed plasma with small radius.

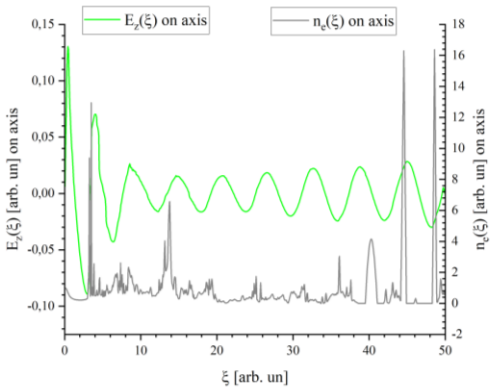

Fig. 9. The on-axis wakefield excitation E_z by single electron bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. Parameters of bunch are equivalent to Fig. 1. The radius of the plasma is equal to a bubble radius

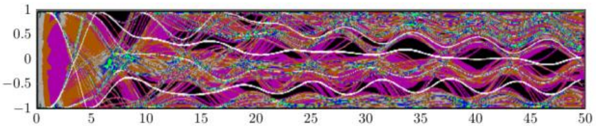

Fig. 10. Spatial distribution of plasma electron density. Case of plasma with small radius

As we can see, the wakefield is not regular (Fig. 9). Therefore, we should use plasma with higher radius.

As we see, the wake in the case of narrow plasma is chaotic (Fig. 10).

And now let us consider the case of plasma with big radius, however it will have Gaussian distribution.

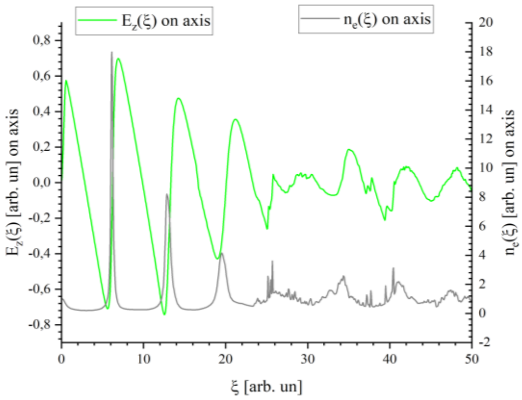

Fig. 11. The on-axis wakefield excitation E_z by single electron bunch. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. Parameters of bunch are equivalent to Fig. 1

From Fig. 11 we can see that in case of Gaussian distributed plasma the wakefield is not regularized. From Figs. 11 and 12 we see there are only two regular bubbles.

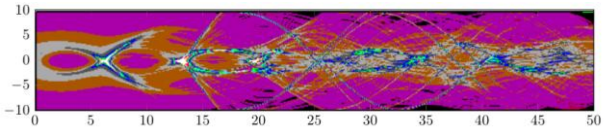

Fig. 12. Spatial distribution of plasma electron density. Case of Gaussian distributed plasma

4. PARAMETERS OPTIMIZATION FOR THE WAKEFIELD REGULARIZATION

In this section we are going to consider the influence of some parameters on the wakefield regularization. From the previous sections we can make a conclusion, that for the most regular wakefield we should consider homogeneous plasma with heavy ions and big radius. Also, if we use additional witness-driver-bunches pair it also helps in the wakefield regularization. We show the optimal parameters for the electron bunches and plasma.

One can see (Fig. 13) in the case of mobile ions the witness-driver-bunches pair helps in the wakefield regularization. In Fig. 14 you can see the plasma electron density distribution.

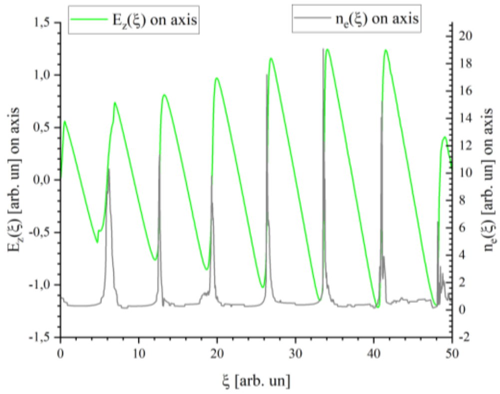

Fig. 13. The on-axis wakefield excitation E_z by driver bunch and following witness-driver-bunches pair. Density of plasma electrons n_e on the axis is shown by gray as a function of the coordinate ξ along the plasma. The length of bunches is equal to 0.19 of wavelength. The radius of bunches is equal to 0.3. The current of all bunches equal 0.27. The relativistic factor of bunches is equal to 1000. Ion mobility parameter 73440

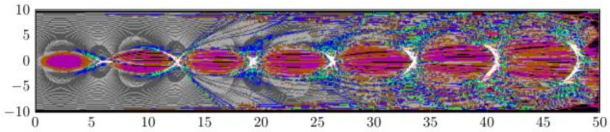

Fig. 14. Spatial distribution of plasma electron density. Case of unitary distributed plasma with mobile ions. Parameter of mobility is equal to 73440

CONCLUSIONS

In blowout regime of wakefield excitation, strong chaotization of wake occurs. However, for electron-positron colliders and X-ray microscopes, a weakly nonlinear regime is proposed with the formation of a regular short chain of bubbles. In this paper in 2D plane geometry, the dependence of the number of formed bubbles and their regularization on the degree of wake nonlinearity and parameters: driver current, ion mobility, transverse plasma size and profile – is studied. We have shown that in a weakly nonlinear regime the regular chain of bubbles becomes longer.

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РЕГУЛЯРИЗАЦІЯ ЗБУДЖЕНОГО КІЛЬВАТЕРНОГО ПОЛЯ У СЛАБКОНЕЛІНІЙНОМУ РЕЖИМІ

І.В. Демиденко

У сильнонелінійному режимі при збудженні кільватерного поля виникає сильна хаотизація збудженого поля. Однак для електронно-позитронних колайдерів і рентгенівських мікроскопів пропонується слабконелінійний режим з утворенням регулярного короткого ланцюжка бульбашок. Для підвищення ефективності кільватерного прискорювача необхідно, щоб участь брали не окремі згустки. У цій роботі у 2D-геометрії досліджено залежність кількості утворених бульбашок та їх регуляризації від ступеня нелінійності кільватерного поля та параметрів: струму драйвера, рухливості іонів, поперечного розміру та профілю плазми. Показано, що в слабконелінійному режимі регулярний ланцюжок бульбашок стає довшим.