TRANSFORMATION RATIO AT EXCITATION OF NONLINEAR WAKEFIELD IN PLASMA BY SHAPED SEQUENCE OF ELECTRON BUNCHES WITH LINEAR GROWTH OF CHARGE

V.I. Maslov, I.N. Onishchenko, I.P. Yarovaya[1]
National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine;
[1]*Karazin Kharkov National University, Kharkov, Ukraine*
E-mail: vmaslov@kipt.kharkov.ua

Using code LCODE, the 2d3v-numerical simulation of nonlinear wakefield excitation in plasma by shaped sequence of relativistic electron bunches with linear growth of charge has been performed. The transformation ratio has been determined taking into account nonlinearity of excited wakefield at shaping of bunches and sequence.

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INTRODUCTION

At electron acceleration by wakefield the transformation ratio is important. It is determined as T_W ratio of the energy, received by accelerated bunches, to energy, lost by sequence of electron bunches, exciting the wakefield at their decelerating in plasma. The transformation ratio can be approximately defined as a ratio $T_E=E_2/E_1$ of the wakefield, which are excited in plasma by the electron bunches, E_2 to the field in which an electron bunch is decelerated E_1.

In 1D case of the alternating decelerated and accelerated bunches, lengths of which are less than wavelength in plasma, the transformation ratio does not exceed two $T\leq 2$. The transformation ratio can be increased at the use sequence of bunches. In this case of bunches of finite sizes the method has been offered in [1] and investigated in [2-4] of increase of transformation ratio. In this case the transformation ratio increases at not very large amplitudes as 2N. N is the number of bunches in sequence. If bunch length equals to the half of wave-length, the porosity between bunches equals to the wave-length.

In [5, 6] it has been found that in the case of one long bunch the density of which grows according to the linear law along bunch, the transformation ratio can be larger

$$T = 2\pi N,$$

where $N=L_b/\lambda$ is the number of wave-length λ, located on length of bunch L_b.

In this paper the transformation ratio increase is investigated in linear and nonlinear cases, using 2.5D code LCODE [7], at charge shaping according to linear law along sequence as well as along each bunch. The bunch length equals to nonlinear wave-length λ. The porosity between bunches also equals λ.

WAKEFIELD EXCITATION IN PLASMA BY SHAPED SEQUENCE OF BUNCHES

Because charges of bunch sequence and of every bunch are shaped along longitudinal coordinate according to linear law, then the charges of bunches follows to the known law 1, 3, 5 etc i.e. $Q_n= (2n-1)Q_1$. At first we consider the case of single bunch, which is injected in plasma. Before this bunch at some distance we place a rectangular bunch of length $\lambda/4$ and small density. At certain bunch current after it the electron bubble and wave braking (see Fig.1) are formed. From Fig.1 one can see that all electrons of bunch are decelerated approximately in the identical longitudinal electric field E_z.

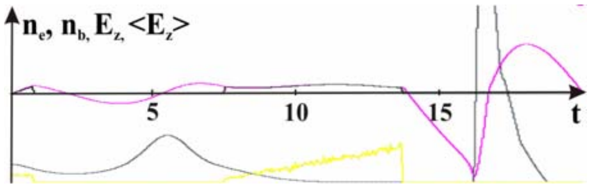

Fig.1. Plasma electron density n_e (gray) in wakefield, longitudinal wakefield E_z (red), density of bunches n_b (yellow) and averaged $<E_z>=\int dr\ r\ E_z n_b/\int dr\ r n_b$ (black)

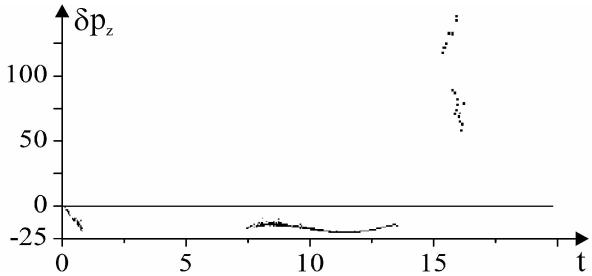

Fig.2. Change of longitudinal momentum of bunches δp_z at wakefield excitation. δp_z and t are normalized on $m_e c^2$ and ω_{pe}

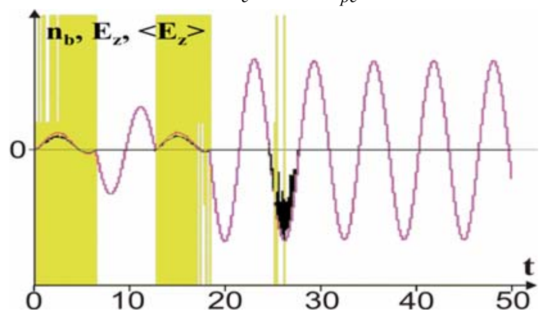

Fig.3. E_z (brown), averaged E_z (black), n_b (yellow)

In other words, the longitudinal electric field E_z, decelerating bunches, approximately does not depend on a coordinate along a bunch.

From Fig.1 one can derive $T_E\approx 8.7$, which is larger then 2π approximately on 30 %.

From Fig.2 one can obtain, that $T_W\approx 7.73$, i.e. $2\pi<T_W<T_E$.

Now we consider the case of two bunches of small current. In this case on length of every bunch-driver large variation of values of decelerating electric-field is observed (Fig.3), that results in the different decelerating of bunch electrons. It does not give to possibility to attain the complete decelerating of electrons of bunches-drivers.

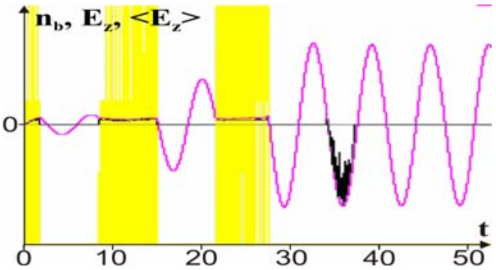

Fig.4. E_z (red), averaged E_z (black), n_b (yellow)

The not maximal transformation ratio is observed in this case. Namely, from Fig.3 one can derive that T_E is equal to $T_E \approx 3$ after 1-st bunch and $T_E \approx 6$ after 2-nd bunch. I.e. we have approximately $T_E \approx 3N$, N is the number of bunches. To remove these defects, we place before bunches the same precursor as well as in the case of one bunch. Then (Fig.4) we get that all bunches are decelerated approximately in identical E_z. In other words, longitudinal electric field E_z, decelerating bunches, in the areas of location of bunches – drivers approximately does not depend on a coordinate along every bunch as well as along a sequence. In this case one can obtain maximal T_W and complete deceleration of drivers (Fig.5).

From Fig.6 one can see that in the nonlinear regime also all electrons of every bunch and all bunches are decelerated approximately in the identical longitudinal electric field E_z. In this case one can obtain maximal T_W and complete deceleration of drivers (Fig.7).

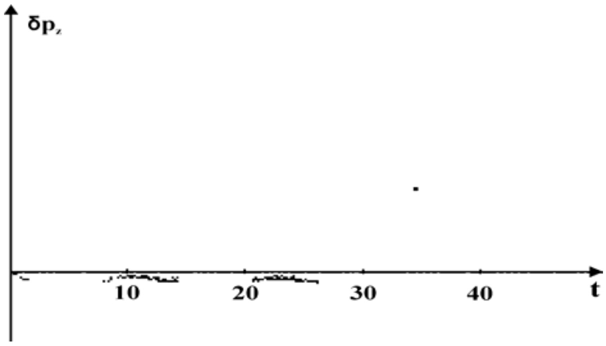

Fig.5. Change of δp_z

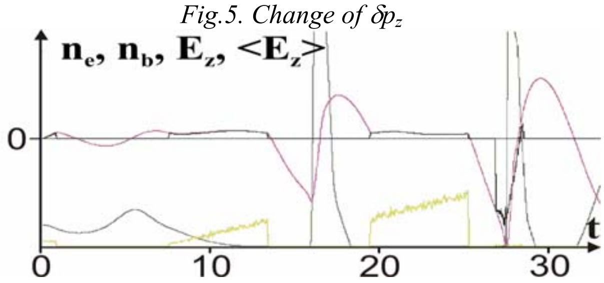

Fig.6. E_z (red), averaged E_z (black), n_b (yellow), n_e (gray)

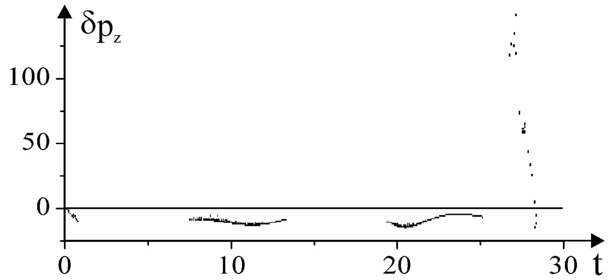

Fig.7. Change of δp_z

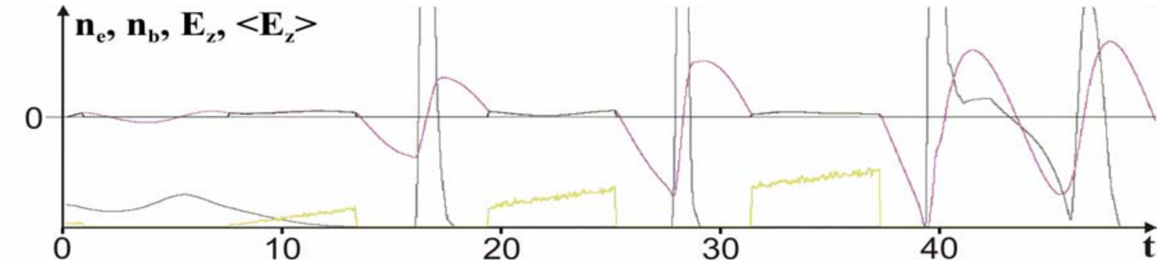

Fig.8. E_z (red), averaged E_z (black), n_b (yellow), n_e (gray)

From Fig.6 one can derive that the transformation ratio equals $T_E \approx 9.4$ after 1-st bunch and $T_E \approx 16.4$ after 2-nd bunch. I.e. $T_E > 2\pi N$ after 1-st bunch in 1.5 times and after 2-nd bunch in 1.3 times.

Now we consider the sequence of three bunches. The precursor is also preceded the sequence. At the certain current of the sequence the electron bubble and wave braking are formed after the last bunch. From Fig.8 one can see that all electrons of every bunch and all bunches are decelerated approximately in identical E_z.

From Fig.8 one can obtain that after the 1-st bunch T_E=7.4, after the 2-nd bunch T_E=14.1, after the 3-rd bunch T_E=19.7. It also as for one and two bunches leads to $T_E > 2\pi N$. Here N is the number of bunches in the sequence.

Similar wakefield distribution and electron dynamics are observed in the case of the sequence of ten bunches (Fig.9, 10).

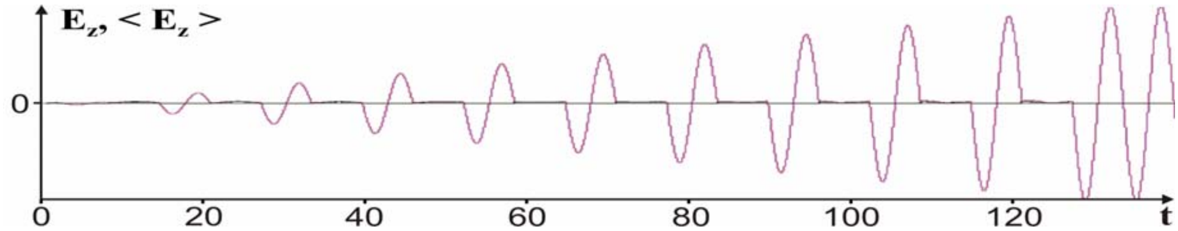

Fig.9. On-axis longitudinal electric field E_z (brown), averaged E_z (black)

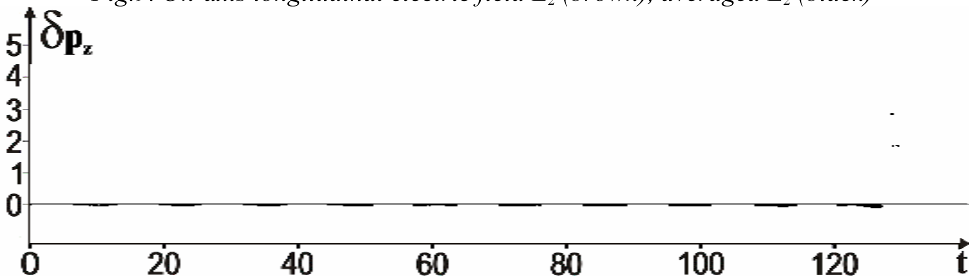

Fig.10. Change of longitudinal momentum of bunches δp_z at wakefield excitation by them

CONCLUSIONS

It has been shown that the longitudinal electric field E_z, decelerating bunches, in the areas of bunches-drivers location approximately does not depend on a coordinate along every bunch and along the sequence of bunches. I.e. it was succeeded to obtain, that all electrons of every lengthy bunch and all bunches of sequence were decelerated by almost identical force.

It has been shown that at the use of sequence of bunches, the charge of which is shaped according to linear law, and at the use before the sequence of short bunch-precursor of small charge the transformation ratio is larger than the maximal known now $2\pi N$ on 30…50 %. Here N is the number of bunches in a sequence.

It the almost ideal wakefield accelerator, because one can obtain maximal T_w in condition of a complete deceleration of drivers by the almost identical fields.

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КОЭФФИЦИЕНТ ТРАНСФОРМАЦИИ ПРИ ВОЗБУЖДЕНИИ НЕЛИНЕЙНОЙ КИЛЬВАТЕРНОЙ ВОЛНЫ В ПЛАЗМЕ ПРОФИЛИРОВАННОЙ ПОСЛЕДОВАТЕЛЬНОСТЬЮ ЭЛЕКТРОННЫХ СГУСТКОВ С ЛИНЕЙНО НАРАСТАЮЩЕЙ ИНТЕНСИВНОСТЬЮ

В.И. Маслов, И.Н. Онищенко, И.П. Яровая

Используя код LCODE, проведено 2d3v-численное моделирование возбуждения нелинейной кильватерной волны в плазме профилированной последовательностью релятивистских электронных сгустков с линейно нарастающей интенсивностью. Определен коэффициент трансформации с учетом нелинейности возбуждаемой кильватерной волны при профилировании сгустков и последовательности.

КОЕФІЦІЄНТ ТРАНСФОРМАЦІЇ ПРИ ЗБУДЖЕННІ НЕЛІНІЙНОЇ КІЛЬВАТЕРНОЇ ХВИЛІ В ПЛАЗМІ ПРОФІЛЬОВАНОЮ ПОСЛІДОВНІСТЮ ЕЛЕКТРОННИХ ЗГУСТКІВ З ЛІНІЙНО НАРОСТАЮЧЕЙ ІНТЕНСИВНІСТЮ

В.І. Маслов, І.М. Оніщенко, І.П. Ярова

Використовуючи код LCODE, проведено 2d3v-чисельне моделювання збудження нелінійної кільватерної хвилі в плазмі профільованою послідовністю релятивістських електронних згустків з лінійно наростаючей інтенсивністю. Визначен коефіцієнт трансформації з урахуванням нелінійності збуджуваної кільватерної хвилі при профілюванні згустків і послідовності.