WAKEFIELD EXCITATION IN PLASMA BY RAMPED SEQUENCE OF RAMPED ELECTRON BUNCHES

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It has been shown that wakefield in the regions, occupied by bunches-drivers, does not depend on a longitudinal coordinate for certain lengths of bunches, distance between bunches and the charge is ramped by linear law. For increase of number of accelerated electrons long sequence of electron bunches-drivers, charge of which is distributed according to linear law along each bunch, providing large transformation ratio and homogeneous wakefield, which enable to completely decelerate bunches-drivers, has been constructed.

PACS: 29.17.+w; 41.75.Lx

INTRODUCTION

The transformation ratio, defined as ratio $T_E=E_2/E_1$ of the wakefield E_2, which is excited in plasma by sequence of the electron bunches, to the field E_1, in which an electron bunch is decelerated, is considered at first with charge shaping along each bunch and along sequence according to linear law and later only along each bunch. In [1] T_E increase is investigated in linear and nonlinear cases at charge shaping according to linear law along sequence as well as along each bunch. The bunch length equals to wave-length $\xi_b=\lambda$. The interbunch gap also equals $\delta\xi=\lambda$. Before this sequence at some distance a rectangular bunch of length $\lambda/4$ and small density has been placed. Then $T_E>2\pi N$ can be derived in nonlinear case, N is the number of bunches. In this paper it is shown that this large transformation ratio can be achieved also for other lengths of bunches $\xi_b=\lambda$, 2λ, ... and for other interbunch gaps $\delta\xi=0$, λ, 2λ, ...

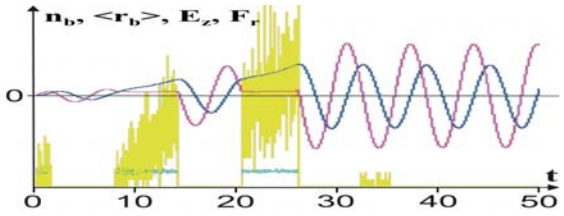


Fig. 1. E_z on a radius equal to the radius of bunch (red), radial wakefield F_r (dark blue), n_b (yellow), radius of bunches r_b (blue)

Also asymptotics of infinite sequence of the electron bunches-drivers and bunches-witnesses has been derived using 2.5 D code lcode [2] for increase of number of accelerated electrons at large transformation ratio. The charge distribution in each this bunch-driver is represented in kind of turned on a corner $\pi/2$ rectangular trapezoid. The transformation ratio $T_E=2\pi N_{fr}$ is achieved in this sequence. N_{fr} is the number of bunches-drivers from the first front of sequence, the charge of which grows along the sequence according to the linear law or according to the known law 1, 3, 5 etc. Similar T_E is achieved in [3, 4] for one long bunch the charge of which grows according to the linear law along bunch and by numerical simulation in [1] for short sequences of the electron bunches-drivers.

1. WAKEFIELD EXCITATION IN PLASMA BY BUNCHES OF SEQUENCE SHAPED ACCORDING TO LINEAR LAW

In many investigations on T_E, performed earlier, it is impossible to obtain the full deceleration of all electrons of bunches, because decelerating wakefield is strongly inhomogeneous along bunch.

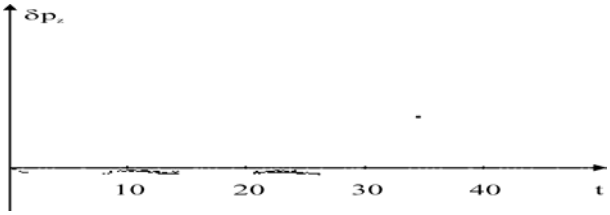


Fig. 2. Change of longitudinal momentum of bunches δp_z at wakefield excitation by them. δp_z and t are normalized on $m_e c^2$ and ω_{pe}

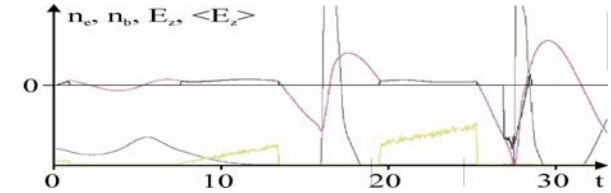


Fig. 3. E_z (red), averaged $<E_z>$ (black), n_b (yellow), n_e (gray)

We investigate the case, when the decelerating wakefield is homogeneous along each bunch. From Fig. 1 one can see that all electrons of all bunches are decelerated approximately in identical longitudinal wakefield E_z in the case $\xi_b=\lambda$, $\delta\xi=\lambda$ at charge shaping according to linear law along sequence as well as along each bunch and using before this sequence at some distance a rectangular bunch of length $\lambda/4$ and small density.

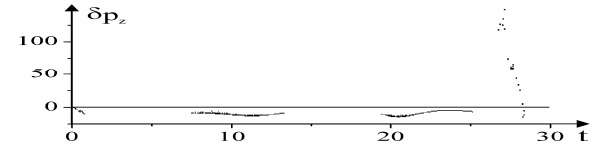


Fig. 4. Change of δp_z in nonlinear case

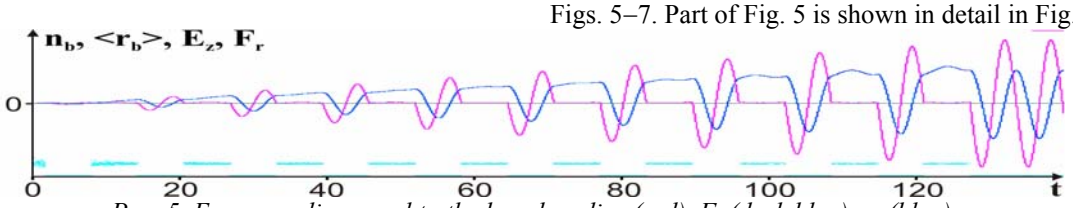
E_z, decelerating bunches, in the areas of location of bunches – drivers approximately does not depend on a coordinate along every bunch as well as along the sequence. In this case one can obtain maximal T_E and

complete deceleration of all electrons of bunches – drivers (Fig. 2).

From Fig. 1 one can see that all bunches are in the areas of the focusing fields.

In nonlinear case (one can see Figs. 3–4) $T_E \approx 9.4$ after 1-st bunch and $T_E \approx 16.4$ after 2-nd bunch. I.e. $T_E > 2\pi N$.

For the case of sequence of ten bunches one can see Figs. 5–7. Part of Fig. 5 is shown in detail in Fig. 7.



Puc. 5. E_z on a radius equal to the bunch radius (red), F_r (dark blue), r_b (blue)

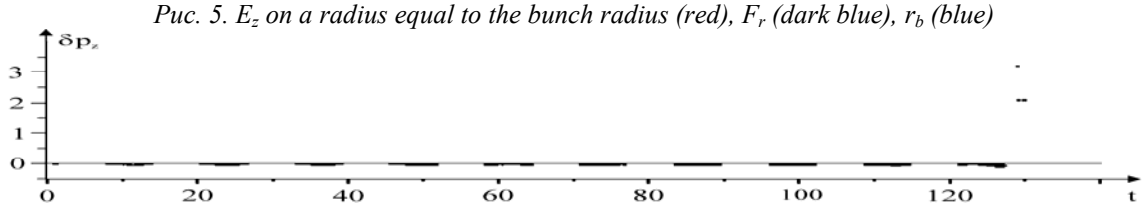


Fig. 6. Change of δp_z at wakefield excitation by 10 bunches

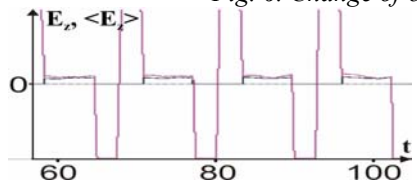


Fig. 7. E_z (brown) and <E_z> (black)

One can select interbunch gap, equal to $\delta\xi = q\lambda$, q=0, 1, 2 (Fig. 8, $\delta\xi = 2\lambda$ at length of bunch, equal to $\xi_b = \lambda$).

One can also select length of bunches, equal to $\xi_b = p\lambda$, p=1, 2, 3, (Fig. 9 at length of bunch and interbunch gap, equal to $\xi_b = 2\lambda$, $\delta\xi = 2\lambda$).

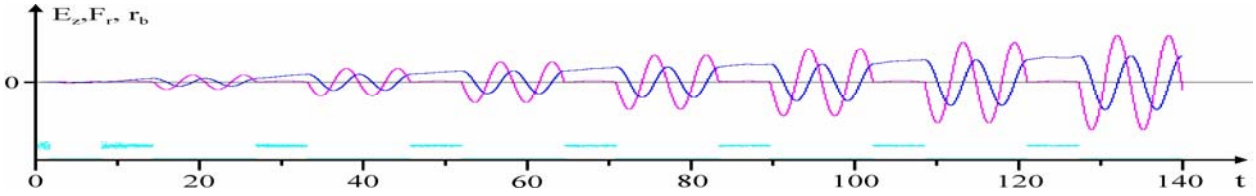


Fig. 8. E_z on a radius equal to the bunch radius (red), F_r (dark blue), r_b (blue)

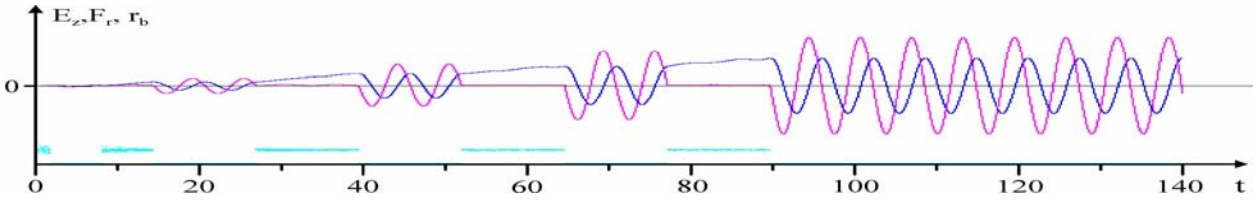


Fig. 9. E_z on a radius equal to the bunch radius (red), F_r (dark blue), r_b (blue)

2. WAKEFIELD EXCITATION WITH HIGH TRANSFORMATION RATIO IN PLASMA BY INFINITE SEQUENCE OF SHAPED BUNCHES-DRIVERS AND BUNCHES-WITNESS ACCELERATION

One can see that large T_E is achieved. However F_r grows along the sequence that can result in instability. However one can obtain a homogeneous stationary case, if to select certain witnesses and to conform them with certain drivers, alternating witnesses (Figs. 10–12).

There are several reasons that cause to derive the optimized sequence of bunches with large T_E:

1) large number of accelerated electrons is needed;

2) large T_E is needed.

However there appeared difficulties:

1) it is impossible strongly to extend the sequence, shaped on the linear law, because a maximal charge is limited;

2) with sequence lengthening, shaped according to the linear law, F_r grows along it, the latter can destroy driver.

As a result the infinite sequence of electron bunches-drivers is derived. The bunches-drivers of asymptotic part of sequence are identical each other and are represented turned on a corner $\pi/2$ rectangular trapezoid. These bunches-drivers are alternated with bunches-witnesses. Each this bunch – driver restore the wakefield amplitude after each bunch-witness. The bunch's charges of the periodic part of sequence equal to $Q_n = (2N_{fr}-1)Q_1$, $n \geq N_{fr}$. N_{fr} is the number of bunches of frontal part of sequence with growing charge. The charge of every bunch is shaped along bunch according to linear law.

The advantages of this sequence are following:

1) large transformation ratio $T_E = 2\pi N_{fr}$;

2) homogeneous E_z for bunches-drivers along every bunch and along the sequence;

3) bunches-drivers $n \geq N_{fr}$ are focused by identical focusing forces;

4) a long sequence of bunches-witnesses.

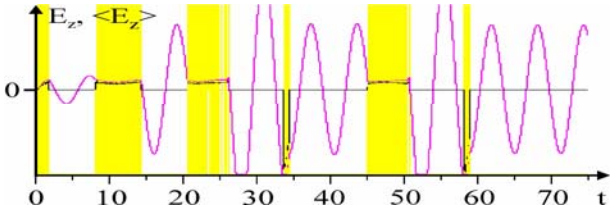


Fig. 10. E_z (red), <E_z> (black), n_b (yellow)

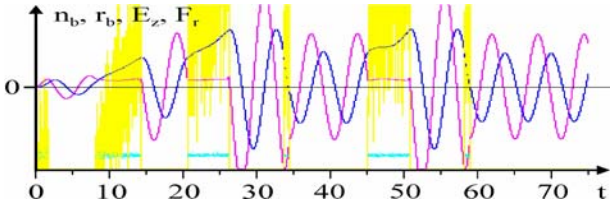


Fig. 11. E_z on a radius equal to the bunch radius (red), F_r (dark blue), r_b (blue), n_b (yellow)

In the head of sequence of bunches a rectangular bunch – precursor, length of which equals λ/4, is placed. Then short sequence of electron bunches, a charge in which grows according to the linear law both along every bunch and along the sequence, follows. After this short sequence an asymptotic long (infinite) periodic sequence of electron bunches-drivers and bunches-witnesses follows. Charges of these bunches-drivers are identical, but they are distributed according to the linear law along every bunch. These bunches-drivers are alternated with bunches-witnesses.

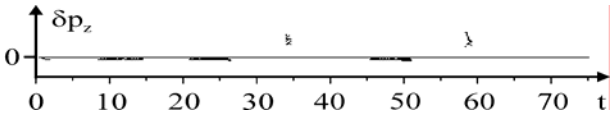


Fig. 12. Change of longitudinal momentum of bunches-drivers and bunches-witnesses δp_z. Two point accelerated bunches alternate the shaped bunches-drivers

CONCLUSIONS

It has been shown that the wakefield E_z, decelerating bunches-drivers, in the areas of bunche-drivers location approximately does not depend on longitudinal coordinate if the charge is shaped according to linear law. I.e. it has been succeeded to obtain, that all electrons of every lengthy bunch and all bunches of sequence are decelerated by almost identical force if lengths of bunches equal $\xi_b=p\lambda$, p=1, 2, 3, … and interbunch gaps equal $\delta\xi=q\lambda$, q=0, 1, 2, ….

The long sequence of electron bunches-drivers and bunches-witnesses has been derived, providing the large transformation ratio, homogeneous wakefield, decelerating bunches-drivers, and long sequence of bunches-witnesses. The charge of this bunch-driver is distributed according to linear law along every bunch.

ACKNOWLEDGEMENTS

The authors thank Prof. K.V.Lotov for the possibility to numerically simulate by his code lcode.

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Article received 07.09.12

ВОЗБУЖДЕНИЕ КИЛЬВАТЕРНОГО ПОЛЯ В ПЛАЗМЕ ПОСЛЕДОВАТЕЛЬНОСТЬЮ ПРОФИЛИРОВАННЫХ ЭЛЕКТРОННЫХ СГУСТКОВ С РАСТУЩИМ ЗАРЯДОМ ПО ЛИНЕЙНОМУ ЗАКОНУ

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

Показано, что кильватерное поле в областях локализации сгустков-драйверов не зависит от продольной координаты при определенных длинах сгустков и промежутках между ними, если заряд профилирован по линейному закону. Для увеличения числа ускоренных электронов построена длинная последовательность электронных сгустков-драйверов, заряд у которых распределен по линейному закону вдоль каждого сгустка, обеспечивающая большой коэффициент трансформации и однородное кильватерное поле, которое позволяет полностью затормозить сгустки-драйверы.

ЗБУДЖЕННЯ КІЛЬВАТЕРНОГО ПОЛЯ В ПЛАЗМІ ПОСЛІДОВНІСТЮ ПРОФІЛЬОВАНИХ ЕЛЕКТРОННИХ ЗГУСТКІВ З ЛІНІЙНО НАРОСТАЮЧИМ ЗАРЯДОМ

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

Показано, що кільватерне поле в межах локалізації згустків-драйверів не залежить від поздовжньої координати при відповідних довжинах згустів та проміжках між ними, якщо заряд профільован відповідно лінійному закону. Для збільшення числа прискорених електронів побудована довга послідовність електронних згустів-драйверів, заряд в яких розподілений по лінійному закону вздовж кожного згустку, яка забезпечує значний коефіцієнт трансформації та однорідне кільватерне поле, яке дозволяє повністю загальмувати згустки-драйвери.