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SIMULATION OF THE IDENTICAL PLATEAUS FORMATION ON PLASMA WAKEFIELD FOR LONG DRIVER-BUNCH AND WITNESS-BUNCHES

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We formulate scenario for the simultaneous enhancement of the charge of accelerated electrons, improving such characteristics as the transformer ratio, efficiency, low energy spread, and emittance of bunches of accelerated electrons in the blowout regime by the simultaneous achievement of the identical plateaus on the accelerating wakefields and other identical plateaus on the decelerating wakefields.

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INTRODUCTION

Permissible electric fields in metal structures are very limited, up to 100 MV/m. Increasing the rate of energy collection faces the problem of breakdown of the RF structure. Thus, with the approach to the limit of capabilities of traditional accelerator schemes, interest in plasma wakefield accelerators has been growing. On the other hand, the modern agenda implies that the acceleration provided by plasma wakefield accelerators is still too small (100 GeV-class electrons) and cannot compete with well-developed modern classical accelerators in quality of the accelerated beam. This is why the plasma wakefields are developed (see [1 - 24]). In order to make the acceleration effective, it is necessary to build a plateau on the accelerating and decelerating electric fields [25 - 31]. In this article, we selected the parameters of driver and witnesses in such a way that all electron beams were in the same accelerating or decelerating fields.

We used beams, the radius of which is equal to 0.3. We present parameter selection 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 particle-in-cell code LCODE that treats plasma electrons and bunches as ensembles of macro-particles. The electron distribution is Gaussian in the transverse direction along the radius. The coordinate system is cylindrical (r, z) and the plasma, beam densities, and longitudinal electric field are drawn as a function that depends on 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, distance normalized on c/ω_{pe}, bunch current I_b on $I_{cr}=\pi mc^3/4e$, fields – on $mc\omega_{pe}/e$, where e, m are the charge and mass of the electron, c is the light velocity.

1. USAGE OF ACCELERATING WAKEFIELD, DISTRIBUTED ACCORDING TO LINEAR DEPENDENCE

In this section, the main goal was to obtain a linear curve in the bubble in the area of the accelerating electric field (Figs. 1, 2). This is justified by the fact that for the linear curve, if a plateau is reached at least at one point, then it can be kept at other points of the configuration. In the acceleration process, witness moves inside the bubble, and since the electric field is linear plateau will simply move in parallel in the longitudinal direction and remain almost the same. This is quite important due to the fact that it guarantees the same acceleration rate for all particles in the bunch. From the Gauss Theorem estimation, it follows that the dependence of the accelerating electric field on the coordinate is plateau-kind for the one-dimensional and three-dimensional cases, and this is very important.

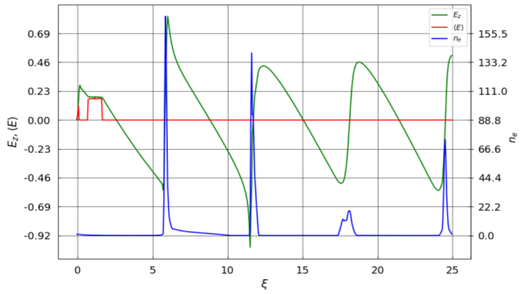

Fig. 1. The on-axis wakefield excitation E_z (green line) by electron driver-bunch. The mean field $E_0=\int n_b E_z r dr/\int n_b r dr$ is shown to be red as a function of the coordinate ξ along the plasma. Plasma electron density is shown by blue. The direction of movement of the driver-bunch is from right to left. The length between the two green peaks is the length of the zone of the first bubble. The length of the driver is 0.9 normalized length units

This has been implemented for the case of a short and a long driver (see Figs. 1 and 2). As it known, the size of the driver must be much larger than the size of the witness for effective acceleration. The same modeling was done for the long driver and the effect is preserved.

Another problem for which the usage of the electrical field with a linear dependence will be useful is that for the transition between the accelerating cells, the injection of witness requires placing it in the maximum of the accelerating field of the bubble with plateau formation, and in the case of a linear section this will be achieved.

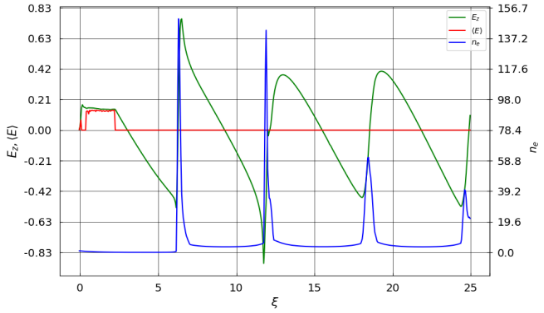

Fig. 2. The graph provides data for a long driver-case, which is twice as long as the one presented in Fig. 1. The designations for the curves are the same as in Fig. 1

2. SHORT AND LONG DRIVER WITH WITNESS

It was observed that if the witness is shifted deeper into the bubble, the accelerating field still remains a plateau-kind due to the linear nature of the electric field along the axis z. Such modeling was done for several shifts. The plateau shifts without distortion, but such a shift affects the mean field. The coincidence of the plateau of the average electric field and the field on the axis z can be achieved by easily adjusting the parameters, namely increasing the current. Otherwise, the average field is slightly different from the field on the axis z.

The beam could change the phases of the bubble when it transits plasma cells. Figs. 3-7 show different shifts, which are related to different phases. There could be two reasons for the phase change. The beam can change phase due to acceleration and shift relative to the bubble or when it accelerates in one plasma cell, go through a vacuum or focusing gap, and enters another plasma cell.

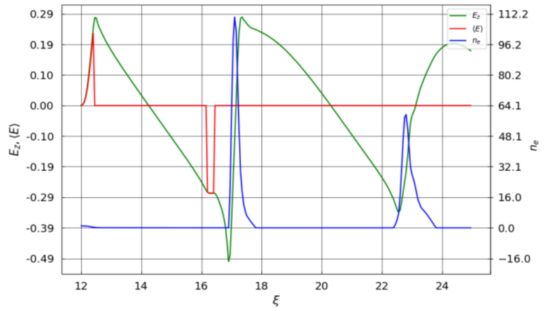

Fig. 3. The distance between the driver and the witness is 3.7

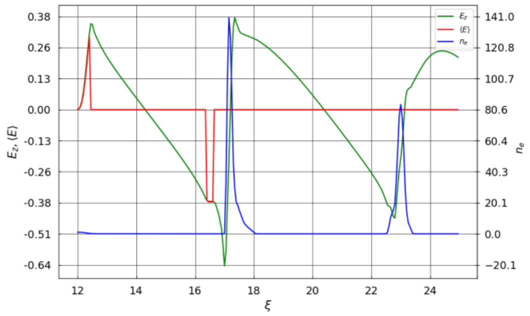

Fig. 4. The distance between the driver and the witness is 3.9

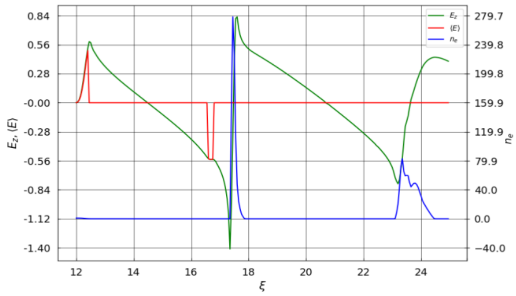

Fig. 5. The graph provides data for shifting witness-case. The distance between the driver and the witness is 4.1

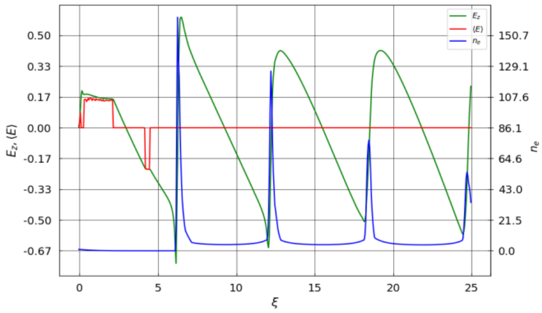

Fig. 6. The distance between the driver and the witness is 4.2

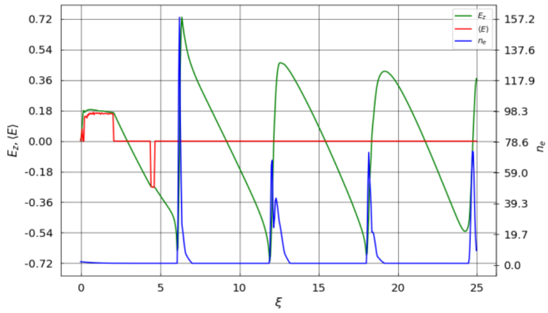

Fig. 7. The distance between the driver and the witness is 4.4

This is also done for the long driver. For effective acceleration, the charge of the driver should be as high as possible. We considered the problem of increasing the length of the driver and we can note that in this case the plateau also collects when the witness is moved into the bubble.

3. PLATEAU IN THE ENTIRE CROSS-SECTION OF THE LONG DRIVER-BUNCH ON THE DECELERATING WAKEFIELD AND THE PLATEAUS IN THE ENTIRE CROSS-SECTIONS OF THE SEVERAL WITNESS-BUNCHES ON THE ACCELERATING WAKEFIELD WITH LARGE TRANSFORMER RATIO

We use the following configuration (Fig. 8) to fulfill four requirements at the same time: the long profiled driver-bunch (with a plateau on the decelerating wakefield in full cross-section of the driver-bunch); a large charge of a short profiled train of three witness-bunches (with identical plateaus on the accelerating wakefields in full cross-sections of the wintess-bunches), large transformer ratio and high efficiency.

Each witness-bunch is put into its own bubble in the right phase.

A short profiled chain of profiled witness-bunches provides identical for all witness-bunches accelerating wakefield, coinciding plateaus for the accelerating wakefield along axis and the plateaus, averaged in the full cross-section of witness-bunches, what also provides the large transformer ratio.

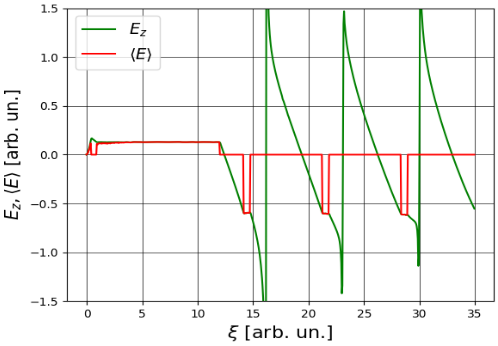

Fig. 8. A wakefield that is almost independent of the longitudinal coordinate and radius along the entire long profiled driver-bunch and identical accelerating wakefields for several short witness-bunches. Transformer ratio equals 4

One can see that a plateau on the decelerating wakefield for the driver-bunch along the axis coincides with an averaged in the entire cross-section of the driver-bunch plateau on the decelerating wakefield. Also, one can see that plateaus are identical for all witness-bunches. The plateaus on the accelerating wakefield for the witness-bunches along axis coincide with an averaged in the full cross-sections of witness-bunch plateaus on the accelerating wakefield. The transformer ratio (=E_{zw}/E_{zdr}) is large (=4).

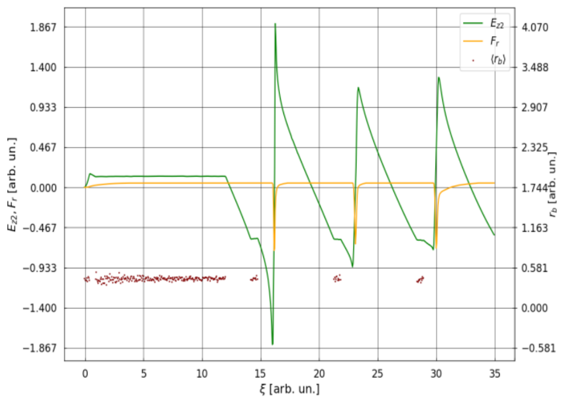

Fig. 9. The off-axis focusing force F_r is shown by orange. The off-axis longitudinal wakefield E_z is shown by green. The brown dots show the locations of the bunches

The plateau on accelerating wakefield coincides with the local maximum of $E_z(r = r_b)$ (Fig. 9). It provides a minimal wakefield after the last witness-bunch and, therefore, provides a high efficiency of the wakefield accelerator.

CONCLUSIONS

To make the wakefield acceleration effective and accelerated electron bunches of high quality the parameters have been selected by particle-in-cell numerical simulation in the blowout regime to build plateaus on the accelerating wakefields for all witness-bunches and on the decelerating wakefield for a driver-bunch in such a way that all beam's electrons were in the same accelerating or decelerating wakefields. A structure from a chain of driver and witnesses was investigated. A case with a high transformer ratio is achieved.

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ЧИСЛОВЕ МОДЕЛЮВАННЯ ФОРМУВАННЯ ОДНАКОВИХ ПЛАТО НА ПЛАЗМОВОМУ КІЛЬВАТЕРНОМУ ПОЛІ ДЛЯ ДОВГОГО ДРАЙВЕРНОГО ЗГУСТКА ТА ПРИСКОРЮВАНИХ ЗГУСТКІВ

Д.О. Шендрик, Р.Т. Овсянников, В.І. Маслов, J. Osterhoff, M. Thevenet

Сформульовано сценарії одночасного підвищення заряду прискорених електронів, покращення таких характеристик, як коефіцієнт трансформації, ККД, малий енергетичний розкид, емітанс пучків прискорених електронів у нелінійному режимі за рахунок одночасного досягнення однакових плато на прискорюючому кільватерному полі та іншого ідентичного плато на сповільнюючому кільватерному полі.