NUMERICAL SIMULATION OF PLASMA WAKEFIELD EXCITATION BY A SEQUENCE OF LASER PULSES

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The results of numeral simulation of plasma wakefield excitation by sequence of laser pulses are presented. It is shown that if laser pulses are placed through one wavelength, the accelerated bunch of electrons is formed and accelerated only after the last laser pulse. If laser pulses are placed through two wavelengths, the electron bunch is formed and accelerated after every laser pulse. Thus the second bunch of electrons after every pulse is non-monoenergetic or it is not formed unlike the case of one pulse.

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INTRODUCTION

The intense plasma wakefield excitation by a single intense laser pulse has allowed to other authors to achieve large accelerating field (see [1...8]). At excitation of the wakefield by one intensive laser pulse two bubbles are formed at certain conditions after it and an electron bunch is accelerated in each of them. I.e. an intensive laser pulse can form a sequence of two accelerated electron bunches. Also after these two bubbles wake is excited. Hence it would be useful to enhance this wake and to use it for the electron bunch acceleration for increase of number of accelerated electrons. I.e. the question arises about possibility of wakefield excitation by sequence of laser pulses. To address this question the authors of this paper study by numerical simulation, using fully relativistic electromagnetic PIC code-UMKA2D3V, self - consistent effect of three short laser pulses on the uniform plasma with density n_0=1.7458·10^{19} cm^{-3}. The amplitude of each pulse equals b=1, 3 or 5. The amplitude is normalized on $E_0 = m_e c\omega_0/(2\pi e)$, ω_0 is the pulse frequency. It is shown that, if laser pulses are distributed through one wavelength of plasma oscillations, pulses effect on the field steepening and bunch of the accelerated electrons is formed only after the last pulse. If laser pulses are distributed through two wavelengths, after every pulse the electron bunch is accelerated. Thus, as every second field steepening is effected by a laser pulse, the second electron bunch after every pulse is not formed unlike the case of one pulse or it is non-monoenergetic beams. Thus, although bubble after the last pulse is excited with a time delay relatively to first bubble, the accelerated bunches in the first and last bubbles can be formed approximately simultaneously, as amplitudes of bubbles grow along the sequence.

RESULTS OF SIMULATION

At first we consider well-known case of the wakefield excitation by one intensive laser pulse. At certain parameters after an intensive laser pulse two bubbles of plasma electrons are formed and in each of them an electron bunch is accelerated (Fig. 1). I.e. an intensive laser pulse forms a sequence of two accelerated electron bunches.

Also after these two plasma electron bubbles a wake is excited (Figs. 2, 3). It would be useful, for increase of number of accelerated electrons, to enhance and use it for electron bunch acceleration.

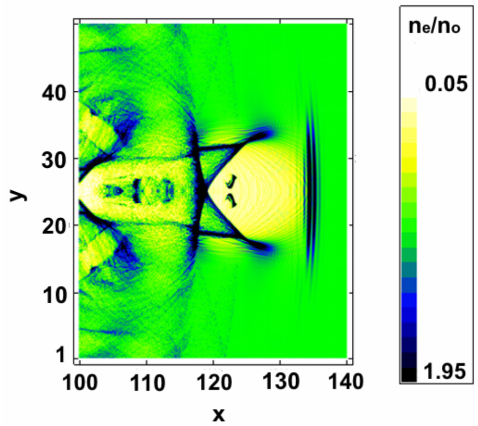

Fig. 1. Two plasma electron bubbles and two electron bunches, accelerated by one laser pulse in the time, when the laser pulse deeply penetrated into the plasma (see Fig. 2) t=140t_0. The amplitude of pulse equals b=5. The pulse half-duration (normalized on t_0) equals t_l = 1. Its half-width (normalized on λ) equals r_0 = 4. λ is the wavelength and $t_0 = 2\pi/\omega_0$ is the period of laser pulse. x and y on the axes are normalized on λ

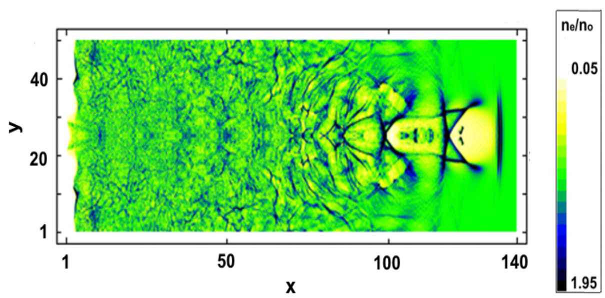

Fig. 2. Two plasma electron bubbles and two electron bunches, accelerated by one laser pulse in the time, when the laser pulse deeply penetrated into the plasma

Now we investigate a sequence of two laser pulses-drivers. In the case of two laser pulses-drivers, if they are distributed through one wavelength of plasma oscillations, pulses effect on the field steepening and bunch of accelerated electrons is formed only after the last pulse (Fig. 4).

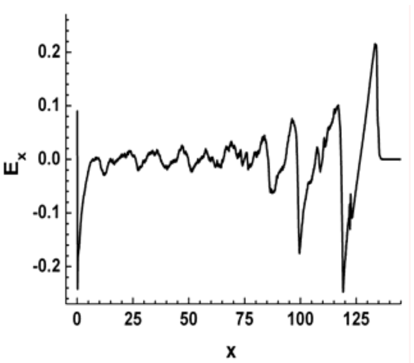

Fig. 3. Longitudinal component of the wakefield excited by one laser pulse in the time, when a laser pulse deeply penetrated into the plasma

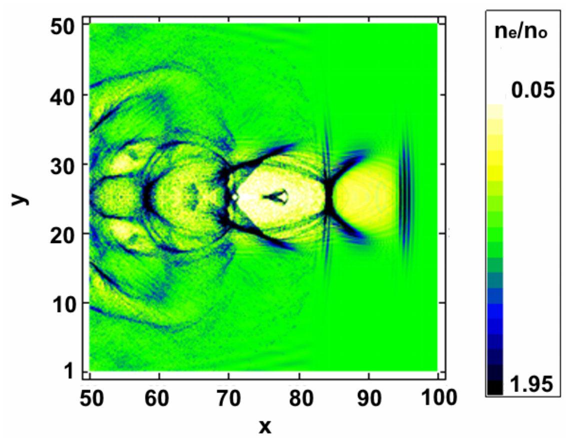

Fig. 4. Wake perturbation from two laser pulses, distributed through one wavelength of plasma oscillations (through δx=10.49) in the time $t=100t_0$. The amplitude of each pulse equals b=3. The half-duration of the first pulse equals $t_l = 1$ and of the second pulse equals $t_l = 2$. The half-width of the first pulse equals $r_0 = 4$ and of the second pulse equals $r_0 = 2$

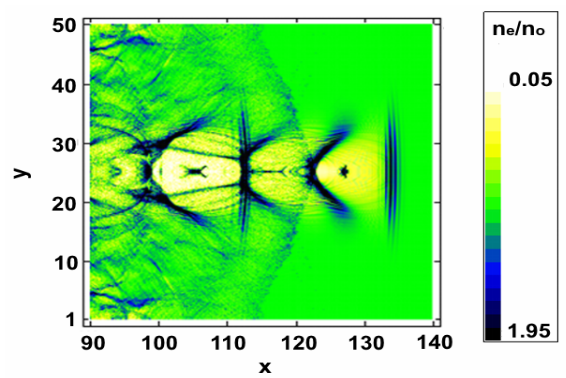

Fig. 5. Sequence of two electron bunches, accelerated by a sequence of two laser pulses, distributed through two wavelengths of plasma oscillations (through δx=22), in the time, when laser pulses deeply penetrated into the plasma $t=140t_0$. The amplitudes of both pulses equal b=3. The half-duration of the first pulse equals $t_l = 1$ and of the second pulse equals $t_l = 2$. The half-width of the first pulse equals $r_0 = 4$ and of the second pulse equals $r_0 = 2$

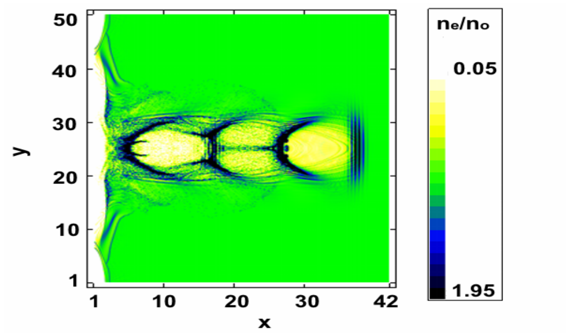

Fig. 6. Appearance of sequence of two electron bunches, accelerated by the sequence of two laser pulses, in the time $t=40t_0$. The pulses are distributed through δx=22. The amplitudes of both pulses equal b=3. The half-duration of the first pulse equals $t_l = 1$ and of the second pulse equals $t_l = 2$. The half-width of the first pulse equals $r_0 = 4$ and of the second pulse equals $r_0 = 2$

If laser pulses are distributed through two wavelengths of plasma oscillations, after every pulse the electron bunch is accelerated (Fig. 5). Thus, as every second field steepening is effected by laser pulse, the second electron bunch after every pulse is not formed (see Fig. 5) unlike the case of one pulse or it is non-monoenergetic bunch (see Fig. 5). Thus, although the plasma electron bubble after the last pulse is formed with a time delay relatively first one, the accelerated electron bunches can be formed by the first and last plasma electron bubbles, as it is observed, approximately simultaneously, if amplitudes of plasma electron bubbles grow along their sequence (Fig. 6).

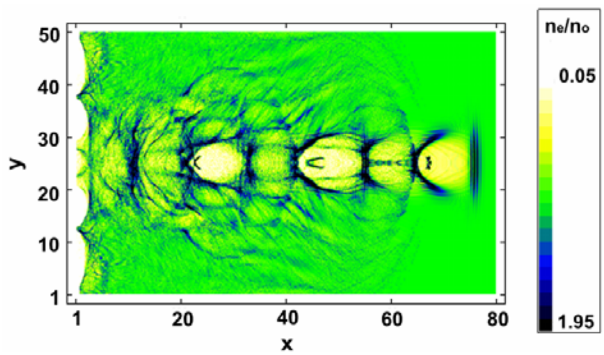

Fig. 7. Wake perturbation of plasma electron density, excited by a sequence of three laser pulses of large intensity, in the time $t=80t_0$. The pulses are distributed through δx=22. The amplitudes of all pulses equal b=3. The half-duration of the first pulse equals $t_l = 1$ and of the second and third pulses equal $t_l = 2$. The half-width of the first pulse equals $r_0 = 4$ and of the second and third pulses equal $r_0 = 2$

If the third laser pulse follows after the second pulse through two wavelengths of plasma oscillations, after third pulse the third electron bunch is also accelerated (Fig. 7). The wakefield, excited by a sequence of three laser pulses of large intensity is shown in Fig. 8.

The wake perturbation from three laser pulses of small intensity is shown in Fig. 9.

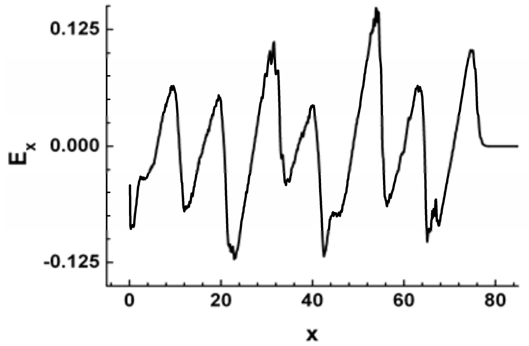

Fig. 8. Longitudinal wakefield, excited by sequence of three laser pulses of large intensity

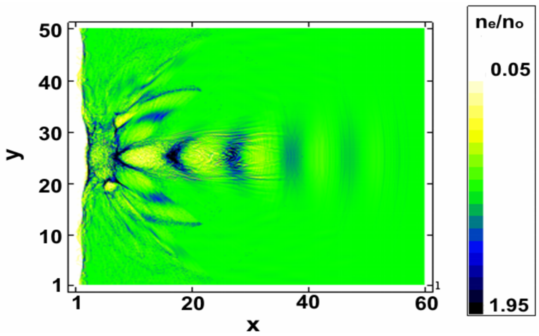

Fig. 9. Wake perturbation from three laser pulses of small intensity in the time $t=60t_0$. The pulses are distributed through $\delta x=10$. The amplitudes of all pulses equal $b=1$. The half-duration of all pulses equals $t_l = 1$. The half-width of all pulses equals $r_0 = 1$

CONCLUSIONS

It is shown that in the case of laser pulses, distributed through one wavelength of plasma oscillations, bunch of accelerated electrons is formed only after the last pulse. If laser pulses are distributed through two wavelengths of plasma oscillations, after every pulse the electron bunch is accelerated. Thus the second electron bunch after every pulse is not formed unlike the case of one pulse or it is non-monoenergetic bunch.

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ЧИСЛЕННОЕ МОДЕЛИРОВАНИЕ ВОЗБУЖДЕНИЯ КИЛЬВАТЕРНОГО ПОЛЯ В ПЛАЗМЕ ПОСЛЕДОВАТЕЛЬНОСТЬЮ ЛАЗЕРНЫХ ИМПУЛЬСОВ

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Проведено численное моделирование возбуждения кильватерных полей в плазме последовательностью лазерных импульсов. В случае последовательности лазерных импульсов, расположенных через одну длину волны, сгусток ускоряемых электронов формируется только за последним импульсом. Если лазерные импульсы расположены через две длины волны, за каждым импульсом ускоряется сгусток электронов. При этом вторые сгустки электронов за каждым импульсом не формируются в отличие от случая одного импульса или они представляют собой немоноэнергетичные пучки.

ЧИСЕЛЬНЕ МОДЕЛЮВАННЯ ЗБУДЖЕННЯ КІЛЬВАТЕРНОГО ПОЛЯ В ПЛАЗМІ ПОСЛІДОВНІСТЮ ЛАЗЕРНИХ ІМПУЛЬСІВ

В.І. Маслов, І.М. Онищенко, О.М. Свистун

Проведено чисельне моделювання збудження кільватерних полів у плазмі послідовністю лазерних імпульсів. У випадку послідовності лазерних імпульсів, розташованих через одну довжину хвилі, згусток прискорюваних електронів формується тільки за останнім імпульсом. Якщо лазерні імпульси розташовані через дві довжини хвилі, за кожним імпульсом прискорюється згусток електронів. При цьому другі згустки електронів за кожним імпульсом не формуються на відміну від випадку одного імпульсу або вони є немоноенергетичними пучками.