ACCELERATION AND FOCUSING OF ELECTRON BUNCHES BY WAKEFIELDS IN PLASMA PRODUCED IN NEUTRAL GAS BY A NONRESONANT SEQUENCE OF BUNCHES

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It is experimentally investigated the possibility of accelerating and focusing of relativistic electron bunches by wakefields excited by their sequence in plasma, produced during its passage through the neutral gas, caused by the displacement of bunches into corresponding phases of excited field in the presence of mismatch between the bunch repetition frequency and plasma frequency. The mismatch is achieved by changing the pressure of the neutral gas at a fixed beam current density. Energy loss of some bunches and energy gain of others in the presence of other mismatch are estimated from the energy spectrum obtained from the imprints on the glass plate of bunches deflected with the transverse magnetic field. Focusing/defocusing of electron bunches is demonstrated by the change of the transverse sizes of imprints of nondeflected bunches and corresponding temporal modulation of the axial current density of the beam measured by Faraday cup of small cross-section

PACS: 41.85.Ne; 41.85.Lc

INTRODUCTION

At present in many research centers intense investigations of plasma wakefields excitation by relativistic electron bunch with a large charge or by their sequence are carried out [1-4]. Such fields can be used fir acceleration [1-4], and focusing [5-9] of the electron bunches.

In the case of a single exciting bunch (driver) for acceleration the other bunch (witness) is used which is injected in the accelerating phase of the field excited by the driver. At that accelerated bunch should be placed in phase region of wakefield, where it is simultaneously accelerated and focused by this field.

For a sequence of bunches, besides of such acceleration scheme, the conditions can be created under which a part of bunches excites wakefield, being in the decelerating phases of the field, and the other part of bunches is accelerated, being in the accelerating phases. At that, one part of bunches is in focusing phases and another one is in defocusing phases of excited field. Such conditions occur when a mismatch between the bunch repetition frequency ω_m and plasma frequency ω_p frequency is put in.

For a large beam current and high pressure of neutral gas plasma density reaches rapidly a "resonance" value, at which the plasma frequency coincides with the frequency of bunch repetition (ω_p=ω_m). In this case, all clusters are in the decelerating phase of the exciting field.

Early [9], we have performed experiments on focusing/defocusing of bunches of a sequence, when mismatch was achieved by decrease beam current propagating in air at atmospheric pressure. Besides, for prevailing of the radial component of the wakefield over longitudinal one, i.e. focusing/defocusing of the bunch over their acceleration/deceleration, in [9], accordingly to [8], by diaphragming bunches were made of an elongated form ($r/l \ll 1$, where r is radius of the bunch, l is its length).

In this paper the acceleration and focusing of electron bunches by wakefields excited by their sequence in plasma produced at passage of a sequence through neutral gas of different pressure. In contrast to [9], the mismatch was achieved by changing the pressure of the neutral gas at fixed beam current. Additionally the conditions $r / l \approx 1$ is fulfilled, at which comparable longitudinal and radial component of the wakefield [8] are excited, i.e. both acceleration/deceleration and focusing/defocusing of the bunches occurs.

1. EXPERIMENTAL SETUP

The experimental setup, at which conducted the experiments were carried out, is shown in Fig. 1. For plasma production and wakefields excitation in it a sequence of relativistic electron bunches of resonant linear electron accelerator "Almaz-2" was used The beam parameters: energy 4.5 MeV, pulsed current 0.5 A, duration of the pulse 2 μs. The pulse consists of a sequence of $6{\cdot}10^3$ bunches, each of duration 60ps, bunches spacing 300 ps, bunch repetition frequency 2805 MHz. Bunch length is 1.7 cm, diameter is 1.0 cm, charge is 0.16 nC.

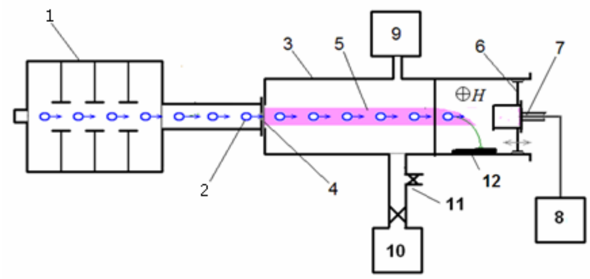


Fig. 1. Scheme of experimental setup:
1 – accelerator; 2 – bunches; 3 – waveguide;
4 – diaphragm, 5 – plasma; 6 – movable plunger;
7 – Faraday cup; 8 – oscilloscope; 9 – vacuum gauge;
10 – vacuum pump; 11 – gas valve; 12 – glass plate

The sequence of bunches, produced by accelerator was injected through Ti foil of thickness 50 μ into a standard copper waveguide of cross-section 72.14×34.04 mm and length 35 cm, filled with air, the pressure of which can be varied from 760 to $5{\cdot}10^{-2}$ Torr. When the waveguide exit was open the wakefield was excited in a mode of the semi-infinite waveguide. To operate in resonator mode the exit end of the waveguide was closed with movable short-circuited plunger, in the center of which there were microwave probe to measure E_z component of excited field, or Faraday cup to measure the beam current.

The density of produced plasma was measured using an open barrel-shaped cavity [10], allowing to measure plasma density in the conditional of high collisional frequency that takes place in our experiment.

2. EXPERIMENTAL RESULTS

The measurements of E_z component of excited field showed that at gas pressure 760 Torr generated resonant plasma (ω_m=ω_p) is produced and the wakefield amplitude rapidly reaches the maximum value and remains constant throughout the pulse duration (Fig. 2,a). At low pressures (P = 40…60 Torr), when the plasma density is less than the resonant value and the condition $\omega_m \neq \omega_p$ is realized, bunches of the sequence are occurred in different phases-decelerating/accelerating and defocusing/focusing ones. With taking into account the topography of the excited field [8], it leads to decrease or to increase in the amplitude of E_z component of wakefield, as it is evidenced by oscillograms E_z (see Fig. 2,b) for the case of frequency mismatch.

a *b*

Fig. 2. Oscillograms of E_z wakefield component (upper) and beam current (bottom): a – P = 760 Torr, b – P = 60 Torr

The imprints of the electron bunches on glass plates at the exit of the accelerator, and after passage through the plasma and deflected by a constant transverse magnetic field are shown in Fig. 3,a,b. The figure shows modified due to the mismatch energy spectra of electrons, as for bunches lost the energy on the wakefield excitation, and for bunches accelerated in the excited field after bunches passage through the plasma. Energy loss of exciting bunches and energy gain of accelerated bunches are in agreement with the value of wakefield amplitude.

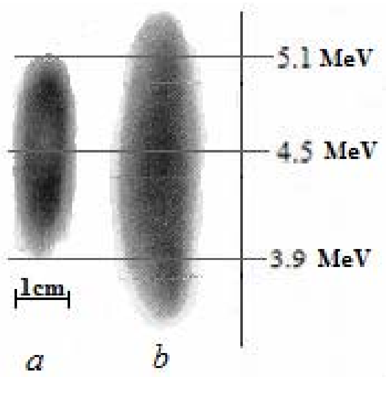
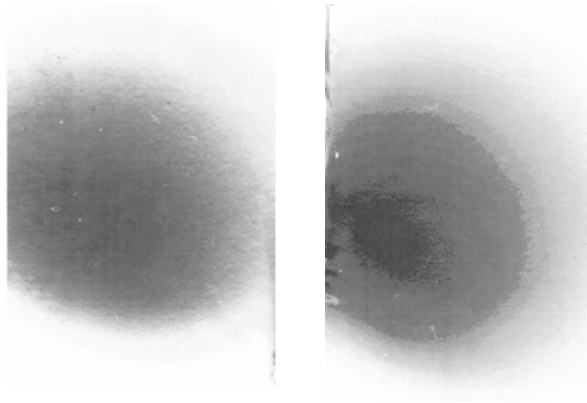


Fig. 3. Imprints on glass plate of the bunches deflected by magnetic field: a – at accelerator exit, b – after passage through the plasma, P = 60 Torr

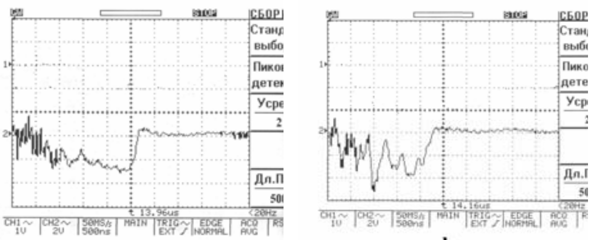
The displacement of the bunches of the sequence over phases of excited wakefield, caused by the mismatch, and arising alternation of focusing/defocusing processes were investigated experimentally by means of imprints of nondeflected bunches on a glass plate. At high pressure of neutral gas (P = 450…760 Torr), when resonant plasma (ω_m=ω_p) is produced, all bunches, coherently exciting wakefield are in negligible but in average defocusing radial component of wakefield [11]. This leads to the angular spread of the electron bunches that registered experimentally and shown in Fig. 4,a When the pressure is reduced to 60 Torr, nonresonant plasma is produced, leading to the appearance of mismatch ($\omega_m \neq \omega_p$). In this case, the part of the bunches gets into the focusing and the other part into defocusing phases of the excited field. In result, as it is demonstrated in Fig. 4,b, the stronger, than in the resonant case, defocusing leads to halo increase and a black area of essential focusing.



a *b*

Fig. 4. Imprints of bunches on the glass plate: a – P=760 Torr, b – P=60 Torr

Periodical focusing and defocusing during the pulse (i.e. along the sequence) leads to modulation in time of the beam current density on the axis. In the experiment, the beam current density measurements were carried out by Faraday cup of small cross-section (5 mm diameter) located on the axis of the resonator at its exit. In the case of resonant plasma Faraday cup registered smoothly changing (almost constant over pulse duration) current density (Fig. 5,a). For nonresonant plasma fall of different parts of bunch sequence into focusing and defocusing phases of excited field leads to modulation of the beam current density on the axis, that is registered experimentally and shown in Fig. 5,b.



a **b**

Fig. 5. Oscillograms of the beam current density measured by a small Faraday cup: a – P = 760 Torr, b – P = 60 Torr

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Article received 07.09.12

УСКОРЕНИЕ И ФОКУСИРОВКА ЭЛЕКТРОННЫХ СГУСТКОВ КИЛЬВАТЕРНЫМИ ПОЛЯМИ В ПЛАЗМЕ, ОБРАЗОВАННОЙ НЕРЕЗОНАНСНОЙ ПОСЛЕДОВАТЕЛЬНОСТЬЮ СГУСТКОВ В НЕЙТРАЛЬНОМ ГАЗЕ

В.А. Киселёв, А.Ф. Линник, И.Н. Онищенко, В.И. Приступа

Экспериментально исследована возможность ускорения и фокусировки релятивистских электронных сгустков кильватерными полями, возбуждаемыми их последовательностью в плазме, создаваемой при ее прохождении через нейтральный газ и обусловленной смещением сгустков в соответствующие фазы возбуждаемого поля при наличии расстройки между частотой следования сгустков и плазменной частотой. Расстройка достигалась изменением давления нейтрального газа при неизменной плотности тока пучка. Потери энергии одних сгустков и ускорение других при наличии расстройки оценивались по энергетическому спектру, полученному из отпечатков на стеклянной пластине сгустков, отклоненных поперечным магнитным полем. Фокусировка/дефокусировка электронных сгустков демонстрируется изменением поперечных размеров отпечатков неотклоненных сгустков и соответствующей временной модуляцией осевой плотности тока пучка, измеренной цилиндром Фарадея малого сечения.

ПРИСКОРЕННЯ І ФОКУСУВАННЯ ЕЛЕКТРОННИХ ЗГУСТКІВ КІЛЬВАТЕРНИМИ ПОЛЯМИ В ПЛАЗМІ, СТВОРЮВАНОЮ НЕРЕЗОНАНСНОЮ ПОСЛІДОВНІСТЮ ЗГУСТКІВ У НЕЙТРАЛЬНОМУ ГАЗІ

В.А. Кисельов, А.Ф. Лінник, І.Н. Оніщенко, В.І. Приступа

Експериментально досліджена можливість прискорювання і фокусування релятивістських електронних згустків кільватерними полями, збуджуваними їх послідовністю у плазмі, створюваної при її проходженні через нейтральний газ і обумовленої зміщенням згустків у відповідні фази збуджуваного поля при наявності розстройки між частотою слідування згустків і плазмовою частотою. Розстройка досягалась зміною тиску нейтрального газу при постійній щільності струму пучка. Втрати енергії одних згустків і прискорення інших при наявності розстройки оцінювались з енергетичного спектру, отриманому з відбитків на скляній пластині згустків, відхилених поперечним магнітним полем. Фокусування/дефокусування електронних згустків демонструється зміною поперечних розмірів відбитків невідхилених згустків і відповідною часовою модуляцією осьової щільності струму пучка, виміряної циліндром Фарадея малого перетину.