MEASUREMENT OF WAKEFIELDS IN PLASMA BY A PROBING ELECTRON BEAM

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The device for measuring intensity of wakefield, excited in plasma by a sequence of bunches of relativistic electrons is presented. Field amplitude is determined by measuring deflection of a probing electron beam (10 keV, 50 μA, of 1 mm diameter), which is injected perpendicularly to a direction of bunches movement. Results of measurement of focusing radial wakefield excited in plasma of density 5×10^{11} cm^{-3} by a sequence of needle electron bunches (each bunch of length 10 mm, diameter 1.5 mm, energy 14 MeV, 2×10^{9} electrons in bunch, number of bunches 1500) are given. The measured radial wakefield strength was 2.5 kV/cm.

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1. INTRODUCTION

Producing of bunches of the ultrahigh energy charged particles based on conventional principles results in the large sizes and high cost of accelerators In this connection there is a necessity to develop advanced methods of acceleration with the high rate of energy gain. One of such methods is charged particles by the wakefields excited in plasma or dielectric by intensive bunches of relativistic electrons [1-3]. For a big number of particles in a bunch and high density of plasma it is possible to obtain the intensity of accelerating electric field by some orders higher comparative to the field intensity in conventional accelerators.

The other not less attractive feature of interaction of a bunch of electrons or their sequence with plasma is focusing of bunches by transversal plasma wakefields. In the works [4-6] it is shown, that relativistic electron bunches can be focused at passage through plasma both by transversal component of wakefield, and by self azimuthal magnetic field at charge neutralization when plasma electrons are pushed out from the interaction region and charge of a bunch is compensated by the staying ions. At that excited transversal focusing fields can considerably exceed focusing gradients of conventional focusing magnetic systems. The focusing of such type is especially claimed by the future high-energy colliders for providing very small transversal sizes of colliding bunches.

Theoretical considerations [7] show that the topography of wakefields excited by bunches of relativistic electrons depends on ratio between the longitudinal and transversal sizes of a bunch. In case of a short bunch ($\sigma_r/\sigma_z\geq1$, where σ_r – diameter of a bunch, σ_z - its length) wakefield with big longitudinal component for acceleration is excited, and in case of a long bunch with a small diameter ($\sigma_r/\sigma_z<<1$) - with big radial component for focusing.

In the given work research of the possibility of measuring focusing transversal wakefield excited in plasma by a sequence of “needle” relativistic electron bunches by means of a probing electron beam is carried out.

2. EXPERIMENTAL SETUP

Experimental researches of wakefield excitation in plasma by relativistic electron bunches of "needle" type ($\sigma_r/\sigma_z<<1$) and their focusing by transversal wakefield was carried out with use of the linear resonant electron accelerator "LIK" (energy of electrons - 14 MeV, current in a macropulse – 0.5 A, macropulse duration - 0,5 μs, number of bunches in macropulse - $1{,}5\cdot10^{6}$, charge of each bunch – 0.3 nC, its length 10mm, diameter – 3.4 mm).

For creation of plasma the coaxial plasma gun was used which in an inner electrode has an aperture of diameter 20 mm through which the relativistic electron bunches passed into the chamber of interaction (Fig. 1). As a chamber was a glass pipe of diameter 10 cm and length 100 cm.

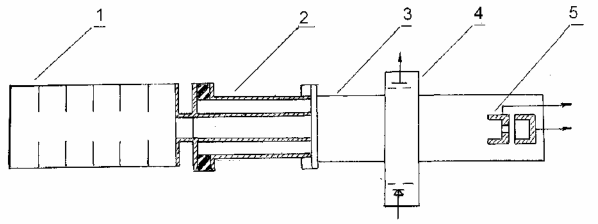

Fig. 1. Scheme of installation: 1 - electron accelerator; 2-plasma gun; 3 - interaction chamber; 4 - unit of probing beam; 5 - double Faraday cup

The density of plasma in the interaction chamber can be changed in limits from 10^{10} up to 10^{13} cm^{-3}. Change of plasma density over the length 50 cm is 10 %.

For measurement of wakefield intensity the probing electron beam of diameter 2 mm with energy 10 keV and a current up to 50 μA, passing across the interaction chamber (Fig. 2) was used.

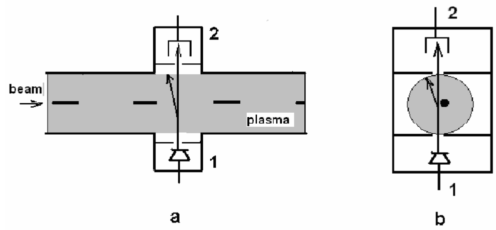

Fig. 2. Scheme of wakefield measurement: (a) of longitudinal component; (b) of transversal component; (1 - electron gun; 2 - Faraday cup)

After passage through the chamber the probing beam was registered by Faraday cup of diameter 10 mm before which the diaphragm with changeable diameter aperture was placed. Changing diameter of diaphragm aperture it is possible to estimate the value of deflection of the probing beam by wakefield judging by the fact of its passage the aperture of a diaphragm and hit on Faraday cup or its deposition on a diaphragm and probing beam current rejection. Basing on the measured value of probing beam deflection the wakefield intensity was determined.

The deflection of a probing beam in wakefield depends on size of aimed parameter (distance between axes of relativistic and probing beams [7]). For determination of aimed parameter the diagnostic system was made, one element of which was the thin metal string, located horizontally under a corner 45° to both directions of movement of driven relativistic beam (sequence of bunches) and probing beam (in the plane of both beams and a string at zero aimed parameter (Fig. 3).

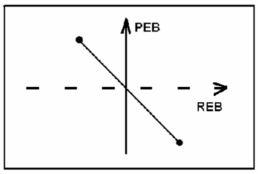

Fig. 3. Scheme of aimed parameter measuring

The string can be moved vertically in the vacuum chamber through sylphon by means of distantly controlled electromotor. With the help of vertically moving string it is possible to determine the position of beams in space, that is to determine the aimed parameter ρ, necessary for measurement of the maximal value in radial distribution of transversal component of excited wakefield. Movement of the probing beam for change of aimed parameter was carried out with the help of the focusing coil and the adjustors located at exit of the electron gun producing the probing beam.

3. EXPERIMENTAL RESULTS

The effect of focusing relativistic bunches at their passage through plasma was registered by double Faraday cup located after the interaction chamber. It consists of two consecutive cups; in the bottom of the first cup there was an aperture in diameter 3 mm through which the part of bunch electrons passed into the second cup (Fig. 4).

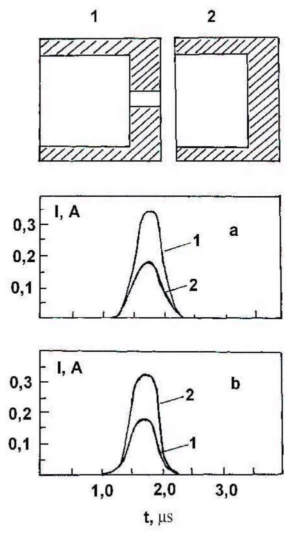

Fig. 4. Double Faraday cup and oscillograms of current of a sequence of relativistic electron bunch on the first cup (1) and on the second cup (2):(a) in vacuum; (b) with plasma in density $n_p = 5{\cdot}10^{11}$ cm^{-3}

Increase of bunch current on the second cup at plasma presence evidences the focusing effect. The maximal increase in a current at the second cup and corresponding current reduction on the first cup were observed at plasma density $n_p = 5{\cdot}10^{11}$ cm^{-3}, when frequency of bunches repetition coincides with plasma frequency ω_p, that is maximal wakefield was excited.

For measurement of intensity of excited wakefield with the help of the probing beam the calibration of probing beam deflection upon electric field intensity was carried out by means of deflecting plates in length 10 mm and distance between them equal 1 cm to which a pulsed voltage in 3 kV and by duration 0,5 µs, equal to pulse duration of a relativistic electron bunch. Plates, between which the probing beam passed, were placed in the region of wakefield excitation.

The oscillograms registering a signal caused by deflection of the probing beam are shown in Fig. 5.

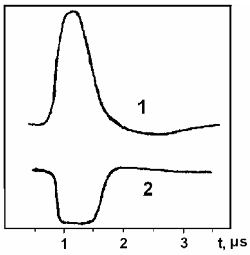

Fig. 5. Oscillograms: 1 - pulsed voltage on the plates; 2-pulse from rejected current of the deflected probing beam

Measurements have shown, that at intensity of field E =3 kV/cm the deflection of the probing beam was 0.3 cm. Results of measurement of probing beam deviation by wakefield are shown in Fig. 6. The maximal deflection when the the probing beam completely falls outside the limits of diaphragm aperture in diameter 2,5 mm, was observed at plasma density of $n_p = 5{\cdot}10^{11}$ cm^{-3} and at value of aimed parameter ρ = 4 mm (Fig. 6,c). Intensity of wakefield thus makes E = 2,5 kV/cm. The maximal amplitude of excited wakefield is observed at density of plasma when plasma frequency ω_p, is equal to frequency of repetition of relativistic electrons bunches. In this case all bunches coherently participate in wakefield build-up. At reduction or increase in plasma density the magnitude of probing beam deflection decreases (Fig. 6,b,d). The oscillogram in Fig. 6,e shows, that at increase in aimed parameter (ρ = 6 mm) the magnitude of probing beam deflection decreases, as one would expect [7].

The value of excited wakefield in experiment appeared on 30 % less, than predicted theoretically [7]. It is caused, apparently, by increase in diameter of relativistic bunches (up to 5 mm in the field of interaction) at their passage through a lavsan foil of 20 µm thickness which separates the accelerator from a plasma gun system.

As it was already marked, relativistic electron bunches are focused at passage through plasma, both by wakefield and self azimuthal magnetic field at neutralization of their space charge. Obviously, both focusing processes are also present in our case. However dependence of magnitude of probing beam deflection upon plasma density and observed maximal transversal wakefield in the case when frequency of bunches repetition is equal to plasma frequency, testifies to focusing relativistic electron bunches in our experiment mainly by transversal wakefield.

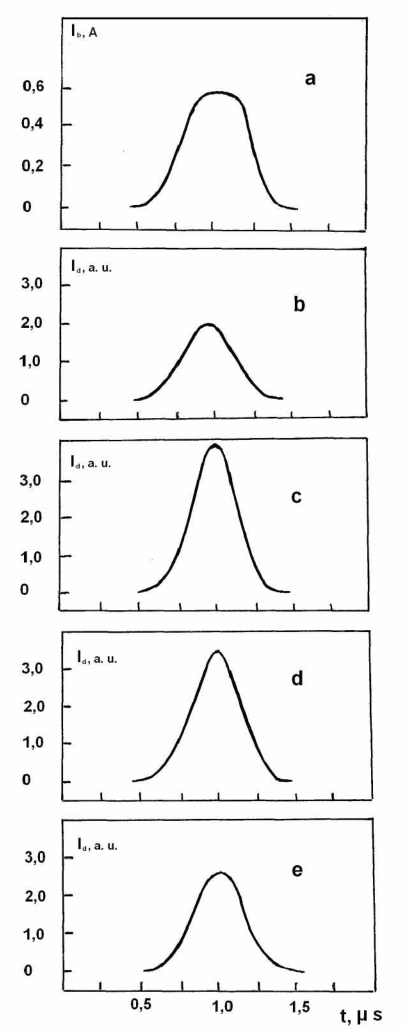

Fig. 6. Oscillograms: (a) impulse of a current of a relativistic electron bunches; (b, c, d, e) pulse of rejected current of the probing beam, (b) $n_p \approx 10^{12}$ cm^{-3}, ρ = 4 mm; (c) $n_p \approx 5{\cdot}10^{11}$ cm^{-3}, ρ = 4 mm; (d) $n_p \approx 10^{11}$ cm^{-3}, ρ = 4 mm; (e) $n_p \approx 10^{11}$ cm^{-3}, ρ = 6 mm

4. CONCLUSIONS

1. The effect of focusing of bunches of relativistic electrons with energy 14 MeV and number of electron in each bunch $2{\cdot}10^9$ is found out at their passage through plasma of density $10^{11}...10^{12}$ cm^{-3} in a case, when the ratio of radius of a bunch to its length is $\sigma_r/\sigma_z \ll 1$.
2. Measurement of value of a transversal component intensity of excited wakefield is carried out with the help of a probing electron beam and appeared equal 2,5 kV/cm
3. The maximal deflection of the probing beam observed at plasma density $n_p = 5{\cdot}10^{11}$ cm^{-3}, when frequency of bunches repetition is equal to plasma frequency ω_p, testifies to excitation in this case the maximal transversal wakefield.
4. Dependence of the magnitude of probing beam deflection upon aimed parameter ρ agreed with theoretical consideration [7].

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REFERENCES

1. Ja. B. Fainberg. The use of plasma waveguide as accelerator structures // *Proc. Symp. CERN.* 1956, v. 1, p. 84-92.
2. P. Chen, J. M. Dawson, R. W Huff, T. Katsouleas. Acceleration of electrons by the interaction of an electron beam with a plasma // *Phys. Rev. Lett.* 1985, v. 34, №7, p. 692-695.
3. M. G. Hogan, C. D. Barnes, C. E. Slayton, C. Jochi et. al. Multi GeV energy gain in a plasma wakefield accelerator. // *Phys. Rev. Lett.* 2005, v. 95, 054802-1-4.
4. T. Katsouleas, J.J. Su, W.B. Dawson, J.M. Dawson. Plasma Physics at the final focus of high-energy colliders. // *Phys. Fluids, B2.* 1990, p.1384 - 1390.
5. G. Hairapetian, P. Davis, T. Katsouleas et. al. Experimental demonstration of dynamic focusing of a relativistic electron bunch by on overdense plasma lens. // *Phys. Rev. Lett.* 1994, v. 72, №15, p. 2403-2408.
6. R. Keinigs, M. E. Jones, W. Gai. The Cerenkov Wake-field Accelerator // *Particle Acceleration.* 1989, v. 24, №4, p. 223-228.
7. V.A.Balakirev, Ja.B.Fainberg, V.A.Kiselev, et. al. Diagnostics of wakefields in plasma with use of a probing electron beam // *JTPh Letters.* 1996, v. 22, №17, p. 31-35.

ИЗМЕРЕНИЕ ПЛАЗМЕННЫХ КИЛЬВАТЕРНЫХ ПОЛЕЙ ЗОНДИРУЮЩИМ ЭЛЕКТРОННЫМ ПУЧКОМ

В.А. Киселев, А.Ф. Линник, И.Н. Онищенко, В.В. Усков

Описано устройство для измерения кильватерных полей, возбуждаемых в плазме последовательностью сгустков релятивистских электронов. Амплитуда поля определялась по отклонению зондирующего электронного пучка (10 кэВ, 50 мкА, с диаметром 1 мм), который инжектировался перпендикулярно по отношению к релятивистским сгусткам. Представлены результаты измерений фокусирующего радиального кильватерного поля, возбуждаемого в плазме с плотностью $5{\times}10^{11}$ $см^{-3}$ последовательностью игольчатых электронных сгустков (каждый сгусток имеет длину 10 мм, диаметр 1,5 мм, энергию 14 МэВ, $2{\times}10^9$ электронов в сгустке, количество сгустков – 1500). Измеренная амплитуда радиального кильватерного поля равна 2,5 кВ/см.

ВИМІРЮВАННЯ ПЛАЗМОВИХ КІЛЬВАТЕРНИХ ПОЛІВ ЗОНДУЮЧИМ ЕЛЕКТРОННИМ ПУЧКОМ

В.А. Кисельов, А.Ф. Лінник, І.М. Онищенко, В.В. Усков

Описано пристрій для вимірювання кільватерних полів, які збуджуються в плазмі послідовністю згустків релятивістських електронів. Амплітуда поля визначалася по відхиленню зондуючого електронного пучка (10 кеВ, 50 мкА, 1 мм в діаметрі), який інжектується перпендикулярно відносно релятивістських згустків. Представлені результати вимірювань фокусуючого радіального кільватерного поля, яке збуджується в плазмі з густиною $5{\times}10^{11}$ $см^{-3}$ послідовністю голкоподібних електронних згустків (кожен згусток має довжину 10 мм, діаметр 1.5 мм, енергію 14 МеВ, $2{\times}10^9$ електронів в згустці, кількість згустків - 1500). Згідно з вимірюваннями амплітуда радіального кільватерного поля становить 2,5 кВ/см.