WAKEFIELD EXCITATION IN PLASMA RESONATOR BY A SEQUENCE OF RELATIVISTIC ELECTRON BUNCHES

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Wakefield excitation in a plasma resonator by a sequence of relativistic electron bunches with the purpose to increase excited field amplitude in comparison to waveguide case is experimentally investigated. A sequence of short electron bunches is produced by the linear resonant accelerator. Plasma resonator is formed at the beam-plasma discharge in rectangular metal waveguide filled with gas and closed by metal foil at entrance and movable short-circuited plunger at exit. Measurements of wakefield amplitude are performed showing considerably higher wakefield amplitude for resonator case.

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1. INTRODUCTION

In our previous paper [1] we have reported the status of experimental installation for investigations of plasma resonator concept of plasma wakefield accelerator [2-4]. Besides plasma production by means of beam-plasma discharge was investigated and wakefield excitation only in semi-infinite plasma waveguide, i.e. without reflecting exit metal wall, was obtained and electron energy spectrum of interacting bunches was measured.

In the present work experiments on plasma wakefield excitation by a regular sequence of relativistic electron bunches in plasma resonator are described. Experimental installation is presented in which in contrast to the installation used in [1] cylindrical waveguide was changed by rectangular one and exit metal greed was replaced by movable short-circuited plunger.

2. EXPERIMENTAL SETUP

Experiments on the investigation of wakefield excitation in plasma resonator are carried out at the installation, which scheme is shown in Fig.1.

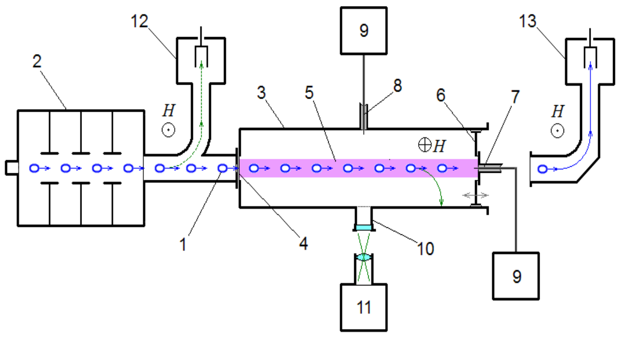

Fig. 1. Schematic of the installation:
1- electron bunches; 2- electron linac; 3- rectangular 10-cm waveguide; 4- Ti-foil; 5- plasma; 6– movable plunger; 7,8 - HF-probes; 9 - HF-oscillations register; 10 - optical window; 11 – spectrograph; 12,13 - magnetic analyzers

For wakefield excitation in plasma a train of bunches, which is produced by means of the linear resonant accelerator is used. Parameters of the beam: energy 4.5 MeV, pulsed current 0.5 A, pulse duration 2 µs, modulation frequency of the beam (bunch repetition frequency) 2805 MHz. Each pulse consists of a periodic sequence of $6\cdot10^3$ electron bunches. Bunch duration is 60 ps and time interval between bunches 300 ps. RMS parameters of each bunch are σ_z=1.7cm, σ_r=0.5cm, σ_θ= 0.05mrad, charge is 0.16nC.

Bunches of relativistic electrons (1) from the accelerator exit (2) are injected into metal resonator (3) through the entrance end-wall closed by a Ti-foil (4) of thickness 35 µm. Resonator is composed from 1-cm rectangular metallic waveguide of cross-section 72x34 mm^2 and length 25cm in entrance end-wall is Ti-foil and exit end-wall is movable short-circuited plunger (6). The length of the resonator can be done equal to divisible half-wavelength of eigen mode of frequency equaled to bunch repetition frequency. The end-walls hermetically closed the waveguide, that allows to change pressure of working gas in the resonator over a wide range (from 10^{-2} up to 760 Torr), at maintenance of high vacuum in accelerator sections. Electron bunches, propagating in working gas, ionize gas and create plasma (5) inside resonator. Several high-frequency probes (7, 8) are installed, which signals are fed the registering systems (9).

Intensity of wakefield excited in plasma is determined by optical methods of diagnostics, in particular measuring spectral lines widening (i.e. using Stark effect). The temperature and density of plasma is measured by integral intensity and the ratio of amplitudes of spectral components of optical radiation. For these purposes the window (10) serves which is hermetically closed by quartz glass and is intended for an output of optical radiation from plasma. To maintain high Q-quality of the resonator and to prevent HF-radiation removal an optical window is closed by a metal grid. The analysis of optical radiation is carried out by means of spectrograph (11) of type ISP-51 and the double optical converter.

Losses of electron beam energy are estimated by change of its energy spectra before its injection into plasma resonator and after passage of the plasma resonator. Energy spectra are measured by means of the magnetic analyzers (12,13) located at the accelerator exit and at the resonator exit. The current of electrons during energy spectrum measuring with magnetic analyzers was registered by Faraday cylinder.

3. EXPERIMENTAL RESULTS

Plasma is produced due to neutral gas ionization by means of electron bunches collisions and beam-plasma discharge. Plasma density n_p in these experiments was determined from its conductivity σ [5]. At high pressure of neutral gas and frequency of the applied field $\omega = 10^4$–$10^7\ s^{-1}$ this conductivity $\sigma = e\ n_p\mu_e$. The electron mobility μ_e at given density and temperature of neutral gas was determined under the tables [6]. The measurement accuracy of plasma density by such method is within the limits of 20 %.

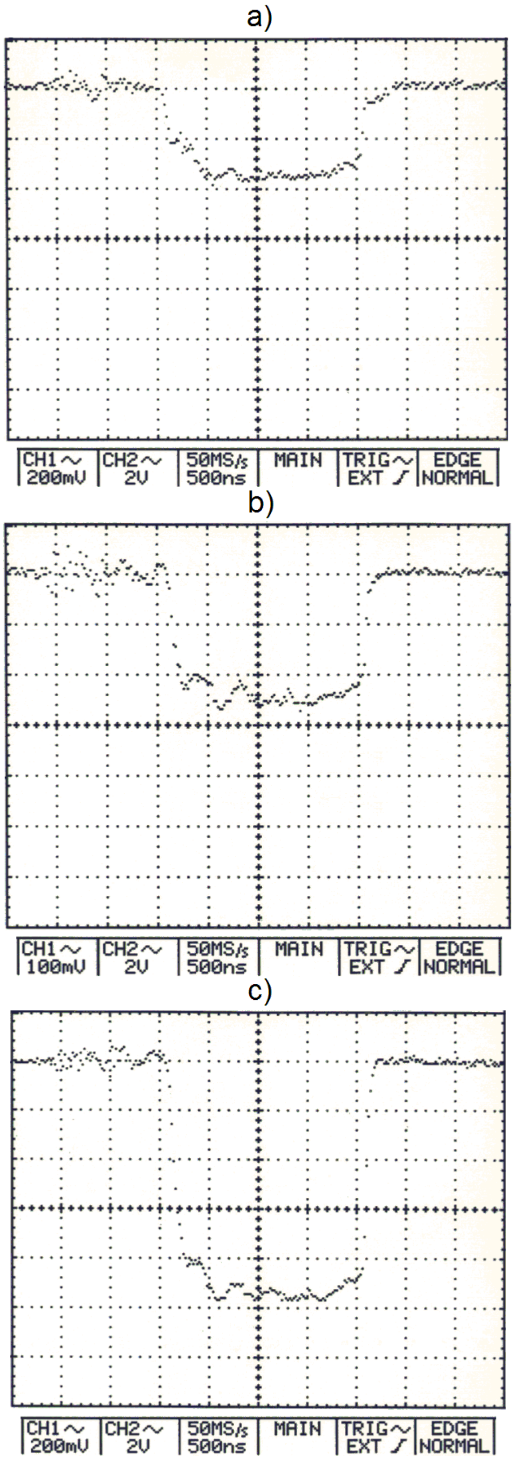

Fig.2. Oscillograms of: (a)-electron beam current, (b)-RF signal of wakefield for semi-infinite plasma waveguide, (c)-RF signal of wakefield for plasma resonator

The results of measurement of plasma density have shown, that in the region of intensive glow (0< l < 10 cm) the plasma is longitudinally uniform, and its density is $n_p \approx 5\times10^{11}\ cm^{-3}$, so the plasma frequency is equaled to frequency of the beam modulation ($\omega_p \approx \omega_M$). At larger distances from the exit (l > 10 cm) plasma density decreases, that is explained by decreasing of the current density of the beam due to its angular divergence and dissipation of the beam electrons during its interaction with plasma in a resonance region.

Excited wakefield measured by RF-probes for semi-infinite and resonator cases are shown in Fig. 2. In Fig. 2a waveform of electron beam macropulse of duration 2μs, containing 6000 bunches, is presented.

It is seen that in both cases (Fig 2b and Fig.2c) wakefield amplitude saturates rapidly, i.e. only a small number of bunches lose energy on amplitude growth. But for the resonator case (Fig.2c) time of amplitude growth much more comparatively to semi-infinite waveguide case (Fig 2b), therefore corresponding number of depositing bunches is considerably more. Accordingly wakefield amplitude for the resonator case is 4-5 times higher.

Note that relatively uniform plasma density is on the length only 10 cm. So the other part of resonator is filled with nonuniform plasma. In such situation transformation of plasma wave (i.e. plasma wakefield) into eigen electromagnetic wave and otherwise for the reflected wave. Because of this complicated picture the estimation of grope velocity, determining wakefield escaping in semi-infinite waveguide case and consequently basing resonator concept advantage becomes difficult.

Longitudinal distribution of wakefield E_z-component obtained by measuring amplitude of RF-signal at various z-position of movable plunger is shown in Fig.3.

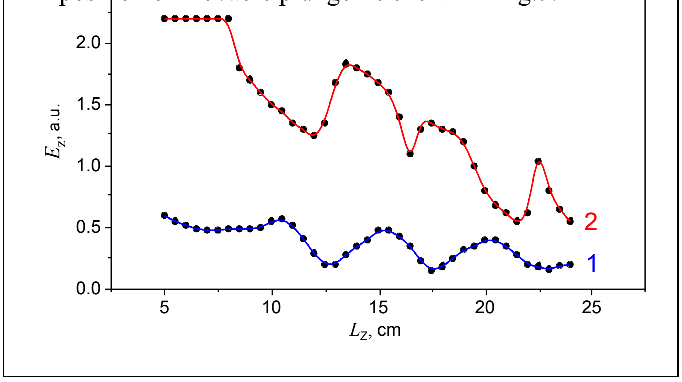

Fig.3. Longitudinal distribution of wakefield Ez –component: 1 – semi-infinite plasma waveguide, 2 – plasma resonator

The main conclusion, which can be maid from Fig.3, is 5 times wakefield exceeding for resonator case.

It can be marked for both cases, even for semi-infinite waveguide case, the oscillating behavior of wakefield distribution that is particular for resonator system. The latter can be caused by nonavoided field reflection in absence of the plunger.

4. CONCLUSIONS

A train of monoenergetic relativistic electron bunches (4.5MeV, 0.5A), produced by linear resonant electron accelerator, generates «resonant» plasma ($\omega p = \omega m$) along length 15cm in gas at atmosphere pressure, owing to collision ionization and beam-plasma discharge.

Use of plasma resonator allows to increase number of bunches, depositing in coherent excitation of plasma wakefield. 4.5 times wakefield amplitude increase in plasma resonator comparing to semi-infinite plasma waveguide is obtained that confirms appropriateness of resonator concept directed on using regular sequence of large quantity of bunches of a small charge instead of a single bunch of equivalent total charge.

Further increase of coherently depositing bunches is supposed to fulfill owing to improvement of resonator Q-quality at lower gas pressure and corresponding decrease of collisions with neutrals.

REFERENCES

1. V.A. Kiselev, A.F. Linnik, V.I. Mirny, I.N. Onishchenko, V.V. Uskov. Experiments on resonator concept of plasma wakefield accelerator driven by a train of relativistic electron bunches / *Problems of Atomic Science and Technology. Series: "Plasma Electronics and New Methods of Acceleration" (6).* 2008, N 4, p.73-76.
2. J.B. Rosenzweig et al. Experimental Observation of Plasma Wake-Field Acceleration // *Phys. Rev. Lett.* 1988, v.61, p.98.
3. A.K. Berezin et al. //*Fiz.Plazmy*. 1994, v. 20, p. 663; *Plasma Phys. Rep.* 1994, v. 20, p. 256.
4. R. Ischebeck. Energy Doubling of 42 GeV Electrons // *12th Advanced Accelerator Concepts Workshop; AIP Conf. Proc.*/ Melville New York, 2006, v. 877, p.3-7.
5. A.S. Fisher, R.H. Ronteel, J. Feinstein, T.L. Delonty // *J. Appl. Phys.* 1988, v. 64, N 2, p. 572-578.
6. L. Olsen // *Phys. Rev*. 1974, v. 9, N 12, p. 2631-2635.

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ВОЗБУЖДЕНИЕ КИЛЬВАТЕРНЫХ ПОЛЕЙ В ПЛАЗМЕННОМ РЕЗОНАТОРЕ ПОСЛЕДОВАТЕЛЬНОСТЬЮ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОННЫХ СГУСТКОВ

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Экспериментально исследуется возбуждение кильватерных полей последовательностью релятивистских электронных сгустков в плазменном резонаторе с целью увеличения амплитуды возбужденного поля по сравнению с волноводным случаем. Последовательность коротких электронных сгустков генерируется линейным резонансным ускорителем. Плазменный резонатор формируется при пучково-плазменном разряде в прямоугольном металлическом волноводе, заполненном газом и закрытым металлической фольгой на входе и подвижным короткозамкнутым плунжером на выходе. Выполнены измерения амплитуды кильватерного поля, показывающие значительно большие амплитуды для резонаторного случая.

ЗБУДЖЕННЯ КІЛЬВАТЕРНИХ ПОЛІВ В ПЛАЗМОВОМУ РЕЗОНАТОРІ ПОСЛІДОВНІСТЮ РЕЛЯТИВІСТСЬКИХ ЕЛЕКТРОННИХ ЗГУСТКІВ

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Експериментально досліджується збудження кільватерних полів послідовністю релятивістських електронних згустків у плазмовому резонаторі з метою збільшення амплітуди збудженого поля порівняно з хвилевідним випадком. Послідовність коротких електронних згустків генерується лінійним резонансним прискорювачем. Плазмовий резонатор формується при пучково-плазмовому розряді в прямокутному металевому хвилеводі, заповненим газом та закритим металевою фольгою на вході й рухомим короткозамкненим плунжером на виході. Виконані виміри амплітуди кільватерного поля, які показують значно більші амплітуди для резонаторного випадку.