EXPERIMENTS ON WAKE FIELD ACCELERATION IN PLASMA AND THE PROGRAM OF THE FURTHER WORKS IN YERPHI*

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Abstract

The use of wake field acceleration basically is aimed to obtaining of high acceleration rate in comparison with traditional methods of acceleration. Meantime in the last years in YerPhI it was offered to use wake field acceleration for acceleration of high-current electron bunches on energy about 100 MeV. Experimental installation for research of formation of high-current electron bunches of the given configuration, necessary for wake field acceleration and acceleration of these bunches in plasma is created. The installation is intended for acceleration of electron bunches with a current of few tens amperes and up to energy 1-2 MeV. For excitation of wake waves in plasma the electron accelerator of direct action with use of high-voltage pulse transformer is used. Results of researches have revealed some properties of formation of high-current bunches, especially restrictions of a electron current because of space charge effects at sub-picoseconds duration of bunches. The basic parameters of the wake field acceleration project on energy about 100 MeV are given, taking into account results of researches on experimental installation.

DEVELOPMENT OF THE PROJECT AND CREATION OF PILOT MODEL OF HIGH CURRENT ACCELERATOR USING WAKE FIELD IN PLASMA

The pilot model of a high current accelerator using wake field waves in plasma was developed. Pilot model consists of the accelerator - injector creating electronic bunch of a necessary configuration; of the plasma chamber for acceleration of the second bunch and from the monitoring system and measurement.

The accelerator - injector (photoelectron gun) is intended for production of double electron bunches with the following parameters:

- Energy of electrons up to 2 MeV
- Length of bunches 30-100 ps
- Distance between of bunches 5-20 cm
- Current in the first bunch up to 100 A
- Current in the second bunch up to 10 A

More widespread now RF electron guns [1-6] cannot provide a combination of two bunches with necessary parameters. In this respect more suitable accelerator of direct action, as in work [5]. However, in this installation the duration of accelerating voltage is about 2 nsec, what is not enough for formation of two bunches with controlled interval between them.

Proceeding from this, the accelerator of direct action with feed from a high-voltage pulse source of a microsecond range is chosen. The source is the air-core pulse transformer, placed in a metal tank with gas under pressure up to 10атм. The design of the pulse transformer is similar to designs of pulse transformers of accelerators of a series ELITE developed in Novosibirsk [7]. The scheme of the pulse transformer with accelerating tube is shown on Fig. 1. The accelerating tube is placed in the central part of the pulse transformer. The accelerating tube consists from 10 sections, between which disks for formation of electric field of a required configuration are located. Isolation rings of accelerating tube are made of organic glass. At choice of material of the photocathode the basic requirement was the opportunity of work of the cathode at bad vacuum, because the design of gun not allows to obtain vacuum better than 10^{-6} torr.

For the photocathode the alloy of magnesium with the small contents of zinc and aluminum is chosen. Investigations of a quantum yield of the photocathode for wavelength 255 nm of radiation from mercury lamp and for wavelength 337 nm of radiation of the nitric laser have shown, that the quantum yield make up 10^{-4} and 10^{-5} electrons per photon, accordingly. Diameter of the photocathode is 15 mm. We investigated the change of the quantum yield in the course of time for some metals at bad vacuum. These researches have shown that within a week the quantum yield decreases for the order.

For illumination of the photocathode and obtaining of a photocurrent up to 100 A the fourth harmonic of the Nd:YAG laser with unstable confocal resonator, working in regime of self-synchronization of modes is used. The resonator is formed from convex mirrors with radius of curvature 2 m with the 100 % reflection coefficient and of concave glass substrate with radius of curvature 4 m, used as an output mirror. As the sating filter the solution of dye №3274 in dichloroethane is used. The initial infiltration of filter is 30 %. For volume of the active medium equal ~ 5 mm, the energy of ultrashort pulses of the first harmonic is ~100 mJ, the energy of maximal pulses is ~20 mJ and duration of pulses is ~40 psec. To obtain the second and fourth harmonic the nonlinear optical crystals KDP are used. A quartz prism carries out separation of these harmonics on exit of the laser. For time synchronization of a laser pulse and starting of the accelerator of electron bunches actively - passive modulation of Q-factor of laser is used, i.e. except for the sating filter; the Pockels cell is also used. The scheme of laser set-up is shown on Fig. 2. The system of formation of a microstructure of laser pulses (formation of double bunches with the given parameters) is analogously to interferometer of Michelson

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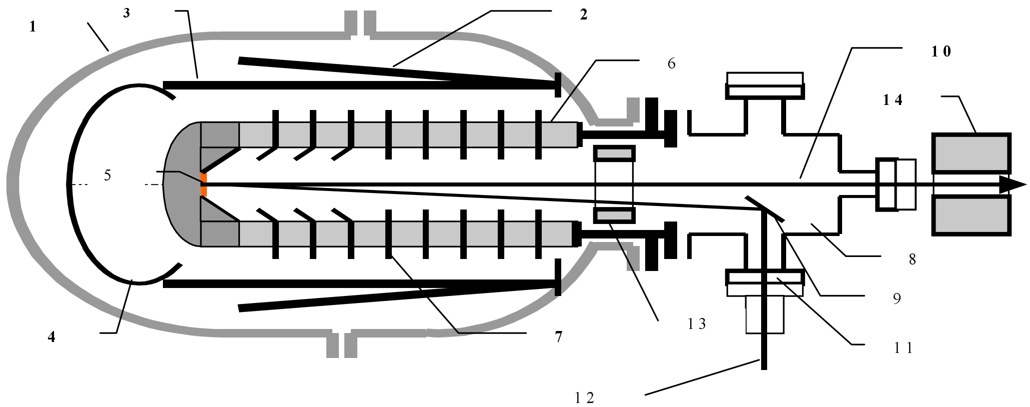

Figure 1: Schematic shape of the accelerator of electron bunchs with photocathode. 1 - tank for gas, 2 - primary winding of the pulse transformer, 3 - secondary winding of the pulse transformer, 4 - high-voltage electrode, 5 - photocathode, 6 - isolation rings of accelerating tube, 7 - electrodes of accelerating tube, 8 - vacuum chamber, 9 - mirror, 10 - electron beam, 11 - vacuum tube, 12- laser beam. 13- magnetic focusing lens, 14 - electromagnetic focusing lens.

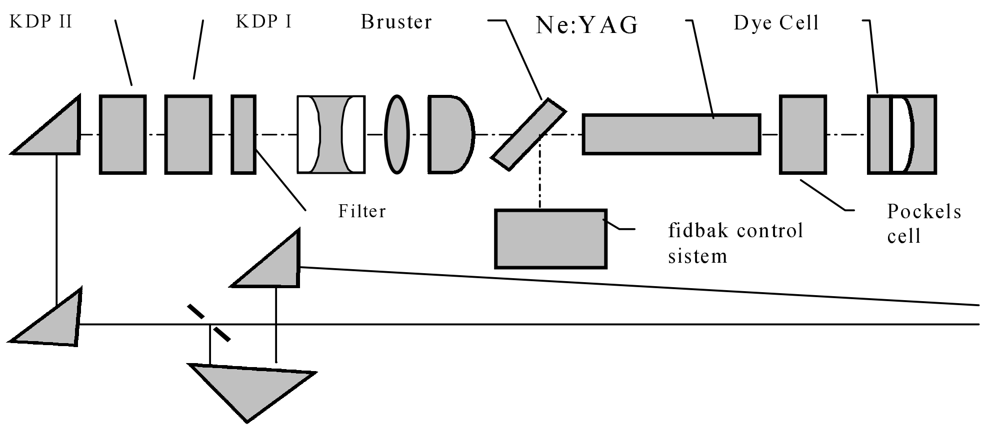

Figure 2: The scheme of laser set-up.

(see Fig2). The amplitude of current or the value of charge in the second bunch is adjusted by choice of reflection factor of half-transmitting mirror, and the distance between bunches is established by shift of a rotary prism.

The parameters of plasma chamber developed and created within the framework of the project ISTC A-013-96, basically meet the requirements of this project. Thus, key parameters of the plasma chamber are

Duration of the discharge	10μs
Pulse current in the discharge	1kA
Power supply voltage	10kV
Chamber gas pressure	0,1Torr
Plasma density	$5\cdot 10^{11}$ cm^{-3}
Length of the plasma chamber	150 cm
Cross-section section of a plasma column	20 cm^2

The density of plasma is defined by discharge regime measurements in the plasma chamber as well as by microwave diagnostics.

Measurement of all physical values of electron beam at each start of the installation and the continuous control of all the technological parameters of the installation is carried out by systems of control and monitoring, based on interaction of client – server. Basically it is three-level model of interaction. The system DOOCS (Distributed Object Oriented Control System) developed in DESY for applications HERA and TTF (TESLA Test Facility) is used as the software [8].

Preliminary researches of operating regimes were carried out by electron beam with comparatively low energy. At energy of electron beam 0.5 MeV, the charge in a bunch reaches up to 2 nC, what corresponds to current of beam about 40 A. Since the quantum yield of the photocathode during this time can decrease considerably and the current does not vary, we can assume that at the given intensity of field the electron current is limited to value of a surface charge of the cathode, but not value of quantum yield or intensity of laser beam. Such dependence it was observed also in

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paper [6]. At diameter of the cathode of 1.5 cm and accelerating voltage 500 kV, the surface charge on the cathode is about 2.2 nC, what well coincides with the measured value of charge in electron bunch. Results of calculation of distribution of electric field

Results of calculation of distribution of electric field and trajectory of electrons coincide with results of measurement of beam section on the exit of photoelectron gun. The beam is enough well formed and on the exit of accelerator has diameter equal 7 mm.

The obtained values of the amplitudes of the wake field waves and the energy gain of the second bunch agree with estimated values.

At a current in the first bunch from 10 up to 100A the acceleration rate is 0.7 kV/cm - 7kV/cm. At active length of 60 cm of the plasma chamber the expected gain of energy is from 42 keV up to 0,4 MeV.

The energy gain of the second bunch was measured as follows. An aluminum foil was placed in front of the bunch detector in the absence of plasma, and the thickness of the foil was chosen so that the signal from the detector disappeared. When the plasma was switched on the signal from the detector appeared. Thickness of a foil was increased so that the signal disappeared again. The measured additional thickness of an aluminum foil was about 0.3 mm, which corresponds to a gain of energy about 120 keV. The accuracy of such measurement cannot be better, than 30%. We will continue the researches of the acceleration processes to reach more detailed and more qualitative results.

DEVELOPMENT AND INVESTIGATION OF THE 100 MeV HIGH CURRENT ACCELERATOR USING WAKE FIELD IN PLASMA

Creation of high current electron accelerating installations for energies about 100 MeV and higher is very actual problem. However, the acceleration of high current electron bunches is problematic enough since the final energy of electrons is determined by the energy of injection.

In the process of excitation of the wake waves in plasma a certain part of the electrons of the first bunch loses energy. The field transformation ratio in the wake field wave is equal to 2. If we allow the energy of the particles in the rear part of the first bunch be reduced to zero, the second bunch can be accelerated to energy $2\gamma_{inj}$. This means that when the energy of the particles of the second bunch increases, the first bunch loses some of its rear electrons and thus becomes shorter. This results in a gradual decrease of the amplitude of the wake field wave.

Higher values of the transformation ratio can be obtained for values $n_b/n_0>1$, i.e. in the case of nonlinear excitation of the wake field waves. In that case the transformation ratio is equal to $(\gamma_{inj} - 1)$ and to achieve a final energy of 100 MeV one must have injection energy higher than 10-15 MeV. For high current direct action accelerators such energies are hard to achieve.

Here we suggest an original method of excitation of wake field waves in plasma by a sequence of bunches. In that case the braking field will reach the maximum value only on the last bunches, while other bunches, being in the relatively weak braking fields, will “work” longer.

Within this proposal we plan to develop a work plan and create the prototype of the high current electron accelerator using wake field waves in plasma. After the analysis of different variants the following bunch combination was chosen for achieving the exit energy of 50 - 100 MeV:

- The number of exciting bunches 10
- The distance between bunches λ_p
- The length of the exciting bunches $\lambda_p/4$ - $\lambda_p/2$
- The charge of a single bunch 10 nC
- The number of accelerated bunches 1
- The length of the accelerated bunch $< \lambda_p/4$
- The charge of the accelerated bunch 10 nC
- The distance between the accelerated and exciting bunches 1,5 λ_p
- The length of the plasma chamber 200cm

Note that the acceleration rate changes along the length of the accelerator by an order, achieving the highest value at the start of the acceleration.

The main stages of the project realization will be:

- The development of the work plan of the high current (up to 100A in a pulse) electron accelerator for energies 50-100MeV using the wake field waves in plasma.
- The experimental testing and approving of different systems and elements of the high current accelerator.
- The production of the prototype of the accelerator and investigation of the acceleration process of the high current bunch.
- The optimization of the parameters of the experimental setup and accomplishment of the bunch energy of 50-100 MeV.

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