THE EXPERIMENTAL STAND FOR RESEARCH OF WAKEFIELD METHOD OF CHARGED PARTICLES ACCELERATION

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The experimental installation and diagnostic equipment with motivation to use for various researches of wakefield method of charged particles acceleration both in plasma and in dielectric structure has been described. The main parameters of a sequence of short relativistic electron bunch and values of physical characteristics of slow-down structures have been presented.

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1. INTRODUCTION

Experimental installation «Almaz-2» is intended for research of excitation of wakefield by a sequence of short bunches of relativistic electrons in plasma created by an external source [1] or by bunch sequence at its injection into neutral gas and/or dielectric structure [2]. In particular, while studying a dielectric structure of round cross-section the consideration of important problems of wakefield excitation for the cases of semi-infinite waveguide, as well as a resonator concept is supposed. As follows from a theory, for semi-infinite waveguide a number of bunches, whose wakefields are composed coherently, occurs to be restricted by carrying out excited wakefields from the system with group velocity [3]. For an increase in the number of coherent bunches it is proposed to use the resonator instead of semi-infinite waveguide. In this approach the excited wakefield is composed by all bunches at fulfillment of two conditions: (i) a multimode operation should be realized, i.e. the length of the resonator should be a multiple of half-integer wave lengths of the resonant fundamental mode, (ii) a coherent composing of wakefields from injected bunches should be provided, i.e. the coincidence of the frequency of the fundamental mode and the frequency of bunch repetition should be fulfilled.

2. EXPERIMENTAL INSTALLATION

The scheme of the experimental stand is shown in Fig.1.

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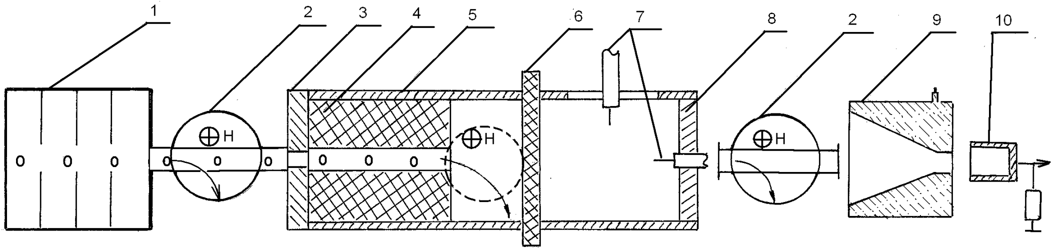

Fig.1. Schematic of experimental installation: 1-linac; 2 - magnetic analyzer; 3 - aperture; 4 - dielectric; 5 - copper tube; 6 - teflon plate; 7 - HF probes; 8 - movable metal screen; 9 - calorimeter; 10 - Faraday cup

An electron beam (a sequence of short bunches) was produced by the linear resonant electron accelerator (1) with the following parameters: energy – 4.5 MeV, current in an impulse – 0.5 A, duration of an impulse – 2 μs, frequency of modulation of E-beam (bunch repetition) – 2808 MHz. E-beam represents itself as a sequence of N =$6\cdot10^3$ bunches each of duration 60 ps and a time interval between them 300 ps. Bunch diameter at the exit of the accelerator was determined from darkening of glass plate and was equal 1 cm.

For determination of dependence of amplitude of excited wakefield upon number of bunches, the duration of impulse of E-beam current was changed by time delay of the HF-impulse of the master oscillator of the klystron feeding the linac, with respect to the high voltage pulse applied to the klystron. Thus, it is possible to obtain E-beam with duration of impulse from 2.0 μs up to 0.2 μs, i.e. the number of bunches was changed within the limits from $6\ 10^2$ up to $6\cdot10^3$.

Such sequence of bunches is injected into the dielectric structure (4), which is made from teflon F-4 ($\varepsilon = 2.1$; tg $\delta=1.5\cdot10^{-4}$ at repetition frequency $f_{rep} = 3\cdot10^9$ Hz). The maximal length of dielectric structure 70 cm, external diameter – 8.6 cm, diameter of an internal aperture for bunch passage – 2.2 cm. The dielectric was placed in a copper pipe of length 100 cm (5). Before the dielectric there was a copper diaphragm of thickness 5 mm with an aperture 2 cm (3).

For research of dependence of amplitude of excited wakefield upon length of dielectric the dielectric structure was composed from pieces to have length from 5 cm up to 70 cm. The dielectric structure consisted from separate teflon cylinders each in length from 5 to 10 cm.

3. DIAGNOSTIC EQUIMENT

For studies into the excited microwave wakefields topography, the microwaves were output through the teflon plate (6) by thickness of 8 mm, which separated a vacuum volume with the dielectric structure from atmosphere. Preliminary experiments have shown that losses of the HF-power of wavelength of λ=10.7 cm after passage of such teflon plate make no more than 2%.

For creation of an external resonator an additional pipe of the same diameter, as the main one, but located on other side of teflon plate, was used. In this pipe there were available a longitudinal slit, in which the HF-probe (7) could move along a pipe, and the metal blind flange (8) by which moving it was possible to change the length of the resonator. In the center of the blind flange there was a HF-probe for measuring E_z component of the excited wakefield. For measurement of amplitude of the fundamental harmonic of excited wakefield, a signal from the probes proceeded along a coaxial cable (the probe was a continuation of the central thread of this cable) to an adjustable attenuator and the resonator which has been adjusted at the frequency of the fundamental harmonic. The signal from the resonator by means of a detector unit with the diode DK-I2M proceeded to oscillograph. Preliminary calibration of the detector has shown, that in a working range of the rectified current (0.04…3 mA) volt-ampere characteristics has linear dependence on strength of HF-wakefield.

In the dielectric structure of similar type waves of type E_{on} are excited, wavelength of which is less than critical for the given waveguide. The knowledge of amplitudes of various harmonics and determination of types of waves is important both from the point of view of studying the dielectric structure operation and as a method of diagnostics of the longitudinal sizes of exciting electron bunches [4].

For an experimental research of multimode regime of dielectric structure excitation it is possible to use waveguides in cut-off regime [5]. At the experimental stand two additional round waveguides with radii 2.7 cm and 1.55 cm which are append to the main waveguide by means of conical transition (Fig.2) are used.

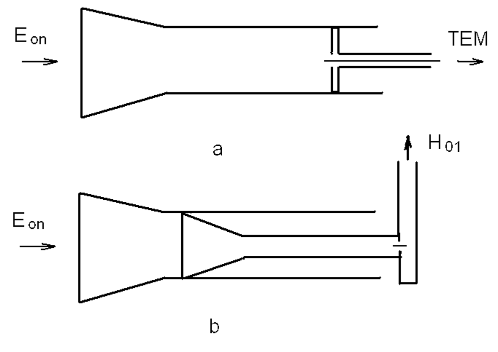

Fig.2. The scheme of conical transition: a – to waveguide with R=2.7 cm; b – to waveguide with R=1.55 cm

In Table 1 critical lengths of waves for waves of type $E_{01} – E_{05}$ in these waveguides are presented.

The knowledge of the critical wavelength allows calculating types of waves which can propagate in waveguides at various frequencies. In Table 2 types of waves which can exist in waveguides for the first five types of waves are presented. Lengths of waves of various harmonics are calculated theoretically.

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Table 1. *Critical wavelength (λ_{cr}, cm)*

Type of waves	R = 4.33 cm with dielectric	R = 4.33 cm	R = 2.7 cm	R = 1.55 cm
E_{01}	16.45	11.34	7.07	4.06
E_{02}	7.16	4.94	3.08	1.77
E_{03}	4.56	3.1	1.94	1.12
E_{04}	3.35	2.3	1.44	0.82
E_{05}	2.56	1.77	1.1	0.63

Table 2. *Types of excited waves*

Frequency (GHz) R waveguide (cm)	2.82	6.57	10.64	14.85	19.1
4.33 with dielectric	E_{01}	E_{01}; E_{02}	E_{01}; E_{02}; E_{03};E_{04}	E_{01};E_{02};E_{03}; E_{04}; E_{05}	E_{01};E_{02};E_{03}; E_{04}; E_{05}; E_{06}
4.33	E_{01}	E_{01}; E_{02}	E_{01}; E_{02}; E_{03}	E_{01};E_{02};E_{03}; E_{04}	E_{01};E_{02};E_{03}; E_{04}; E_{05}
2.7	-	E_{01}	E_{01}; E_{02}	E_{01}; E_{02}	E_{01}; E_{02}; E_{03}
1.55	-	-	E_{01}	E_{01}	E_{01}; E_{02}

Energy losses of an electron bunch at its interaction with a structure are measured by the magnetic analyzers (2) located at the accelerator exit and behind the dielectric structure. The diaphragm with a slit before an entrance to the second analyzer formed a resonant system, so for realizing semi-infinite waveguide approach the diaphragm was covered by an absorber of microwave radiation. Besides, the energy spectra of electron bunch and its transversal size can be investigated when obtaining darkening trace of the bunch on a glass plate after its declining in a constant magnetic field and passage through the copper pipe wall of thickness 1mm. The transversal size of the bunch and transversal distribution of electron density can be investigated by a movable sectioned cylinder.

Measurements of the overall energy of excited wakefields can be carried out by means of a calorimeter (9) which design is shown in Fig.3. The measured energy of excited wakefields is within the range of 0.05J… 6 кJ, the coefficient of absorption of energy of excited wakefields is not below 0.9 within the frequency range 3...60 GHz. The main peculiarity of the given calorimeter is a ferroceramic sensor for measuring an increase in working liquid volume.

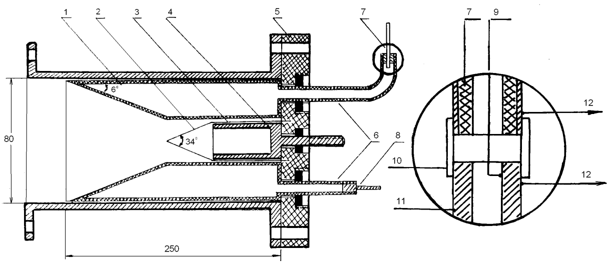

Fig.3. Scheme of a sensitive calorimeter. 1 - absorbing section; 2 – reflecting cone; 3 – connecting pipe from a stainless steel; 4 – Faraday cap; 5 – ebonite flange; 6 – glass branch tubes; 7 – ferroceramic tube; 8 - piston for regulation of water level; 9 – copper conductor; 10 – connecting dielectric tube; 11 – copper tube; 12 – to device for capacity measuring

As the relation between the absorbed energy W, the increase of temperature ΔT and the increase in working liquid volume ΔV is linear, ΔV does not depend on the initial volume of working liquid and distribution of energy over its volume [6]. The volume change of a working liquid at small W is of value $\Delta V=\alpha_0 W/\rho_0 C_0$, where α_0 – the coefficient of linear expansion, ρ_0 – the density, and C_0 – the thermal capacity of liquid at initial temperature.

The determination of increase in the liquid volume was done by a sensor which basic element is a ferroceramic tube with an internal diameter 1.8 mm and working length 11mm. The increase in volume is transformed into the increase in length of working liquid column. The tube was taken from ferroceramic condenser KT-1. Conducting covering on its internal surface was carefully etched.

The liquid column length (distilled water with admixture NaCl) was determined by a value of the capacity formed by the liquid column and conducting covering on the external surface of tube. As ferroceramic has a great value of dielectric permeability (e.g. ε=3100), the change of capacity, determined by $\Delta C=2\pi\varepsilon\varepsilon_0\Delta l/ln(b/a)$ where $\Delta l=\Delta V/\pi a^2$ – change of length of liquid column in tube, b – the external diameter of tube, and the capacitive sensitivity of the sensor makes significant value $\Delta C/\Delta l \approx 620$ pF/mm.

The energy sensitivity of the sensor is $\Delta C/\Delta W \approx 14.6$ pF/J. Minimal registered energy is determined by minimal measured change of capacity. At relative error of capacity measurement 0.5 pF (for some industrial measuring instruments) the minimal registered energy makes $W_{min}<0.05$ J. Having used the bridge scheme for capacity measurement, the minimal registered energy can be easily lowered up to value less than 0.01J.

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ЭКСПЕРИМЕНТАЛЬНЫЙ СТЕНД ДЛЯ ИССЛЕДОВАНИЯ КИЛЬВАТЕРНОГО МЕТОДА УСКОРЕНИЯ ЗАРЯЖЕННЫХ ЧАСТИЦ

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Приведено описание экспериментальной установки и диагностического оборудования с мотивацией использования при различного рода исследований кильватерного метода ускорения заряженных частиц как в плазме, так и в диэлектрических структурах. Представлены основные параметры последовательности коротких релятивистских электронных сгустков и величины физических характеристик замедляющих структур.

ЕКСПЕРИМЕНТАЛЬНИЙ СТЕНД ДЛЯ ДОСЛІДЖЕННЯ КІЛЬВАТЕРНОГО МЕТОДУ ПРИСКОРЕННЯ ЗАРЯДЖЕНИХ ЧАСТОК

В.О. Кисельов, А.Ф. Лінник, І.М. Оніщенко, М.І. Оніщенко, Г.В. Сотніков, В.В. Усков

Приведено опис експериментальної установки та діагностичного приладдя з мотивацією використання при різного роду дослідженнях кільватерного методу прискорення заряджених часток як у плазмі, так і в діелектричних структурах. Представлені основні параметри послідовності коротких релятивістських електронних згустків і величини фізичних характеристик уповільнюючих структур.