ACCELERATION OF ELECTRONS AT WAKEFIELD EXCITATION BY A SEQUENCE OF RELATIVISTIC ELECTRON BUNCHES IN DIELECTRIC RESONATOR

V.A. Kiselev, A.F. Linnik, V.I. Mirnyj, I.N. Onishchenko, V.V. Uskov

NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine,
E-mail: onish@kipt.kharkov.ua

Method is proposed to divide a regular sequence of electron bunches into parts of bunches driving wakefield and witness bunches, which should be accelerated. It allows to avoid the necessity of additional electron accelerator for witness bunches producing and the necessity of precision short time techniques of injection phase adjusting. The idea concludes to the frequency detuning between bunches repetition frequency and the frequency of the fundamental mode of excited wakefield. Experiments were carried out on the linear resonant accelerator "Almaz-2", which injected in the dielectric resonator a sequence of 6000 short bunches of relativistic electrons with energy 4.5MeV, charge 0.16 nC and duration 60psec each, the repetition interval 360 ps. Frequency detuning was entered by change of frequency of the master generator of the klystron within the limits of one percent so that the phase taper on the length of bunches sequence achieved 2π. Energy spectra of electrons of bunches sequence, which have been propagated through the dielectric resonator are measured and analyzed.

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1. INTRODUCTION

Experiments on electrons acceleration by wakefield excited in plasma or dielectric by a single relativistic electron bunch or by a sequence of such bunches are supposed the availability of witness bunch injected into accelerating phase of wakefield. For general two-beam concept the witness bunch is produced separately from the driving bunch that needs an additional accelerator. In [1] witness bunch was extracted from the train and was time-delayed at its transportation by another path using magnets "trombone". This scheme requires high precise short time technique. In recent outstanding experiment at SLAC on energy doubling of the intense bunch at plasma wakefield acceleration [2]. In this case due to the strong nonlinear interaction of the large charge bunch with plasma, selfconsistently, the head of the bunch is the driver and its tail is the witness. In multi-bunch concept both for plasma wakefield acceleration [3] and for dielectric wakefield acceleration [4] the problem is how to force one or several bunches from the train became the witness by a simple way, i.e. to obtain accelerated bunches against a background of driving bunches.

2. EXPERIMENTAL INSTALLATION

The scheme of the installation is presented in Fig.1. For producing the sequence of relativistic electron bunches resonant linear electron accelerator "Almaz-2" was used. Relativistic electron beam of energy 4.5 MeV is a repetition (frequency 2Hz) of macroimpulses (duration 2 μs, pulsed current 0.5 A, each of them contains $6\cdot10^3$ electron bunches each of 60 ps duration and time interval between them 300 ps. Repetition frequency of bunches can be changed by a variation of frequency f_m of the master generator of the klystron, feeding the accelerator, within the limits of from 2799 MHz up to 2804 MHz. It allows changing the phase of bunches injection in excited wakefield from 0 up to 2 p depending on their location inside macroimpulse. Appearance under this procedure the change of electron energy spectrum width within the limits of from 8 up to 22 % does not break the condition of smallness of bunch length in comparison with length of excited wave and consequently does not lead to hit of a part of electrons of each bunch into accelerating phase.

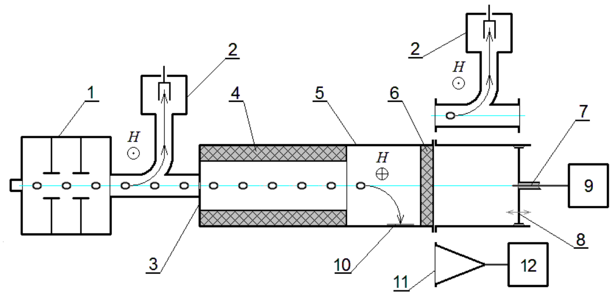

Fig.1. Scheme of the experimental installation: 1 – electron accelerator, 2 – magnetic analyzer, 3- aperture, 4 – dielectric plates, 5 – rectangular cupper waveguide, 6 – Teflon plug, 7 – RF-probe, 8 – short-circuiting plunger, 9 – horn antenna, 10 – power measuring instrument

The sequence of bunches was injected into dielectric resonator representing a rectangular metal wave guide of cross-section 85mm×180mm with metal end faces, in which close to wide walls dielectric plates (Teflon; $\varepsilon = 2.1$; $tg\delta = 1.5\cdot10^{-4}$) were installed, forming vacuum channel of cross-section 52 × 180 mm for bunches propagation. By means of the RF-probes the longitudinal component E_z of excited wakefield was registered. Electron energy spectra were determined by magnetic analyzer and by analyzing the prints of bunches obtained on a glass plate after their passage through the resonator and subsequent deflection of them in a transversal magnetic field in the plane parallel to the dielectric plates.

3. EXPERIMENTAL RESULTS

3.1. COINCIDANCE OF FREQUENCIES $f_0=f_m$

At coincidence of the resonator eigen frequency f_0 and the frequency of following of bunches (repetition rate), which is equal to modulation frequency f_m, i.e. $f_0 = f_m$, all bunches appear in a decelerating phase of an excited wave and lose their energy, increasing the amplitude of excited wakefield during the whole macroimpulse.

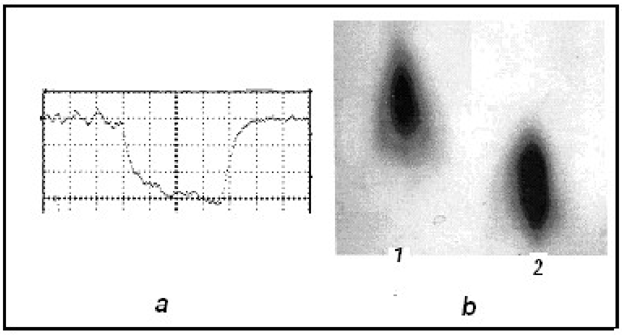

Fig. 2. Oscillogram of E_z - component of excited wakefield for the case $f_0 = f_m$ (a). Prints of bunches deflected in magnetic field after their passage through: 1- empty resonator, 2 - dielectric resonator (b)

It is demonstrated by the oscillogram of a signal, taken from the RF-probe, measuring E_z –component of wakefield, and presented in Fig. 2a. Signal of E_z grows during the whole macroimpulse duration.

Correspondingly to the considered case electron energy spectra of the bunches which have passed through the resonator without dielectric (1) and at presence of dielectric plates (2) are shown in Fig. 2b. From Fig. 2b it is visible, that, all bunches after passage through dielectric resonator lose their energy and they as a whole are displaced to the smaller energy region.

3.2. SMALL DETUNING $\Delta f = f_0 - f_m$ = 0.5 MHz

At a small increase of detuning $\Delta f = f_0 - f_m > 0$ the beam-resonator interaction becomes more complicated. In this case the forward part of bunches from the sequence loses energy on wakefield excitation and the second part of them is occurred in accelerating phase because of the greater period of bunches repetition than the period of the excited field.

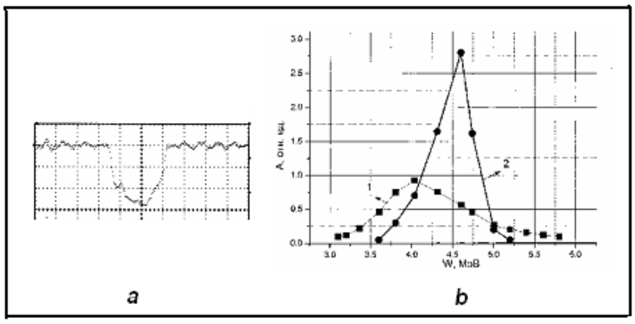

Fig. 3. Oscillogram of E_z - component of excited wakefield for the case $\Delta f = f_0 - f_m$ = 0.5 MHz (a). Electron energy spectra of bunches after passage through: 1 - empty resonator, 2 - dielectric resonator (b)

The oscillogram of the RF-signal, presented in Fig. 3a for Δf = 0.5 MHz, growth of amplitude of wakefield during passage of bunches losing energy and amplitude decrease during time of second part of bunches acceleration is observed.

Accordingly, in this case electron energy spectrum of passed bunches measured by magnetic analyzer becomes wider comparing to initial electron energy spectrum of injected bunches (Fig. 3b (1)) and contains not only decelerated electrons, as it is observed in the first case, but accelerated electrons too (Fig. 3b (2)).

3.3. LARGER DETUNING $\Delta f = f_0 - f_m$ = 1 MHz

For further increasing frequency detuning Δf it is possible to change an amount of bunches from the sequence, which excite wakefield, and an amount of bunches, which are accelerated in excited field. Moreover the sequence can be broken into several parts of exciting (driving) and accelerated (witness) bunches.

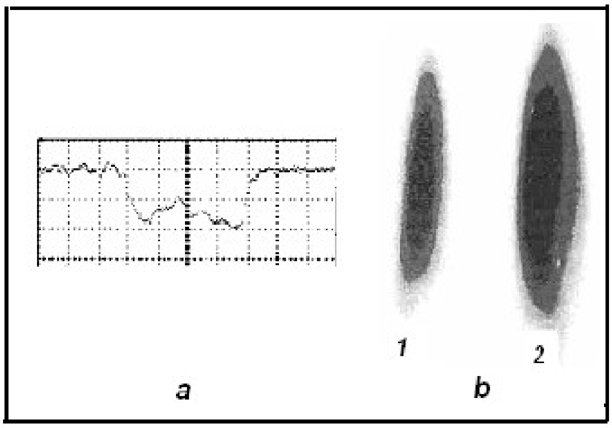

Fig. 4. Oscillogram of E_z - component of excited wakefield for the case $f_0 - f_m$ = 1MHz (a). Prints of bunches deflected in magnetic field after their passage through: 1 - empty resonator, 2 - dielectric resonator (b)

Indeed, at large enough detuning (e.g. see Fig. 4 for $\Delta f = f_0 - f_m$ = 1 MHz) the mode is realized when bunches of the first part of the sequence excite wakefield, bunches of the second part are accelerated, bunches of the third part again excite wakefield, bunches of the forth part are accelerated in the field excited by bunches of the third part. Respectively the RF-signal (see the oscillogram rice Fig. 3a) shows twice repeating growth and decrease of wakefield.

Accordingly to such behavior of excited field electron energy spectrum is widening both in low energy region and in higher energy region, higher the initial energy of the electrons (Fig. 4b (2)).

4. SUMMARY

Thus, it is experimentally shown, that usage of detuning between eigen frequency of the dielectric resonator and frequency of bunches sequence (repetition rate) allows to obtain from the same sequence of the bunches both the driving bunches which are exciting wakefield and the bunches which are being accelerated. This method simplifies researches of the two-beam wakefield accelerator concept since it does not require injection of witness bunch(es), produced by additional accelerator, and avoid the severe problem of adjusting witness injection into accelerating phase in such very short pulsed systems.

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УСКОРЕНИЕ ЭЛЕКТРОНОВ ПРИ ВОЗБУЖДЕНИИ КИЛЬВАТЕРНЫХ ПОЛЕЙ ПОСЛЕДОВАТЕЛЬНОСТЬЮ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОННЫХ СГУСТКОВ В ДИЭЛЕКТРИЧЕСКИХ РЕЗОНАТОРАХ

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

Предложен метод разделения регулярной последовательности электронных сгустков на сгустки, возбуждающие кильватерное поле, и сгустки-свидетели, которые должны ускоряться. Это позволяет избежать необходимости в дополнительном ускорителе для получения сгустков-свидетелей и прецизионной коротко-импульсной техники для выбора фазы инжекции. Идея сводится к введению расстройки между частотой следования сгустков и частотой основной моды возбуждаемого кильватерного поля. Эксперименты проводились на линейном резонансном ускорителе «Алмаз-2», который инжектировал в диэлектрический резонатор последовательность 6000 коротких сгустков релятивистских электронов с энергией 4.5МэВ, зарядом 0.16 нКл и длительностью каждого 60 пс, время повторения 360 пс. Расстройка частоты вводилась изменением частоты задающего генератора клистрона в пределах одного процента, так что набег фазы на длине последовательности сгустков достигал 2π. Измерялись и анализировались энергетические спектры электронов последовательности сгустков, прошедших через диэлектрический резонатор.

ПРИСКОРЕННЯ ЕЛЕКТРОНІВ ПРИ ЗБУДЖЕННІ КІЛЬВАТЕРНИХ ПОЛІВ ПОСЛІДОВНІСТЮ РЕЛЯТИВІСТСЬКИХ ЕЛЕКТРОННИХ ЗГУСТКІВ В ДІЕЛЕКТРИЧНИХ РЕЗОНАТОРАХ

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

Запропоновано метод поділення регулярної послідовності електронних згустків на згустки, що збуджують кільватерне поле і згустки-свідки, які повинні прискорюватися. Це дозволяє уникнути необхідності в додатковому прискорювачі для отримання згустків-свідків і прецизійної короткоімпульсної техніки для вибору фази інжекції. Ідея зводиться до введення розладу між частотою проходження згустків і частотою основної моди кільватерного поля, що збуджується. Експерименти проводились на лінійному резонансному прискорювачі «Алмаз-2», який інжектував в діелектричний резонатор послідовність 6000 коротких згустків релятивістських електронів з енергією 4.5 МеВ, зарядом 0.16 нКл і тривалістю кожного 60 пс, інтервал повторення 360 пс. Розлад частоти вводився змінюванням частоти задавальног генератора клістрона в межах одного процента, так що набіг фази на довжині послідовності згустків сягав 2π. Вимірювались і аналізувались енергетичні спектри електронів послідовності згустків, що пройшли через діелектричний резонатор.