WAKEFIELD EXCITATION BY SEQUENCES OF RELATIVISTIC ELECTRON BUNCHES IN DIELECTRIC CAVITY AT DETUNING BUNCH REPETITION FREQUENCY AND FREQUENCY OF EIGEN PRINCIPAL MODE

V.A. Balakirev, I.N. Onishchenko, A.P. Tolstoluzhsky

National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

Process of wakefield excitation by short and long sequences of relativistic electron bunches with finite both longitudinal and the transverse sizes is investigated. It is shown that at the presence of detuning between the bunch repetition frequency and the frequency of excited synchronous oscillations the beating of oscillations in time is formed. The first part of the sequence of bunches loses energy on wakefield excitation resulting in wakefield amplitude growth. The second part of the sequence of bunches gains energy resulting in wakefield amplitude decrease. Thus, in the dielectric cavity the regime of relativistic electrons autoacceleration can be realized by introduction of frequency detuning.

PACS:41.75.Jv, 41.75.Lx, 41.75.Ht, 96.50.Pw

INTRODUCTION

For the realization of the wakefield acceleration method in dielectric slow wave structures the dielectric cavities can be used [1, 2]. Using of the dielectric cavity in the most interesting case of the long sequence of relativistic electron bunches is especially effective. The number of bunches in the sequence produced with linear accelerators can reach several thousands. Under resonance conditions, when the repetition frequency of bunches coincides with one of the fundamental frequencies of the dielectric cavity, an effect of the accumulation of wake field takes place, which will lead to a significant increase in the amplitude of the excited field. In this case the problem of accelerated bunches injection can be solved by introducing a small detuning between the repetition frequency of bunches and the fundamental oscillation frequency of the dielectric cavity. Under these conditions in the dielectric cavity the temporal wakefield beating is excited, contrary to the dielectric waveguide when under similar conditions spatial beating takes place. Certain part of the electron bunches is decelerated and spends its energy to excite wakefield in the volume of the dielectric cavity. Then, starting from a certain point of time a wakefield phase changes to π and subsequent bunches fall into the accelerating phase of the field and gain energy.

In this paper the process of wakefield excitation by sequence of relativistic electron bunches in dielectric cavity at detuning bunch repetition frequency and frequency of eigen principal mode is investigated.

1. STATEMENT OF PROBLEM. BASIC EQUATIONS

Consider the problem in the following statement. The dielectric cavity is formed by a perfectly conducting metal cylindrical cavity whose volume is completely filled with a uniform dielectric permittivity ε . Dielectric loss is absent. From the left end of the cavity the periodic sequence of electron bunches with given longitudinal and transverse profiles of the electron density is injected. The repetition frequency of bunches ω_b is different from the frequency of oscillations ω_{mn} in the value of detuning $\delta\omega_{mn} = \omega_{mn} - \omega_b$. Let's find the wakefield excited in dielectric cavity by a sequence of relativistic electron bunches in the approximation of a given motion of the bunches. The problem will be solved as follows. We will find wakefield of elementary charge, having the form of a thin ring with charge dQ . Elementary charge density of an infinitely thin ring has the form

$$d\rho_b = \frac{dQ(r_0,t_0)}{v_0}\frac{\delta(r-r_0)}{2\pi r_o}\delta(t-t_0-\frac{z}{v_0}), \qquad (1)$$

$$dQ(r_0,t_0) = \frac{Q}{v_0\sigma_b t_b} R\left(\frac{r_0}{r_b}\right) T\left(\frac{t_0}{t_b}\right) 2\pi r_0 dr_0 dt_0, \qquad (2)$$

where Q is full charge of bunch, t_0 is time of entry of elementary charge, r_0 is radius ring, v_0 is bunch velocity, t_b, r_b are characteristic duration and transverse bunch size, $R(r_0/r_b)$ is function described transversal profile of bunch density $\sigma_b = \pi r_b^2$ is characteristic square of bunch transverse section, and $T(t_0/t_b)$ is longitudinal profile. These functions are satisfied of the normalization conditions $\int\limits_0^1 R(x)dx = 1, \int\limits_0^1 T(\tau)d\tau = 1$.

Elementary charge located in the cavity in the time interval $t_0 + L/v_0 \geq t \geq t_0$, L/v_0 is time of the passage of elementary charge through cavity, L is cavity length.

After defining field of the elementary ring bunch (1) $E_{ZG}(r_0,t_0,r,z,t-t_0)$ define the wakefield of entire bunch by integrate on initial radial coordinate r_0 , and time of entry t_0

$$E_{zw} = \int\limits_0^{r_b} 2\pi r_0 dr_0 \int\limits_0^{t_b} dt_0 E_{ZG}(r_0,t_0,r,z,t-t_0).$$

After realization the algorithm described above, we obtain the following expression for the wake field excited by a single bunch in the dielectric cavity

$$E_{zw} = \frac{8Q_b c^2(\beta_0^2\varepsilon-1)}{v_0\varepsilon^2 a^2 L t_b}\sum_{n=1}^{\infty}\Pi_n \frac{J_0(\lambda_n \frac{r}{a})}{J_1^2(\lambda_n \frac{r}{a})}\sum_{m=0}^{\infty}\alpha_m S_m(t)\cos(k_m z), \qquad (3)$$

where $\beta_0 = v_0/c$, a is cavity radius,

$$\Pi_n = \int_0^1 R(x) J_0\left(\lambda_n \frac{r_b}{a} x\right) x dx\,, \qquad (4)$$

$$S_m(t) = \int_0^1 T\left(\frac{t_0}{t_b}\right) Z_{mn}(t - t_0) dt_0\,, \qquad (5)$$

$$Z_{mn}(t-t_0) = \left\{ \frac{\theta(t - t_0 - L/v_0)}{\omega_{mn}^2 - \omega_m^2} \left[\begin{array}{l} \omega_m \sin\omega_m (t - t_0) - \\ (-1)^m \omega_{mn} \sin\omega_{mn}(t - t_0 - L/v_0) \end{array} \right] - \right.$$
$$\left. - \frac{\theta(t-t_0)}{\omega_n^2 - \omega_m^2} \left[\omega_m \sin\omega_m (t - t_0) - \omega_{mn} \sin\omega_{mn}(t - t_0) \right] \right\},$$

$\omega_m = k_m v_0$, $k_m = \pi m / L$, $\quad \omega_{mn} = \frac{c}{\sqrt{\varepsilon}} \left(k_m^2 + \frac{\lambda_n^2}{a^2} \right)^{1/2}$ are frequencies of fundamental oscillations of dielectric cavity, $\theta(t) = \begin{cases} 1, & t > 0, \\ 0, & t \le 0 \end{cases}$ is Heaviside unit function, $\alpha = 1/2$ for $m = 0$ and $\alpha = 1$ for $m \ge 1$.

In the case of the sequence of N bunches the total wakefield is the sum of wakefields both of bunches, which are inside of cavity volume at current time, and bunches, which passed through the cavity. We choose a particular form of profile bunches and assume that the transverse density profile has a Gaussian shape

$$R\left(\frac{r_0}{r_b}\right) = \frac{1}{r_b^2} e^{-\frac{r_0^2}{2r_b^2}}\,,$$

and longitudinal profile has rectangular form

$$T\left(\frac{t_0}{t_b}\right) = \begin{cases} 1, & 1 \ge \frac{t_0}{t_b} \ge 0 \\ 0, & \frac{t_0}{t_b} < 0,\ \ \frac{t_0}{t_b} > 1 \end{cases}.$$

For such model of the bunch profile the expression for wakefield of a single bunch is described by the expression

$$E_{zw}(t,r,z) = E_{1w}(t_b \ge t \ge 0, r, z) + E_{2w}(L/v_0 \ge t > t_b, r, z) +$$
$$+ E_{3w}(L/v_0 + t_b \ge t > L/v_0, r, z) + E_{4w}(t > L/v_0 + t_b, r, z).$$

First term

$$E_{1w} = E_0 \sum_{n=1}^{\infty} F_n(r) \sum_{m=0}^{\infty} \frac{\alpha_m \cos(k_m z)}{\left(\omega_{mn}^2 - \omega_m^2\right) t_b^2} \left[\cos\omega_m t - \cos\omega_{mn} t \right],$$

where $F_n(r) = \dfrac{J_0(\lambda_n \frac{r}{a})}{J_1^2(\lambda_n \frac{r}{a})} e^{-\frac{1}{2}\left(\frac{\lambda_n r_b}{a^2}\right)^2}$,

$$E_0 = \frac{8 Q_b c t_b (\beta_0^2 \varepsilon - 1)}{\beta_0 \varepsilon^2 a^2 L},$$

describes the field, excited by bunch in the process of its injection (enter) into cavity $t_b \ge t \ge 0$.

Second term

$$E_{2w} = E_0 \sum_{n=1}^{\infty} F_n(r) \sum_{m=0}^{\infty} \frac{\alpha_m \cos(k_m z)}{\left(\omega_{mn}^2 - \omega_m^2\right) t_b^2} \left[\begin{array}{l} \cos\omega_m (t - t_b) - \cos\omega_m t) \\ -\cos\omega_{mn}(t - t_b) + \cos\omega_{mn} t \end{array} \right]$$

describes the excitation wakefield bunch under its propagation in the volume of the dielectric cavity $L/v_0 \ge t > t_b$. This time interval corresponds to the regime excitation which is fully equivalent to a semi-infinite dielectric waveguides [3, 4].

The third term accounts wakefield excited in the process of bunch exiting from cavity $L/v_0 + t_b \ge t > L/v_0$

$$E_{3w} = E_0 \sum_{n=1}^{\infty} F_n(r) \sum_{m=0}^{\infty} \frac{\alpha_m \cos(k_m z)}{\left(\omega_{mn}^2 - \omega_m^2\right) t_b^2} \times$$
$$\times \left\{ \begin{array}{l} \cos\omega_m (t - t_b) + \cos\omega_{mn} t) \\ -\cos\omega_{mn}(t - t_b) + (-1)^m \left[1 + \cos\omega_{mn}(t - t_b) \right] \end{array} \right\}.$$

And finally, the fourth term describes the field in the cavity after the bunch left cavity $t > L/v_0 + t_b$

$$E_{4w} = E_0 \sum_{n=1}^{\infty} F_n(r) \sum_{m=0}^{\infty} \frac{\alpha_m \cos(k_m z)}{\left(\omega_{mn}^2 - \omega_m^2\right) t_b^2} \left\{ \begin{array}{l} \cos\omega_{mn} t - \cos\omega_{mn}(t - t_b) - \\ -(-1)^m \left[\begin{array}{l} \cos\omega_{mn}(t - L/v_0) + \\ + \cos\omega_{mn}(t - L/v_0 - t_b) \end{array} \right] \end{array} \right\}$$

.

2. WAKEFIELD EXCITATION IN DIELECTRIC CAVITY BY A SINGLE ELECTRON BUNCH

At the beginning the dynamics of wakefield excitation in dielectric cavity by a single bunch with density profile indicated in the previous section is considered. The solution of this problem is necessary for numerical testing the above analytical expressions for the excited wakefield. Numerical calculations were performed for the following parameters of the dielectric cavity and the electron bunch: length of the cavity is $L = 63.85\ cm$, its radius $a = 4.325\ cm$, dielectric permittivity is $\varepsilon = 2.1$, value of characteristic radius of bunch is $r_b / a = 0.25$, bunch duration is $t_b / T_1 = 1/6$, $T_1 = 1/f_1$, $f_1 = 2.804\ GHz$ is frequency oscillation which is in Cerenkov resonance with the bunch. Synchronous with respect to bunch is the oscillation with indexes $n = 1$, $m = 12$. For a given frequency the cavity length contains six wavelengths. Particle energy of the electron bunch is $4.5\ MeV$, charge of bunch is $Q = 0.32\ nC$.

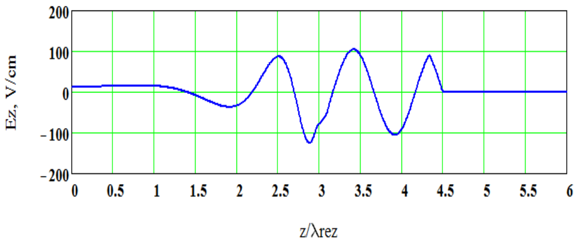


Fig. 1. Wakefield distribution in the volume of dielectric cavity at time $\tau / 2\pi = 4.5$

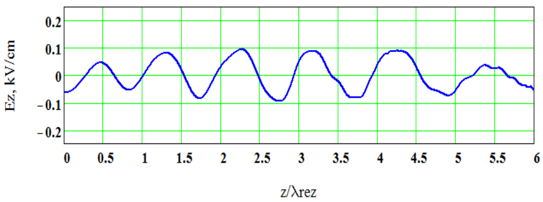


Fig. 2. Wakefield distribution in the volume of dielectric cavity at time $\tau / 2\pi = 40.8$

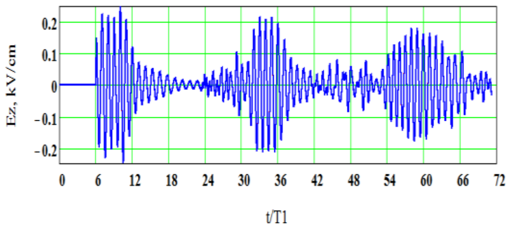


Fig. 3. The dependence of the electric field at the cavity output end

In Fig. 1 it is shown the distribution of wake electric field along the length of the cavity at the moment $\tau/2\pi = 4.5$, $\tau = 2\pi f_1 t$. The main radial harmonic ($n=1$) takes into account only. At this time, leading front of the bunch is in a plane $z/\lambda_{res} = 4.5$, where $\lambda_{res} = c/f_1$ is wavelength of resonant oscillation. In this situation, the regime of semi-infinite dielectric waveguide is realized [3, 4]. As seen from Fig. 1, in front of the bunch wakefield is absent. In the region of bunch the field grows practically under the linear law. Behind the bunch 3 full oscillations of the Cherenkov wakefield is excited, and then the tail of the transition radiation of low level is observed. The transit time of the bunch through the cavity is $\tau_{transit}/2\pi = 6$. Group front passes through the cavity length during $\tau_g/2\pi = 12.6$. After bunch left cavity, Cherenkov radiation pulse propagates with the group velocity. Multiple reflections and dispersion spreading of the wave packet leads to monochromatization field distribution along the cavity (Fig. 2, $\tau/2\pi = 40.81$). In Fig. 3 dependence on the wake electric field on time at the output end of the dielectric cavity $z = L$ is presented. Field appears at the time of arrival the bunch to the output end $\tau_b/2\pi = 6$. After the bunch leaves the cavity, the pulse of reflected Cherenkov radiation is formed and the transition radiation is excited when bunch crosses perfectly conducting end of the cavity. Increase the number of oscillations in the pulse of Cherenkov radiation is apparently connected with superposition of direct and reflected pulses. Further, the reflected pulse circulates in the cavity with the group velocity and undergoes dispersion spreading. The pulse is monochromated with decreasing amplitude. We will consider now a case of a long bunch $\tau_b/2\pi = 1/2$. In Fig. 4 distribution of wakefield along the cavity is presented to the same timepoint $\tau/2\pi = 4.5$, as in case of the short bunch. It is seen that the bunch region contains half length wake wave

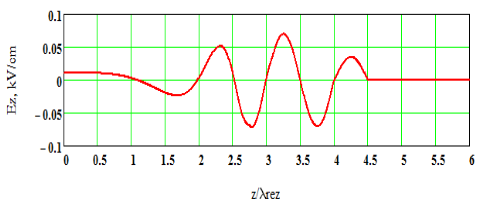


Fig. 4. The electric field distribution along the cavity at the moment $\tau/2\pi = 4.5$ for bunch length $\tau_b = \pi$

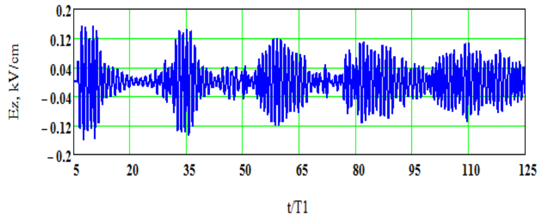


Fig. 5. Dependence of the electric field at the output end of the cavity for long bunch

excited by the forward front of the bunch. Behind the back front amplitude wakefield doubles so as wakefield of forward and back front are added. Next picture wakefield repeats wakefield of the short-bunch.

In Fig. 5 the dependence of wakefield on time at the output end of the dielectric cavity with long time of observation is presented. The dispersive spreading of the circulating pulse and its monochromatization are clearly seen. Note, that increasing the duration of the bunch while keeping its total charge leads to the decrease of the wakefield amplitude.

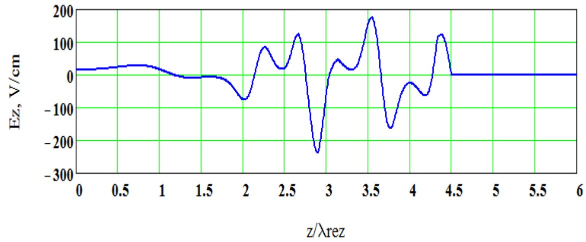


Fig. 6. The electric field distribution along the cavity at the moment $\tau/2\pi = 4.5$ taking into account five radial modes, $\tau_b = \pi/3$

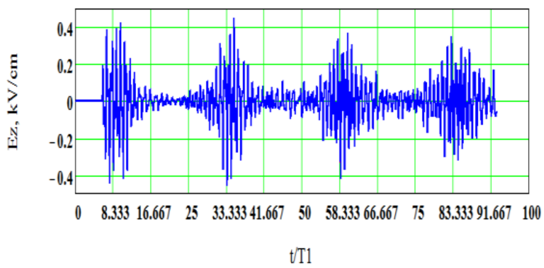


Fig. 7. Dependence of the electric field at the output end of the cavity taking into account 5 radial modes, $\tau_b = \pi/3$

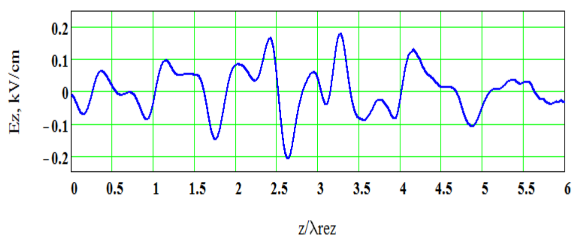


Fig. 8. The electric field distribution along the cavity at the moment $\tau/2\pi = 40.81$ taking into account 5 radial modes, $\tau_b = \pi/3$

This result is understandable, since with increasing duration of the bunch the coherence of wakefield radiated by bunch degrades. One-mode approximation ($n=1$) on radial index gives simple qualitative picture of the excitation wakefield by electron bunch of finite size in dielectric cavity. A more realistic picture can be obtained by taking into account all excited radial harmonics. In Fig. 6 distribution of wakefield of the short electron bunch $\tau_b/2\pi=1/6$ along the cavity is presented to the timepoint $\tau/2\pi=4.5$ taking into account 5 radial harmonics. The increasing of numbers of radial harmonics didn't lead to noticeable change of numerical results. Before the bunch the wakefield is absent. Then nonsinusoidal pulse of Cherenkov wakefield is excited. Behind Cherenkov wakefield the tail of quickly decreasing transition radiation propagates. In Fig. 7 dependence on time of the wakefield at the output end of the cavity in the multimode regime on radial index n is presented. The field has an appearance of pulses sequences. However, unlike one-mode regime, oscillations inside pulse are nonsinusoidal.

In Fig. 8 field distribution along the dielectric cavity in multimode regime at the timepoint $\tau/2\pi=40.81$ is presented. Distribution of the field has nonregular character. We will note that in the multimode regime the maximum value of the wakefield increased, approximately, twice. Thus duration of peaks of the field of opposite polarity was significantly reduced.

3. WAKEFIELD EXCITATION IN THE DIELECTRIC CAVITY BY SEQUENCE OF ELECTRON BUNCHES OF FINITE SIZE IN THE PRESENCE OF DETUNING BETWEEN THE REPETITION FREQUENCY BUNCHES AND THE FUNDAMENTAL OSCILLATION FREQUENCY

Wakefield in dielectric cavity excited by a sequence of relativistic electron bunches is the simple sum of wakefield single bunches. Let's consider, firstly, the simplest case of the short cavity $L=\lambda_{res}/2$ ($\lambda_{res}=10.642\ cm$). Wherein the spatial period repetition of bunches is λ_{res}. Thus, in the cavity may be only one bunch. Duration bunches is $t_b/T=\tau_b/2\pi=1/6$. In Fig. 9,a dependence of the wakefield on time at the output end of the dielectric cavity in resonant case is presented. The sequence of bunches is in the resonance with the main oscillation $n=1,\ m=1$ of the cavity. The sequence was chosen from 20 bunches. From this figure it is seen that in the resonant case the coherent addition of fields of individual bunches takes place. Amplitude of wakefield thus linearly grows over time. After cavity passing by the last bunch amplitude of wake field remains constant. In the presence of detuning the picture of wakefield excitation qualitatively changes. (Fig. 9,b). One beating of the wakefield is formed.

At the chosen number of bunches and detuning shift of the phase of wakefield behind the last bunch is equal 2π. Therefore value of wakefield behind last bunch becomes zero. As whole amplitude of wakefield grows in the beginning and bunches lose energy on wakefield excitation. After the tenth bunch the phase of wakefield changes on π and the subsequent bunches gain energy and amplitude of wakefield decreases.

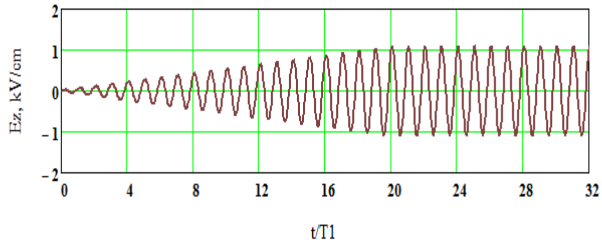


Fig. 9,a. Dependence of wakefield at output end of short cavity $L=\lambda_{res}/2$. in the case of resonance sequence bunches, $N=20$

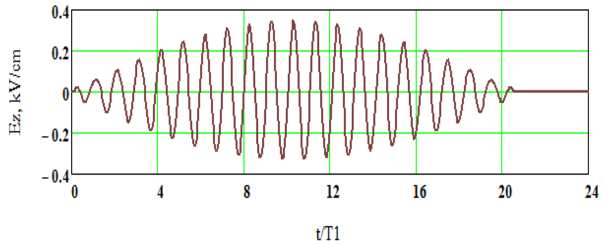


Fig 9,b. Dependence of wakefield at output end of short cavity $L=\lambda_{res}/2$ in the case of nonresonance sequence bunches $N=20$, value of detuning is $\Delta\omega/\omega=0.02$

Secondly, consider the case of long cavity $L=6\lambda_{res}$. In Figs. 10,a; 10,b dependences of the wakefield on time at the output end of the dielectric cavity are presented. Calculations are performed for 100 bunches. Oscillations with indexes $40\geq m\geq 0,\ 5\geq n\geq 1$ were considered. In resonant case the linear growth of amplitude of the wakefield is observed. In the presence of the detuning $\Delta\omega/\omega=10^{-2}$ one beating is formed. It is seen noticeable influence of the nonresonance longitudinal and transverse harmonics. We will note also that in the presence of detuning the maximum amplitude of the wakefield is decreased approximately by 3 times. In Fig. 10,c the picture of the wakefield excitation for quantity of bunches in chains $N=115$ and the same value of the detuning is presented. In this case after passing of all chain amplitude of wakefield does not vanish. Last 15 bunches excite field, then the field amplitude remains constant. In Figs. 11,a; 11,b results of numerical calculations with number of bunches $N=200$ are presented. In volume of the cavity there are at the same time 6 bunches. Bunches are in synchronism with oscillation $n=1,\ m=12$. In Figs. 12,a; 12,b for comparison dependences of the wakefield at the output end of cavity taking into account oscillations with one radial index $n=1$ and longitudinal indexes $40\geq m\geq 0$ and taking into account oscillations with radial and longitudinal indexes $5\geq n\geq 1;\ 40\geq m\geq 0$ are presented. It is seen that the accounting of the highest radial modes doesn't change quantitative characteristics of the wakefield as well as the qualitative picture excitation of the wakefield is conserved. We will note that both in resonant, and in not resonant cases nonmonotonic change of wakefield amplitude is observed. This is explained by finite time of signal circulation with group velocity on feedback chain. We will note also that the accounting of the highest radial harmonics leads to some increasing of the wakefield level behind the last bunch in the presence of detuning.

We will discuss results of numerical calculations with different quantity of bunches in chain $N = 400$ (Fig. 13,a) and $N = 900$ (Fig. 13,b) and the fixed value of the detuning $\Delta\omega/\omega = 2.5\cdot10^{-4}$. In the first case one beating of the wakefield is formed. In the second case two beating, and also wake of the wakefield from the last 100 bunches are observed. Increase of bunches number in chain to 1000 (Fig. 14) lead to increasing of intensity wake electric field to 18 keV/cm.

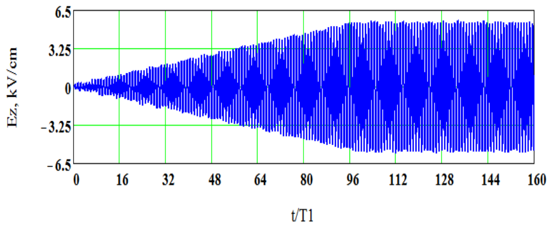


Fig. 10,a. Dependence of wakefield at output end of long cavity in the case of resonant sequence of bunches, $N = 100$

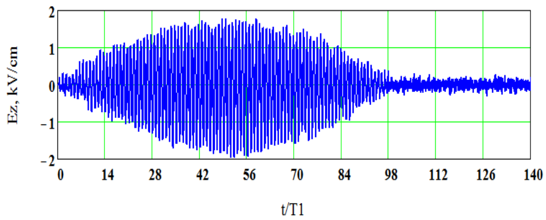


Fig. 10,b. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N = 100$, detuning is $\Delta\omega/\omega = 10^{-2}$

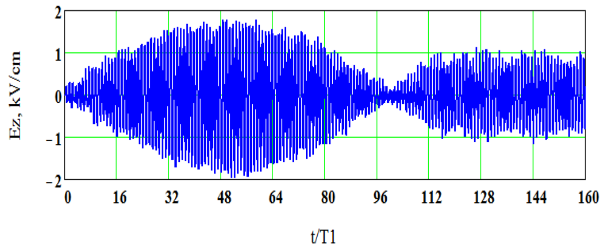


Fig. 10,c. Dependence of wakefield at output end of long resonator in the case of nonresonanant sequence of bunches, $N = 115$, detuning is $\Delta\omega/\omega = 10^{-2}$

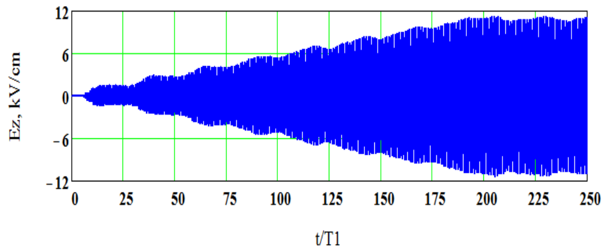
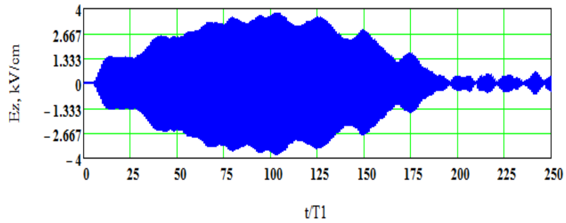


Fig. 11,a. Dependence of wakefield at output end of long cavity in the case of resonant sequence of bunches, $N = 200$ (one mode regime for radial index $n = 1$)



F

Fig. 11,b. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N = 200$, detuning is $\Delta\omega/\omega = 5\cdot10^{-3}$ (one mode regime for radial index $n = 1$)

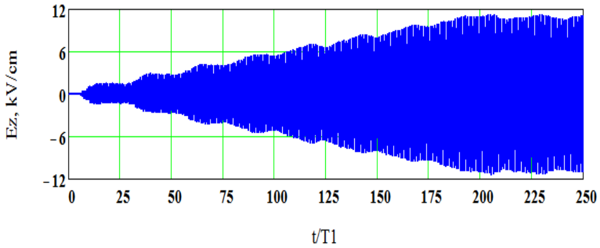


Fig. 12,a. Dependence of wakefield to output end of long cavity in the case of resonant sequence of bunches, $N = 200$ (multimode regime for radial index $5 \geq n \geq 1$)

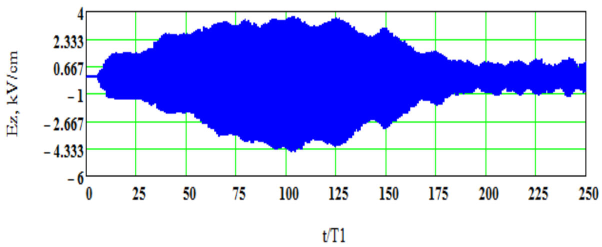


Fig. 12,b. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N = 200$, detuning is $\Delta\omega/\omega = 5\cdot10^{-3}$ (multimode regime for radial index $5 \geq n \geq 1$)

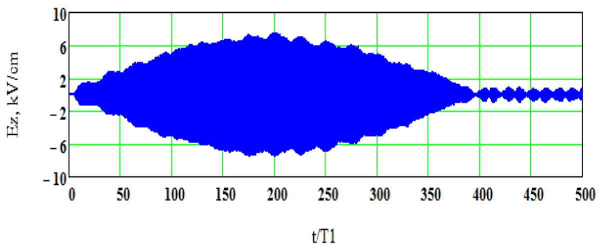


Fig. 13,a. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N = 400$, detuning is $\Delta\omega/\omega = 2.5\cdot10^{-4}$ (multimode regime for radial index $5 \geq n \geq 1$)

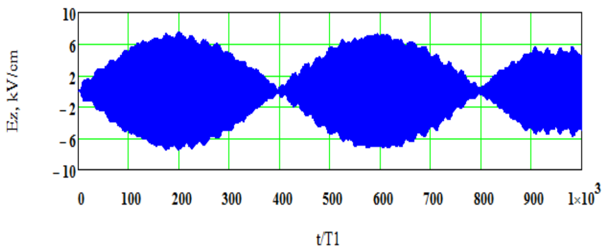


Fig. 13,b. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N = 900$, detuning is $\Delta\omega/\omega = 2.5\cdot10^{-4}$ (multimode regime for radial index $5 \geq n \geq 1$)

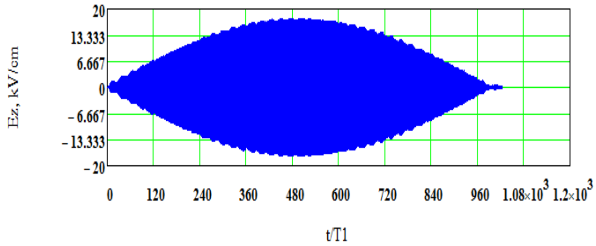


Fig. 14. Dependence of wakefield at output end of long cavity in the case of nonresonant sequence of bunches, $N=1000$, detuning is $\Delta\omega/\omega=1.0\cdot10^{-4}$ (multimode regime for radial index $5\geq n\geq 1$)

CONCLUSIONS

Thus, in the paper the dynamics of wakefield excitation by short, and long chains of relativistic electron bunches having finite both longitudinal and the transverse sizes is investigated. It is shown that at the presence of detuning between the bunch repetition frequency and the frequency of excited synchronous oscillations the beating of oscillations in time is formed.

The first half of bunches loses energy on wakefield excitation and field amplitude grows. The second half of chain of bunches gains energy and amplitude of wakefield decreases. Thus, in the dielectric cavity by introduction of detuning the autoacceleration regime can be realized.

ACKNOWLEDGEMENTS

This work was supported by the US Department of Energy/NNSA through the Global Initiatives for Proliferation Prevention (GIPP) Program in Partnership with the Science and Technology Center in Ukraine (Project ANL-T2-247-UA and STCU Agreement P522).

REFERENCES

1. V.A. Balakirev, I.N. Onishchenko, D.Y. Sidorenko, G.V. Sotnikov. Acceleration of charged particles by wakefield in dielectric cavity with channel for the exciting bunch // *Zh. Tekh. Fiz. Pis'ma.* 2003, v. 29, №14, p. 39-45.
2. J.H. Kim, J. Han, M. Joon, S.Y. Park. Theory of wakefields in a dielectric-filled cavity // *Phys. Rev. Special Topics-Accelerators and Beams.* 2010, v. 13, № 071302, p. 071302-1.
3. V.A. Balakirev, I.N. Onishchenko, D.Y. Sidorenko, G.V. Sotnikov. Excitation of wakefield by relativistic electron bunch in a semi-infinite dielectric waveguide // *Zh. Eksp. Teor. Fiz.* 2001, v. 120, № 1, p. 41-51.
4. I.N. Onishchenko, D.Y. Sidorenko, G.V. Sotnikov. Structure of electromagnetic field excited by an electron bunch in a semi-infinite dielectric filled waveguide // *Phys. Rev. E.* 2002, v. 65, № 6, p. 066501.

Article received 25.10.2014

ВОЗБУЖДЕНИЕ КИЛЬВАТЕРНЫХ ПОЛЕЙ ПОСЛЕДОВАТЕЛЬНОСТЬЮ РЕЛЯТИВИСТСКИХ ЭЛЕКТРОННЫХ СГУСТКОВ В ДИЭЛЕКТРИЧЕСКОМ РЕЗОНАТОРЕ ПРИ НАЛИЧИИ РАССТРОЙКИ МЕЖДУ ЧАСТОТОЙ СЛЕДОВАНИЯ СГУСТКОВ И ЧАСТОТОЙ ОСНОВНОЙ МОДЫ

В.А. Балакирев, И.Н. Онищенко, А.П. Толстолужский

Исследован процесс возбуждения кильватерных полей в диэлектрическом резонаторе как короткой, так и длинной цепочками релятивистских электронных сгустков, имеющих конечные продольные и поперечные размеры. Показано, что при наличии расстройки между частотой следования сгустков и резонансной частотой собственного колебания формируется биение возбуждаемых колебаний. Первая половина сгустков теряет энергию на возбуждение кильватерного поля, при этом амплитуда поля растет. Вторая половина электронных сгустков в цепочке приобретает энергию от поля. Амплитуда кильватерного поля соответственно убывает. Следовательно, в диэлектрическом резонаторе путем введения расстройки может быть реализован режим автоускорения.

ЗБУДЖЕННЯ КІЛЬВАТЕРНИХ ПОЛІВ ПОСЛІДОВНІСТЮ РЕЛЯТИВІСТСЬКИХ ЕЛЕКТРОННИХ ЗГУСТКІВ У ДІЕЛЕКТРИЧНОМУ РЕЗОНАТОРІ ЗА НАЯВНОСТІ РОЗЛАДУ МІЖ ЧАСТОТОЮ СЛІДУВАННЯ ЗГУСТКІВ І ЧАСТОТОЮ ОСНОВНОЇ МОДИ

В.А. Балакірев, І.М. Оніщенко, О.П. Толстолужський

Досліджено процес збудження кільватерних полів у діелектричному резонаторі як короткими, так і довгими ланцюжками релятивістських електронних згустків, що мають скінчені поздовжні та поперечні розміри. Показано, що при наявності розладу між частотою проходження згустків і резонансною частотою власного коливання формується биття збуджуваних коливань. Перша половина згустків втрачає енергію на збудження кільватерного поля, при цьому амплітуда поля росте. Друга половина електронних згустків у ланцюжку одержує енергію від поля. Амплітуда кільватерного поля відповідно убуває. Отже, у діелектричному резонаторі шляхом введення розладу може бути реалізовано режим автоприскорення.