

About Wakefields Excited by an Electron Bunch Train in a Section of Dielectric Waveguide*

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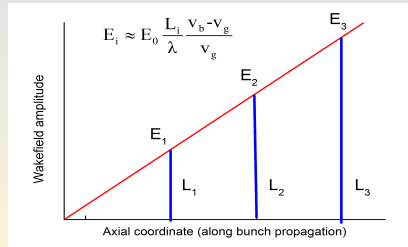
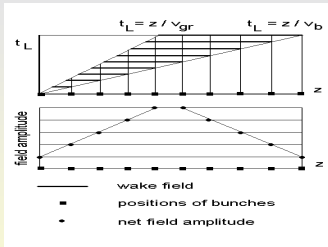


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Wakefield in semi-infinite waveguide



- For increase in amplitude of a wakefield instead of a single bunch it is possible to use sequence of bunches following with wakefield period
- In ideally matched section of a dielectric waveguide (DWG), at injection of long sequence of bunches, the maximum amplitude of a wakefield is proportional to length of a waveguide section [because of group velocity, V.A. Balakirev et al. J. Exp. Theor. Phys. 93, 33 (2001)]

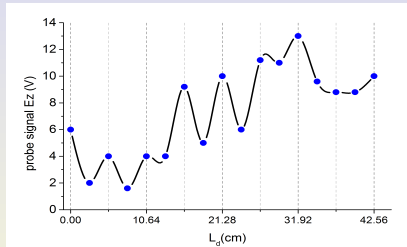


Process of wakefield setting. Axial distribution of wakefield amplitude in matched DWG: at left - initial state when 1st bunch has reached the WG end, at right - stable state

Experimental measurements of $E_z(L_d)$



With purpose of verification of above equation we carried out a serious experiments and obtained the next dependence $E_z(L_d)$



Probe signal at the end of vacuum part of dielectric unit[V.A.Kisel'jov et al]

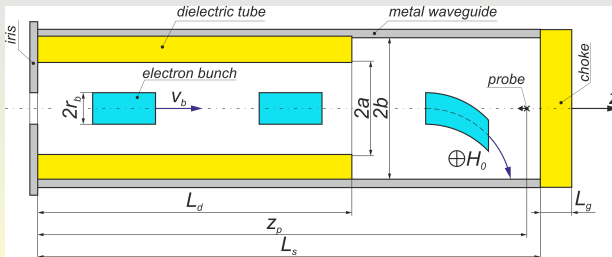
- The wakefield increases in average when increasing a dielectric tube length.
- However amplitude has **oscillating behaviour** (period=5.32cm). **Why?**

Structure under investigation



In order to understand such dependence of wakefield amplitude we carried out PIC simulations of wakefield excitations in a section of DWG and subsequent radiation in vacuum.

Geometry of the unit and parameters of bunch train is very close to experimental conditions. This geometry accounts by natural way any reflections (internal and from ends of DWG).



Geometry of DWG. Choke and tube are fabricated from the same material.

Parameters used for the simulations of DWS

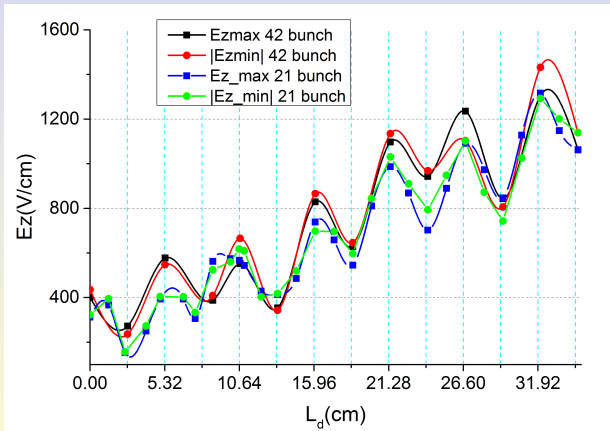


OD of dielectric tube, $2b$	85 mm
ID of dielectric tube, $2a$	21.1 mm
Relative dielectric constant (teflon)	2.045
Wavelength of E_{01} mode, λ	$\approx 106.4\text{ mm}$
Group velocity of E_{01} mode in dielectric tube	$\approx 0.5c$
Group velocity of E_{01} mode in vacuum part	$\approx 0.25c$
Total waveguide length, L_s	650 mm
Dielectric choke length (if any), $L_g = \lambda/2$	53.2 mm
Bunch energy	4.5 MeV
Bunch charge	0.32 nC
Bunch diameter, $2r_b$	10 mm
Bunch axial RMS size σ_z	8.87 mm
Number of bunches, N_b	$1 \div 101$
Intensity of ext. magnetic field at z-axis (if any), H_0	1 kOe

Radiation into vacuum without choke



E_z on the average grows with increasing of L_d , oscillating under the sinusoidal law with the period equal to $\lambda/2$ of the lowest mode of resonance oscillations.

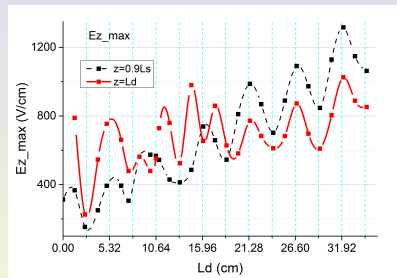
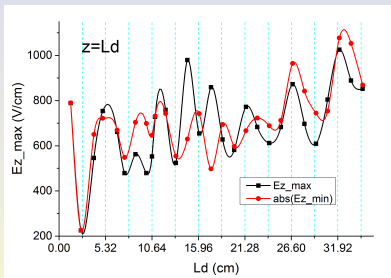


Max and min of E_z at $z = 0.9L_s$, $r = 0$ versus L_d for different number of bunches in the train. Vertical grid lines are drawn every $\lambda/4$

Wakefield in dielectric tube



- For short L_d there is no simple dependence of $E_z(L_d)$
- The average rising dependen. appears for rather long dielectrics $L_d > 1.5\lambda$
- This dependence coincides with dependence of the field registered at the end of structure, in its vacuum part (right figure)



At left: Max and min of E_z at $z = L_d$ versus L_d for $N_b = 21$. At right: comparison max of E_z in vacuum region and dielectric tube

Thus, having measured fields in the vacuum part it is possible to draw a conclusion about behavior of wakefield in the die. plug depending on its length.

Possible simple explanation



Let's consider only Cherenkov part of total excited field.

- without reflections $E_z(z) \propto z$ (as it is pointed out in Introduction)
- because of BC $E_r(z = 0) = 0$ a longitudinal electric field
 $E_z(z) \propto \cos(2\pi z/\lambda)$
- Thus at the left boundary of dielectric-vacuum interface
 $E_z(z = L_d - 0) \propto L_d \cos(2\pi L_d/\lambda)$
- at the right boundary $E_z(z = L_d + 0)$ is described the similar dependence from L_d because $E_z(z = L_d + 0) = \varepsilon E_z(z = L_d - 0)$
- if $L_d = \lambda(2n + 1)/4$ then $E_z(z = L_d + 0) = 0$, i.e. excited wakefield is reflected from die.-vac. boundary, no wakefield in vacuum part of the unit
- If $L_d = \lambda n/2$ then $E_z(z = L_d) \propto L_d$ is maximal because $|\cos(2\pi L_d/\lambda)| = 1$. Besides the partially reflected wave is coherently added with a direct wave, and the full field grows in a tube and in vacuum.

This explanation is valid for single mode excitation. If we have multi-mode structure it is not possible to nullify amplitudes of all modes simultaneously, and total field drops to finite value for $L_d = (2n + 1)\lambda/4$.

- The field radiated from the dielectric tube and recorded in vacuum part of a cylindrical waveguide has character of the sinusoid growing when increasing in length of dielectric tube
- Such dependence of the field amplitude can be explained: a) by dependence of transmission coefficient from the length of dielectric tube and b) coherent addition of a wakefield, reflected from both ends of a section, and direct wakefield dragged by bunches
- For the wakefield inside dielectric tube the certain, on average rising dependence appears only for rather long dielectrics $L_d \geq 1.5\lambda$
- Thus, when using a long dielectric tubes, having measured fields in vacuum part of structure it is possible to draw a conclusion about the dependence of a wakefield in the dielectric tube from its length.