Electron Cloud Memory Effects

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Abstract

Electron cloud is a concern for many modern and future accelerator facilities. There are a number of undesired effects attributed to the presence of electron clouds. Among them are coherent instabilities, emittance growth, cryogenic heat load, synchronous phase shift and pressure rise. In long bunch trains one can observe the emittance growth getting faster along the train. This coupled bunch effect is mainly due to the growing electron cloud density along the bunch train. In this paper we address other mechanisms that can lead to the coupled-bunch electron cloud effects.

1. Introduction

2. Long Range Wakefields due to Secondary Emission

We start our analysis assuming a perfectly circular beam pipe of radius R_p. Moreover, we assume that bunches propagating through this pipe are short longitudinally and much smaller than R_p transversely. All bunches have one and the same radius σ_r. Additionally, the electron cloud populating this pipe is radially symmetric as well. If all the bunches propagate exactly on the pipe axis, the electron distribution remains radially symmetric.

In the following we assume that one of the bunches is horizontally off-centered by x_0. The electrostatic potential of the bunch is then approximately given by the Green's function [**?**]:

$$G(x,y,x_0,y_0) = \frac{1}{4\pi\epsilon_0} \ln\left(\frac{\bar{R}^2 r_0^2}{R^2 a_0^2}\right), \tag{1}$$

where $\bar{R} = \sqrt{(r_0^2 x - R_p^2 x_0)^2 + (r_0^2 y - R_p^2 y_0)^2}/r_0^2$,

$r_0 = \sqrt{x_0^2 + y_0^2}$ and $R = \sqrt{(x-x_0)^2 + (y-y_0)^2}$.

If $0 < x_0 << R_p$ and $y_0 = 0$, one can expand Eq. 1 to get:

$$G(x,y,x_0,y_0) \approx \frac{1}{4\pi\epsilon_0}\left(\ln\left[\frac{R_p^2}{x^2+y^2}\right] + \frac{2xx_0}{x^2+y^2}\right) \tag{2}$$

We then analyze the electric fields at radius $R >> x_0$ from pipe center. To obtain them one needs to multiply Eq. 6 by local bunch line density $\lambda_i(z)$ and get the derivative in x and y directions:

$$E_x(x,y) \approx \frac{e\lambda_i}{2\pi\epsilon_0}\left(\frac{x}{R^2} + \frac{x_0(x^2-y^2)}{R^4}\right) \tag{3}$$

and

$$E_y(x,y) \approx \frac{e\lambda_i}{2\pi\epsilon_0}\left(\frac{y}{R^2}+\frac{2x_0xy}{R^4}\right). \tag{4}$$

The kick approximation Ref.[kick] gives the following velocity change in x and y directions:

$$\Delta V_x(x,y) \approx 2N_ir_ec\left(\frac{x}{R^2}+\frac{x_0(x^2-y^2)}{R^4}\right) \tag{5}$$

and

$$\Delta V_y(x,y) \approx 2N_ir_ec\left(\frac{y}{R^2}+\frac{2x_0xy}{R^4}\right). \tag{6}$$

As expected, one sees that the horizontal kicks are larger on the side closer to the bunch and smaller on the opposite side. Moreover, $\Delta V_y(x,y) > \Delta V_y(-x,y)$ if $x>0$.

Depending on the beam intensity most of the electrons can get energy either below the position of the SEY maximum or above. Additional features of secondary emission arise when Fig. 1 shows schematically the process of secondary emission in case of an off-centered bunch.

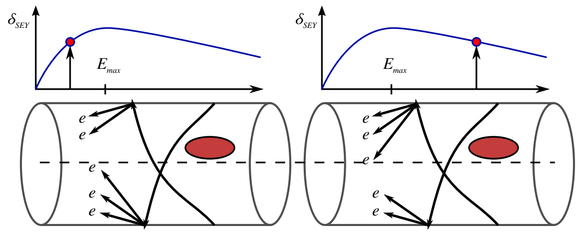

Figure 1: (Color) Schematic representation of the secondary emission process for off-centered bunch for two different bunch populations.

3. Simulations

The numerical model is the same as in Ref.[Petrov2014]. The simulation parameters are listed in Table.[table] In this section we focus on the dipole region mainly. In reality primary electrons are bound to the magnetic field lines. Moreover, secondary electrons move along approximately the same field lines as the primary ones. Thus the electrons stay approximately in one and the same plane and the approximation of 2D grid and 2D electron motion is rather valid. In contrast in field-free regions physical electrons can move freely in all the directions. Hence, in the gap between two consecutive bunches electrons can diffuse significantly.

3.1. Single-bunch wakefields

In this subsection we analyze the features of the electron cloud wakefields in cyllindrical geometry including secondary emission. To begin with, we assume a uniform cloud populating the beam pipe. We start with the simulation of the single-bunch wakefields. Figs. 2 and 3 show the fields induced in the cylindrically symmetric pipe. The fields on the pipe axis and the fields on the offcentered bunch axis are shown. The depicted wakefields were calculated for different offsets of the bunch. In addition Figs. 4 and 5 show the same fields but averaged over the bunch longitudinal profile. One sees that the field acting on the bunch depends linearly on the offset. Moreover, the field on the pipe axis does not vanish until the following bunch and depends rather linearly on the bunch offset.

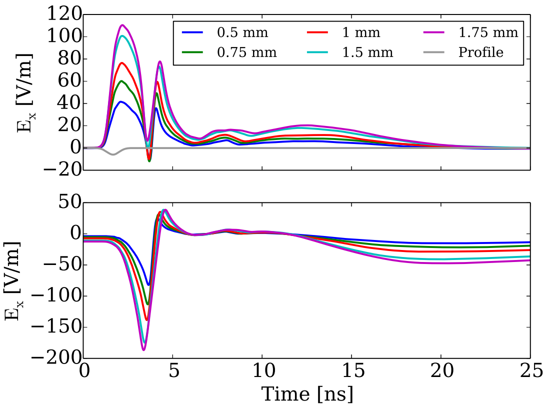

Figure 2: (Color) Transverse electric field induced by the pinching electron cloud on the pipe axis (upper) and on the bunch axis (lower) in the field-free pipe.

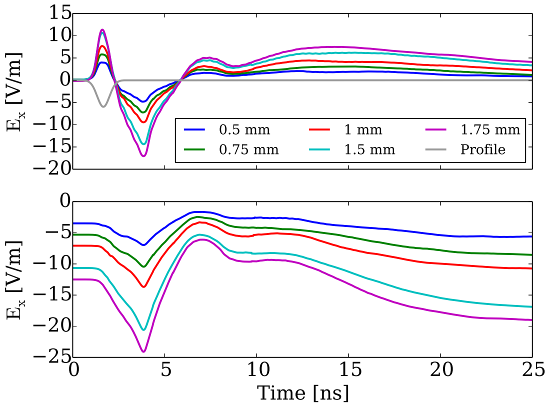

Figure 3: (Color)Transverse electric field induced by the pinching electron cloud on the pipe axis (upper) and on the bunch axis (lower) in the dipole magnetic field.

3.2. Basic characteristics of long-range wakefields

Figs. 6 and 7 show the same fields as in Subsection 3.1 on axis covering however four following bunches. One can see that the fields become negligible (below the noise level) in the field-free pipe, but stay observable in the dipole region. The growing amplitude

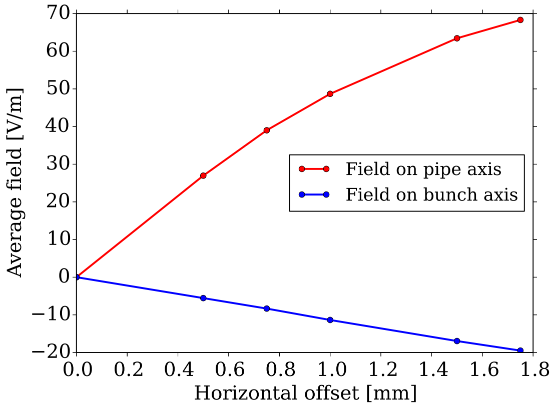

Figure 4: (Color) Electron cloud transverse electric field averaged over the bunch profile in the field-free pipe.

of the field is due to the growing electron cloud density. The vertical offset in the dipole region (not shown) leads to the similar fast decaying wakefield as in the field-free region.

3.3. Simulations for Round Geometry

3.4. Simulations for Rectangular Geometry

3.5. Simulations for Realistic LHC Geometry

3.6. Conclusion and Outlook

References

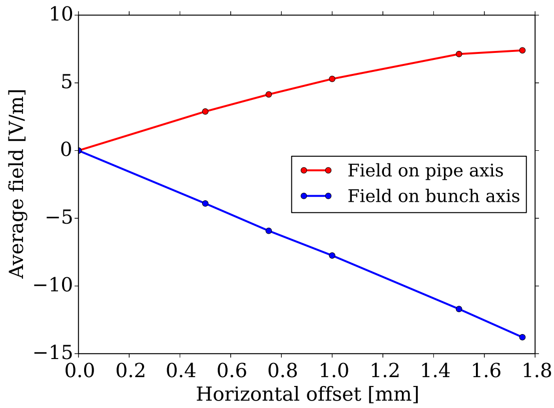

Figure 5: (Color) Electron cloud transverse electric field averaged over the bunch profile in the dipole magnetic field.

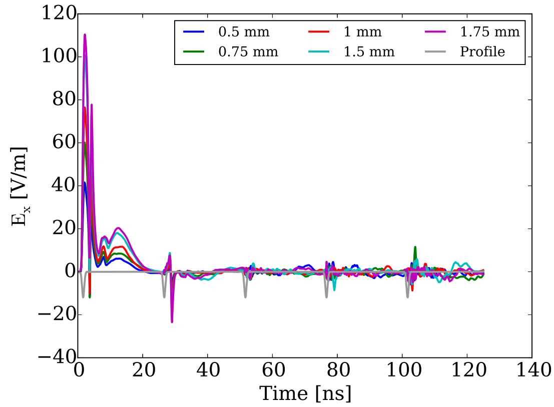

Figure 6: (Color) Transverse electron cloud electric fields induced by the offcentered bunchin the range of several bunch spacings in the field-free pipe.

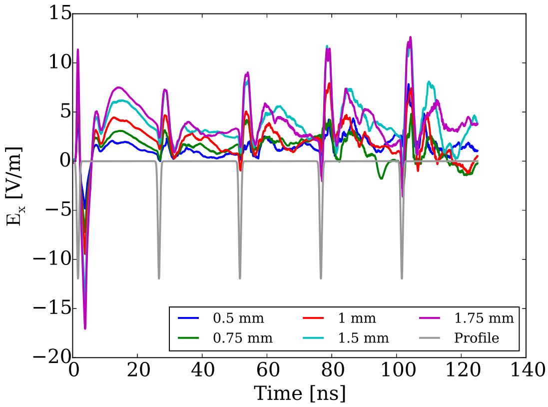

Figure 7: (Color) Transverse electron cloud electric fields induced by the offcentered bunchin the range of several bunch spacings in the external dipole magnetic field.