EFFECTS OF WAKE FIELDS IN THE CLIC BDS*

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Abstract

The wake fields due to collimators in the Beam Delivery System of CLIC are modeled using a conventional approach. According to the chosen ranges of parameters, differences in the transverse kicks due to both the geometric and resistive wall components for different regimes are highlighted (inductive or diffractive for the geometric wake fields, short- or long-range, ac or dc for the resistive wall wake fields). A module for particle tracking along the BDS including the effect of wake fields has been implemented in PLACET and first tracking results are shown.

INTRODUCTION AND MOTIVATIONS

Wake fields in the CLIC Beam Delivery System (BDS) can cause severe single or multi-bunch effects leading to luminosity loss. Jitter amplification and emittance growth, for example, can be driven by wake fields and degrade the electron or positron beam quality at the IP with a consequent luminosity drop. The main contributions to wake fields in the BDS are:

- Geometric and resistive wall wake fields of the tapered and flat parts of the collimators (pipe radius changes and small apertures).
- Resistive wall wakes of the beam pipe, which are especially important in the regions of the final quadrupoles (where the β functions are very large).
- High Order Modes as well as Low Order Modes induced in crab cavities (possibly used in the BDS to tilt the bunches at the IP and compensate the crossing angle, they usually do not operate on the fundamental mode of the cavity) [1]

In this paper we concentrate on single bunch effects of the collimator transverse wake fields on a nominal bunch that goes through the CLIC BDS and how they affect the accelerator performances.

Collimators can have round or flat geometries (in x or y, depending on whether they are supposed to collimate in x for horizontal betatron or energy cleaning, or in y for vertical betatron cleaning). Longitudinally, they are defined by the tapered parts (length L_T, in which the radius of the beam pipe b smoothly changes ($b(s)$) to the collimator gap size g and vice versa, and the flat part (length L_F) in between. Obviously, the tapering angle is $\alpha = \tan((b-g)/L_T)$ for a linear taper. Transversely, a flat collimator has a width (height) h such that $h \gg b(s)$ all along the structure (which means basically $h \gg b$, because usually $b > b(s) > g$). For

two-stage collimation systems, both spoilers (thin collimators without the flat part) and absorbers (long collimators) are needed. The tapered parts of the collimators are responsible for geometric wake fields, which are excited because of the longitudinal change in the cross section of the beam chamber. Both the tapered and the flat part of the collimators contribute to the resistive wall wake fields, because of the finite conductivity of the collimator material. This component of the wake field is usually very strong because of the small collimator apertures.

In the next Section we present the approach that we have used for modeling the collimator wake fields in the most general way. Formulae for both the geometric and the resistive wall components of the wakes in different regimes are shown and their ranges of validity are specified. Section III is devoted to tracking. We briefly describe how a collimator wake field module was implemented in the existing PLACET code [2] and sample results in terms of luminosity reduction as a function of jitter amplitude or collimator misalignment are discussed. Lastly, conclusions are drawn and the ongoing as well as the planned work are presented in Section IV.

MODEL FOR THE COLLIMATOR WAKE FIELDS

The collimator wake fields are separately described through their two components: geometric wake due to the change of cross section, and resistive wall wake due to the finite conductivity of the collimator material. We review in the following the formulae that need to be used for both and the regimes in which they are applicable.

Geometric wake

The impedance of a taper is purely imaginary and consequently the wake field of a test particle only affects the witness particles longitudinally placed at the same z as the source particle. The kick (in x and y) felt by a particle situated at the z coordinate of a Gaussian bunch with r.m.s. size σ_z, N particles and traveling at an energy γ, after it crosses a round taper of changing radius $b(s)$ is [3]:

$$\Delta y' = \frac{2Nr_e}{\gamma\sqrt{2\pi}\sigma_z} \int_0^{L_T} \left(\frac{b'^2}{b^2}\right) ds \cdot \exp\left(\frac{z^2}{2\sigma_z^2}\right) \Delta y \ , \ (1)$$

where Δy is the local offset of the beam. For a flat taper (for instance, vertical) the kick has a dipole part ($\propto \Delta y$) and a quadrupole part ($\propto y$, coordinate of the witness particle) and reads [4]:

$$\Delta y' = \frac{2Nr_e}{\gamma\sqrt{2\pi}\sigma_z} \left[2y \int_0^{L_T} \left(\frac{b'^2}{b^2}\right) ds + \left(\pi h \int_0^{L_T} \left(\frac{b'^2}{b^3}\right) ds \right. \right.$$

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$$-2\int_0^{L_T}\left(\frac{b'^2}{b^2}\right)ds\right)\Delta y\right]\cdot\exp\left(\frac{z^2}{2\sigma_z^2}\right) \quad (2)$$

The formulae above are true only for smooth tapering ($\alpha \ll g\sigma_z/h^2$, also called inductive regime) [5]. In diffractive regime ($\alpha \gg g\sigma_z/h^2$), one should use for round tapers:

$$\Delta y' = \frac{\sqrt{2}Nr_e}{\gamma g^2}\exp\left(\frac{z^2}{2\sigma_z^2}\right)\Delta y \;, \quad (3)$$

and in the intermediate regime:

$$\Delta y' = \frac{\sqrt{2\alpha}2.7Nr_e}{\gamma\sqrt{\sigma_z g}}\exp\left(\frac{z^2}{2\sigma_z^2}\right)\Delta y \;, \quad (4)$$

and then simply replace Δy with $(0.85\Delta y + 0.43y)$ ("Yokoya prescription" [6]) for flat tapers.

Resistive wall wake

According to the distances at which the wake generated by a traveling source charge is calculated, also resistive wall wake fields can be classified into three different regimes. If $0.63(2g^2/(Z_0\sigma))^{1/3} \ll |z| \ll (2g^2c\sigma\mu_0)$ we are in long-range regime and the kick given by a piece ds of the collimator can be computed from the standard resistive wall wake field [7]:

$$\Delta y'(s) = \frac{4Nr_e\sqrt{\lambda}ds\Delta y}{\sqrt{2}\pi\gamma\sigma_z b^3(s)}\int_0^\infty\frac{1}{\sqrt{z'}}\exp\left[-\frac{(z+z')^2}{2\sigma_z^2}\right]dz' \quad (5)$$

For short bunches, such that $|z| < 0.63(2g^2/(Z_0\sigma))^{1/3}$, the formula for the resistive wall wake field is far more complicated and reads [8]:

$$W_1^\perp(z,s) = \frac{cZ_0}{\pi b^3(s)}\left[\frac{s_0\exp(-\alpha_t\frac{z}{s_0})}{3(\alpha_t^2+k_t^2)}\cdot\right.$$

$$\cdot\left(\alpha_t\cos(k_t\frac{z}{s_0})+k_t\sin(k_t\frac{z}{s_0})-\alpha_t\right)$$

$$\left.-\frac{\sqrt{2}}{\pi}\int_0^z\int_0^\infty\frac{x^2\exp(-x^2\frac{z'}{s_0})dx}{x^6+8}dz'dx\right] \quad (6)$$

having defined $s_0(s) = (2b(s)^2/(Z_0\sigma))^{1/3}$, and α_t and k_t as the poles from Ref. [8], which are equal to 1 and $\sqrt{3}$, respectively, in dc-conductivity regime, and change according to a known behavior going to higher frequencies (shorter bunch lengths), when the ac drop of conductivity becomes significant. The kick can be computed from:

$$\Delta y'(s) = \frac{Nr_e ds\Delta y}{\gamma\sqrt{2\pi}\sigma_z}\int_0^\infty W_1^\perp(z',s)\exp\left[-\frac{(z+z')^2}{2\sigma_z^2}\right]dz' \quad (7)$$

In order to generalize these formulae from round structures to flat collimators we only need to replace Δy with $(0.85\Delta y + 0.43y)$.

These kicks need to be integrated over the whole collimator length to obtain the total kick acting on each bunch particle after it has traveled through the whole length of the collimator $\Delta y' = \int_{\mathrm{coll}}\Delta y'(s)ds$.

Wake field module

A module for the calculation of the collimator wake fields in different regimes has been constructed to be subsequently implemented in the PLACET tracking code. Given a set of parameters (defined through the *beam* and *collimator* structures), the module first determines the type of regime (geometric: inductive, diffractive or intermediate, and resistive: long- or short-range, dc or ac-conductivity), then evaluates the kick on a bunch particle as function of its longitudinal (and transverse, if the collimator is flat and there is a quadrupole component of the wake) position and applies it to the particle accordingly.

The geometric component of the wake has the same shape as the bunch and is usually negligible with respect to the overall contribution given by the resistive wall. Figures 1 show the typical shape of the resistive wall wake along the bunch in the long- and short-range regimes. In the short-range case, two components of the wake are separatedly plotted (corresponding to the two addends in Eq. 6, the broadband-like first term and the integral), which have opposite signs and thus partially compensate each other.
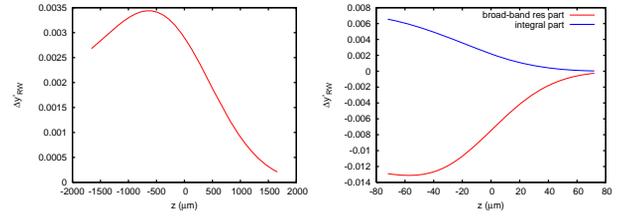
Figure 1: Resistive wall wake fields in the long- (left) and short-range (right) regimes. Kicks are shown in units of μrad.

IMPLEMENTATION IN PLACET AND TRACKING RESULTS

The collimator wake field module has been implemented in the PLACET tracking code in order to study the effect of the wake fields on the CLIC performances. A basic set of CLIC parameters is given in Table 1. To perform this study, we have tracked electrons and positrons through the Main Linac and then through the BDS, adding the kicks from the wake fields of a specific set of collimators from the CLIC linear collimation system [9] (see Table 2). We have assumed the tapering angles of the collimators to be 30 mrad and their length to be 177 mm in the case of Be spoilers (corresponding to about $0.5\lambda_{\mathrm{Be}}$) or 712 mm (corresponding to $20\lambda_{\mathrm{Cu-Ti}}$) in the case of Cu-Ti absorbers. We only considered the most critical subset of the full set of CLIC BDS collimators [9]

Amplitude jitters up to $\pm 1\cdot\sigma_{x,y}$ set at the beginning of the BDS or misalignments of the collimators have been considered in order to calculate the corresponding luminosity reduction curves. Figures 2 show transverse phase space portraits at the IP with and without the collimator wake

fields (with a small jitter of $0.5\sigma_y$). The effect is quite evident and a consequent luminosity drop is to be expected.
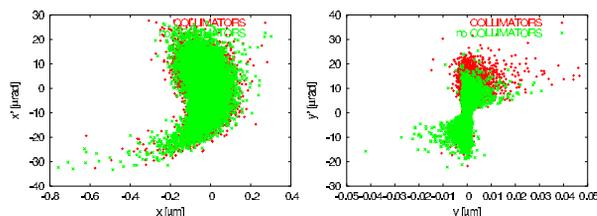
Figure 2: Horizontal (left) and vertical (right) phase space portraits at the end of the BDS including or not including the collimator wake fields in the tracking.

Table 1: CLIC parameters

Name	Symbol	Unit	Value
Energy	E	GeV	1500
Hor. emittance	ϵ_x	nm	680
Vert. emittance	ϵ_y	nm	10
Bunch length	σ_z	μm	35
Bunch population	N		5.6×10^9

Table 2: List of collimators used in the tracking

#	β_x[m]	β_y[m]	D_x [m]	a_x [mm]	a_y [mm]
0	1406.3	70682	0.27	3.51	25.4
1	3213.0	39271	0.42	5.4	25.4
2	114.0	483.2	0.	10.	0.1
3	270.0	101.3	0.	0.08	10.
4	114.0	483.1	0.	10.	0.1
5	270.0	101.3	0.	0.08	10.
6	114.0	483.2	0.	10.	0.1
7	270.0	101.3	0.	0.08	10.
8	114.0	483.1	0.	10.	0.1
9	270.0	101.3	0.	0.08	10.

Figures 3 and 4 show the luminosity reduction curves for vertical jitters and vertical misalignment of the collimators, where luminosity is plotted as a function of the initial jitter or the collimator offset, respectively. It is clear that both the jitter and the collimator offset can cause significant luminosity loss, which increases with increasing amplitude of jitter or offset. As expected Fig. 4, the luminosity only depends on the vertical displacements of the vertical collimators and is insensitive to the vertical displacement of the horizontal collimators (betatron horizontal and energy collimators). Because of the large horizontal beam sizes, displacements by few or few tens of μm of energy collimators have actually been found to have little effect in the horizontal plane, as well.

CONCLUSIONS AND OUTLOOK

Tracking with collimator wake fields has been made possible by implementing conventional models of geometric and resistive wall effects in the PLACET code. The CLIC luminosity loss has been computed for different amplitude
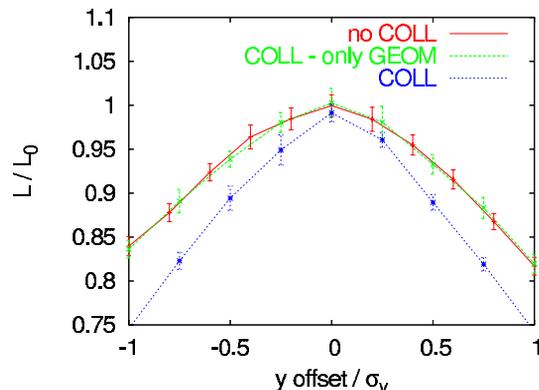
Figure 3: CLIC Luminosity versus initial vertical jitters.
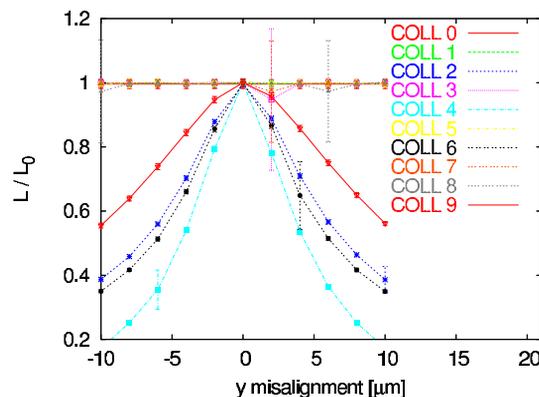
Figure 4: CLIC Luminosity versus vertical collimator offset.

jitters and collimator offsets.
In the future more detailed studies are planned, e.g. parameter studies for bunch length and bunch charge and a study of the dependence on the collimator gap, which could entail the necessity of having a nonlinear collimator system to minimize the effect of wake fields. Integrated simulations from the bunch compressor through the main linac up to the BDS including the whole set of collimators are also foreseen to have a complete picture of the effects of wake fields on the CLIC bunch evolution.

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