MULTI-BUNCH EFFECT OF RESISTIVE WALL IN THE CLIC BDS

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Abstract

Wake fields in the CLIC Beam Delivery System (BDS) can cause severe single or multi-bunch effects leading to luminosity loss. The main contributors in the BDS are geometric and resistive wall wake fields of the collimators and resistive wall wakes of the beam pipe. The present work focuses only on the multi-bunch effects from resistive wall. Using particle tracking with wake fields through the BDS, we have established the aperture radius, above which the effect of the wake fields becomes negligible. Our simulations were later extended to include a realistic aperture model along the BDS as well as the collimators. The two cases of 3 TeV and 500 GeV have been examined.

INTRODUCTION

Collective effects are of great importance for the ultimate performances of a particle accelerator. In particular, wake fields can cause severe single or multi-bunch effects leading to luminosity loss. The main contributions to wake fields in the CLIC BDS are first, the geometric and resistive wall wake fields of the tapered and flat parts of the collimators (pipe radius changes and small apertures) and second, the resistive wall wakes of the beam pipe, in general due to the small pipe radius and which can give a large contribution especially in the regions of the final quadrupoles (where the β functions are very large).
Quantifying the effects of the resistive beam pipe on the CLIC main beam in the BDS is of primary importance, because it has a direct and significant impact on the specification of the final pipe radius, at least in some parts of the BDS (i.e., where there are no constraints from the magnet apertures). The aim of this paper is to determine the thresholds of resistive wall multi-bunch instability in terms of pipe radius by means of numerical simulations.

RESISTIVE WALL

While travelling through a smooth and not perfectly conducting pipe of small radius, a particle generates a delayed electromagnetic (e.m.) field in the vacuum chamber, called wake field. Those fields can interact with the following particles both on the long and short range through the resulting Lorentz force, kicking the particles out of the ideal trajectory. The integrated effect of the wake fields on the particles over a device of the accelerator can be described by the wake functions W. In this paper, we make use of the classical resistive wall formula [1] for the dipolar wake functions in the long range:

$$W(z) = -\frac{c}{\pi b^3}\sqrt{\frac{Z_0}{\sigma \pi z}}L \quad , \qquad (1)$$

In Eq. 1, z is the relative position to the source particle, b the pipe radius, c the speed of light, Z_0 the vacuum impedance, σ the wall conductivity and L the length of the accelerator element. Equation 1 is valid for a wall thickness d much larger than the skin depth δ, $d \gg \delta$, and for separation time between bunches Δt in the domain $b/\chi c \gg \Delta t \gg b\chi^{1/3}/c$, with $\chi = \frac{c}{4\pi\sigma b}$.

TRACKING CODE

We make use of a particle tracking code conceived for linear machines. Each bunch of the train is treated as a certain number of macroelectrons. The code includes multi-bunch effect due to interaction with an impedance (resonator impedance, resistive wall with the classic formula or with inductive by-pass). Simulations can be run through a transfer line made of FODO cells or through a lattice given by an external twiss file (MAD-X structure), using the linear matrix formalism to transform their phase space coordinates. We consider the beam to be longitudinally rigid and no longitudinal wake fields are applied but acceleration can be included optionnaly by means of the variation of the relativistic gamma along the line. At each step of the line, we compute the integrated effect of the resistive wall wake field and apply the resulting kick, Eq. 2, given to the particles within one bunch in consequence of the effect of all the preceding bunches.

$$\Delta u'(z) = \frac{e^2 N}{E_0}\sum_{j=1}^{k-1}\langle u\rangle_j W[|k-j|\Delta t_b c] \qquad (2)$$

In Eq. 2, N is the number of particles per bunch, E_0 the energy of the beam, $\langle u\rangle_j$ the mean transverse position of the bunch j, k the total number of bunches and Δt_b the seperation time between subsequent bunches. The bunches can all be off-centered at the same value or cosinus-like at the entrance of the line. The code also includes the possibility of reading out tabulated values of the wake functions and interpolate them in case the pipe radius of an element of the BDS is too small for Eq. 1 to be valid.

APPLICATION TO THE CLIC BDS

Assuming the material to be copper, we first show results for a model in which we suppose a smooth pipe with

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constant radius all along the BDS. In a second part we implement a more realistic aperture model in which we take into account the realistic aperture of the magnets along the beam line and study its effect on the beam dynamics, including collimators in a third part. The parameters of the bunches in the BDS are presented in Tab. 1. Neglecting single bunch effects, all the macro-electrons within the first bunch feel no resistive wall effect so that the motion of the first bunch of the train is unaffected. Thus, at each element along the line, we take the offset and angle of the first bunch as a reference. On the other hand, the last bunch feels the effect of all the preceding ones. We therefore plot the offset difference between the last bunch and the first bunch (and also angle differences in [4]) along the elements of the line and assume that the resistive wall effect becomes negligible when the differences are converging to the same value for increasing radii. Simulations were done for chamber apertures from 4 mm (minimum value for Eq. 1 to be valid) up to 14 mm.

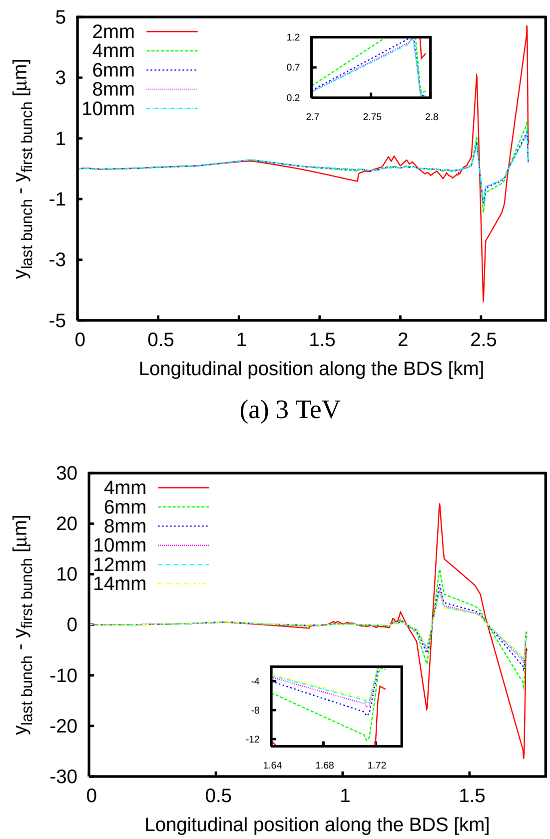
At 3 TeV and 500 GeV, the vertical emittance is smaller than the horizontal one (see Tab. 1). Moreover, the vertical betatron function is larger than the horizontal one [2] so that the effect of the wake field is larger in the vertical plane. Based on these two facts, our criterion to establish the minimum acceptable aperture will require the effect in the vertical plane to be negligible. In our simulations, we give all the bunches the same initial offsets at the entrance of the BDS of $\sigma_{x,y}/2$. Additionally, simulations at 1 TeV using the 3 TeV BDS lattice have been run, due to requests from the CLIC experiments.

Table 1: CLIC Parameters at 500 GeV and 3 TeV CEM

Parameters	**500 GeV / 3TeV**
Luminosity (x 10^{34})	2.3 / 5.9
Bunch charge (x 10^{9})	6.8 / 3.72
Bunch separation (ns)	0.5 / 0.5
Beam pulse duration (ns)	177 / 156
Bunch length (σ_z) (μm)	72 / 44
Hor. norm. emit. (nm rad)	2400 / 660
Vert. norm. emit. (nm rad)	25 / 20
BDS length (km)	1.73 / 2.79

Constant Radius

The offset differences last to first bunch along the BDS is shown in Fig. 1 (a) for the 3 TeV case and (b) for 500 GeV. The curves converge for $b = 8$ mm at 3 TeV and for $b = 12$ mm at 500 GeV. Our study suggest larger apertures at 500 GeV than at 3 TeV, which is due to the different lattice [3] and parameters of the machine (more bunches and more particles per bunch at 500 GeV than at 3 TeV). At 1 TeV, the beam is less rigid and therefore it is found that a larger aperture is required, the resistive wall effect is suppressed for $b = 14$ mm [4].



(a) 3 TeV

(b) 500 TeV

Figure 1: Resistive wall effect over the BDS for smooth pipes with different radius values.

Aperture Model

In this part, we include the aperture constraints coming from the magnets (found on [2]). At 3 TeV, there are two sectors where the apertures to be taken into account in the simulations are different from the beam pipe aperture. Firstly, in the region of energy collimation, the required aperture is higher than the beam pipe (around 25 mm scaled for a 8 mm beam pipe) in order to accomodate a high dispersion function of the beam. Secondly, in the Final Focusing System (FFS), the apertures of the magnets are smaller than the beam pipe in order for the magnet to reach higher magnetic fields. Considering this model, simulations have shown that the resistive wall effect at 3 TeV is suppressed for pipe radius larger than 6 mm, see Fig. 2. We would have expected a larger threshold than for the constant radius case, because of the smaller apertures in the FFS, where the β functions are high. In fact, we have found that the energy collimation section had an unpredicted stabilizing effect on the beam [4]. There, the wake functions are smaller due to the large aperture (see Eq. 1), which implies a smaller kick to all the bunches in this region. They become less off-centered, and then, even if the wake-functions in the FFS are larger, the resulting effect is smaller. The same behaviour has been observed at 1 TeV [4] with a required aperture of 10 mm.

At 500 GeV, there are no constraints from the magnets

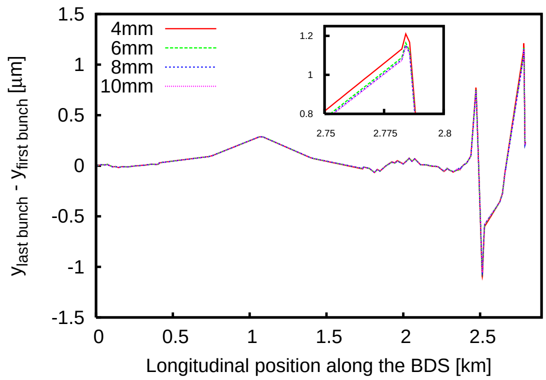


Figure 2: Resistive wall effect over the BDS considering a realistic aperture model at 3 TeV.

in the FFS since they require apertures not smaller than 14 mm, in order to accomodate enough space for the beam. In the energy collimation region, the lattice has been designed with apertures of roughly 14 mm. Both values are larger than the required aperture found in the first part. Therefore, as expected, we drew the same conclusions with this model as with the constant radius case [4].

Collimators

We finally also include the collimators [5] in our simulations. At 3 TeV, we assume that the spoilers are made of beryllium and extend over 177 mm (0.5 radiation-length (r.l.), with a vertical gap of 0.1 mm. The absorber are made of copper-coated titanium and extend over 712 mm (20 r.l.), with a vertical gap of 1 mm. With such small apertures, the range of validity of Eq. 1 is incompatible with the CLIC beam parameters, as we can see in Fig. 3 where we compare the classical formula with values as calculated in [6]. We therefore take those computed values to correctly evaluate the effect of the collimators. The wake functions are weighted by the Yokoya coefficients [7] before being applied to the bunches in order to account for the flat structure of the collimators. We can see in Fig. 4 that the effect is almost suppresed for $b = 8$ mm, and at $b = 10$ mm, it has disappeared. No simulations have been carried out for the 500 GeV energy case (the collimator parameters are not fixed yet). Compared to Fig. 1, we see that the value of the offset differences is higher than in the two previous cases, which shows that the collimators play a crucial role in the resistive wall effect. There, the wake functions are much larger than in the rest of the BDS. But compared to the FFS, the β functions in the collimation sector are very small [3], which keeps the effect of the collimators limited.

CONCLUSION AND OUTLOOK

We could establish minimum values of the beam pipe radius above which the resistive wall effect becomes negligible on the multi-bunch scale. From our study, a minimum

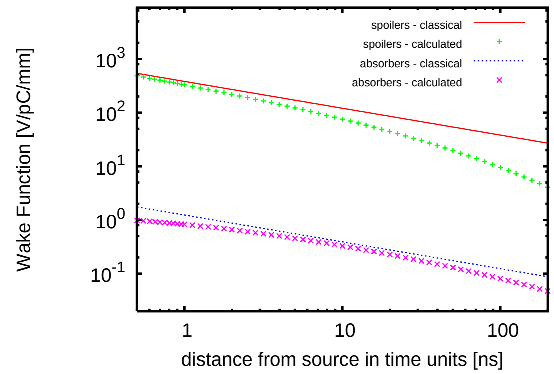


Figure 3: Comparing the classical (see Eq. 1) and the calculated wake functions [6] for beryllium spoilers and copper-coated titanium absorbers.

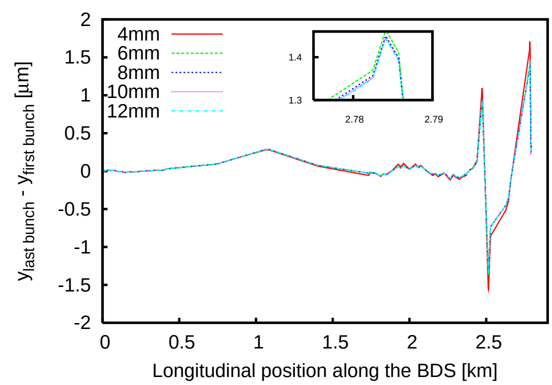


Figure 4: Resistive wall effect at 3 TeV considering a realistic aperture model and the collimators.

pipe radius of 12 mm at 500 GeV, and 10 mm at 3 TeV should be used in order to keep the optimum performances of the CLIC in the BDS. However, we only focused on the multi-bunch resistive wall effect from transverse dipolar wake fields on the beam. This study is a necessary starting point but in the following, both resistive wall and geometric single bunch effects should also be included.

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