DESIGN OF MOMENTUM SPOILERS FOR THE COMPACT LINEAR COLLIDER*

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Abstract

The postlinac energy collimation system of the Compact Linear Collider (CLIC) protects the machine by intercepting mis-steered beams due to possible failure modes in the linac. The collimation is based in a spoiler-absorber scheme. The mission of the spoiler is to protect the main downstream absorber by dispersing the beam, via multiple Coulomb scattering, in case of a direct hit. We present the design of energy spoilers for CLIC, considering the following requirements: spoiler survival to the deep impact of an entire bunch train, and minimisation of spoiler wakefield effects during normal operation. Different configurations of the spoiler are studied in order to achieve an optimum performance.

INTRODUCTION

The Compact Linear Collider (CLIC), operating at beam energies of the order of TeV, will collide beams with transverse energy density of the order of GJ/mm^2 (~6.2x10^{18} GeV/mm^2), resulting in a very high damage potential of the beam. Therefore, protection is necessary against mis-steered or errant beams, which can hit and damage components of the machine. In CLIC a postlinac energy collimation system is dedicated to intercept these mis-steered beams. This collimation system consists of an absorber and an upstream thin spoiler or scraper, whose purpose is to increase the angular divergence of an incident beam. This increases the beam size at the downstream absorber and reduces thus the risk of material damage in the absorber.

The mission of the spoiler for the CLIC energy collimators in the BDS is to protect the main absorber by dispersing the beam, via multiple Coulomb scattering, in case of a direct hit. This will reduce the beam energy density and therefore avoid severe radiation damage. To ensure that dispersion the beam must traverse at least 0.5 radiation lengths (X_0) of material at any point.

CLIC COLLIMATION SYSTEM

The CLIC beam delivery system (BDS), downstream of the main linac, consists of a 460 m long final focus system (FFS) [1], and almost 2000 m long collimation system.

Recently, the CLIC BDS has been optimised and updated according the new beam parameters [2]. However, no significant changes have been done to the collimation section where we can distinguish between two sections:

A 1375 m long section downstream of the main linac for energy collimation. This section fulfils an important protection function intercepting mis-steered beams, which may be produced by failure modes in the linac1. These failure modes determine the energy collimation depth. For CLIC a thin spoiler (0.5 radiation lengths) made of beryllium, located at a position with non-zero horizontal dispersion (D_x = 0.27 m), and a thick downstream absorber (20 radiation lengths) are dedicated to protect against beams with off-energy of about ±1.5 % of the nominal energy [3]. We have set the collimator aperture to intercept beam with energy deviation larger than 1.3 %.

Table 1: Overall Parameters of CLIC for centre-of-mass Energy of 3 TeV.

Parameter	Value
Centre-of-mass energy (TeV)	3
Energy spread (%)	1
Photons/electron	2.2
Main linac RF frequency (GHz)	11.994
Linac repetition rate (Hz)	50
Particles/bunch at IP (x10^9)	3.72
Bunch/pulse	312
Bunch length (μm)	45
Bunch separation (ns)	0.5
Bunch train length (μs)	0.156
Emittances $\gamma\varepsilon_x$/ $\gamma\varepsilon_y$ (10^{-8} rad•m)	66/2
Unloaded/loaded gradient (MV/m)	120/100
Beam power/beam (MW)	14
Total site AC power (MW)	322
Overall length (km)	47.9

Downstream of the energy collimation section, a dispersion-free section is dedicated to betatron collimation, i.e., to clean the transverse halo of the beam, reducing thus the experimental background in the interaction region. In total eight spoilers made of Be and and eight copper (Cu)-coated Titanium (Ti) absorbers are devoted to collimate the two transverse phases x-x' and y-y'. In this case, the necessary collimation depths are determined from the conditions that beam particles and synchrotron radiation photons emitted in the final quadrupoles should not hit any magnet apertures on the incoming side of the interaction point. According to this criterium, for the case of CLIC with 3 TeV centre-of-mass energy, the collimation depths were estimated to be less than 14 σ_x (horizontal plane) and 83 σ_y (vertical plane)

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[4]. However, due to nonzero dispersion across the final doublet, the number for the horizontal beam size σ_x includes both betatron and dispersive components, roughly equal in magnitude, such that the actual horizontal collimation depth at a place with zero dispersion needs to be √2 smaller, or about 10 σ_x. Due to recent changes in the vertical emittance (see Table 1) and the vertical beta function across the final doublet the initial vertical depth 83 σ_y has been reduced to 44 σ_y [5].

Unlike the momentum spoiler, the spoilers in the betatron collimation section were designed to be sacrificial, i.e. they would certainly be destroyed if they suffer the direct impact of a bunch train (for example, if the momentum collimators are not set properly).

CLIC SPOILER DESIGN CRITERIA

The spoiler effect on the beam during normal operation due to wakefield effects has to be reduced to a minimum. To achieve that, both the geometric contribution as well as the resistive contribution to the wakefield need to be minimised. A geometry with shallow leading and trailing tapers is used to reduce the impact on the geometry contribution and a high conductive material is recommended for the latter one. Therefore the first geometry considered has tapers with an angle of 0.03 radians and a center flat section of 0.5 radiation lengths of material. The material best suited for the tapers must be highly conductive as well as practically transparent for the beam, therefore present a large radiation length, to minimise the deposition of energy and avoid potential damage from the beam. Beryllium was selected for this purpose. For the flat section the requirement is to have a material with high conductivity as well as high fracture and melting temperature points. The options considered in this study are Titanium alloy (Ti6Al4V) and Beryllium. The alloy is more resistive than the Beryllium but its shorter radiation length, allowing for a shorter spoiler geometry, combined with its high fracture and melting points make it a good option. Beryllium tapers with Titanium alloy core is the most probable option for the ILC betatron collimation system spoiler design in the BDS as it could survive direct bunch hits at the same time that it allows for a reduction of length. As length does not seem to be an issue in the CLIC BDS the option with the Beryllium flat top presents the additional advantage of a better wakefield performance. Figure 1 and Table 2 describe all the different geometrical values used in the spoiler design.

Table 2: Geometrical Parameters of the CLIC Energy Spoiler.

Parameter	Value
Vertical half gap h [mm]	25.4
Horizontal half gap a [mm]	3.51
Tapered part radius b [mm]	6.21
Tapered part length L_T [mm]	90.0
Taper angle θ_T [mm]	0.03
Flat part length L_F [X_0]	0.50

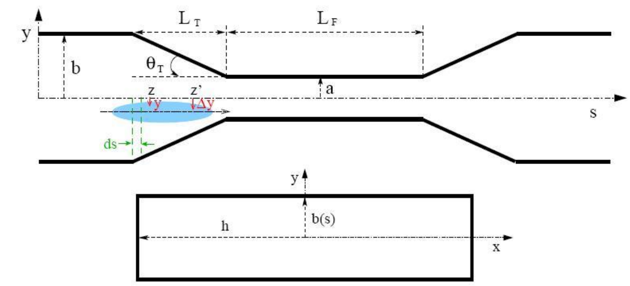

Figure 1: Top: longitudinal view of a tapered collimator. An oncoming particle bunch is schematically represented by the solid ellipse. Bottom: cross-sectional view in the case of a rectangular collimator.

The spoiler design has to survive the impact of the 312 bunches from the train. Each bunch is composed of 3.72E9 electrons at an energy of 1.5 TeV. The horizontal and vertical beam sizes at the spoiler's position is 796 and 21.9 microns respectively. That kind of impact was simulated for both options using FLUKA [6, 7].

SIMULATION RESULTS

Figures 2 and 4 show the temperature increment inside the spoiler material due to a train of bunches hitting at the same position (i.e. without jitter), 2 mm from its top as shown in figures 3 and 5. This temperature increment is the maximum one and is located in a volume of material surrounding the beam. The Beryllium spoiler, figure 2, will not reach melting temperature (1267 K) but it will reach fracture temperature (370 K) in the trailing taper. The Titanium alloy flat top of the other spoiler option, figure 4, would probably surpass fracture temperature (1710 K) and it is close to its melting temperature of 1941 K. In this case the trailing taper, made out of Beryllium, will reach its fracture point as well.

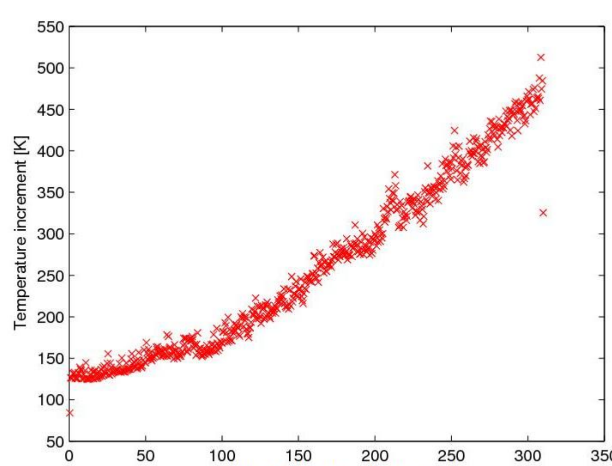

Figure 2: Instantaneous increment of temperature in a Be spoiler with shallow tapers and L_F = 17.65 cm due to the impact of an entire CLIC bunch train.

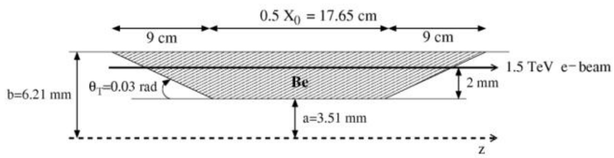

Figure 3: Schematic of the geometry used for the Be spoiler. Figure is not to scale and the taper angle has been exaggerated.

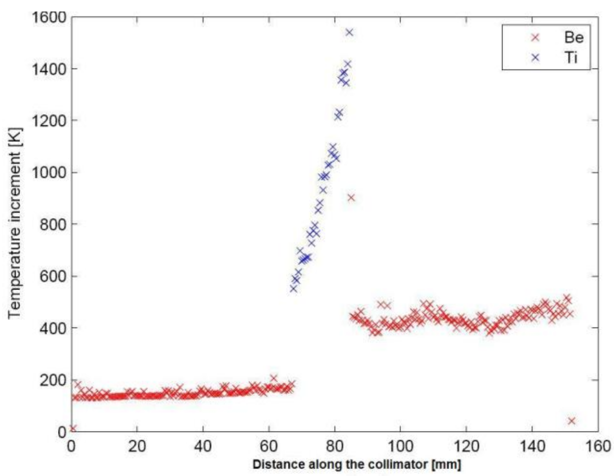

Figure 4: Instantaneous increment of temperature in a Be spoiler with shallow tapers and L_F = 17.65 cm due to the impact of an entire CLIC bunch train.

Figure 5 shows the geometry used in the Ti alloy flat top plus Be tapers case. The Beryllium option flat top would have a length of 17.65 cm instead of the 1.8 of the alloy.

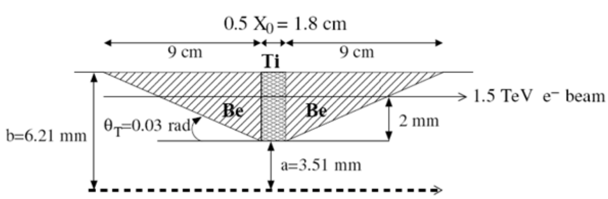

Figure 5: Schematic of the geometry used for the Ti alloy spoiler plus Be tapers. Figure is not to scale and the taper angle has been exaggerated.

Table 3: Summary of Simulated Results

Spoiler	Max. ΔT[K]	Fracture temp. [K]	Melting temp. [K]	Result
Full Be	~500	370	1267	Fracture
Ti alloy + Be tap.	~500*/ 1600**	370*/ 1710**	1267*/ 1941**	Fracture

* For the Be.
** For the Ti alloy.

Table 3 summarises the instantaneous increment of temperature due to the collision of the bunch train into the two different spoiler options. Such instantaneous increment of temperature would translate into micro-fractures inside both materials. The Ti alloy is also dangerously close to reaching melting temperature.

CONCLUSIONS

While it is relatively clear what reaching melting temperature on the spoiler would mean: material being blown into the vacuum vessel, irregularities on the surface of the spoiler, etc; it is not clear what the effects of a micro-fracture would imply. Therefore further studies are needed to understand the effect of fractures on spoiler properties as well as research other spoiler configurations that would allow full survivability. These studies should be done in parallel with a wakefield study to optimise the design, both using numerical codes and test beam experiments, as have already been done for the ILC spoilers [8]. Also studies of activation and residual equivalent dose rate once prototypes start to be designed. Another issue would be the design of a system that would detect damage in the spoilers.

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