THERMO-MECHANICAL ANALYSIS OF THE CLIC POST-LINAC ENERGY COLLIMATORS

J. Resta-Lopez, IFIC (CSIC-UV), Valencia, Spain
J. L. Fernandez-Hernando, ASTeC, Daresbury, UK
A. Latina, CERN, Geneva, Switzerland

Abstract

The post-linac energy collimation system of the Compact Linear Collider (CLIC) has been designed for passive protection of the Beam Delivery System (BDS) against miss-steered beams due to failure modes in the main linac. In this paper, a thermo-mechanical analysis of the CLIC energy collimators is presented. This study is based on simulations using the codes FLUKA and ANSYS when an entire bunch train hits the collimators. Different failure mode scenarios in the main linac are considered. The aim is to improve the collimator in order to make a reliable and robust design so that survives without damage the impact of a full bunch train in case of likely events generating energy errors.

INTRODUCTION

The CLIC post-linac collimation system [1, 2] has been designed to play an essential role in reducing the detector background at the Interaction Point (IP), and protecting the machine by minimising the activation and damage of sensitive accelerator components. The first post-linac collimation section is dedicated to energy collimation. It is based in a spoiler-absorber scheme which protects the BDS against miss-steered beams. Failure modes in the main linac resulting in energy errors are the most likely scenarios to generate miss-steered beams in the BDS.

The CLIC energy collimators have been designed with the requirement of surviving the impact of a full bunch train. In this paper the robustness of the energy spoiler is investigated. A study of the thermo-mechanical features of the collimators is performed using the codes FLUKA [3] and ANSYS [4]. For a spoiler made of beryllium, preliminary simulations in Ref. [5] showed that fractures may be generated on the spoiler surface after a bunch train (312 bunches) hits it. However, it must be pointed out that in those simulations a monochromatic pencil beam with the nominal parameters was considered, which is a quite pessimistic and non-realistic scenario. In this paper we have improved those simulations, considering more realistic damage scenarios, and studying the beam distribution at the spoiler position. Here we focus on failure modes causing a significant energy deviation at the end of the main linac and subsequent beam impact on the energy spoiler in the BDS. Failures causing betatron errors are studied elsewhere [6].

FAILURE MODES

Here we review failure modes in the CLIC main linac which can originate energy errors. We are specially interested on energy offsets generating big transverse orbit amplitude in the BDS, in such a way that the beam hits the energy spoiler. Concretely the following failure modes affecting energy are investigated: injection phase error, RF breakdown, missing drive beam and change in the beam charge.

Tracking simulations through the main linac and the BDS for a nominal CLIC beam have been performed using the code PLACET [7]. In the main linac the beam is accelerated from the initial energy 9 GeV to the final energy 1.5 TeV. A perfect linac has been assumed, i.e. no lattice imperfections have been introduced. In this simulations we have assumed fast failures produced between two pulses. After introducing the failure error, the bunch train (312 bunches) is tracked through the main linac. For the beam density study in the BDS, the multi-bunch distribution at the exit of the main linac is binned in 10000 macroparticles and tracked along the BDS. Then we obtain the transverse beam distribution at the energy spoiler, and use it as the input for the thermo-mechanical evaluation of the spoiler.

Injection Phase Error

If the beam is injected into the linac at a wrong phase, the beam energy deviates from the nominal value and is miss-steered. Figure 1 shows the trajectory of the beam centroid in the BDS for different injection phase errors at the main linac entrance. For phase error $\gtrsim +5^o$ and phase error $\lesssim -3^o$ the beam hits the energy spoiler (ESP). For instance, for -5^o phase error one has an energy loss $\Delta E/E_0 \simeq -2.4\%$, and the beam impinges on the surface of the spoiler jaw at $x = -6.67$ mm from the beam axis. The transverse beam distribution at ESP for -5^o phase error is shown in Fig. 2. In this case, the rms vertical and horizontal beam sizes are $\sigma_y = 26.45$ μm and $\sigma_x = 757.72$ μm, respectively, with approximately 1% full energy spread.

RF Cavity Fail

A significant energy deviation could also be generated by the fail or misfunction of a certain number of RF cavities (e.g., RF breakdown, missing drive beam). For simplicity, here we consider the dramatic case of the total and simultaneous fail of several RF structures. Figure 3 shows the

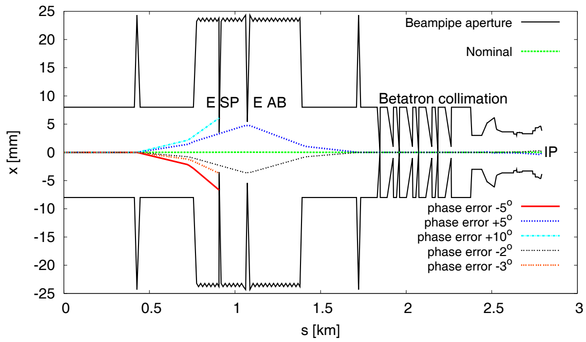

Figure 1: Beam trajectories in the BDS considering different phase errors at the main linac entrance. The beampipe aperture limit is shown as well as the collimator apertures.

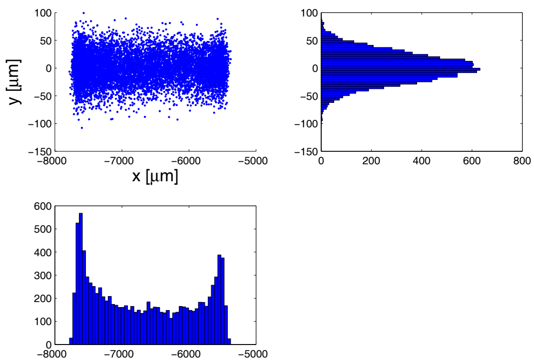

Figure 2: Particle distribution at the energy spoiler (ESP) for a phase error -5^o.

beam trajectory in the BDS when different number of cavities are switched off in the last section of the main linac. When more than 1000 cavities are switched off, the beam impinges on ESP. For example, if 1500 cavities fail in the last part of the linac, we have a deep impact on the ESP surface at $x = -5.23$ mm from the beam axis. For this case, the corresponding beam distribution at ESP is shown in Fig. 4, where $\sigma_x \simeq 1$ mm, $\sigma_y = 25.4$ μm, 1471 GeV mean energy and 1.15% full energy spread.

In terms of spoiler damage, the case of the total failure of a series of RF cavities at the start of the linac is less critical, since the energy spread increases and the beam suffers a rapid filamentation. For instance, for more than 400 RF structures switched off at the beginning of the linac, we obtain that about 55% of the beam distribution is lost along the linac and at the beginning of the BDS, and a significant reduction of the transverse beam density occurs due to filamentation.

Beam Charge Error

We have also evaluated the energy deviation due to beam charge variation in the range $[-50\%, +50\%]$ charge error. However, for this case, the resulting energy deviation

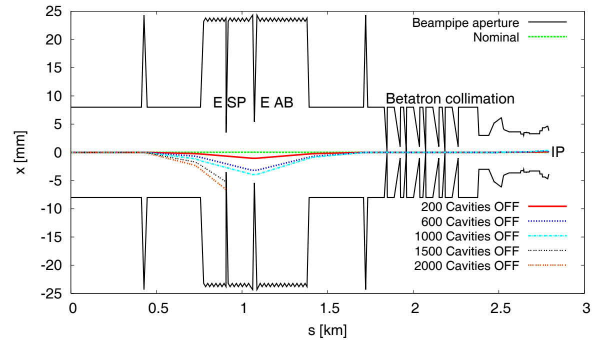

Figure 3: Beam trajectories in the BDS considering different number of RF cavities switched off at the end of the main linac. The beampipe aperture limit is shown as well as the collimator apertures.

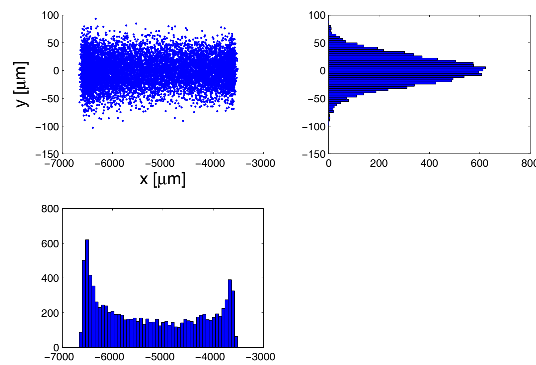

Figure 4: Particle distribution at the energy spoiler (ESP) assuming 1500 RF structures off at the end of the main linac.

is relatively small for the beam to be caught in the energy spoiler.

ENERGY SPOILER

The spoilers are thin devices ($\lesssim$ 1 radiation length) which scrape the beam halo and, if accidentally struck by a full power beam, will increase the volume of the phase space occupied by the incident beam via multiple Coulomb scattering. In this way, the transverse density of the scattered beam is reduced for passive protection of the downstream absorber (see Ref. [1] for more details). Figure 5 shows the geometric structure of a conventional spoiler, with design parameters in Table 1.

We have evaluated the damage level of the CLIC energy spoiler when a full bunch-train deeply impinges on it for the following critical failure scenarios (see previous section):

- Case 1: injection phase error of -5^o in the main linac.
- Case 2: A number of 1500 RF cavities fails in the last section of the main linac.

ISBN 978-3-95450-115-1

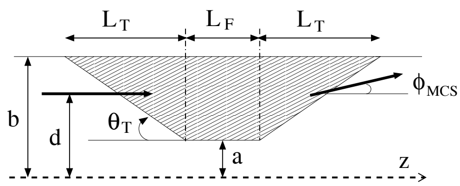

Figure 5: Spoiler jaw longitudinal view.

Table 1: Design Parameters of the CLIC Energy Spoiler

Parameter	Spoiler ESP
Geometry	Rectangular
Hor. half-gap a_x [mm]	3.51
Vert. half-gap a_y [mm]	8.0
Tapered part radius b [mm]	8.0
Tapered part length L_T [mm]	90.0
Taper angle θ_T [mrad]	50.0
Flat part length L_F [radiation length]	0.05
Material	Be

The transverse particle distribution at ESP for both case 1 (Fig. 2) and case 2 (Fig. 4) is used as input for the thermo-mechanical analysis of the spoiler. The heat load in the spoiler is calculated using the FLUKA Monte Carlo code [3] for particle tracking and particle interactions with matter. Then the mechanical stress build-up due to the thermal shock is evaluated using the code ANSYS [4]. In this study the figure of merit is the equivalent stress s_{eq}, also called *von Mises stress*,

$$s_{\text{eq}} = \frac{1}{\sqrt{2}}\sqrt{(s_1 - s_2)^2 + (s_2 - s_3)^2 + (s_3 - s_1)^2}, \quad (1)$$

where s_1, s_2 and s_3 are the principal stresses at a given position in the three main directions of the working coordinate system, which in our case is Cartesian.

Figure 6 shows the equivalent stress evolution during 500 μs after a full CLIC bunch train has impinged on the spoiler. The result is compared with the deformation limit (tensile yield strength) for Be, 240 MPa, and with the fracture limit (ultimate tensile strength) for Be, 370 MPa. For the case 1, s_{eq} reaches a peak (after 300 μs) which surpasses the fracture limit. For the case 2, s_{eq} is well below the fracture limit, but it stabilises near the deformation limit, so there might be a permanent deformation.

CONCLUSIONS

Studies on failure modes in the CLIC main linac are in progress. The aim is to investigate and identify realistic failure mode scenarios which are critical in terms of collimator damage. Concretely we have studied failures which could generate a significant beam energy deviation, in such a way that the beam directly impacts on the energy spoiler. A beam tracking simulation along the linac and the BDS, assuming failure modes between pulses, allowed us to obtain the beam trajectory and the transverse density of the bunch train at the energy spoiler position. This information has been used as input to the thermal-mechanical analysis of the spoiler, using the codes FLUKA and ANSYS. Two different scenarios that lead to deep beam impact on the energy spoiler have been analysed. Results show that, considering the nominal beam parameters, it may be difficult to avoid fracture or there might be a permanent deformation of the spoiler surface. Further studies have to be performed to evaluate the real magnitude of the fracture or the deformation. For example, a permanent deformation could translate into an increase of the roughness of the surface of the spoiler, hence increasing wakefield effects.

One can conclude that guaranteeing the energy survivability of the present CLIC spoiler design, assuming the nominal beam parameters of CLIC, is very challenging. In order to reduce the risk of damage to the spoiler, alternative materials and geometric designs of the spoiler are being studied. Another alternative solution could be the use of nonlinear optics [8].

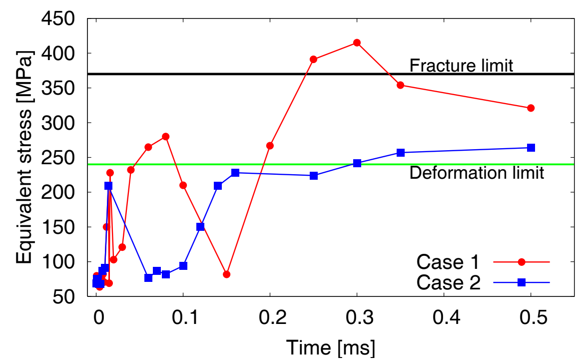

Figure 6: Equivalent stress as a function of time after a bunch train has hit the spoiler surface for the following failure mode scenarios: for -5^o injection phase error (case 1) and for 1500 RF cavities switched off (case 2).

REFERENCES

[1] J. Resta-Lopez et al., CLIC-Note-883 (2011).

[2] CLIC CDR, 2012.

[3] A. Fasso et al., "FLUKA: a multi-particle transport code", CERN-2005-10 (2005).

[4] `http://www.ansys.com` (ANSYS® v. 11.0 Academic Research.

[5] J. L. Fernandez-Hernando et al., Proc. of IPAC11, San Sebastián, Spain, TUPS041.

[6] C. Omar Maidana et al., These Proceedings, THPPR041.

[7] `https://savannah.cern.ch/projects/placet`

[8] J. Resta-Lopez, A. Faus-Golfe, These Proceedings, TUPPR017.