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TUNING OF CLIC-FINAL FOCUS SYSTEM 3 TeV BASELINE DESIGN UNDER STATIC AND DYNAMIC IMPERFECTIONS

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Abstract

In this paper we present the tuning study of the Compact Linear Collider - Final Focus System (CLIC-FFS) 3 TeV baseline design under static and dynamic imperfections for the first time. The motion of the FFS magnets due to ground motion and the impact of active and passive mechanisms envisaged to stabilize both e^- and e^+ systems are described. It is found that the Pre-isolator required for stabilization of the Final Doublet drives the performance of the collider at the final stages of the tuning process. The obtained tuning performance depending on the stabilization techniques are discussed in detail.

INTRODUCTION

The Compact Linear Collider (CLIC) [1] aims to collide e^- and e^+ at the Interaction Point (IP), at center-of-mass energy of 3 TeV, delivering a nominal luminosity ($\mathcal{L}_0$) of 5.9×10^{34} cm^{-2} s^{-1} to the experiments. The required transverse beam sizes at the IP ($\sigma^*_{x,y}$), of the CLIC baseline design, are 40 nm and 1 nm in the horizontal and vertical planes, respectively. These nano-beam sizes are achieved by means of the Final Focus System (FFS) based on the local chromaticity correction, first proposed in [2]. The Final Doublet (FD), composed of the last two quadrupole magnets of the FFS namely QF1 and QD0, is responsible to focus the beam in both planes at the IP. For the CLIC baseline design QD0 is located 3.5 m upstream the IP, falling into the detector volume which makes the machine detector interface rather complicated. An alternative CLIC-FFS design is being pursued in which QD0 is placed outside the detector offering a simple solution at the expense of increasing the chromaticity introduced by the FD. Given the unprecedented small vertical beta-function at the IP ($\beta^*_y = 68\mu m$), required to reach the 1 nm vertical spot size, significant tuning difficulties under machine imperfections are expected as they scale as $1/\sqrt{\beta^*_{x,y}}$, according to [3].

Tuning studies at the FFS assuming realistic imperfections are mandatory to asses its feasibility. Usually, simulations of 100 machines with different static imperfections are considered to verify the robustness of the FFS of both e^- and e^+ systems against machine imperfections. Past tuning studies [4] of the CLIC-FFS baseline design showed that 90% of the machines reach a $\mathcal{L} \geq$97% of $\mathcal{L}_0$ after 15000 luminosity measurements when considering only static imperfections such as beam position monitor alignment and resolution and strength errors and alignment of the magnets in both beamlines. This is 13% shorter than the target goal, being 110% of $\mathcal{L}_0$. The 10% extra margin of $\mathcal{L}$ accounts for dynamic imperfections.

Dynamic imperfections are the next ingredient to be included into simulations in order to address their impact on the tuning performance. Among all possible dynamic imperfections, technical equipment noise (e.g. power supply ripple), magnetic stray-fields and Ground Motion (GM) are expected to be the most dominant. The latter is the one considered into this paper. Currently the impact of magnetic stray-fields is under study [5] by the CLIC collaboration, the present status is reported in [6].

In the following sections a description of the GM model implemented in the study as well as the considered mitigation techniques are presented. The tuning study which includes the considered imperfections, its algorithm and the results obtained in terms of luminosity and time are presented.

GROUND MOTION

Different GM models based on measurements performed in accelerator laboratories and on historical data have been established [7], also an extensive review of the current state has been given in [8]. Two different generators are available for the ground model, one for short time and another one for long time scales ('ATL-law'). The short range describes precisely the motion within minutes although it could be partially used for longer times as it contains some of the low frequency spectra. In contrast the ATL-law model is only valid for periods longer than few hours. Several sites have been measured and the obtained models are shown in Fig. 1.

Ground motion will cause a luminosity degradation due to local and global dynamic effects. A beam-beam offset at the IP is mainly introduced by the local motion of the FD. Moreover an emittance growth will occur due to the global motion of all magnets of the FFS. Therefore several mitigation techniques are required to limit the movement of

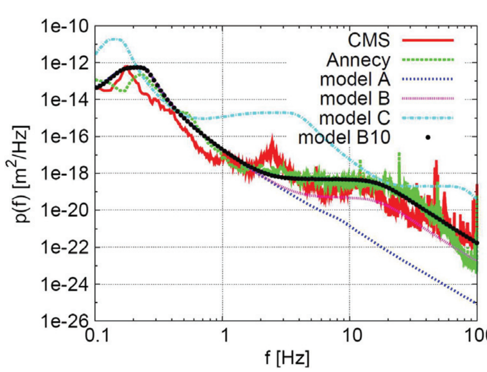

Figure 1: Power spectral density of ground motion at several sites and models. Figure taken from [9].

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the magnets due to ground motion within tolerable levels, as discussed in [9]. Firstly, a large mass namely the pre-isolator [10] is designed to satisfy the sub-nm tolerances required in the vertical plane [11] for both QF1 and QD0, as a consequence of the small vertical beam size at the IP. In addition an IP beam position feed-back [12] is also foreseen to correct for the relative offset of the lepton beams observed via the deflection angle of the colliding beams.

The global mitigation technique includes an active stabilization system [14] on top of which the girders are mounted on, and an orbit feed-back which uses beam position readings to suppress the observed beam oscillations due to GM [15].

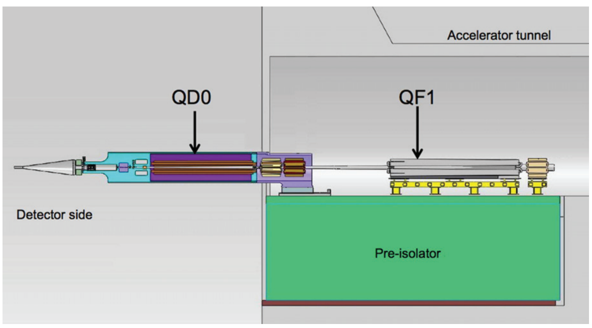

Figure 2: Sketch of the adopted GM mitigation technique for the FD magnets (QD0 and QF1). In green, the large mass representing the pre-isolator. Figure taken from [13].

TUNING STUDY

Monte-Carlo simulations are used to asses the tunability of the CLIC-FFS against machine imperfections. a total of 100 machines lattices with different static imperfections are randomly generated by distributing the imperfections on magnets and BPMs. The list of considered static imperfections is shown in Table 1. After that the tuning algorithm is applied for each machine. The algorithm is the same as used in the tuning study under static imperfections [4], which consists of beam-based correction techniques and the scan of a set of pre-computed knobs that target the most dominant linear and non-linear aberrations at the IP. During the scan of the knobs the ground motion generator computes the new position of the magnets at every luminosity measurement. The IP is the origin of our reference system used to determine the motion of both FFSs, thus all computed displacements are with respect to the IP. The GM model B10 shown previously in Fig. 2 is the one considered in our study since it fits the measurements at LAPP in Annecy (France), region close to the future CLIC site and it also includes the technical noise measured in the CMS hall. The considered time interval for evaluation of the new position of the girders due to GM is chosen to be 0.02 s, since CLIC is running at a repetition frequency of 50 Hz. Therefore the short time GM generator is used. However it should be noted that in reality the time between luminosity measurements is expected to be around 0.8 s, in order to obtain a measurement resolution below 1% which is required for tuning, as discussed in [16]. Nevertheless an extra buffer time of 1.2 s should be given for allowing the hardware (e.g magnet movers) to properly set to the required values obtained by the tuning knobs (to be done in future studies).

Table 1: List of considered static imperfections included in the current study

Imperfection	Unit	σ_{error}
BPM Transverse Alignment	[μm]	10
BPM Roll	[μrad]	300
BPM Resolution	[nm]	20
Magnet Transverse Alignment	[μm]	10
Magnet Roll	[μrad]	300
Magnet Strength	[%]	0.01

The GM mitigation techniques presented in the previous section, namely the active stabilization system, the beam-based orbit feedback and the pre-isolator, are implemented in our simulations. Additionally an ideal IP feed-back is also included in our algorithm, since the relative offset between the e^- and e^+ beams at the IP obtained after tracking, is removed before collision. Typically 100 000 macro-particles are tracked through both systems by means of the tracking code, PLACET [17], after, the luminosity is evaluated by GUINEA-PIG [18].

Due to the expected large number of knobs scan or luminosity measurements required for tuning, the simulation effectively expands over few weeks, though in reality the collider will reach convergence in just few hours. Therefore the time stamp before and after each scan is kept through the entire simulation.

Tuning Results

Results are presented at in form of accumulated histograms, since the tuning target is specified for 90% of the simulated machines. Fig. 3 shows the accumulated luminosity histogram obtained in 4 different conditions; after beam-based alignment corrections are applied (red), after scanning the linear knobs (green), after scanning the non-linear knobs (blue) and after scanning the non-linear knobs without including the pre-isolator in the simulation (black), see later the justification. Fig. 4 shows the mean value of the obtained luminosity for all 100 machines versus the number of luminosity measurements. Surprisingly, the number of luminosity measurements required by the non-linear knobs, shown by the blue curve of Fig. 3, is roughly 24000, though the luminosity only improves about 10%. During this period the evolution of the machines is driven by GM which makes the scanning of the knobs a non effective process. The mean value of the luminosity stays within 10% without experiencing a clear improvement nor a substantial degradation. Looking into detail, the cause of this behavior is the pre-isolator designed to stabilize the FD quadrupoles. When it was removed from the model the luminosity starts to notably improve for all machines, as shown by the black curve in Fig. 4. It should be noted that convergence has

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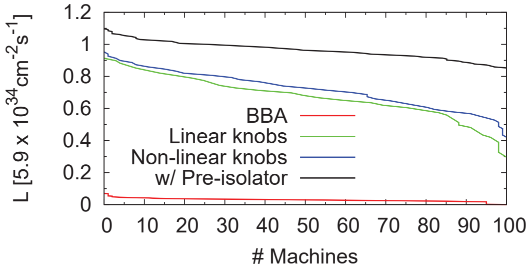

Figure 3: Accumulated histograms obtained throughout the tuning procedure. Red curve shows the results after applying the beam-based alignment corrections. Green and blue curves show the histograms obtained after applying the linear and non-linear knobs, respectively. Black curve is obtained after scanning linear and non-linear knobs without the pre-isolator.

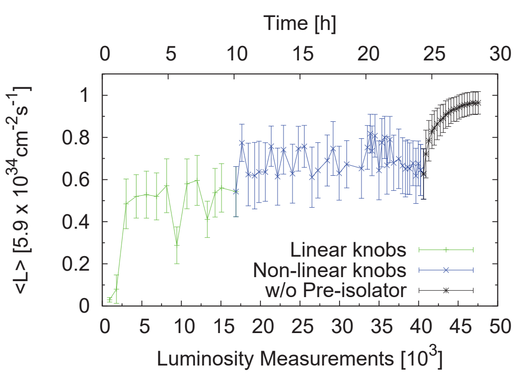

Figure 4: Evolution of the mean value of the luminosity and its standard deviation of the 100 machines versus luminosity measurement or equivalently in time (top horizontal axis) if assuming that each $\mathcal{L}$ measurement takes 2 s. The colour code correspond to the different tuning conditions presented in Fig. 3. The corresponding time in hours is shown on the upper horizontal axis.

not yet been reached, though the gain after every scan is becoming smaller, bringing the tuning study into a slow but steady process, as it was already observed in the static tuning study [4]. So far, 90% of the machines reach a $\mathcal{L} \geq 89\%$ of $\mathcal{L}_0$ after ≈47000 luminosity measurements. However 24000 measurements were not effective due to the presence of the pre-isolator, see blue curve in Fig. 4. Investigating into the impact of the pre-isolator onto the system dynamics, it was found that basically it decouples the motion of the FD quadrupoles with respect to the rest of the beamline. Fig. 5 shows the rms position of every quadrupole in of both e^- and e^+ FFSs with and without pre-isolator over a period of 2 seconds.

In terms of the real tuning time, the 23000 effective luminosity measurements would translate into more than 12 hours if assuming that every luminosity measurement is obtained after 2 seconds.

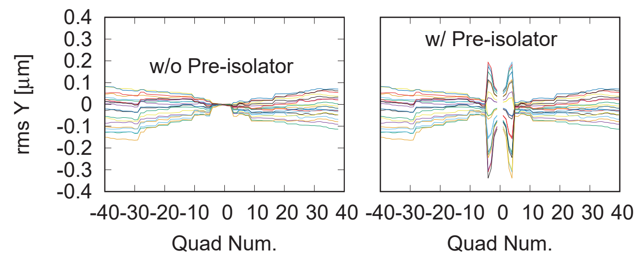

Figure 5: Left and right plots show the vertical position of the quadrupole magnets of the CLIC-FFSs, without and with the pre-isolator, respectively. The IP is at the origin of the x-axis. The interval time between lines is 0.1 s.

CONCLUSIONS

The CLIC-FFS tuning study has included for the first time static and dynamic imperfections into the tuning procedure. Transverse alignments and rotations imperfections of the system components, BPM reading errors and magnet strength errors are the static imperfections assigned at the start of the tuning. Dynamic contributions to the magnets motion due to ground motion are now also included into simulations, which brings the study into a more realistic scenario. The number of luminosity measurements required for tuning 90 % of the machines at a luminosity ≥ 89% of $\mathcal{L}_0$ is of the order of 47000, though 24000 measurements were not effective due to the presence of the pre-isolator. Removing this element from the simulation was essential to reach the mentioned performance, therefore the alternative design of the CLIC-FFS with longer L^* [19] would be the preferable design also from a tuning perspective, since there is no need of such a pre-isolator element as QD0 is placed outside the detector volume.

Additional knob scans could further improve this results at expenses of increasing the number of measurements. However this number could be reduced by improving the procedure, for instance the knobs should be always scanned on the largest e^- or e^+ beam size at the IP.

Looking into next studies, a more complete set of dynamic imperfections such as power supplies stability or magnet movers precision should be included. Also the interval time used by the GM generator should be increased from 0.02 s to 2 s to fully address the impact of GM on a short time scale. In addition the performance of the orbit feed-back could also be integrated into the simulations, but the complexity and computing time of the simulations would increase significantly. These results are comparable to ones obtained for the International Linear Collider (ILC) [20] where 90 % of the machines reach ≥85 % of $\mathcal{L}_0$ (more details can be found in [21]). It should be mentioned that although the machines reach comparable performances, the ILC study includes a more complete static and dynamic imperfections.

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