CLIC TUNING PERFORMANCE UNDER REALISTIC ERROR CONDITIONS

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Abstract

In this paper we present the latest results regarding the tuning study of the baseline design of the CLIC Final Focus System. In previous studies, 90% of the machines reach 90% of the nominal luminosity, when considering beam position monitor errors and transverse misalignments of magnets for a single beam case. In the present study, roll misalignments and strength errors are also included for both e^- and e^+ beamlines, making the study a more realistic one. First, second and third order knobs are implemented in the tuning procedure to target the most relevant beam size aberrations. In order to minimise the total number of luminosity measurements a simultaneous scan of various knobs has been developed to cope with the non-fully orthogonality of the knobs. The obtained results for single and double beam studies are presented.

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 $5.9 \cdot 10^{34}$ cm^{-2} s^{-1} to the experiments. The required transverse beam sizes at the IP ($\sigma_{x,y}^*$) for the baseline design of the FFS of CLIC, are 40 nm and 1 nm in the horizontal and vertical planes respectively. These small beam sizes imposes unprecedented tuning difficulties to the CLIC Final Focus System (FFS), which is based on local chromaticity correction scheme [2]. Assessing the tunability of the system under realistic error conditions is of vital importance to determine its feasibility. Monte-Carlo simulations are used to sample different initial error configurations. The tuning goal is that 90 % of the machines reach 110 % of $\mathcal{L}_0$, the 10% extra margin over $\mathcal{L}_0$ is set to account for dynamic imperfections. Past tuning studies were conducted for single beam (i.e. e^- and e^+ were assumed to be identical) and double beam. The results can be found in [3] and [4] respectively. In both studies, beam position monitor errors and transverse misalignments of the magnets were considered in simulations. The single beam study showed that 90 % of the machines reach ≥90 % of $\mathcal{L}_0$ after 18000 luminosity measurements. The double beam study was initiated and the first results showed that only 20 % of the machines reach ≥20 % of $\mathcal{L}_0$. In the following, we present the latest tuning results of a more realistic case, since additional errors as roll misalignments and strength errors are included in both e^- and e^+ beamlines. The results of two tuning studies are presented, the first one (*Single Beam*) assumes identical e^- and e^+ systems, whereas the second one (*Double Beam*) treats the systems independently.

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Table 1: List of Errors Included in Study

Error	Unit	σ_{error}
BPM resolution	[nm]	10
Magnet Alignment (x,y)	[μm]	10
Magnet Roll	[μrad]	300
Strength	[%]	0.01

TUNING STUDY

100 different machines are simulated using the tracking code PLACET [5]. Each beam is populated by 10^6 lepton, which are transported from the entrance of the FFS to the IP. The obtained beam distributions at the IP are then handled to GUINEA-PIG [6] for evaluating the luminosity with an error of about 1 % [3].

Errors

The static errors assumed in this study are randomly assigned to the elements of both e^- and e^+ systems, following a Gaussian distribution of width σ_{error}. The complete list of errors are summarised in Table 1.

Procedure

Once errors are included in the model the obtained luminosity is a few orders of magnitude lower than the nominal one. The procedure consists of different steps. Initially beam-based alignment (BBA) techniques, *1-to-1* [7] and *Dispersion-free-steering* [8] (DFS) are applied with all non-linear magnets switched off. After flattening the orbit and reproducing the dispersion profile at its best, the non-linear magnets are switched on and aligned, one by one using the so-called shunting technique [9, 10]. In following iterations DFS is repeated but with the multipole magnets at their nominal strength. At this point the most important beam aberrations present at the IP are waist shift, coupling and dispersion. A set of linear knobs is pre-computed using sextupole displacements in the transverse plane to target the mentioned aberrations. Additionally, dispersion-knobs, constructed by means of the existing correctors, are also obtained by decomposing the dispersion response matrix using *SVD*-analysis. Only the first four singular values are found to reduce the beam size. The linear and dispersion knobs are iteratively scanned until no further improvement in terms of luminosity is observed. At this point the IP beam distributions are analysed to figure out the remaining aberrations present in the system. Figure 1 shows the cumulative histograms of IP beam sizes when the second order aberrations are individually removed. Thus the lower curves on Fig. 1 correspond to those aberrations that would reduce σ_x^*
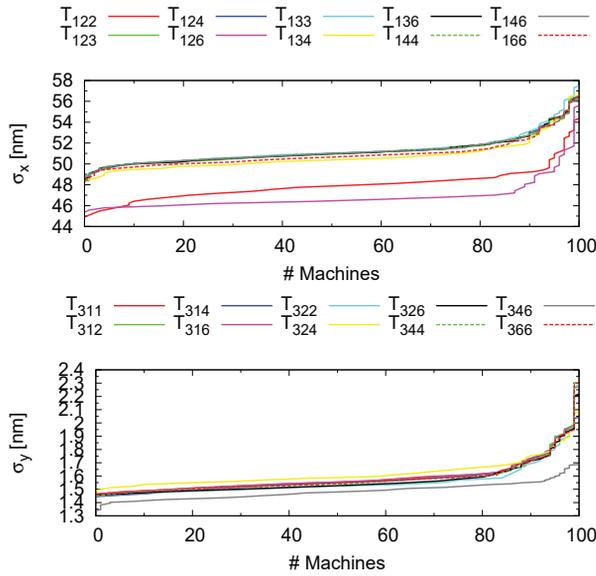
Figure 1: Cumulative histograms over 100 IP beam distributions of σ_x^* (top) and σ_y^* (bottom), when individually removing the second order correlations.

Figure 2: Relative variation of T_{126}, T_{122}, T_{346} and T_{322} correlations when scanning the second order knobs.

(top plot) and σ_y^* (bottom plot) the most. Knobs to target the T_{126}, T_{122}, T_{346} and T_{322} aberrations are necessary to further improve the tuning performance of the procedure. The aberrations are defined as,

$$T_{i,j,k} = \frac{< x_i, x_j, x_k >}{\sigma_{x_i}\sigma_{x_j}\sigma_{x_k}} \qquad (1)$$

where $1 \leq i, j, k \leq 6$ and $x_{i,j,k}$ can be x, x', y', y', s or $\frac{\Delta p}{p}$. The mentioned second order knobs, are constructed by means of magnet strength variations of sextupole magnets. To better target the T_{322} aberration, coupling between the y, x', x' coordinates, 4 skew sextupole magnets are introduced in each beamline, following the same criteria as discussed in [13]. The obtained second order knobs are shown in Fig. 2, it is clear that their orthogonality is compromised. The designed knobs are optimized against luminosity, by applying the Brent [11] minimization algorithm, as it is fast and robust against noisy signals. However due to the non-fully orthogonality of the designed knobs, an alternative optimization method is developed, as a counter-measure to the observed coupling between the knobs. Indeed scanning the complete set of non-linear knobs, by using the Simplex [14] algorithm, would equally or better correct for all targeted aberrations in less measurements, than individually scanning the knobs by the Brent method, described above. Though it should be mentioned that the Simplex approach is not as robust as the parabolic fit when optimizing for noisy signals.

The second order knobs introduce linear correlations that need to be corrected by scanning the linear knobs. Therefore each set of linear and non-linear knobs are scanned iteratively until convergence is achieved. Once no further improvement is observed we proceed to analyse the remaining aberrations. One discovers that the 3rd order aberration
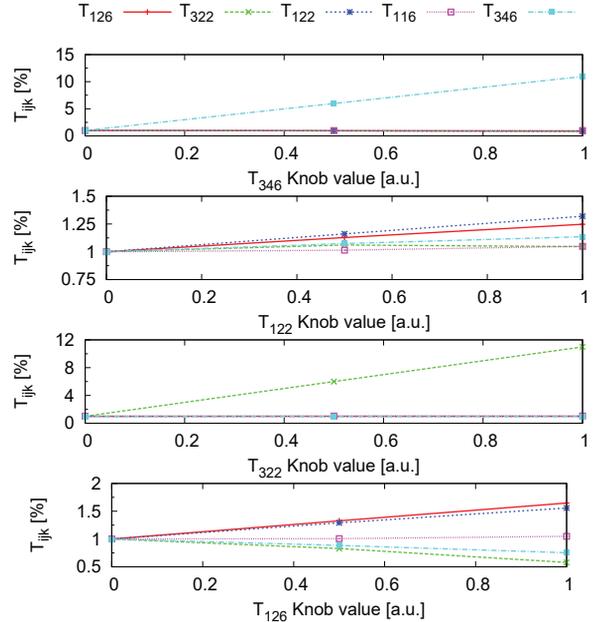
U_{3222}, becomes relevant as the first and second order correlations are significantly minimised. To target this high-order aberration, the octupole magnet present in the vicinity of the final doublet quadrupoles is used.

TUNING RESULTS

Single Beam

In this case, the luminosity is computed assuming that both systems are identical, in other words, the same beam distribution at the IP is assigned for both e^- and e^+ beamlines. Figure 3 shows the accumulated luminosity histogram obtained for 100 machines at every tuning scan. The first one (red-solid curve) correspond to the luminosity obtained after applying the BBA correction algorithm. By optimizing iteratively the linear knobs, 90% of the machines reach $\geq 80\%$ of $\mathcal{L}_0$. It is worth mentioning that some machines required additional BBA steps to reach the mentioned luminosity. Afterwards the 2nd order knobs are scanned (green-dashed curve), boosting the obtained luminosity up to ≥ 95 % of $\mathcal{L}_0$ for 90 % of the machines. In order to further improve the results, U_{3222}-knob is included in the tuning procedure (blue curve). By doing so, we managed to bring 90 % of the machines to a $\mathcal{L} \geq 102$ % of $\mathcal{L}_0$. The non-labelled curves in Fig. 3 show intermediate scans. Each scan comprises the optimization of one set of knobs, namely DFS, linear or non-linear knobs. The total number of luminosity measurements is of the order of ≈ 6000. Figure 4 shows the evolution of the mean value of luminosity for the single beam case (red) for the 40 scans.
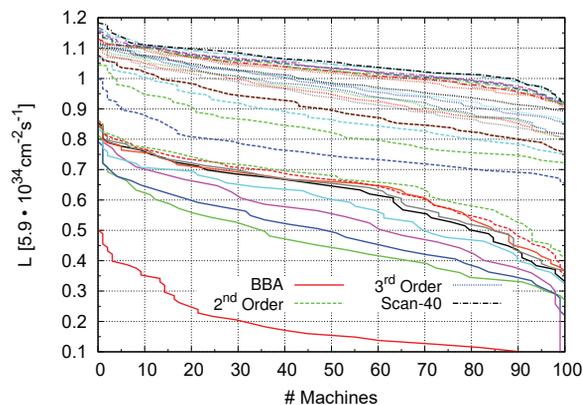
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Figure 3: Tuning results for single beam case study. Each curve is the accumulated luminosity histogram obtained for 100 machines after every scan.

Double Beam

In this case the e^- and e^+ systems are treated independently. The number of luminosity measurements is going to be at least double with respect to the single beam case. In practice the knobs cannot be simultaneously scanned for both e^- and e^+ systems, otherwise one would not know which beam is shrinking.

The tuning procedure is slightly modified to account for 2 independent systems. Firstly, after applying the BBA algorithms, the relative offset between e^- and e^+ at the IP is of the order of few microns. Secondly, the orbit deflections introduced when offsetting the sextupoles, by the so-called feed-down effect perturb the orbit, leading to a relative offset of few tens of nm at the IP between the e^- and e^+ beams. In reality the orbit feedback would correct for that, this allows us to remove the centroid position of the beams before calculating the luminosity.

Figure 5 shows the accumulated luminosity histogram obtained for 100 machines after every scan. The 4 curves labelled on the plot correspond to the same steps as described in the single beam case. By optimizing iteratively the linear knobs, 90% of the machines reach $\geq 79\%$ of $\mathcal{L}_0$. Optimization of 2nd order knobs boosts the luminosity of 90 % of the machines to ≥ 92 % of $\mathcal{L}_0$. Finally, optimizing U_{3222}-knob increases $\mathcal{L} \geq 97$ % of $\mathcal{L}_0$ for 90 % of the machines. 52 scans are required to reach 97 % of $\mathcal{L}_0$. The total number of luminosity measurements is of the order of ≈ 15000. Figure 4 shows the evolution of the mean value of luminosity for the double beam case (blue) for the 52 scans. Although convergence has not been achieved, it is also noticeable that the gain provided at each scan is diminishing at each scan.

CONCLUSIONS

The CLIC-FFS tuning study has made a significant progress since the CDR publication in terms of performance but also reducing the number of iterations by a factor 3. Thanks to a better tuning procedure that effectively targets the most common aberrations at the IP. A more complete
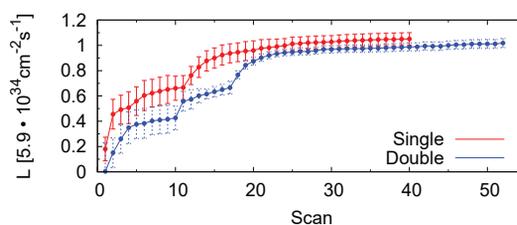

Figure 4: Tuning convergence for single (red) and double (blue) beam studies. Each dot is the mean value of 100 machines, while the error bar is the standard deviation at each scan.
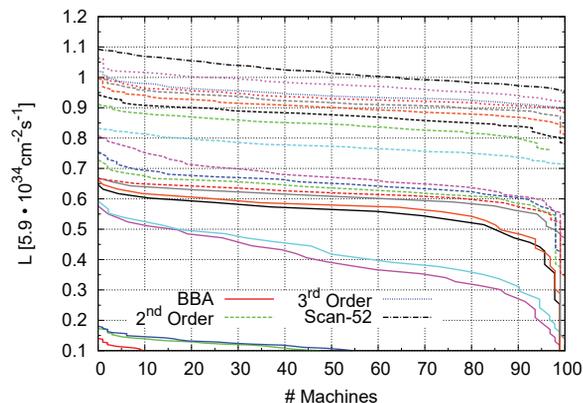

Figure 5: Tuning results for 2 beams case study. Each curve is the accumulated luminosity histogram obtained for 100 machines after every scan.

set of static errors and the fact that we are tuning both e^- and e^+ as independent systems, brings the study into a more realistic scenario. The luminosity obtained for 90% of the machines is $\geq 102\%$ and $\geq 97\%$ for the single and double beam cases, respectively. The 5 % difference might be reduced by additional knobs scan. However the number of iterations of the double beam case is a factor 2.5 times larger than for the single case, meaning that, the tuning convergence is about 25% slower if not more, that when treating the systems independently.

Concerning the tuning goal, none of the studies reach the target, though they are getting closer. It would be required to include the dynamic imperfections, as ground motion, jitter, etc. into the simulation, in order to address the real impact of dynamic effects on luminosity and tuning time.

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