CLIC BDS TUNING, ALIGNMENT AND FEEDBACKS INTEGRATED SIMULATIONS

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Abstract

The CLIC BDS tuning, alignment and feedbacks studies have been typically performed independently and only over particular sections of the BDS. An effort is being put to integrate all these procedures to realistically evaluate the luminosity performance.

INTRODUCTION

The most important challenge faced by the CLIC BDS is the mitigation of static and dynamic imperfections. The FFS is largely sensitive to small imperfections that need to be corrected by means of sophisticated alignment and tuning algorithms. The static imperfections and the algorithms to cancel them are first described followed by the foreseen feedbacks for the CLIC BDS.

BDS SENSITIVITY TO MISALIGNMENTS

The CLIC beam has to be steered through the middle of the quadrupoles with a very high precision. To achieve this, several steps will have to be performed, which include accurate pre-alignment, active quadrupole stabilization, beam-based alignment methods and beam-based feedback. To study the final precision that should be reached on the steering of the beam through the quadrupoles and thus also on the beam position monitors (BPMs), a study on the allowed offsets of the individual quadrupoles in the BDS has been performed. In this study the potential beam offset at the IP has been corrected in order to include emittance growth and beam shape effects only. For every single quadrupole in the BDS the offset that corresponds to a 2% luminosity loss has been calculated and is shown in Fig. 1. As can be seen there is a large difference between the allowed tolerances of the individual quadrupole offsets. The final doublet quadrupoles are the most sensitive with tolerances of few nanometers.

ONE-TO-ONE AND DFS IN THE BDS

Traditional one-to-one, linear and non-linear Dispersion Free Steering (DFS) alignment algorithms have proven successful if applied to the CLIC collimation section only [1]. On the contrary the convergence of these algorithms is poor when applied to the FFS, only few percent of the original emittance growth is recovered for different initial rms misalignment values, while the traditional one-to-one even fails, see Fig. 2.

From one hand the non-linear fields hinder the success of the method and from the other hand the high level of radiation in the quadrupole of the FFS makes the methods insensitive to BPM resolution. For the same reasons moving the quadrupole instead of using dipole correctors does not help if traditional algorithms are employed. Different solutions are under investigation: coupled one-to-one and DFS in order to take into account the coupling produced by misaligned multipoles, kick minimization technique together with quad shunting [2].

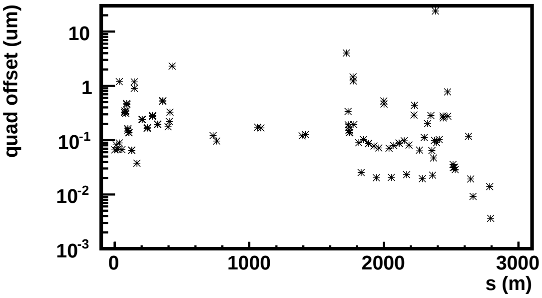

Figure 1: Quadrupole offset tolerance for a 2% luminosity loss along the BDS with corrected IP offset. The final doublet to the right of the plot contains the most critical quadrupoles.

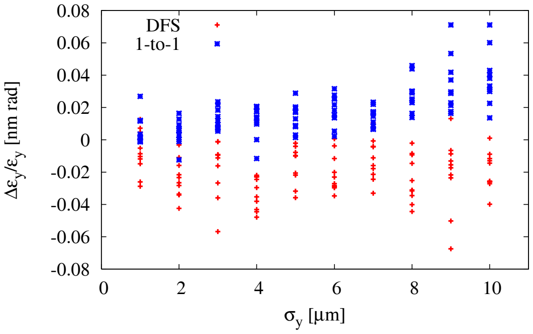

Figure 2: Relative values of final emittance recovered when traditional 1-to-1 and non-linear DFS corrections are applied to the FFS only according to different initial rms misalignment values. Different dipole strength have been used to compute the response matrix.

FFS TUNING: STATUS AND PLANS

Figure 3 shows the beam size if realistic imperfections are included in the BDS but no beam-based correction is performed. The most likely value is about 1 μm, three orders of magnitude larger than the 1 nm from the ideal design. The machine will be tuned by varying the different lattice parameters in order to optimise the luminosity. The aim is to achieve a luminosity of more than 90% of

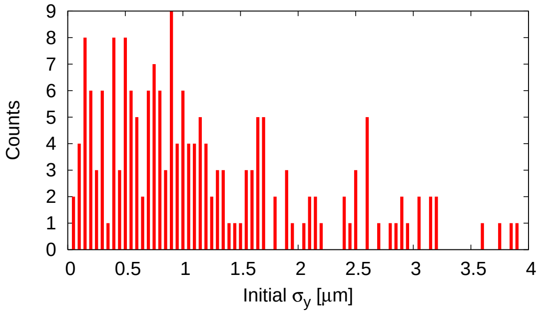

Figure 3: Probability distribution of the CLIC vertical IP beam size assuming realistic beam line imperfections.

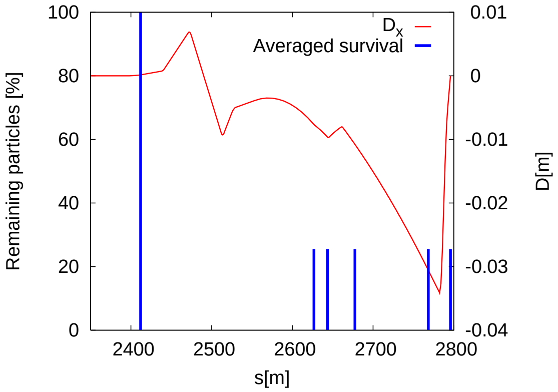

Figure 4: Average particle population along the FFS by taking 10 μm misalignments and considering the nominal FFS aperture for 100 different seeds.

the maximum possible value–which is 20% larger than the nominal value– with a probability in excess of 90%.

By tuning we understand the process of bringing up the machine luminosity to the ideal performance by varying the available lattice parameters. Currently, the success ratio of a stand-alone tuning procedure based on the Simplex algorithm is about 80%, slightly below the required 90% [3]. Several ways to improve the success ratio of the tuning procedure are presently under investigation like the use of the most suitable beam-based alignment techniques and the construction of effective knobs that act on a single beam observable. The beam size tuning at intermediate points within the FFS is also presently under investigation. If this tuning approach turned successful a beam size measurement station could be installed in the FFS.

In the first steps of the studies it has been observed that a very important fraction of the beam particles are lost in the beam pipe [3] when having assigned 10 μm transverse misalignments. Figure 4 shows the statistical average particle population along the FFS. About 75% of the particles are lost in the first dipole section. This represents an unrealistic starting point to any alignment or tuning simulation. The first step is to steer the beam trough the entire FFS without detecting any beam loss. This 0^{th} order tuning, the beam steering, has already been successfully implemented in PLACET [4].

FEEDBACK

One of the main issues of the beam delivery system is to ensure that dynamic imperfections do not lead to a large loss of luminosity. Of particular concern are transverse motions of beam line magnets, due to ground motion or technical noise, and time varying magnetic stray fields are of concern. Here, we will focus on the magnet motion, the magnetic stray fields are discussed in [5].

The level of ground motion is site dependent. In addition, the technical installations will induce vibrations, e.g. due to cooling water flow. The supports and the magnets themselves will further amplify or damp the motion. This can be described in frequency domain by a transfer function T: $y(\omega, s) = T(\omega, s)y_0(\omega, s)$. We have modified our ground motion generator to include such transfer functions. These corresponding mechanical models are being developed by a working group and will be included into a fully integrated study of the luminosity stability as they become available.

A concept of the mitigation of ground motion induced beam orbit jitter has been developed. It consists of several ingredients:

- Careful magnet and support design. In particular, from a range of cantilever support designs for the final quadrupoles that has been proposed by detector experts [6] we have chosen one with a resonance frequency close to the beam repetition frequency of 50 Hz, which shows little impact on the beam-beam jitter.
- On a pulse-to-pulse basis beam-based orbit feedback can be used. This feedback can reduce low-frequency motion.
- Component stabilization using a mechanical feedback that is based on ground motion sensors. These sensors allow to monitor the ground motion permanently, hence the feedback can act at higher frequencies than the beam-based feedback. This can be described by a transfer function similar to the impact of the support.
- One can use the ground motion sensors on the magnets to predict the orbit of the beam just before its arrival and use kickers to correct the orbit. This feedforward is somewhat similar to the ground motion sensor based feedback. But it is useful in two cases. Firstly, if the residual ground motion measured at the mechanically stabilized magnets is above the sensor noise level, which appears to be the case in a number of experiments, one can exploit this knowledge for further correction. Secondly, such a feedforward is less costly than the mechanical stabilization so it can be used if it is sufficient to achieve the performance goal.
- At the interaction point an intra-pulse feedback can be used to minimize the beam-beam offset.

All of these options can be combined. This combined system needs to be optimised overall.

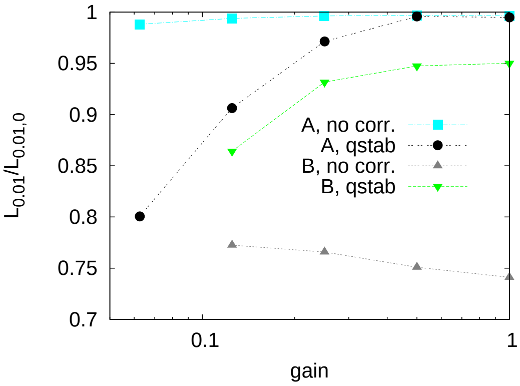

Figure 5: The impact of orbit feedback gain and final doublet stabilization on the luminosity, calculated with a simplified model.

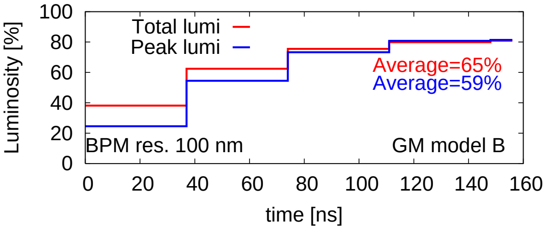

Figure 6: Illustration of IP feedback combined with beam-based alignment techniques without quadrupole stabilization.

The variation of the impact of ground motion is shown in Fig. 5. Two ground motion models from reference [7] are used for the simulation, ground motion model A corresponds to the LEP tunnel—a very quiet site—and model B corresponds to a more noisy tunnel close to SLAC. For this study, we neglect any amplification of the ground motion by the elements or there supports and use a simplified beam-based pulse-to-pulse orbit feedback. In case of ground motion A the beam-based orbit feedback is sufficient to ensure the luminosity, while in case of ground motion B a reduction of 25 % has to be expected. This loss is dominated by the motion of the final doublets, which strongly kick the beam. If these magnets are mechanically stabilized perfectly, the luminosity loss can be reduced to an almost acceptable 5% for a high gain on the beam-based feedback, stabilization of more magnets will further improve this. It should be noted that the luminosity loss at low orbit feedback gains results from a slow coherent motion of the whole machine with respect to the perfectly stabilized final doublets.

A first step towards these integrated simulations has been done combining the IP feedback [2] and the beam-based alignment techniques over 0.04 s without assuming any quadrupole stabilization, see Fig. 6. To demonstrate the expected performance quadrupole stabilization and the sensors feedbacks should be in place. The BPM resolution should be scanned to meet the specification.

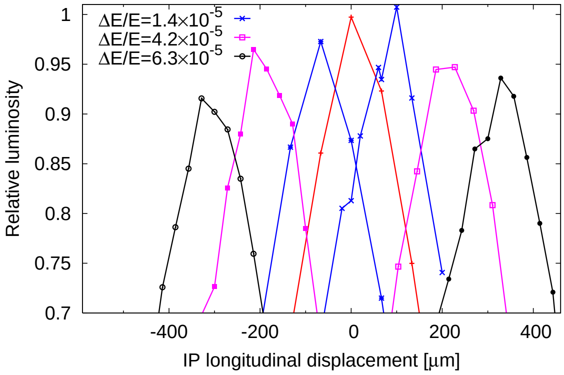

Figure 7: Scanning the IP longitudinal location for different energy changes in the Final Doublet.

IP WAIST FEEDBACK VIA A RF CAVITY

Jitter of the beam arrival time at the collision point can lead to significant luminosity loss since the two beams will not collide in the waist. However, a relative jitter of the timing of the two beams can already be measured when they are still in the central complex before they are transported to the beginning of the main linacs. The expected collision timing jitter can then be corrected by adjusting the beam waist at the collision point in a feed-forward fashion [8]. One option to change the waist is to modify the beam energy right before the FD via a RF cavity, see Fig. 7. A relative change in the energy of the beam before the FD by 6.3×10^{-5} yields an IP waist shift of about 350 μm and 7% luminosity loss. Eventhough the perfomance can still be improved this relaxes the tolerances by a factor of 6. This RF cavity could allow to scan the waist over a single bunch train considerably speeding up the waist correction.

CONCLUSIONS

A large effort is being put in the investigation of beam-based alignment, tuning and feedback techniques to guarantee the CLIC luminosity performance in presence of realistic errors. After the best algorithms have been identified integrated simulations should be performed to assess its performance, starting from the tuning with static errors and finishing with all the feedbacks running simultaneously on a machine with stabilized quadrupoles. Ground motion and stabilization models should be included.

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