ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPRO069

FIRST STUDIES OF TWO-BEAM TUNING IN THE CLIC BDS

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Abstract

Beam tuning in the beam delivery system (BDS) is one of the major challenges for the future linear colliders. Up to now single beam tuning has been performed, both in simulations and experiments at the Accelerator Test Facility (ATF). However, in future linear colliders, due to fast detuning of the final focus optics both beamlines will need to be tuned simultaneously. In this paper a first two-beam tuning study for the Compact Linear Collider (CLIC) BDS is presented applying the usual toolbox of beam-based alignment (BBA) and sextupole knobs.

INTRODUCTION

CLIC

The CLIC is an international study for a potential future linear lepton collider, colliding positrons and electrons at up to 3 TeV centre of mass energy [1]. The design is based on normal conducting elements, making use of a novel two-beam acceleration scheme in order to have a reasonable power consumption. The CLIC requires a small vertical emittance and beam size at the interaction point (IP) in the nanometer range to achieve its nominal luminosity. This is an unprecedented small beam size for linear colliders, which imposes strict alignment tolerances for the machine. The pre-alignment has a transversal misalignment requirement of about 10 μm (also called static imperfections), while the dynamic imperfections can only be fractions of a nm for the most sensitive magnets [2].

Final Focus System

One of the main tasks of the CLIC BDS is to focus the beam to the small sizes required at the IP. To achieve this, the last part of the BDS, the Final Focus System (FFS) forms a large and almost parallel beam at the entrance of the Final Doublet (FD), which contains two strong quadrupole lenses. For the nominal energy, the beam size at the IP is $\sigma = \sqrt{\beta^* \epsilon}$, where ϵ is the beam emittance and β^* is the betatron function at the IP. However, for a beam with an energy spread σ_δ, the beam size is diluted by the chromaticity of these strong lenses. The chromaticity is defined as:

$$\xi = \frac{d\beta^*/\beta^*}{dE/E} \tag{1}$$

and it scales approximately like $\xi \sim \frac{L^*+L_q/2}{\beta^*}$, where L^* is the distance from the IP to the last quadrupole and L_q is the quadrupole length. Thus the chromatic dilution of the beam size $\sigma_\delta \frac{L^*+L_q/2}{\beta^*}$ may be very large. The design of the FFS is driven primarily by the necessity of compensating the chromaticity of the FD.

There are two different approaches to the compensation of the chromatic effects, the traditional scheme, based on dedicated chromatic correction sections for each plane; and the local correction scheme, based on the local correction of the chromaticity [3] using extra higher order magnets for the cancellation of aberrations [4]. This paper will focus on the local correction scheme, see Figure 1, which is the CLIC baseline.

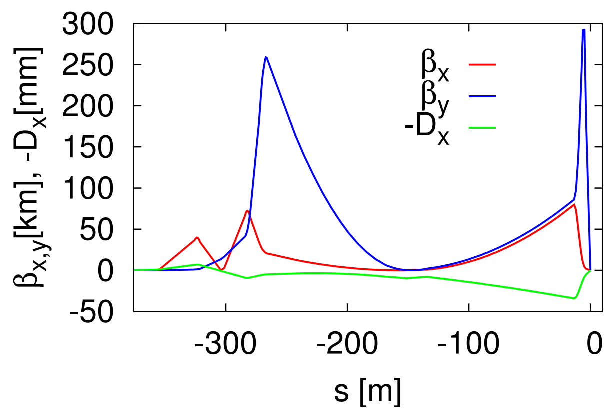

Figure 1: Optics of the CLIC Final Focus local correction scheme.

Table 1: Key Parameters of the CLIC FFS at the IP

Parameter	Units	Value
Total (peak 1%) lumi.	$cm^{-2}s^{-1}$	$5.9(2.0) \cdot 10^{34}$
Beam energy	TeV	1.5
Last drift length L^*	m	3.5
Nom. beam size σ_x/σ_y	nm	45/1
Nom. beta func. β_x/β_y	mm	10/0.07
Nom. bunch length σ_z	μm	44
Bunch population		$3.7 \cdot 10^9$
Train repetition rate	Hz	50
Crossing angle	mrad	20

The CLIC FFS is characterised by the parameters shown in Table 1. The CLIC FFS uses sextupoles next to the final doublets to correct the local chromaticity. A bend upstream generates dispersion across the FD, which is required for the sextupoles and non-linear elements to cancel the chromaticity. The dispersion at the IP is zero and the angular dispersion is about 1.4 mrad, i.e. small enough that it does not significantly increase the beam divergence. Half of the total horizontal chromaticity of the final focus is generated upstream of the bend in order for the sextupoles to simultaneously cancel the chromaticity and the second-order dispersion. The horizontal and the vertical sextupoles are inter-

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leaved in this design, so they generate third-order geometric aberrations. Additional sextupoles upstream and in proper phases with the FD sextupoles partially cancel these third order aberrations. The residual higher order aberrations are further minimized with octupoles and decapoles.

The crossing angle at the IP is 20 mrad. Crab cavities are required to rotate the bunches for a head on collision. They apply a z-dependent horizontal deflection to the bunch that is nominally zero at the centre of the bunch. Without crab cavities 90% of the achievable luminosity would be lost.

BEAM TUNING STATUS

The correction of the static imperfections of the FFS is not straightforward. Besides the challenging target specifications, due to the high beam energy the synchrotron radiation makes the correction response highly non-linear. Advanced simulations have been developed in order to try to achieve the required tuning performance [5]. The most recent status is presented in [6]. The baseline design allows for a 10% reduction of the luminosity due to static imperfections (compared to a theoretical perfectly aligned machine), and another 10% reduction from dynamic imperfections. Currently the best results are achieved using a combination of beam-based alignment techniques (BBA), a Simplex algorithm optimising the luminosity, and orthogonal sextupole knobs. These techniques are described in detail in [5] and [7]. Some of these techniques have been applied successfully at the Accelerator Test Facility (ATF) [8], which is a single beamline scaled demonstrator of the local correction FFS for both the International Linear Collider (ILC) [9] and the CLIC.

TWO-BEAM TUNING

Motivation

In the beam tuning simulation studies and experiments performed so far, beam tuning has been performed with a single beamline. For the luminosity determination in simulation the beam is collided with its mirror image. This is done to reduce the simulation time. However, in future linear colliders, due to fast detuning of the final focus optics both beams will need to be tuned simultaneously. As self-collision is often optimal, the luminosity at the start of the tuning will be lower when simulating two beamlines compared to a single beamline. And since the luminosity measurement is typically less precise for lower luminosity, tuning with both beamlines might take considerably longer time than for each beamline individually as finding the optimum for each sextupole knob will be more difficult. Thus additional luminosity loss might be expected simulating both beamlines. Furthermore, two beam tuning poses an additional constraint since after BBA the beamlines need to be aligned with respect to each other. This means that the FD pre-alignment of both beamlines needs to be good enough.

The possible increased number of tuning iterations is a concern since depending on the ground motion model, the CLIC loses up to 10% of luminosity in 1 hour even with a ground motion optimised orbit feedback system [10]. Therefore, beam tuning needs to be performed almost continuously and a fast beam tuning procedure and therefore fast luminosity measurement are essential. The CLIC can measure luminosity with a 1% precision in 20 trains by looking at the hadronic pair production [5].

Despite these additional difficulties tuning two beamlines, two-beam tuning studies performed for the ILC have shown that the number of tuning iterations need not be increased much more than a factor two and that the luminosity performance can mostly be maintained [11].

Tuning Procedure

For the two-beam studies, just as for the single beamline simulations, static misalignments of all BDS magnets and beam position monitors (BPMs) are assumed with a normal distribution and a standard deviation of 10 μm and BPM resolutions of 10 nm. The current single beam tuning procedure is applied, which consists of the following steps:

- BBA
  - 1-to-1 correction
  - Target Dispersion Steering (Dispersion Free Steering (DFS) like method) to correct the dispersion.
  - Multipole shunting: vary the multipole positions to centre the multipoles
- Sextupole knobs
  - First iteration of sextupole knobs
  - Target Dispersion Steering
  - Second iteration of sextupole knobs

The tuning procedure is split in two parts. The first part are BBA techniques and uses the BPM signals. It can be performed simultaneously for both beams. For the first two steps, the 1-to-1 correction and first iteration of DFS, the multipoles are switched off. The second part of the tuning procedure consists of varying the position of the last five sextupoles in the FFS. For each beamline there are ten independent orthogonal sextupole knobs. Since the luminosity signal is used for optimisation, each beam has to be optimised separately. The beams are alternated after each sextupole knob to reach a high and precise luminosity signal quickly. For most of the misalignment seeds a second and possible additional iterations of sextupole knobs are beneficial. The Simplex algorithm has not been chosen for the moment due to the large number of iterations that it requires, but could be added afterwards if necessary. The tuning steps are explained in more detail in [5] and [7].

As with the one beam tuning studies simulations are performed with the beam tracking code PLACET [12] and the code Guinea-Pig [13] for the beam-beam interaction and luminosity calculation. To speed up the tuning simulations an automatic centering of the beams, which means an almost ideal IP feedback system, has been assumed.

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First Results

The results for the first part of the two-beam tuning are shown in Figs. 2 and 3. For 100 simulation seeds, which means 200 beamlines, the BBA techniques are applied and the vertical beam size at the IP is shown for each seed after different steps of BBA. For the converged seeds, the average vertical beam size at the IP is about 560 nm after 1-to-1 steering (labeled "121"), about 160 nm after DFS and about 5 nm after the full procedure. About 10% of the seeds did not converge and need to be checked in more detail. The results are close to the results of [7].

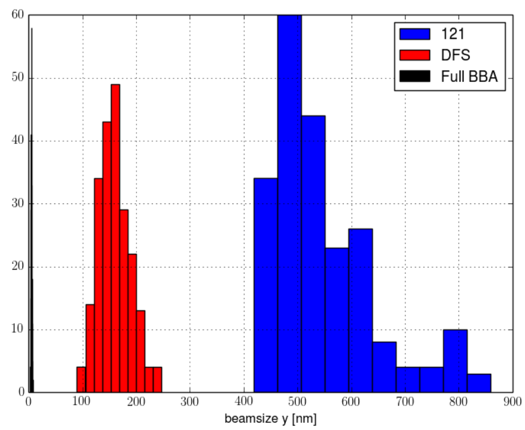

Figure 2: Vertical beam size at the IP after different steps of the BBA procedure for 100 simulation seeds (200 beamlines).

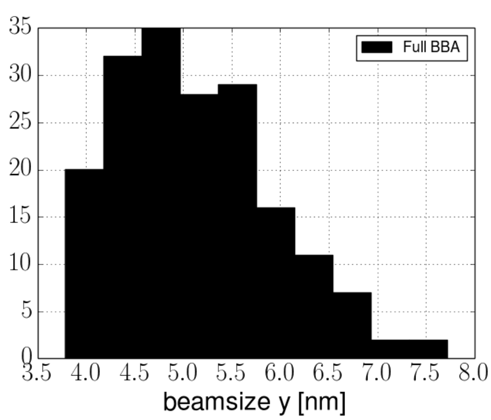

Figure 3: Vertical beam size at the IP after full BBA procedure for 100 simulation seeds (200 beamlines).

One iteration of sextupole knobs was applied to the successful beam based aligned simulation seeds. The best simulation seeds have reached about 60% of the nominal luminosity. A second and possible third iteration of sextupole knobs are needed but have not been performed yet. It is expected that these additional iterations will improve the results considerably, since due to the low and therefore less precise luminosity signal at the start of the first iteration, the sextupole knobs that were applied first might not have been optimised perfectly.

CONCLUSIONS AND OUTLOOK

In this paper two-beam tuning for the Compact Linear Collider (CLIC) Beam Delivery System has been discussed for the first time. First preliminary simulation results are presented applying the usual toolbox of beam-based alignment methods and sextupole knobs. The first results are encouraging but more simulations are needed and will be continued. As a preliminary conclusion it seems that the two-beam tuning difficulty might be comparable to tuning a single beam. In addition to the usual toolbox some additional techniques like quadrupole shunting, mover minimisation methods and second order sextupole knobs might need to be studied to reach the challenging luminosity target.

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