CERN – EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CLIC – Note – 1098

ADVANCED BBA TECHNIQUES FOR THE FINAL FOCUSES OF FUTURE LINEAR COLLIDERS

Jochem Snuverink[3], Ryan Bodenstein[2], Andrea Latina[1], Daniel Schulte[1], Rogelio Tomas[1]

[1]CERN, Geneva, Switzerland
[2]John Adams Institute at Oxford University, Oxford, United Kingdom
[3]John Adams Institute at Royal Holloway, University of London, Egham, United Kingdom

Abstract

Tuning the Final-Focus System of future linear colliders is one of the open challenges the linear collider community is undertaking. Future colliders like ILC and CLIC will feature complex lattice design to focus the beams to nanometer level at the Interaction Point. Standard Beam-Based Alignment (BBA) techniques have proven to hardly meet the requirements in terms of acceptable emittance growth, in both machines. A set of new techniques, respectively called: nonlinear Dispersion-Free Steering (DFS), DFS-knobs scan, and hybrid DFS-knobs with beamsize measurements, have been put in place to cope with the challenge. This paper will reveal the key ideas behind the new techniques, and compare their effectiveness w.r.t. the conventional BBA tuning procedures.

7th International Particle Accelerator Conference, Busan, Korea, 8 - 13 May 2016
Geneva, Switzerland
12 May 2016

ADVANCED BBA TECHNIQUES FOR THE FINAL FOCUSES OF FUTURE LINEAR COLLIDERS

J. Snuverink, John Adams Institute at Royal Holloway, University of London, Egham, UK
R. M. Bodenstein, John Adams Institute at Oxford University, Oxford, UK
A. Latina, D. Schulte, R. Tomás, CERN, Geneva, Switzerland

Abstract

Tuning the Final-Focus System of future linear colliders is one of the open challenges the linear collider community is undertaking. Future colliders like ILC and CLIC will feature complex lattice design to focus the beams to nanometer level at the Interaction Point. Standard Beam-Based Alignment (BBA) techniques have proven to hardly meet the requirements in terms of acceptable emittance growth, in both machines. A set of new techniques, respectively called: nonlinear Dispersion-Free Steering (DFS), DFS-knobs scan, and hybrid DFS-knobs with beamsize measurements, have been put in place to cope with the challenge. This paper will reveal the key ideas behind the new techniques, and compare their effectiveness w.r.t. the conventional BBA tuning procedures.

INTRODUCTION

Future linear lepton colliders like the ILC [1] and CLIC [2] have a very small vertical beam size at the interaction point (IP), 6 and 1 nanometer respectively. The task of the final focus system (FFS) is to focus the beam to the required beamsize at the IP. Both ILC and CLIC have the same FFS design as their baseline, the so-called local FFS [3]. The required beamsize imposes strict alignment tolerances for the machine. At CLIC, for example, the pre-alignment has a transversal misalignment tolerance of about 10 μm (also called static imperfections), while the dynamic imperfections can only be fractions of a nm for the most sensitive magnets. The correction of the static imperfections is not straight forward. Not only are the target specifications challenging, but with the high beam energy, especially in the case of CLIC with a beam energy of 1.5 TeV, the synchrotron radiation effects makes the tuning response highly non-linear.

Tuning Method

Luminosity tuning of the FFS usually consists of two stages. The first stage is the beam-based alignment (BBA), where beam position monitor (BPM) measurements are utilised to steer the beam through the FFS as well as possible with correction algorithms. The second stage optimises the luminosity signal by changing various magnet strengths and positions. While the BPM measurements can be read out and corrected for every bunch train for each of the two beam lines, the luminosity signal is typically much slower. For example, for CLIC a luminosity measurement will take at least 20 trains [4]. Since the FFS is detuning due to dynamic effects like ground motion, it is important to tune quickly.

A simplex algorithm optimising the luminosity has currently achieved the best results for the CLIC FFS. This method requires a large number of luminosity measurements since it varies the position of all FFS magnets. Therefore, faster methods are currently being pursued. For CLIC the following faster method has been studied in detail in [4–6] and consists of the following steps:

- BBA
  - 1-to-1 correction
  - Target Dispersion Steering (Dispersion Free Steering (DFS) like method) to correct the dispersion.
- Sextupole knobs
  - First iteration of sextupole knobs
  - Target Dispersion Steering
  - Second iteration of sextupole knobs

The BBA method is outlined in [7]. The first dispersion correction method is with the higher order magnets switched off and the second method is with these magnets switched on. Since the FFS is designed to have a non-zero dispersion, this method is technically not a dispersion free steering method, but will hereafter be referred to as DFS for convenience. The DFS algorithm solves the following linear system of equations:

$$\begin{pmatrix} \mathbf{b} \\ \omega(\boldsymbol{\eta}-\boldsymbol{\eta_0}) \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \omega\mathbf{D} \\ \beta\mathbf{I} \end{pmatrix} \boldsymbol{\theta} \quad (1)$$

Here, $\mathbf{b}$ are the BPM measurements (vertical and/or horizontal), $\boldsymbol{\eta}$ is the dispersion at the same BPMs and $\boldsymbol{\eta_0}$ the design dispersion. $\mathbf{R}$ is the orbit response matrix, $\mathbf{D}$ is the dispersion response matrix, $\mathbf{I}$ is the identity matrix, and $\boldsymbol{\theta}$ are the corrector values. ω and β are weighting factors, ω for the contribution factor between dispersion and orbit, and β for the regulation of the inverse. The optimal values of β and ω depend on the BPM resolution and the noise in the system. For the dispersion measurement a test beam with a different energy is tracked through the FFS. An energy difference of the order of a few per-mille is sufficient. The system is solved for the corrector values $\boldsymbol{\theta}$ by calculating the inverse of the response matrices with the Singular Value Decomposition (SVD) method.

The sextupole knobs are designed to correct the beam aberrations and vary the position of the last five sextupoles. A knob is optimised by maximising the luminosity signal. For each beamline there are ten independent orthogonal sextupole knobs. A description can be found in [4].

TUNING ISSUES

While the results in [7] were excellent, the synchrotron radiation was not taken into account. As mentioned in the introduction the synchrotron radiation makes the tuning highly non-linear. For the so-called traditional CLIC FFS [8], which is an alternative FFS design, the results of the procedure are shown with synchrotron radiation for 110 misalignment seeds in Fig. 1. It can be seen that overall the results are good, but a few of the seeds are not reaching the required small beamsize after sextupole knobs. The simulation studies are performed with the beam tracking code PLACET [9] and the code Guinea-Pig [10] for the beam-beam interaction and luminosity calculation.

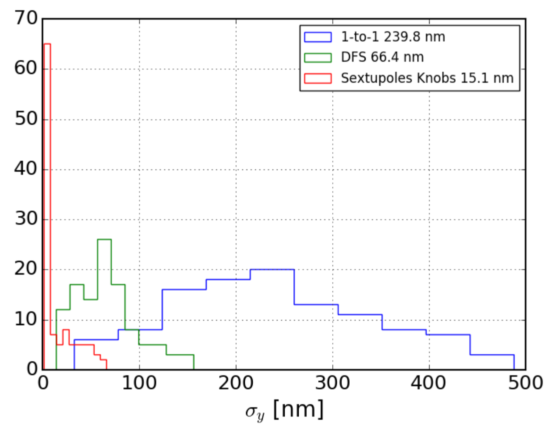

Figure 1: Histogram of the vertical beam sizes of 110 seeds in the CLIC FFS. The three phases of the tuning procedure are shown and their average beamsize is indicated.

A second issue with the tuning procedure can be seen in Fig. 2. After the second iteration of the sextupole knobs, the luminosity is sometimes lower than after the first iteration. This can happen since the second DFS iteration does not optimise luminosity and while advantageous for most seeds, it can be detrimental for others.

IMPROVEMENTS TO BBA TECHNIQUES

In this section suggestions and new techniques are proposed that can mitigate the aforementioned issues. Unfortunately, the tuning procedure is CPU-intensive so that not all proposed techniques are tested yet.

Updated Response Matrix

Currently the BBA utilises response matrices **R** and **D** obtained from simulation of a perfect beamline. Therefore, the response matrices are not perfectly describing the system. Measuring the response matrices from the misaligned beamline directly with the BPMs can improve this. By measuring the response matrices regularly during the BBA correction, this will in addition reduce the effect of the non-linearity of the system, since to first order the response matrix will be correct. This method is currently under study.

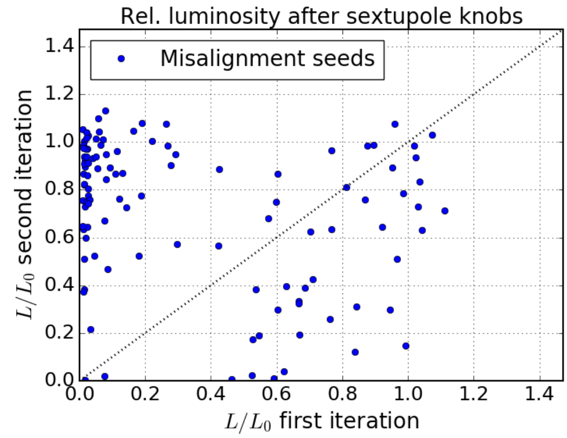

Figure 2: Relative luminosity after the first and second iteration of the sextupole knobs for the different misalignment seeds.

Non-linear DFS

To describe the non-linearity of the system better, the second order response matrices $\mathbf{R}'$ and $\mathbf{D}'$ can be taken into account. The DFS equations will then look:

$$\begin{pmatrix} \mathbf{b} \\ \mathbf{b}^2 \\ \omega(\boldsymbol{\eta}-\boldsymbol{\eta}_0) \\ \omega'(\boldsymbol{\eta}-\boldsymbol{\eta}_0)^2 \\ \mathbf{0} \end{pmatrix} = \begin{pmatrix} \mathbf{R} \\ \mathbf{R}' \\ \omega\mathbf{D} \\ \omega'\mathbf{D}' \\ \beta\mathbf{I} \end{pmatrix} \boldsymbol{\theta} \tag{2}$$

While in theory a better description of the system, the main drawback is that the second order matrices $\mathbf{R}'$ and $\mathbf{D}'$ will need to be measured from the misaligned beamline directly, and this will be time intensive on a real machine. However, in simulation this can be done quickly, and this method could be used in simulation to improve the understanding of the system.

DFS Knobs

Instead of matching the orbit and the dispersion with DFS one can maximise the luminosity signal directly as with the sextupole knobs. This will thus prevent the degradation of the luminosity signal as was observed. Then knobs need to be constructed from Eq. (1). This can be done by taking the singular vectors of the SVD of the system. The first four singular vectors (directions) are shown in Fig. 3. It can be seen that despite the coupled nature of the system, the method has decoupled it in horizontal and vertical directions. By construction these are mutually orthogonal.

This method has been tested on the traditional CLIC FFS [11]. To keep the number of knobs and therefore the luminosity measurements under control, the first four singular vectors have been chosen. Furthermore, maximising the luminosity signal only works when the signal is already at a certain level. Therefore, this method is only applied for the

ISBN 978-3-95450-147-2

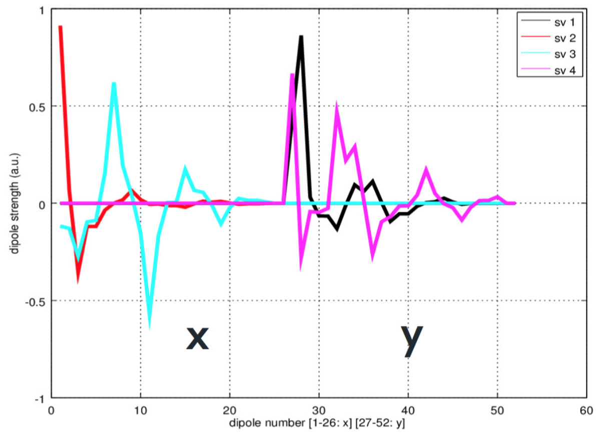

Figure 3: First four singular vectors of the SVD of the DFS method. The dipole corrector number is on the horizontal axis and its corresponding strength in arbitrary units on the vertical axis.

second DFS iteration and only when the luminosity is above 3%.

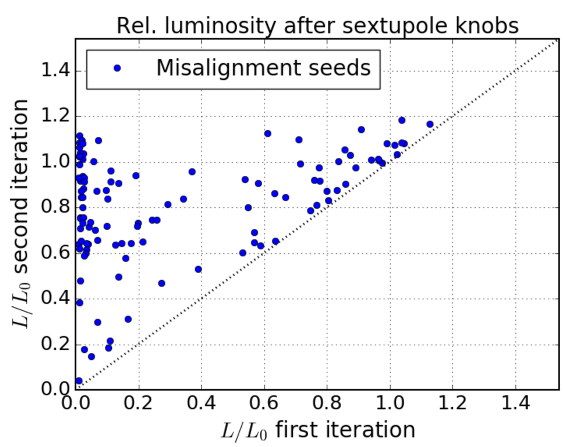

Figure 4: Relative luminosity after the first and second iteration of the DFS and sextupole knobs for the different misalignment seeds.

In Fig. 4 the relative luminosity is shown after the first and second iteration of the DFS and sextupole knobs. It can be seen that the luminosity is indeed no longer lower in the second iteration for any of the misalignment seeds. The average luminosity is also improved as can be seen in Fig. 5. This is especially so when multiple iterations tuning procedure are performed. More tuning results with the DFS knobs are shown in [11]. Currently the DFS knobs are constructed from the response matrices obtained from a perfect beamline. DFS knobs could potentially benefit from a measured response matrix.

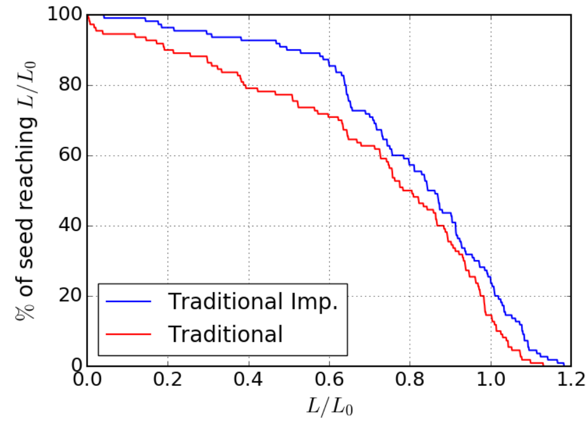

Figure 5: The survival plot for the single beam tuning after the first iteration of the tuning procedure. The vertical axis shows the cumulative percentage of machines reaching a given luminosity.

DFS Knobs with Beamsize Measurements

In both ILC and CLIC, beamsize and emittance measurements will be performed along the main linac and beam delivery system using laser-wire scanners. Laser-wires are well suited because they are non-invasive devices that can be used continuously during machine operation. The current state of the art can measure the beamsize with a precision of about a μm [12].

These beamsize measurement can be used in the BBA procedure as an observable just like was done for the luminosity with the DFS knobs. This could especially be useful for when the luminosity signal is not good enough yet for optimisation. The main disadvantage is that the beamsize measurement is slow compared to luminosity signal and especially to the BPM measurements.

CONCLUSIONS AND OUTLOOK

The current BBA techniques used for tuning the FFS of the future linear lepton colliders have proven to hardly meet the requirements in terms of emittance growth and luminosity requirements. Several possible improvements and new techniques are suggested. The novel DFS knobs technique has been implemented and analysed in detail. It is shown to improve the tuning for CLIC and address some of the issues of the original method. While the results have been improved, more improvements are still needed and some of the suggested techniques will be tested in the near future.

REFERENCES

[1] T. Behnke *et al.*, arXiv:1306.6327. See also http://www.linearcollider.org/ILC/TDR for a full list of contributing institutes.

[2] CLIC collaboration, "A multi-TeV Linear Collider based on CLIC Technology", 2012.

[3] P. Raimondi, A. Seryi, “Novel Final Focus Design for Future Linear Colliders", Phys. Rev. Lett. **86**, 7 (2001).

[4] B. Dalena *et al.*, “Beam delivery system tuning and luminosity monitoring in the Compact Linear Collider”, PRSTAB 15, 2012.

[5] Y. Levinsen *et al.*, “Tuning of the CLIC BDS", In Proc. of IPAC14, p.3788, 2014.

[6] J. Snuverink *et al.*, “First Studies of Two-Beam Tuning in the CLIC BDS", In Proc. of IPAC14, p.1195, 2014.

[7] A. Latina, P. Raimondi, “A novel alignment procedure for the final focus of future linear colliders", LINAC 2010, p.109, 2010.

[8] H. Garcia Morales, R. Tomas. “Final Focus Systems for Multi-TeV Linear Colliders". Phys. Rev. ST Accel. Beams 17, 101001 (2014).

[9] A. Latina *et al.*, “Evolution of the Tracking Code PLACET”, In Proc. of IPAC13, p.1014, 2013.

[10] D. Schulte, “Beam-Beam Simulations with GUINEA-PIG", In Proc. of ICAP98, p. 127, 1998.

[11] J. Snuverink *et al.*, “Two-beam Tuning in the CLIC BDS", IPAC2016, THPMR047, 2016.

[12] L. Nevay *et al.*, “Laserwire at the Accelerator Test Facility 2 with submicrometer resolution", PRSTAB 17, 2014.

ISBN 978-3-95450-147-2