ISBN: 978-3-95450-208-0 doi:10.18429/JACoW-IPAC2019-MOPMP018

BEAM-BASED BEAMLINE ELEMENT ALIGNMENT FOR THE MAIN LINAC OF THE 380 GeV STAGE OF CLIC

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Abstract

The extremely small vertical beam size required at the interaction point of future linear colliders, such as the Compact Linear Collider (CLIC), calls for a very small vertical emittance. The strong wakefields in the high frequency 12 GHz CLIC accelerating structures set tight tolerances on the alignment of the main linac's beamline elements and on the correction of the beam orbit through them in order to maintain a small emittance growth. This paper presents the emittance growth due to each type of beamline element misalignment in the designed 380 GeV centre-of-mass energy first-stage of CLIC, and the emittance growth following a series of beam-based alignment (BBA) procedures. The BBA techniques used are one-to-one steering, followed by dispersion free steering and finally accelerating structure alignment using wakefield monitors.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed electron-positron collider, with an ultimate centre-of-mass collision energy of 3 TeV [1]. A first-stage design at a lower energy of 380 GeV, aimed at top quark and Higgs particle production, is currently being proposed [2]. In order to achieve the required collider luminosity, CLIC requires a tightly controlled emittance growth. This is particularly important in the main linac, where static imperfections enhance the strong wakefield environment resulting from the large number of 12 GHz accelerating structures.

The key alignment specifications have been set for the 3 TeV CLIC design [1], to achieve an emittance growth of < 5 nm with a 90% likelihood. In principle, several of the tolerances could be relaxed by a factor of about two at 380 GeV compared to 3 TeV, since the main linac is shorter. However, this would require upgrading the systems for better performance when the energy is upgraded. Hence the system design and the specifications remain unchanged; these are detailed in Table 1, together with the results discussed below [3].

SIMULATION

The emittance growth has been evaluated in PLACET [4] for the main linac lattices of both the drive-beam-based and klystron-based 380 GeV CLIC designs [2]. The bunch charges and lengths used are given in Table 2.

An incoming emittance of 10 nm and an incoming RMS fractional energy spread of 1.6% in the main linac were assumed. The main linac RF phases were adjusted to obtain an RMS fractional energy spread of 0.35% at the end of the main linac. The exact distribution of RF phase assignments along the main linac has a small effect ($\leq$ 5%) on the final emittance growth, and we quote here the results for the case where an RF phase of 8° is used for the first 75% of accelerating structures and 30° for the rest.

For a perfectly aligned machine, a natural emittance growth of 0.01 nm is observed. One thousand machines were then simulated for each static imperfection, with the size of the imperfection drawn from a Gaussian distribution with a standard deviation equal to the allowed tolerance in Table 1. The imperfections were applied by defining the `Clic` survey using `SurveyErrorSet` in PLACET.

For each of the machines that was simulated, a series of three successive correction techniques was applied to resteer the beam:

- **One-to-one steering (1-2-1)** – Each quadrupole is used to move the beam into the centre of the next BPM downstream [5]. This is implemented in PLACET using `TestSimpleCorrection`.
- **Dispersion free steering (DFS)** – Both orbit and dispersion are corrected simultaneously, effectively overcoming systematic errors due to BPM offsets [6]. The main linac is split into groups of BPMs and correctors, called bins, that are corrected one after the other. In each bin the beam is not only steered into the centres of the BPMs but also the differences of the trajectories of beams at different energies are minimised [7]. This is implemented in PLACET using `TestMeasuredCorrection`.
- **Accelerating structure realignment using wakefield monitors (RF)** – Emittance growth due to wakefield effects in the accelerating cavities is reduced by moving the supports of the girders where the cavities are placed on [4]. The sum of the squared positions read in the accelerating structures' wakefield monitors is minimised. This is implemented in PLACET using `TestRfAlignment`.

RESULTS

The resulting emittance growth for the drive-beam design of the main linac, averaged over 1000 machines, for each imperfection and after each of the correction techniques is shown in Table 1. The final emittance growth, with all imperfections and after all three correction techniques, is $<$ 1 nm, averaged over 1000 machines. The emittance growth has a stochastic probability distribution, as can be seen in Fig. 1, with a probability that 90% of the machines remain below 1.5 nm emittance growth, which is well within the budget.

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Table 1: RMS alignment error specifications for the main linac components and the resulting emittance growth for the CLIC 380 GeV drive-beam-based design. The values after 1-2-1, DFS and RF correction are shown.

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
Girder end point	Wire reference	12 μm	12.91	12.81	0.07
Girder end point	Articulation point	5 μm	1.31	1.30	0.02
Quadrupole roll	Longitudinal axis	100 μrad	0.05	0.05	0.05
BPM offset	Wire reference	14 μm	188.99	7.12	0.06
Cavity offset	Girder axis	14 μm	5.39	5.35	0.03
Cavity tilt	Girder axis	141 μrad	0.12	0.40	0.27
BPM resolution		0.1 μm	0.02	0.76	0.03
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.35
All			215.63	26.96	0.81

Table 2: Bunch Charge and Length for the Drive-Beam-Based and Klystron-Based 380 GeV CLIC Designs

		Drive-beam-based	Klystron-based
Charge	(10^9)	5.2	3.87
Length	(μm)	70	60

Table 3: RMS alignment error specifications for the main linac components and the resulting emittance growth for the CLIC 380 GeV klystron-based design. The values after after 1-2-1, DFS and RF correction are shown.

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
Girder end point	Wire reference	12 μm	11.37	11.31	0.07
Girder end point	Articulation point	5 μm	1.45	1.45	0.02
Quadrupole roll	Longitudinal axis	100 μrad	0.04	0.04	0.04
BPM offset	Wire reference	14 μm	154.54	14.01	0.10
Cavity offset	Girder axis	14 μm	5.51	5.50	0.04
Cavity tilt	Girder axis	141 μrad	0.10	0.47	0.25
BPM resolution		0.1 μm	0.02	0.98	0.02
Wake monitor	Structure centre	3.5 μm	0.01	0.01	0.40
All			178.13	31.31	0.86

The emittance growth for the CLIC 380 GeV klystron-based design [2] of the main linac was also evaluated. The beam dynamics does not differ from the drive-beam-based design. The increase of the wakefields due to the smaller accelerating structure aperture is, by design, compensated by the reduced bunch charge and length (Table 2). The expected emittance growth is shown in Table 3 and the probability distribution in Fig. 2. The final emittance growth, with all imperfections and after all three correction techniques, is < 1 nm, averaged over 1000 machines, with a probability that 90% of the machines remain below 1.5 nm emittance growth, which is well within the budget.

CONCLUSIONS

The effect and correction of static imperfections has been studied for both the drive-beam-based and klystron-based designs for the main linac of the 380 GeV first-stage of CLIC. For both designs, the emittance growth due to static imperfections following 1-2-1, DFS and RF correction is < 1 nm, averaged over 1000 machines, with 90% of the machines remaining below 1.5 nm emittance growth. The emittance growth for the 380 GeV design is much smaller than the average emittance growth of 2.34 nm for the main linac in the 3 TeV design, where 95% of the machines have an emittance growth below 5 nm [1]. Therefore, both the 380 GeV and 3 TeV designs present an emittance growth in the main linac which falls within the < 5 nm budget for 90% of the machines.

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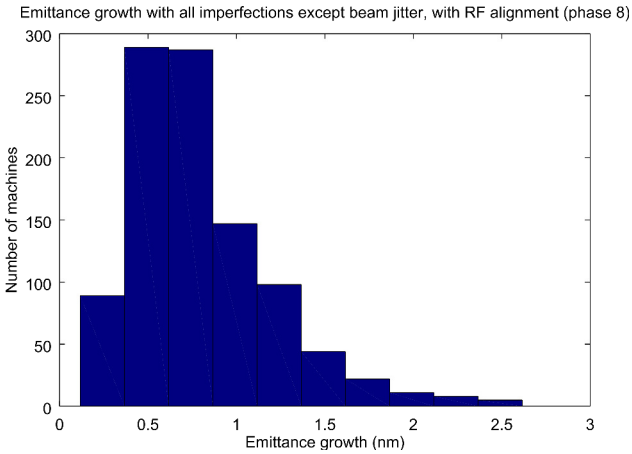

Figure 1: Distribution of the emittance growth over 1000 machines with all static imperfections implemented, after 1-2-1, DFS and RF correction, for the CLIC 380 GeV drive-beam-based design.

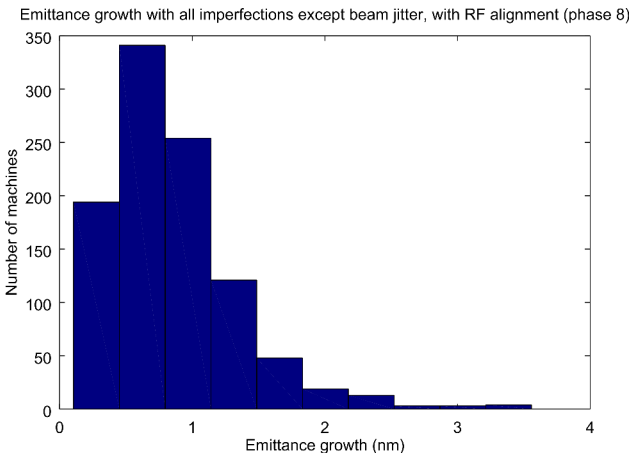

Figure 2: Distribution of the emittance growth over 1000 machines with all static imperfections implemented, after 1-2-1, DFS and RF correction, for the CLIC 380 GeV klystron-based design.

REFERENCES

[1] M. Aicheler *et al.*, "A multi-TeV linear collider based on CLIC technology: CLIC conceptual design report", Geneva, Tech. Rep. CERN-2012-007. SLAC-R-985. KEK-Report-2012-1. PSI-12-01. JAI-2012-001, 2012. doi: 10.5170/CERN-2012-007.

[2] M. Aicheler *et al.*, "The Compact Linear Collider (CLIC) – Project Implementation Plan", Geneva, CERN Yellow Reports: Monographs, Vol. 4/2018, CERN-2018-010-M, 2018. doi: 10.23731/CYRM-2018-004.

[3] N. Blaskovic Kraljevic, and D. Schulte, "Beam-based beamline element alignment for the main linac of the 380 GeV stage of CLIC", Geneva, CERN-ACC-2018-0053. CLIC-Note-1140, 2018.

[4] A. Latina *et al.*, "Recent Improvements in the Tracking Code PLACET", in *Proc. 11th European Particle Accelerator Conf. (EPAC'08)*, Genoa, Italy, Jun. 2008, paper TUPP094, pp. 1750–1752.

[5] D. Schulte, "The CLIC Main Linac Lattice at 1 TeV", Tech. Rep. CERN-OPEN-98-013. CLIC-Note-356, Geneva, 1998.

[6] A. Latina *et al.*, "Experimental demonstration of a global dispersion-free steering, correction at the new linac test facility at SLAC", Phys. Rev. ST Accel. Beams, 17(4):042803, 2014.

[7] D. Schulte, "Different Options for Dispersion Free Steering in the CLIC Main Linac", in *Proc. 21st Particle Accelerator Conf. (PAC'05)*, Knoxville, TN, USA, May 2005, paper RPPP011, pp. 1251–1253.