BEAM-BASED ALIGNMENT IN THE NEW CLIC MAIN LINAC

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Abstract

In the main linac of the compact linear collider (CLIC) the beam induced wakefield and dispersive effects will be strong. In the paper the reference beam-based alignment procedure for the new CLIC parameters is specified and the resulting tolerances for static imperfections are detailed.

INTRODUCTION

In 2008, new overall CLIC parameters have been defined [1]. They are based on an optimisation of the project cost and take into account boundary conditions from the RF structure design and the beam dynamics, the most important parameters are listed in table 1. A new main linac lattice has been developed for the new beam parameters.

Emittance preservation in the main linac is one of the challenges for CLIC. The target is to limit the total emittance growth in the vertical plane to less than $10\,\mathrm{nm}$. Half of this budget is foreseen for dynamic imperfections, which are treated elsewhere. $5\,\mathrm{nm}$ are the budget for static imperfections. Since there is a significant variation of the static emittance growth from one case to the next, it is required that 90% of the simulated machines meet this target.

All components of the CLIC main linac are mounted on movable girders. Most girder support eight accelerating structures. On some girders the first few of the structures have been replaced with a beam position monitor (BPM) and a quadrupole, which are mounted on a common support that can be moved independently of the girder. Each girder is linked to the preceding girder forming an articulation point that allows to move the two girder ends together with the help of motors. The BPM/quadrupole support can also be moved with motors; the step size of these motors is of the order of $1\,\mu\mathrm{m}$. The quadrupoles are held transversely stable to the nanometre level by piezo movers, which can be used to move the quadrupoles up to about $10\,\mu\mathrm{m}$. The beam orbit is corrected by moving the quadrupoles transversely, for large corrections using the motors for smaller corrections using the piezo movers.

The model of the pre-alignment performance contains two main contributions. The first is the error of the reference line to which the pre-alignment system attempts to align all the beam line components. The second is given by local imperfections that are not correlated over a longer distance. Here, both contributions are studied independently.

Table 1: Important initial beam parameters for the new CLIC main linac.

Parameter	symbol	unit	value
Bunch charge	N	particles	$3.72 \cdot 10^9$
Bunch length	σ_z	μm	45
hor. emittance	ϵ_x	nm	600
vert. emittance	ϵ_y	nm	10

BEAM-BASED ALIGNMENT PROCEDURE

The beam-based alignment of the linac is performed in three stages. First, the beam is steered through the centres of the BPMs. This ensures that it will pass without losses. Then dispersion free steering is applied. For this procedure the nominal beam and a test beam are used. The test beam has a lower initial energy than the nominal beam and is accelerated at a lower gradient. The initial energy is modified by changing the RF phase in the bunch compressor, which in turn also changes the bunch length. The change in main linac gradient is achieved by modifying the drive beam current in the whole main linac. The procedure consists of the following steps:

- The whole linac is subdivided into bins with a length of 36 quadrupoles and BPMs each. The bins overlapp by 18 quadrupoles. Starting from the up-stream (lowest energy) bin each bin is aligned in turn.
- The beam trajectory of the probe and the nominal beam are measured.
- The required quadrupole motions are calculated to minimise

$$\sum_{i=1}^{N}\left(w_i(x_{i,1})^2+\sum_{j=2}^{m}w_{i,j}(x_{i,1}-x_{i,j})^2\right)$$

  We chose $w_i = 1$ and $w_{i,j} = 1000$; the results obviously change with different choices.
- The expected new BPM readings are calculated and the nominal zero of the BPMs moved to this value.
- The quadrupoles are moved to steer the nominal beam into the new reference points of the BPMs.

Finally, the accelerating structures are aligned to the beam. Each structure is equipped with a wake field monitor that allows to measure the beam offset. The procedure applied is very simple. Starting with the first girder the downstream end-point of the girder is moved in order to reduce the mean beam offset in the structures to zero. This automatically moves the upstream endpoint of the next girder but does not affect any of the already aligned upstream girders. During this procedure the beam is permanently kept centered in the BPMs and it is continued up to the end of the main linac.

After the RF alignment emittance and luminosity tuning knobs can be used to further improve the emittance or luminosity. Different designs can be used for these knobs, e.g. a number of structures can be moved transversely thus applying an additional wakefield kick to the beam. The structures are moved until the emittance that is monitored at the end of the main lianc is minimised. Similar knobs can be constructed for structure tilts or quadrupole rolls. However, we aim to achieve the targert performance without these knobs and keep them a a margin.

Alternative methods could be used to replace the dispersion free steering, in particular ballistic alignment and kick minimisation.

All results presented in the following are based on simulations with PLACET [2].

LOCAL PRE-ALIGNMENT

For the local imperfections it is assumed that the reference line is perfectly straight over the whole machine. The misalignement is the modelled starting from a perfect machine and applying successively the imperfections in table 2. All values for the imperfections are drawn from a Gaussian distribution.

- Each quadrupole is offset and rolled around the longitudinal axis.
- Each BPM is misaligned, the value used in the simulation is a combination of the wire-reference to exeternal BPM error and the internal BPM error.
- The wakefield monitor in each structure is misaligned with respect to the structure.
- The structure is misaligned and tilted with respect to the supporting girder.
- The endpoints of the girders are misaligned with respect to the articulation points; all structures on the girders are moved accordingly.
- The articulation point between the girders are misaligned.

The simulations have been performed for each of the different imperfections individually. This allows to estimate the impact of each error source, it scales with the square of the error size. The results are listed in table 2, the emittance growth along the machine is shown in figure 1. An important imperfection is the accuracy of the BPM position with respect to the reference line. This error is dominated by the misalignment of the BPM by the pre-alignment system and the internal BPM accuracy. In the table the two contributions are grouped into a single value. All imperfections are imortant along the whole linac with the exception of the structure tilt, which is dominated by the very first part of the linac. It may be possible to fix this problem by modifying the alignement method at this location, e.g. by locally optimising the weight differently from the rest of the machine.

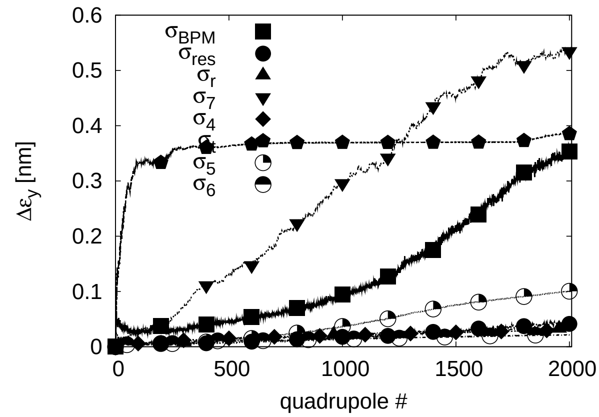

Figure 1: Emittance growth along the CLIC main linac for the different imperfections.

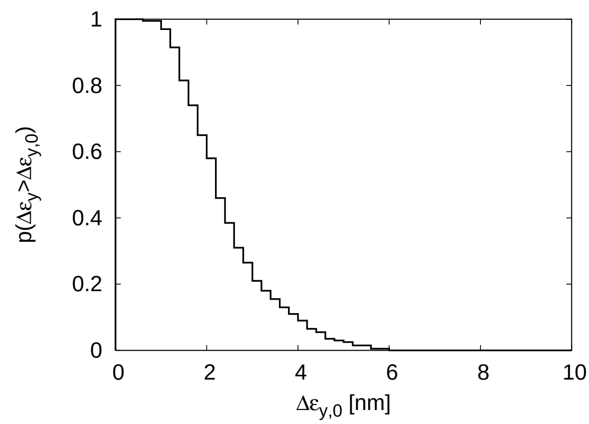

Figure 2: Probability distribution of the final emittance growth if all imperfections are considered, except for the wire system.

The misalignment of the articulation points leads to emittance growth, which is acceptable but noticeable given the assumed prealignment performance. This is a result of the specific implementation of the procedure to align the structures to the beam. All girders are aligned in sequence starting with the upstream one. For each girder only the downstream end is adjusted until the mean structure offset is zero. Moving the upstream and the downstream end of the girder would in principle allow to completely recover from any misalignment of the articulation points. But it makes the alignment procedure more complex since a common solution has to be found for all the girders in the main linac. Additional articulation point after each quadrupole would allow to simplify the method, as only all the giders between two quadrupoles would need to be aligned simultaneously.

WIRE REFERENCE SYSTEM

The reference line is defined by a system of overlapping wires. All wires have the same length and the overlapp is

Table 2: List of individual imperfections and resulting emittance growth. The accelerating structure tilt is dominated by the internal error of the accelerating structure not by the mechanical alignment of the structure on the girder.

imperfection	with respect to	symbol	value	emitt. growth
BPM offset	wire reference	σ_{BPM}	$14\,\mu$m	$0.367\,\mathrm{nm}$
BPM resolution		σ_{res}	$0.1\,\mu$m	$0.04\,\mathrm{nm}$
accelerating structure offset	girder axis	σ_4	$10\,\mu$m	$0.03\,\mathrm{nm}$
accelerating structure tilt	girder axis	σ_t	$200\,\mu$radian	$0.38\,\mathrm{nm}$
articulation point offset	wire reference	σ_5	$10\,\mu$m	$0.1\,\mathrm{nm}$
girder end point	articulation point	σ_6	$5\,\mu$m	$0.02\,\mathrm{nm}$
wake monitor	structure centre	σ_7	$5\,\mu$m	$0.54\,\mathrm{nm}$
quadrupole roll	longitudinal axis	σ_r	$100\,\mu$radian	$0.12\,\mathrm{nm}$
all				$2.34\,\mathrm{nm}$

Table 3: Main parameters for the different wire reference systems studied.

case	wire length	no of pits	sensor accuracy	$\Delta\epsilon_y[\mathrm{nm}]$
1a	403.2	7	$20\,\mu$m	0.09
1b	403.2	7	$5\,\mu$m	≈ 0.01
2a	400	2	$5\,\mu$m	≈ 0.01
2b	400	3	$5\,\mu$m	≈ 0.01
2c	400	6	$5\,\mu$m	≈ 0.01

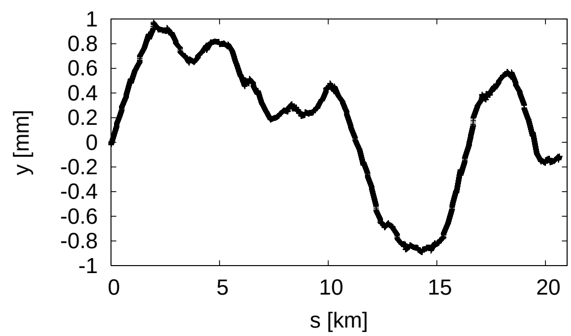

Figure 3: An example of the misalignment of the main linac elements due to the wire reference system.

half the wire length. This system has been simulated [3] and the end-points of the wires have been determined in real space for a number of random seeds. This data has been used as the basis for the present pre-alignment simulations. Relevant parameters of the cases that were studied are listen in table 3, an example of the linac misalignments can be seen in figure 3.

It is assumed that each wire is perfectly straight. The end points of each girder are aligned using one of the wires. After half a wire length we switch from using one wire to using the newly starting parallel wire. The position of the end points is not interpolated using the information of two wires. In principle, this would allow obtain a smother alignment but it would be more costly as two sensors would be required for each point. At the points where on switches from one wire to the next this leads to a very rapid change in the position of the elements.

The simulations show in all cases an acceptable emittance growth, see table 3. The wire sensor accuracy is an important parameter with a strong impact on the emittance growth while the number of external reference points does not impact the results singificantly. Further studies should asses the impact of the wire length. Also the impact of other errors will need to be studied, in particular errors of the assumed wire sag.

CONCLUSION

The emittance growth due to imperfections has been studied in the new CLIC main linac. The most important contributions arise from the final misalignements of the accelerating structures due to the limited accuracy of the wake field monitors, from the tilt of the structures, the BPM misalignments and the quadrupole roll. The sum of the imperfections lead to an emittance growth that is acceptable.

The imperfection of the reference line also impacts the emittance growth. Simulations show that the accuracy of the wire sensors is relevant. But even a relatively bad accuracy of $20\,\mu$m leads to an additional emittance growth of only $0.1\,\mathrm{nm}$, which is still acceptable. For a good wire sensor resolution of $5\,\mu$m the emittance growth is only $0.01\,\mathrm{nm}$ and does not depend significantly on the number of pits used. Further studies will be needed to evaluate other imperfections of the reference system errors, e.g. errors in the sag of the wires.

AKNOWLEDGEMENT

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REFERENCES

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[2] A. Latina et al., “Recent Improvements in the tracking code PLACET”, EPAC 2008.

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