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STATUS OF THE CLIC RTML STUDIES

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Abstract

Over the last months the general layout of the CLIC ring to main linac transport (RTML) has stabilized and most important lattices have been designed. This allowed us to study their performance and to start studies of tolerances on magnetic stray fields and on magnet misalignment. Additionally, beam lines could be improved in terms of performance and flexibility. We discuss the overall layout as will be described in the CLIC conceptual design report, highlight the improvements which have been made and show results of tolerance studies.

INTRODUCTION

The ring to main linac transport (RTML) for the CLIC [1, 2] main beam consists of a variety of beam lines, each serving a distinct function. They are all required to properly transport, shape and characterize the particle distributions prior to their acceleration in the main linac to collision energy. Electron and positron beams share the booster linac, all other beam lines are separated (Fig. 1). A general overview of the RTML was given in [3, 4].

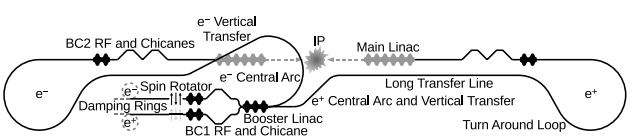

Figure 1: Conceptual layout of the RTML showing its main components.

Tight tolerances are imposed on the performance of the RTML, particularly on the emittance growth. Table 1 shows beam parameters as delivered by the damping rings, i.e. at the start of the RTML. Table 2 shows beam parameters as required by the main linac, i.e. at the end of the RTML.

GENERAL LAYOUT

To achieve a more compact site it was requested to make the injector part of CLIC parallel to the main tunnel. This choice is transparent for the injectors and the main linac, but of course adds some complexity to the RTML and breaks symmetry between electron and positron beam lines. In the new layout a 180 deg arc is required to send outwards the electron beam. It is followed by a horizontal dog-leg which includes in its straight section the vertical transfer from ground to tunnel level. For the positrons only such a dog-leg is required. Naturally, the path lengths which are travelled by electrons and positrons will differ. Since both beams share the same booster linac, they need to have in any case a timing offset, which must be corrected for proper timing at the interaction point. Hence, the path length difference along the central arcs adds to the complexity but does not create a new problem.

Table 1: Beam parameters at the start of RTML.

Property	Symbol	Value	Unit
Energy	E_0	2.86	GeV
Bunch length	σ_s	1600	μm
Total energy spread	$\sigma_{E,tot}$	0.13	%
Normalized emittance	$\varepsilon_{n,x}$	500	nm rad
	$\varepsilon_{n,y}$	5	nm rad

Table 2: Required beam parameters at the end of RTML.

Property	Symbol	Value	Unit
Energy	E_0	9	GeV
Bunch length	σ_s	44	μm
Total energy spread	$\sigma_{E,tot}$	< 1.7	%
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad

One important advantage of the new layout is that the electron spin rotator can be located at low energy in front of the first bunch compression. Any spin dilution which could be induced due to energy spread will be compensated since the sum of the bends traversed by the electrons from spin rotator exit to main linac entrance is zero (figure-eight movement). On the other hand, the positrons will traverse a net bending of 180 deg which would induce a loss of 2% of polarization. Still, for the moment it was decided to reserve its space also in front of BC1. The electron spin rotator is under study and will be integrated into the RTML soon [5].

Initial parameters have changed since a relaxation of the damping ring design was required [6], which lead to an increase of longitudinal emittance from 4000 eV m to 6000 eV m. The bunch compression systems had to be adapted by increasing the RF voltages and lowering chicane strengths.

PERFORMANCE STUDIES

Lattice files following closely the baseline RTML layout have been created for the codes ELEGANT [7, 8] and PLACET [9]. The spin rotator is the only major beam line

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which is still missing, it is replaced at the moment by a simple periodic transfer line of 100 m length. The total length of the RTML lattice is about 26.3 km, 21 km of these are due to the long transfer line.

Figure 2 shows longitudinal phase space distribution and profiles of the electrons at the end of the RTML as simulated by ELEGANT and PLACET. Incoherent synchrotron radiation and cavity wake fields are taken into account. The lattice is perfectly aligned and has no magnetic errors. The incoming particle distribution was Gaussian. The two simulations agree very well. Small deviations are due to differing calculations of the wake fields resulting in slightly different energy distributions and thus compression. The agreement in the transverse planes is even better which is reflected by the final emittances of

$$\varepsilon_{\mathrm{n,x}} = 549.7 \text{ nm rad (ELEGANT) vs}$$
$$\varepsilon_{\mathrm{n,x}} = 551.7 \text{ nm rad (PLACET) and}$$
$$\varepsilon_{\mathrm{n,y}} = 5.847 \text{ nm rad (ELEGANT) vs}$$
$$\varepsilon_{\mathrm{n,y}} = 5.914 \text{ nm rad (PLACET).}$$

Simulations for the positron beam show the same good agreement. But since the central arc is not required incoherent synchrotron radiation is about 40% weaker, i.e. the final horizontal emittance is lower by almost 20 nm rad.

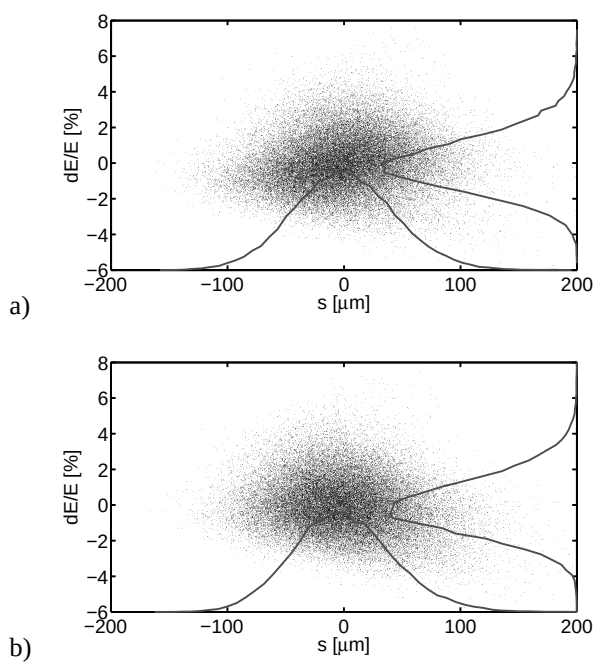

Figure 2: Longitudinal phase space distributions and profiles at the exit of the RTML simulated by ELEGANT (a) and PLACET (b). The profiles are scaled to the same arbitrary units.

Coherent synchrotron radiation was only simulated using ELEGANT. An additional emittance growth of $\Delta\varepsilon_{\mathrm{n,x}} = 15$ nm rad is induced by it mainly in the chicanes of BC1 and BC2. The shielding effect of the vacuum chambers [10] was not taken into account. This effect is expected to reduce the contribution of CSR to emittance significantly. In any case, the performance of the error-free RTML lattices is good enough to leave sufficient margin for static and dynamic errors like misalignment, magnetic field jitter or magnetic stray fields.

An effort is on-going to perform start-to-end simulations including all CLIC beam lines. Currently these start at the main linac entrance and the RTML will be added soon [11].

ALIGNMENT ERRORS

Studies of alignment tolerances were started for the beam lines which are assumed to require tightest tolerances. These are the booster linac due to cavity misalignment and wake fields, the vertical transfer due to the extremely small vertical emittance, the long transfer line due to its length and the turn around loop due to its complex lattice with strong quadrupoles and sextupoles. Since the lattice of the central electron arc is extracted from the turn around loop it does not need to be studied as well even though we expect tight tolerances.

During the course of these studies we figured out that the turn around loop has extremely small tolerances and any error will spoil vertical emittance by an unacceptable amount. An improvement of the lattice is ongoing, which will also apply to other arcs along the RTML.

First studies of the long transfer line revealed that its quadrupoles require an acceptable but still tight alignment of about $100 - 200\ \mu$m (Fig. 3). Even when applying 1-to-1 steering an average emittance growth of up to 1 nm rad would remain in the vertical plane. The 90th percentile is even two times larger. More sophisticated correction strategies might reduce emittance growth further and thus could allow larger misalignments.

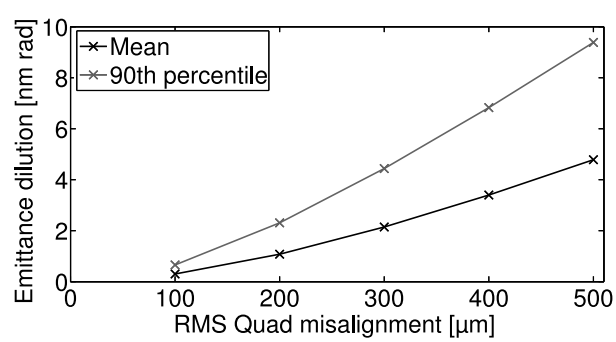

Figure 3: Dilution of vertical emittance induced by quadrupole misalignments in the long transfer line after 1-to-1 steering.

MAGNETIC STRAY FIELDS

Contrary to magnetic field errors, which are errors of magnets within a beam line, magnetic stray fields are produced by external sources, i.e. by sources which are not part of the beam line lattice. These sources can be any technical installation of the accelerator itself, e.g. vacuum

pump, any technical installation near the accelerator, e.g. power lines, or even geological conditions of the accelerator site, e.g. fluctuations in the earth magnetic field. A detailed study of magnetic stray fields is described in [12].

The main concern in the RTML are the long transfer lines. Not only due to their length, but also due to their weak focusing. The beams can easily accumulate deflections due to stray fields resulting in unacceptable beam offsets or angles which might even dilute emittances. To mitigate tolerances it is forseen to include feed-forward systems behind the turn around loops. These loops are long enough, 1.5 km, to gain sufficient time after performing measurements to process these and to apply corrections. Prerequisite is that the loops transport beams with errors in position and angle without spoiling emittance.

The stray field studies revealed the same problem of the turn around loop as the misalignment studies. It has an extremely small acceptance for incoming vertical beam jitter. This will also be taken into account for its re-design.

An assumption which yields a worst case scenario is that the stray fields are periodic with a certain wavelength all along the long transfer line. In Fig. 4 tolerances are given for a growth of the vertical emittance by 8% and an offset of 14 μm, both corresponding to a loss in luminosity of 2%. The offset is calculated in normalized phase space as $\tilde{y}_{\mathrm{N}} = \sqrt{y_{\mathrm{N}}^2 + y_{\mathrm{N}}'^2}$. Tightest tolerances are required at wavelengths similar to the betatron wavelength. The emittance tolerates a lot larger stray fields than the offset. Hence, by adding a feed-forward system which corrects the offsets one can mitigate the effective tolerance to the level of the tolerance given by emittance growth. Its gain factor needs to be at least as good as the result of the division of the two tolerance curves, i.e. 10 to 100 depending on wavelength.

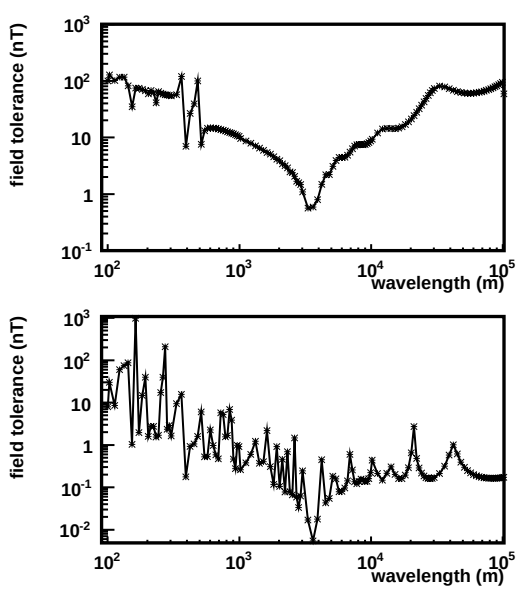

Figure 4: Tolerance on periodic magnetic stray fields along the long transfer line for an allowed emittance growth of 8% (a) and an allowed offset of 14 μm (b).

SUMMARY

In view of the upcoming CLIC conceptual design report, layout and lattices of the main beam RTML have been reviewed and improved. Start-to-end simulations were performed and studies of the influence of imperfections like misalignment, magnetic field jitter and magnetic stray fields were started.

The lattices are almost complete and follow closely but the baseline layout. Emphasis was put on creating and optimizing beam lines which are expected to have a strong impact on beam quality. Shorter transfer lines and arcs were created for completeness but were not fully trimmed.

Simulations show that the performance of the perfect RTML, i.e. the RTML without alignment and magnetic errors but with cavity wake fields and synchrotron radiation, is good. Sufficient budget is left for the impact of static and dynamic errors.

The studies on imperfections reveal some tight tolerances which require further inquiries. A feed-forward system will be installed as part of a mitigation strategy. The turn around loops have been identified to require further optimizations. This effort has been started.

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