CLIC MAIN BEAM DYNAMICS IN THE RING TO MAIN LINAC TRANSPORT

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Abstract

Prior to acceleration in the main linac, the particle beams created in the centrally located injector have to be transported to the outer ends of the CLIC site. This transport should not only preserve the beam quality but also shape, characterize and tune the phase space distribution to match the requirements at the entrance of the main linac. Hence, the performance of the transport downstream of the damping rings up to the main linac, the so called RTML, is crucial for the overall performance of CLIC. We discuss the different parts of the RTML and the occurring beam dynamics challenges. Their status is outlined and results of beam dynamics simulations are presented.

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. The main systems are

- two bunch compressors
- a booster linac
- a vertical transfer line
- a long transfer line
- a turn around loop
- a spin rotator

In addition, there are collimators, diagnostics, feedback and feedforward systems. They are all required to transport, shape and characterize the particle bunches prior to their acceleration to collision energy (Fig. 1). Intermediate spectrometer beam lines with dumps are required for commissioning. Electron and positron beams share the booster linac, all other beam lines are separated.

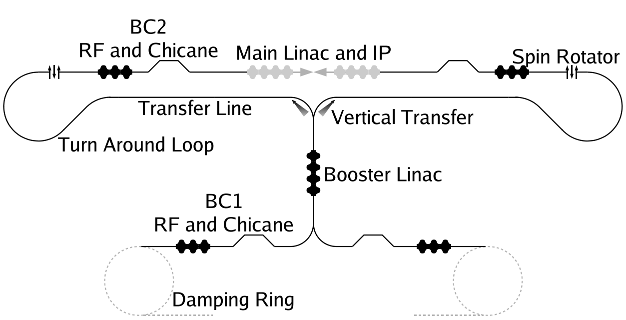

Figure 1: Conceptual layout of the RTML showing the main components.

Table 1: Beam Parameters at the Start of RTML

Property	Symbol	Value	Unit
Electron energy	E_0	2.86	GeV
Bunch charge	Q_0	0.65	nC
Bunch length	σ_s	1300	μm
Total energy spread	$\sigma_{E,tot}$	0.11	%
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
Electron energy	E_0	8	GeV
Bunch charge	Q_0	> 0.6	nC
Bunch length	σ_s	44	μm
Total energy spread	$\sigma_{E,tot}$	< 1.5	%
Normalized emittance	$\varepsilon_{n,x}$	< 600	nm rad
	$\varepsilon_{n,y}$	< 10	nm rad

Tight tolerances are imposed on the performance of the RTML, particularly on the emittance growth. Table 1 shows the beam parameters as delivered by the damping rings, i.e. at the start of the RTML. Table 2 shows the beam parameters as required by the main linac, i.e. at the end of the RTML. Both parameter sets have been recently re-optimized to fit better the needs of the damping rings and the RTML [3]. Since the influence on the main linac has not yet been fully studied the parameters might require another revision. But it seems likely that they will become baseline. In any case the RTML must be flexible enough to allow small changes in initial or final parameters.

In the following section the individual beam lines are described including the most important beam dynamics challenges. Afterwards, simulation results are presented.

BEAM LINES

The beam lines will be described in order of their appearance in the RTML, BC2 being the only exception since it will be described in the same sub-section as BC1. Currently, the beam lines for e^+ and e^- beams are considered to be the same.

Bunch Compressors

Two bunch compressors (BC1 and BC2) are foreseen, one at the beginning of the RTML and one at its end. Both consist of RF cavities to induce the energy chirp and a magnetic chicane to achieve the compression. Such a setup allows to limit non-linearities in the energy distribution induced by the booster linac and to limit the energy spread in the turn around loop. The chicanes had been optimized with respect to emittance growth induced by coherent synchrotron radiation (CSR) in reference [4]. The design of the BC2 RF is complicated by the fact that strong wake fields counteract the development of the energy chirp. To ease its design, it is discussed to substitute the magnetic chicane, i.e. a beam line with negative R_{56}, by a beam line with positive R_{56}. This needs to be studied.

Booster Linac

A single booster linac accelerates alternately electrons and positrons. The acceleration is required to reduce space charge forces in the long transfer line and to lower the relative energy spread in the turn around loop, which eases the loop design. In [5] a systematic study of wake field effects using different lattices has been performed. Previous studies were described in [6]. A lattice was designed which reduces the influence of wake fields on beam emittance and which is tolerant with respect to misalignment.

Transfer Lines

More than 20 km of straight transfer line are required to transport the beams from the centrally located injector to the outer ends of the site. Weak quadrupoles are utilized to achieve a simple FODO lattice. The beam pipe will have a large diameter of about 10 cm to reduce resistive wall wake fields. In reference [7] it was highlighted that, for the ILC RTML, such long transfer lines are extremely sensitive to stray magnetic fields. Preliminary studies for the CLIC RTML showed similar behavior. The fast beam-ion instability must also be carefully examined.

Another important transport line in the RTML is the vertical transfer line from ground level, where all of the injector beam lines are located, down to tunnel level, where the main linac are located. This beam line will be located between the booster linac and the long transfer line. A major concern is CSR due to the vertical bends which could easily spoil the extremely low vertical emittance. This beam line has not yet been studied.

Turn Around Loop

To direct the beam into the main linac a turn around loop will be installed at the end of the long transfer line. Its lattice design is tightly constrained by the beam parameters. The bunches will be $\sigma_s \approx 150$ μm short, will have an energy spread of $\sigma_{E,tot}/E_0 \approx 0.4$ % and an energy of $E_0 = 8$ GeV. To avoid an elongation of the bunches the lattice must be isochronous. Hence, strong quadrupoles are required to reverse the sign of the dispersion and strong sextupoles must be used to limit the chromatic errors by the quadrupoles. The turn around loop lattice has been studied in [4] and a revision was made in [8]. It consists of a 180 degrees arc to send back the beam and a a dogleg with two 60 degrees arcs to correct for the transverse offset. In Fig. 2 beta functions, dispersion and momentum-compaction factor along a single cell are plotted.

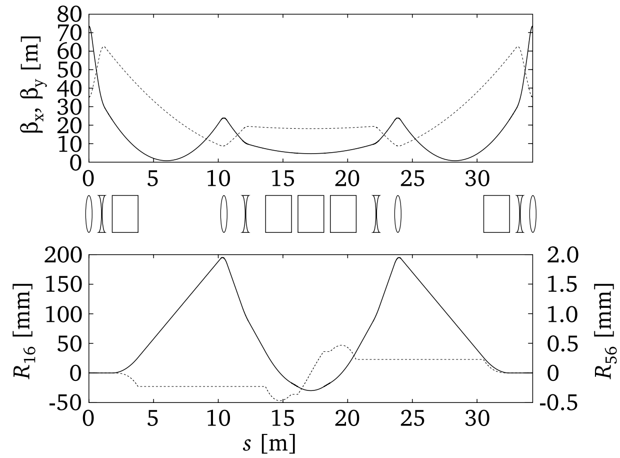

Figure 2: Beta functions β_x (upper, solid) and β_y (upper, dashed), dispersion R_{16} (lower,solid) and momentum-compaction factor R_{56} (lower, dashed) along a single cell of the turn around loop.

In the current lattice the rather large energy leads to a huge ISR-induced emittance growth of $\Delta\varepsilon_{n,x}^{(ISR)} \approx 30$ nm rad. This was the reason for lowering the energy from 9 GeV, which doubles the ISR emittance growth, to 8 GeV. CSR in the bends was found to be rather small.

Spin Rotator

Polarized electrons and later on polarized positrons will be utilized in CLIC. They have to be created at the source and their polarization has to be transported without losses up to the interaction point. Spin dilution can be avoided by aligning the spin vector parallel to the magnetic field lines in dipoles. This is already achieved in front of the pre-damping rings and all dipoles of the RTML, except for the dipoles of the vertical transport, bend in the same plane as the damping ring dipoles. Consequently, a single spin rotator at the end of the RTML should be sufficient to freely adjust the orientation of the spin vector at the interaction point. To reduce the footprint of the CLIC site, it was proposed to locate the spin rotator before the turn around loop. It has to be studied whether or not the spin dilution induced in the turn around loop and the vertical transfer is tolerable. Studies on the spin rotator will be started soon. Presumably the ILC spin rotator will be used as a starting point.

SIMULATIONS

Previously, all beam lines had been studied and optimized individually using perfectly Gaussian particle distributions. Since some effects only show up when realistic distributions are used, an effort was made to connect the available lattices and to perform start-to-end simulations of the RTML including wake fields, incoherent and coherent synchrotron radiation. Currently, these simulations include the two bunch compressors, the booster linac, the long transfer line and the turn around loop. They are connected by simple optics matching sections. Since these lattices are considered most important for beam dynamics, the results are a good approximation to the overall RTML performance. The spin rotator and the vertical transfer line are the only important beam lines which are still missing. Simulations are performed using the codes ELEGANT [9, 10] and PLACET [11] to crosscheck the validity of the results.

In Fig. 3 results of simulations are compared including the influence of longitudinal and transverse cavity wake fields and incoherent synchrotron radiation (ISR). Both codes result in almost the same longitudinal phase space distribution. Longitudinal profile and energy distribution still resemble closely the initially Gaussian distribution. The wake fields create some tails, but these carry rather low charge. In the transverse planes the deformation is almost invisible, but some emittance growth, $\Delta\varepsilon_{\rm n,x}^{\rm (ELEGANT)} \approx$ 50 nm rad and $\Delta\varepsilon_{\rm n,x}^{\rm (PLACET)} \approx 60$ nm rad, occurs in the horizontal plane. The dilution is partly due to ISR in the turn around loop and partly due to the wake fields in the RF cavities. Some fraction is also due to chromatic effects in the loop and in the matching sections. Especially, the matching sections have not yet been fully optimized. In the vertical plane no emittance dilution occurs.

The difference between ELEGANT and PLACET needs to be studied further, but the agreement is already very good. Simulations including only ISR and no wake fields show almost perfect agreement. Hence, it seems likely that differing implementations of wake fields or insufficient setup of the wake field calculation in one of the simulations is the source of the discrepancy.

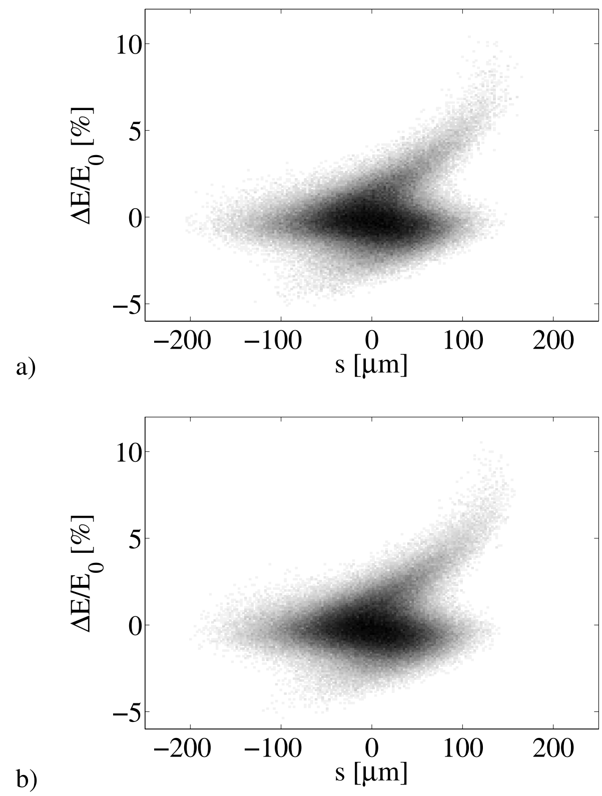

Figure 3: Longitudinal phase space distributions at the exit of the RTML simulated by ELEGANT (a) and PLACET (b).

SUMMARY

A significant progress has been made in the design of the CLIC main beam RTML. Lattices are existing for most of the important systems and they have been optimized to meet specifications. Previously, the lattices have been studied and optimized separately taking effects like ISR, CSR and cavity wake fields into account. Now, to perform start-to-end simulations, the individual beam lines have been connected with optics matching sections. The codes ELEGANT and PLACET were used to simulate the influence of ISR and cavity wake fields. Their results are in very good agreement. Since lattices are now existing for two codes it should be a lot easier to proceed with beam dynamics studies. Coherent synchrotron radiation will be added soon, afterwards misalignment studies will be started.

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