

CLIC RING TO MAIN LINAC

F. Stulle, D. Schulte, J. Snuverink, CERN, Geneva, Switzerland

A. Latina, Fermilab, Batavia, IL, USA

S. Molloy, Royal Holloway, University of London, Surrey, Great Britain

Abstract

The low emittance transport had been identified as one of the feasibility issues for CLIC. We discuss beam dynamics challenges occurring in the beam lines connecting the damping rings and the main linac. And we outline how these motivate design choices for the general RTML layout as well as its integration into the overall CLIC layout. Constraints originating from longitudinal dynamics and stabilization requirements of beam energy and phase at the main linac entrance are emphasized.

INTRODUCTION

The multi-TeV linear collider CLIC consists of a main beam, which is used for collisions, and a drive beam, which is used to produce the RF power needed to accelerate the main beam. Both beams have to fulfill tight constraints to allow proper acceleration in the main linac and proper collision at the interaction point (IP). The drive beam part is discussed in [1]. Here we focus on the ring to main linac transport (RTML) connecting damping rings and main linac. We discuss its functions and constraints.

Relative timing of main beam and drive beam as well as relative timing of electrons and positrons at the IP is required to be $\sigma_\phi < 0.1$ deg (12 GHz). Transverse beam position jitter at RTML exit needs to stay below 10% of the RMS beam sizes. Constraints on the beam at the RTML exit are summarized in Table 1. They have to be matched within a filling time of the main linac cavities, which is 60 ns. Table 2 summarizes beam parameters at the entrance of the RTML. Constraints on incoming beam phase and energy will be calculated.

GENERAL LAYOUT

The RTML is used for transport, acceleration, bunch compression and spin rotation. The layout of the transfer lines is strongly driven by civil engineering constraints. Design considerations for the other three are given in the following. A sketch of the RTML is shown in Fig. 1.

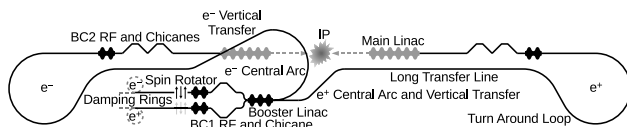


Figure 1: Conceptual layout of the RTML showing its main components.

Table 1: Required Beam Properties at the End of the RTML

Property	Value	Unit	Jitter Tolerance
Particle energy	E_f	9 GeV	$\pm 0.2\%$
Bunch length	σ_{sf}	44 μm	$\pm 0.5\%$
Tot. energy spr.	$\sigma_{E,\text{tot}}$	< 1.7 %	$\pm 0.2\%$
Norm. emittance	$\varepsilon_{n,x}$	< 600 nm rad	$\pm 5\%$
	$\varepsilon_{n,y}$	< 10 nm rad	$\pm 5\%$
Bunch phase	ϕ	0 deg	± 0.1 deg
Position	$\langle x \rangle, \langle y \rangle$	0 m	$\pm 0.1 \sigma_{x,y}$

Table 2: Beam Properties at the Start of the RTML

Property	Value	Unit
Particle energy	E_i	2.86 GeV
Bunch length	σ_{si}	1600 μm
Total energy spread	$\sigma_{E,\text{tot}}$	0.13 %
Normalized emittance	$\varepsilon_{n,x}$	500 nm rad
	$\varepsilon_{n,y}$	5 nm rad

Booster Linac

The damping rings cannot be placed at too high energies due to synchrotron radiation losses and the main linac cannot start at too low energies due to wake fields. Hence, a booster linac is needed to provide the required energy matching. To reduce cost a single booster linac is shared by electrons and positrons. The impact of short range wake fields has been studied in [2] and was found to be acceptable. Studies of long range wake fields started recently. First results point out that tighter alignment tolerances will have to be achieved to mitigate their impact.

Bunch Compression

The bunches need to be compressed in a first stage (BC1) to a length sufficiently short to reduce non-linearities induced by the sinusoidal RF of the booster linac. On the other hand, they have to remain long to suppress coherent synchrotron radiation (CSR) in the arcs and loops, to avoid chromatic emittance dilution since the energy spread is coupled to bunch length by conservation of longitudinal emittance and to increase leverage of the RF for the second compression stage (BC2) to reduce its voltage. Additional arguments stem from constraints on beam properties and technical systems. An intermediate bunch length of 300 μm was found to be a good compromise [3].

Spin Rotator

To avoid depolarization due to energy spread the spin vector should be parallel to the magnetic field vector in bending magnets. But at the IP the spin vector has to be oriented to any direction requested by particle physics. Hence, a spin rotator must be either located at a location not being followed by any beam deflection, or at a location which is only followed by bends compensating each other, i.e. the sum of the bend angles is zero. Since central arc and turn around loop compensate each other the electron spin rotator can be placed at the very beginning of the RTML [4].

TOLERANCES

We evaluate constraints on BC2, booster linac, BC1 and the initial beam assuming the absence of any active correction. Details will be published in Ref. [5].

Two cases need to be distinguished depending on the choice of the phase reference system [1]. Either external phase references (EPR) are used or the out-going beams (OBR), i.e. the ones traveling towards the turn around loops. The choice influences the phasing of the BC2 RF cavities and the performance of feed-forward systems, which will be included to mitigate these tolerances.

BC2

A jitter σ_θ of the deflection angle θ in the BC2 chicane dipoles will induce a beam phase jitter of

$$\sigma_\phi = \frac{2\pi f_{ML}}{c} r_{56,BC2} \frac{\sigma_\theta}{\theta}. \quad (1)$$

$f_{ML} = 12$ GHz is the main linac frequency. BC2 consists of two chicanes with $r_{56,BC2a} = -1.38$ cm and $r_{56,BC2b} = -0.60$ cm resulting in $\frac{\sigma_\theta}{\theta} < 5 \times 10^{-4}$.

Since the BC2 RF cavities run 90 deg off-crest an RF phase jitter $\sigma_{\varphi,BC2}$ induces an energy jitter, which in turn converts into a beam phase jitter in the chicanes:

$$\sigma_\phi = \frac{f_{ML}}{f_{BC2}} \sigma_{\varphi,BC2} r_{56,BC2} u_{BC2}. \quad (2)$$

The cavities run at a frequency of $f_{BC2} = 12$ GHz and induce an energy chirp of $u_{BC2} = \frac{1}{E} \frac{dE}{ds} = -41.3$ m⁻¹. Hence, $\sigma_{\varphi,BC2} < 0.12$ deg (12 GHz) is required.

In case the RF amplitude A_{BC2} jitters by $\sigma_{A,BC2}$ the bunch length σ_{sf} behind the chicanes will jitter by

$$\sqrt{\langle \sigma_{sf}^2 \rangle} \approx \frac{1}{2} \frac{\sigma_{A,BC2}^2}{A_{BC2}^2} \frac{\sigma_{si}^2}{\sigma_{sf,0}} + \sigma_{sf,0}. \quad (3)$$

To stabilize σ_{sf} to 1% A_{BC2} has to jitter by less than 2%.

Constraints on BC2 itself do not depend on the phase reference. But constraints on the beam entering BC2 do. In the OBR case BC2 is transparent for incoming beam phase jitter. Hence, it must stay below 0.1 deg (12 GHz). In the EPR case incoming phase jitter will be fully converted into energy jitter. Hence, to stay within energy limits of

0.2% a phase stability of 0.7 deg (12 GHz) is required. Like an RF phase jitter an incoming energy jitter will induce a beam phase jitter. Consequently, the energy jitter must stay within 3.5×10^{-4} , which is the same value that would be induced by the maximum allowed RF phase jitter.

Booster Linac

To match the energy tolerance given above the booster linac RF amplitude A_B must be stable to

$$\frac{\sigma_{A,B}}{A_B} = \frac{\sigma_\phi c}{2\pi f_{ML} r_{56,BC2}} \frac{E_f}{E_f - E_i}. \quad (4)$$

This results in $\frac{\sigma_{A,B}}{A_B} < 5.1 \times 10^{-4}$. An RF phase error of 1.8 deg (2 GHz) would induce the same energy error and also an energy chirp error of 1 m⁻¹, which is the limit to stabilize the bunch length to 1%.

The booster linac is almost transparent for phase and energy errors of the incoming bunch. Hence, the beam phase has to match either 0.7 deg (12 GHz) (EPR) or 0.1 deg (12 GHz) (OBR) and the beam energy has to be stable to 1.1×10^{-3} , which is the value required at the BC2 entrance scaled by the acceleration factor.

BC1

For BC1 the same error sources as for BC2 have to be evaluated. The chicane magnets have to be stable to 3.7×10^{-4} (EPR) or 5.3×10^{-5} (OBR), the RF phase has to be stable to 0.14 deg (2 GHz) (EPR) or 0.02 deg (2 GHz) (OBR) and the RF amplitude has to be $< 2\%$.

Initial Beam

Beam phase jitter will be only partially compensated in BC1. It has to be either 0.7 deg (2 GHz) (EPR) or 0.1 deg (2 GHz) (OBR) to match phase requirements at the booster linac entrance. To match the energy requirements the beam phase must stay below 0.4 deg (2 GHz). Energy jitter has to stay below 3.8×10^{-4} (EPR) or 5.4×10^{-5} (OBR) to limit beam phase jitter induced in the BC1 chicane.

Feed-Forward System

The tightest specifications are imposed on the energy of the incoming beam $\frac{\sigma_E}{E} < 3.8 \times 10^{-4}$ (EPR) or 5.4×10^{-5} (OBR), the phase of the BC1 RF $\sigma_{\varphi,BC1} < 0.14$ deg (2 GHz) (EPR) or 0.02 deg (2 GHz) (OBR) and the booster linac amplitude $\frac{\sigma_{A,B}}{A_B} < 5.1 \times 10^{-4}$.

Trying to mitigate these by parameter optimizations leads to contradicting requirements, e.g. to loosen BC1 RF phase constraints it is necessary to compress less in BC1, but then compression in BC2 will be stronger leading to tighter constraints on the booster linac amplitude.

Feed-forward systems can mitigate all constraints on booster linac, BC1 and initial beam by about an order of magnitude. Unfortunately, errors from BC2 can only be corrected using a feedback.

To correct the relative timing of electrons and positrons a feed-forward system will be installed close to the IP, measurements are performed close to the central site before the beams travel outwards. A second feed-forward system will be installed at the turn around loops to correct the two beams individually. Beam phase and energy are measured in front of the loop or in its first arcs, corrections are applied at the end. Another important use of this feed-forward system will be to mitigate beam deflections which are induced due to magnet misalignment and strength errors or due to magnetic stray fields.

PERFORMANCE STUDIES

Lattices of the RTML are available for the codes PELEGANT [6] and PLACET [7]. They consist of all beam lines which are important for detailed beam dynamics studies, now including the electron spin rotator. In Ref. [8] the turn around loops were identified to require improved error acceptance, which was successfully achieved.

After improving the setup of the short range wake fields the agreement of simulation results is perfect. Figure 2 shows the longitudinal phase space distribution of the electrons at the end of the RTML for an artificial case where the initial uncorrelated energy spread has been set to zero. This has been done to highlight possible differences in tracking and application of incoherent synchrotron radiation and short range wake fields in the cavities. The lattices are perfectly aligned and have no magnetic errors. The incoming particle distribution was Gaussian in all six dimensions.

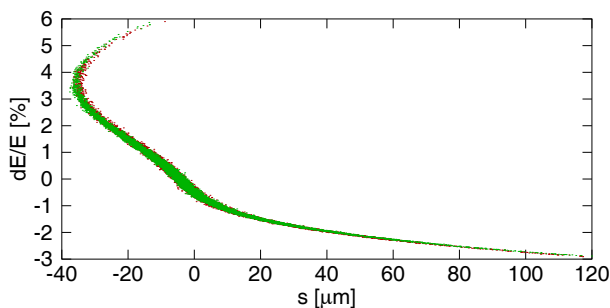


Figure 2: Longitudinal phase space distributions of the electrons at the exit of the RTML simulated by ELEGANT (green) and PLACET (red).

The growth of the transverse emittances is well within specifications, $\Delta\epsilon_{n,x} = 48$ nm rad and $\Delta\epsilon_{n,y} = 0.8$ nm rad, and leaves sufficient budget for emittance growth induced by static and dynamic imperfections and coherent synchrotron radiation.

Magnetic Stray Fields

An overview of the impact of magnetic stray fields was given in [8] and [9]. Following the improvement of the turn around loops they are not anymore limiting the tolerances on magnetic stray fields. Now limiting are the leverage of

the feed-forward system and the allowed beam offset at the main linac entrance. Tolerances on magnetic stray fields are still tight, 1–10 nT, and additional mitigation strategies like magnetic shielding are under investigation.

Alignment Errors

Previous studies [8] of misalignment in the long transfer lines have been refined. Alignment tolerances were slightly tightened but still allow an initial RMS misalignment of 100 μm to limit vertical emittance growth to less than 2 nm rad after applying one-to-one steering.

Following the revision of the turn around loop misalignment studies have been started. First results show that one-to-one steering will not be sufficient even if assuming an RMS misalignment of just 10 μm . Strong coupling was found which needs to be corrected using skew quadrupoles. Also residual dispersion seems to have some impact and dispersion free steering should reduce emittance growth considerably.

SUMMARY

The RTML has to fulfill several different functions and has to match tight constraints on beam properties and performance of technical systems, e.g. RF phases and amplitudes. Tightest constraints are imposed on the energy of the incoming beam, the phase of the BC1 RF and the booster linac amplitude. A feed-forward system will be required to mitigate these as well as beam position jitter induced by magnetic stray fields and other sources of beam deflection.

Lattices for beam dynamics simulations have been reviewed and completed. The simulations show good performance and sufficient budget for static and dynamic errors. Studies of these errors are on-going.

REFERENCES

- [1] D. Schulte et al., “Status of the CLIC Phase and Amplitude Stabilisation Concept”, these proceedings
- [2] D. Wang, “Design Study of the CLIC Booster Linac with FODO Lattice”, EUROTeV Report 2008-092, January 2009
- [3] F. Stulle et al., “Conceptual Design of Bunch Compressors and Turn Around Loops for a Multi-TeV Linear Collider”, EUROTeV Report 2008-025, August 2008
- [4] A. Latina et al., “A Spin Rotator for the Compact Linear Collider”, in proceedings of IPAC2010, May 2010
- [5] F. Stulle, “Beam phase and energy tolerances in the CLIC RTML”, to be published
- [6] Y. Wang, M. Borland, “PELEGANT: A parallel accelerator simulation code for electron generation and tracking”, in proc. of the 12th Adv. Acc. Concepts Workshop, July 2006
- [7] A. Latina et al., “Recent improvements in the tracking code PLACET”, in proceedings of EPAC2008, June 2008
- [8] F. Stulle et al., “Status of the CLIC RTML studies”, in proceedings of IPAC10, May 2010
- [9] J. Snuverink et al., “Impact of Dynamic Magnetic Fields on the CLIC Main Beam”, in proc. of IPAC10, May 2010