FEED FORWARD ORBIT CORRECTION IN THE CLIC RING TO MAIN LINAC TRANSFER LINES

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Abstract

The emittance growth in the betatron collimation system of the 27 km long transfer lines between the CLIC damping rings and the main LINAC depends strongly on the transverse orbit jitter. The resulting stability requirements of the damping ring extraction elements seem extremely difficult to achieve. Position and angle feed forward systems in these long transfer lines bring the specified parameters of the extraction elements within reach. The designs of the optics and feed forward hardware are presented together with tracking simulations of the systems.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed electron-positron collider with a centre of mass energy of 3 TeV. CLIC relies on very low emittance beams to achieve the design luminosity of 5.9×10^{34} cm^{-2}s^{-1} [1].

The Ring to Main Linac (RTML) transfer lines connect the damping rings (DRs) to the main linacs and are approximately 27 km each in length. Limiting emittance growth over this distance is one of the major challenges of the machine design. Emittance growth through the betatron collimation system, denoted as "BC" in Fig. 1, is strongly dependent on the beam jitter through the collimator jaws, which is directly related to the stability of the DR extraction system [2]. Table 1 shows the breakdown of emittance growth budget for the RTML. The design budget is the expected emittance growth for a perfect machine due to synchrotron radiation and beam coupling impedance. The static budget is allocated for systematic imperfections such as field and alignment errors. The dynamic budget is allocated for stochastic imperfections such as beam jitter, ground motion and electrical noise. The feed forward systems (FFs) are designed to minimise the emittance growth due to beam jitter, which is defined as dynamic emittance growth.

The RTML FFs offer an elegant solution to the stringent limits on beam jitter through the betatron collimation system and hardware stability for the DR extraction system [3].

Table 1: RTML Emittance Growth Budget

		Design	Static	Dynamic
ε_x=500 nm	$\Delta\varepsilon_x$	60 nm	20 nm	20 nm
ε_y=5 nm	$\Delta\varepsilon_y$	1 nm	2 nm	2 nm

FEED FORWARD CORRECTION

Each RTML line would consist of two FFs, namely FF1 and FF2, as shown in Fig. 1. The prefix e and p signifies the electron or positron RTML transfer line. The turnaround loop (TAL) in each RTML is identical and therefore are as the FF2 systems. However the geometry of the two central arcs (CAs) are different. The electron CA is a 180° bend, whereas the positron CA is an s-shaped chicane. The FF1 systems are required to limit emittance growth through the RTML, while the FF2 systems limit jitter and hence emittance growth through the betatron collimation system.

The FFs use upstream beam position monitors (BPMs) to measure the orbit deviation of the particle bunches. The BPM signals would be processed with analogue and digital electronics to determine the kicks required for downstream kickers which would be used to correct the orbit deviations and angles.

The BPM signals cut across the arcs, taking a shorter path than the beam (Fig. 1), allowing time to measure and correct the same bunch train. To achieve this, fast electronics and high speed data transmission are required. This is particularly challenging for pFF1 as the FF signals travel only a slightly shorter distance than the beam. The FF signals should arrive at the kickers at least 150 ns earlier than the beam to allow for the latency of the FF systems. The average radius of curvature for the arcs is 305 m [3]. For the high transmission velocity required for pFF1, free space optical communication would be the only solution.

The design of the CLIC RTML FF systems assumes similar technology to the FONT feedback system at ATF2, KEK, Japan [4]. Table 2 compares the main hardware parameters for the RTML FFs and for the FONT system; further details of the FONT system are presented in [5].

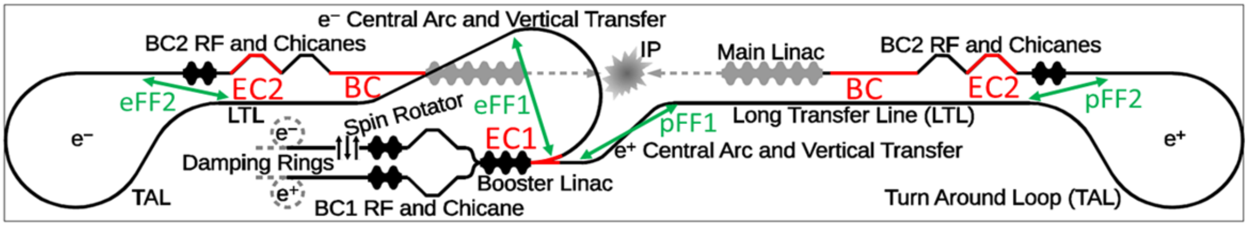

Figure 1: Sketch of the CLIC RTML [1].

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Table 2: Hardware Parameters for RTML FFs and FONT

Parameter	RTML FFs	FONT
Beam energy	9 GeV	1.3 GeV
BPM resolution	1-2 µm	~400 nm
BPM radius	60 mm	14 mm
Analogue latency	~30 ns	10 ns
Digital latency	< 190 ns	~80 ns
Maximum kicker deflection	θ_V=±22 nrad θ_H=±68 nrad	θ_V=±20 µrad
Kicker length	1 m	0.3 m
Kicker aperture	60 mm	14 mm

The optics has been designed to optimise the sensitivity of position and angle measurements in the BPM regions, as well as the precision of corrections in the kicker regions. It can be shown that the beam size should be the same in each BPM or kicker, $\alpha=0$, the phase advance should be an odd multiple of $\pi/2$ and the β-function should be as large as possible [5]. However, the length of the BPM and kicker regions is proportional to β_{max}; therefore β_{max} should be determined by the BPM resolution and the expected beam jitter in the BPM region. For the FF BPM and kicker regions a FODO lattice has been selected as the simplest optics to fulfil the requirements. The horizontal and vertical BPMs and kickers are located at the maxima of their respective β-functions.

TRACKING SIMULATIONS

Tracking simulations were performed using PLACET [6] to assess the performance of the FFs under different situations. For each study the tracking simulation was run using 50,000 Gaussian distributed macro-particles. Effects such as incoherent synchrotron radiation and wakefields have been taken into account for each study.

Three case studies were undertaken. First, tracking simulations were performed to investigate emittance growth and jitter amplification through the RTML due to initial beam jitter at the start of the RTML. The initial beam jitter is assumed to be entirely due to the DR extraction hardware. For this study, perfect BPM resolution and kicker stability was assumed to determine the ideal performance of the FFs. The vertical emittance at the end of the RTML is shown in Fig. 2 with and without the FF corrections; the results for the horizontal plane are similar.

The results of the tracking simulations show the horizontal emittance growth is reduced by a factor of ~4 and the vertical by a factor of ~3; the jitter amplification in both planes is reduced by a factor of ~6.

The second study performed was similar to the first but a limited BPM resolution was considered. For each initial jitter value, the tracking simulation was run 1000 times and Gaussian distributed random numbers were added to each BPM measurement to provide a measurement error. The results for vertical emittance growth are shown in Fig. 3.

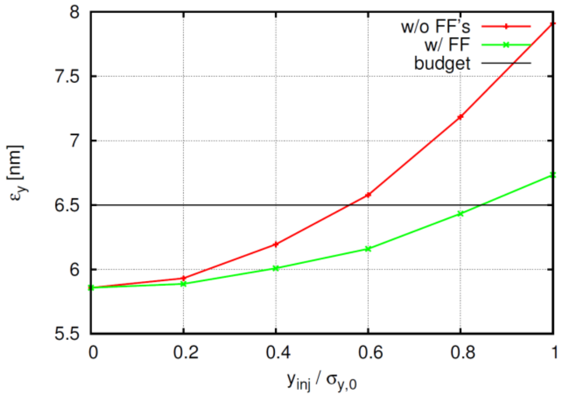

Figure 2: Vertical emittance growth at the end of the RTML vs. initial jitter.

The vertical emittance growth is strongly dependent on the BPM resolution although by changing the optics in the BPM region this could be rectified if it were to pose a problem. Due to the larger emittance in the horizontal plane, the BPM resolution has a negligible effect on horizontal emittance growth. No statistically significant change in jitter amplification was observed in either plane; therefore negligible emittance growth in the betatron collimation region is expected.

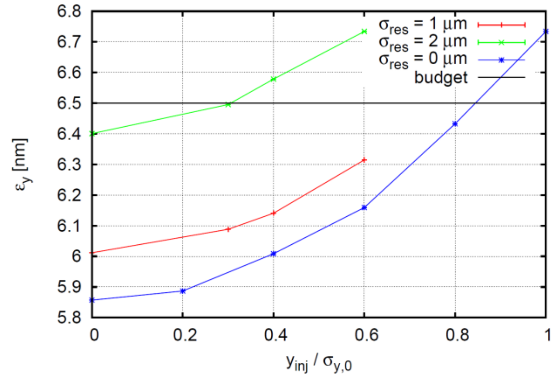

Figure 3: Horizontal and vertical jitter amplification (a,b) and emittance growth (c,d) with BPM resolution.

The final study investigated the impact of systematic errors on the performance of the BPM system. For this study particles were tracked through the RTML with no initial beam jitter, but a position offset was added to one of the BPM measurements. Each BPM was studied separately and the impact on emittance growth is shown in Fig. 4.

As with the FONT feedback system, the BPM offsets could be removed digitally in firmware with an error of the order of the BPM resolution. The tolerance on systematic errors is ~20 µm horizontally and ~2 µm vertically. In both planes this corresponds to ~0.6 σ, which is significantly larger than the expected beam jitter in the BPM regions. Therefore the systematic errors are not expected to cause significant emittance growth in either plane.

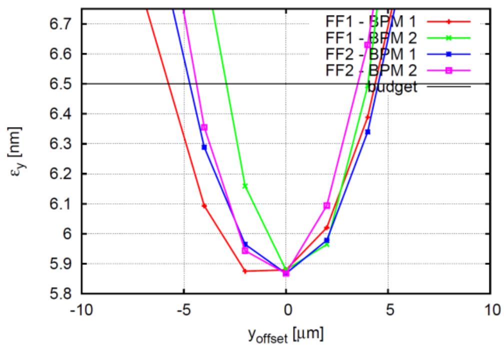

Figure 4: Horizontal emittance at the end of the RTML vs. initial jitter with BPM resolution included.

Based on the tracking simulations and estimated BPM resolution, the FFs should be able to reduce the beam jitter in the betatron collimation system to ~0.022 σ horizontally and ~0.026 σ vertically. This level of jitter would result in negligible emittance growth in the collimation region due to wakefields. Additionally, the jitter tolerances after the DR extraction system are relaxed from 0.1 σ to ~0.4 σ in each plane. This in turn reduces the stability and homogeneity requirements of the extraction kicker and septa.

DR EXTRACTION STABILITY

The CLIC DR extraction system consists of an electromagnetic kicker and two DC septum magnets (Fig. 5) [2].

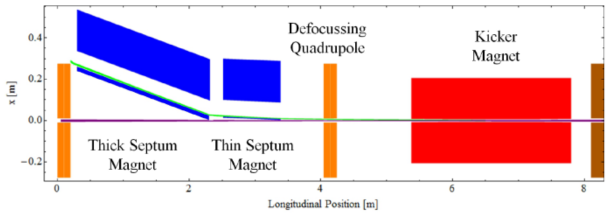

Figure 5: Diagram of the CLIC DR extraction system.

The estimated stability requirements for the extraction system are based on three main assumptions. Firstly, each extraction element provides an equal contribution to the extracted beam jitter. Secondly, the stability of each element consists of temporal and spatial contributions which are combined in quadrature. Finally, sextupole terms are the only source of inhomogeneity.

The stability requirements are summarised in Table 3. The spatial stability is the field quality, δ_F, which is defined as the maximum tolerable change in field over the profile of a 6 σ beam envelope. The temporal stability for the kicker is called the pulse quality, δ_P, and is defined as the fractional noise on the kicker pulse due to ripple and pulse-to-pulse jitter. The temporal stability for the septa is assumed to be due to jitter on the power converter (PC) and is defined as the power converter stability, PCS, which is the fractional noise on the PC.

Table 3: Kicker and Septa Stability Requirements

Parameter	**CLIC CDR [1]**	**No FFs**	**With FFs**
Kicker			
δ_P	1×10^{-4}	3.7×10^{-5}	1×10^{-4}
δ_F	1×10^{-4}	3.7×10^{-5}	1.9×10^{-4}
Stability	2×10^{-4}	5.3×10^{-5}	2.1×10^{-4}
Thin septum			
PCS	-	1.8×10^{-5}	7.6×10^{-5}
δ_F	2×10^{-5}	1.8×10^{-5}	7.6×10^{-5}
Stability	2×10^{-5}	2.7×10^{-5}	1.1×10^{-4}
Thick septum			
PCS	-	1.3×10^{-6}	5×10^{-6}
δ_F	2×10^{-6}	1.3×10^{-6}	5×10^{-6}
Stability	2×10^{-6}	1.8×10^{-6}	7.1×10^{-6}

CONCLUSIONS

Position and angle feed forward systems proposed for the CLIC RTML are presented. The hardware and optics requirements have been considered and tracking simulations performed. A BPM resolution of 1-2 µm appears achievable and would not significantly degrade the performance of the FFs. Systematic offsets could be compensated with digital firmware and are therefore not foreseen to pose a problem.

The stability requirements of the damping ring extraction system can be relaxed by a factor of 4 due to the FFs. The stability requirements remain however challenging and require further studies.

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