EMITTANCE OPTIMISATION IN THE DRIVE BEAM RECOMBINATION COMPLEX AT CTF3

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Abstract

According to the Conceptual Design Report, the power to accelerate the main colliding beams of CLIC is taken from parallel high intensity (100 A), low energy (2.37 GeV) beams. These beams are generated by long trains, accelerated by conventional klystrons and then time-compressed in the so called Drive-Beam Recombination Complex (DBRC). A scaled version of the DBRC has been built at the CLIC Test Facility (CTF3) at CERN in order to prove its principle and study any arising feasibility issues. One of the main constraints is the emittance control during the recombination process. This work presents an overview of the studies ongoing at CTF3, keeping in view possible improvements of the nominal CLIC design. In particular, a generic feedback algorithm to solve (quasi-)linear systems has been implemented and used in order to optimise the process by tuning the energy of the beam and steer the orbits in the different lines, as well matching the design dispersion. Current results and possible room for further optimisation will be shown.

INTRODUCTION

The CLIC study [1] aims to develop a realistic design of a multi-TeV e^+e^- linear collider for the post-LHC era in high energy physics. Based on a novel two-beam acceleration scheme, it required the construction of the CLIC Test Facility (CTF3) [2] at CERN in order to prove the key concept of the challenging design [3]. One of the key issues to be considered in the two-beam scheme is the Drive Beam emittance growth during the recombination process. In the current studies we discuss the mechanism of emittance degradation and present possible solutions to minimise it by means of a generic linear feedback application.

THE CLIC TEST FACILITY (CTF3)

The CTF3 facility is designed as a proof-of-principle experiment to study feasibility issues of the CLIC two-beam acceleration technology. The CTF3 layout is presented in Fig. 1. The Drive Beam with the current of 4 A is accelerated in the ~70 m long linac, filled by fully-loaded accelerating structures powered by 3 GHz klystrons. The linac is followed by the recombination area, where the drive-beam intensity is multiplied up to a factor 8. In the final experimental area called CLEX the Test Beam Line (TBL) and the Two Beam Test Stand (TBTS) are located. The Drive Beam deceleration and power production are tested in the TBL, in the TBTS the dual-beam acceleration scheme is tested using a parallel low-intensity probe beam called CALIFES generated in the same area.

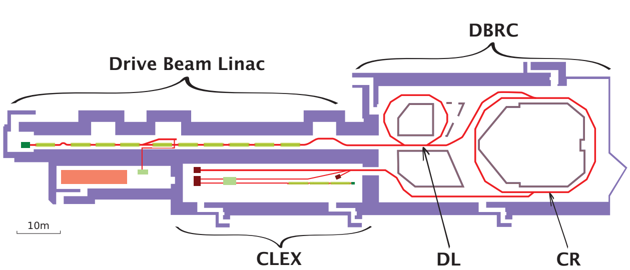

Figure 1: Layout of the CTF3 test facility at CERN.

The drive-beam bunching system and the following linac configuration result in the generation of a long ~1.2 μs beam train of bunches at 1.5 GHz. Every 140 ns the bunching phase is changed by 180 degrees. This identifies 8 sub-trains 140 ns long. Approaching the Delay Loop (DL) a 1.5 GHz RF deflector kicks only the odd sub-trains inside the loop, and it deflects the even ones straight to the next transfer line. The length of the DL, ~42 m, is tuned to be exactly an integer number of the wavelength at 1.5 GHz. For this length once an odd sub-train of the beam has done a turn in the DL, it is interleaved by the same RF deflector with the incoming even sub-train. This results in 4 trains of bunches at 3 GHz, 140 ns long and separated from each other by 140 ns.

These trains are then accumulated in the Combiner Ring (CR) where a similar system of two 3 GHz RF deflectors interleaves them in a single 12 GHz train that is afterwards extracted and delivered to the CLEX experimental area. The length of CR is 84 m such that the first train arrives synchronised with the injection of the second train after its first turn. It is important to mention that the first injected train is stored in the CR for three and an half turns, while the last train is only passing once through the first half of the ring and, combined with the other trains, is immediately extracted in the following transfer line (TL2).

Table 1 reports the main Drive Beam nominal parameters for CTF3.

Table 1: Main Nominal Parameters of the CTF3 Drive Beam Before and After the Recombination Process

	Before	After
Energy	120 MeV	120 MeV
Energy spread	2% (FWHM)	2% (FWHM)
Pulse length	1.2 μs	140 ns
Intensity	4 A	~30 A
Bunch frequency	1.5 GHz	12 GHz
Normalized emittance		
- horizontal	< 100 μm	150 μm
- vertical	< 100 μm	150 μm

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PROJECTED EMITTANCE GROWTH

A convenient method to define the emittance ϵ for Gaussian beams is by using the sigma-matrix:

$$\Sigma = \begin{pmatrix} < x^2 > & < xx' > \\ < xx' > & < x'^2 > \end{pmatrix};$$

$$\epsilon = \det(\Sigma), \quad (1)$$

where x is the transverse position and x' is the transverse angle. During the recombination process each of the eight initially inline sub-pulses takes a different path in the various lines of the DBRC before being recombined into a single shorter train. This can cause emittance growth due to mismatches from focusing and steering.

We performed preliminary simulations of the recombination process in CR at CTF3 by means of Twiss function calculation using MAD-X [4]. We assumed that the 4 incoming trains are identical, Gaussian and with no energy spread and considering only linear optical elements. Simulations showed that an orbit injection error of 0.5 mm results in an emittance growth of 10% at the end of the recombination following the definition given by Eq. 1. As shown in Fig. 2 the final projection of the four ellipses representing the four combined trains occupies a bigger area than the nominal matched beam. The final phase-space distribution does not

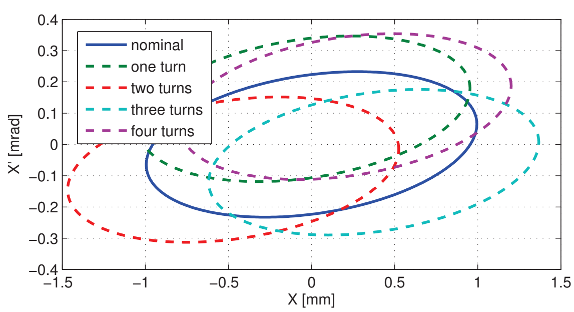

Figure 2: Transverse phase-space ellipses of monochromatic Gaussian beams injected with an orbit error of 0.5 mm, after various number of turns in the CR at CTF3.

have an elliptical shape but in the simplified model the definition of emittance of Eq. 1 allows simple approximation of the recombination dynamics and it can be used to study the contribution of different sources to emittance growth.

Another source of emittance growth may arrises from a transverse optic mismatch at injection as shown in Fig. 3. In this case the centroid of the beam does not move in phase space, but the shape of the ellipse changes for the different trains. Simulations showed that for 50% β_x mismatch the extracted beam may have a final emittance growth of about 10% of the nominal value.

The energy spread of the bunches, in combination with energy variation along the uncombined beam pulse induces a combined effect already observed in [5]. Due to non-linear dispersion and chromatic effects both the ellipse centroids

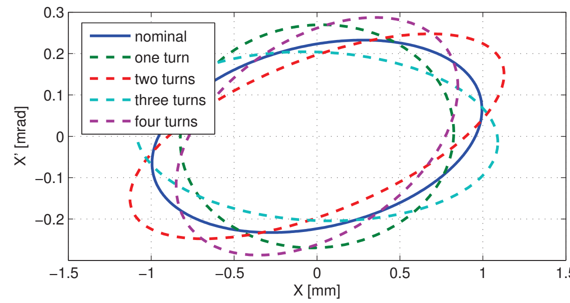

Figure 3: Transverse phase-space ellipses of monochromatic Gaussian beams injected with an initial β_x 1.5 times the nominal closed solution, after various number of turns in the CR at CTF3.

and shapes may move in phase space differently as a function of the number of turns. Ongoing simulations show that this might be the main source of emittance growth after correcting orbit and transverse matching.

LINEAR FEEDBACK TOOL

In order to minimise the orbit-related emittance growth, software to control the beam orbit in different lines of CTF3 was developed. Due to the generality of the problem the generic tool was written in MATLAB [6] and it was interfaced with the CERN accelerator control system. The tool is able to measure the linear response matrix between a set of generic actuators and observables, and uses the inverted matrix to move the beam observables to the desired values.

Similar to the approach of [7], we chose to use a Regularised Linear Regression algorithm to measure the generic response matrix of the system under study. With our approach we are able to measure the response matrix not only by exciting the actuators one after the other, but also by exciting many or all of them at each iteration and by looking at the effect on all the observables. In the specific case of orbit correction, this allows to overcome aperture limitations by exciting local bumps, to keep the response matrix updated in case of machine drifts by using all the correctors settings and orbits readings, and to extend the use of the feedback to quasi-linear systems.

During the correction process one is able to assign different weights to different observables, to set boundaries to the actuators, and to give a weight on the minimisation of actuators. This allows to avoid divergences in the correction.

EXPERIMENTAL RESULTS

Initial tests of the algorithm have been performed in the orbit steering on the Drive Beam linac with positive results, not reported here.

One of the possible sources of emittance growth during the recombination process has been identified in a non constant energy along the initial long pulse. Different feedback systems have already been studied and implemented in [8], and they are currently used to mitigate this effect. With our

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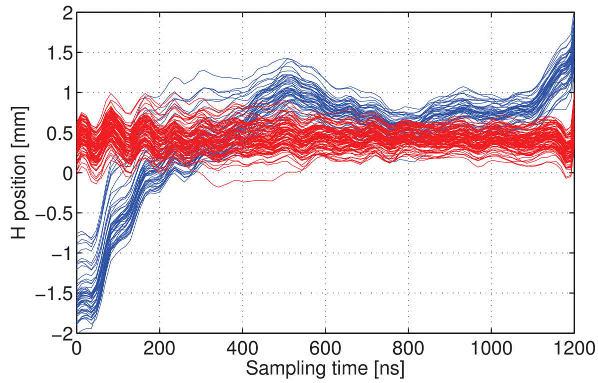

Figure 4: Horizontal beam profile at the end of the linac in a dispersive BPM for different single shots. The blue lines are before energy flattening correction, the red lines after the correction.

feedback we easily reproduced a specific energy feedback. By considering the horizontal beam position in a BPM located at a non-zero dispersion one can translate the beam position along the pulse with energy variation. In Fig. 4 the results are shown. The initial variation in horizontal beam position along the pulse is nicely corrected after adjusting the power provided to the last fully-loaded accelerating structure of the linac.

Figure 4 shows that the beam may also be affected by a relatively high pulse to pulse energy jitter. This makes the beam operations and optimisation sometimes challenging in DL and CR due to the high (~1 m) maximum nominal dispersion.

In Fig. 5 we show a result of the application of our feedback algorithm to the orbit closure in the CR. In this case the observables are the differences in beam position at CR BPMs location within the first and second turn. Only the BPMs marked with a green dashed line have been used as

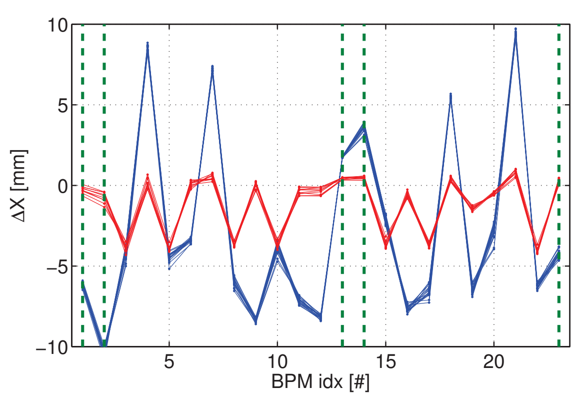

Figure 5: Difference between the first and second turn horizontal orbit of a short (< 280 ns) pulse circulating in the CR. Each line is an average over 10 consecutive pulses. The blue and red lines are respectively before and after orbit closure correction.

observables. This is because the other BPMs installed in the CR suffer a charging up effect and the beam position measured at later turns is not fully reliable. Given this limitation the orbit closure looks to be successful within 1 mm on the used BPMs, making measurable improvements compared to the initial case. The explanation of the 5 mm difference at some BPM location is still under investigation.

CONCLUSIONS

A new tool to implement linear feedbacks for generic parameter optimisation has been developed and its power has been demonstrated. This tool is currently used in daily operations to steer the beam in the different beam lines of CTF3, as well to adjust the beam-energy profile along the pulse.

It has been shown that the orbit control and correction is only one of the possible uses of the developed tools. A complementary tool has been implemented to continuously wiggle the beam current provided by the injector and so enhance the pulse to pulse energy jitter of the Drive Beam. By a principal component analysis of the beam jitter it was possible to have quasi-online measurement of the dispersion pattern in the machine. Taking this as observable and the beam steerers as actuators, one could measure the response matrix of the correctors on dispersion, and so implement a dispersion-free or dispersion-matching steering.

A full experimental and numerical program to measure the impact of orbit and dispersion mismatch, as well as beam energy distribution on emittance growth is ongoing and we plan to have results by the end of the 2014 run.

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