PERFORMANCE SIMULATIONS OF A PHASE STABILIZATION SYSTEM PROTOTYPE FOR CTF3

A. Gerbershagen, D. Schulte, P. Skowronski, T. Persson, E. Ikarios, CERN, Geneva, Switzerland
P. N. Burrows, G.B. Christian, C. Perry, John Adams Institute, University of Oxford, Oxford, UK

Abstract

The CLIC drive beam provides RF power for acceleration of the main beam, and hence the drive beam's longitudinal phase tolerances are very tight. A feedforward chicane consisting of four electromagnetic kickers is proposed as a correction system for the phase errors, which should allow loosening of the tolerances. A prototype of such a chicane system developed by CERN, INFN and the University of Oxford, is planned to be installed at CTF3 in 2012. The present paper summarizes the parameters of the planned phase correction system and presents simulations, which are used to make predictions of the performance of such a feedforward system at CTF3.

INTRODUCTION

The Compact Linear Collider (CLIC) is a proposed linear e^+e^- collider in development at CERN [1]. Different designs of the collider exist, with energies ranging from 0.5 to 3 TeV, with 3 TeV being the baseline design energy.

CLIC is based on the two-beam-scheme, in which the main beam is accelerated by the RF power extracted from the drive beam. Errors on the RF wave phase have a significant impact on CLIC luminosity: the simulations show that luminosity is reduced by 2% for 0.3° of RF phase error [2]. Since the RF wave is generated by the drive beam, the tolerances for several parameters of the drive beam are very strict as well, e.g. the tolerance for longitudinal bunch phase being 0.25° at 12 GHz (17 µm) [3].

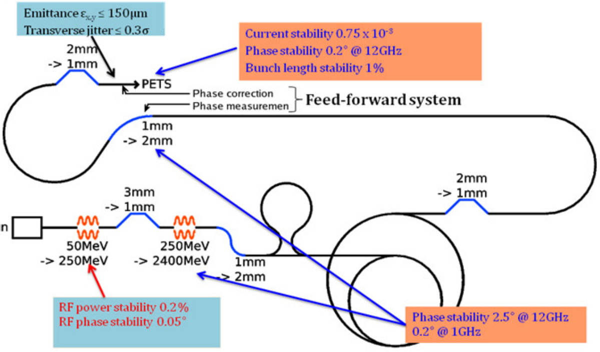

Figure 1: Layout of the CLIC drive beam with the relevant tolerances and feed-forward system [4].

FEED-FORWARD SYSTEM FOR CLIC

It is necessary to reduce the bunch phase error by a factor 10 before the decelerators. For this purpose, a feed-forward system is being designed. This system will be composed of a phase monitor, an amplifier and 4 electromagnetic kickers, which should provide transverse kicks to the beam sent through a chicane. Depending on the measured phase, the chicane trajectory can be set longer or shorter, thereby varying the time of flight of the bunches in the chicane and hence modifying their longitudinal position (see Fig. 2). The requirement is that the feed-forward system should be able to correct phase errors as large as 10° to the required average stability of 0.1° at 12 GHz [5]. Simulations show that it is possible to stabilize the longitudinal phase of the CLIC drive beam to a required degree with the help of such a feed-forward system [6].

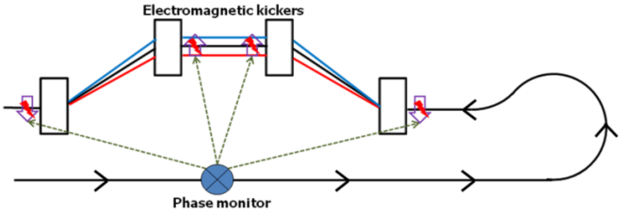

Figure 2: Scheme of the feed-forward chicane [5].

The baseline design is to install the system at the final turnarounds before the decelerators (24 per beam), since it gives the possibility to use the phase measurement information at the electromagnetic kicker at the same time as the corresponding bunches arrive at the respective kicker position. The system being as close as possible to the decelerator ensures that no significant phase changes will occur between the correction and the power extraction. An alternative design implies the installation of the system upstream, before the beam splits into 24 channels leading to the decelerators. This would reduce the number of required feed-forward systems from 24 to 1 per beam, potentially reducing the costs, but would make the design of the single feed-forward system more challenging.

FEED-FORWARD SYSTEM FOR CTF3

CLIC Test Facility (CTF3) is a facility at CERN, constructed in order to test the central concepts of CLIC, such as power extraction, two beam acceleration and recombination, as well as to make experiments with the stabilization systems for CLIC (see Fig. 3).

A first prototype of the phase correction system for CTF3 is currently under development and is planned to be installed at the end of 2012. Three experiments are planned:

- Pulse-to-pulse feedback system for the correction of the mean phase of the trains.
- Feedback system for the correction of the static errors within the trains.

- Feed-forward system for the correction of higher-frequency components.

These experiments are not set up in order to achieve at CTF3 the stability level required for CLIC, but for testing the phase correction system in order to predict and improve its performance when applied at CLIC.

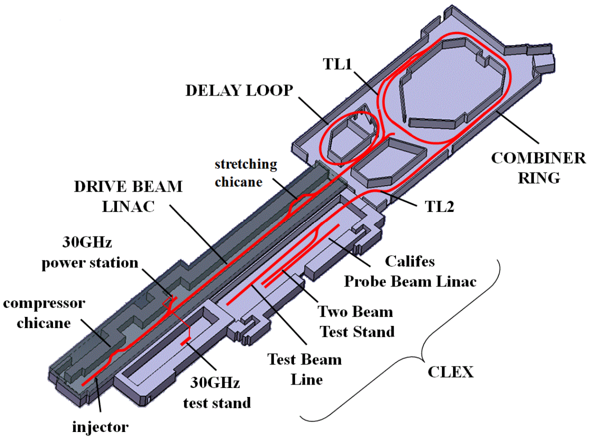

Figure 3: Layout of CLIC Test Facility (CTF3).

The phase stabilization feed-forward system at CTF3 is designed in the following way – it should perform the phase measurement before the combiner ring at the Transfer Line 1 (TL1) chicane and send the signal to the amplifier, which will activate the kickers and correct the beam in the Transfer Line 2 (TL2) chicane (Fig. 4). The design of the chicane is different for CTF3 and CLIC: since at CTF3 there is not enough space for a full chicane with 4 electromagnetic kickers, the correction system is planned to be integrated into the TL2 chicane [5].

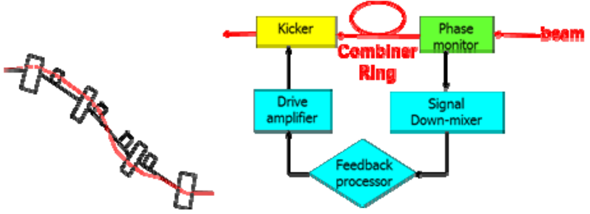

Figure 4: Left –beam trajectory in TL2 chicane bent by the feed-forward kickers. Right – scheme of feed-forward system modules [5].

The bunches need 380 ns to propagate from TL1 to TL2, hence this defines the total latency of the feed-forward system (though it is possible to increase this time by circulating the bunches in the combiner ring). The demonstration of the phase correction will initially be performed on the non-combined beam of 3 GHz bunch frequency with train length of 280 ns in the first stage. The eventual goal is to be able to correct the combined beam of 12 GHz. The system should be usable up to 420ns train length.

The phase monitor is a custom resonant cavity which is planned to have a bandwidth of 50-100 MHz and a latency of 5 ns. The bandwidth of the amplifier will be ~50 MHz with an eventual target of 70 MHz for the future designs. The 960 mm electrodes of the electromagnetic kicker with aperture of 40 mm should provide a kick range of ± 1.2 kV and a beam trajectory angle kick of up to ±1 mrad and hence a maximal phase correction of ± 17° at 12 GHz [5] with the current amplifier design.

SIMULATION OF FEED-FORWARD SYSTEM PERFORMANCE

The simulations are set up to estimate the expected correction factor for the feedback and feed-forward systems at CTF3. They are based on data taken at CTF3 on 30/11/2011 with the currently installed phase monitors.

The phase measurement can be performed at CTF3 at the moment at seven positions; the most relevant measurements are at TL1 and TL2, since these are the positions, where the monitor and the kicker of the feed-forward system will be installed.

Performance Simulation of Feedback Correction

For the feedback correction simulation we correct the mean phase of the train at the TL2 dog-leg chicane by the measured mean phase of the previous train at the same position (TL2). As a first order approximation we assume that the amplifier and the electromagnetic kicker do not induce additional noise.

As a figure of merit we consider the standard deviation of the average phase of the train over a period of measurement. It is defined as

$$\sigma = \sqrt{\frac{1}{M}\sum_{m=1}^{M}(\varphi_{train})_m^2}$$

with M being the number of the trains (383 in our case) and

$$\varphi_{train} = \frac{1}{N}\sum_{n=1}^{N}\varphi_n$$

being the average phase within the train, where N is the number of the bunches per train and φ_n the measured phase of the bunch. Since it is not possible to measure the phase of each bunch individually, we use the time resolution steps of ~10 ns. The feedback is calculated by

$$(\varphi_{train,fb})_m = (\varphi_{train})_m - a\cdot(\varphi_{train})_{m-1}$$

The correlation constant between two subsequent train mean values is 0.61, so in addition to calculating the simple 1-to-1 feedback with a=1, the calculation with a=0.61 has been performed (see Fig. 5).

Table 1: Standard Deviation of Train Mean Phase with and without Feedback

Feedback type	σ in degrees at 12 GHz
No feedback	5.25
1-to-1 feedback	4.59
1-to-0.61 feedback	4.14

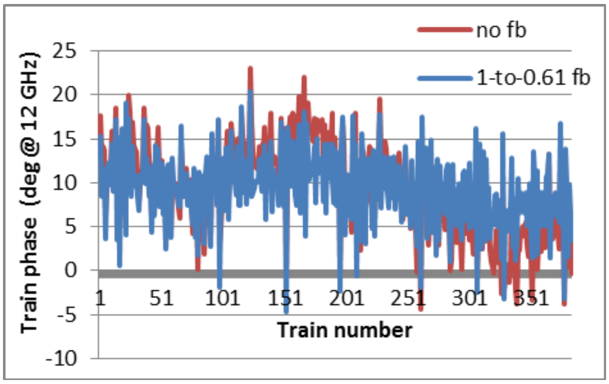

Figure 5: Train mean phase with and without feedback.

Performance Simulation of Feed-forward Correction

The feed-forward system prototype is designed to make an intra-train correction of the CTF3 drive beam phase. In order to simulate its performance, the measurement at TL1 chicane is used as an input signal for the corrector.

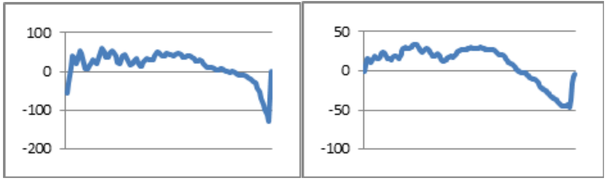

Figure 6: Average measured phase along one train (in deg at 12 GHz). Left – at TL1 chicane, right – at TL2 chicane.

Since the feed-forward is an intra-train correction, it is more useful to use as figure of merit the standard deviation

$$\sigma = \sqrt{\frac{1}{M \cdot N}\sum_{m=1}^{M}\sum_{n=1}^{N}(\varphi_{mn})^2}$$

with M being the number of the trains and N being the number of the 10 ns time step within the train, as previously. Feed-forward is calculated with

$$\varphi_{mn,ff} = \varphi_{mn} - \frac{1}{b}\sum_{i=n-b/2}^{n+b/2} a \cdot \varphi_{mi}$$

with b being the bandwidth of the feedforward system. The bandwidth of the amplifier is ~50 MHz, which means that the rise time of the signal for the kicker is ~20 ns. The measurements on the previous FONT amplifiers show that signal rise is linear; this has been the assumption for the current simulation as well.

In the same manner as for the feedback, 1-to-1 correction with a=1 has been performed. Also, since the correlation between the measurements at TL1 and TL2 is 0.85 (Fig. 6), and the standard deviation of the measurements is different (see table 2), a feed-forward has been calculated by multiplying the signal amplitude at TL1 with $a = 0.84 \cdot \frac{\sigma_{TL2}}{\sigma_{TL1}} = 0.5$.

Also the limitation of the maximal correction which can be provided (± 17° at 12 GHz) has been considered.

Table 2: Standard Deviation of Bunch Phase with and without Feed-forward

Monitor position and feed-forward type	σ in degrees at 12 GHz
TL1	39.48
TL2 without feed-forward	23.30
TL2 with 1-to-1 feed-forward	23.66
TL2 with 1-to-0.5 feed-forward	13.51
TL2 with 1-to-0.5 feed-forward with 17 deg maximal correction	14.75

Phase Error Propagation along the CTF3

The measurement data shows that a large proportion of the phase error is created in the stretching chicane (which has R_{56}=0.46), hence the energy error in the LINAC is transformed into the phase error at this chicane. Sources for the energy error can be errors in amplitude and phase of bunch compressor and LINAC as well as the phase error of incoming beam.

The correlation between the measurements along the beamline at CTF3 is not high enough to allow the test of feed-forward functionality by a direct measurement before and after the kicker. In case the measurement resolution will not significantly improve with the new phase monitors, one should consider alternative ways of feed-forward functionality testing, e.g. performing the measurement at the same monitor with feedforward system being subsequently turned on and off.

SUMMARY AND OUTLOOK

A prototype of CLIC phase feed-forward system is currently under development and has to be tested at CTF3. It is planned to be installed at the end of 2012. Measurements of CTF3 drive beam phase error have been performed and allow us to perform simulations in order to predict the impact of the prototype on the phase errors. These predictions show that the prototype will have a measurable effect on CTF3 phase errors, allowing the experimental test of its functionality. The correction range of feed-forward system of ± 17° at 12 GHz sets only slight limitation on the effectiveness of the correction and hence an additional feedback system is optional.

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