DESIGN, HARDWARE TESTS AND FIRST RESULTS FROM THE CLIC DRIVE BEAM PHASE FEED-FORWARD PROTOTYPE AT CTF3*

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Abstract

In the CLIC two beam acceleration concept the phase synchronisation between the main beam and the RF power extracted from the drive beam must be maintained to within 0.2 degrees of 12 GHz [1, 2]. A drive beam phase feed-forward system with bandwidth above 17.5 MHz is required to reduce the drive beam phase jitter to this level [3]. The system will correct the drive beam phase by varying the path length through a chicane via the use of fast strip line kickers. A prototype of the system is in the final stages of installation at the CLIC test facility CTF3 at CERN. This paper presents results from preparations for the phase feedforward system relating to optics improvements, the development of a slow phase feedback that will be run in parallel with the feedforward system and first tests of the kicker amplifier and kickers.

INTRODUCTION

The RF power used to accelerate the main beam in the proposed linear collider CLIC is extracted from a second 'drive beam'. To ensure the efficiency of this concept a drive beam 'phase feedforward' system is required to achieve a timing stability of 50 fs rms, or equivalently a phase stability of 0.2 degrees of 12 GHz (the CLIC drive beam bunch spacing) [1, 2]. This system poses a significant hardware challenge in terms of the bandwidth, resolution and latency of the components and therefore a prototype of the system is in the final stages of development at the CLIC test facility CTF3 at CERN.

A schematic of the CTF3 phase feedforward system is shown in Fig. 1. The phase will be corrected utilising two kickers placed prior to the first and last dipole in the pre-existing chicane in the TL2 transfer line. By varying the voltage applied to the kickers the beam can be deflected on to longer or shorter paths through the chicane, thus inducing a phase shift. The goal is to demonstrate a 30 MHz bandwidth phase correction with a resolution of 0.2 degrees of 12 GHz. The required hardware consists of three precise phase monitors [4, 5] and two strip line kickers [5] designed and fabricated by INFN/LNF Frascati, and a kicker amplifier and digital processor [6] from the John Adams Institute at Oxford University. More detailed descriptions can be found in [7].

The latency of the feedforward system, including cable lengths and the latency of each component, must be below

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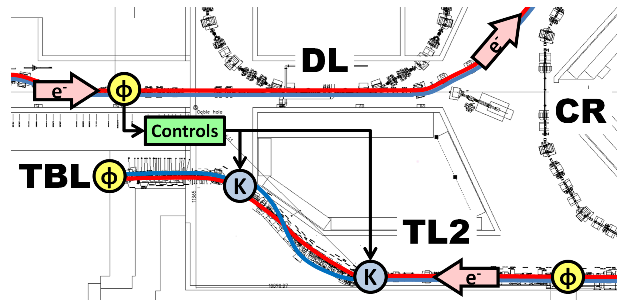

Figure 1: Simplified schematic of the phase feedforward system. Red and blue lines depict orbits for bunches arriving late and early at the first phase monitor, ϕ, respectively. The trajectory through the TL2 chicane is changed using two kickers, K.

the 380 ns beam time of flight between the first monitor and the first kicker.

OPTICS AND MODEL CORRECTIONS

The phase feedforward system imposes strict constraints on multiple optical parameters of the chicane and therefore an accurate model becomes critical. The key parameter for the phase feedforward system is the transfer matrix coefficient R_{52}. However, large R_{52} values drive the optics towards large horiztonal dispersion and this must be kept as low as possible and always under $|D_x| = 2.0$ m due to the large drive beam energy spread of 1% rms and 10 cm physical aperture. Additional constraints ensure the beam leaves the correction chicane on the nominal trajectory irrespective of the given kick. Fig. 2 shows the solution that has been used for the system commissioning. It limits the maximum dispersion to 1.2 m whilst yielding an R_{52} value of −0.7 m to give a correction range of ±10°.

Response matrix and dispersion measurements were completed for several variants of the optics in order to identify unambiguously and correct any errors present in the MADX model. As shown in Fig. 3 large errors in the model were immediately apparent and there were two key areas in which modifications were required. Firstly, there was a large uncertainty on the magnetic properties of a type of quadrupole reclaimed from the CELSIUS machine, with 16 out of the 27 quadrupoles in TL2 being of this type. The agreement with data was improved by increasing the strength of these magnets by 7% in the model. Secondly, in other sections of CTF3 large discrepancies in the edge focusing of the (typically above 25°) dipoles had been observed. Further

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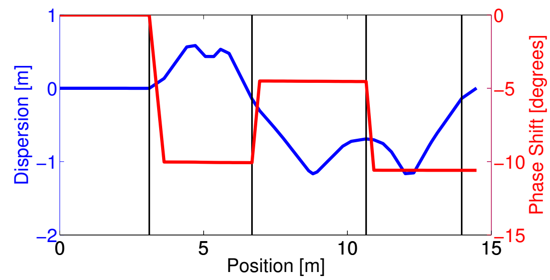

Figure 2: Phase feedforward optics dispersion and phase shift with the maximal kick. Vertical lines mark the positions of dipoles in the correction chicane.

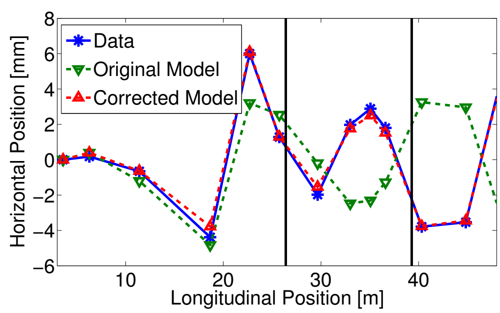

Figure 3: Optics kick measurements before and after applying corrections to the MADX model of TL2. Vertical lines mark the region of the TL2 chicane.

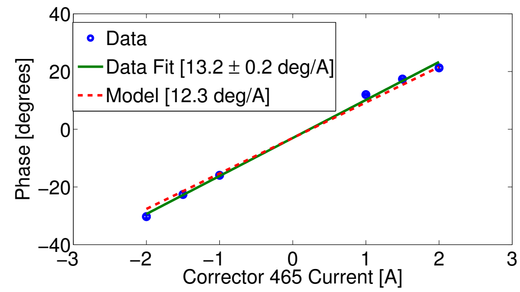

Figure 4: Dependence of phase measured in the downstream monitor on the corrector currents.

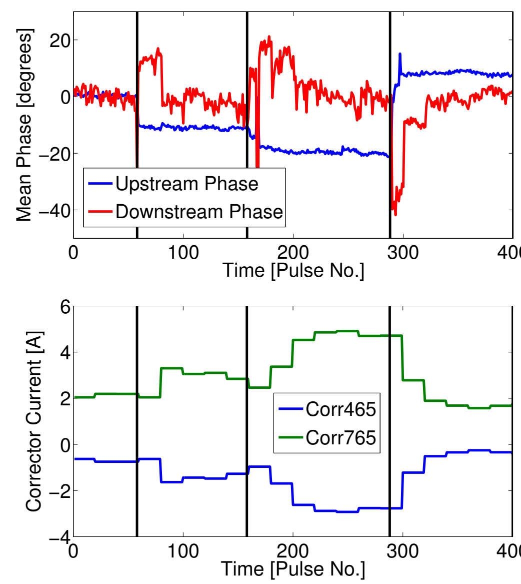

Figure 5: Mean phase (top) and corrector settings (bottom) during the slow correction run. Vertical lines mark the times that the phase was shifted using the stretching chicane.

improvements to the model were made by altering the horizontal and vertical focusing properties of the 7 dipoles in TL2 (4 in the correction chicane and 3 earlier in the line). With all the corrections in place, the mean position difference between the model and data in Fig. 3 is reduced from 3.0 ± 0.7 mm to 0.2 ± 0.1 mm.

SLOW PHASE FEEDBACK

To ensure that the targeted 0.2° resolution of the phase feedforward correction can be achieved care must be taken to prevent slow drifts in the mean pulse phase outside of its limited correction range (up to 10° with the current optics). As a result a 'slow phase feedback' or 'slow correction' will be run in parallel to stabilise the mean phase from pulse to pulse. All the required hardware for this system is in place and the first tests proving the feasibility of the concept have been completed as shown here.

The slow correction functions in the same way as the phase feedforward system but uses two magnetic correctors installed with approximately a 30 cm longitudinal offset from the mid-point of each feedforward kicker (the feedforward kickers are installed inside the aperture of the magnetic correctors). The first corrector is referred to as corrector 465 and the second as 765, based on their location along TL2. In addition, the slow correction uses the downstream phase measurement (after the TL2 chicane) as the input to the feedback, whereas the feedforward system uses the upstream measurement (between the end of the linac and the delay loop, see Fig. 1). As only one high precision phase monitor was available, the downstream monitor used is of a different type with worse resolution (around 1° instead of 0.1°).

The phase shift per ampere applied to the correctors was calculated to be 13.2 ± 0.2 degrees/A in close agreement with the model prediction of 12.3 degrees/A as shown in Fig. 4. This verifies that the phase can be manipulated by applying kicks in the chicane and that the optics is functioning as expected. Given the phase shift per ampere the required change in corrector currents to remove a phase offset in the downstream monitor can be calculated, forming the slow correction.

In order to test the slow correction the phase of the beam was changed in steps by changing the strength of the stretching chicane dipoles after the linac, see Fig. 5. The phase was changed by ±10° at the times marked with black lines. Note that the phase shift has opposite sign in the two monitors due to calibration differences. The response of the correctors to the changing phase is also shown in Fig. 5, in which the phase steps are also visible. The corrector currents are

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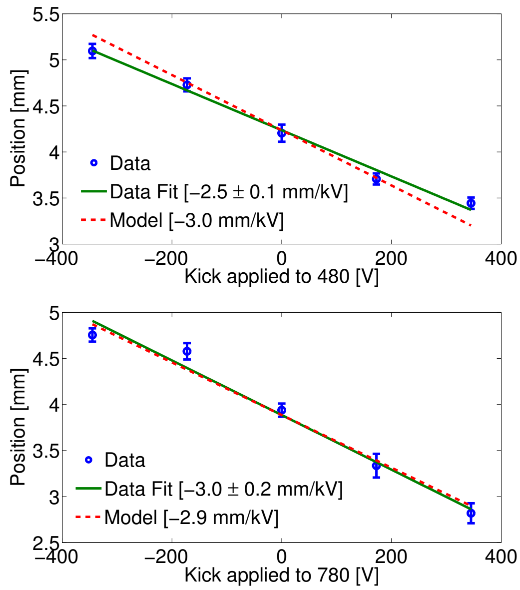

Figure 6: Response to the first (top) and second (bottom) kicker in the first BPM after the chicane.

recalculated every 20 pulses based on the measured mean phase over that time period.

Despite the large jitter in the downstream phase measurement the stability in the mean phase was sufficient to systematically observe the slow feedback correcting the phase back towards the nominal phase. During the averaging time (20 pulses) after each change of the stretching chicane the phase shift is initially seen in both phase measurements before the slow correction reacts. After the averaging time the mean phase in the downstream monitor is moved close to zero by the feedback. Between pulses 63 and 400 in Fig. 5 a mean (absolute) phase offset of 13.0° ± 2.0° in the first 20 pulses after each phase shift was corrected to a mean offset of −0.2° ± 0.8° after the reaction of the slow correction.

TESTS OF FEEDFORWARD KICKERS

The first stage (single module per kicker) amplifier was available prior to the start of the CTF3 summer shutdown to allow performance and installation cross-checks in preparation for running the phase feedforward system following the shutdown. Each amplifier module will ultimately provide a peak output of 600 V (with the full 1.2 kV coming from four modules combined), although for the tests shown here the module was limited to 345 V, which should correspond to a 0.3 mrad beam deflection when applied to the kickers.

In order to verify that each kicker was performing as expected the amplifier was used to create a long 3 µs output pulse with constant amplitude. The use of the long amplifier pulse ensures that the kicker was powered for the duration of the passage of the 1 µs beam pulse prior to having precise latency and beam time of flight measurements, which will allow the time of arrival of the amplifier and beam pulses to be matched exactly.

Each kicker was powered individually with different output voltages and the response to the kick was observed in the BPMs. The measured offset in the first BPM after the TL2 chicane as a function of the kick voltage compared to the expectation from the MADX model is shown in Fig. 6. The model and data agree to within 3% for the second kicker and 16% for the first kicker (which is a further 10 m upstream from the BPM).

By comparing the timing of the beam induced signal on the kickers to the time of arrival of the amplifier output pulse at the kickers it was possible to determine whether the phase feedforward correction could have been applied within the latency requirements. The amplifier pulse arrived 8 ns late for the first (upstream) kicker thus the 40 m (210 ns) kicker cables will be rerouted and shortened to bring the latency within budget.

CONCLUSIONS

The final pieces of hardware, including the design specification kicker amplifier and additional phase monitors, will be available to allow tests of the phase feedforward system to begin in late 2014. In preparation, work on the correction chicane optics, a slow phase feedback to prevent drifts outside the phase feedforward range and tests of the amplifier and feedforward kickers have been completed. Large errors in the quadrupole strengths and dipole edge focusing in the MADX model of the TL2 line were corrected. New optics for the TL2 chicane matched from the improved model give a correction range of ±10 degrees whilst keeping dispersion below 1.2 m. Tests of the slow feedback with this optics in place demonstrated a correction in the mean beam pulse phase from 13.0° ± 2.0° to −0.2° ± 0.8°. Finally, the feedforward kickers were powered for the first time and the magnitude of the position offset measured in the BPMs as a result of the kick was found to agree with model expectations. However, the kicker cables will have to be shortened by at least 10 ns to bring the system latency within budget.

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