Design, Hardware Tests and First Results from the CLIC Drive Beam Phase Feedforward Prototype at CTF3

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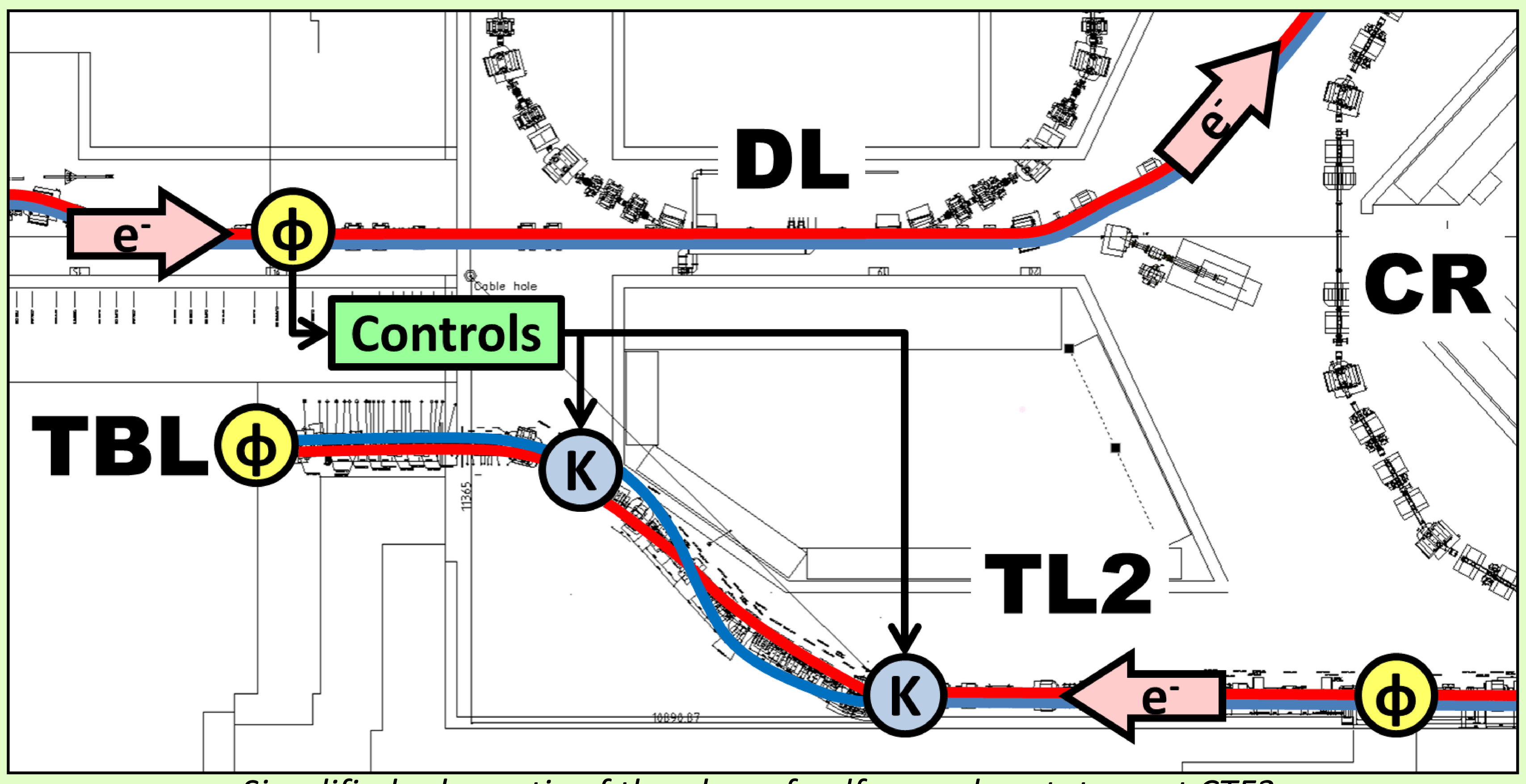
Motivation

- In the CLIC two beam acceleration scheme the RF power that accelerates the main beam is extracted from a second ***"drive beam"***. The phase (or time) synchronisation between the two beams must be maintained to within ***0.2 degrees of 12 GHz*** (50 fs) to ensure the efficiency of this concept [1,2].
- A ***phase feedforward system*** with ***bandwidth above 17.5 MHz*** [3] is required to reduce the drive beam phase jitter to this level. A prototype of the system is being commissioned at the CLIC test facility CTF3 at CERN to prove its feasibility.

CTF3 Phase Feedforward System

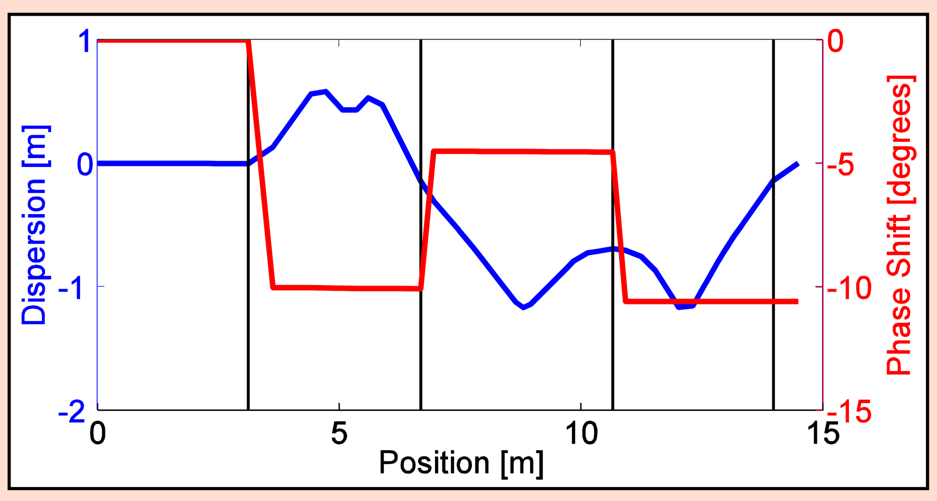
- The phase is corrected using two kickers placed prior to the first and last dipoles in the pre-existing ***chicane*** in the TL2 transfer line: ***bunches arriving late*** are deflected on to ***shorter paths*** and ***bunches arriving early*** on to ***longer paths*** through the chicane.
- Hardware: Three ***phase monitors*** and two strip line ***kickers*** (INFN/LNF Frascati) [4,5,7], kicker ***amplifiers*** and ***digital processor*** (JAI, Oxford University) [6,7].
- ***Latency*** of the system (including cable lengths) must be less than the ***380 ns*** time of flight between the first monitor and the first kicker.
- Goal: ***30 MHz bandwidth*** correction with ***0.2 degrees of 12 GHz resolution***.



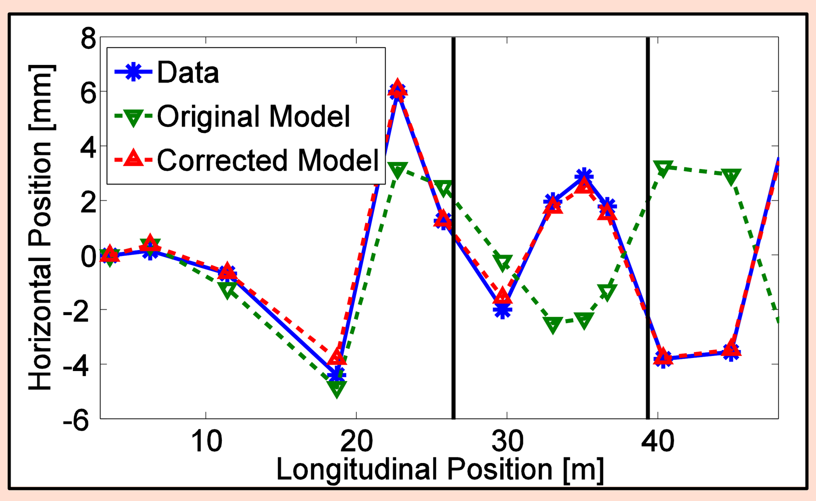
Simplified schematic of the phase feedforward prototype at CTF3.

Correction Chicane Optics

- The correction range for a given transverse kick is proportional to ***R52***, and therefore it should be ***as large as possible***.
- ***Dispersion*** must be kept ***below 2.0 m*** due to the drive beam energy spread of 1% rms at CTF3 and 10 cm physical aperture.
- Optics used for system commissioning: Dispersion below 1.2 m with R52 of 0.7 m, giving a ***phase shift of 10 degrees with the maximal 1.2 kV*** applied to the kickers.
- ***Response matrix measurements*** identified ***large errors*** in the ***MADX model*** of TL2, in particular the ***strength of quadrupoles*** reclaimed from the CELSIUS machine and the ***focusing behaviour*** of the 7 ***dipoles*** in the line.
- The ***mean position offset*** between the model and data was ***reduced from 3.0 ± 0.7 mm to 0.2 ± 0.1 mm*** by correcting these model parameters.



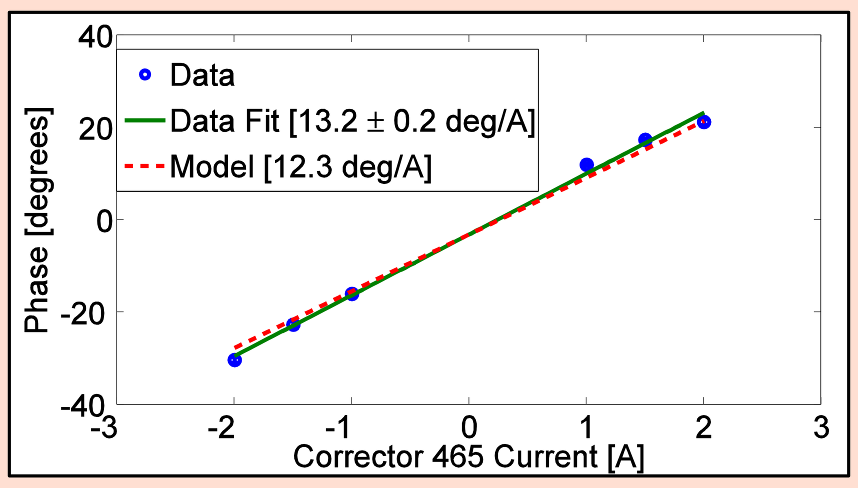
Phase Feedforward optics dispersion and phase shift with maximal kick.



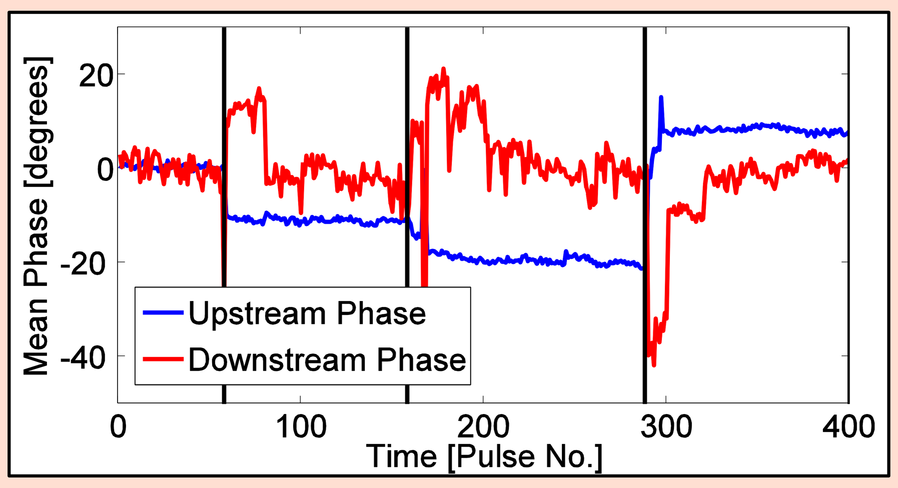
Optics response matrix measurements showing effect of MADX model corrections.

Slow Phase Feedback

- A CTF3 specific slow phase feedback will ***prevent slow drifts*** in the mean beam pulse phase outside the ***limited correction range*** of the feedforward system.
- The slow feedback uses ***two magnetic correctors*** installed in the TL2 chicane to vary the path length in the same way as the feedforward system. The phase monitor after the correction chicane is used as the input to the feedback loop.
- The phase shift per ampere applied to the correctors was calculated to be ***13.2 ± 0.2 degrees/A***, close to the model prediction of ***12.3 degrees/A***. This verifies the ability to shift the phase using the TL2 chicane.
- To test the slow feedback the ***mean beam phase was shifted ±10 degrees*** by changing the strength of the stretching chicane dipoles in the CTF3 linac.
- The ***corrector settings were recalculated every 20 pulses*** based on the mean phase over that time period.
- A ***mean phase offset of 13.0 ± 2.0 degrees*** after each phase shift was ***reduced to -0.2 ± 0.8 degrees*** after the reaction of the slow phase feedback.



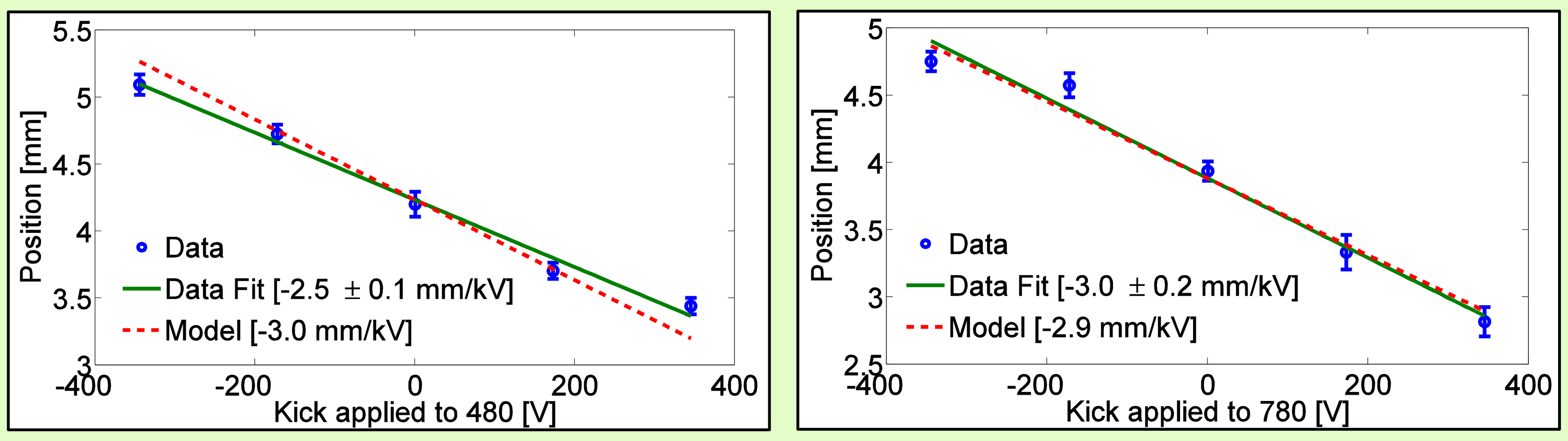
Phase shift per ampere applied to correctors.



Mean phase during a slow feedback test run.

Tests of Kickers

- The first stage amplifier (limited to 345 V out of the design 1.2 kV) was available to allow installation and performance cross-checks of the feedforward kickers.
- The beam response in the BPMs to a ***constant voltage applied to each kicker*** was observed. The measured 3 mm/kV ***position offset agrees with the MADX model*** (within the remaining optics errors)**.**
- By comparing the timing of the ***beam induced signal*** on the kickers to the time of arrival of the amplifier output pulse a ***8 ns latency deficit*** for the first kicker was found. The ***kicker cables will be shortened*** to meet the latency requirements.



Response to the first (left) and second (right) feedforward kicker in a BPM.

Conclusions

- The phase feedforward prototype at CTF3 is in the final stages of commissioning. It is a significant hardware challenge in terms of the bandwidth and power of the components. The final pieces of hardware will be in place to allow phase feedforward tests to begin in late 2014.
- In preparation, work on the correction chicane optics and MADX model, the development of a slow phase feedback to prevent drifts outside the phase feedforward range and tests of the amplifiers and feedforward kickers have been completed successfully.

References: [1] D. Schulte et al., MOP024, LINAC10; [2] CLIC Collaboration, CERN-2012-007; [3] A. Gerbershagen, 2013 PhD Thesis, University of Oxford; [4] F. Marcellini et al., WEPEB035, IPAC10; [5] A. Ghigo et al., TUPC007, IPAC11; [6] N. Blaskovic et al., THOAA02, IPAC2014; [7] P. Skowronski et al., WEOBB203, IPAC2013.