Demonstration of 50 fs stability of an electron beam at the CLIC Test Facility CTF3

J. Roberts,[*] R. Corsini, and P. Skowronski
CERN, Geneva
(CTF3 Collaboration)

P. Burrows, G. Christian, and C. Perry
John Adams Institute
Oxford University
(FONT Group)

(Dated: January 23, 2017)

Here is the abstract.

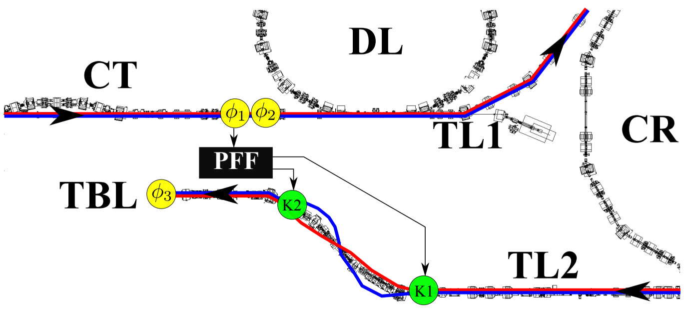

FIG. 1. Schematic of the PFF system at CTF3.

I. INTRODUCTION

CLIC is a proposal for a linear electron positron collider, using a novel two beam acceleration concept to achieve a collision energy of up to 3 TeV....

As part of this scheme strict requirements on the stability of the drive beam, including phase stability which must be better than 0.2 degrees at 12 GHz (or about 50 fs)...

All phases quoted in this paper are in degrees at 12 GHz.

Try to apply to XFELs/other applications that need high phase stability if possible...

Expected phase stability with no correction is 2 degrees. Phase feedforward system proposed to reduce incoming phase jitter by an order of magnitude prior to power extraction...

Prototype of the system at the CLIC test facility CTF3...

II. SYSTEM DESIGN

A schematic of the PFF system is shown in Fig. 1. The system corrects the phase using two electromagnetic kickers installed before the first and last dipole in a four bend chicane (in the TL2 transfer line). The beam's path length through the chicane depends on the magnitude and polarity of the voltage applied to the kickers. The phase is measured using a monitor upstream of the chicane (in the CT beam line), and then corrected by setting the kicker voltage to deflect bunches arriving early at the phase monitor on to longer trajectories in the chicane, and bunches arriving late on to shorter trajectories. Downstream of the chicane, in the TBL line, another phase monitor is placed to measure the effects of the correction.

The beam time of flight between the upstream phase monitor and the first kicker in the chicane is 380 ns. By bypassing the combiner ring (CR) and TL1 transfer line, see Fig. 1, the total cable length required to transport signals between the monitor and kickers is shorter, approximately 250 ns. The PFF correction in the chicane can therefore be applied to the same bunch initially measured at the phase monitor, providing the total system hardware latency is less than 130 ns. The system has a bandwidth of around 30 MHz, able to remove phase variations along the 1.2 μs CTF3 beam pulse, as well as any offsets in the overall mean phase.

A. Hardware

The PFF system uses three phase monitors, two electromagnetic kickers, kicker amplifiers and a digitiser/feedforward controller.

The three phase monitors are designed and built by INFN Frascati, with the associated electronics built by CERN. The monitors are 12 GHz resonating cavities with a dipole and monopole mode present. The output from opposing vertical pairs of feedthroughs are summed in hybrids to create a position independent signal. This signal is split and mixed with a reference 12 GHz signal in eight separate mixers. The output from the eight mixers is combined, allowing a resolution of 0.126 degrees to be achieved whilst maintaining good linearity. This resolution is determined by comparing the measurements of the two monitors installed in the CT line.

[*] Also at JAI, Oxford University.; Jack.Roberts@cern.ch

The two electromagnetic kickers were also designed and built by INFN Frascati, and are based on the DAFNE design. A voltage of 1.26 kV applied to the downstream end of the kicker strips yields a horizontal deflection of 1 mrad for the 135 MeV CTF3 beam.

The kicker amplifiers have been designed and built by the John Adams Institue/Oxford University. For an input voltage of 2 V gives an output of up to 700 V. Response linear within 3% for input voltages up to 1.2 V, then starts to saturate. Bandwidth 47 MHz for small signal variations up to 20% max output...

Finally, the Feedforward digitiser and controller (FONT5a board) was also designed and built by John Adams Institute/Oxford University. This takes the processed phase monitor signals then calculates and outputs the appropriate voltage with which to drive the amplifier. 9 ADCs, FPGA, 4 DACs... Digitises output from phase monitor electronics, calculates amplifier output based on set gain values, deals with correction timing...

B. Optics

Two kickers are placed before first and last dipole in the chicane. Installed inside wide aperture quadrupoles to maintain functionality of the lattice...

Key figure of merit for the PFF optics is the transfer matrix coefficient R52, which relates the applied kick to the resulting phase shift...

PFF system should not degrade transverse stability of beam after chicane. Can be achieved by requiring R11=-1 and R12=0 between kickers...

All this must be achieved whilst keeping dispersion low, matching betas etc. within constraints of pre-existing buildings. Achieved R52 0.74m with max dispersion 1.16m...

But had to accept R56 of -0.18m. Means introduction of additional energy dependent jitter downstream not present upstream. PFF system (at CTF) requires residual R56 below 1cm to achieve 97% correlation. Created new optics for TL1 line with varying R56, to control this effect...

C. Commissioning

(MIGHT BE BETTER TO MERGE POINTS HERE IN TO OTHER SECTIONS?)

Correction range is 5.5 degrees, consistent with kicker design and amplifier output. Means only a portion of the CTF3 pulse can be corrected due to phase sag (or maybe could avoid this by only including central part of pulse in plots)...

Beam time of flight 380 ns between first phase monitor and first kicker. Overall measured system latency is 350 ns, including all hardware and cables. Correct same bunch originally measured...

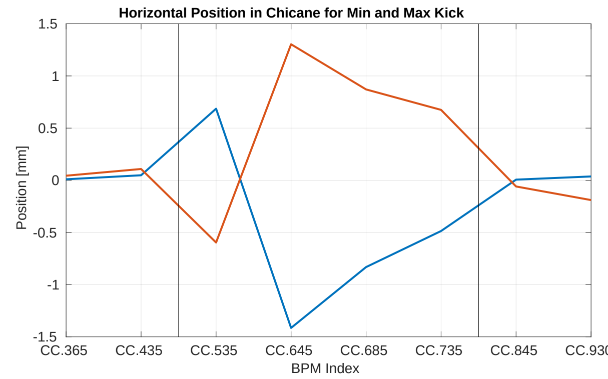

FIG. 2. Orbit closure.

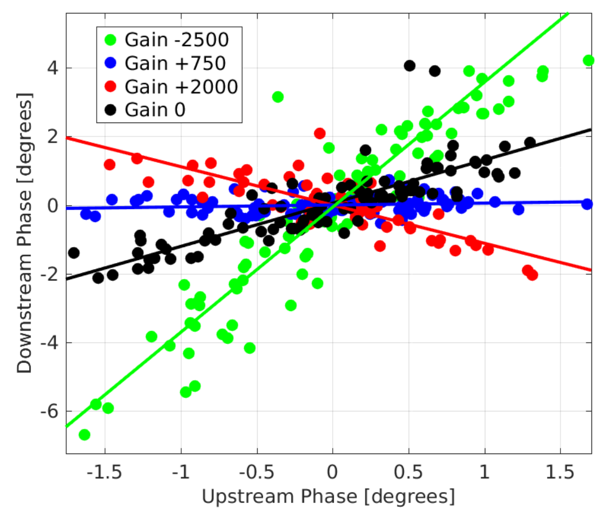

FIG. 3. Gain scan - NEED NEW DATA.

(Need to) demonstrate that downstream orbit is independent of applied kick...

III. RESULTS

A. Gain Scan

Theoretical limit on the corrected jitter is $\sigma_d\sqrt{1-\rho_{ud}^2}$...

Optimal gain value is $g = \rho\sigma_d/\sigma_u$...

Would like new data here but would be nice to: have a scan with clear jitter vs. gain relationship (difficult because of propagation drifts). Otherwise, scatter plot like one I've included could be used to demonstrate effect...

B. Mean Jitter

(General question: With/without wiggling, mean and point-by-point – probably can't include all 4? Which to

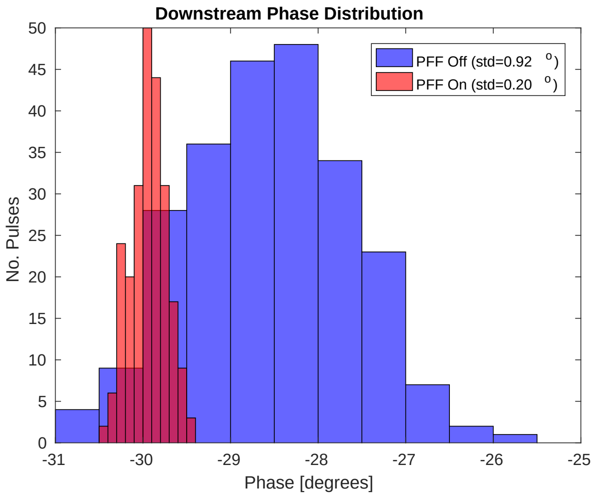

FIG. 4. Best mean phase jitter.

focus on? Need to at least quote lowest achieved jitter, but wiggling results can look more impressive in plots)

Achieved jitter on the mean phase of 0.24 degrees...

Consistent with theoretical value of (TO CALCULATE) given initial correlation, jitter in this dataset...

Assuming 0.1 degrees resolution on mean (best achieved), measured jitter corresponds to actual beam jitter of 0.22 degrees...

C. Pulse Shape

High bandwidth correction - not only correcting the mean but also variations along the pulse...

Peak-to-peak variation of 5.76 degrees in initial phase reduced to 0.65 degrees in corrected phase – OR – standard deviation of phases reduced from 1.68 to 0.26 degrees...

D. Point-by-point Jitter

Point-by-point jitter of x degrees achieved across a x ns portion of the pulse, agrees with simulated value...

Limited by variations in phase propagation along the pulse (energy differences etc.), plus resolution slightly worse for point by point than for mean.

IV. CONCLUSIONS

PFF prototype at CTF3 has demonstrated phase stability close to CLIC requirements...

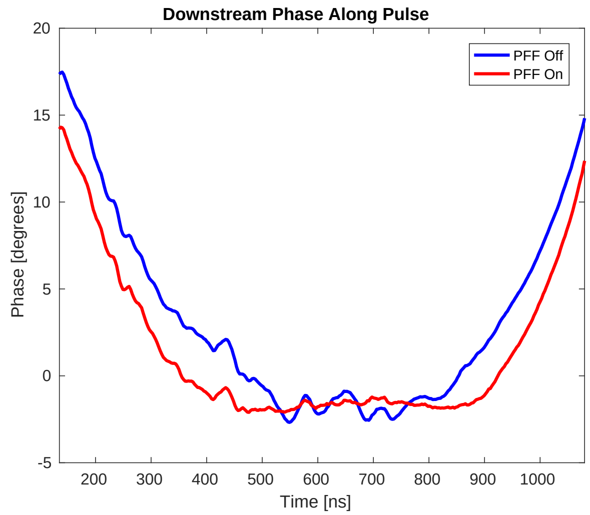

FIG. 5. Correction of pulse shape.

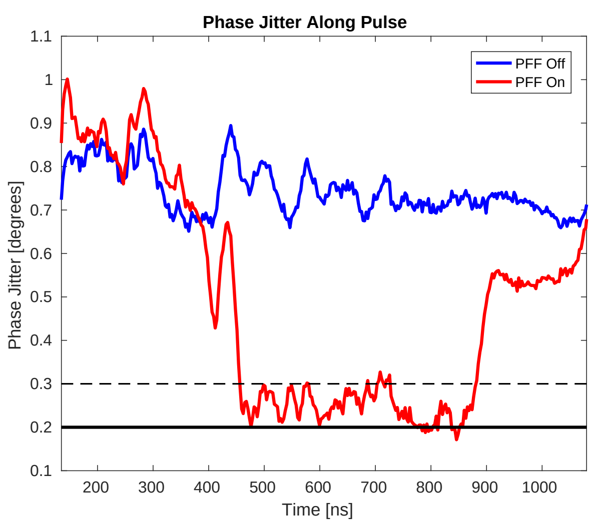

FIG. 6. Point-by-point jitter.