NANOSECOND-TIMESCALE INTRA-BUNCH-TRAIN FEEDBACK FOR THE LINEAR COLLIDER: RESULTS OF THE FONT2 RUN

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Abstract

We report on experimental results from the December 2003/January 2004 data run of the Feedback On Nanosecond Timescales (FONT) experiment at the Next Linear Collider Test Accelerator at SLAC. We built a second-generation prototype intra-train beam-based feedback system incorporating beam position monitors, fast analogue signal processors, a feedback circuit, fast-risetime amplifiers and stripline kickers. We applied a novel real-time charge-normalisation scheme to account for beam current variations along the train. We used the system to correct the position of the 170-nanosecond-long bunchtrain at NLCTA. We achieved a latency of 53 nanoseconds, representing a significant improvement on FONT1 (2002), and providing a demonstration of intra-train feedback for the Linear Collider.

INTRODUCTION

A number of fast beam-based feedback systems are required at the Linear Collider. At the interaction point (IP) a very fast system, operating on nanosecond timescales within each bunchtrain, is required to compensate for residual ground-motion-induced jitter on the final quadrupole magnets by steering the electron and positron beams into collision. A pulse-to-pulse feedback system is envisaged for optimising the luminosity on timescales corresponding to 5-100 Hz. Slower feedbacks, operating in the 0.1 – 1 Hz range, will control the beam orbit through the Beam Delivery System.

The key components of each such system are beam position monitors (BPMs) for registering the beam orbit; fast signal processors to translate the raw BPM pickoff signals into a normalised position output; feedback circuits, including delay loops, for applying gain and taking account of system latency; amplifiers to provide the required output drive signals; and kickers for applying the position (or angle) correction to the beam. A schematic of the IP intra-train feedback is shown in Figure 1, for the case in which the electron and positron beams cross with a small angle.

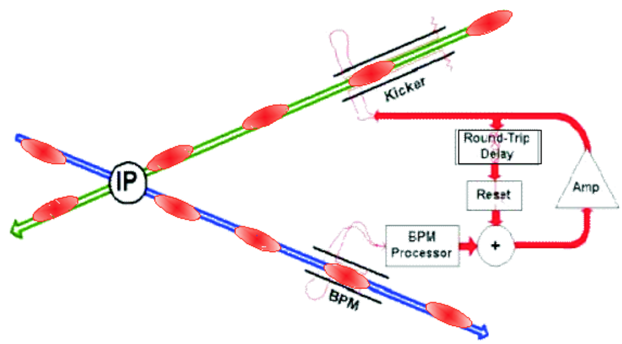

Figure 1: Schematic of IP intra-train feedback system for an interaction region with a crossing angle. The deflection of the outgoing beam is registered in a BPM and a correcting kick applied to the incoming other beam.

FONT OVERVIEW

FONT is a collaboration between UK academic groups (QMUL, Oxford, Daresbury) and the NLC Group at SLAC with the purpose of prototyping and testing IP feedback components. Two rounds of beam tests have taken place at the NLC Test Accelerator (NLCTA) at SLAC.

A schematic of the experimental configuration in the NLCTA beamline is illustrated in Figure 2. The layout is functionally equivalent to the Linear Collider intra-train feedback system. An upstream dipole magnet is used to steer the beam so as to introduce a controllable position offset in a downstream BPM. A signal processor and a feedback circuit provide a correction signal to drive the upstream kicker so as to steer the beam back into nominal vertical position.

The electron bunchtrain can be made as long as 170 ns; this is roughly half the length of the train planned for GLC/NLC [1,2] and approximately 50% longer than the train envisaged at CLIC [3]. However, the bunch spacing is c. 87 ps (X-band frequency), which is considerably shorter than the 1.4ns spacing of GLC/NLC or 0.7ns spacing of CLIC. The beam energy is typically 65 MeV. The beam is quite large, typically around 1 mm, and the vertical position jitter is at the level of 50 microns from pulse to pulse. There can be a significant charge variation along the length of the train, with deviations at worst up to 50% of nominal charge. Calculation of the beam position signal therefore requires that the charge variation be taken into consideration in the BPM signal processor.

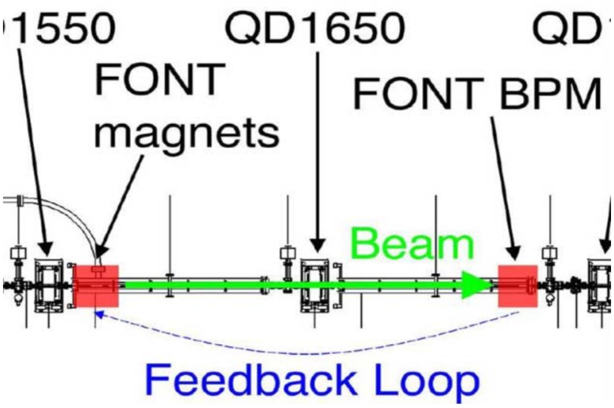

Figure 2: Schematic of the NLCTA beamline showing location of the dipole, kickers and BPMs.

Data runs were taken in the summer of 2002 (FONT1) and the winter of 2003 (FONT2) in both of which the feedback loop was closed. Results from FONT1 were reported at PAC 2003 [4]; a 10:1 position correction was successfully applied within a total latency period of 67 ns. The electronics contributed c. 35 ns to the latency budget.

FONT2

A number of improvements were made to the beamline hardware for the FONT2 setup:

- Two witness BPMs were added to provide an independent monitor of the feedback performance.
- A second upstream stripline kicker was added to reduce the amplifier drive power while maintaining correction strength capability. This allowed a solid-state amplifier design to replace the 3kW tube amplifer used in FONT1.
- The separation between the feedback BPM and kickers was reduced by roughly a factor of two, to about 2m. This allowed more passes through the feedback loop within the duration of the 170ns bunchtrain.
- A 'beam flattener' was added so as to smooth out slowly-varying position structure within the bunchtrain.

The hardware layout is shown in Figures 3 and 4.

The BPM signals were mixed from X-band to baseband in a two-stage down-mixing process with an intermediate frequency stage of 400 MHz. Normalisation by the beam charge was performed in real-time by taking the difference between the top and bottom pickoff signals using logarithmic amplifers. The correction signal was fed to solid state amplifiers (maximum power roughly 800 W each) which drove the two kickers.

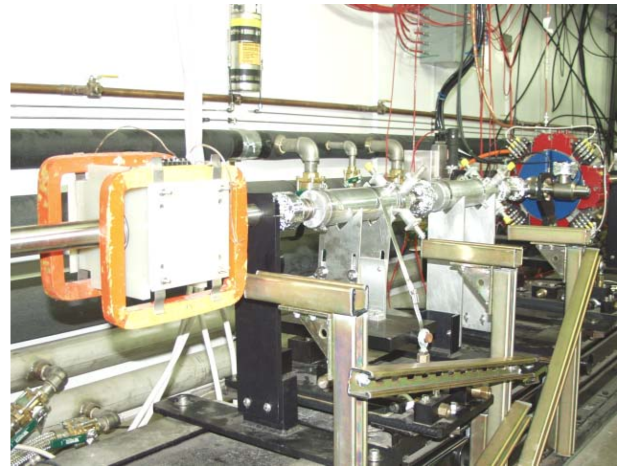

Figure 3: Upstream section of the FONT2 experiment in the NLCTA beamline, showing the dipole magnet for beam steering and the two kickers for beam position correction.

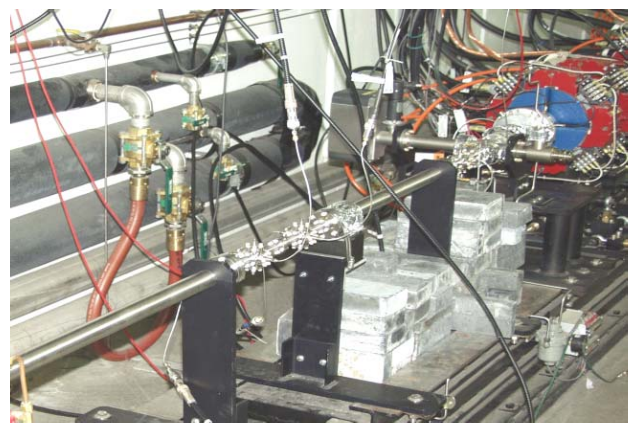

Figure 4: Downstream section of the FONT2 experiment, showing the suite of 3 BPMs. The upstream BPM forms the sensor of the feedback loop; the two downstream BPMs act as independent monitors of the beam position after the correction

Results from the FONT2 run in January 2004 are shown in Figure 5. The system was able to make a 14:1 correction in beam position within a latency period of 53 ns, of which 37 ns is from the speed of the electronics and 16 ns due to time-of-flight of the beam and return correction signal.

BEAM FLATTENER

The design of the beam flattener is illustrated in Figure 6. A 'snapshot' of the beam profile is recorded with a digital oscilloscope. The deviation of the profile w.r.t. the mean is calculated in Matlab, reversed in sign, and added in to the feedback signal. This provides a correction for beam position structure within the bunchtrain that varies slowly on the timescale of the train repetition frequency (few Hz). The performance with beam is illustrated in Figure 7. The bandwidth is limited to about 30MHz by the kicker driver amplifier.

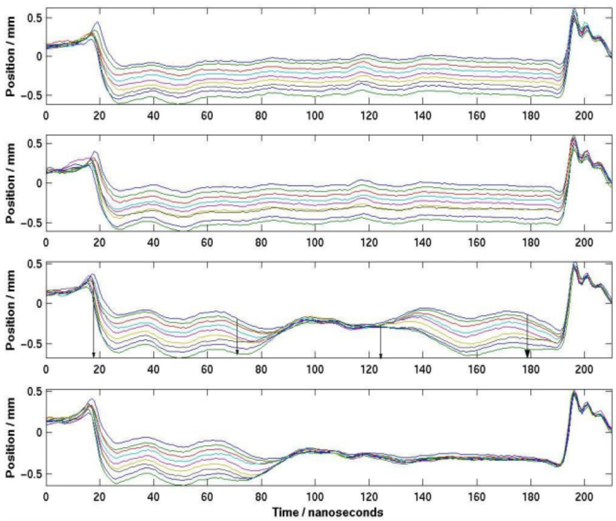

Figure 5: Results from FONT2. Top: beam starting positions. Upper middle: action of the 'beam flattener' to remove slowly-varying components in the bunch position structure within the train. Lower middle: effect of the feedback without delay loop. The arrows show the boundaries between the latency periods during the system operation; 3.2 latency periods are apparent. Bottom: full system including delay-loop feedback.

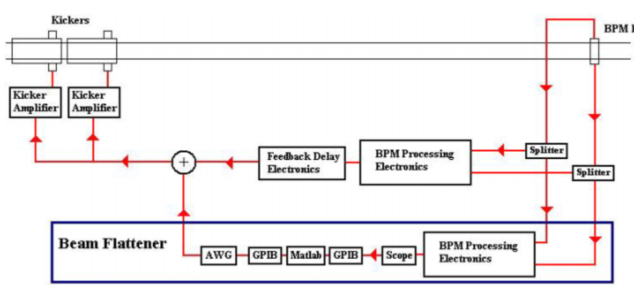

Figure 6: functional design of the beam flattener.

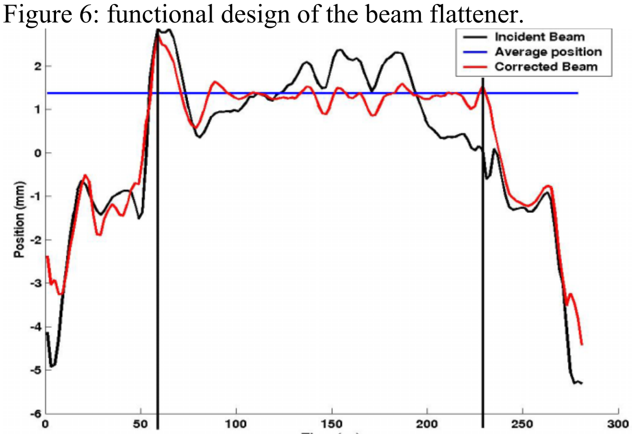

Figure 7: Operation of the beam flattener. The incoming bunch profile (black) is compared with the mean position (blue) and corrected (red) via the feedback signal.

PLANS FOR FONT3

A FONT3/FEATHER system is now being planned for operation in the Accelerator Test Facility (ATF) extraction line. The aim is to utilise the FEATHER [5] adjustable-gap kicker and incorporate fast FONT-style signal processing and a custom solid-state amplifier. The hardware performance goals include development of a 'superfast' BPM signal processor (latency roughly 5 ns) and an integrated solid state amplifier and feedback circuit with a similar total latency.

Several important tests can be attempted:

- Stabilisation of the ATF 20-bunch train at the micron level. This requires the same amplifier power and BPM resolution as would be needed at the Linear Collider to stabilise the beam to the nanometre level. This is hence a scale model for the real IP feedback system.
- Extraction of 3 trains per pulse, with train-to-train stabilisation at the sub-micron level. This would augment the 'nanoBPM' programme [6] by steering the beam into the fiducial region of the cavity nanometre-resolution BPMs.
- Demonstration of a high-stability ramped kicker amplifier for intra-train beam steering. This could be used for fast beam-beam deflection calibration at the Linear Collider.

Designs for hardware for these tests are being developed with the intention of testing prototype systems with beam in 2005/6.

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