FEEDBACK ON NANOSECOND TIMESCALES (FONT): RESULTS FROM FIRST BEAM TESTS AT THE NLCTA AT SLAC

P.N. Burrows (Queen Mary, University of London)

Abstract

We report on the first beam tests of the Feedback on Nanosecond Timescales (FONT) project to develop beam-based intra-train feedback for the Linear Collider.

INTRODUCTION

In order to achieve the design luminosity, in excess of 10^{34}/cm^2/s, the vertical beam size in the next generation electron-positron Linear Collider must be of order a nanometre: 3 nm (J/NLC), 5 nm (TESLA), 0.7 nm, (CLIC). Any source of beam motion which results in relative vertical offsets of the two beams at the interaction point (IP) at the nanometre level will clearly reduce the luminosity from the design value. Maintaining vertical beam overlap is hence a particularly challenging goal for all these designs.

In order to keep the luminosity LOSS below 80% the beam-beam miss distance must be kept below 40, 30 and 5 nanometres for TESLA, J/NLC and CLIC, respectively. In order to keep the loss below 10% the beam overlap must be maintained to better than $1\sigma_y$, i.e. below 5 nanometres in all cases.

The many kinds of potential beam motion may be characterised in two classes: (i) slow drifts resulting from, for example, thermal excursions or component settling, with characteristic timescales varying from seconds to months; (ii) ground motion on a timescale comparable with the machine repetition time. Both kinds of motion were experienced in the decade-long experience at the SLAC Linear Collider (SLC), and were dealt with by employing slow- and fast-feedback systems, respectively. Cultural 'noise' is expected to dominate the ground motion spectrum at frequencies above 1 Hz and, depending on the site, could be at the level of tens of nanometres (r.m.s.). If uncorrected this would cause an a priori large and unknown vertical offset between the electron and positron beams that is DIFFERENT on each successive machine cycle.

Stabilisation of the effects of ground motion will hence be key to successful operation of the future Linear Collider; without it the luminosity may be 1-2 orders of magnitude below the design value, and the physics potential will not be realised.

LUMINOSITY RECOVERY

We are addressing the design of an intra-bunch-train fast-feedback (FB) system for the next-generation Linear Collider (LC). Other essential feedback systems that operate on longer timescales are discussed in [1]. A schematic of our system is shown in Figure 1. It comprises a fast beam position monitor (BPM) to detect the relative mis-alignment of the leading electron (or positron) bunches just downstream of the IP, a feedback loop, and a fast kicker for kicking later positron (or electron) bunches into collision. The latency of the system should be small enough so that it is able to make several iterative corrections to the beam position within the duration of the bunchtrain, i.e. the latency should be significantly less than 100 nanoseconds for J/NLC and CLIC. For TESLA the situation is more relaxed since there are 2820 bunches separated by 337 ns; a system with a sub-100-nanosecond latency would therefore be capable of bunch-to-bunch feedback.

We have written a simulation package for the feedback system, based on MATLAB/Simulink, that incorporates the beam-beam dynamics (based on GUINEAPIG) and the responses of the hardware components [2]. This allows us to study the feedback operation in 'closed loop' mode. We can also include arbitrary ground-motion model inputs, and multi-bunch wakefield effects, via simulation of the linac and beam delivery system using PLACET/MERLIN (TESLA) or a modified version of LIAR (J/NLC). We have used this simulation infrastructure to show that an intra-train FB system is capable of recovering more than 80% of the design luminosity, which would otherwise be lost due to ground motion.

FONT1: FIRST PROTOTYPE INTRA-TRAIN FEEDBACK SYSTEM

System components and beamline installation

We chose to develop our first prototype FONT experiment at the Next Linear Collider Test Accelerator (NLCTA) at SLAC since the length of the bunch train there can be made as long as 170 ns, which is close to the 270 ns in the J/NLC design and the 100 ns for CLIC, and the train charge of up to 10^{11} electrons is also close to the respective specifications. The time structure of the beam at NLCTA is such that bunches are spaced at X-band frequency, 11.424 GHz, corresponding to 0.08 ns between bunches. This is an order of magnitude shorter than the bunch spacing at J/NLC (1.4 ns) or CLIC (0.7 ns), which makes the test somewhat more difficult.

The layout of the FONT1 components in the NLCTA beamline is shown in Figure 2. The beam enters from the left and is first steered vertically using a dipole magnet (not shown). The beam position is measured roughly 4m downstream at the BPM. The position signal is processed and fed to a kicker that sits within the same assembly as the dipole. The kicker to BPM distance was chosen to match the separation between the IP and the FONT components
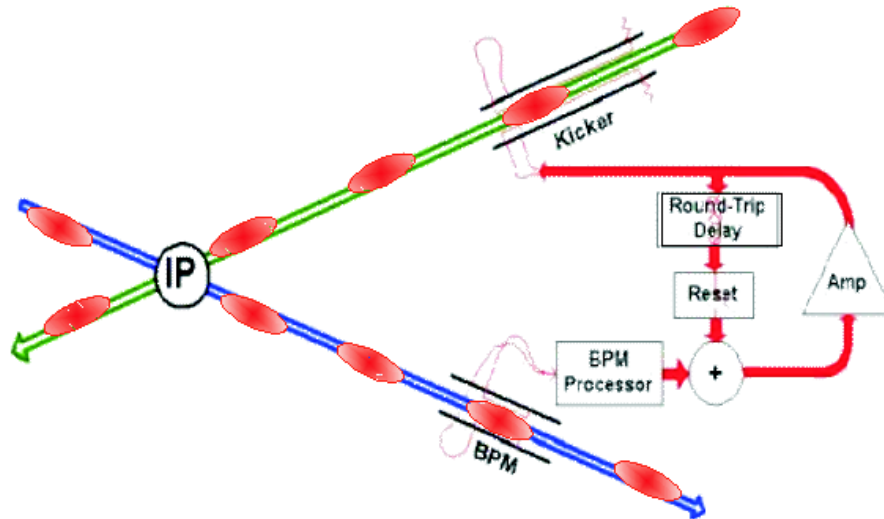
Figure 1: Schematic of the FONT system, showing the position of the BPM and kicker and the function of the FB loop, for an interaction region with a crossing angle.

in the real IR (Figure 1), so as to make the round-trip signal propagation time roughly the same.

We measured the signal propagation delays through our components and estimated the latency of the hardware to be 33 ns, comprising: 5 ns (BPM processor), 5ns (variable-gain preamplifier), 11 ns (Normalisation/FB circuit), 10 ns (kicker amplifier) and 2 ns (kicker fill time). We estimated the beam flight time between the kicker and BPM to be 14 ns, and the return signal cable propagation time to be 18 ns. Thus we estimated a total latency of 65 ns for the FONT1 test.

Results

We summarise the results in Figure 3. The top plot shows the vertical position of the NLCTA bunchtrain as recorded in the FONT BPM for 5 different initial positions that were set using the dipole. For these top plots the FB system was off, and these represent the starting positions of the deliberately offset beam.

The middle plot of Figure 3 represents the effect of the feed-forward part of the system, with the delay loop switched off. After one latency period the effect of the kicker on the beam is registered at the BPM. With a high gain choice the beam is steered almost perfectly to nominal position, independent of the starting position. After a further latency period the BPM registers a modified beam position that corresponds to the fact that the kicker was supplied with a reduced drive signal: the dispersion among the 5 corrected beam positions hence increases. This is precisely as designed, since the result of the first kicker correction reduces the position offset and hence also the second drive signal. After a further half latency period the entire bunchtrain has passed and the BPM signal falls to zero.

The bottom plot illustrates in addition the action of the delay loop. In the last half latency period before the bunch-train has passed the effect of the delay loop can be seen: the correction applied after the first latency period is preserved and the beam remains steered close to nominal position. Note that we made no attempt to optimise in detail the kicker gain; also, the gain of the delay loop was set to unity and was not tuned.

From these results we conclude that we have made a correction to an electron beam that corresponds to 1.5 passes through a feed-forward, and a half-pass through a delay-loop feedback, system. The measured latency is 66 ns, which compares well with the a priori expected value of 65 ns. This represents a first proof of principle that such a system can operate on a timescale of relevance to the J/NLC or CLIC LC designs.

Plans

We propose to make a number of substantial improvements to the FONT setup at NLCTA, and to take further data in 2003. These include: the addition of two witness BPMs; optimised electronics with reduced latency; reconfiguration of beamline components in order to shorten the latency by about 16ns, thereby allowing a second pass around the delay loop and a more rigorous test of the full FB concept; building a new, solid-state amplifier; and correction of high-frequency position structure within the bunchtrain.

REFERENCES

[1] A. Seryi, these proceedings.

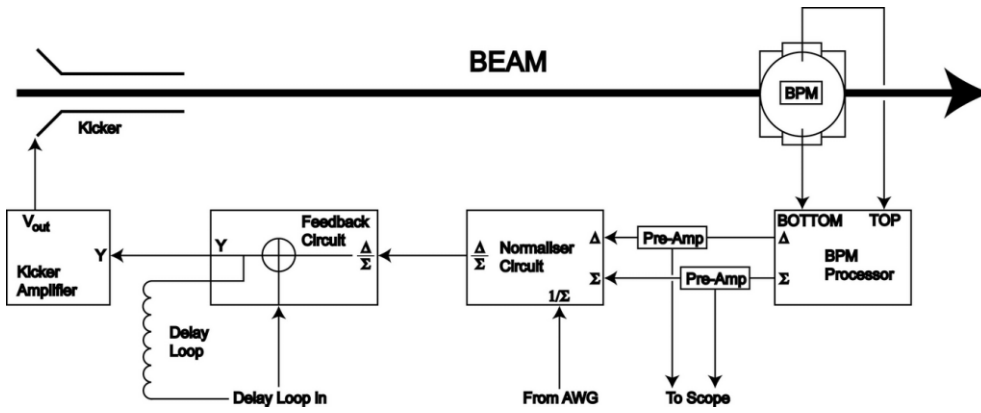[2] G. White: these proceedings.

Figure 2: Schematic of FONT1 system in the NLCTA beamline.
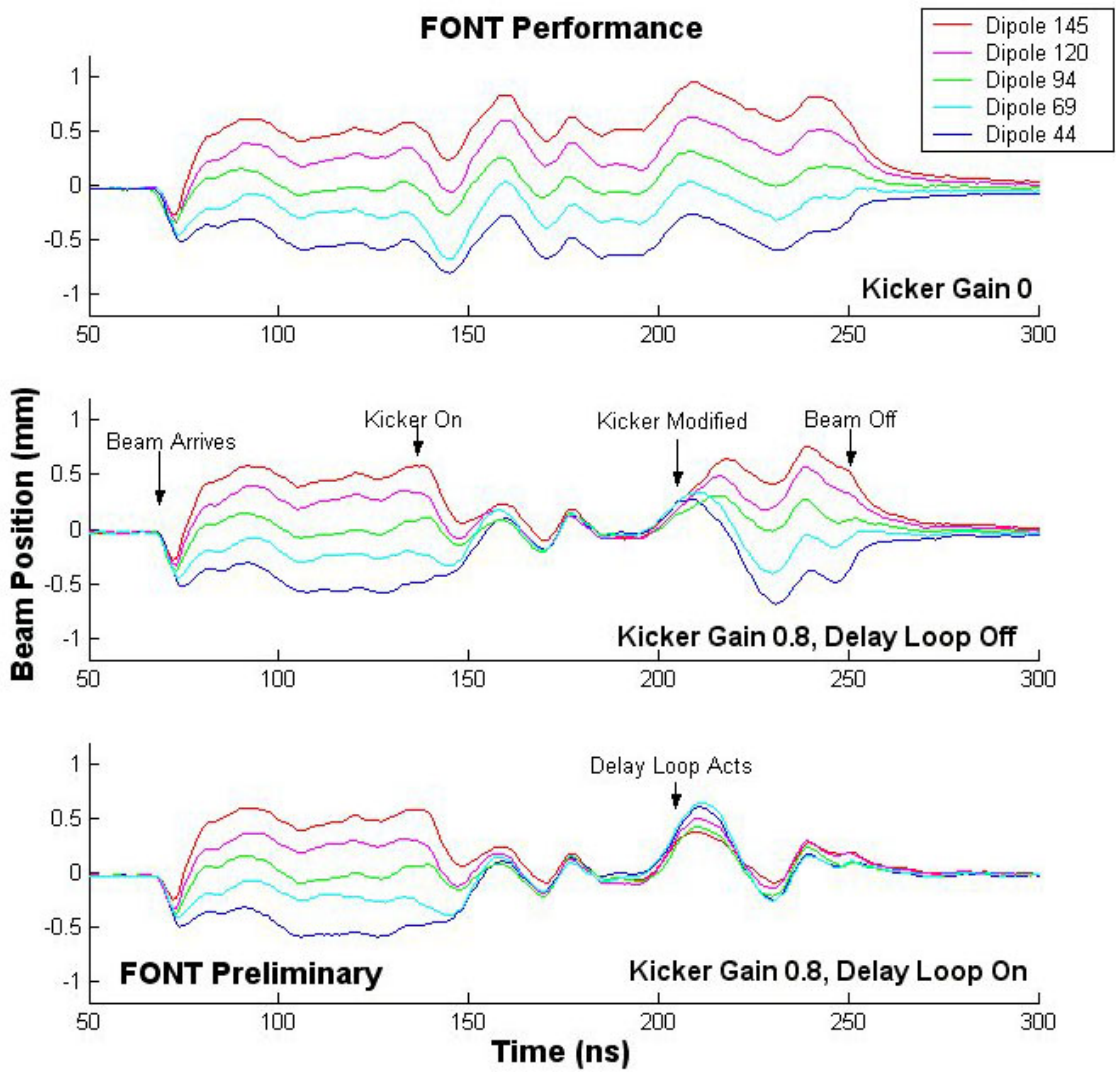

Figure 3: Operation of FONT1. Top: initial beam offsets; middle: with the delay-loop off; bottom: with the delay loop on.