LATEST PERFORMANCE RESULTS FROM THE FONT 5 INTRA TRAIN BEAM POSITION FEEDBACK SYSTEM AT ATF

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Abstract

A prototype ultra-fast beam-based feedback system for deployment in single-pass beamlines, such as a future lepton collider (ILC or CLIC) or a free-electron laser, has been fabricated and is being tested in the extraction and final focus lines of the Accelerator Test Facility (ATF) at KEK. FONT5 is an intra-train feedback system for stabilising the beam orbit via different methods: a position and angle feedback correction in the extraction line or a vertical feedforward correction applied at the interaction point (IP). Two systems comprise three stripline beam position monitors (BPMs) and two stripline kickers in the extraction line, two cavity BPMs and a stripline kicker at the IP, a custom FPGA-based digital processing board, custom kicker-drive amplifiers and low-latency analogue front-end BPM processors. Latest results from the experiment are presented. These include beam position correction in the extraction line, as well as preliminary results of beam correction at the IP.

INTRODUCTION

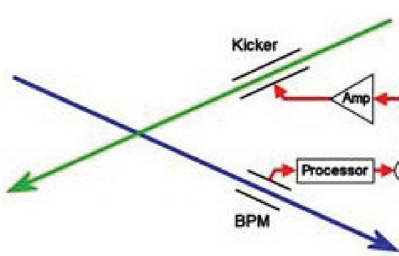

Figure 1: Schematic of IP intra-train feedback system with a crossing angle.

A number of fast beam-based feedback systems are required at the International Linear Collider (ILC) [1]. At the interaction point (IP) a very fast system, operating on nanosecond timescales within each bunch train, is required to compensate for residual vibration-induced jitter on the final-focus magnets by steering the electron and positron beams into collision. The deflection of the outgoing beam is measured in a beam position monitor (BPM) and a correcting kick applied to the incoming other beam. A pulse-to-pulse feedback system is envisaged for optimising the luminosity on timescales corresponding to 5 Hz. Slower feedbacks, operating in the $0.1 - 1$ Hz range, will control the beam orbit through the Linacs and Beam Delivery System.

The key components of each such system are BPMs for measuring the beam orbit; fast signal processors to translate the raw BPM pickoff signals into a 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 Fig. 1, for the case in which the beams cross with a small angle; the current ILC design incorporates a crossing angle of 14 mrad. Critical issues for the intra-train feedback performance include the latency of the system, as this affects the number of corrections that can be made within the duration of the bunch train, and the feedback algorithm.

We report the latest results on the development and beam testing of an ILC prototype system that incorporates a digital feedback processor based on a state-of-the-art Field Programmable Gate Array (FPGA) [2]. The use of a digital processor allows for the implementation of more sophisticated algorithms which can be optimised for possible beam jitter scenarios at ILC. However, a penalty is paid in terms of a longer signal processing latency due to the time taken for digitisation and digital logic operations. This approach is possible for ILC given the long, multi-bunch train, which includes parameter sets with c. 3000/6000 bunches separated by c. 300/150 ns respectively. Initial results were reported previously in [3] and [4].

FONT 5 DESIGN

A schematic of the upstream FONT5 feedback system prototype and the experimental configuration in the upgraded ATF extraction beamline, ATF2, is shown in Fig. 2. Two stripline BPMs (P2, P3) are used to provide vertical beam position inputs to the feedback. Two stripline kickers (K1, K2) are used to provide fast vertical beam corrections. A third stripline BPM (P1) is used to witness the incoming beam conditions. Upstream dipole corrector magnets (not shown) can be used to steer the beam so as to introduce a controllable vertical position offset in the BPMs. Each BPM signal is initially processed in a front-end analogue signal processor. The analogue output is then sampled, digitised and processed in the digital feedback board. Ana-

ISBN 978-3-95450-122-9

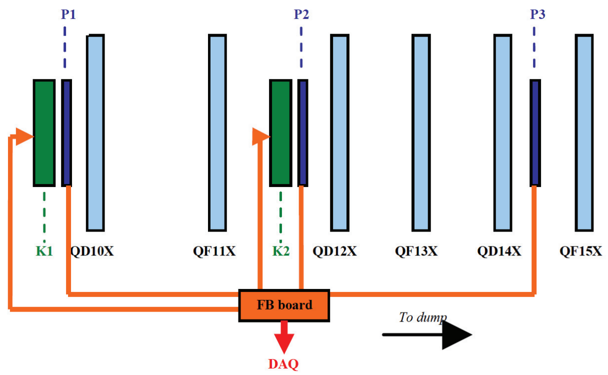

Figure 2: Schematic of FONT5 at the ATF2 extraction beamline showing the relative locations of the kickers, BPMs and the elements of the feedback system.

logue output correction signals are sent to a fast amplifier that drives each kicker.

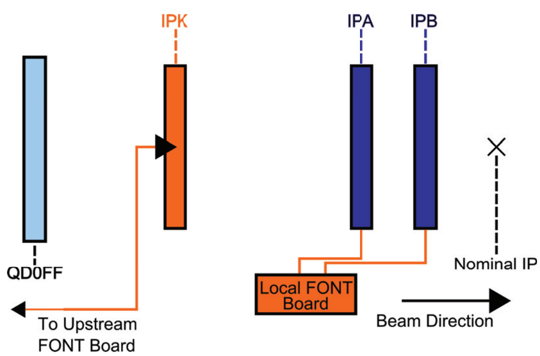

Figure 3: Schematic of IP region at the ATF2 final focus beamline showing the relative locations of the kickers, BPMs and the elements of the feedback system.

A schematic of the ATF IP system is shown in Fig. 3. It comprises two C-Band cavity BPMs (IPA, IPB) and a stripline kicker (IPK). The upstream magnet QD0FF (also shown) can be used to steer the beam by introducing a vertical position offset or to move the beam waist up or down the beamline.

The ATF can provide an extracted train that comprises up to 3 bunches separated by an interval that is selectable in the range $140-300$ ns. This provides a short ILC-like train which can be used for controlled feedback system tests. FONT5 has been designed as a bunch-by-bunch feedback with a latency goal of around 140 ns, meeting the minimum ILC specification of c. 150 ns bunch spacing. This allows measurement of the first bunch position and correction of both the second and third ATF bunches.

The design of the front-end stripline BPM signal processor is described in [5] and [6]. The top and bottom (y) stripline BPM signals are added with a resistive coupler and subtracted using a hybrid, to form a sum and difference signal respectively. The resulting signals are band-pass filtered and down-mixed with a 714 MHz local oscillator signal which is phase-locked to the beam. The resulting baseband signals are low-pass filtered. The hybrid, filters and mixer were selected to have latencies of the order of a few nanoseconds to yield a total processor latency of 10 ns [5,6].

The cavity BPM processing scheme described here [7] consists of a two stage system, the first downmixing the cavity signal to 714 MHz and the second to baseband. The baseband signal is then digitised by a local FONT5 digital board. In addition a high speed cable is strung along the beamline connecting the upstream and downstream systems and allowing a feedforward signal to be transmitted between the two points.

Two custom digital feedback processing boards are installed at ATF, one upstream and one at the IP. On each board there are 9 analogue signal input channels in which digitisation is performed using ADCs with a maximum conversion rate of 400 MS/s, and 2 analogue output channels formed using DACs, which can be clocked at up to 210 MHz. The digital signal processing is based on a Xilinx Virtex5 FPGA [2]. The FPGA is clocked with a 357 MHz source derived from the ATF master oscillator and hence locked to the beam. The ADCs are clocked at 357 MHz. The analogue BPM processor output signals are sampled on peak to provide the input signals to the feedback. The gain stage is implemented alongside the reciprocal of the sum signal for beam charge normalisation via a lookup table stored in FPGA RAM. The delay loop is implemented as an accumulator in the FPGA. The output is converted back to analogue and used as input to the kicker amplifier. A pre-beam trigger signal is used to enable the amplifier drive output from the digital board.

The driver amplifier was manufactured by TMD Technologies [8] and provides ± 30 A of drive current into the kicker. The rise-time is 35 ns from the time of the input signal to reach 90% of peak output. The output pulse length was specified to be up to 10 microseconds.

UPSTREAM FEEDBACK RESULTS

We report the results of beam tests of the system in 2012/13; earlier results were reported in [3] and [4]. The upstream coupled loop feedback system was recommissioned and its impact on the beam near the IP was measured.

For the purpose of obtaining optimal spatial correlation between bunches in the extracted bunch train the ATF damping ring was set up to extract 2 bunches with a separation of 274.4 ns.

The upstream system was first set up and the optimal gain was selected using the methods described in [4]. The system was then operated in an interleaved mode with the feedback applied on alternate machine pulses. IPA was then used to measure the effects of the system near the beam waist.

The performance of the system is shown in Fig. 4 which shows vertical beam position (jitter) of the second bunch in

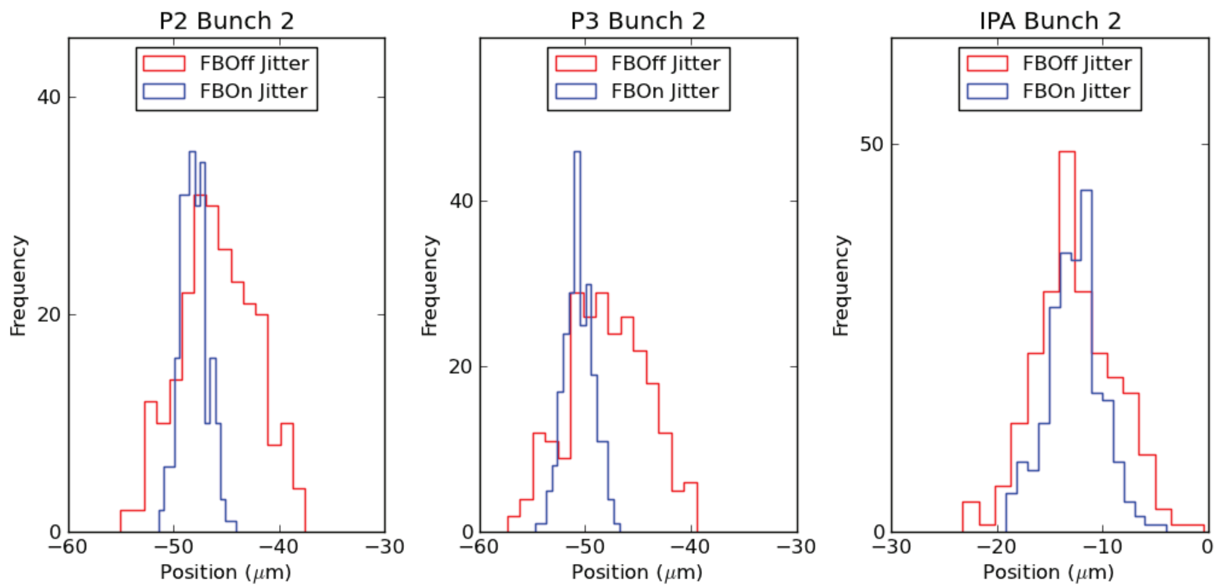

Figure 4: Distribution of vertical beam positions for the $2nd$ bunch for upstream feedback run.

the two upstream feedback BPMs and IPA. With the feedback off the second bunch RMS jitter was measured to be $3.6 \pm 0.2\mu$m in P2, $3.7 \pm 0.2\mu$m in P3 and $3.9 \pm 0.2\mu$m in IPA. With feedback on the second bunch RMS jitter was measured to be $1.3 \pm 0.1\mu$m in P2, $1.4 \pm 0.1\mu$m in P3 and $2.6 \pm 0.1\mu$m in IPA. The level of correction upstream is as expected given the bunch to bunch correlations of 94% measured with the same data. Although a correction is seen at IPA it is clear that the level of jitter reduction seen in the upstream system does not propagate downstream fully; work is currently ongoing to improve the propagation of the jitter reduction.

FEEDFORWARD RESULTS

During feedforward the beam position is measured by the upstream system and the kick required to stabilise the beam calculated and converted to analogue. This signal is then output and sent down the high-speed cable to a kicker amplifier located in the IP region. The signal from this amplifier is then sent to the IP kicker. Via this approach it is possible to stabilise the beam locally near the IP.

The accelerator was set up as previously to obtain the best possible bunch to bunch correlations. The beam waist was moved to be close to IPB using the QD0FF magnet.

The system was operated in interleaved mode with the feedforward correction applied on every other machine pulse. The performance of the system in this mode is shown in Fig. 5. With feedforward off the second bunch jitter was measured to be $4.5 \pm 0.2\mu$m, with the feedforward correction applied the second bunch jitter was measured to be $2.9 \pm 0.1\mu$m. The jitter in the upstream BPMs remained unaffected and IPA was not calibrated for this experiment. A clear feedforward correction was observed. Work is currently ongoing to try and improve the level of performance achieved via gain optimisation.

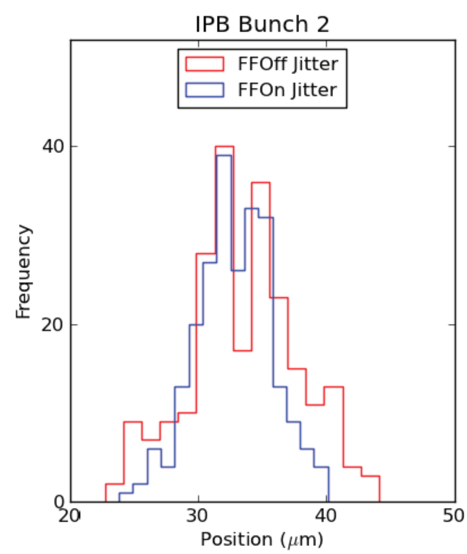

Figure 5: Distribution of vertical beam positions for the second bunch in IPB during a feedforward run.

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ISBN 978-3-95450-122-9