A SUB-MICRON RESOLUTION, WIDE-BAND, STRIPLINE BPM SYSTEM FOR DRIVING BUNCH-BY-BUNCH FEED-BACK AND FEED-FORWARD SYSTEMS AT ATF

G.B. Christian, D.R. Bett, N. Blaskovic Kraljevic, P.N. Burrows, M.R. Davis, Y. Kim, C. Perry
John Adams Institute for Accelerator Science, University of Oxford, UK

Abstract

A low-latency, sub-micron resolution stripline beam position monitoring (BPM) system has been developed and tested with beam at the KEK Accelerator Test Facility (ATF2), where it has been used as part of a beam stabilisation system. The fast analogue front-end signal processor is based on a single-stage RF down-mixer and a position resolution below 400 nm has been demonstrated for beam intensities of 1 nC, with single-pass beam. The BPM position data are digitised by fast ADCs on an FPGA-based digital feedback controller, which is used to drive either a pair of kickers local to the BPMs and nominally orthogonal in phase, in closed-loop feedback mode, or a downstream kicker in the ATF2 final focus region, in feedforward mode. The beam jitter is measured downstream of the final focus system with high resolution, low-Q, cavity BPMs, and the relative performance of both systems in stabilising the beam is compared.

INTRODUCTION

The designs for the International Linear Collider (ILC) [1] and the Compact Linear Collider (CLIC) [2] require beams stable at the nanometre level at the interaction point (IP). In support of this, the goal of the ATF2 collaboration based at KEK, Japan is to achieve position stability at the notional IP of approximately 2 nm. To this end, the Feedback On Nanosecond Timescales (FONT) project [3] operates a position and angle feedback system in the extraction line of the Accelerator Test Facility (ATF) [4]. In order to achieve the required level of position stability at the IP, the FONT feedback system needs to stabilise the beam to 1 micron at the entrance to the final focus system; this requires a BPM processing scheme capable of delivering position signals accurate to the sub-micron level on a timescale of the order of 10 ns. The FONT beam position monitoring system makes use of 3 12 cm stripline BPMs, which are located in the diagnostics section of the ATF extraction line (FONTP1, FONTP2, FONTP3)(Fig. 1). The BPMs are connected to specially developed analogue processing electronics [5] in order to deliver appropriate position signals to an FPGA-based digital hardware module [6] that digitizes the signals and returns the sampled data to a computer where they are logged.

BPM PROCESSOR DESIGN

A schematic of the processor module is shown in Figure 2. The operation is as follows: the top (V_A) and bottom (V_B) stripline BPM signals are subtracted using a 180-degree hybrid to form a difference (Δ) signal and are added using a resistive coupler to form a sum signal. The resulting signals are then band-pass filtered and down-mixed with a 714 MHz local oscillator (LO) signal phase-locked to the beam before being low-pass filtered and amplified using 16dB low-noise amplifiers. The hybrid, filters and mixer were selected to have latencies of the order of a few nanoseconds in order to yield a total processor latency of 10 ns [7]. The phasing of the LO with respect to the beam signal is maintained using an adjustable phase shifter on the LO input to the processor. In the sum channel, a 90-degree hybrid is used to downmix the raw sum signal with two orthogonal phases of the LO, producing an in-phase sum signal (Σ) and quadrature-phase sum signal (Σ_Q). The phase of the difference channel is accurately matched to that of the in-phase sum signal via a custom loopback cable in the sum channel. Hence the optimal phasing of both the Δ and Σ signals is achieved by minimising the Σ_Q signal.

The three output signals (Δ, Σ, Σ_Q) are digitized using analogue-to-digital converters (ADCs) on the FONT5 digital board, capable of converting at up to 400 MHz with 14-bit resolution. Low-noise amplifiers, with a gain of 16 dB, built into the processor modules are used to boost the input levels to just above the digitiser noise floor, and hence maximise the dynamic range of the measurement system. The ADCs, and sampling logic of the FPGA, are clocked in a system-synchronous mode at 357 MHz, this being a convenient frequency derived from the machine RF. The ADC clock may be delayed in increments of 70 ps to allow sampling at the exact time the bunch arrives. There are nine ADCs in total and so a single board is able to fully record the data from three BPMs.

SYSTEM PERFORMANCE

Two stripline BPMs (FONTP2 and FONTP3) have been used to drive bunch-to-bunch correction systems in the extraction and final focus line at ATF2 (Fig. 1), in two different modes of operation. In *upstream feedback* mode they drive a pair of kickers local to the BPMs and nominally orthogonal in betatron phase, to form a two-phase closed-loop feedback system to stabilise the position and angle of the beam at the entrance to the final focus. In *feedforward* mode the correction signal is sent down a fast cable to a kicker in the IP region, IPK. For these demonstrations, a beam consisting of two bunches separated by 274.4 ns was used. The correction of the beam in the IP region was witnesses with two C-band cavity BPMs. The results of a demonstration of local IP kickers utilising these BPMs is presented in [7].

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPME009

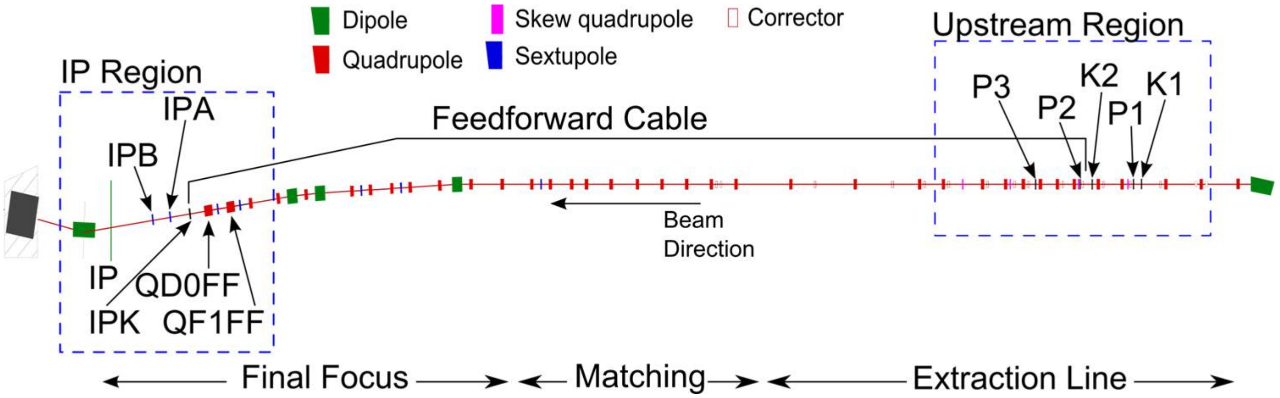

Figure 1: layout of the ATF extraction and final focus beamline with the FONT regions marked.

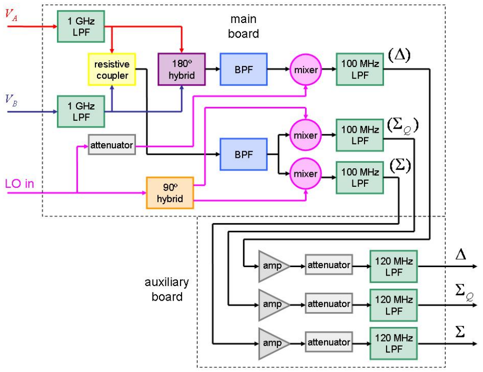

Figure 2: FONT analogue signal processor design.

Upstream Feedback

Results with stripline BPMs driving the upstream feedback system have been presented previously [8], where the results have been at the feedback control BPMs themselves. Figure 3 shows the result of the feedback operation both at the two control BPMs, FONTP2 and FONTP3, and also at the at a downstream location ~25 metres from the feedback kickers, MFB1FF, at a horizontal image point of the IP, where the vertical beam jitter is large. For these results a stripline BPM at MFB1FF was instrumented with the high resolution processor, and the resolution was confirmed to be less than 300 nm (Fig. 4), using the three BPM method where measurements from two of the BPMs are used to predict the position in the third. The feedback results (Fig. 3) show that the best correction ratio achieved at FONTP2 and FONTP3, a factor of ~ 2.5, can be maintained out to a location approximately half way along the final focus.

Figure 5 shows the results of the upstream feedback as measured with the C-band cavity BPMs in the ATF2 IP region. For these data, the beam was focussed vertically very close to the location of IPBPM-B such that beam jitter was significantly larger than the noise limit, which was measured to be 100 nm [9]. For correction factors of ~ 2 achieved at the upstream stripline BPMs, it can be seen that with upstream feedback only a modest correction is observable at IPBPM-B, with the beam jitter being reduced from ~360 nm to ~300 nm. This could be indicative of an additional source of jitter between the upstream correction system and the IP region, and studies are on-going to understand this.

Feedforward

Results from the alternative correction scheme, IP feedforward, are shown in Fig. 6. In this configuration an linear combination of position information from FONTP2 and FONTP3 is sent along a fast cable to drive a stripline kicker positioned just upstream of the IP chamber. The weights of the BPM measurements are derived from a fit of the IP data to the upstream measurements, and the response at the IP to an angular kick at the kicker. In this way the feedforward should be able to remove any correlation between the upstream and IP data. Fig. 6 shows the measured vertical beam jitter, though a scan of the beam waist as measured at IPBPM-B, with both the feedforward system switched on and off. At the minimum of the jitter, corresponding to the beam waist coinciding with the location of the cavity, the feedforward system is unable to make any correction as the measurement of the beam jitter is already noise limited, however off-waist correction factors of up to ~2 were observed, for example from ~300 nm with the feedforward correction switched, down to ~150 nm.

REFERENCES

[1] T. Behnke et a;, The International Linear Collider Technical Design Report.

[2] `http://clic-study.web.cern.ch/CLIC-Study/`

[3] `http://www-pnp.physics.ox.ac.uk/~font/`

[4] B. Grishanov et al, ATF2 Proposal, vol.2.

[5] R. Apsimon, DPhil Thesis, University of Oxford (2011)

[6] B. Constance, DPhil Thesis, University of Oxford (2011)

[7] N. Blaskovic Kraljevic et al., IPAC2014, THOAA02, *these proceedings*

[8] P.N. Burrows et al., Proceedings IPAC13, WEPME053

[9] M.R. Davis et al., Proceedings IBIC2013, WEBL2

ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-TUPME009

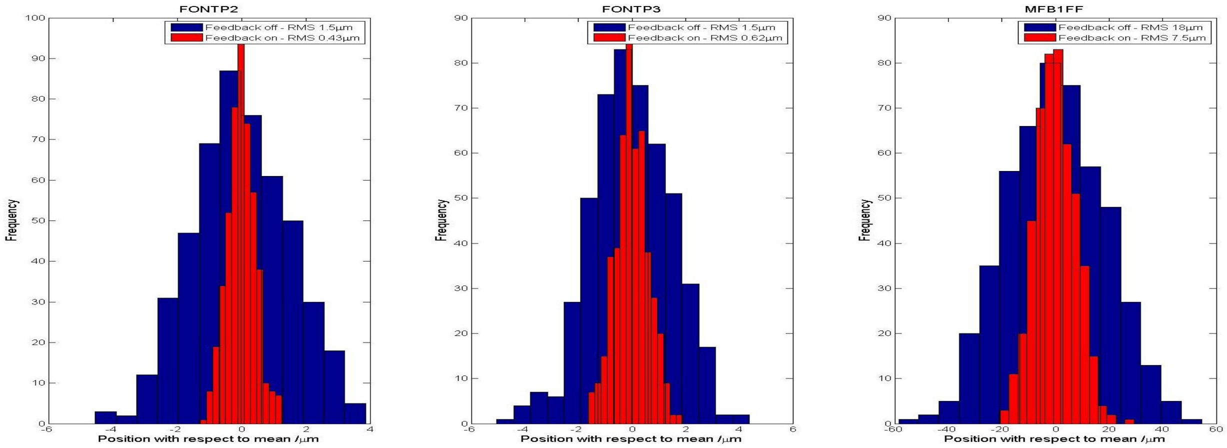

Figure 3: Histograms of position distribution with feedback off (blue) and feedback on (red) showing the effect of the upstream feedback system at FONTP2, FONTP3, and MFB1FF. RMS values for the jitter are given at each BPM.

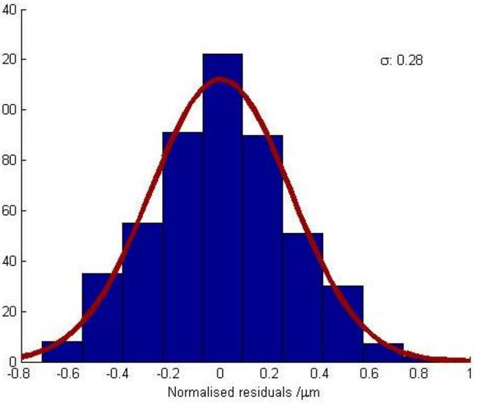

Figure 4: Histogram of normalised residuals for the system of three BPMs with FONTP2, FONTP3, and MFB1FF, obtained by predicting the position at one BPM given the measured positions in the other two, and the transfer matrices as derived from the model. A Gaussian fit to the data is plotted (red) and the width is given in microns.

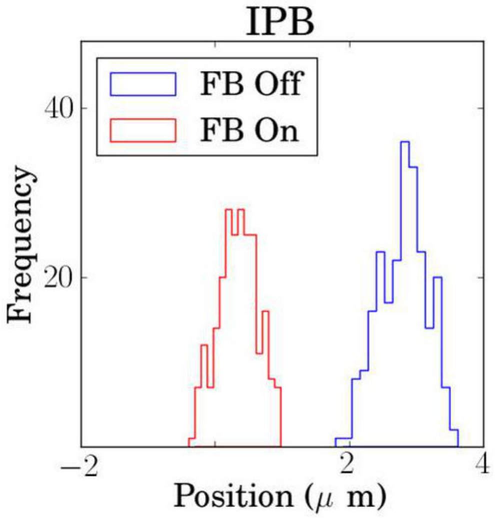

Figure 5: Distribution of vertical position for the second bunch at IPBPM-B, with (red) and without (blue) the application of upstream feedback.

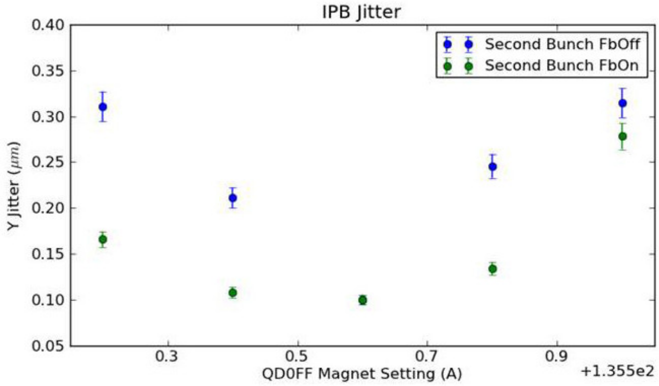

Figure 6: Vertical jitter at for the second bunch at IPBPM-B as a function of the QD0FF current, with feedforward correction on (green) and off (blue).