Grant Agreement No: 645479

E-JADE

Europe-Japan Accelerator Development Exchange Programme

Horizon 2020 / Marie Skłodowska-Curie Research and Innovation Staff Exchange (RISE)

DELIVERABLE REPORT

FEEDBACK-1

DELIVERABLE: 11

Document identifier:	E-Jade.Deliverable.WP2.Feedback-1.v1
Due date of deliverable:	End of Month 24 (December 2016)
Report release date:	03/02/2017
Work package:	WP2: Nanometre Scale Beam Handling at the ATF
Lead beneficiary:	UOXF
Document status:	Final / public

Delivery Slip

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Approved by	General Assembly		03/02/2017

Deliverable:

Report on operation of collision point feedback system.

Executive summary:

The FONT Group has developed several beam-position feedback systems as prototypes for an interaction-point beam-collision feedback system for ILC or CLIC. This report describes the beam-position feedback developed for the interaction point of the KEK ATF2. Results produced as part of the E-JADE programme are reported for beam stabilisation employing a cavity Beam Position Monitor (BPM) to provide a beam position signal input. The vertical beam position has been stabilised to c. 70 nm. This work is significant also in the context of Tasks 2.1 (Beam Size Minimisation) and 2.5 (Beam Instrumentation and control).

1. INTRODUCTION

An overview of the ATF2 extraction and final focus beamlines showing the positions of the FONT5 system components in the IP region is given in Fig. 1. The IP region contains three C-band cavity BPMs (IPA, IPB and IPC) operated on an (x,y) mover system [2], with IPB being used in the single-loop IP feedback system described below. The IP feedback correction is applied using a stripline kicker (IPK). The final focus magnets (QF1FF, QD0FF) can be used to steer the beam by introducing a position offset or to move the x and y beam waists longitudinally along the beamline. The offset of the QF7FF magnet can be used to change the pitch of the beam trajectory through the IP region.

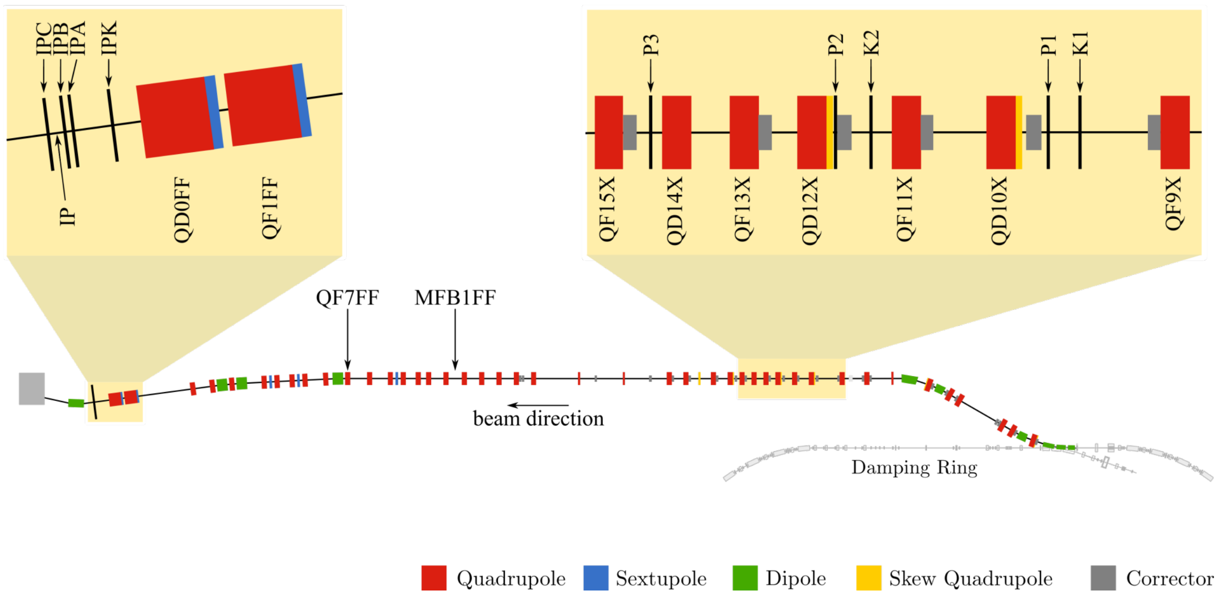

Fig. 1: Layout of the ATF2 extraction and final focus beamline with the FONT regions zoomed in.

A schematic of the IP feedback system is given in Fig. 2. Determining the position of the beam at IPB requires both the dipole mode signal of IPB and the monopole mode signal of a reference cavity (Ref). The cavities were designed such that the y-port frequency of both signals is 6.426 GHz [3]. The signals are down-mixed to baseband using a two-stage down-mixer [1], as follows. The first stage down-mixer (M1) takes the 6.426 GHz reference and IPB signals and mixes each with an external, common 5.712 GHz local oscillator (LO) to produce down-mixed signals at 714 MHz. The second stage down-mixer (M2) mixes the IPB 714 MHz signal using the reference 714 MHz as LO, giving two baseband signals: I (IPB and reference mixed in phase) and Q (IPB and reference mixed in quadrature). The I and Q signals are subsequently digitised in the FONT5 digital board (Fig. 3) and normalised by the beam bunch charge; the charge is deduced from the amplitude of the reference cavity signal. The charge-normalised I and Q signals are calibrated against known beam position offsets (by moving the BPM mover), allowing the IPB vertical beam position to be known in terms of a linear combination of charge-normalised I and Q.

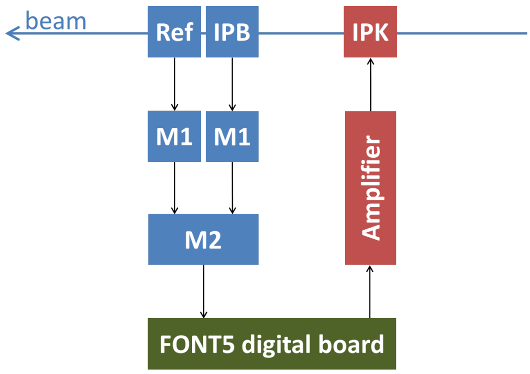

Fig. 2: Schematic of IP feedback system showing the cavity BPM (IPB), reference cavity (Ref), first and second down-mixer stages (M1 and M2), FONT5 digital board, amplifier and kicker (IPK).

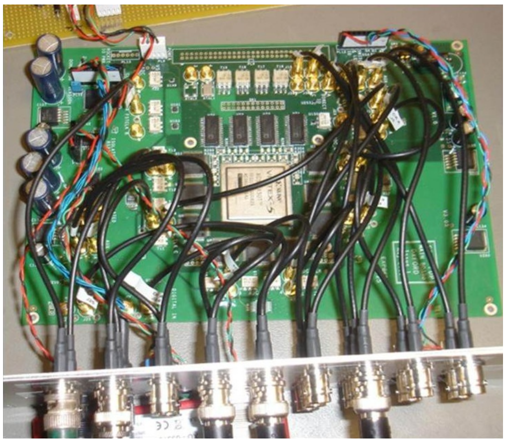

Fig. 3: FONT5 digital feedback board.

2. BEAM TEST RESULTS

We summarise here the results of beam tests of the FONT5 system. Further results are reported in [4]. A detailed schematic of the hardware configuration is given in Fig. 4.

The accelerator was set up to provide two bunches per pulse of beam extracted from the damping ring, with a bunch separation of 215.6 ns. This separation was found typically to provide a high degree of measured vertical spatial correlation between the two bunches. The feedback tests therefore involve measuring the vertical position of bunch one and correcting the vertical position of bunch two. The system was typically operated in an 'interleaved' mode, whereby the feedback correction was toggled on and off on alternate machine pulses; the feedback 'off' pulses thereby provide a continual 'pedestal' measure of the uncorrected beam position. For the purpose of recording data with BPM IPB the longitudinal location of the beam waist in the IP region was adjusted by varying the strengths of the two final focus magnets QF1FF and QD0FF. For the results reported here the beam waist was typically set near the position of IPB.

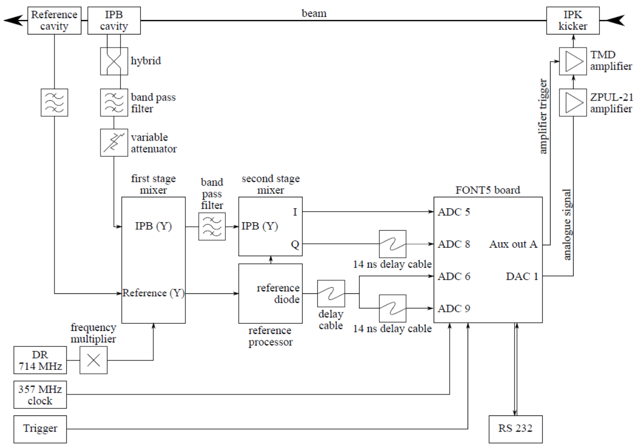

Fig. 4: Schematic of configuration of IP feedback system.

The IP feedback system latency was measured and found to be 212 ns [5]. The performance of the feedback system was measured using IPB; Fig. 5 shows the vertical position of both bunches with feedback off and on. The IP feedback reduced the vertical beam jitter from an r.m.s. deviation of 420 nm to 74 nm (Table 1). Fig. 6 shows the bunch 2 position versus bunch 1 position for this data set. The feedback removes the correlated component between the bunches, reducing the bunch-to-bunch position correlation from 98.2 % to approximately zero (Table 1).
The jitter that can be attained with feedback on (σ_{Y_2}) can be calculated from the feedback off values for the jitter of the two bunches (σ_{y_1}, σ_{y_2}) and their correlation ($\rho_{y_1 y_2}$):

$$\sigma_{Y_2}^2 = \sigma_{y_1}^2 + \sigma_{y_2}^2 - 2\sigma_{y_1}\sigma_{y_2}\rho_{y_1 y_2} \geq 2\sigma_r^2$$

where σ_r is the BPM resolution [10]. The above equation yields $\sigma_{Y_2} = 79.4$ nm, suggesting $\sigma_r \sim 50$ nm.

Table 1: Position jitter of bunch 1 (σ_{y_1}) and 2 (σ_{y_2}) and bunch-to-bunch position correlation ($\rho_{y_1 y_2}$) with and without application of the IP feedback correction

Feedback	σ_{y_1} (nm)	σ_{y_2} (nm)	$\rho_{y_1 y_2}$ (%)
Off	412 $\pm$ 29	420 $\pm$ 30	$+98.2^{+0.3}_{-0.4}$
On	389 $\pm$ 28	74 $\pm$ 5	-13 ± 10

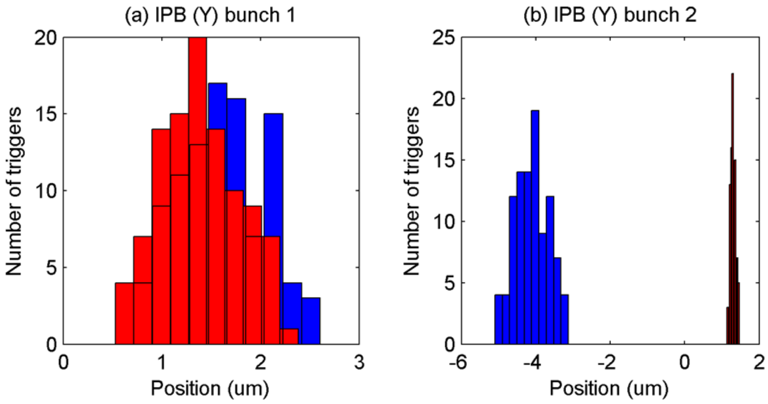

Fig. 5: Distribution of the vertical position of (a) bunch 1 and (b) bunch 2 in IPB with (red) and without (blue) application of the IP feedback correction.

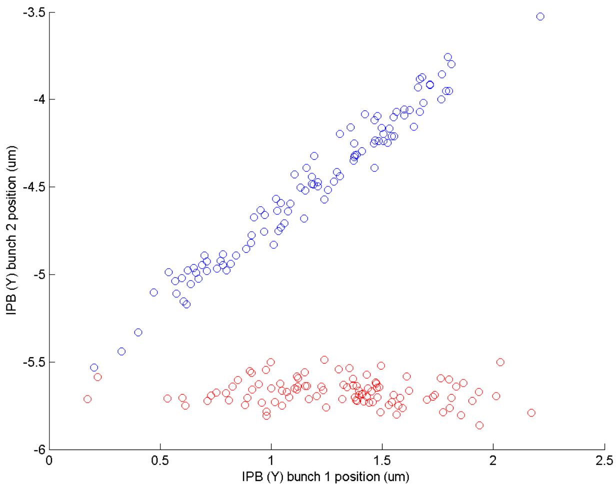

Fig. 6: Vertical position for bunch 2 versus bunch 1 in IPB with (red) and without (blue) application of the IP feedback correction.

3. FUTURE PROSPECTS

Future plans consist in using two IP BPMs in order to stabilise the beam at a location between them. Preliminary measurements have been taken simultaneously at BPMs IPB and IPC, located equidistantly either side of the IP. Given the absence of magnetic fields in the IP region, the beam trajectories can be calculated by linearly interpolating the positions measured at the two BPMs.

In addition to the benefit of stabilising the beam at a location other than the BPM itself, the use of two BPMs to perform the measurement has the potential of improving the position resolution available to the feedback system. In the configuration where IPB and IPC are used to stabilise the beam at the IP, the vertical position at the IP would be taken as the average of the vertical positions measured at IPB and IPC. Thus, the error on this mean position would be $\sigma_r/\sqrt{2}$ where σ_r is the resolution of either BPM. The challenge in this mode of operation results from the requirement of a large BPM dynamic range of over 10 μm whilst preserving the BPM resolution.

4. REFERENCES

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