ISBN: 978-3-95450-168-7 doi:10.18429/JACoW-IPAC2015-MOPHA003

STATUS OF ATF2 IP-BPM PROJECT

O.R. Blanco, CERN, Geneva, Switzerland and LAL, U-PSUD, CNRS/IN2P3, Orsay, France
P. Bambade, F. Bogard, P. Cornebise, S. Wallon
LAL, U-PSUD, CNRS/IN2P3, Orsay, France
N. Blaskovic Kraljevic, D.R. Bett, T. Bromwich, P.N. Burrows, G.B. Christian, C. Perry
John Adams Institute for Accelerator Science at University of Oxford, UK
S. Araki, KEK, Tsukuba, Japan
Y. Honda, K. Kubo, S. Kuroda, T. Naito, T. Okugi, T. Tauchi, N. Terunuma
KEK, Tsukuba, Japan and School of High Energy Accelerator Science, SOKENDAI, Ibaraki, Japan
E.-S. Kim, S. Jang, Kyungpook National University, S. Korea

Abstract

The efforts during the second half of 2014 towards nanometric beam position measurement and stabilization at the Interaction Point (IP) section of the Accelerator Test Facility (ATF) at KEK are presented. Recent improvements to the beam position monitor (BPM) data analysis and processing electronics, as well as the installation of a new set of C-Band BPMs, are reviewed.

INTRODUCTION

The main objective of the Accelerator Test Facility (ATF) at the High Energy Accelerator Research Organization (KEK) in Tsukuba, Japan, is to serve as an R&D platform for the technology required for linear accelerators, in particular the International Linear Collider (ILC). The ATF has already achieved a record minimum vertical beam emittance [1, 2], and so attention moves to the next step: reduction in the vertical beam size at the IP. Beam size reduction using local chromaticity correction is explored at the ATF in an extension of the original beam line known as ATF2 [3, 4]. The ATF2 lattice is the final focus system (FFS) of the ILC scaled down to 100 m and exists to demonstrate two goals: (**goal 1**) a vertical beamsize at the IP of 37 nm (**goal 2**) stabilization of the beam position at the IP to the level of a few nanometres.

In 2014 a vertical beam size of about 55 nm was measured at ATF2 [5]. Subsequently, a smaller beam size, of down to 44 nm, has been achieved [6] through systematic tuning. This demonstrates the local chromaticity correction method, though only at charges below 0.1×10^{10} particles per bunch.

The identified issue of intensity dependence is currently being explored by the ATF2 collaboration. However, even at low intensities the beam size remains above the designed 37 nm. Possible causes are: (1) increase of the incoming beam emittance throughout the ATF2 line, (2) systematic errors and resolution limitations on the beam size monitor (IPBSM), (3) beam drift beyond the tolerable margin and (4) undetected optics mismatch.

The last two issues can be addressed by measuring the beam trajectory in the IP region after the final doublet. In addition, looking forward to **goal 2**, high resolution beam position measurement is a requirement for beam stabilization.

BPM SYSTEM DESCRIPTION

A set of three cavities, two upstream and one downstream of the nominal IP, are used to measure the beam trajectory in the IP region and thus provide enough information to reconstruct the bunch position and angle at the IP.

The three cavities (IPA, IPB and IPC) are rectangular and resonate in the TM_{210} mode at 5.7 GHz in the horizontal plane and TM_{120} at 6.4 GHz in the vertical plane. They have a design decay time of 20 ns and sensitivities to bunch position of 2.2 μV/nm/nC (horizontal) and 3.7 μV/nm/nC (vertical). Two additional cylindrical cavities, one per resonant frequency, are placed downstream of the IP to measure the bunch charge and to downmix the C-Band frequency signals; these are the reference cavities.

Each position measurement cavity has two output ports in antiphase per plane connected to independent processing electronics to downmix the signals, separate them into two orthogonal components called I and Q, and set the gain according to beam charge conditions. A set of remotely-controllable attenuators, variable between 0-70 dB in steps of 10 dB, is used to increase the linear range of electronics at the expense of resolution.

The acquisition system samples the two downmixed orthogonal waveforms per cavity per plane over the decay time. This amounts to 14 simultaneous channels: I and Q waveforms for both x and y for each of the three position measurement cavities plus the charge signal from each reference cavity.

A local beam-based feedback system has been installed at the IP in order to stabilise the beam position. This system comprises a stripline kicker just upstream of the IP chamber, a fast kicker amplifier and a digital feedback controller. The feedback can be driven by any of the three IPBPM raw output signals or a linear combination of the signals from any two BPMs. The system is designed for operation on a bunch train of two or more bunches, separated by greater than 150–200 ns, where the measurement of the first bunch provides the input to the feedback system and the correction is applied to subsequent bunches.

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IMPROVEMENTS DURING 2014

The initial BPM installation [7] had alignment issues attributed to loose tolerances between the inner cavity surface and the external reference points [8]. During 2014, new cavities were fabricated and installed in the ATF2 line. This set of BPMs has been in use since November 2014.

A dedicated acquisition system built around an SIS digitizer has recently been introduced. The resolution is 14-bits, the dynamic range is either 2 or 5 V, and the sampling frequency is configurable with 238 MHz being the typical value. This is an important step towards integration of the IP position measurements into the existing ATF control system.

SYSTEM TESTS

The system has been tested during the Nov-Dec 2014 period of ATF operation with three sets of optics: (1) parallel beam (large beam size at waist and hence approximately constant beam size through the IP region) (2) nominal and (3) low beta.

While the beam is running the cavity position is systematically changed and the I and Q waveforms are acquired and analysed offline to obtain the calibration factors. The beam jitter is determined from measurement of the bunch position over several hundred pulses with a static BPM mover setting.

The I and Q waveforms are analysed by choosing a single sample on the signal. Averaging or integrating the samples may do little to improve the analysis due to the presence of (714 ± 10) MHz band pass filters in the processing electronics as part of an investigation into the reduction of large unwanted static waveform components.

For recent tests, a two bunch beam was used with a bunch spacing of 215.6 ns and the signals from IPBy were input to the feedback system. The longitudinal position of the beam focus was moved closer to the location of IPB by changing the strength of the final focus quadrupoles. This reduces the beam jitter at IPB allowing operation without additional attenuation and hence maximal sensitivity.

The following are some of the most relevant results:

Reference Cavity Response

The response of the 6.4 GHz reference cavity Ref_y was scanned w.r.t. a current transformer (CT) in the ATF2 line for charges between 0.1 to 1 × 10^{10} particles per bunch. Equation (1) is the fit result with accuracy of 2.3%.

$$\text{Predicted } CT = -1.63516 \ln\left(\frac{Ref_y + 120420}{122937}\right) \quad (1)$$

Position Cavity Calibration

The system response with attenuation can be seen in Fig. 1 where the variation of calibration is within ±5% for a charge between (0.4 ∼ 0.5) × 10^{10} particles, except for IPBy at 0 dB. This is due to saturation of the electronics for that BPM.

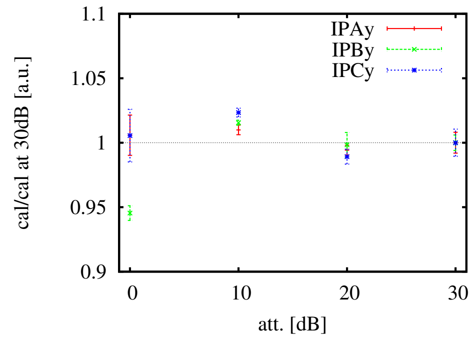

Figure 1: Vertical calibrations scaled down and normalized to the measurement at 30 dB attenuation.

Resolution

Resolution is quoted in nm by using the calibration results. It is limited by the cavity sensitivity, the electronics noise floor and the acquisition system resolution. The expected position resolution is 37 nm at 0.46×10^{10} particles per bunch if only the vertical plane is used, based on the published result [9].

Noise floor The BPMs, processing electronics and connections along the BPM signal path generate noise limiting the minimum detectable waveform. This minimum is estimated from a measurement of the jitter as a function of the attenuation value. At large attenuations the noise floor is bigger than the BPM signal, while at low attenuations the opposite is true. There is an inflection point where the two are comparable. The cavity calibrations are used to convert the noise floor to nm.

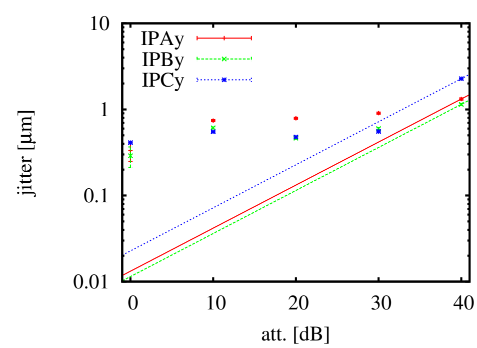

Figure 2: Jitter measurement for the 3 BPMs. The dotted lines are extrapolation of noise at 40 dB.

The readings from the 3 BPMs are shown in Fig. 2. Jitter for the three BPMs is on the order of ∼ 300 – 400 nm. At 40 dB the noise dominates the signal and by extrapolation the resolution limits are 13 nm for IPAy, 11 nm for IPBy, and 23 nm for IPCy at 0 dB. The study was repeated whilst minimising the beam jitter at IPB and the extrapolated performance at 0 dB agrees with that presented in Fig. 2. The minimum beam jitter measured at any of the three BPMs is ∼ 50 nm. IPC has a significantly worse resolution limit than IPA and IPB. Two possibilities arise: the electronics noise is larger for IPC or the sensitivity is lower.

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Table 1: IPBPMs Status

PARAMETER	REQUIREMENT	STATUS	Comments
Resolution	~nm@1×10^{10}	<50nm@$0.4 \sim 0.5 \times 10^{10}$	Calibration factors within 5% linearity BPM/Electronics noise : 10 nm per cavity IPC sensitivity and/or gain : +20 nm X to Y coupling is still unexplored
Dynamic Range	~10μm + extra	9 ~ 11 μm@10 dB att.	Cavity response is linear within 5% Electronics starts to saturate at 0.4×10^{10} IPBy Q' signal saturates at 0 dB
Compatibility	IPBSM, EPICS	In progress	Calibration software: Initial version released and in use. Requires comparison with offline results. Jitter analysis software: Initial version released and in use. Requires comparison with offline analysis. IP-BSM, requires study of resolution at low charge, $0.1 \sim 0.5 \times 10^{10}$. Requires synchronization with ATF EPICS.
Feedback	Operative	Tested	Jitter reduction to 67 nm. Limited by BPM resolution.

Trajectory Reconstruction Two BPMs are used to measure the bunch position and to predict the measurement of the third BPM. The residuals from subtraction of BPM prediction and measurement will depend on the resolution of each BPM.

As longitudinal distances are known within ±0.1 mm over 250 mm, i.e. to better than 1% precision, geometrical factors can be used to predict the beam trajectory [10] (assuming that all three BPMs have the same resolution). The advantage of this method is that it is independent of the beam optics as it does not fit parameters to the predictions.

The results from geometrical and fitting estimations agree within ±1 nm, and show 47-52 nm resolution with variations due to the waveform analysis method.

Feedback

Feedback has been tested by the FONT group [11]. Figure 3 shows the results of a data run with the feedback system employed in interleaved mode, i.e. with the feedback system enabled for alternate machine pulses. The incoming beam jitter of ~ 400 nm is reduced to 67 nm with the feedback operating. The observed performance limit of 67 nm is consistent with the measurement resolution, measured independently to be ~50 nm (see above), as the absolute limit to the correction attainable is a factor $\sqrt{2}$ times larger than the resolution.

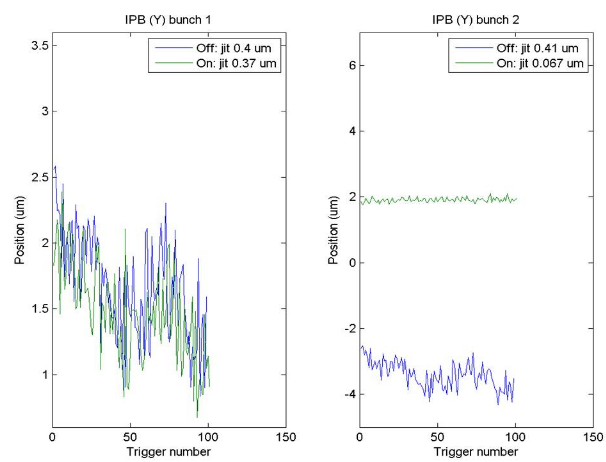

Figure 3: Effect on second bunch position (right) from first bunch position (left) feedback.

STATUS AND CONCLUSIONS

The current system status is found in Table 1.

Precise electronics gain measurements with reduction of losses is required to identify whether the electronics noise floor is larger than designed or the cavities sensitivity is lower. Note that only the vertical plane signals have been used for this analysis but the use of all BPM signals is foreseen for the first beam operations in 2015.

The compatibility with other subsystems, such as the EPICS data repository and the Shintake monitor for beam size measurement, is still ongoing. The first step is the measurement of resolution at low charges. There is progress in the development of software to integrate the IPBPM signals during normal operation; however, the data storage synchronization needs to be reviewed.

The FONT feedback system has been tested and results are consistent with the measured resolution.

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