CAVITY BEAM POSITION MONITOR IN MULTIPLE BUNCH OPERATION FOR THE ATF2 INTERACTION POINT REGION

Y. I. Kim*, D. R. Bett, N. Blaskovic Kraljevic, P. N. Burrows, G. B. Christian, M. R. Davis, C. Perry
John Adams Institute at the University of Oxford, Oxford, OX1 3RH, UK,
S. T. Boogert, A. Lyapin, John Adams Institute at Royal Holloway, Egham, Surrey, TW20 0EX UK,
Y. Honda, T. Tauchi, N. Terunuma, J. Urakawa, KEK, 1-1 Oho, Ibaraki 305-0801, Japan,
J. Frisch, D. McCormick, J. Nelson, G. R. White
SLAC National Laboratory, Menlo Park, CA 94025, USA

Abstract

Ultra-high position resolution cavity beam position monitors (BPMs) have been developed to measure the beam position and to be linked to control the beam position stability within a few nanometres in the vertical direction at the focus, Interaction Point (IP), of the Accelerator Test Facility 2 (ATF2). In addition, for feedback applications a lower-Q and hence faster decay time system is desirable. Specialised cavities which is called Interaction Point BPM (IPBPM) has been tested in the ATF2 extraction beam line. Using IPBPMs, a position resolution of less than 5 nm has been measured in single bunch operation. Multibunch operation is also planned at ATF2 for the beam stabilisation. The nominal operation bunch spacing for the International Linear Collider (ILC) is 308 ns so the multibunch operation bunch spacing is ILC like. The IPBPM should be able to measure beam position to nanometre precision in multibunch modes. Therefore the position resolution in multibunch operation was also measured at ATF2 extraction line. The analysis method of cavity signals, calibration and results of multibunch operation are discussed in this proceeding.

INTRODUCTION

The Accelerator Test Facility 2 (ATF2) at KEK, Japan, is a scaled test beam line for the international linear collider (ILC) [1] final focus system [2]. High resolution beam position monitors around the IP area (IPBPMs) have been developed in order to measure the electron beam position in that region with a resolution of a few nanometres in the vertical plane. Currently, the standard operation mode at ATF2 is single bunch, however, multiple bunch operation with a bunch spacing similar to the one foreseen for the ILC, around 300 ns, is also possible. This paper describes analysis of the signal, processing methods and results for multibunch mode.

Accelerator Test Facility 2

There are two goals of the ATF2: firstly, to demonstrate focusing to a vertical beam size of 37 nm; secondly, to achieve an orbit stability at the few nanometre level at the focal point in the vertical plane [3]. The ATF2 collaboration has recently made significant progress towards the first goal, with a measured vertical beam size of $<$ 100 nm [4] although only at relatively low bunch charges.

This paper is mainly related to the second goal which is the beam stabilisation in the vertical plane. The position resolution has been measured less than 5 nm for a 0.7 $\times 10^{10}$ e/bunch beam with a range of 5 μm [5]. The IPBPMs should be able to measure beam position with nanometre precision in multiple bunch mode for nanometre scale stabilisation. It is also essential to understand the signal processing of the cavity signals for the IP feedback [6].

Interaction Point Cavity Beam Position Monitor

The IPBPM system is described detail in [5, 7] so only the key parameters are shown in here. Figure 1 shows a photo of one of the IPBPMs which was installed at IP area of the ATF2 beam line.

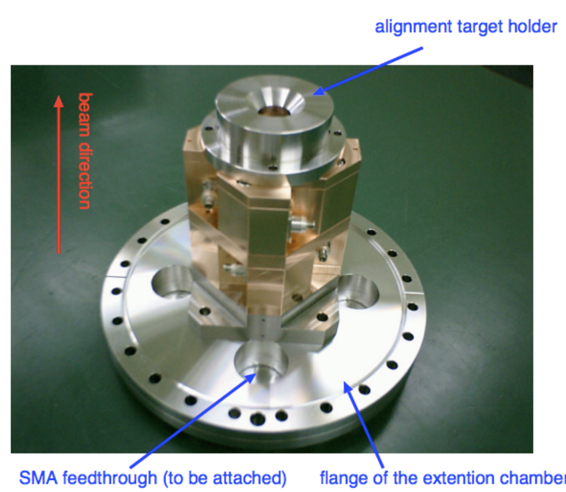

Figure 1: IPBPM assembly as installed at IP area of the ATF2 beam line [8].

Table 1 shows simulated parameters of the IPBPM, resonant frequency of the dipole modes f_0, the coupling strength β, the loaded quality factor Q_L, the internal quality factor Q_0,the external quality factor $Q_{\rm ext}$ and decay time τ.

* Youngim.Kim@physics.ox.ac.uk

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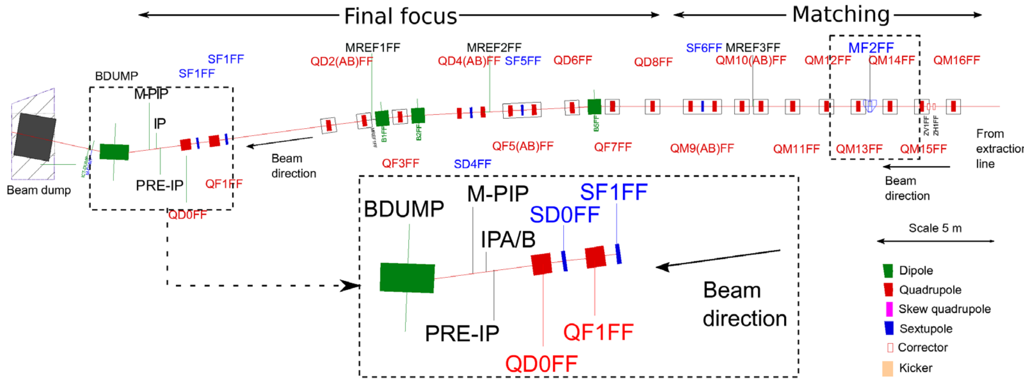

Figure 2: Layout of the ATF2 from the β matching section onwards to the IP and dump. A zoom of the IP region is shown.

Table 1: Simulated Parameters of IPBPM [7].

Parameter	x direction	y direction
f_0 [GHz]	5.7086	6.4336
β	1.578	3.154
Q_L	2070	1207
Q_0	5337	5015
Q_{ext}	3382	1590
R/Q at 1 mm (Ω)	0.549	1.598
τ [ns]	58	30

MEASUREMENT

We operated the ATF2 beam in multibunch mode during the 2012 - 2013 operation, using two bunch of 0.3×10^{10} particles per bunch separated by Δt_b =274 ns. It is long enough compared to the in thedecay time of the cavity, $\tau =$ 30 ns for $Q_L = 1200$ in the y direction.

Figure 2 shows the layout of the ATF2 from the β matching section onwards to the IP and dump. The IP region is zoomed. Four IPBPM cavities were installed at upstream of ATF2 beam line for the ultra-high resolution measurement [5], just upstream of QM16FF on Figure 2. Two cavities were installed inside of the IP chamber at ATF2 focus area [9]. Two additional C-band cavity BPMs [10] have been installed to measure the resolution of IPBPMs, one upstream and one downstream of the IP.

Signal Processing

There are two main methods used for cavity BPM signal processing; zero intermediate frequency (IF) and nonzero IF. The zero IF signal processing scheme is useful for real-time feedback applications, as additional signal processing is not required. The digital down-conversion (DDC) algorithm, which is used for C and S band ATF2 cavity BPM signal processing, is used to extract information for nonzero IF signals [10].

The signal processing of the multibunch operation data is the same as single bunch operation data. Figure 3 shows an example of the raw zero and nonzero IF frequency digitised waveforms in two bunch operation. The green trace is DDC amplitude. There is a strong peak at the beginning of second bunch signal of zero IF, possible transients. It is not clear to see on nonzero IF signals. We discuss about DDC in here because nonzero IF signal processing is more complicated than zero IF signal. The DDC algo-

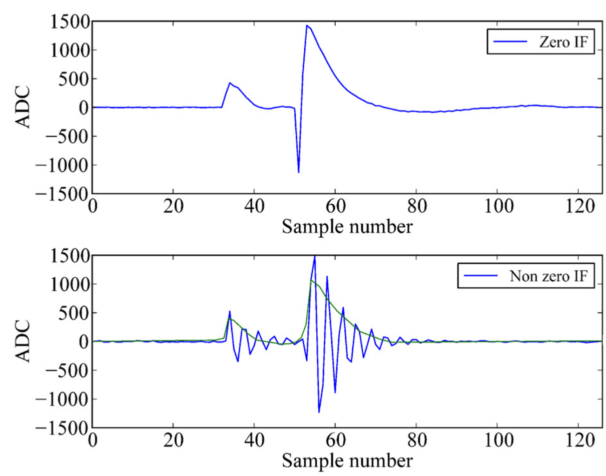

Figure 3: An example of the raw zero and nonzero IF frequency digitised waveforms from the IPBPM electronics in two bunch operation. Green trace is DDC amplitude.

rithm requires three parameters: the digital local oscillator (LO) frequency ω_{DDC}, digital filter bandwidth Δ_{DDC} and sampling time t_{DDC}. A Gaussian filter is applied to the down-converted signals. The IPBPM has a lower Q than regular C band cavity BPM at ATF2 so a wider filter width is chosen. The filter width for two bunch data analysis is set the same for the single bunch data analysis.

If the cavity decay time τ is much longer than the bunch spacing it is not easy to extract information of each bunch due to the signal overlapping which means pollution from previous bunch. The bunch spacing is longer than the cavity decay time τ = 30 ns in y direction so their signal overlapping is smaller than regular C-band cavity BPMs [11] at ATF2. Signal subtraction is not used in IP feedback so we do not use signal subtraction for this analysis.

Figure 4 shows an example of the DDC amplitude and

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phase of dipole and reference cavity signals. The reference cavity has a higher Q so the decay time is much longer than dipole cavity as shown in Figure 4. The DDC phase should be constant [10]. If there is gradient then the software oscillator for DDC is at the wrong frequency. As reference cavity has higher Q the signal overlapping is larger than IPBPM so sample point should be chosen carefully.

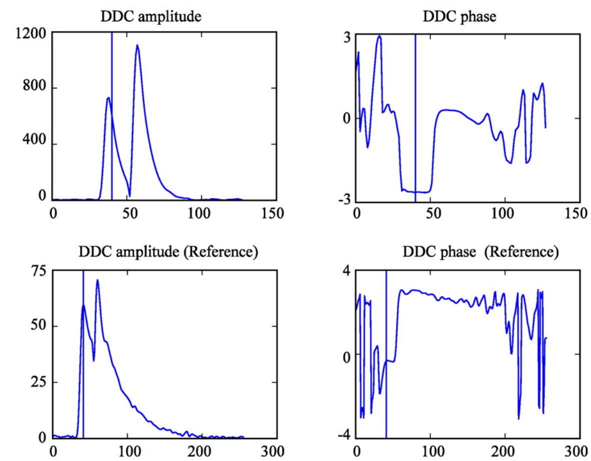

Figure 4: An example of the DDC amplitude and phase of dipole and reference cavity signals. Blue vertical bar is the location for the sampling.

Calibration

Calibration is needed to convert electronics output signals and waveforms information into the beam position [10]. Figure 5 and 6 show an example of vertical calibration for zero IF signal processing for the first and second bunches from cavities which were installed at the IP area. The top left plot shows I and Q as a function of pulse number, the top right plot shows I versus Q, the bottom left shows I' as a function of beam position, the bottom right is Q' as a function of beam position. There is phase advance with respect to each other [11]. From Figure 5 and 6 I versus Q plots we can see phase advance of 0.13 rad. which agrees well with the expected $2\pi\times$ 100 kHz $\times$ 274 ns = 0.17 rad.

The typical calibration range for cavity BPM system at ATF2 is $\pm$ 250 μm to $\pm$ 500 μm [10] depending on the beam jitter. The IPBPM system has narrow range, up to a few μm. The calibration range could be tens of micrometers with attenuation and few micrometers without attenuation. This is why we cannot see clear steps with different beam positions in Figure 5 and 6.

Resolution

The BPM resolution is defined as the root-mean-square (RMS) of the residual between the position measured in the BPM in question and the position predicted in this BPM by the other BPMs. The residual was calculated using the

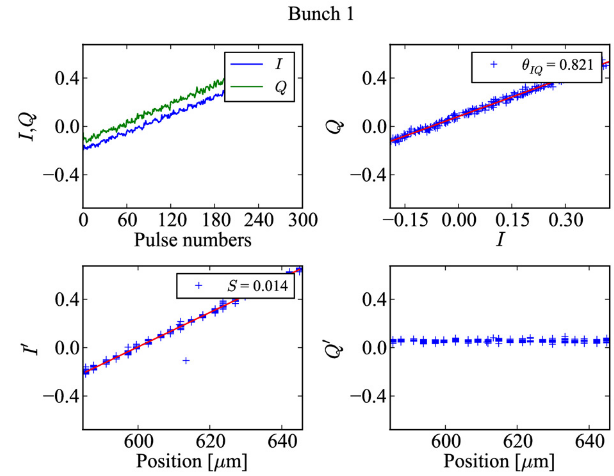

Figure 5: An example of vertical calibration for the first bunch with 10 dB attenuation.

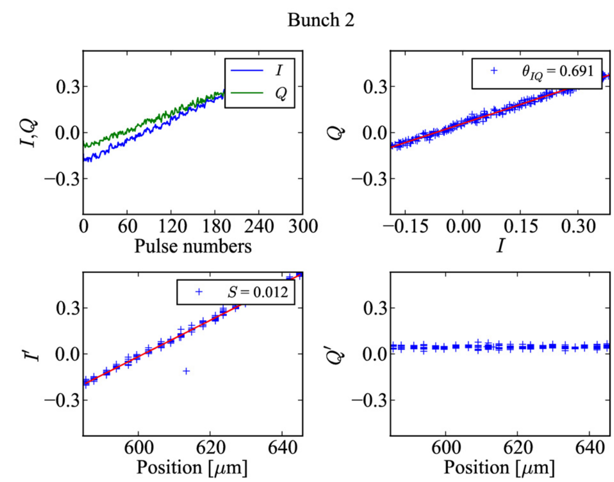

Figure 6: An example of vertical calibration for the second bunch with 10 dB attenuation.

singular value decomposition (SVD) method. For the upstream study, calibration was done with attenuation due to narrow dynamic range and large beam jitter. The calibration constants were therefore extrapolated from the calibration results with attenuations to unattenuated for the resolution data [5]. Dedicated 500 pulse data were taken twice directly after the calibration, once with the same attenuation as the calibration and repeated without attenuation. The resolution of the first bunch is 14 nm and the second one is 24 nm without attenuation and 432 nm and 718 nm for the first and second bunch, respectively with 30 dB attenuation. These results are well agreed with and without attenuation as expected.

Measurement of the BPM resolution in the IP area is complicated by the large angular divergence of the focusing beam. It is not easy to reconstruct the beam orbit using other BPMs in the IP area. The vertical focus of the ATF2 was shifted by varying the strength of QD0FF magnet cur-

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rent to put an upper limit on the resolution of the IPBPMs. The minimum measured jitter on IPBPMs at IP area is below 100 nm.

CONCLUSION AND DISCUSSION

Using cavity BPMs for IP feedback and beam stabilisation at the ATF2 is an important goal for the ATF2 project. IPBPMs were installed at upstream and IP area of the ATF2 for high resolution and IP feedback studies. As the decay time τ of the IPBPM is 30 ns and bunch spacing is 274 for two bunch signal overlapping is small. The signal subtraction is not applied for the analysis. The resolution of IPBPM at upstream is 14 nm and 24 nm for the first and second bunches, respectively. Determining the resolution of the IPBPMs at IP area is complicated due to the large angular divergence around the IP.

The signal subtraction can be applied to improve the precision for multibunch operation. The reference cavity has higher-Q so mixer is still on when the next bunch arrives. It is not easy to extract information from reference cavity. It could be good to have low-Q for reference cavity. The resolution measurement at IP area can be improved with careful steering beam which means not saturated BPM signals for better reconstruct beam orbit. The present IPBPM system has a narrow dynamic range so we sometimes need to use attenuation due to large beam jitter and bunch offset which has the effect of decreasing the BPM resolution. It would be good to think how to stabilise the beam at IP area in nanometre scale with IPBPMs with and without attenuation.

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REFERENCES

[1] T. Behnke, J. E. Brau, B. Foster, J. Fuster, M. Harrison, *et al.*, The International Linear Collider Technical Design Report - Volume 1: Executive Summary, (2013).

[2] P. Raimondi and A. Seryi, ”Novel Final Focus Design for Future Linear Colliders“, Phys. Rev. Lett. **86**, 7, (2001).

[3] B. I. Grishanov *et al.*, (ATF2 Collaboration), ATF2 Proposal, (2005).

[4] G. R. White it et al., ”Experimental validation of a novel compact focusing scheme for future energy frontier linear lepton colliders” (2013). To be published in Phys.Rev.Lett.

[5] Y. I. Kim, Doctoral thesis, Kyungpook National University, Daegu, Korea, (2012).

[6] P. N. Burrows *et al*, WEPME053, IPAC13, Shanghai, China.

[7] Y. Inoue *et al.*, PRSTAB **11**, 062801, (2008).

[8] Y. Inoue *et al.*, KEK report, (2008).

[9] Y. I. Kim *et al.*, IPAC-2013-MOPWA058,IPAC'13, (2013).

[10] Y. I Kim *et al*, “Cavity beam position monitor system for the Accelerator Test Facility 2,” PRST-AB, Vol **15**, No 5, 10.04.2012, p.042801.

[11] N. Joshi *et al.*, IPAC-2011-TUPC164, IPAC'11, (2011).

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