DIGITAL EBPMs AT DIAMOND: OPERATIONAL EXPERIENCE AND INTEGRATION INTO A FAST GLOBAL ORBIT FEEDBACK

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Abstract

We present our experience with the Libera Electron Beam Position Monitor (EBPM) during the first months of operation at Diamond. Measurement noise and beam current dependence with beam are compared to earlier lab measurements. Where discrepancies between the performance in the lab and in the application are observed, the causes have been investigated. Furthermore, results of the integration of the EBPMs into a Fast Orbit Feedback (FOFB) system are presented, including measurements of orbit motion spectra with and without FOFB.

INTRODUCTION

Diamond is using 168 Libera EBPMs in its storage ring. These have served most valuable information from first turns during commissioning of the storage ring, to beam based alignment of the BPM readings to quadrupole centres and slow orbit feedback implemented through the EPICS interface and a MatLab based correction routine. The next stage of their integration into Diamonds operation is the FOFB, which has been implemented during the first months of Diamond's operations and has recently been successfully operated for the first time. Prior to and during these tests we discovered some unexpected deviations of key performances when measured on the installed units as compared to lab measurements. It has turned out that many of these deviations from lab measurements were related to the fact that the installed BPM cables running from the button pickups to the EBPM electronics do no provide the four signals with equal phase to the inputs of the electronics.

All data in the following paragraphs refers to Diamond's current operating conditions of 125 mA, 66% fill and all BPM data presented is calculated with scaling factor of 10 mm.

BEAM CURRENT DEPENDENCE

Beam current dependence (BCD) of the position reading was found to be considerably more than the 1 μm specified and achieved in the lab for the 300-60 mA range. To study this with stored beam, we filled to 125 mA, started recording positions, and then artificially decreased the lifetime to have a decay to 60 mA within a few minutes. This test was done without orbit feedback, but prior stability tests have proven that no position in the orbit would grow to more than a few μm within such a period of time without correction. The deviation of EBPM readings from the value at 125 mA (see figure 1) is thus seen as

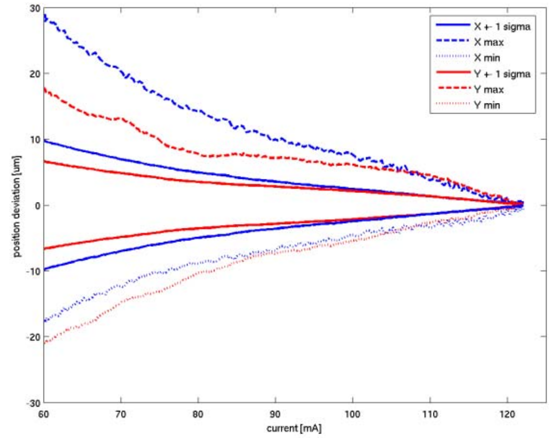

Figure 1: Measured beam current dependence of 48 BPMs in the storage ring

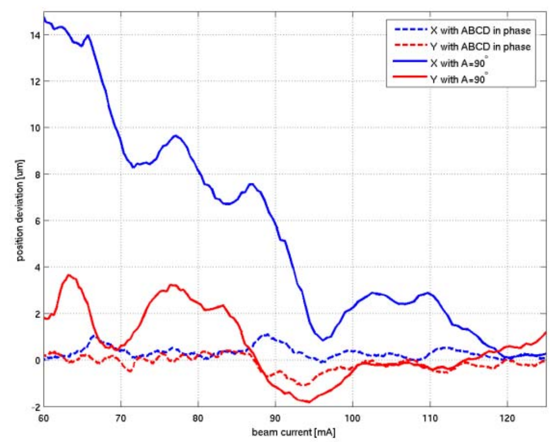

Figure 2: Measured beam current dependence of one BPM in the lab

evidence for the beam current dependence of the position reading. In further lab tests with simulated beam signals, we introduced a phase shift (extra length of cable) for one of the inputs of the EBPM electronics. It was found that for a phase shift of 90° between this one and the other inputs, the influence on performance was largest (see figure 2). We thus conclude, that problems with the installation and termination of BPM cables on site (many cables and connectors had to be replaced) have led to an uncertain phase match on the inputs of the EBPMs and has thus deteriorated the BCD performance. Lowering the BPM internal attenuations seems to improve the situation to some degree (bringing down the deviations from 14 to

symbol	frequency [Hz]	multiples of f_R
f_{RF}	499,654,097	936
f_S	117,440,065	$220{\cdot}(1-\epsilon)$
f_R	533,818	1
f_{FA}	10,072	$\frac{1}{53}\cdot(1-\epsilon)$
f_{Swi}	13,345	$\frac{1}{40}\cdot(1-\epsilon)$
f_{Swe}	13,345	$\frac{1}{40}$
f_{Sre}	1,668	$\frac{1}{320}$

Table 1: Clock frequencies and decimation ratios of the Diamond Libera EBPM.

4 μm on the one tested unit in the lab), but the only solution currently known to entirely restore the performance would be to precision cut the BPM cables to equal lengths within 4 cm (phase match of 30°) for each set of four.

FAST ACQUISITION DATA

The lab tests also revealed that the fast acquisition (FA) data, which is to be used in the FOFB, showed some strong interference lines appearing in the particularly interesting frequency range up to 100Hz. To understand the origin of these lines, the possible interactions between the different decimations and clocks inside Libera need to be revisited.

Table 1 shows the relevant frequencies in relation to the storage ring revolution frequency f_R. All internal frequencies are derived from the sampling clock f_S which is locked to a multiple of f_R and can be tuned at a small fractional offset $|\epsilon| < 50$ ppm. This tuning is required to avoid harmonics of the input signal (or its revolution frequency sidebands in case of a non-uniform fill) folding back (through the undersampling) to the same intermediate frequency f_{IF} as the signal itself [1]:

$$f_{IF} = |f_{RF} - 4f_S| = (56 - 880\epsilon)f_R \qquad (1)$$

$$f_{54} = |54f_{RF} - 230f_S| = (56 + 50600\epsilon)f_R \qquad (2)$$

$$f_{56} = |56f_{RF} - 238f_S| = (56 - 52360\epsilon)f_R \qquad (3)$$

$$f_{3+4} = |3f_{RF} + 4f_R - 13f_S| = (56 + 2860\epsilon)f_R \qquad (4)$$

This calculations show that with $\epsilon = 0$ (no offset) both the 54^{th} and 56^{th} harmonic of the input signal as well as the 4^{th} revolution frequency sideband of the 3^{rd} harmonic fold back to the same intermediate frequency and will cause low frequency noise in the calculated position. This problem can be easily addressed by offset tuning (we typically use $\epsilon = 34$ ppm), which will shift all these frequencies far enough away.

However, this has led to a new problem when automatic switching of the Libera's input multiplexer at f_{Swi} (which is the internal switching frequency derived from the sample clock) is used together with a non uniform fill of the storage ring. As a result of the offset, the switching is no longer

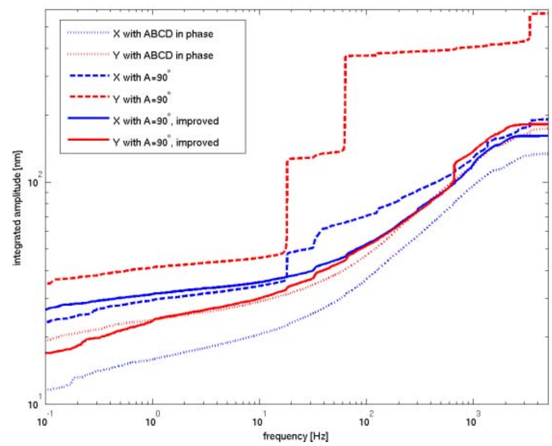

Figure 3: Integrated noise spectra from FA data recorded for 100s measured in the lab

synchronous to the fill pattern, it now slowly "walks" through the fill:

$$f_{b1} = 40f_{Swi} - f_R = \epsilon f_R \qquad (5)$$

With our typical ϵ this results in beating at f_{b1}=18.2 Hz. Clearly, ϵ cannot be increased enough to move this frequency away from the interesting range. However, locking the switching directly to the externally supplied machine revolution frequency (which was achieved by a change to the FPGA code by Instrumentation Technologies) removed this problem. The switching then happens at f_{Swe} in synchronicity to the machine revolution.

However, when a phase shift between the input signals was introduced, a new interference started to appear (see figure 3). This could be identified as the 6^{th} harmonic of the switch revolution frequency f_{Sre} folding back as a result of the decimation to the FA sampling frequency f_{FA}:

$$f_{b2} = f_{FA} - 6f_{Sre} = \left(\frac{1+\epsilon}{53} - \frac{6}{320}\right)f_R \approx \frac{1}{8480}f_R \qquad (6)$$

To suppress $f_{b2} \approx 63$ Hz, the FIR decimation filter and IIR notch filters in the FA chain have been optimised. This is easily done by changing the filter coefficients which are dynamically loaded into the FPGA during runtime. The new FIR filter has been designed to provide sharp notches at precise multiples of $3f_{Sre}$ (see figure 4) and thus almost completely restores the original performance even in the presence of a phase offset on the input (see figure 3).

INTEGRATION INTO FOFB

Using the Multi Gigabit Transceivers (MGBT) on the front of Libera, we have created a fast communication network between all storage ring EBPMs and an additional 26 (one for each cell plus two observers) computation nodes (MVME5550 PowerPC processor boards equipped with PMC modules with MGBT). Position and control data

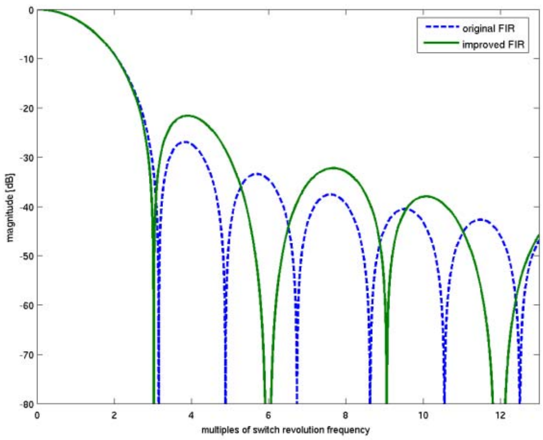

Figure 4: Comparison of original FIR filter and improved FIR with optimised notches

are distributed between all 194 nodes of this network using an in house developed Communication Controller [2].

Position data is exchanged at f_{FA} and all EBPMs are synchronised to output each set of new data at the same time within one machine revolution (1.8μs). The PMC modules issue an interrupt to the CPU 50 μs after the first data packet has been received. By this time, all data packets should have arrived; any missing positions will be marked as invalid. The CPU then converts the position data from fixed point to floating point notation, enabling the use of fast Altivec operations in the matrix multiplication with the inverse response matrix. Each CPU has to multiply with 7 lines of the matrix for each plane to produce correction values for the 7 corrector magnets in each plane per cell. The corrector coils are built into the sextupole magnets and work through a 2 mm stainless steel chamber. The 3 dB bandwidth of the magnet/chamber combination is estimated to be $>$500 Hz, however, the corrector power supplies are currently running with an internal 100 Hz low pass. This low pass currently limits the performance achievable by the feedback loop, whereas the delays in the loop (see table 2) should allow correction to $>$200 Hz.

The FOFB is currently in the commissioning stage and has successfully been running at full rate and with all EBPMs and correctors. The PID loop is currently using only the P and I terms and will require further optimisation. With these preliminary settings, very reasonable suppression could be achieved, in particular for the beam movements around 16 Hz and 25 Hz which have been found to be caused by ground motion (see figure 5). The overall integrated noise in the FA bandwidth (2 kHz) has been reduced in both planes from H/V 4μm/1μm to 1.5μm/0.9μm. More importantly, for frequencies up to 100Hz, the integrated noise has been reduced from 4μm/0.9μm to 1μm/0.4μm.

Already in its present configuration the FOFB is far superior to the slow orbit feedback (SOFB) which operates with one correction per second. While movements of ID

reason	delay [μs]
group delay of FIR	148
group delay of 2 IIR (0-500 Hz)	60-71
transport to PMCs	35.5-38.5
time reserved for data to arrive	50
DMA to CPU memory	49
conversion fixed to float	5
matrix multiplication $2 \cdot 7 \cdot 168$	4
PID controller	1
write to power supply controller	3
maximum total	331

Table 2: Delays in the fast feedback loop. Group delays are calculated, all other values are measured.

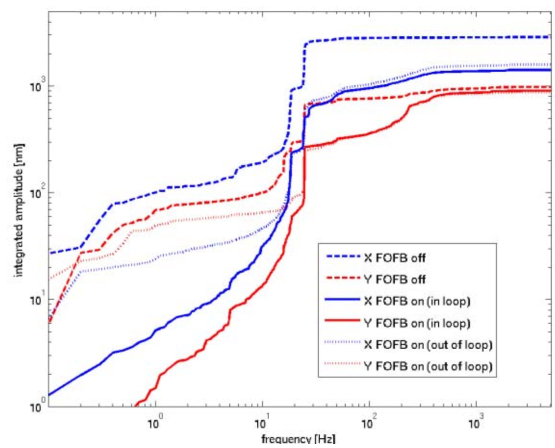

Figure 5: Performance of FOFB during commissioning. Integrated position noise has been measured on the beam with FOFB off and on, both with EBPMs in the feedback loop and out of the feedback loop.

gaps or energisation of the multipole wiggler produce small but observable orbit distortions with the SOFB, with the FOFB no orbit movement could be observed in such a case.

CONCLUSIONS

The Diamond EBPM system has been improved to allow reliable performance in a FOFB. The FOFB has been implemented and tested successfully. Future work with improved PID parameters and possibly increased corrector power supply bandwidth should further improve the performance of the FOFB.

REFERENCES

[1] G. Rehm, M. Abbott, “Performance Verification of the Diamond EBPM electronics”, in *Proceedings of DIPAC 2005*

[2] I.S. Uzun, R. Bartolini, G. Rehm, J.A. Dobbing, M.T. Heron, J. Rowland, “Initial Design of the Fast Orbit Feedback System for Diamond Light Source”, in *Proceedings of the 10th ICALEPCS 2005*