COMMISSIONING OF THE FAST ORBIT FEEDBACK SYSTEM AT THE AUSTRALIAN SYNCHROTRON

Y.-R. E. Tan†, S. Chen, T. D. Cornall, A. Michalczyk, A. Starritt,
E. J. Vettoor, SLSA, Clayton, Australia
B. Dickson, Arrayware Pty Ltd, Scoresby, Australia
D. J. Peake, DETECT Australia, Bundoora, Australia
D. de O. Tavares, LNLS, Campinas, Brazil

Abstract

An FPGA based fast orbit feedback system (FOFB) developed at the Australian Synchrotron aims to improve the stability of the electron beam by reducing the impact of moving insertion devices and targeting orbit perturbations at the mains frequency (50 Hz, 100 Hz and 300 Hz). The feedback system uses a PI controller with harmonic suppressors in parallel to specifically target perturbations at the mains frequency and its harmonics. This report will present the results of the commissioning of the FOFB system demonstrating a reduction in the integrated RMS motion up to 300 Hz by 75% to 90%.

DESIGN

The design of the FOFB at the Australian Synchrotron (AS) has been reported in references [1,2,3] and has been designed to reduce the RMS beam motion to under 10% of the beamsize at all BPM locations up to 100 Hz and a unity gain bandwidth of greater than 300 Hz. A key constraint of the project was to develop the feedback processing on an FPGA as a strategic decision to develop our capacity to work with FPGAs in the future. The FOFB system can be split into four sub-systems: (1) beam position measurement and aggregation, (2) feedback controller, (3) corrector magnets and power supply and (4) the control system and a slow orbit feedback. A schematic of the system is shown in Figure 1.

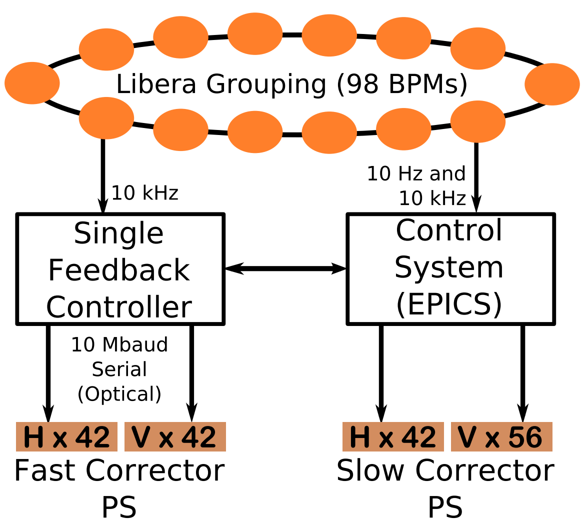

Figure 1: FOFB system with a single feedback controller controlling the fast corrector power supplies.

Beam Position Measurement

The beam position in the storage ring is measured using Instrumentation Technologies' Libera Electron beam processor. A real-time stream of position data is aggregated across the 98 BPMs by using Libera Grouping at a rate of 10 kHz (Fast Acquisition data). The topology of the Libera Grouping implemented here is a single ring with one level of redundancy. The data is transmitted to the feedback controller over UDP using a GbE link.

Feedback Controller

The firmware of the feedback controller was developed jointly between our engineers and a local development house, Arrayware. The approach taken was to develop all the interface modules in HDL and use Matlab's Simulink™/HDL Coder™ combination to generate the controller module, PIH. The simplified system architecture is shown in Figure 2.

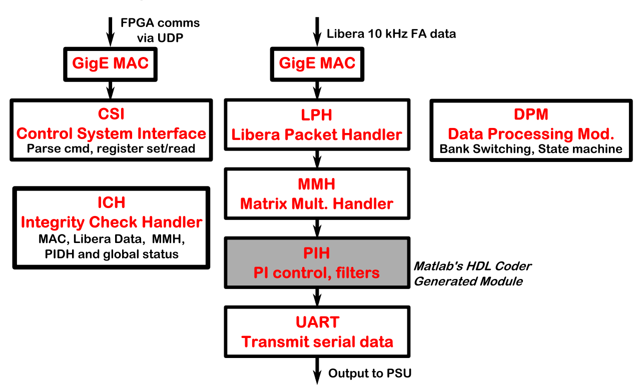

Figure 2: Simplified system architecture developed by Arrayware and AS.

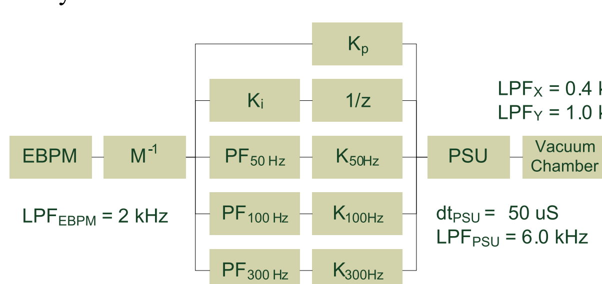

Figure 3: Controller for the FOFB where the harmonic suppressors are implemented using 2nd order IIR peak filters (biquad filters in direct form 2).

† Eugene.tan@synchrotron.org.au

The feedback controller receives data from the BPMs, decodes the information and translates this into corrector current values using an inverted BPM-Corrector response matrix, M^{-1}, provided through the control system. The feedback uses a P and I controller with three harmonic filters in parallel as described in Figure 3 [4]. The corrector current values are sent to the magnet power supplies via optical fibres using a 10 Mbaud serial protocol. The chosen platform for the controller is a Xilinx Virtex-6 LX240T FPGA.

Corrector Magnets and Power Supply

The existing slow correctors are secondary windings on the sextupoles and the new fast correctors are tertiary coils windings. As the maximum expected correction at 50 Hz is only 100 mA, the new fast power supplies designed and built by DETECT Australia are bipolar 1 A power supplies (18 V).

Control System and Slow Orbit Feedback

The orbit feedback system uses a combination of slow correctors for the bulk of the corrections and the fast correctors to compensate for beam motion above DC, following the method used at Soleil [5].

Before the FOFB is enabled, the orbit with the lowest RMS deviation from zero using the slow correctors/feedback is used as the reference orbit, u_{ref}. The slow feedback updates at 1 Hz and monitors the FOFB system. If the FOFB is enabled the update rate drops to 0.1 Hz and the orbit error, du, that the slow feedback uses to correct the orbit is

$$du = u - u_{ref} - M\overline{U}$$

where u is the current horizontal/vertical position, u_{ref} is the reference horizontal/vertical position, $\overline{U}$ is the time averaged horizontal/vertical fast corrector current and the matrix M is the fast corrector to BPM response matrix. The slow orbit feedback also uses the dispersion function to calculate feedback on the RF frequency.

COMMISSIONING RESULTS

After several weeks of firmware debugging in February 2017 the complete system with harmonic suppressors was ready for testing. A significant improvement in the feedback gain was measured when using an FPGA platform as shown in Figure 4 and Table 1. The parameters for the feedback system that require optimisation are the inverted matrix, k_p, k_i, and the three sets of filter coefficients.

Table 1: FOFB bandwidth, Comparing between a PC and FPGA Based Platform

	Horiz. BW$_{-3dB}$	Vert. BW$_{-3dB}$
PC (RT Linux)	170 Hz	150 Hz
FPGA	250 Hz	450 Hz

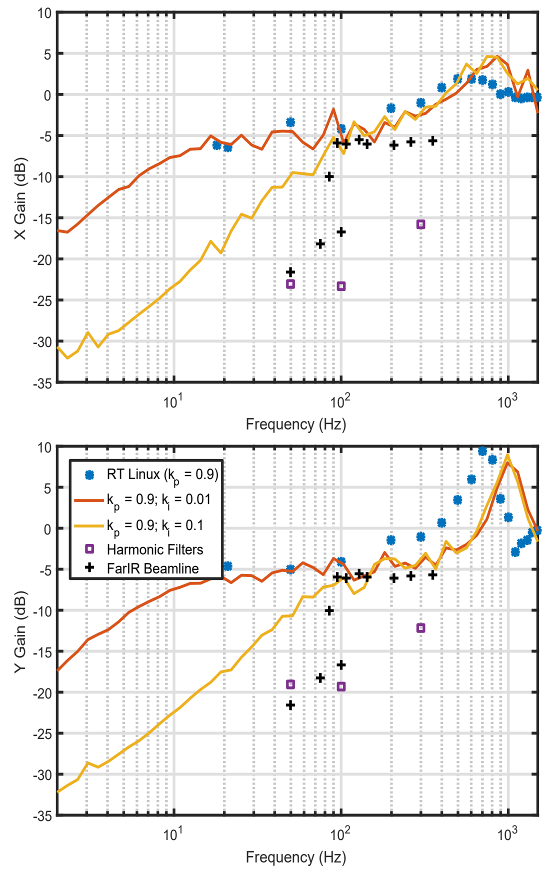

Figure 4: A comparison of the closed loop gain* of the PC and FPGA based feedback system. We also show the effect of different integral gain coefficients and effectiveness of the harmonic suppressors.

The control system, EPICS, stores the corrector-BPM response matrix and uses singular value decomposition (SVD) to calculate the Tikhonov regularised psudo-inverse [6]. If all singular values are used in the psudo-inverse or if singular value truncation is used, the integral gain, k_i, could not exceed 0.01. Increasing the k_i made the system unstable. With a Tikhonov regularised psudo-inverse, the system is far more stable and the integral gain can be increased to 0.10. Figure 4 shows the improvement in the low frequency damping with the higher k_i value.

In Figure 5 we note that the largest contributor to the beam motion is at 50 Hz and 100 Hz. The source is believed to be stray earth currents running along the metal work around the storage ring that is capacitively coupled from high voltage supply cables that power the RF and other sub-systems. To target these frequencies, harmonic suppressors at 50 Hz, 100 Hz and 300 Hz have been implemented [4] and provide between -20 dB and -10 dB gain at the specific frequencies. The coefficients were calculated in Matlab and can be updated during runtime.

* $U_{gain} = 20\log_{10}(\,\text{abs}(\,\text{FFT}(u)\,) / \text{abs}(\,\text{FFT}(u_0)\,)\,)$

ISBN 978-3-95450-182-3

The benefit of this system is that if additional low frequency damping is required the coefficients for one of the filters can be updated to target frequencies in a particular band between (for example: between 17 Hz and 30 Hz). This was tested and was able to achieve a -20 dB gain is that frequency range.

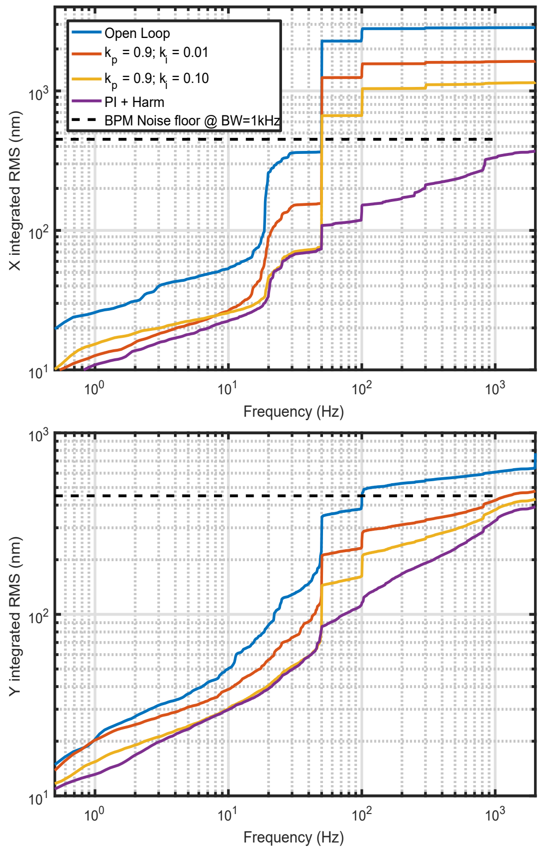

Figure 5: Integrated RMS showing that the FOFB is now damping beam motion down to the noise floor of the BPMs which is at 450 nm for a bandwidth of 1 kHz.

The FOFB system now ensures that the movement of one insertion devices (generates beam motion up to ~15 Hz) in one sector does not affect the stability of the electron beam in all other locations. Figure 6 shows a particularly detrimental elliptical polarisation scan that highlights that SOFB by itself is unable to compensate and makes the problem worse. The measured effect of the FOFB has also been observed on the IR beamline (see Figure 4 and Figure 7).

CONCLUSION AND FUTURE PLANS

The FOFB is now part of daily operations and in the past three months the system has maintained an uptime of 94%. With a more stable beam position we have started to note some BPM's reported position are drifting randomly or step changing by a few um. Preliminary investigations have confirmed that the issue is internal to the BPMs as the drifts were also observed when under equal load on all 4 channels from a signal generator.

The next stage of the development is to implement a way to inject a waveform to the output of feedback system to simplify the system gain measurements and to use the FOFB system to measure a corrector-BPM response matrix in a few seconds.

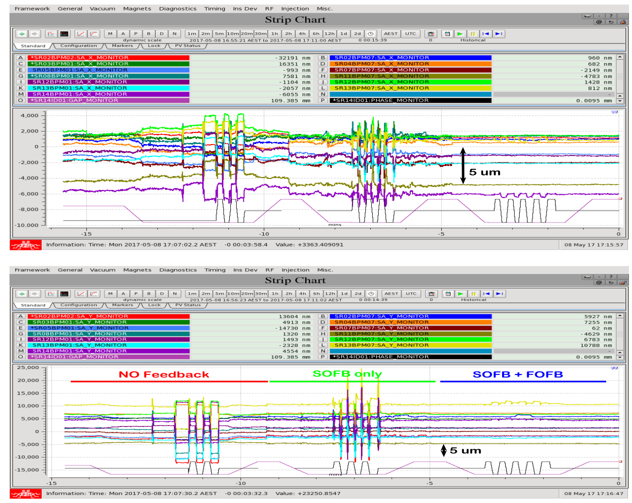

Figure 6: The effect of an APPLE2 undulator scanning in elliptical polarisation mode. Horizontal (top) and Vertical (bottom) beam position (10 Hz BW) is monitored showing significantly improved orbit stability in the presence of moving insertion devices.

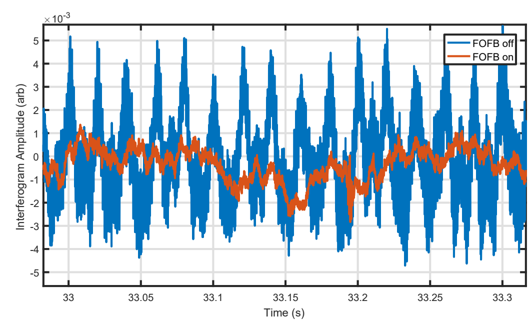

Figure 7: FarIR beamline's interferometer data showing a significant reduction in the 50 Hz noise.

REFERENCES

[1] Y.-R. E. Tan, T. D. Cornall, S. A. Griffiths, S. Murphy, E. J. Vettoor, "FPGA Based Fast Orbit Feedback System for the Australian Synchrotron", in *Proc. IBIC'2012*, Tsukuba, Japan, October 2012, paper TUPA37, pp 437-440.

[2] Y.-R. E. Tan, T. D. Cornall, E. J. Vettoor, A. Michalczyk, N. Basten, D. J. Peake, "Fast Orbit Feedback System at the Australian Synchrotron", in *Proc. IBIC'2015*, Melbourne, Australia, September 2015, paper TUPB002, pp 293-297.

[3] Y.-R. E. Tan, D. de O. Tavares, D. J. Peake, "Fast Orbit Feedback System with Linux PREEMPT_RT",

in Proc. IBIC'2016, Barcelona, Spain, September 2016, WEPG08, pp 630-633.
[4] M. Lonza, d. Bulfone, V. Forchi, G. Gaio, "Commissioning of the Elettra Fast Orbit Feedback System", in *Proc. PAC07*, Albuquerque, USA, MOPAN024, pp 203-205.
[5] N. Hubert, L. Cassinari, J-D. Denard, A. Nadji, L. Nadolski, "Global Orbit Feedback Systems Down to DC using Fast and Slow Correctors", in *Proc. DIPAC09*, Basel, Switzerland, MPPC01, pp. 27-31.
[6] Rowland, J., M. G. Abbott, J. A. Dobbing, M. T. Heron, I. Martin, G. Rehm, and I. Uzun, "Status of the Diamond fast orbit feedback system", *Matrix*, vol. 102, p. 103, 2007.

ISBN 978-3-95450-182-3