COMMISSIONING OF THE AUSTRALIAN SYNCHROTRON WITH LIBERA EBPPS AND MATLAB

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Abstract

The Australian Synchrotron (AS) is equipped with a full compliment of 98 BPMs attached to Libera Electron Beam Position Processors (EBPPs) [1] that are capable of measuring turn-by-turn/first turn and averaged beam positions simultaneously. The BPM system coupled with Matlab applications has simplified the process of commissioning. This report will highlight how the various tools have been utilised and show the results of some studies.

INTRODUCTION

The Australian Synchrotron (AS) storage ring is a 14 cell, Chasman-Green type lattice with 3 families of quadrupoles, 4 families of sextupoles and a total of 42 horizontal correctors and 56 vertical correctors [2]. Each cell has been fitted with 7 BPMs, totalling 98 BPMs, all of which are connected to EBPPs.

EBPPs are being used at facilities such as Soleil and Diamond (just to name a few) and are versatile diagnostic tools. The specifications for the BPM system at the AS are RMS values of < 0.2 μm (slow, 1kHz BW) and < 6 μm (turn by turn, 1 MHz BW) between 10 and 200 mA. Additionally the beam current (10 – 200 mA) and thermal (±1°C) dependence needs to be < 2 μm. Many of these parameters have yet to be characterised.

On the control side over the last few years the use of a suite of applications written in Matlab at synchrotron facilities for accelerator physics studies and commissioning has grown. The core of this suite of applications now includes AT [3], MCA, LOCO [5] and Middle Layer [4]. The integrated system of programs and scripts has made it an ideal tool for us at the AS.

The sections below will outline the BPM system and its capabilities followed by some of the applications that have been used during commissioning and the results.

BPM GEOMETRY

The four BPM buttons (from Kyocera) are separated in the vacuum chambers by 20 mm (H) and 32 mm (V). Using POISSON it is possible to simulate the fields with the geometry of the BPM blocks. The results gave BPM coefficients of k_x = 14.60 mm and k_y = 14.66 mm (LOCO results later put these values closer to ~15.3 mm ±1%).

$$x = k_x\left(\frac{V_A - V_B - V_C + V_D}{\sum V_i}\right) \qquad y = k_y\left(\frac{V_A + V_B - V_C - V_D}{\sum V_i}\right)$$

The error estimates in the position due to the pincushion effect was also investigated (see Figure 1). Within a region of x = ±3 mm and y = ±2 mm the apparent position is accurate to < 5%. Given that most studies will not involve orbits > 1 mm, inverting the pincushion effect is not seen as necessary.

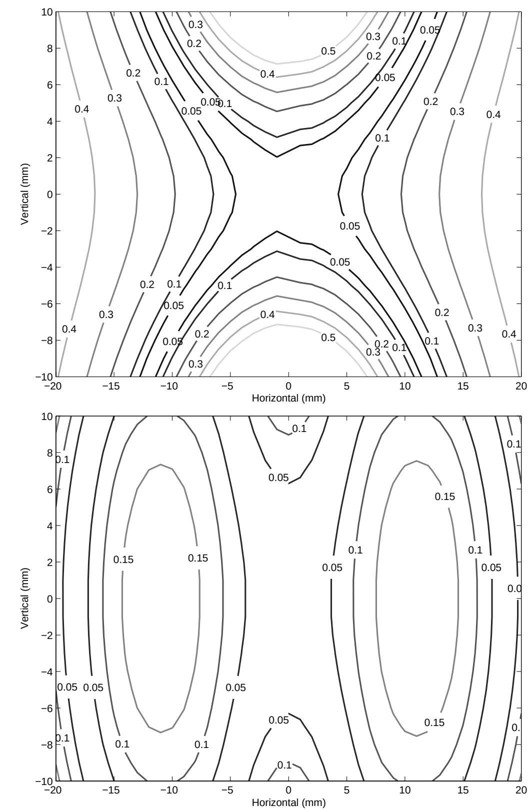

Figure 1 Relative error in the horizontal (TOP) and vertical (BOTTOM) position as a function of the actual beam position in x and y due to the pincushion effect.

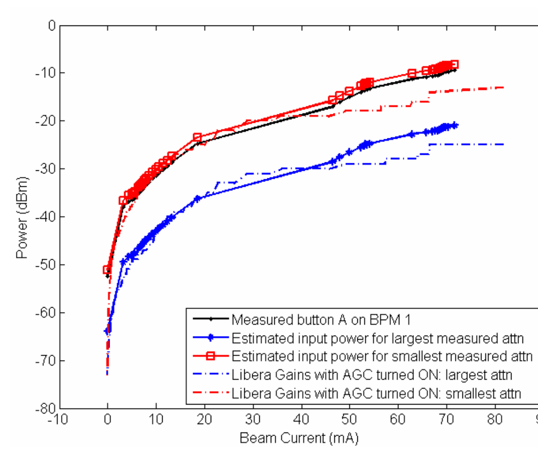

Figure 2 This plot shows a range of input power levels of the BPM signals going into the Libera based on measured signals (solid) and on gain settings of the EBPPs when Automatic Gain Control is turned on (dotted).

LIBERA

All 98 BPMs are connected to EBPPs with LMR200 cables rated at 0.25 dB/m. With cable lengths ranging from 18.7 to 64.0 m the expected dynamic range was 11.3 dB. However post installation measurements indicate that the attenuations were closer to 0.29 dB/m with a dynamic range of 12.8 dB. This is corroborated by the results in Figure 2 that show a dynamic range of 13 dB based on the gain settings of the EBPPs when the gain control is turned on. At the orbit interlock current threshold of 10 mA the power levels range from -42.4 dBm to -29.6 dBm. These are sufficient for accelerator physics studies.

The EBPPs are only supplied with the machine clock (revolution frequency of 1.388 MHz) to synchronise the AD converter and a trigger signal at a rate of 1 Hz. The EBPPs can also use other signals such as the system clock and a post mortem trigger [1] however they are not needed in the near future. A single set of the signals is generated by the timing system and is distributed via a series of fan-out units to the EBPPs. Ideally the BPM signals for a particular turn should arrive at the same time as the trigger at the EBPPs. In the current setup this is not possible for all the BPMs and the time difference between the signal and trigger can be as much as 1.1 μs. This means that without offsets in the data there is a 1.5 turn disparity between BPMs. The latest upgrade to the Libera will have features to compensate for this effect.

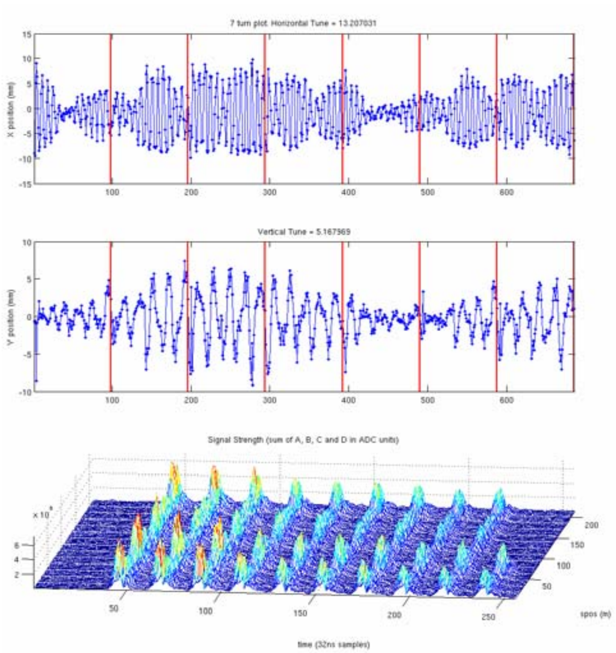

Figure 3 First turns plots showing the horizontal (top) and vertical (middle) orbit over 7 turns. Each section split by a vertical line is a snapshot of the orbit around the ring. The sum signal for 10 turns is shown in the bottom plot.

First Turns and Turn-by-Turn

Early in the commissioning when striving for first turns the initial version of the EPICS driver (developed at Diamond) for the EBPPs made it possible to effectively retrieve data sampled at 33.5 ns for first turn monitoring. Figure 3 shows one of the first turn plots after achieving ~30 turns. The data displayed has been offset to account for the timing issues mentioned before. The tunes in Figure 3 were obtained by a simple FFT over the 7 turn orbit, however due to the limited amount of data and noise the tunes were only used as a rough guide. Nonetheless they were close to the nominal tunes for the first day lattice (ν_x = 13.3 and ν_y = 5.2). The rise and fall of the peaks in the sum signal is due to the variation in the attenuations of the BPM cables around the ring. Comparisons between the strength of the sum signal and the cable attenuations showed near perfect correlation.

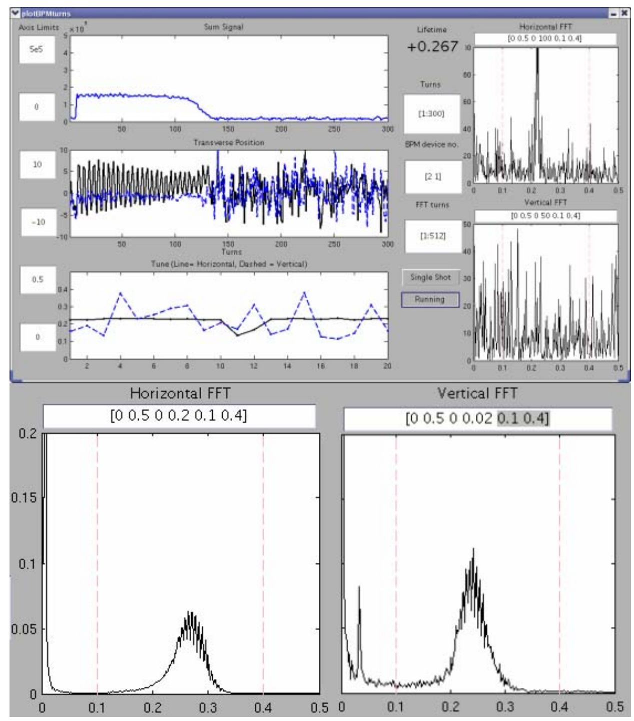

Figure 4 There are two GUIs here showing ~130 turns (top GUI) and the tunes (bottom). The GUIs developed in Matlab show the turn-by-turn sum signal (top left), position (middle left), fractional tune based on FFT peaks (bottom left) and an FFT on the horizontal (top right) and vertical (bottom right).

Shortly after achieving multiple turns, the beam was stored with no sextupoles and therefore at the natural chromaticity with a broad tune spread. The tune measurement system [7] was not sensitive enough to detect the tunes. It was however possible to use the injection kickers to excite the beam and apply an FFT on the turn-by-turn data to detect the tunes. This showed a tune spread of around 0.035 and 0.030, and with $\xi_{x,y} \approx$ -31,-24 the natural energy spread is therefore around 0.11% to 0.13%. This agrees quite well with the model of 0.10%. A simple display for the turn-by-turn data from the BPMs was developed in Matlab (screen shots are shown in Figure 4).

Slow Acquisition

The narrow band measurements for the EBPPs are referred to as the slow acquisition data (update rate of 10 Hz). Early measurements of the noise showed as much as 5 μm RMS however by detuning the machine clock PLL the noise level was reduced to ~0.2 μm RMS (see Figure 5). This is acceptable, however there is still room for improvement if we want μm level control of the orbit.

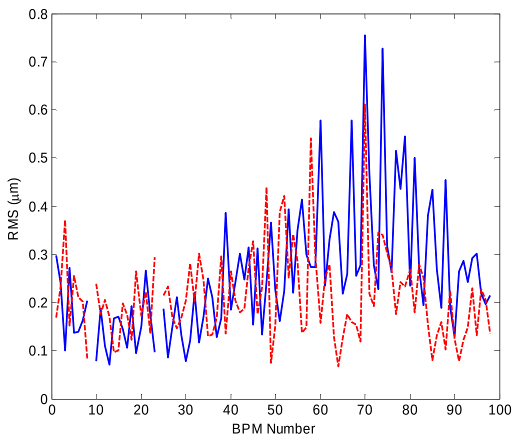

Figure 5 Noise measurement of the slow acquisition data in the horizontal (solid) and vertical (dotted) over 300 seconds at 85 mA (80% even fill pattern).

MATLAB SOFTWARE SUITE

Beam Based Alignment

Otherwise referred to as quadrupole centring in the code, this program only requires one to configure some initial scripts to define the groupings of BPM, corrector and quadrupole as well as the strength of the shunts. The algorithm is simple and involves taking a suitable corrector to sweep the beam through the BPM of interest. At designated points the nearest quadrupole to the BPM of interest is shunted and the change in the orbits around the Storage Ring is measured. Quadrupole field modulation with sinusoidal signals is not used. A complete run will take up to 3.5 hours using 4 points (8 measurements in total for a BPM). The current measured offsets do not show any systematic errors and has a max of 2.4 mm and deviation of 0.52 mm [6]. The current resolution is ~10 μm and requires further optimisation.

Response Matrices

This usually refers to corrector-BPM response matrices however as part of the suite of tools one can just as easily measure a sextupole-chromaticity response matrix as it is a program to measure linear maps from one parameter space to another. For example, a linear map was generated from a model to create a quadrupole-dispersion/tune map (3 by 3 matrix) that has since been used in an algorithm to globally fix the tunes and dispersion. Corrector-BPM response matrices take about 10 minutes to complete.

Orbit Correction

Orbit correction is typically done using "orbitgui" [8] that uses a measured response matrix and dispersion. The dispersion is used to distinguish the energy components in the orbit and corrector pattern. The program makes it easy to manipulate the orbit with ready access to the singular values. An RMS of the orbit of 16 μm has been achieved with corrector RMS values of 0.11 (H) and 0.06 (V) mrad (max of 1.5 mrad).

LOCO and Beta Function Measurement

With LOCO it is possible compute the lattice functions and calculate the necessary changes to reduce the beta beating and control the tunes and dispersion. The variations (deviation/mean) in the quadrupole power supply settings are QFA (0.1%), QDA (1.0%) and QFB (0.2%). Routine cycling of magnets has been in place to minimise hysteresis effects. Using LOCO the lattice has been configured for both zero and distributed dispersion (lower emittance). The quadrupole shunt measurement takes bout 15 minutes to complete and has shown strong correlations with the results from LOCO [7].

CONCLUSION AND REMARKS

The BPM system and tools for accelerator physics studies are in place and are well understood. The results shown have been promising however there remains a lot of work to be done to optimise the BPM system and improve the resolution.

ACKNOWLEDGEMENTS

Gunther Rhem, Michael Abbott and Yuri Chernousko at Diamond for their contributions to the BPM system.

REFERENCES

[1] A. Kosicek, "Libera Electron Beam Position Processor", PAC 2005, p. 4284.
[2] G. S. LeBlanc, M. J. Boland, Y.-R. E. Tan, "The Australian Synchrotron, Project Storage Ring And Injection System Overview", EPAC 2004, p. 2263.
[3] A. Terebilo, "Accelerator Modelling With Matlab Accelerator Toolbox", PAC 2001, p. 3203.
[4] G. Portmann, J, Corbett, A. Terebilo, "An Accelerator Control Middle Layer Using Matlab", PAC 2005, p. 4009.
[5] J. Safranek, G. Portmann, A. Terebilo, C. Steier, "Matlab-Based LOCO", EPAC 2002, p. 1184
[6] G. S. LeBlanc, "Status of the Australian Synchrotron", these proceedings.
[7] M. J. Spencer, M. J. Boland, R. Dowd, G. S. LeBlanc, Y.-R. E. Tan, "Tune And Lifetime Studies At The Australian Synchrotron", these proceedings.
[8] J. Corbett, A. Terebilo, "Interactive Orbit Control In Matlab", PAC 2001, p813.