STORAGE RING TURN-BY-TURN BPMS AT THE AUSTRALIAN SYNCHROTRON

Y.-R. E. Tan, M. Spencer, M. J. Boland, R. Dowd, G. S. LeBlanc
Australian Synchrotron, Melbourne, Australia

Abstract

The Australian Synchrotron's Storage Ring is equipped with a full compliment of 98 Libera Electron Beam Position Processors from I-Tech (EBPPs) [1]. The EBPPs are capable of measuring beam position data at turn-by-turn (TBT) rates and have long history buffers. TBT data from the EBPPs has been used to determine the linear optics of the storage ring lattice using techniques developed at other facilities. This is a useful complement to other methods of determining the linear optics such as LOCO. Characteristics of the EBPPs such as beam current dependence have been studied during commissioning and will also be presented.

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]. The current working point of the lattice is 13.29 (H) and 5.216 (V) with distributed dispersion. Each cell has been fitted with 7 BPMs, totalling 98 BPMs all of which are connected to EBPPs.

Each of the 4 BPM buttons is separated in stainless steel vacuum chambers by 20 mm (H) and 32 mm (V). Using POISSON, simulations gave gain factors of ~14.6 mm in both planes. Results from LOCO later put these values closer to ~15.3 ±1% [3].

The specifications that were given for the BPM electronics covered beam currents between 10-200 mA. The resolution had to be < 0.2 μm for slow acquisition data (~1kHz BW) and < 6 μm for TBT measurements. In addition the beam current and thermal dependence was specified to be < 2 μm. Characterising each in turn has begun and some of the results are presented in the next section.

In the sections following, preliminary results on using TBT data and the ICA technique [5] to recreate the machine functions will be presented along with a brief description of the orbit interlock system.

It should be noted that currently all the EBPPs are operating with version 1.2 of the firmware and driver. The latest updates (version 1.41) come with improvements in resolution and interlock detection had not been installed when these measurements were taken.

BPM CHARACTERISATION

Resolution

The resolution of the BPM system has been measured for various beam currents as well as for two different fill patterns. Figure 1 shows the RMS noise for TBT data and slow acquisition (SA) data (~1kHz BW) plotted against the average EBPPs' internal gain settings in dBm. The gain values are a rough measure of the input power into the EBPPs as set by the Auto Gain Control (AGC).

With a normal fill of 81% of the storage ring the EBPPs have nearly met the initial specifications however there are relatively large variations in the resolution between BPMs. The variation from BPM to BPM seems to exhibit a systematic pattern and still needs further investigation. The decrease in the resolution with an increasingly less "continuous" fill pattern has been expected.

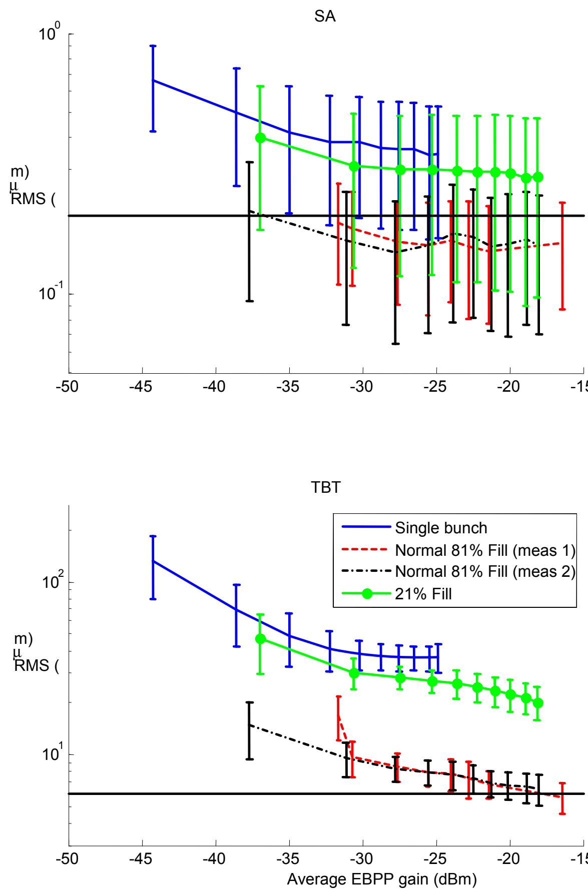

Figure 1: Average resolution of 96 BPMs for SA data (top) and TBT data (bottom). The error bars are a one sigma spread of the resolutions across 96 BPMs. The solid horizontal lines are the values in the specifications. "81% fill" means a continuous fill of 81% of the buckets in the storage ring. Single bunch measurements were taken in 1 mA steps from 1–10 mA. 21% fill measurements were taken in 3 mA steps from 3–30 mA. 81% fill measurements were taken in 10 mA steps from 10–100/125 mA.

Beam Current Dependence (BCD)

The measured beam current dependence is shown in Figure 2. A maximum orbit deviation of 128 µm was observed between 30 and 100 mA. From investigations carried out by Diamond [4] it was shown that a phase mismatch > 30° can result in significant increases in beam current dependence in the EBPPs. Figure 2 clearly identifies some BPMs with significant beam current dependencies. These BPMs will be checked in the coming weeks to verify if phase matching of the BPM cables will help minimise the current dependency.

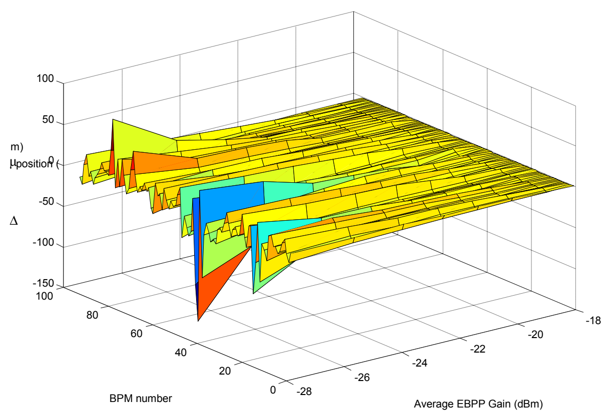

Figure 2: The plot above shows the absolute change in the beam position with respect to the beam position at 100 mA (gain ~ -18) for all the BPMs in the storage ring.

BPM Coupling

Using LOCO and a measured response matrix it is possible to fit for BPM coupling using rolls as well as "crunch". Rolls, crunch and gain values are used in the following way

$$\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \sin(\theta) \\ -\sin(\theta) & \cos(\theta) \end{bmatrix} \begin{bmatrix} 1 & C \\ C & 1 \end{bmatrix} \begin{bmatrix} k_x & 1 \\ 1 & k_y \end{bmatrix} \begin{bmatrix} x_{raw} \\ y_{raw} \end{bmatrix}$$

where θ is the roll, $k_{x,y}$ are the BPM gains and C the crunch value. Crunch can arise when there is an attenuation mismatch between the 4 buttons and is a measure of the virtual coupling between planes. Simulations of the attenuation mismatch were done using a simple model with a circular chamber. This is valid within a small region about the geometric centre of the buttons. The simulations have shown that a 0.2 dB difference in a single channel can result in crunch values (coupling) of ~1%. In Figure 3 we see a plot of the crunch values fitted using LOCO and the simulated values using the measured attenuations of the BPM cables (post installation). The results show a good correlation after the measured values are offset by 2%. This 2% offset is inherent in the EBPP's analogue board.

The roll values calculated by LOCO indicate rolls of up to 10 mrad. This is unusually large and rough initial measurements in one sector only indicated a maximum roll of 2.5 mrad while the calculated values indicated a maximum of 8.3 mrad. A careful survey will be carried out in the near future to correlate the results.

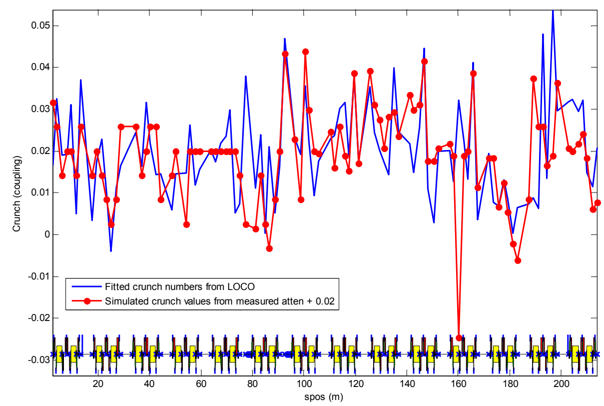

Figure 3: A good correlation between simulated crunch values based on measured attenuations and calculated values using LOCO. The 2% offset in the simulated data reflects the inherent coupling on the EBPP's analogue board.

Synchronisation Between BPMs

For TBT data to be useful the BPMs have to be synchronised to catch the same turn. The delays between BPMs that were calculated early on in the commissioning period showed relatively large delays. The equation was simple and took into account the time of flight around the ring, delay times for the signal to reach the EBPPs and the delay time of the timing signals. Figure 4 shows a plot of measured data revealing the relative delays and the calculated values.

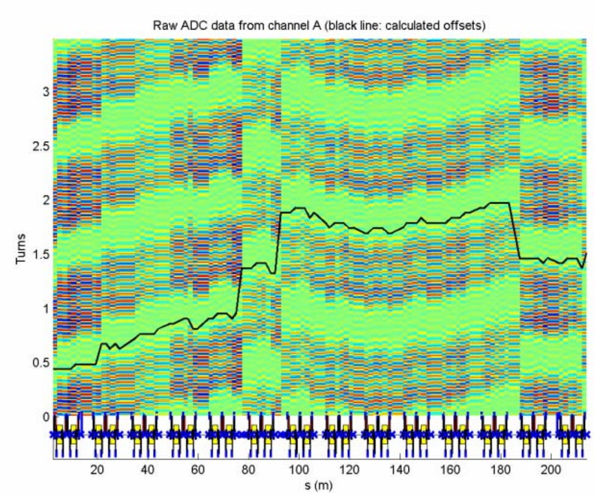

Figure 4: The above is a surface plot of raw data directly from the ADC on one channel of the EBPPs. The vertical axis is time measured in units of the revolution period and shows that for a given turn, the synchronicity between BPMs is out by ~1.5 turns (1.08 µs). The solid line represents the calculated delay given by the time of flight and various signal delays.

This has meant that measuring TBT "pictures" of the orbits around the ring have not been accurate. This was made obvious when trying to characterise the 5 turn storage ring injection kickers by comparing simulations with measured data. Facilities implemented in the newer firmware (version 1.4) will be able to rectify this issue.

MACHINE FUNCTIONS

The convenience of having TBT data on all BPMs has aided significantly in the commissioning of the storage ring as well as a day to day diagnostic for instabilities and injection problems, and tune measurement. Recently, techniques such as Independent Component Analysis (ICA) [5] have been developed to extract lattice functions from TBT data. The technique has been used here to try to extract the machine functions.

The beam was excited using the storage ring injection kickers up to an amplitude of ~0.6 mm in the horizontal plane. This ensured a strong horizontal signal and sufficiently strong vertical signal through local coupling. TBT data was extracted from all BPMs and analysed in a Matlab software package called FastICA [6] to extract spatial and temporal functions that can be used to derive the $\beta_{x,y}$, as well as the fractional tune. At the time of writing the calibration factor required in equation 6 of [5] had yet to be calculated so one was adopted to match the relative amplitudes of the $\beta_{x,y}$ calculated through LOCO. As the results are affected by BPM gains, the calculated corrections from LOCO were used to treat the TBT data before being analysed. 4 sets of measurements were taken and the results are shown in Figure 5.

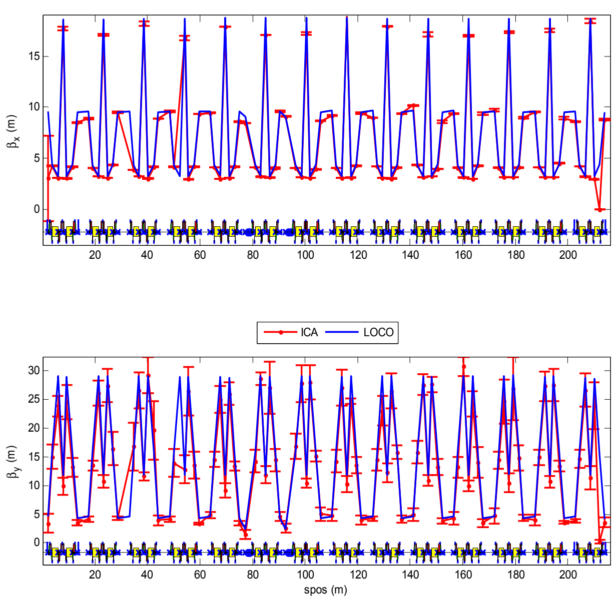

Figure 5: Plot of horizontal (top) and vertical (bottom) beta functions at the BPMs as calculated using ICA and LOCO. Error bars in the ICA calculated betas represents a one sigma spread from the 4 data sets. The beta beating seen in the ICA plot is not reflected in the LOCO plot.

The results by and large correlate however the beating seen in the ICA calculated $\beta_{x,y}$ are not reflected in those calculated in LOCO. It is not understood why this is the case. Though not shown here, the synchronicity problem outlined earlier is clearly seen when comparing the phase advance calculated with ICA and LOCO. It is possible that the continuing optimisation of the BPM system will see both results converging on the one solution.

ORBIT INTERLOCK

The calculated requirement for orbit interlock is to dump the beam in under 200 ms. Orbit interlocks for ID straights have been implemented using two methods during commissioning; through EPICS and through the EBPPs interlocking utility. The EPICS version uses a beam position record that updates at a rate of ~70 ms in two BPMs around the straight sections. This was limited by the processing power available on the EBPPs where the EPICS IOC resided. The position and angle at the centre of the straight is then calculated and checked for interlocking conditions. The total delay was measured at around 120-160 ms using self triggered DD data. Though under the 200 ms requirement, it was far from ideal.

The second method used the EBPP's utility to interlock the position at the BPMs and not calculate the position and angle at the centre of the straight. The total time taken was measured to be ~50 ms and is dictated by the cycle times of the various PLCs and relays in the orbit interlock chain (EBPPs delay is < 1 ms).

CONCLUSION

The BPM system's resolution has been shown to be satisfactory with values < 0.2 µm for SA data under normal conditions. Work however needs to be done to address beam current dependencies, BPM coupling and BPM to BPM synchronisation. There have been positive results in using TBT data to extract machine functions. The cause of the observed beta beating (not reflected in LOCO calculations) is an ongoing investigation.

REFERENCES

[1] A. Kosicek, "Libera Electron Beam Position Processor", PAC 2005, p. 4248.

[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] M. J. Spencer, *et. al.* "LOCO At The Australian Synchrotron", these proceedings.

[4] G. Rehm, *et. al*,. "Digital EBPMs At DIAMOND: Operational Experience And Integration Into A Fast Global Orbit Feedback", DIPAC 2007, http://felino.elettra.trieste.it/papers/MOD1A01.pdf

[5] X. Huang, *et. al.,* "Application of independent component analysis to Fermilab Booster", PRST-AB, 8, 064001, 2005.

[6] H. Gavert, *et. al.*, FastICA package version 2.5 published on 19-10-2005

