PRELIMINARY OPERATIONAL EXPERIENCES OF A BUNCH-BY-BUNCH TRANSVERSE FEEDBACK SYSTEM AT THE AUSTRALIAN SYNCHROTRON

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Abstract

The Australian Synchrotron storage ring has a high resistive wall impedance in the vertical plane. Presently the instability from this impedance is being controlled by increasing the vertical chromaticity. However new in-vacuum insertion devices that significantly increase the ring impedance will demand chromatic corrections beyond the capabilities of the sextupole magnets. A transverse bunch-by-bunch (BBB) feedback system has been commissioned to combat the vertical instability and provide beam diagnostics. A high frequency narrow band mode that could not be damped was initially encountered with IVUs at specific gaps preventing the system from being implemented during user beam. Study into the lattice has lead to a configuration of the sextupoles that can be used for user operations.

INTRODUCTION

The Australian Synchrotron (AS) is a 3rd generation light source situated in Melbourne, Australia. An overview of the design can be found in Reference [1]. The storage ring is 216 m in circumference and operates at an RF frequency of 500 MHz. There are currently 9 operational beamlines with three of these relying on small-gap in-vacuum undulators (IVU). The introduction of more insertion devices will increase the impedance of the ring and so a plan has been made to increase the damping capabilities of the ring with an active feedback system.

TRANSVERSE BUNCH-BY-BUNCH FEEDBACK

In modern third-generation synchrotron storage rings coupled-bunch instabilities can place a limitation on the maximum stored current. As the stored current approaches this threshold, the growth rate of the instability overcomes the natural damping of the ring and the beam will increase in effective emmittance. Figure 1 shows how dramatic this effect can be on the beam. Normally this is controlled by increasing the chromaticity of the lattice such that the effective impedance of the ring is reduced. The effectiveness of this approach is limited by the available strength of sextupole magnets and the growth rate of the instabilities.

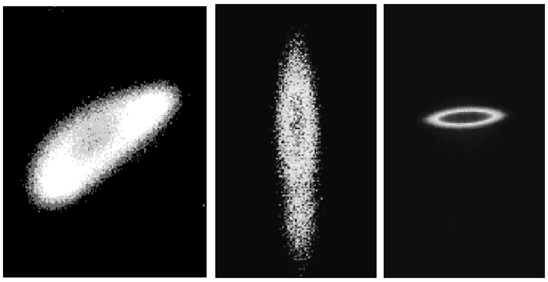
At the Australian Synchrotron the standard user lattice operates at a chromaticity of $[\xi_x, \xi_y] = [3, 11]$ in order to store our nominal current of 200 mA with a full range of insertion device gaps.

With more insertion devices planned for the ring, the instabilities may grow beyond our ability to control them purely using sextupole magnets. Another approach is available to add additional damping to the ring in the form of an active bunch-by-bunch feedback system.

An active feedback system has been designed and commissioned at the Australian Synchrotron to combat coupled-bunch instabilities, and has been described in detail in Reference [2]. It consists of a set of button-style Beam Position Monitors (BPMs) connected to a set of RF hybrids to provide an X and Y coordinate for each bunch. After passing through an ITech Libera analogue front end, a set of ADCs are used to sample the beam position over time and an FPGA calculates a corrective signal using a Finite Impulse Response filter (FIR). The signal is then fed into a DAC and placed onto the beam using a set of differential stripline kickers. The digital functionality (ADC, FPGA and DAC) is provided by an ITech Libera Bunch-By-Bunch system, running a combination of ITech and in-house developed code.

In this way we have both the pickup and actuator built into a closed loop system where an increase in the movement of a bunch causes the increase in the strength of the corrective waveform.

Initially the system was successful in damping the resistive wall instabilities that would prevent storage of the nominal 200 mA of current even without the IVUs inserted. Storage of 200 mA without IVUs was successfully completed at a chromaticity of [2,2]. Efforts to control the instabilities with the IVUs in was hampered by the discov-



(a) Both horizontal and vertical instabilities (b) Vertical instability (c) Stable Beam

Figure 1: Some examples of the effect a coupled bunch instability can have on the transverse profile of the beam, as measured by the X-ray Diagnostic Beamline (XDB). From left to right the plots show: a) BBB off b) horizontal BBB active and c) both BBB systems active.

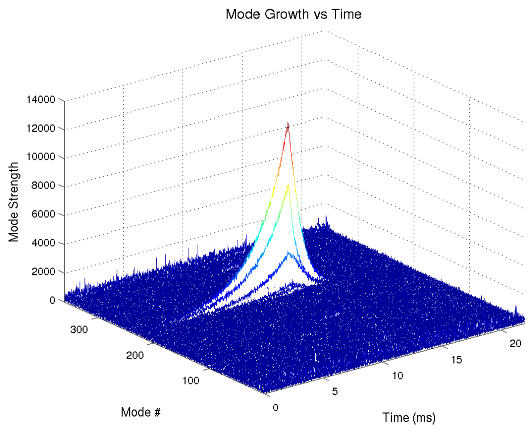


Figure 2: A grow/damp measurement showing the strong growth rate of a resonator centered about mode 228 (of 360). This instabilities shows up only at discrete low IVU gaps (6.8 mm for example).

ery of a strong narrow-band resonator impedance at discrete low IVU gaps (6.8 mm for example). The resonator would appear and disappear with a movement of 100 μm and is believed to be caused by the flexible IVU tapers providing the transition between the beampipe and the copper wakeshields. Initial FEM analysis of the tapers has not shown any resonant modes but further study into this is planned.

Figure 2 shows the growth of the resonator at mode 228 (of 360) which is far stronger than the resistive wall instability growth rates (described in more detail in [3]).

Horizontal tune sidebands had been measured in the vertical data during the resonator growths, so the horizontal BBB system was comissioned as well, as initially the focus had been on vertical instabilities. It was also discovered that lowering the harmonic sextupole strength with the chromatic sextupole strength reduced the growth rate of the resonator instability.

The system now has been shown to be effective at increasing the effective damping of the lattice, allowing operations at a reduced chromaticity of $[\xi_x, \xi_y] = [4, 2]$, at all IVU gaps.

USER OPERATIONS

Long-term Test

If the BBB feedback system is going to be used during user beamtime then it must be shown to be stable over a long time period. During a machine studies period, a low chromaticity lattice was used to test the BBB system for stability. The beam was injected to 150 mA and allowed to decay over an 8 hour period. Figure 3 shows the result of the test.

Successful operation of the BBB system allowed for in increase in both vertical and horizontal dynamic aperture, though the IVUs impose a smaller physical aperture in the vertical. In spite of this, the increase in horizontal dynamic aperture allowed for a 10% (40 to 44 hrs) increase in lifetime with IVUs at minimum gaps (IVU03/IVU13 at 6.60 mm and IVU05 at 6.06 mm). With no step losses or increased loss of the beam, the system is stable for an extended period of time. Studies need to be conducted with realistic movement of insertion devices similar to standard experimental settings, but the IVUs have been scanned at all gaps independently with no instabilities seen.

Bunch Cleaning

Many light sources worldwide are becoming increasingly interested in controlling the bunch purity of their fill patterns, with a long bunch train for regular experiments and a single high current "camshaft" bunch for pump-probe measurements. It is important to maintain a high bunch purity in order to prevent parasite bunches producing X-rays which interact with the sample before the pump measurement. At the Australian Synchrotron, the injection system is capable of targeting single buckets during injection [4], but a variety of conditions during injection can lead to a higher than desired electron population in neighbouring buckets.

A technique known as bunch cleaning [5] can be employed to force unwanted bunches to exit the beampipe while keeping the bunches needed for experiments. Using software designed for the FPGA within the BBB system, the unwanted bunches are excited at a harmonic of the vertical tune frequency while the wanted bunches receive the standard corrective waveform. The motion of the excited bunches is increased beyond the acceptance of the ring and they are lost. To increase the speed of loss, a set of vertical scrapers are brought to within ±2mm of stable beam.

Figure 4 shows the evolution of the fill pattern as the bunch cleaning signal is used to keep bunch number 40 to 350 and the single bunch at position 359. A high dynamic range device modelled after the bunch purity device con-

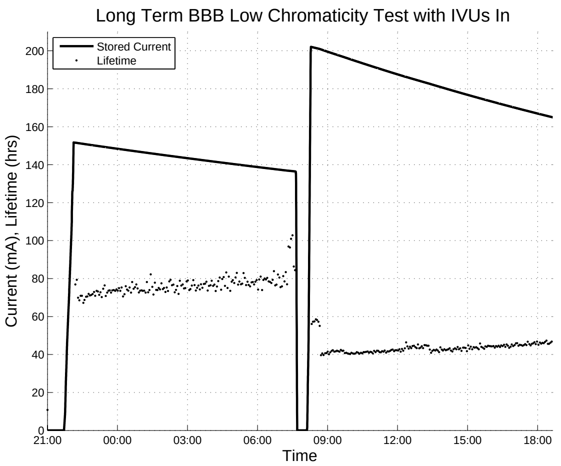


Figure 3: The results of a long term test of the BBB feedback system. Machine studies shifted to user time at 08:00.

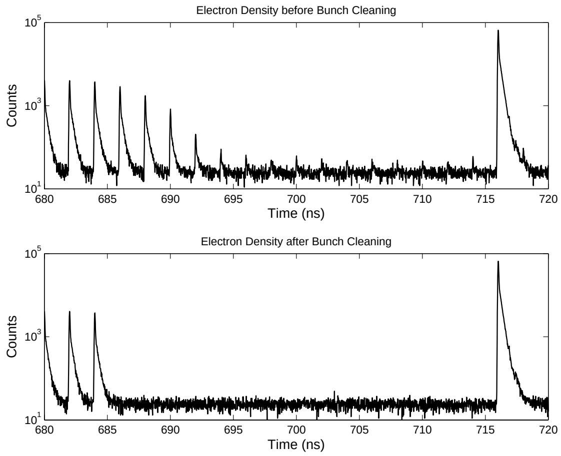


Figure 4: The effect of bunch cleaning on electron density. A high dynamic range detection system, the Bunch Purity Monitor, was used to measure statistical distribution of electrons in the ring.

Table 1: Change in integrated counts for the main bunch and parasite bunch during bunch cleaning. Data taken directly from Figure 4 after a background subtraction of 32 counts per histogram bin.

	Parasite Bunch	Main Bunch	Purity
Before	108	568659	2×10^{-4}
After	2	567990	3.5×10^{-6}

structed at Diamond [6] called the Bunch Purity Monitor was used to measure the distribution of electrons within the ring. The initial fill was injected using a "pattern fill" with a long bunch train from the injection chain. This leads to the parasitic bunches seen between the regular fill and single bunch. Parasitic bunches such as these will produce synchrotron radiation at times not intended for the experiment.

Initial results with bunch cleaning (shown in Figure 4 and Table 1) show promising results, with the purity for a high-current single bunch increasing from 2×10^{-4} to 3.5×10^{-6}.

Harmonic Sextupole Scan

In order to control the chromaticity within the ring, the AS lattice has two families of chromatic sextupoles (SDB and SFB). Increasing the strength of the chromatic sextupoles reduces the dynamic aperture of the ring, so to recover some of the aperture two families of harmonic sextupoles are used (SDA and SFA).

To optimize settings, the SDA and SFA families were scanned in strength and the lifetime of each lattice measured. A single bunch of 10 mA was injected into the ring to maximise DCCT response, allowing for a more accurate lifetime measurement.

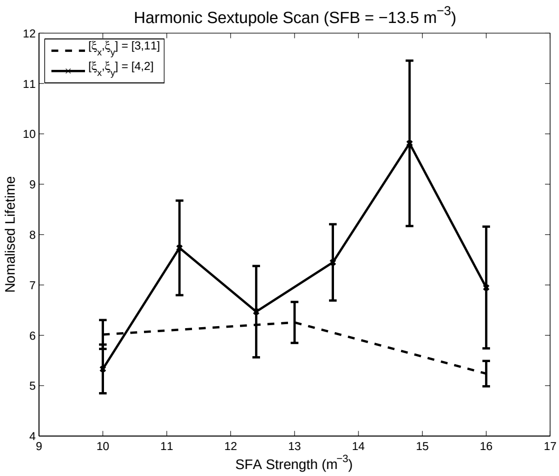


Figure 5: A scan of harmonic sextupole strengths versus lifetime. The scan was done with the chromaticity set to $[\xi_x, \xi_y] = [4, 2]$ and a 10 mA single bunch. The increase in lifetime from 6.2 hours to 9.8 hours is due to an increase in dynamic aperture.

Figure 5 shows that careful selection of sextupole strengths allow for an increase in lifetime from 6.2 hours to 9.8 hours for a single 10 mA bunch at low chromaticity.

CONCLUSION AND FURTHER WORK

The bunch-by-bunch transverse feedback system for the Australian Synchrotron storage ring has been successfully commissioned. It has increased the damping of the ring, allowing a reduction in chromaticity from $[\xi_x, \xi_y] = [3, 11]$ to $[\xi_x, \xi_y] = [4, 2]$. The increase in dynamic aperture allowed for a 10% increase in lifetime from 40 to 44 hours at regular user fill with all of the insertion devices at minimum gap.

Further work needs to be done to implement these results during experimental user time. Long term stability tests involving a more realistic movement of insertion devices as well as implementation user time online beam diagnostics are planned.

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