OPERATION AND STORAGE RING CALIBRATION WITH THE TRANSVERSE BUNCH-BY-BUNCH FEEDBACK SYSTEM AT THE AUSTRALIAN SYNCHROTRON

D. J. Peake, K.P. Wootton, R.P. Rassool, University of Melbourne, VIC, Australia
M.J. Boland, Y.-R. Tan, Australian Synchrotron, Clayton, VIC, Australia

Abstract

The first operational experience with the transverse bunch-by-bunch feedback system for the storage ring shows a doubling of the lifetime and the ability to damp instabilities caused by IVU gap changes. The system was also used to calibrate the ring by doing simultaneous measurements on several single bunches with different bunch currents.

INTRODUCTION

Results from the transverse bunch-by-bunch feedback system commissioning, diagnostic tools, bunch cleaning and beam lifetime improvements have been reported previously [1–3]. Here we report on the operational results from using the system under user beam conditions. There were two main goals for the operational setup; i) damping the high order mode instabilities induced by the the IVUs at specific gaps; and ii) reducing the chromaticity in order to increase the beam lifetime. Experimentally the two goals could not be simultaneously optimised, so a compromise was reached that nonetheless resulted in an increased lifetime and a stable beam for all IVU gaps.

IVU INDUCED INSTABILITIES

IVU Gaps and Instability Modes

At very narrow ranges of IVU gaps high order mode instabilities are induced in the storage ring. The harmonic number of the storage ring is 360, so the possible coupled bunch modes are $m = 0 - 359$. Table 1 list some basic properties of the IVUs and the unstable gaps and modes that are present.

Table 1: ASLS IVU Parameters and Instabilities at Low Chromaticity $\xi_x = 3, \xi_y = 3$

ID	Min. Gap [mm]	Unstable [mm]	Modes
IVU3	6.6	6.8, 7.1	197, 227
IVU5	6.0	6.2, 6.5, 10	197, 224, 227
IVU13	6.6	6.6, 7.7	197

The instabilities are present for ± 50 μm variation of the gaps and the gaps at which they occur have changed over the past few years.

Phase Tuning with Grow/Damp Measurements

The technique of allowing an instability mode to grow for a few ms and then damping it again by briefly opening and closing the loop was used to optimise the kick phase. Figure 1 shows the damping time variation with a change in the final two tap filter of DAC signal that gets sent to the stripline kicker. The higher order mode 224 is very sensitive to the kick phase and the optimal phase varies for each mode. A compromise was reached between optimal phase for the higher order modes and the resistive wall low modes.

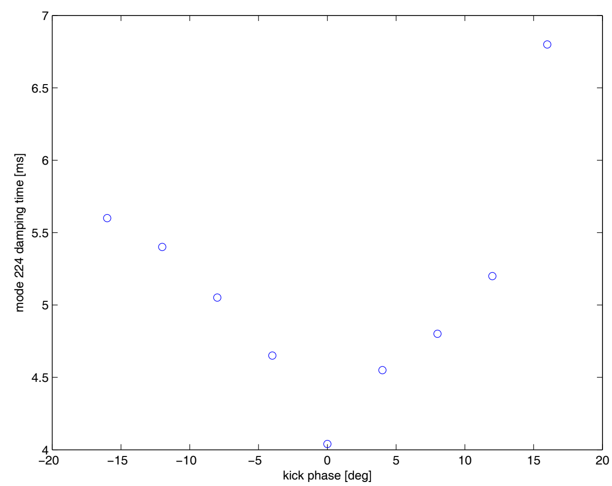

Figure 1: Damping time vs kick phase for mode 224 with IVU5 closed.

This technique was used at each of the observed instability modes and the an indication of the typical growth and damping times of the modes is presented in Table 2. One of the limitations of the system is the optimal phase for damping a mode is not necessarily the same phase for each mode. The main reason for this is believed to the be the frequency dependent phase shift of the kicker amplifier.

Table 2: Coupled Bunch Instability Grow/Damp Times

Mode	Growth Time [ms]	Damping Time [ms]
197	7.5	20
224	25	4
227	3.5	6.5
359	5	1

SEXTUPOLE OPTIMISATION

The original work on optimising the lattice with the harmonic sextupoles is described in Ref. [4] and includes the details of the lattice. Since that study IVUs that induce beam instabilities have been added to the ring and thus the optimisation criteria have changed due to practical experience with the ring.

Motivation

There are a number of competing parameters that need to be considered for the optimisation of the sextupoles:

- lowering the chromaticity;
- damping all coupled bunch instabilities;
- improving the lifetime;

The chromaticity was increased after the IVUs went into the storage ring to counter the coupled bunch instabilities during user operation but the subsequent spread of the tune peaks into synchrotron side bands interfered with machine studies. Using the BBB feedback system the chromaticity can be lowered and the tune synchrotron sidebands reduced, making it easier to excite the beam as more power can be absorbed by the beam at the main tune peak. Figure 2 shows the vertical tune spread decrease with lower vertical chromaticity.

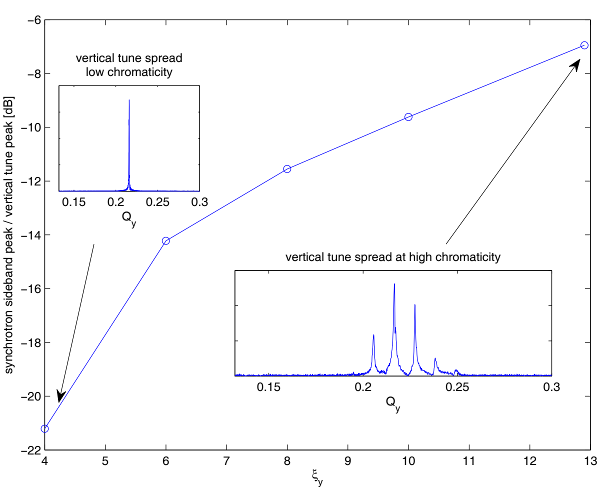

Figure 2: Tune spread vs vertical chromaticity.

In the future this improvement is planned to be exploited to put the system into positive feedback for a short time to excite the beam to large amplitudes and then measure the tune shifts with amplitude.

Lifetime Optimisation

From a user beamline point of view the lifetime is probably the most critical parameter that can be improved with the bunch-by-bunch feedback system. For a given working point the harmonic sextupoles (SFA, SDA) can be adjusted to control the tune shifts with amplitude and momentum. The initial figure of merit for the harmonic sextupole scanning before the IVUs were installed was the restoration of the dynamic aperture lost at high chromaticities. This aim was achieved with the harmonic sextupoles approximately equal and opposite in sign and at high strength.

Table 3 shows the normal user beam at high chromaticity with the IVUs at minimum gap has a lifetime of 28 hr. With the bunch-by-bunch system the chromaticity can be lowered and all instabilities damped if the harmonic sextupoles are at low strength. However the lifetime can be further improved, in fact doubled that of the present user mode, if the harmonic sextupoles are unbalanced. At high harmonic sextupole strengths the growth rate of coupled bunch instabilities is also higher. This experimental lifetime results are not in agreement with earlier modelling which indicated that the best lifetime is achieved with balanced harmonic sextupoles [4]. The relationship between

Table 3: Beam Lifetime with IVUs at Minimum Gaps

ξ_x, ξ_y	SFA,SDA [1/m^3]	Lifetime [hr]
3.5,12.9	34,-33	28
2,3.5	12,-12	42
2,3.5	30,-24	56

the strengths of the four sextupole families (2 chromatic and 2 harmonic) and storage rings natural damping rate and beam lifetime needs further investigation.

RESULTS USER OPERATIONS TESTS

In order to fully test the feedback system the IVU gaps were scanned at random time intervals to the gaps that are set by users to test the beam stability under normal operations. Figure 3 shows the IVU gaps for one much test shift and Fig. 4 shows that no current was lost due to exciting an instability with the IVU gap changes the beam was stable and did not blow up in the vertical plane.

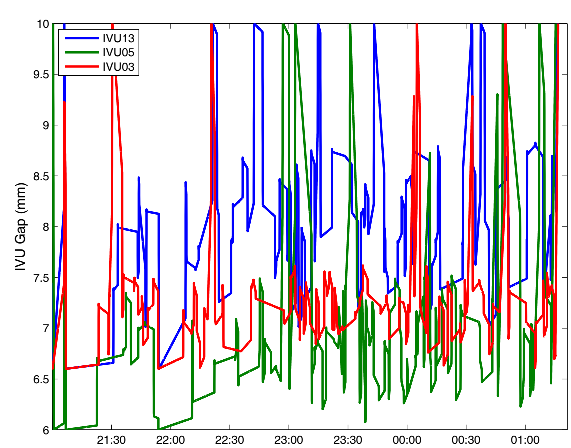

Figure 3: Test of transverse bunch-by-bunch feedback system with varying IVU gaps.

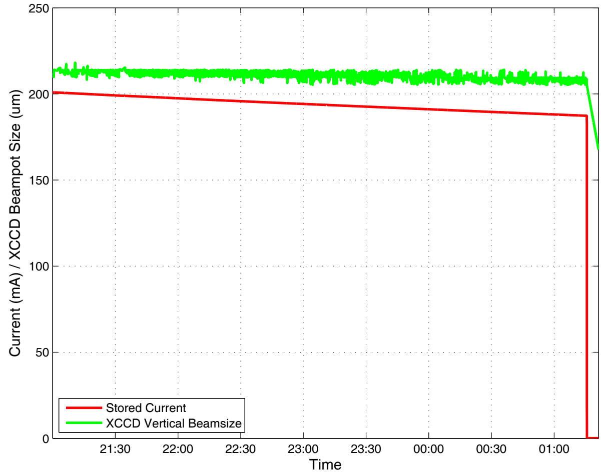

Figure 4: Beam current and vertical beam size during IVU gap scanning.

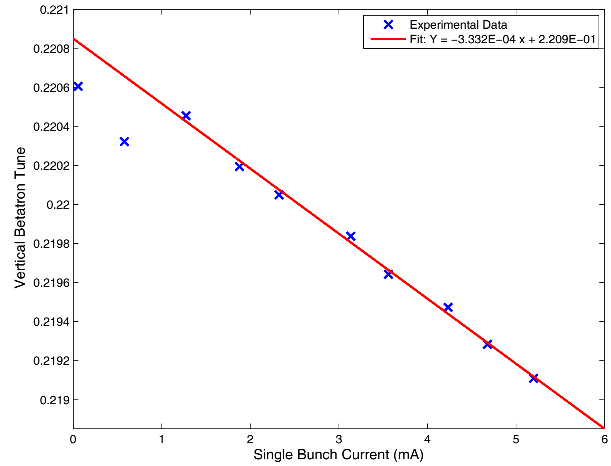

Figure 5: Single shot tune shift with bunch current measurement.

LATTICE CALIBRATION

Storage Ring Impedance

As part of testing the diagnostic capability some single bunch excitation studies were performed. One such measurement was on a sparsely filled ring with ten single bunches, each with a different bunch current, which were excited and the response measure with the feedback system. The imaginary part of the ring impedance can then be deduced from the change in tune with respect to the change in current, given by

$$\frac{\Delta Q}{\Delta I_b} = \frac{1}{|m+1|} \frac{e\beta c^2}{2\omega_\beta E_0 L_b} \mathrm{Im}\{Z_{eff}\}, \tag{1}$$

where Q is the tune, m is the azimuthal mode, E_0 is the nominal energy of the beam and L_b is the bunch length and Z_{eff} is the effective impedance. The data from a single measurement are shown in Fig. 5 where the first two points at low current have large errors which can be imporved by taking multiple data sets.

These measurements have been regularly made to keep a close account of the impedance budget of the storage ring (see Ref. [5]), in particular before and after the installation of insertion device chambers and in vacuum IDs. This new technique will simplify and improve the accuracy of these impedance measurements.

CONCLUSION

The transverse bunch-by-bunch feedback system was finely tuned to damp all the higher order modes induced by varying the IVU gaps during user beam. A compromise was reached in the setting of the harmonic sextupoles that increased the growth rate of instabilities but also resulted in a doubling of the beam lifetime at low chromaticity and with all IVUs at minimum gaps. Future plans are to use the excite/damp capabilities of the system to calibrate the non-linear dynamics and reconcile a discrepancy with the harmonic sextupole modelling. A novel technique for rapidly deducing the ring impedance was also demonstrated.

REFERENCES

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