GROWTH/DAMP MEASUREMENTS AND BUNCH-BY-BUNCH DIAGNOSTICS ON THE AUSTRALIAN SYNCHROTRON STORAGE RING

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Abstract

Recently a transverse bunch-by-bunch feedback system was commissioned to combat the resistive-wall instability in the storage ring. Presently the instability is being controlled by increasing the vertical chromaticity but new diagnostic tools have been developed to characterise the instability under different machine configurations in order to tune the feedback system for future user operation. The FPGA that comes with the feedback system also provides powerful possibilities for diagnostic measurements. Results will be presented for growth/damp measurements to quantitatively characterise instability growth rates and bunch-by-bunch diagnostics such as tune.

INTRODUCTION

The Australian Synchrotron storage ring now has 3 IVU IDs of approximately 6 mm minimum gap installed, which has reduced the beam current threshold for resistive wall instabilities in the vertical plane to below the maximum user beam current of 200 mA. The instability has been charaterised in Ref. [2, 3] and Figure 1 shows the vertical beam blow up effect measured on the x-ray diagnostic beamline. The instability is presently being controlled during user operations by increasing the vertical chromaticity to 11.

a) b)

Figure 1: X-ray beam spot with vertical feedback in a) open and b) closed loop.

A transverse bunch-by-bunch feedback system (BBB) was designed and commissioned for the Australian Synchrotron electron storage ring, the details of which have been reported previously [1]. Figure 1 shows the x-ray beamspot succesfully damped vertically once the loop was closed on the BBB after phasing and timing the frontend, FIR filters and kicker amplifiers. This result shows the system works in principle, however the commissioning phase did not include charaterising the system and tuning it for user operation. Since the hardware commissioning, diagnostic software has been developed to monitor the beam which will enable the characterisation and optimisation the system for stable user operation. Initial results of the system characterisation with beam are presented here.

EXPERIMENTAL SETUP

Storage Ring Fill Pattern

The storage ring was set to a chromaticity of $\xi_x = 3$ and $\xi_y = 0.6$ and using the fill pattern feedback injection [4] a square fill pattern was injected. The instability threshold current was gradually approached using two methods: i) keeping a fixed bunch current and increasing the number of bunches, and ii) keeping the number of bunches fixed and increasing the bunch current. Using this technique the instability threshold could be reached in a controlled and reproducible way. It was found experimentally that by filling 155 of the 360 RF buckets with 0.39 $\pm$ 0.02 mA (or 5% bunch current variation) the instability would blow the beam up vertically without losing current (see Figure 1). By sitting right at the threshold it was possible to test the BBB feedback by adjusting many parameters. With 154 buckets filled there were no signs of the instability but while injecting the 155^{th} the instability developed. When the BBB feedback was in closed loop and a parameter change removed the damping, sometimes bucket 155 alone was kicked out of the ring.

Growth/Damp Measurement

Growth/Damp measurements were performed once the BBB was in closed loop mode by turning off and then back on the FIR filters as shown in the schematic in Figure 2.

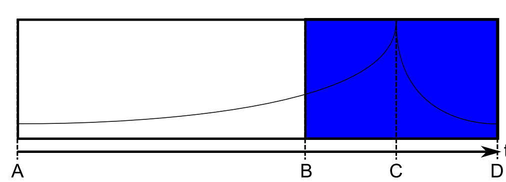

Figure 2: The timing graph for the grow damp measurements. A: Stop feedback, B: Start Data Acquisition, C: Restore feedback, D: Readout DAQ buffer.

The delay time between turing the filters off and on was adjusted to achieve a large peak in the ADC measuring the bunch position. The instability was kept from growing too large so the that beam could be damped within the maximum acquisition time of the FPGA (22 ms). A typical growth/damp data set is shown in Figure .

Using this technology the final phase adjustment on the filter before the DAC output was tuned to maximise the

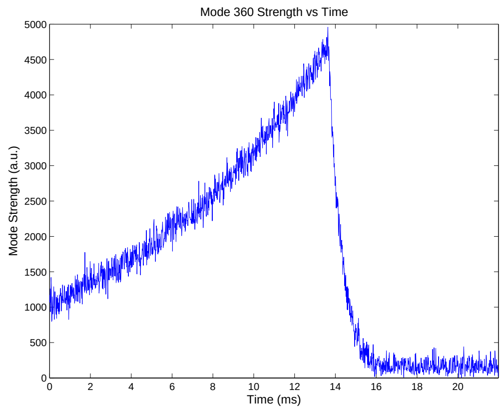

Figure 3: An example growth and damping cycle of mode 360.

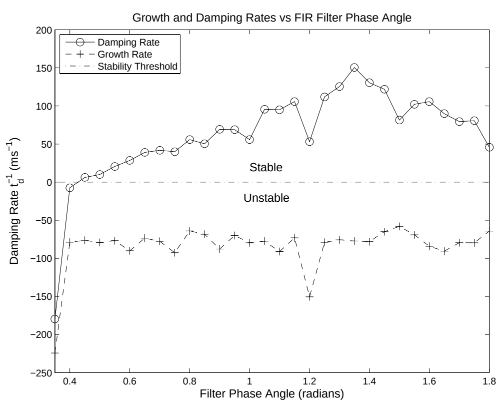

Figure 4: Mode 360 damping rate versus the Finite Impulse Response Filter Angle. It is important that the final corrective pulse placed onto the beam by the kickers is a sinusoid phase shifted by π radians from the beam motion at the kickers.

damping rate. Figure 4 shows the phase angle scan and measured growth and damp rates. As expected the growth rate remained constant as the nature of the instability did not change, however the damping rate varied as the feedback was moved in and out of phase.

A test of the kicker amplifier performance was also conducted to see if the system was saturating. The damp rate was measured while the gain was varied from the minimum to the maximum value. As shown in Figure 5 the damping rate increased smoothly right to the maximum gain, indicating there was no saturation in the system.

Current Dependence

The growth rate of the instability was mapped out with increasing current at two different settings of the vertical chromaticity. Figure 6 shows that the growth rate increases with bunch current and decreases with higher chromaticity settings. This type of data will be used to predict the condition under which the BBB system can stabilise the beam for user runs.

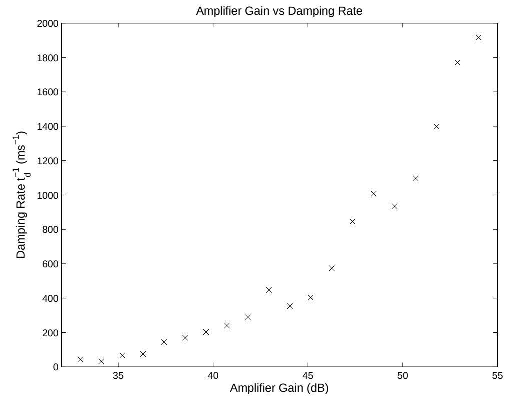

Figure 5: Mode 360 Damping Rate vs Amplifier Gain. The total beam current is 80 mA, evenly filled into 155/360 buckets.

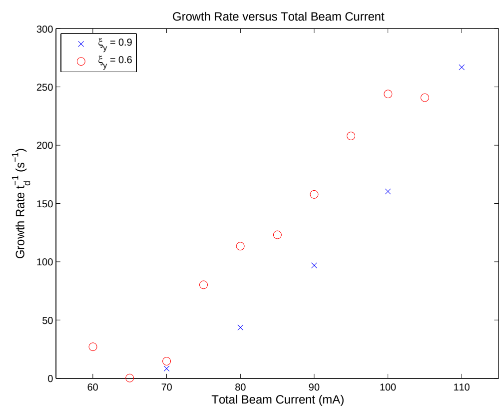

Figure 6: Mode 360 growth rate versus current, for vertical chromaticities of 0.9 and 0.6.

Mode Analysis

Coupled bunch instabilities are characterised by a coherent movement between the bunches, usually coupled through a wake field. Each bunch still oscillates at the tune frequency, but there is a phase difference between bunches given by:

$$\Delta\Phi = m\frac{2\pi}{M} \tag{1}$$

where M is the number of bunches, and m is the mode number. In the frequency realm, these phase differences can be measured as sidebands of the revolution frequency.

$$\omega = p\,\omega_{rf} \pm (m+\nu)\omega_0 \tag{2}$$

where p is an integer, ω_{rf} is the frequency of the storage ring RF cavities, m is the mode number, ν is the tune and w_0 is the revolution frequency.

By taking an FFT across the bunch dimension (length M) the modal growth can be plotted versus time. The modal damping rate is especially important as it can highlight problems in the tuning of the feedback system. A slight mistune in the placement of the corrective kicker pulse onto the beam may not be seen in low order modes, since the phase change between two bunches will be quite small (as shown in Equation 1). Higher order modes are more sensitive to the damping signal phase changes, as the phase change between bunches will approach 180° so a pulse intended to damp bunch N will excite bunch $N+1$.

The measured mode strengths are shown in Figure for both open and closed loop, demonstrating that the BBB system is effectively suppressing the modes excited by the vertical instability.

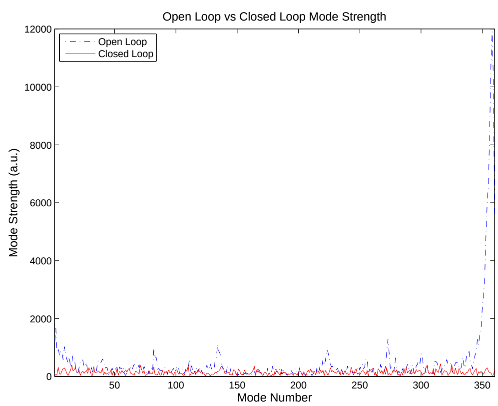

Figure 7: Open loop versus closed loop mode strength.

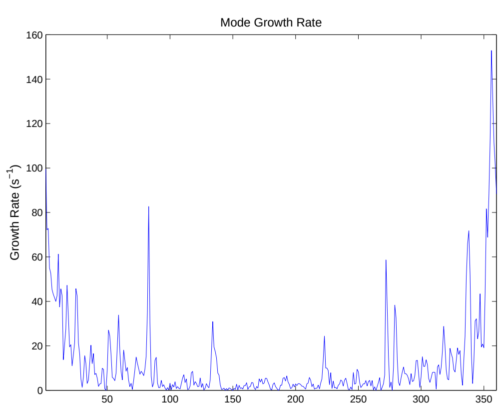

Figure 8: The median growth rate for each mode, taken from 30 grow/damp measurements.

A growth rate (τ_G^{-1}) of 109 ms^{-1} was measured for mode 360 which corresponds to a growth time of 9.2 ms. Vertical radiative damping has been calculated to be 4.82 ms based on a model of the ring lattice.

BEAM DIAGNOSTICS

By taking an FFT along the time access of each bunch a spectrum like the one shown in Figure 9 is obtained which allows for a tune measurement of each bunch individually. At the moment, growdamp measurements are used to provide the necessary amplitude in the position space to measure the tune, but in the future single bunch excitation of a stable beam could be used to provide continuous tune measurements.

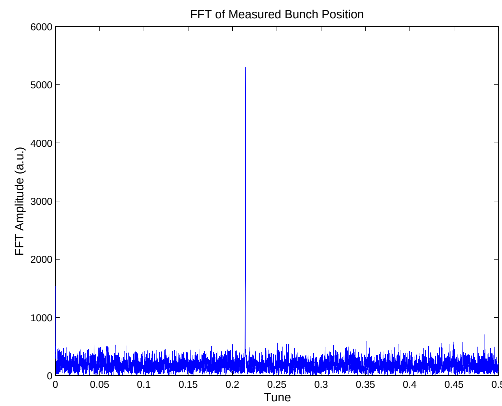

Figure 9: Single bunch FFT measurement during a grow/damp measurement. The peak shown is at the storage ring vertical tune of 0.2147.

CONCLUSION

Diagnostics to tune and optimise the transverse Bunch-By-Bunch feedback system have been developed for the Australian Synchrotron storage ring. Initially they have been used to perform growth/damp measurements in order to characterise observed vertical resistive-wall instability. Studies of beam parameters such as tune and mode dependant instability growth rates have been performed. These techniques will be used to bring the feedback system in to stable operation for user runs in the future.

REFERENCES

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