TIME RESOLVED TUNE MEASUREMENTS AND STABILITY ANAYLSIS OF THE AUSTRALIAN SYNCHTORON BOOSTER.

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Abstract

The Australian Synchrotron booster accelerates electrons from 100 MeV to 3 GeV in 600 ms. The fractional tune components that were measured are presented in two graphical formats showing the time-resolved measurement of the horizontal and vertical tunes. This experiment demonstrated that the current in the booster was extremely sensitive to the ratio of BF to BD combined-function magnets. Large variations of the fractional tunes were found to follow the differences in the gradients of the BD and BF combined-function magnet ramping curves and with this knowledge, alterations were made to the ramping table increasing the efficiency of the booster by an average of 40%. Rapid fluctuation of the tunes meant that it could not be distinguished during the first 80 ms of the ramp. Multiple side bands to the revolution harmonic were visible during a minimal sweep time of 5 ms, during this first 80 ms.

INTRODUCTION

Description of the Booster

The Australian Synchrotron booster lattice consists of four superperiods, each segment containing eight bending horizontally defocusing (BD) and seven bending horizontally focusing (BF) combined function magnets. The magnetic field of these combined function magnets range from 0.0418 to 1.253 T during the ramp.

Ramp Cycle and Losses

The original ramping curve and current plot is shown in Figure 1. There is a gradual beam loss only during the first 80 ms of the ramp. Investigations into the cause of these losses lead to the measurements of the booster tunes and variation up the ramp.

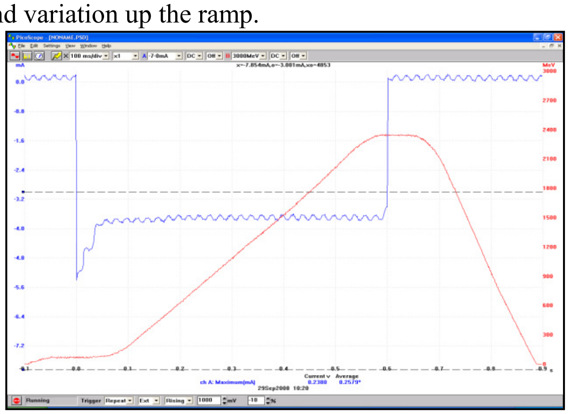

Figure 1: Circulating beam current (negative scale) during energy ramping (multi-bunch mode).

TUNE MEASUREMENTS

The tune measurements were made using a swept spectrum analyser with a tuneable band-pass. A 5 ms sweep of frequencies in the range of interest was conducted and this signal was applied to the beam using strip lines. A 180 degree offset splitter was used to combine two diagonal pickups to remove the DC component and improve the signal from the pickup. This signal was subjected to a Fast Fourier Transform (FFT), allowing the fractional tunes to be calculated from the side bands to the revolution harmonic in the frequency domain. Previous measurements of the fractional tunes of the Australian Synchrotron booster have been made using a sweep time of 100 ms and as a result, the rapid fluctuations of the tune values near the beginning of the ramp until now have not been visible [1].

EXPERIMENTAL RESULTS

The fractional tune values over the first 80 ms were virtually undecipherable, with the beam found to be incredibly unstable. Large drifts in the tunes were visible as shown in figures 2 and 3, showing the tune variation as a function of time and on a tune-space plot.

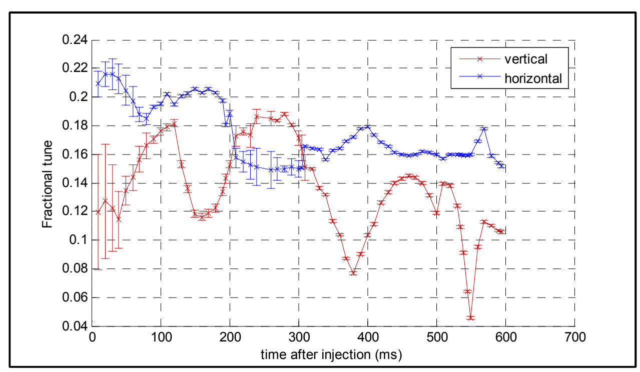

Figure 2 Fractional tunes variation with time after injection.

Beam Stability

As mentioned above, the tune varied rapidly during the first 80 ms of the ramp, corresponding to where the losses were observed (Figure 1). Figure 4 shows numerous screen shots of the tune side band overlaid, taken 10 ms after injection. This gives a clear indication of the range over which the tunes fluctuated, corresponding to a fractional tune range of 0.08 to 0.16.

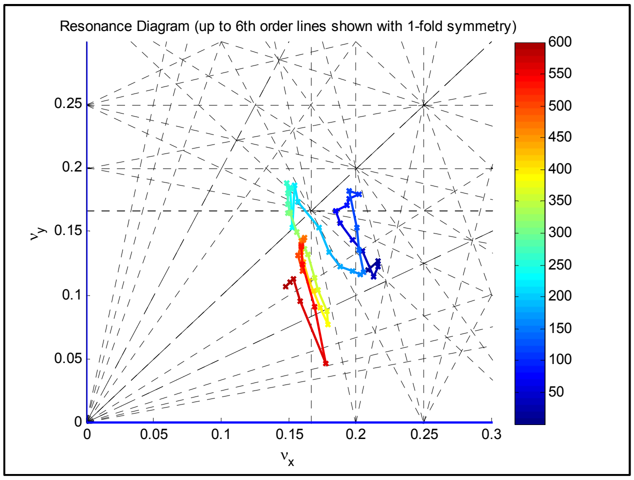

Figure 3. Tune space plot showing the fractional tune movement during the 600ms ramp.

It is also worth noting that not only did the fractional tune traverse a wide range of values, the tune movement was also very rapid. Figure 5 shows one screen shot where it appears there are four side bands present. This screen shot was taken with a sweep time of 5 ms, indicating a shift of the tune by 0.07 within 5 ms.

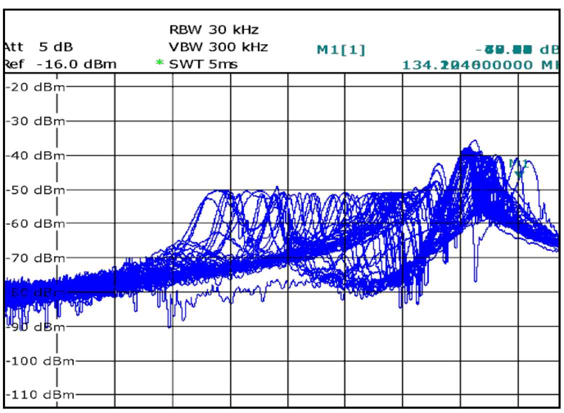

Figure 4. Multiple side band peaks overlaid.

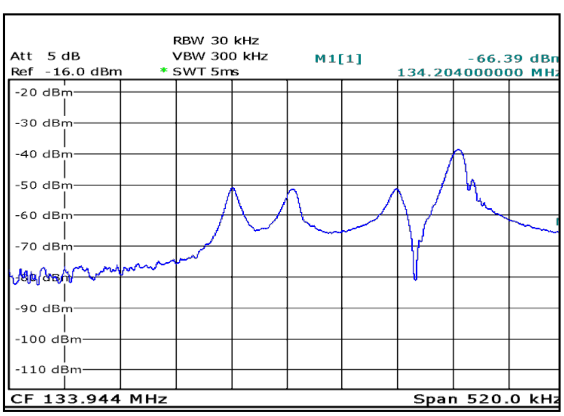

Figure 5. Screenshot showing 4 side band peaks appearing with a sweep time of 5ms.

Tune Excursions

The large jumps in the tune, evident in figure 6, can be explained by comparing the ratio of the focusing to defocusing magnet strengths. Figure 6 shows the difference in the gradient of the BD ramping values to the gradient of the BF ramping values plotted against time. On the same graph the horizontal and vertical tunes are shown, illustrating the correlation between the magnet gradients and the fractional tunes. This effect is particularly noticeable at 370 ms, 490 ms and 545 ms, where the tunes change direction due to a step in the difference between the focusing and defocusing magnets, displaying the sensitivity of the of the tunes to the difference in gradients. It is likely that the quadrupoles would also contribute to this effect, however the due to the comparatively weaker focusing strength of the quadrupoles the influence would likely be small.

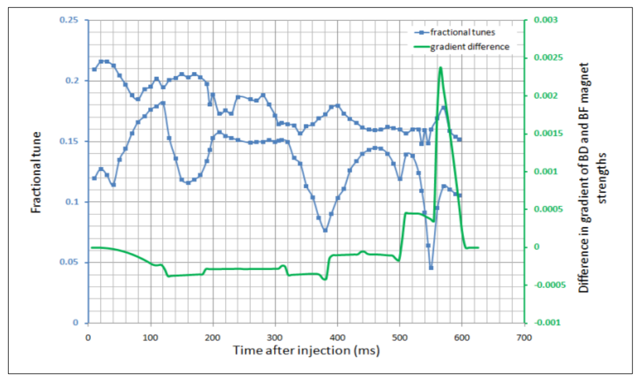

Figure 6. Correlation of fractional tune movement to the difference in gradient of BD and BF magnets.

Using this data it would be possible to remove these excursions in the tunes, however as can be seen by comparing figures 1 and 2, there does not appear to be any losses in current caused by them.

Sensitivity to BD/BF Ratio

A ratio of the BF to BD magnet strengths of slightly greater than one is needed in order to avoid a strong resonance near the beginning of the ramp.

Changes to the ratio of BF to BD can induce many other changes, due to the new closed orbit path the bunches would travel. A wider orbit is equivalent to the electrons having a larger momentum and arriving at the RF cavity later, increasing the likelihood that electrons could slip out of the bucket, effectively decreasing the momentum acceptance. For these reasons, the BD/BF ratio was set to one, and this configuration was extended into the ramp as far as allowed, before reaching the very harmful 4th order resonance at 70 ms.

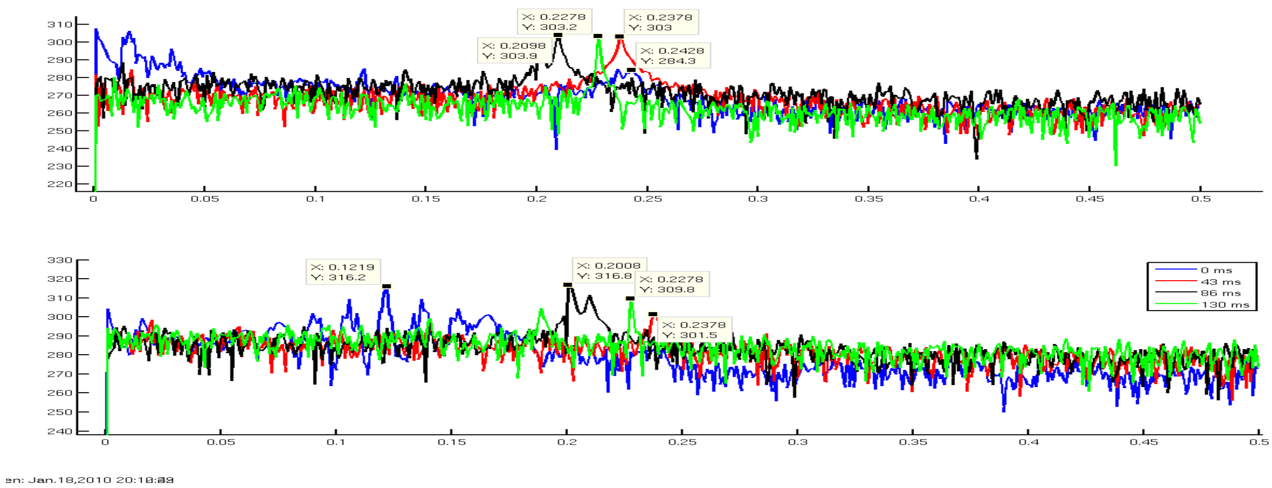

Figure 7. The tunes were measured using a Libera beam position processor [3] connected to a BPM during the first 130 ms of the ramp using the extraction kicker to excite the beam.

At this point the ratio was alerted by the smallest amount allowable in order to avoid the resonance. This significantly reduced the losses, increasing the current efficiency by an average of 40%. The shot-to-shot variation in the current also significantly reduced due to this change from 42.8% to 3.5%. Attempts to avoid the resonance using quadrupoles alone were unsuccessful due to the limited number and strength of these magnets.

DIAGNOSTIC UPGRADE

The recent upgrade to the BPM diagnostic system in the booster [2] has made it possible to accurately and easily measure the closed orbit around the booster during the ramp. The booster was left in a static state to capture and store 100 MeV electrons (setpoints at the injection point of the ramp) for one second at an injection rate of 1 Hz. A response matrix (Figure 8) was measured and LOCO used to extract gains and coupling factors. The predicted tunes from LOCO were n_x=0.229, n_y=0.185 and n_s=0.019. In comparison the tunes from turn-by-turn data from the Libera gave (averaging over 10 samples) tunes of nux=0.231, nuy=0.192 and nus=0.017, agreeing with LOCO predictions to within 5%.

With the magnets ramping the tunes were measured with turn-by-turn data for the first 130 ms and are shown in Figure 7. Again the excitation for the turn-by-turn data was from the extraction kicker with an appropriate delay.

CONCLUSION

This experiment demonstrated that the current in the booster was extremely sensitive to the ratio of BF to BD combine function magnets. It was also found that a variation in the ratio of BD to BF was necessary in order to avoid a strong resonance that could not be avoided by altering the quadrupoles alone. By extending the constant ratio further into the ramp, the current was increased by an average of 40%.

The fractional tunes were found to vary by large amounts during the ramp due to differences in the gradients of the BD and BF families.

These new tools will become useful for maintaining a stable beam for the implementation of top-up and further improvements to injection efficiencies.

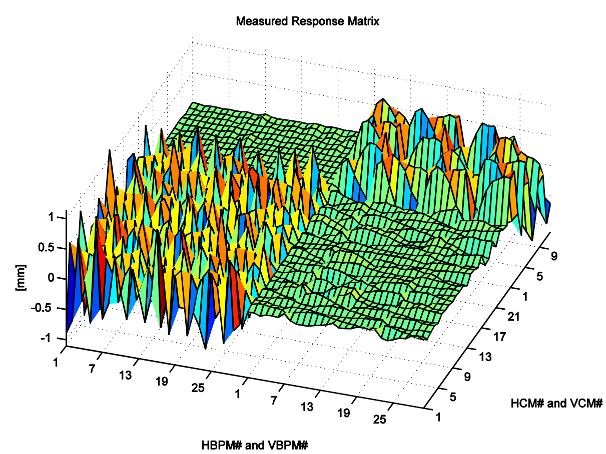

Figure 8. Corrector BPM response matrix for 100 MeV electrons at an injection rate of 1 Hz.

REFERENCES

[1] S. Weber *et al.* "Final Commissioning Results from the Injection System for the Australia Synchrotron Project", IPAC07, Albuquerque, TUPMN007, p. 926 (2007); http://www.JACoW.org.

[2] E. van garderen *et al.* "Upgrade of the Booster Beam Position Monitors at the Australian Synchrotron", these proceedings

[3] Y.-R. E. Tan *et al.* ``Commissioning the Australian Synchrotron with Libera EBPPS and Matlab'', APAC, 2007