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STUDYING INSTABILITIES IN THE CANADIAN LIGHT SOURCE STORAGE RING USING THE TRANSVERSE FEEDBACK SYSTEM

S. Martens, D. Bertwistle, M. J. Boland*[1], Canadian Light Source, Saskatoon, Canada
[1]also at University of Saskatchewan, Dept. of Phys. and Eng. Phys., Saskatoon, Canada
P. Hartmann, DELTA, TU Dortmund University, Germany

Abstract

The transverse feedback system at the Canadian Light Source (CLS) can identify, categorize, and mitigate against periodic instabilities that arise in the storage ring beam. By quickly opening and closing the feedback loop, previously mitigated instabilities will be allowed to grow briefly before being damped by the system. The resulting growth in the beam oscillation amplitude curve can be analyzed to determine growth/damp rates and modes of the coupled bunch oscillations. Further measurements can be collected via active excitement of modes rather than passive growth. These grow/damp and excite/damp curves have been collected and analyzed for various storage ring beam properties, including beam energy, machine chromaticity, and in-vacuum insertion device gap widths.

OVERVIEW AND MOTIVATION

A third-generation synchrotron storage ring is subject to several instabilities arising from the electromagnetic interaction between the stored electron bunches and the vacuum chamber. These instabilities can grow over time and, without intervention, can increase the size of the beam, reducing the brilliance of the synchrotron radiation supplied to beamlines, or in extreme cases cause the loss of the beam entirely. The addition of multiple in-vacuum insertion devices in third generation synchrotron storage rings can further compound the effect of these instabilities. Intervention via active feedback systems can be used to mitigate against these instabilities. A transverse feedback system (TFBS) produced by the commercial supplier Dimtel Inc. was recently installed at the CLS that uses a beam position monitor (BPM) and response network to identify, categorize, and mitigate against these coupled bunch instabilities [1].

By quickly opening and closing the feedback loop, previously mitigated instabilities will be allowed to grow briefly before being damped by the system. The resulting growth in the beam oscillation envelope can be analyzed to determine growth/damp rates and modes of the coupled bunch instabilities. These results can provide better understanding of the storage ring's behavior and may influence the design of future storage rings at the CLS2 and elsewhere.

THEORY

Wake fields arise in a storage ring via interaction between the fields generated from a relativistic charge bunch and the vacuum chamber. Radiation will scatter when encountering metallic objects or changes in the boundary conditions of the ring. Scattered radiation will then interact with subsequent bunches and perturb their motion.

Wake fields give rise to coupled bunch instabilities. When M Bunches oscillate at the tune frequency of the synchrotron, they give rise to M modes via a phase difference between bunches $\delta\phi$:

$$\delta\phi = \frac{2\pi n}{M} \tag{1}$$

Where n is the mode number. The CLS storage ring operates with 285 bunches which yields 285 modes. The growth/damping rate T, of these modes over time can modelled as an exponential [2] of the form:

$$y = Ae^{\tau T} \tag{2}$$

EXPERIMENT

Grow Damp Measurements

Experiments with the transverse feedback system were conducted during development shifts throughout 2021. The storage ring was set up in its standard operating mode with top-up disabled. A chromaticity of $\xi_{x,y} = 0$ was used, and all insertion device gaps not actively being experimented with were left fully opened. The TFBS was set up in Grow/Damp mode. This operation mode disables the feedback network which allows instabilities to grow briefly before re-enabling the feedback which dampens the instability. Custom code was written to connect to existing Dimtel MATLAB code to collect and sort data from the TFBS and any Process Variables (PVs) of interest during measurements. Five grow damp measurements were taken at each step during each experiment. Measurements were performed while varying the insertion device (ID) gap width for the five in-vacuum insertion devices with adjustable gap-widths. In addition, measurements were done while varying the horizontal and vertical machine chromaticity.

Excite Damp Measurements

Results from grow damp measurements showed large growth in the highest and lowest modes, typically the product of resistive wall instabilities. As a consequence, the structure of the remaining modal growths were lost beneath the much larger amplitudes of the highest and lowest modes. To view the modal structure of the remaining modes, a series of excite damp measurements were deemed necessary. The storage ring was set up identically to the grow damp measurements performed previously. The TFBS software

* mark.boland@lightsource.ca

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was set up to deliberately excite specific modes individually. By excluding the highest and lowest modes in the storage ring, structure of the damping rates was able to be measured, an example is shown in Fig. 1. These excite damp measurements took considerably more time and storage than the previous grow damp measurements. Consequently, a full sweep of all modes was not able to be performed while varying ID gap widths. Instead, full scans of all modes were only done with all IDs fully open, or when one specific ID was closed to its minimum gap width. The modes which reacted most strongly to the ID being moved to its minimum gap were noted and only those modes were excited while adjusting the gap systematically, shown in Fig. 2. This allowed excite damp measurements to be performed within the limited development shift time available.

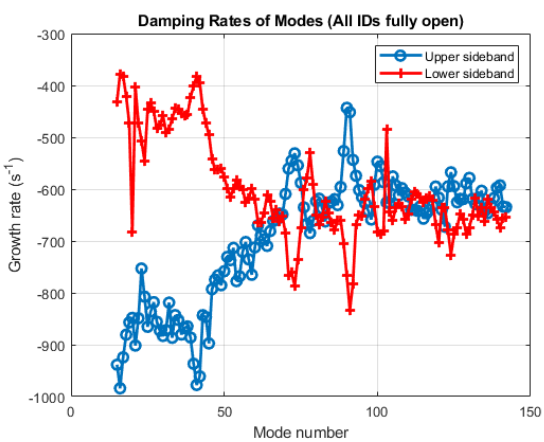

Figure 1: Structure of modal damping rates. Note that the upper and lower sidebands are the sidebands of the revolution harmonic, and correspond to the lower and upper halves of the 255 scanned modes, respectively. The top and bottom 15 modes are omitted.

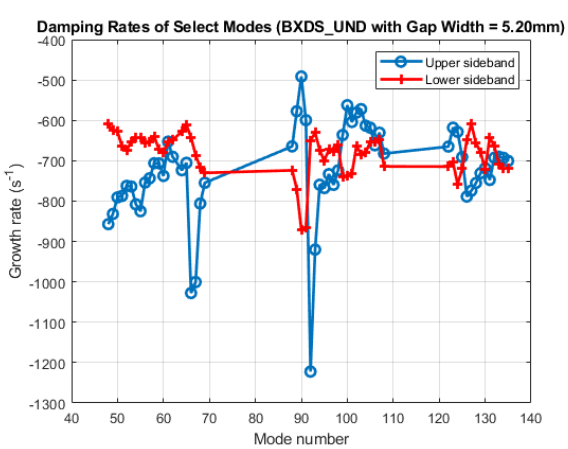

Figure 2: Selection of modal damping rates for the In-vacuum Undulator on the Brockhouse beamline (BXDS_UND).

RESULTS

Grow damp experiments showed expected results indicative of resistive wall effects [3, 4]. In repeated measurements, the highest and lowest modes routinely dominated results as they grew much more quickly than the mid-range modes prior to damping, seen in Fig. 3. The growth rate of these modes decreased with larger insertion device gap widths, seen in Fig. 4. Little structure was present and able to be measured in the mid-range modes.

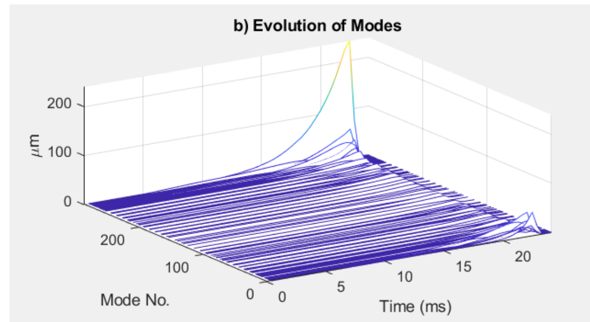

Figure 3: Typical result from a grow/damp measurement at the CLS storage ring. Mode damping was suspended for 23ms. The excitation of the highest and lowest modes are believed to be caused by the resistive-wall effect.

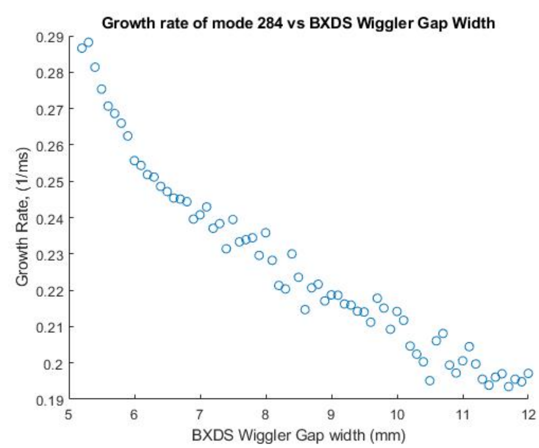

Figure 4: Modal growth rates of the top 284th mode. The growth rate slows as the gap width increases.

Results from excite damp measurements showed significant effects on the stability of specific modes when insertion devices had their gap width set to a specific distance. The Brockhouse Wiggler (BXDS_WIGG) in the storage ring shows a significant instability at low gap widths centred around modes 105 and 180, shown on Fig. 5. A sweep was performed to view how the instability changes at different wiggler gap widths. This instability persisted across multiple scans. Adjusting the gap of the IVW will change the cutoff frequency and the instability frequency. Adjusting the gap from 5.2 mm to 7.0 mm produced nine distinct peaks on different modes seen on Fig. 6. Results similar to these have been seen elsewhere on in-vacuum insertion devices [5].

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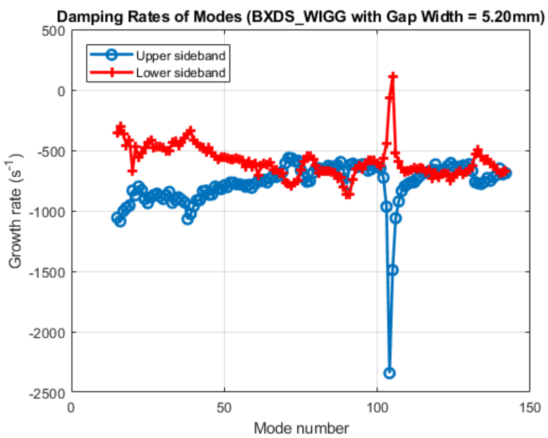

Figure 5: Decay rates on the Brockhouse Wiggler at the minimum gap width of 5.20 mm. Note the large spike in the growth rates present around mode 105 (corresponding to mode 180 on the lower sideband).

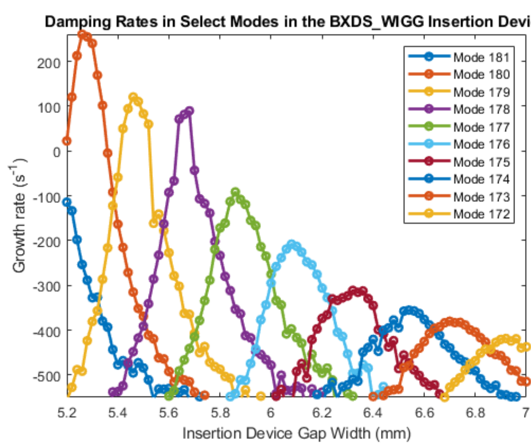

Figure 6: Decay rates of modes around mode 180. Each subsequent mode has a peak instability at a different gap width. Data on each peak is found in Table 1.

CONCLUSION

The use of excite damp measurements has been used to find instabilities in the CLS storage ring that may not be apparent in grow damp experiments. Work is currently being done to check how these results compare against EM simulation using wakefield solvers, an example of which is shown in Fig. 7. Additional upcoming work includes measurement of the coupled bunch mode instabilities while adjusting vertical angles and offsets in the Brockhouse Wiggler.

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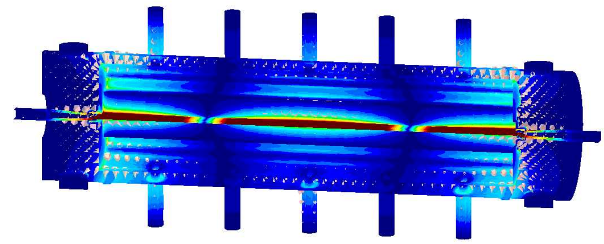

Figure 7: An eigenmode simulation of the Brockhouse beamline wiggler performed using GDFIDL [6] at 219 MHz.

APPENDIX

Table 1: Table of Modal Peaks Seen on Brockhouse Wiggler Instability

Mode Index	Gap Width at Peak	Mode Frequency
180	5.26 mm	183.69 MHz
179	5.46 mm	185.44 MHz
178	5.68 mm	187.20 MHz
177	5.86 mm	188.95 MHz
176	6.08 mm	190.71 MHz
175	6.32 mm	192.46 MHz
174	6.54 mm	194.22 MHz
173	6.70 mm	195.97 MHz
172	6.92 mm	197.73 MHz

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