OPERATIONAL AND BEAM STUDY RESULTS OF MEASUREMENTS WITH THE TRANSVERSE FEEDBACK SYSTEM AT THE CANADIAN LIGHT SOURCE

S. Martens*, T. Batten†, 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

Abstract

A transverse bunch-by-bunch feedback system has been installed in the storage ring at the Canadian Light Source (CLS) to counteract beam instabilities. The 2.9 GeV electron storage ring is 171 m in circumference with 13 insertion devices currently installed, each contributing to the impedance of the ring and lowering the instability threshold. The new Transverse Feedback System (TFBS) provides improved bunch isolation, higher bandwidth amplification and diagnostics to study, understand and damp these instabilities. This paper will show and overview of the system setup, examples of operational performance and results of the diagnostic capabilities, including tune feedback, grow/damp measurements, and excite/damp measurements.

SYSTEM OVERVIEW

The Canadian Light Source storage ring is a third generation light source. Current standard operation uses 220 mA of stored electron current in the ring. The storage ring uses a compact lattice consisting of twelve double-bend achromat cells [1]. A table of storage ring parameters is listed in Table 1 [2]. Recent improvements have allowed the ring to transition from a fill-decay operation to a top-up operation, keeping the beam current consistent. The storage ring is subject to coupled bunch instabilities that arise via interaction between the vacuum chamber and the stored electron current. Changes over time to the configuration of the storage ring have impacted the growth of these instabilities. To improve diagnostics and stability for the beam, the existing Transverse Feedback System (TFBS) was upgraded to include Dimtel Equipment to identify and mitigate against coupled bunch instabilities.

Table 1: CLS Ring Parameters

Circumference	170.88 m
Beam Energy	2.9 GeV
Beam Current	220 mA
Periodicity	12 Cell
RF Frequency	500 MHz
Harmonic Number	285
Momentum Compaction	0.0038

OPERATIONS

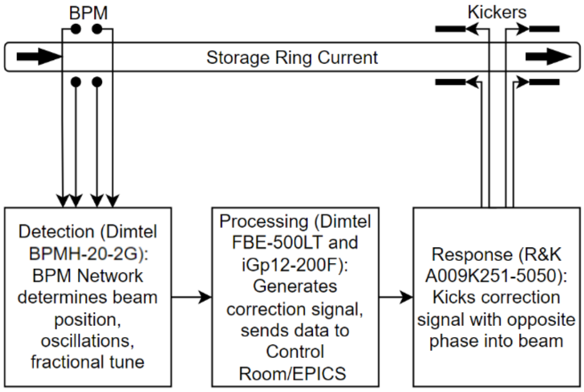

Figure 1: Transverse Feedback System Diagram and Hardware.

The Dimtel TFBS is currently in use in the storage ring to provide active damping against coupled bunch instabilities. In addition, it is used to provide bunch cleaning, tune measurements, tune feedback and diagnostics for beam instabilities in experiments.

TFBS Description

The TFBS uses three main elements depicted in Fig. 1. It uses a beam position monitor for detection, a network unit and processing system for analysis, and a kicker network for response. The four button BPM sends data to a hybrid RF-passive network unit which produces horizontal, vertical, and sum outputs. These signals are sent to the Bunch-By-Bunch Feedback front/back end unit and three 500 MHz processing units. The BPM signals are converted into a series of correction signals and sent to the response system which uses four broad-band RF power amplifiers and two kicker assemblies [3]. The 500 MHz RF signal is also input into the system to synchronise the timing [4]. The correction signal is applied to the beam to mitigate the instability identified by the processing system.

Tune Measurement and Feedback for Operations

The betatron tune of a synchrotron corresponds to the oscillation frequency of transverse motion within the ring. The number of complete oscillations within a single revolution of the ring is the integer tune, while the fractional oscillation corresponds to the fractional oscillation after a single turn [5]. The fractional tune can be measured by the

---

* Stephen.Martens@lightsource.ca
† Tonia.Batten@lightsource.ca
‡ mark.boland@lightsource.ca

TFBS parasitically by tracking the beam motion spectrum. A "notch" appears at the betatron frequency - tracking the location of the notch allows for tracking of the tune [4], seen in Fig. 2. Previous systems were unable to measure the tune without causing unacceptable orbit perturbations.

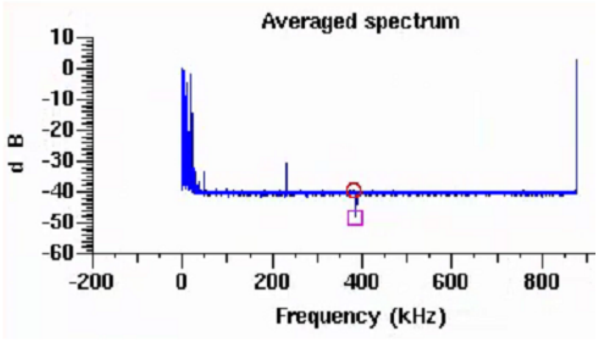

Figure 2: Transverse Feedback System displaying the averaged spectrum of the system. Note the "notch" in the spectrum identified with the square marker. This notch appears at the betatron frequency and tracking it allows for parasitic tune measurement.

The addition of the tune tracking provided by the TFBS also allows for a tune feedback system. Tune feedback collects fractional tune tracking measurements and identifies the difference from the set fractional tune. Quadrupoles in the storage ring lattice can be adjusted via a quadrupole feed-forward technique to correct tune shifts as they occur [6]. Tune feedback has successfully been implemented in October 2020 and is stabilizing the fractional tune during standard operation. The addition of tune feedback yields improved beam lifetime and injection efficiency [3].

DIAGNOSTICS FOR BEAM INSTABILITIES

The upgraded Dimtel TFBS allows for the measurement of coupled bunch instabilities across modes inside the storage ring. A ring with N bunches gives rise to N coupled bunch modes that can grow as a product of coupled bunch instabilities. Manipulation of the feedback network can allow these instabilities to grow intentionally, after which the growth and damping rates of modes along a single axis can be identified while varying storage ring conditions such as in-vacuum insertion device gaps.

Grow Damp Experiments

Early diagnostic experiments involved the use of grow damp measurements. The TFBS provides a "grow/damp enable" switch in software. A maximum of a 25.2 ms acquisition period is used to collect beam spot size data along one axis across all bunches. Some fraction of the acquisition period is dedicated to growth, and the remaining period is dedicated to damping. Upon enabling grow damps in software, the feedback network will be disabled across all bunches for the duration of the growth period. During this time, existing coupled bunch instabilities will cause the beam size to grow. At the end of the growth period, the feedback network is re-enabled and active damping against these instabilities resumes. Collected data is analysed using existing Dimtel MATLAB scripts which converts bunch data into modal data. An example can be seen in Figs. 3 and 4. Fitting exponentials to these modal growths can be done to find growth and damping rates and compared while varying storage ring parameters. Top-up of current is disabled throughout the experiment period as injection interfered with measurements. Results often showed large growths on the highest modes with little other structure present which is typically indicative of resistive wall instabilities [7, 8].

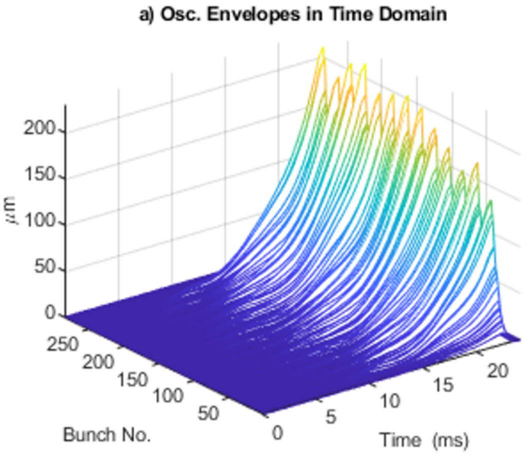

Figure 3: Example of Bunch Growth from a grow damp measurement. This measurement was taken while varying the gap width on the in-vacuum undulator (IVU) for the Brockhouse Beamline.

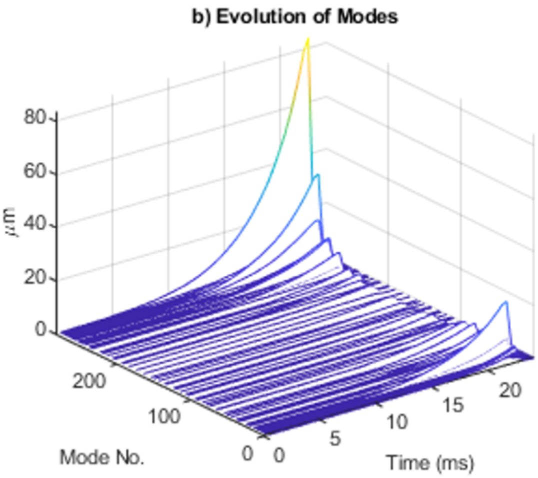

Figure 4: Example of Modal Growth from the same grow damp measurement as Fig. 3.

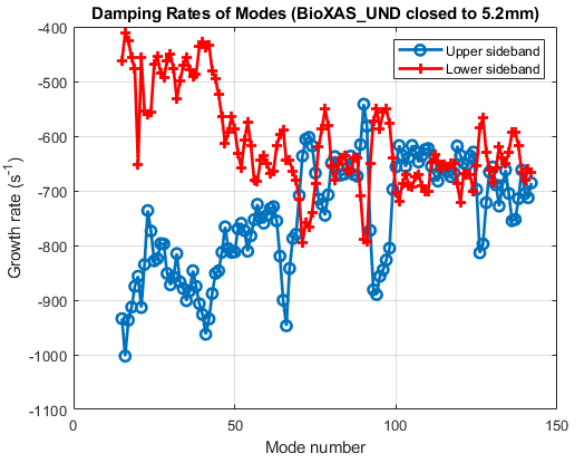

Figure 5: Example of modal damping rates from an excite damp experiment while varying the in-vacuum undulator gap width for the BioXAS beamline. The upper and lower sidebands are the sidebands of the revolution harmonic, and represent the first and second halves of the 285 modes in the CLS storage ring. The first and last 15 modes are removed.

Excite Damp Experiments

Later diagnostic experiments moved to using excite damp measurements. Grow damp measurements allow instabilities to grow passively by disabling the feedback network while excite damp measurements drive the feedback network to excite a specific mode deliberately. The iGp12 software was configured to have a gain of 0 during the growth period while an additional driving factor was prepared for every mode. Excitation would occur only on whichever modes were specified in Dimtel excite damp scripts. The damping acquisition period would occur over 10.0 ms with an additional 1.0 ms buffer [9].

Excite damp experiments were able to detect instabilities appearing on mid-range modes that could not be found with grow damps. Resistive wall effects that present on the highest modes make the stored beam too unstable too quickly during grow damp measurements for other modes to begin to show signs of unstable growth. Excite damp measurements can detect these instabilities due to their single-mode acquisition. Only the damping period of the acquisition is of interest as the growth period is largely driven by the intentional excitation by the feedback system rather than some property of the storage ring. The single-mode acquisition causes excite damp measurements to take significantly longer and require more storage space for raw data compared to grow damp measurements. These additional costs can be reduced by only scanning a pre-defined selection of modes rather than a full sweep. Examples of a sweep across all mid-range modes and of a pre-defined selection of modes can be seen in Figs. 5 and 6, respectively.

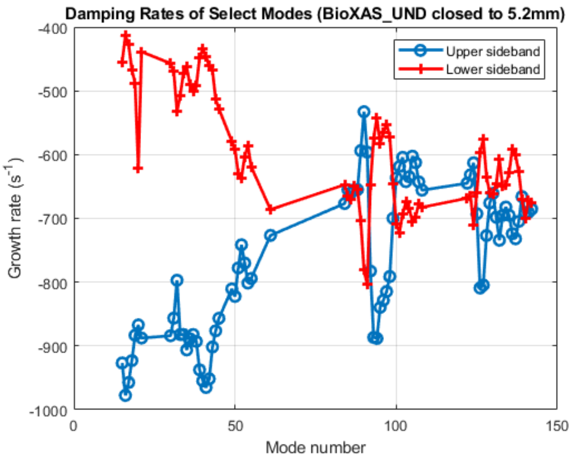

Figure 6: The same measurement as in Fig. 5, but a much smaller pre-defined selection of modes are scanned. Doing so significantly speeds up each scan.

CONCLUSION

The Dimtel Transverse Feedback System has integrated into the existing storage ring control system. The feedback system has been used to successfully mitigate against instabilities that arise in the storage ring. Tune measurement and feedback is also enabled by new TFBS. The new system has also been used in multiple kinds of diagnostic experiments to detect and identify sources of coupled bunch instabilities in the machine.

ACKNOWLEDGEMENTS

Many thanks to Dmitry Teytelman of Dimtel Inc. for his instruction, discussions and training in the setup and experimentation using the Transverse Feedback System. Research at the CLS is funded by the Canada Foundation for Innovation (CFI), the National Research Council Canada (NRC), Natural Sciences and Engineering Research Council of Canada (NSERC), the Canadian Institutes of Health Research (CIHR), Western Economic Diversification Canada (WD), the Government of Saskatchewan, and the University of Saskatchewan.

REFERENCES

[1] J. Cutler, D. Chapman, and R. Lamb, “Brightest Light in Canada: The Canadian Light Source,” *Synchrotron Radiat. News*, vol. 31, pp. 26–31, 2018. `doi:10.1080/08940886.2018.1409557`

[2] L. Dallin *et al.*, “Canadian Light Source Status and Commissioning Results,” in *Proc. EPAC’04*, Lucerne, Switzerland, Jul. 2004. `http://accelconf.web.cern.ch/e04/papers/THPKF007.pdf`

[3] T. Batten and J. Vogt, “Upgrade of the Transverse Feedback System at the Canadian Light Source,” presented at University of Saskatchewan, 2021, unpublished.

[4] D. Teytelman, *Bunch-by-bunch feedback and diagnostics in CLS*, 2018. `https://wiki.dimtel.com/lib/exe/fetch.php?media=dim:cls_analysis_07feb18.pdf`

[5] R. Steinhagen, *Tune and chromaticity diagnostics*, 2009. `https://www.tandfonline.com/doi/full/10.1080/08940886.2018.1409557`

[6] C. H. Kuo, J. Chen, P. C. Chiu, K. T. Hsu, and K. H. Hu, "Preliminary Tune Feedback Study in the Taiwan Light Source," in *Proc. DIPAC'11*, Hamburg, Germany, May 2011, pp. 491–493. `https://jacow.org/DIPAC2011/papers/TUPD79.pdf`

[7] S. Wang, M. G. Billing, S. Poprocki, D. L. Rubin, and D. Sagan, "Resistive Wall Instability and Impedance Studies of Narrow Undulator Chamber in CHESS-U," in *Proc. IPAC'17*, Copenhagen, Denmark, May 2017, pp. 3204–3207. `doi:10.18429/JACoW-IPAC2017-WEPIK110`

[8] A. Wolski, *Resistive Wall Instability in the NLC Main Damping Rings*, 2004, `https://escholarship.org/uc/item/3xc585kj`

[9] D. Teytelman, private communication about Excite Damp experiment, 2022.