ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP087

STATUS OF LONGITUDINAL BUNCH-BY-BUNCH FEEDBACK SYSTEM AT THE UPGRADED ADVANCED PHOTON SOURCE*

P. Kallakuri†, A. Brill, W. Cheng, L. Emery, R. Lindberg, U. Wienands
Argonne National Laboratory, Lemont, IL, USA

© Content from this work may be used under the terms of the CC BY 4.0 licence (© 2025). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

Abstract

The upgraded Advanced Photon Source (APS) is using twelve Radio Frequency (RF) cavities from the original APS RF system to compensate for beam energy loss. Undamped higher order modes (HOMs) from these cavities pose a risk of instability under the new APS conditions. Dimtel iGp12 processor-based bunch-by-bunch Longitudinal Feedback (LFB) system is developed to address longitudinal coupled-bunch instabilities caused by HOMs. These instabilities are exacerbated by the reduced synchrotron frequency and faster growth rates in presence of bunch lengthening system. The mitigation strategy involves initially reducing growth rates through precise cavity temperature tuning, followed by employing the LFB system to effectively manage residual growth rates. Resonance cavity temperatures of the HOMs have been characterized under APS conditions, providing a reference for tuning in the upgraded APS operation. The LFB system is designed to operate in both phase and energy sensing modes. This paper presents the feedback configuration, initial commissioning results with phase and energy sensing modes, and the feedback setup for operations.

INTRODUCTION

The upgraded Advanced Photon Source is using 12 RF cavities from the original APS 352 MHz RF system to make up the energy loss of the beam. Additionally, a 1408 MHz (4th-harmonic) superconducting Bunch Lengthening System (BLS) is installed to improve beam lifetime. The RF cavities have mostly undamped higher order modes, which may have instability growth rates greater than the radiation damping under the upgraded APS operating conditions. Design studies indicated the potential for longitudinal coupled-bunch instabilities driven by the HOMs of the RF cavities. Dimtel [1] bunch-by-bunch longitudinal feedback (LFB) system is installed to deal with the instabilities. The presence of the BLS introduces additional complexity, as instability growth rates increase with decreasing synchrotron frequency. Furthermore, the increased synchrotron frequency spread associated with the BLS makes feedback control more challenging. To address this, a dual mitigation strategy has been developed that combines precise RF cavity temperature tuning with the bunch-by-bunch feedback system. Temperature tuning of the HOM frequencies can effectively shift harmful modes away from synchrotron sidebands, significantly reducing growth rates and relaxing the requirements on the feedback system. After temperature tuning, the longitudinal feedback system can more effectively damp the remaining modest growth rates. The resonance temperatures of RF cavity HOMs have been characterized under APS operating conditions [2, 3]. The longitudinal feedback system's front-end has been utilized as a diagnostic tool to map the resonant cavity water temperatures corresponding to HOMs. Growth rates for each mode across 324 bunches were measured by selectively exciting individual modes. A comprehensive dataset of HOM resonance peaks over a wide range of cavity temperatures has been collected. This mapping serves as a reference for optimal cavity temperature tuning during upgraded APS operation, even with variations in the working RF frequency and cavity power.

Traditionally, longitudinal feedback systems rely on measured bunch phase for feedback corrections. However, the synchrotron period is longer with the higher harmonic cavity in operation, requiring faster detection and correction of unstable motion seeded by energy errors. Energy sensing is a suitable option in this scenario, as it detects energy errors based on the transverse offset of the beam in a dispersive region. The front-end of the LFB system has been designed to operate in both phase-sensing and energy-sensing configurations. This paper presents the architecture of the feedback system, initial commissioning results, and details of the user operation setup.

FEEDBACK SYSTEM ARCHITECTURE

General block diagram of the longitudinal bunch by bunch feedback system is shown in Fig. 1. Beam position monitor (BPM) is used for beam pickup. Phase sensing uses sum signal from a non dispersive BPM and energy sensing uses ΔX signal from a dispersive BPM. Front-end electronics provide baseband signal to the controller on iGp12 processor which computes correction signals, and back-end processes the signal to provide an analog output to RF power amplifiers.

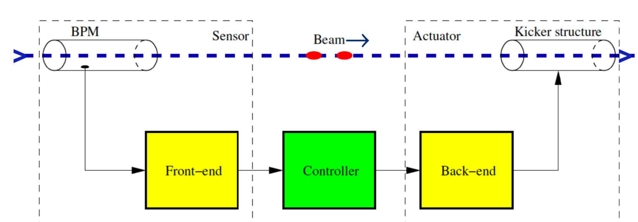

Figure 1: Block diagram of the closed loop feedback configuration

Physical layout of the longitudinal feedback system at upgraded APS is shown in Fig. 2. Sampling Rate of the feedback processor is 352.055 MHz, max. damping rate is 500/s, and back-end 3 dB bandwidth is 60 MHz. Two

---
* This work was supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-ACO2-O6CH11357.

† pkallakuri@anl.gov

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP087

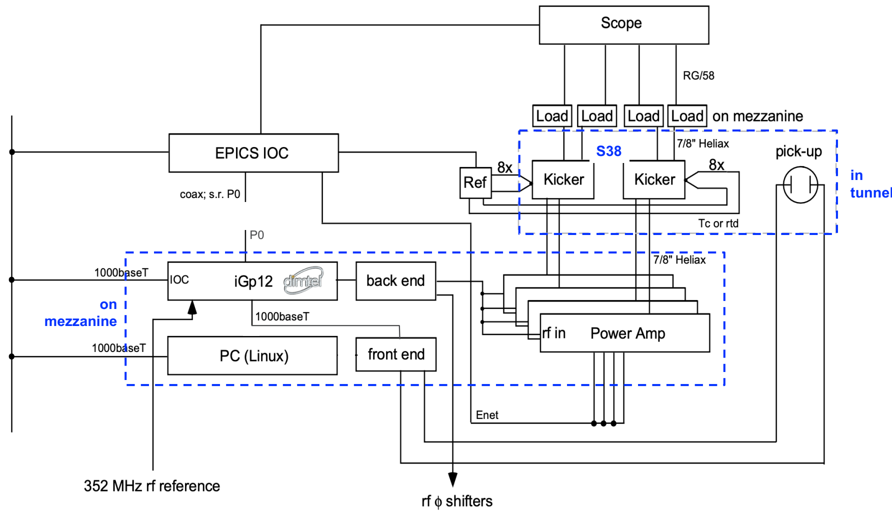

Figure 2: Longitudinal feedback system layout at upgraded APS.

cavity kickers provide electric field to the beam, correcting the energy deviation. Kicker voltage is 2.2 kV per kicker, each kicker has two wide-band power amplifiers with max. output power 500 W per amplifier and output bandwidth is 850-1200 MHz.

COMMISSIONING AND SETUP FOR USER OPERATIONS

The longitudinal feedback system was initially tested using the phase sensing configuration. Subsequently, we successfully implemented the energy sensing configuration, marking the first application of its kind in longitudinal feedback systems. The setup for energy sensing involved several modifications and optimizations. The analog front-end ΔX output from the dispersive pickup is used for the digitizer. The front-end phase was adjusted to maximize signal amplitude. The finite impulse response (FIR) filter settings, feedback down-sampling rate, and shift gain values were carefully tuned. There were no changes made to the feedback timing, fiducial delay, or back-end phase settings during the transition to energy sensing mode. Preliminary analysis revealed that the energy sensing configuration is more effective in damping unstable modes compared to phase sensing. Even at shift gain 3 it reliably suppressed the unstable mode compared to shift gain of 6 needed in phase sensing mode. Also, the spectrum data is less noisy compared to phase sensing.

Currently, the longitudinal feedback system is operating in energy sensing mode for user operations. Efforts are ongoing to further investigate and characterize the effectiveness of both configurations. The grow-damp diagnostic capabilities of the Dimtel feedback system are being utilized to characterize the damping rates achieved by the feedback system. Modal amplitudes for mode 34 and mode 16, obtained from grow-damp measurements, are presented in Fig. 3. With the bunch-lengthening cavity in operation, a feedback damping rate of 11 ms has been achieved. However, further work is required to gain a deeper understanding of the operational conditions and enhance the feedback damping performance.

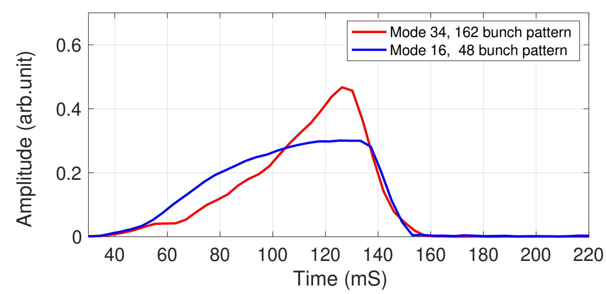

Figure 3: Modal amplitudes from grow-damp measurements.

We have encountered instabilities arising from cavity higher-order modes during the ramp-up of beam current and bunch-lengthening system voltage. So far, three significant cavity HOMs have been identified: mode 88 from S37C3 (Sector 37 Cavity 3), mode 34 from S40C1, and mode 138 from S40C3. The amplitudes of these modes were reduced by adjusting the respective cavity water temperatures, which effectively shifted the HOM frequencies away from resonance with the beam. Notably, the longitudinal feedback system was able to damp the growing instabilities of Mode 88 and Mode 34 even without temperature tuning. Figure 4 presents the modal amplitude data highlighting mode 88 instability and subsequent suppression of the mode either through temperature tuning or by relying solely on the longitudinal feedback system.

Setup for User Operations

The longitudinal feedback is employed for user operation with standard lattice (typically 162 bunches or more) and in timing mode (with 48 bunches). For standard operation with 216 bunches the beam current is 200 mA and BLS voltage is 1100 kV. For timing mode with 48 bunches the beam current is 130 mA with BLS voltage at 900 kV. The evolution

Content from this work may be used under the terms of the CC BY 4.0 licence (© 2025). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

ISBN: 978-3-95450-261-5 ISSN: 2673-7000 doi: 10.18429/JACoW-NAPAC2025-MOP087

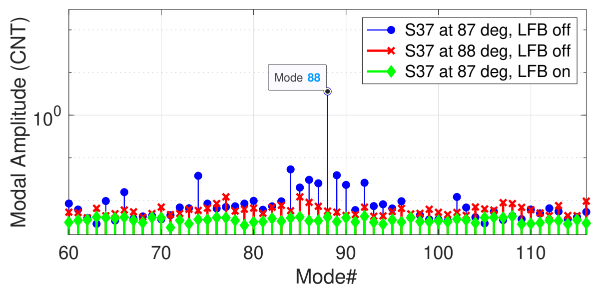

Figure 4: Modal amplitudes of highlighting mode 88 instability (in blue), suppression by cavity temperature tuning (in red) and with LFB alone (in green).

of the averaged bunch spectrum as the beam current and BLS voltage ramp up to operational values for the 48-bunch pattern is shown in Fig. 5. The dominant frequencies in the spectrum shift due to changes in the synchrotron frequency, which are influenced by both the BLS voltage and beam loading effects. To ensure optimal performance, the feedback settings must be adjusted to account for the shifts in peak amplitude frequencies at the operational beam current. To further analyze and understand the behavior of the bunch spectrum, we have developed new procedures to measure the mode-0 and higher-order mode synchrotron frequencies.

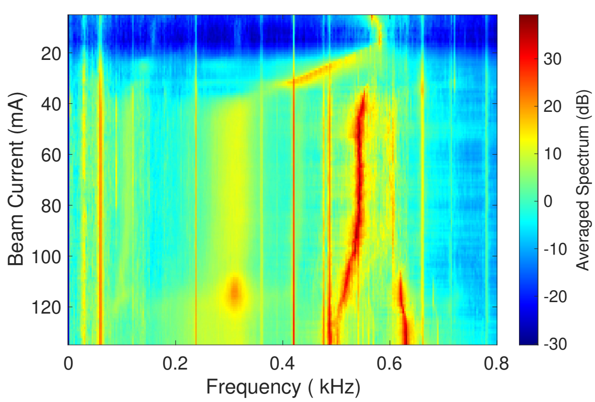

Figure 5: Averaged bunch spectrum during the fill from zero current to 130 mA in 48 bunch operation.

Figure 6 compares the averaged spectrum data for open-loop operation and closed-loop operation using two different FIR filters. The filter coefficients for Filter 1 and Filter 2 are provided in Fig. 7.

The broad peak around 290 Hz in Fig. 6 corresponds to the HOM synchrotron tune. This resonance is effectively suppressed when Filter 1 is applied in the feedback loop, making it the optimal choice for beam currents around 115 mA. At higher beam currents (> 120 mA), a significant peak emerges around 620 Hz. Filter 2 reduces the amplitude of this peak, leading to improved orbit motion. However, Filter 2 has no effect on the broad synchrotron resonance near 290 Hz and shifted the peak by 20 Hz. We are investigating the origin of the 620 Hz frequency peak that appears at higher beam currents and BLS voltage settings. Additionally, we are working on refining measurement procedures to analyze spread of synchrotron frequencies within the bunch. These

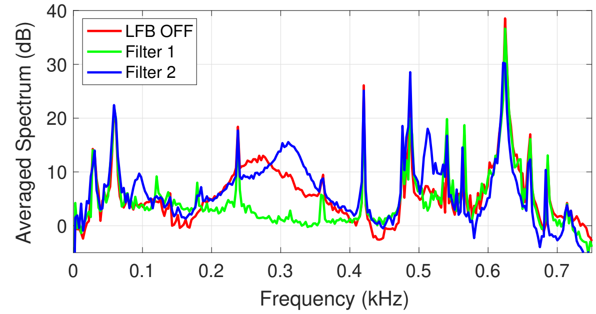

Figure 6: Averaged spectrum in open loop and with two feedback filter settings. Beam current is 130 mA, BLS voltage is 900 kV with 48 bunch pattern.

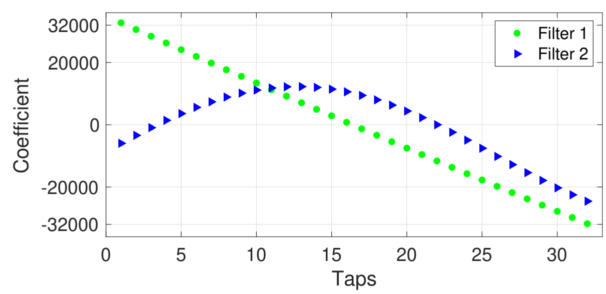

Figure 7: FIR filter coefficients. Feedback down sampling is 20 with shift-gain 3.

efforts aim to optimize the feedback controller for enhanced performance under varying operational conditions.

CONCLUSIONS

The Dimtel iGp12 processor-based longitudinal feedback system has been successfully commissioned at the upgraded APS. Initial testing was conducted using phase sensing, followed by the implementation of an energy sensing configuration the first of its kind in longitudinal feedback systems. Energy sensing has proven effective in damping unstable modes during initial analysis and is actively used in operations. Characterization of resonance cavity temperatures under APS operating conditions has provided a valuable reference for tuning temperatures for upgraded APS. Instabilities driven by higher-order modes were successfully mitigated. Ongoing efforts to refine feedback settings, measure synchrotron frequency shifts, and analyze synchrotron tune spread are focused on further enhancing system performance and operational stability.

REFERENCES

[1] Dimtel, `http://dimtel.com`

[2] L. Emery, P. S. Kallakuri, D. Teytelman, and U. Wienands, “Precision Cavity Higher-Order Mode Tuning Scheme for Stabilizing the Stored Beam in the Advanced Photon Source Upgrade”, in *Proc. NAPAC’19*, Lansing, MI, USA, Sep. 2019, pp. 670–672. `doi:10.18429/JACoW-NAPAC2019-WEPLM04`

[3] K. C. Harkay *et al.*, “Characterizing the Coupled Bunch Driving Terms in a Storage Ring”, in *Proc. IBIC’17*, Grand Rapids, MI, USA, Aug. 2017, pp. 21–27. `doi:10.18429/JACoW-IBIC2017-MO3AB1`

© Content from this work may be used under the terms of the CC BY 4.0 licence (© 2025). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.