INTEGRATION OF X-RAY DIAGNOSTICS INTO FAST ORBIT FEEDBACK FOR LOCAL SOURCE STABILIZATION AT NSLS-II

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Abstract

We present an accelerator-based X-ray beam stabilization approach that integrates X-ray beam position monitor (XBPM) signals into the fast orbit feedback (FOFB) system at NSLS-II. A high-speed electrometer and fiber-optic data link were developed to transmit XBPM position data to the storage-ring feedback controller at a 10 kHz rate. On the accelerator side, the XBPM signal is incorporated into the FOFB infrastructure as a virtual beam position monitor, allowing photon beam motion to be corrected through the electron beam orbit using fast corrector magnets. Experimental tests demonstrate suppression of dominant beamline vibration peaks near 27 Hz and 120 Hz when the feedback is enabled. These results demonstrate the feasibility of integrating photon diagnostics into accelerator feedback systems for improved X-ray beam stability and motivate the development of unified photon–electron feedback architectures for routine operation.

INTRODUCTION

Modern synchrotron experiments increasingly require high stability of the delivered X-ray beam, particularly for techniques that rely on precise beam positioning. Storage rings typically employ fast orbit feedback systems to stabilize the electron beam orbit using signals from electron beam position monitors (BPMs). While this approach effectively suppresses electron orbit motion, it does not directly measure the photon beam delivered to beamlines. As a result, residual X-ray beam motion may occur when disturbances originate from beamline optics rather than from the electron beam itself.

To address this limitation, we developed a system that integrates X-ray beam position monitor signals into the existing FOFB infrastructure at the Hard X-ray Nanoprobe (HXN) beamline of the National Synchrotron Light Source II.

In this approach, the X-ray beam position is used as the feedback signal while the electron beam orbit acts as the actuator through fast corrector magnets. This paper describes the architecture of the system and demonstrates its operation for source stabilization using X-ray diagnostics.

SYSTEM ARCHITECTURE

The X-ray feedback system integrates photon beam diagnostics with the accelerator FOFB infrastructure, as illustrated in Fig. 1. X-ray beam position is measured using diamond X-ray beam position monitors installed along the Hard X-ray Nanoprobe beamline of the National Synchrotron Light Source II. The XBPM electrodes generate photocurrent proportional to the incident X-ray beam intensity, and beam position is computed using the difference-over-sum method. The resulting beam position signals serve as the input to the feedback system.

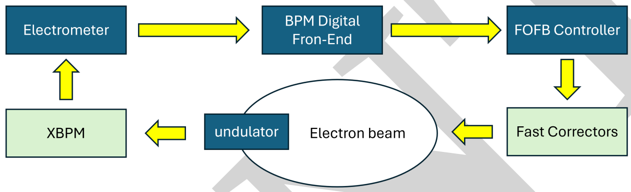

Figure 1: Conceptual architecture of the X-ray feedback system. X-ray beam position measured by the XBPM is digitized by a high-speed electrometer and transmitted to the accelerator feedback system through the BPM digital front-end. The fast orbit feedback controller drives fast corrector magnets to adjust the electron beam orbit near the insertion device, forming a closed-loop X-ray feedback system.

The XBPM currents are read out using a four-channel high-speed electrometer developed at NSLS-II. The electrometer digitizes the detector currents using high-resolution analog-to-digital converters and performs real-time signal processing in FPGA logic to calculate beam position and intensity [1]. The FPGA processes the electrode signals and generates beam position data streams at approximately 10 kHz, providing a data rate suitable for integration into the existing feedback system [2].

The processed XBPM position data are transmitted from the beamline electronics to the accelerator feedback system through a high-speed optical fiber link. This fiber-optic connection provides a low-latency communication path between the beamline instrumentation and the storage-ring control system. At the accelerator side, a digital front-end module receives the transmitted data and converts them into a format compatible with the BPM data stream used by the FOFB system [3]. In this configuration, the X-ray beam position signal can be treated as an additional virtual BPM input by the controller without modification of the core feedback algorithm.

The feedback system calculates the required orbit correction and drives fast corrector magnets distributed around the storage ring. To confine the feedback action near the beamline insertion device, a local orbit bump was implemented using multiple fast corrector magnets to control the electron beam position and angle at the insertion device source point.

This configuration minimizes orbit perturbation elsewhere in the storage ring while allowing the electron beam source position to be adjusted in response to the XBPM signal.

Photographs of the main hardware components used in the system are shown in Fig. 2, including the XBPM detector, the electrometer readout unit, and the BPM digital front-end used to receive XBPM position data for the feedback system.

Figure 2: Hardware components of the X-ray feedback system. (a) Diamond X-ray beam position monitor installed in the HXN beamline. (b) NSLS-II electrometer used for XBPM signal readout and digital processing. (c) BPM digital front-end in the storage-ring mezzanine used to receive XBPM position data and interface with the fast orbit feedback system.

EXPERIMENTAL DEMONSTRATION

The integrated feedback system was tested at the HXN beamline using the downstream XBPM as the feedback input signal. A local orbit bump using fast corrector magnets controlled the electron beam position and angle at the insertion device source point. In this configuration, the X-ray beam position measured by the XBPM was used as the feedback error signal while the electron beam orbit served as the actuator through the feedback system.

Figure 3 shows the power spectral density of the X-ray beam position measured at the beamline with the feedback disabled and enabled. With the X-ray feedback enabled, the dominant vibration peaks near 27 Hz and 120 Hz are reduced by more than 80%. A detailed analysis of the feedback performance and beam stability improvements is reported in Ref. [4, 5].

SUMMARY

An accelerator-based X-ray beam stabilization system has been developed by integrating X-ray beam position monitor signals into the fast orbit feedback infrastructure at NSLS-II. The system combines XBPM diagnostics, a high-speed electrometer readout, and a fiber-optic data path to deliver photon beam position data to the storage-ring feedback controller at 10 kHz.

A local orbit bump implemented using multiple correctors confines the feedback action near the beamline insertion device and reduces orbit leakage to the rest of the storage ring to below 1 μm RMS. Experimental tests demonstrate successful operation of the integrated feedback loop and show that X-ray–driven source feedback can significantly suppress beamline-induced vibrations. These results demonstrate the feasibility of incorporating photon diagnostics into accelerator feedback systems for improved X-ray beam stability.

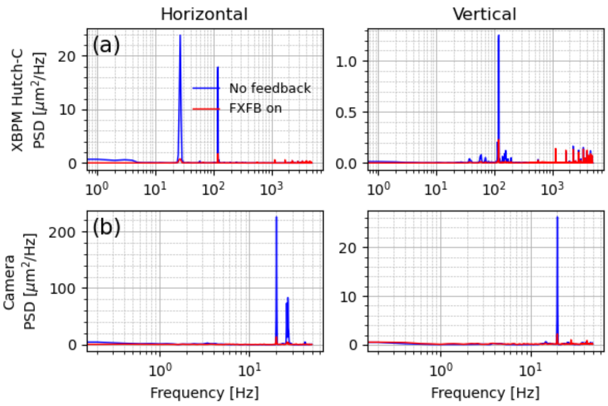

Figure 3: Power spectral density of the X-ray beam position with the X-ray feedback disabled and enabled. (a) PSD measured by the XBPM at Hutch-C along the HXN beamline. (b) PSD measured by the beamline camera at the focusing optics. The dominant vibration peaks near 27 Hz and 120 Hz are significantly suppressed when the feedback is enabled.

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