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THE CONTROL AND MONITORING SYSTEM FOR THE APS-U FRONT-END XBPM*

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Abstract

The Advanced Photon Source Upgrade (APS-U) project aims to enhance the performance and capabilities of the APS, delivering brighter and more coherent x-ray beams to support cutting-edge scientific research. A critical component of this upgrade is the front-end X-ray Beam Position Monitor (XBPM) system, which plays a vital role in ensuring beam stability and precision. This paper presents the design and implementation of the control and monitoring system for the APS-U front-end XBPM. The system integrates advanced hardware and software solutions to achieve real-time monitoring of x-ray beam position. Key features include high-resolution data acquisition, robust signal processing algorithms, and seamless integration with the APS-U control architecture. The system utilizes the Experimental Physics and Industrial Control System (EPICS) input/output controllers (IOCs) to interface with front-end instruments. By leveraging EPICS IOCs, the system achieves high reliability and flexibility.

INTRODUCTION

The original APS XBPM system relied on a commercial VME-based DSP card to acquire and process X-ray blade signals for determining beam position for both bending magnet (BM) and insertion device (ID) beamlines. It also processed position data from narrowband RF BPMs adjacent to each insertion device, integrating with the storage-ring fast-feedback system and providing filtered data to both the feedback system and the EPICS control system [1].

Figure 1 shows the original XBPM system diagram. This system served reliably for over 20 years.

The APS-U project introduced significant upgrades to front-end and insertion devices to handle increased power. Two new types of insertion device front ends were implemented:

- High heat load front end (HHLFE) for dual inline undulator sources.
- Canted front end (CFE) for two canted undulators with a cant angle of 1 mrad [2].

These front ends employ novel XBPMs—HHLFE-XBPM and CFE-XBPM—to monitor beam stability. All ID front ends now feature these XBPMs to ensure long-term beamline stability, while BM front ends were minimally modified and reused. The upgraded XBPM front-end electronics provide Ethernet interfaces, delivering beam position information to EPICS IOCs for further processing.

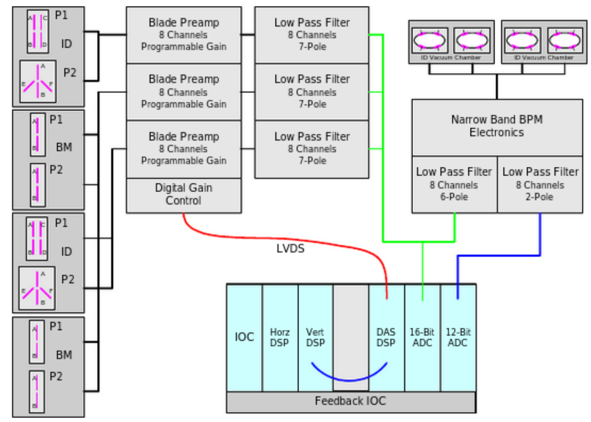

Figure 1: Original APS XBPM system diagram.

CONTROL SYSTEM OVERVIEW

ID Front-End XBPMs

The APS-U ID front-end features two X-ray beam position monitor assemblies:

- XBPM1: Uses array detectors to detect X-ray beam and calculate the X-ray beam position. Figure 2 shows the concept.
- XBPM2: Utilizes X-ray fluorescence from the exit mask to read out the beam position at the mask.

For the CFE, XBPM2 monitors beam positions of both upstream (US) and downstream (DS) undulator beams.

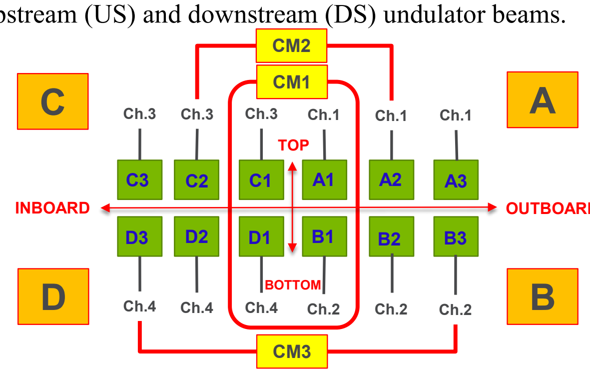

Figure 2: Concept of XBPM1 with array detectors.

BM Front-End XBPMs

The BM front end has two X-ray beam position monitors, each equipped with molybdenum photoemission blades.

Typically:

- Each ID XBPM1 uses three picoammeters.
- Each ID XBPM2 uses one picoammeter.
- Each BM XBPM uses one picoammeter.

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System Software Structure

Figure 3 shows the software structure of ID XBPM. The upstream and downstream insertion devices are running independently. Hence their XBPMs are considered independent devices from each other. The top-level program (GUI) deals with EPICS process variables in both level 0 and level 1. Figure 4 shows the concept of the BMFE XBPM software structure.

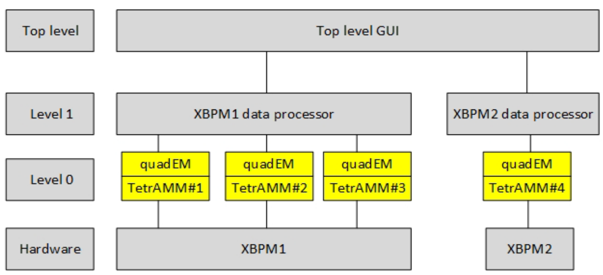

Figure 3: Software structure of ID XBPM data processing.

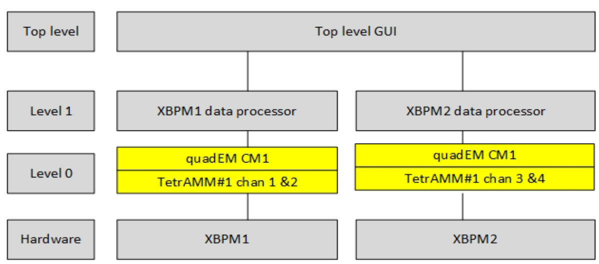

Figure 4: Software structure of BMFE XBPM data processing.

FRONT-END ELECTRONICS

The system employs CAENels TetrAMM picoammeters [3] to measure XBPM detector signals. The TetrAMM is a four-channel, 24-bit resolution, wide-bandwidth, wide-dynamic range picoammeter with an integrated high-voltage bias source (0–500 V). Key features include:

- Bipolar current measurements from 120 nA (with ~15 fA resolution) up to 120 µA (15 pA resolution).
- Sampling frequencies up to 100 kHz for four channels at 24-bit resolution.
- Low temperature drift, high linearity, and low noise for high-precision current measurements [3].

The device provides communication using TCP/IP over 1 Gbit/s Ethernet.

SYSTEM SOFTWARE

The APS comprises 40 sectors, with XBPMs currently installed from sector 1 to 35. Each sector has one XBPM IOC, capable of handling all three XBPM types.

IOC Modules

The XBPM IOC uses the following EPICS modules:

- asynDriver: A general-purpose facility for interfacing with a wide variety of hardware devices and communication protocols.
- areaDetector: An application for managing and processing data from area (2D) detectors, such as CCD cameras, CMOS cameras, X-ray detectors, and other imaging devices.
- quadEM: Provides an interface for controlling quadrant electrometers and acquiring data from them. It supports a variety of hardware devices to integrate seamlessly into EPICS-based control systems.
- iocStd: Provides standard facilities for APS IOCs, including preconfigured templates for required standard functionalities.
- iocStats: Provides records for monitoring IOC health and status, along with control records.
- CaPutLog: Logs Channel Access put operations.
- Autosave: Automatically saves EPICS process variable values to files and restores them upon IOC reboot.
- seq: EPICS State Notation Language compiler and runtime sequencer.

ID XBPM1 Data Processing

The IOC performs the following algorithms:

- Background Subtraction: Evaluates and subtracts BM background signals when undulator power is low.
- Normalization: Normalizes the undulator signal to correct for detector asymmetry.
- Position Calculation: Calculates horizontal and vertical undulator beam positions.
- Statistics Collection: Computes filtered beam position data over 1, 8, and 64 seconds, estimating RMS beam motion and XBPM resolution for both unfiltered and filtered outputs.

These algorithms are implemented within the IOC database.

Gap-Dependent Calibration

The XBPM references a comprehensive table of gap-dependent calibration factors, offsets, and weighting factors. A dedicated software module stores these values and interpolates as needed for gaps not explicitly listed.

Frozen Detection

During initial testing and commissioning, instances were observed where the XBPM IOC lost communication with front-end electronics, or hardware issues caused the XBPM signal to remain static. To address this, an EPICS IOC sequence program was developed to detect frozen status by monitoring input currents and applying a frozen detection algorithm, with results displayed on the user interface.

Filter and Statistics Module

The APS data logger records machine performance using filtered RF BPM process variables. Three filter levels are implemented, with cutoff frequencies of 0.16 Hz, 0.02 Hz, and 0.0025 Hz. The APS-U XBPM system mirrors this approach, utilizing exponential moving average (EMA) filters for their simplicity and responsiveness. Standard deviations of filtered XBPM data are calculated, along with real-time differential noise (resolution) estimates.

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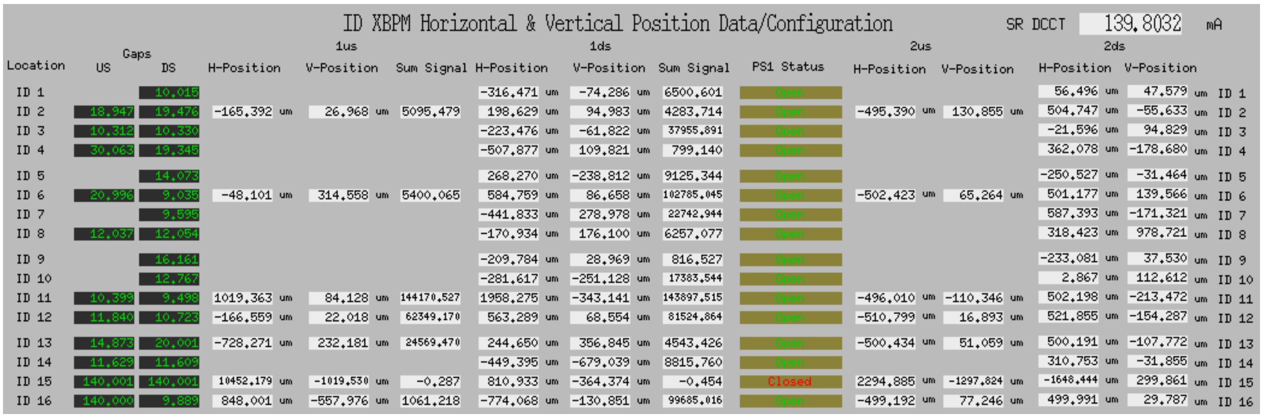

Figure 5: Part of ID XBPM overview user interface.

Software Management

EPICS-sumo [4] is used to manage EPICS module dependencies, while Git provides version control for EPICS IOC software.

IOC Boot Management

A general tool, systemd, is employed for APS-U control system applications, enabling reboot or shutdown of all or individual XBPM IOCs.

USER INTERFACE

The EPICS client tool MEDM is used to create the user interface, which includes:

- Top-Level Display: Overview of horizontal and vertical XBPM positions for all sector ID and BM front ends.
- Second-Level Display: Detailed information for individual XBPMs, with navigation to further details.
- Low-Level Display: In-depth data on filtered XBPM and noise, front-end electronics measurements and setup, gap-dependent calibration parameters, background coefficient setup, XBPM profiles for machine studies and commissioning, and normalization parameter setup.

Figures 5–7 illustrate various user interface displays.

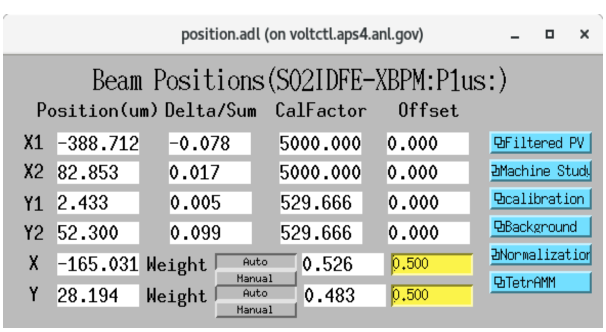

Figure 6: IDFE XBPM user interface.

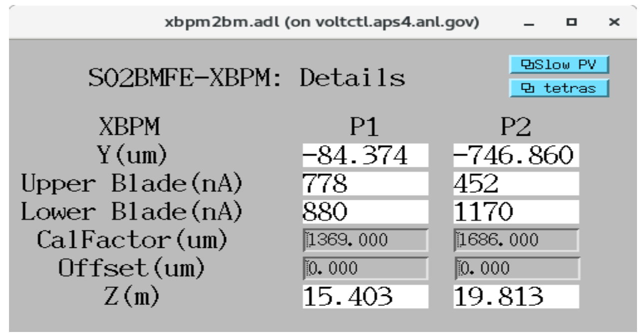

Figure 7: BMFE XBPM user interface.

CONCLUSION

The APS-U XBPM control and data processing system has proven effective, greatly aiding beamline commissioning and machine studies. It is expected to play a critical role in the APS-U storage-ring fast orbit feedback system, providing users with a more stable beam.

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REFERENCES

[1] F. Lenkszus, G. Decker, L. Erwin, M. Hahne, R. Laird, and O. Singh, "New X-ray BPM Data Acquisition System for the APS", in Proc. PAC'01, Chicago, IL, USA, Jun. 2001, paper TOPB011, pp. 289-291. doi: `10.1109/PAC.2001.987496`

[2] Y. Jaski *et al.*, "Front End Designs for the Advanced Photon Source Multi-bend Achromats Upgrade", in *Proc. MEDSI'18*, Paris, France, Jun. 2018, pp. 388-390. `doi:10.18429/JACoW-MEDSI2018-THPH24`

[3] TetrAMM Product Information, `https://www.caenels.com/product/tetramm/`

[4] EPICS-sumo, `https://epics-sumo.sourceforge.io/`