ADVANCED X-RAY BEAM POSITION MONITOR SYSTEM DESIGN AT THE APS*

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Abstract

As part of the Advanced Photon Source (APS) Upgrade, new x-ray beamline front ends are planned that include extensive integrated x-ray diagnostic capability. The high-heat-load front-end (HHLFE) design includes a grazing-incidence insertion device x-ray beam position monitor (GRID-XBPM) utilizing Cu K-edge x-ray fluorescence from x-rays striking a pair of copper absorbers. At a 1.0˚ grazing incidence angle, the XBPM assembly is designed to withstand 17 kW power from two inline Undulator A devices at 150-mA stored beam. A second XBPM located outside of the accelerator enclosure monitors fluorescence from the beamline exit mask, which is a critical beamline-defining aperture. In addition, an intensity monitor is used to detect x-ray flux passing through a front-end mask inside the enclosure, while a second intensity monitor is located immediately downstream of the exit mask. Details of these designs and expected performance will be presented.

INTRODUCTION

The ongoing Advanced Photon Source Upgrade (APS-U) requires major improvements in x-ray beam stability. The stability goals are to be achieved on multiple beamlines with two inline Undulators A's delivering beam power up to 17 kW at 150-mA stored current. Since the modern storage ring orbit feedback systems have demonstrated submicron stabilities, the actual x-ray beam stability delivered to the user is determined by the accuracy of the beam position monitors. In the past several years, the APS has made a major effort in developing a hard x-ray BPM. The new device uses the 8-keV Cu K-edge x-ray fluorescence (XRF) from the front-end limiting apertures to infer the undulator beam's core position [1,2]. An experimental test with two inline undulators showed that the XBPM has nearly 70-fold improvement in rejection of bend magnet radiation background and a gap-independent calibration in one of the two dimensions [3]. Based on this successful demonstration, the GRID-XBPM was included as a standard device for the new HHLFEs being developed for the APS-U. In this paper, we report the engineering design of the new XBPM system, including a GRID-XBPM, the second XBPM at the end of the front end, and the two intensity monitors to assist for beam-based alignment of front end apertures. We will also report on the latest design development of a new XBPM based on Compton scattering.

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THE FIRST XBPM

Figure 1 shows the first XBPM. It is a GRID-XBPM consisting of two GlidCop absorbers, positioned on the left and right sides of the undulator beam axis. At 1.0˚ grazing incidence angle, they intercept up to 11.5 kW of undulator power during user operations and are able to withstand the full beam in case of mis-steering. The XBPM reads out vertical positions using x-ray pinhole camera optics, with a calibration independent of undulator gaps. It derives horizontal beam position from the difference/sum of the x-ray detector signals from the left and right absorbers. Hence the horizontal position calibration depends on the beam sizes, or undulator gaps. To meet the stringent stability requirements, the pinhole camera and detectors are mechanically isolated from the absorbers, and its height above the floor is monitored in real time by a mechanical motion sensor mounted on an Invar rod. External perturbations to the XBPM include: (1) the annual air pressure variation of 0.6% [4], which distorts the XBPM support plate; and (2) the thermal load of the x-ray beam on the XBPM assembly. Table 1 summarizes the ANSYS analyses for the impacts of these external perturbations. We can see that most distortions are within specifications. The thermal-distortion-induced vertical detector position change will be monitored and corrected in real time with the mechanical motion sensor or treated as gap-dependent XBPM offset.

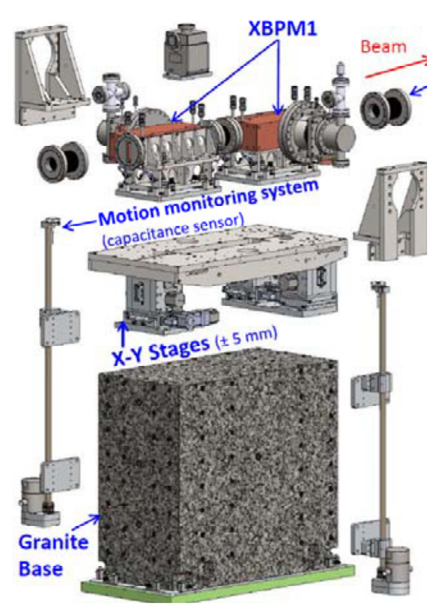

Figure 1: The GRID-XBPM for the APS-U high-heat-load front end.

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Table 1: Externally Induced XBPM Position Change

	Angular	Vertical
Barometric Pressure (0.6% rms)	±0.4 µrad	0.04 µm
Beam Load	±0.4 µrad	7 µm
Specifications	2 µrad	3 µm

THE SECOND XBPM

The exit mask of the HHLFE is a critical component of the beamline. It defines the exit aperture of the front end and protects the downstream bremsstrahlung shield from radiation damage. During normal beam operations, it intercepts up to 3.5 kW x-ray power. The fluorescence photons generated by the intercepted beam will be used by the second XBPM to infer the core beam position utilizing yet another set of pinhole camera optics. Figure 2 shows the arrangement of the XBPM2 components. Four silicon photodiodes are used to read out the horizontal and vertical positions of the x-ray footprint on the exit mask. This XBPM will not be linked to the orbit feedback system, but its information will be recorded and logged during user operations.

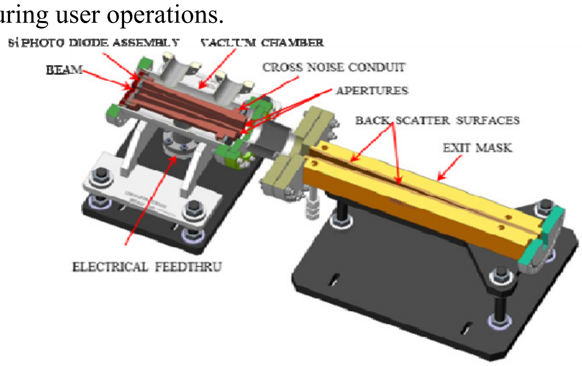

Figure 2: XBPM 2 design. A pair of apertures and four Si PIN diodes form a pinhole camera to read out the position of the x-ray footprint on the exit mask.

THE INTENSITY MONITORS

Two beam intensity monitors, IM1 and IM2, are planned for the new front ends. During normal operations, up to 100-W x-ray photons will be removed from the beam by the front-end beryllium windows, including 30-W x-rays by Rayleigh and Compton scatterings. These scattered photons can be detected using metallic photocathodes or silicon photodiodes, and the signal can be used to center the undulator beam on the exit mask by scanning the electron beam. The symmetry points of the scanning curve serve as the fiducial marks of the XBPM, allowing the operator to put the XBPM back to its standard state after each shutdown, or after the XBPM and its electronics are repaired or serviced. Figure 3 shows the design of the IM2: A large-area gold-coated photocathode is used to capture the scattered radiation from the Be window. The inset shows the estimate photocurrent as a function of undulator K-value, using known x-ray scattering cross sections [5]. For the operating range of Undulator A, the signal current remains in microampere range within a dynamic range of 1:7.

The first intensity monitor (IM1) uses the x-ray fluorescence from the photon shutter to measure the beam intensity passing through the upstream apertures inside the front end. By design, it will be used to fiducialize the GRID-XBPM during machine studies before user operations. Since it is a retrofit to existing photon shutters, the challenging part is to make the signal proportional to the total beam intensity but independent of the beam position on the grazing incidence shutter. Figure 4 shows the arrangement of IM1 components: a combination of an aperture edge and an EDM'd detector mask is used to minimize the signal's beam position dependence.

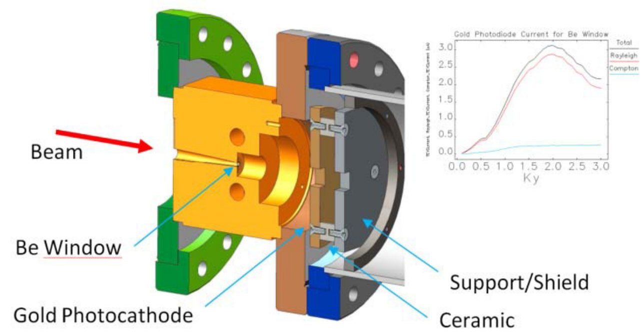

Figure 3: IM2 uses Rayleigh- and Compton-scattered x-rays from the Be window to monitor the x-ray beam intensity. Inset: A photodiode is used to detect x-rays.

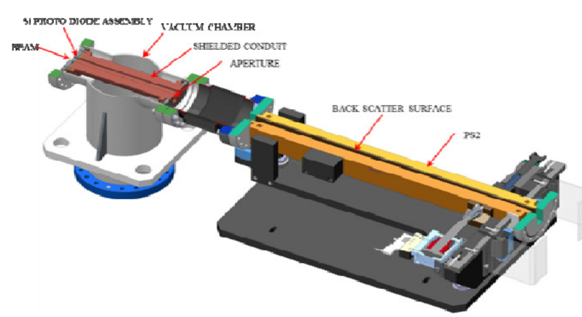

Figure 4: IM1 uses Cu K-edge XRF to measure the x-ray beam intensity when the photon shutter is closed.

SYSTEM DESIGN

Figure 5 shows the schematic of the new XBPM system inside the new orbit feedback system for the APS-U. With a reference from a common hydrostatic leveling system, real-time motion sensors will be used to monitor the positions of the RFBPM and the XBPM to compensate for the thermal expansion/distortion of the vacuum chamber supports. The RFBPM and GRID-XBPM will be used to monitor beam position and angle changes, and to provide information for orbit corrections.

For the x-ray beam exiting the front end, IM2 and XBPM2 will record its intensity and position information in real time and serve as independent validation of the x-ray beam stability achieved by the entire system.

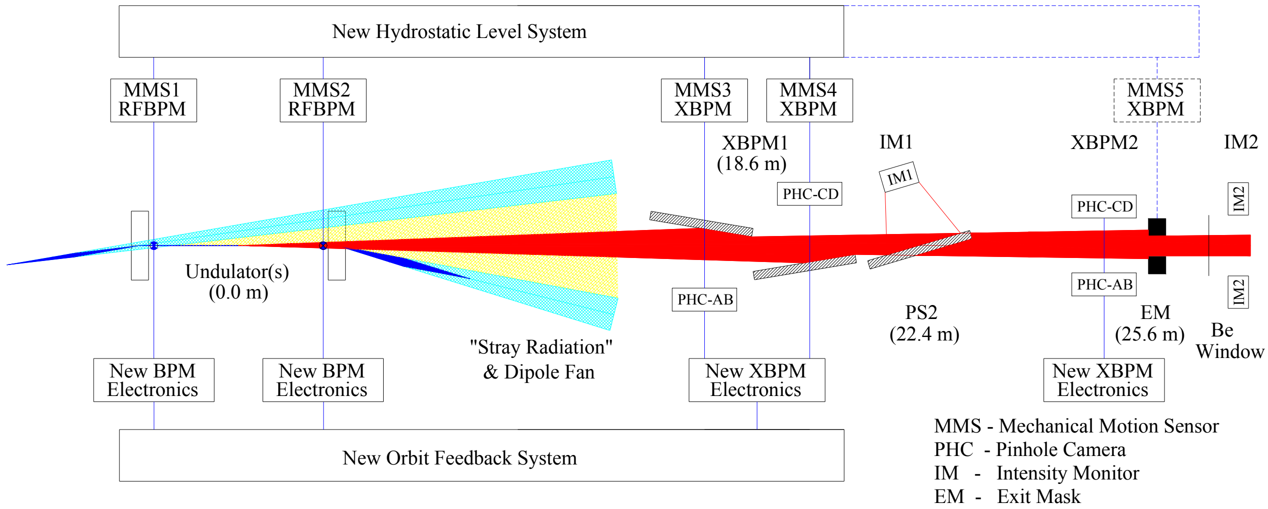

Figure 5: In the APS-U orbit feedback system, the XBPM system is responsible for measuring the x-ray beam angle and monitoring the x-ray beam intensity and position outside of the feedback loop.

SUMMARY AND DEVELOPMENTS

The engineering designs of the x-ray beam position monitor system for the APS high-heat-load front ends are complete. The components are being procured and manufactured. Installation of the first complete set is planned for early 2014.

The grazing-incidence design has demonstrated that a reliable XBPM can be built wherever a beam aperture can survive the beam, and the combination of beam apertures with position measurements simplifies operations of the beam-based alignment and improves its accuracy. However, the design also carries higher cost and requires longer beamline space.

For canted undulator front ends, where two undulator beams are separated by 1 mrad, with each carrying only 8.5-kW power, we are currently developing a different design based on Compton scattering from low-Z materials. Figure 6 shows a prototype: two grazing-incidence diamond blades are inserted from the top and bottom of the beam. At ~ 1.75 mm from the axis, they intercept ~ 500 W from each undulator. A set of pinhole optics and diamond detectors are mounted below and above the diamond blades to read out the horizontal beam position; the vertical beam position is derived from the difference/sum of the signals from the two blades. Initial ANSYS analysis shows that the diamond blades will survive a direct hit by the undulator beam during mis-steering if an appropriate heat spreader material, e.g., Mo-Cu, is used. A preliminary x-ray simulation shows that the signal current will be in the range of tens of μA for closed undulator gap (10.5 mm), and hundreds of nA for open gap (30 mm). This is welcome news for the data acquisition system since the dynamic range requirement is less stringent than that for the HHLFE GRID-XBPM with vertical absorbers. Optimization of the design is still in progress and experimental tests are planned for the near future.

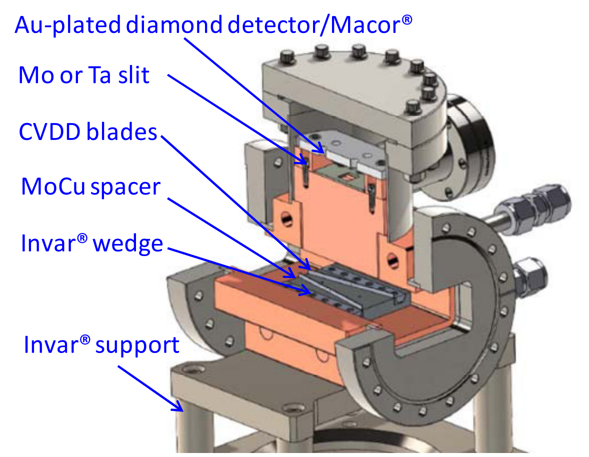

Figure 6: Compton-scattering XBPM conceptual design for the APS canted undulator front end.

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