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NEXT GENERATION X-RAY BEAM POSITION MONITOR SYSTEM FOR THE ADVANCED PHOTON SOURCE MBA UPGRADE*

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Abstract

The Advanced Photon Source (APS) upgrade from double-bend achromats (DBA) to multi-bend achromats (MBA) lattice has increased the need for reliable diagnostic systems. This upgrade will decrease the size of the photon beam drastically and beam current will be increased from 100 mA to 200 mA. The small beam and intense heat loads provided by the upgraded APS requires unique and innovative approaches to beam position monitoring. To meet the need for a reliable diagnostic system for the APS upgrade, the next generation X-ray Beam Position Monitoring System (XBPM) is required which includes the first XBPM (XBPM1), the Intensity Monitor (IM1) and the second XBPM (XBPM2). This paper presents progress and status of the current configuration of the XBPM system especially the development work involving the IM1 and XBPM2.

The R&D work to develop an alternative XBPM1 using the Compton scattering principle is also presented.

INTRODUCTION

Improved beam stability is critical for the Advanced Photon Source Upgrade (APS-U). The APS-U will require keeping short-term beam angle change below 0.25 µrad and long-term angle drift below 0.6 µrad. In conjunction with four Radio Frequency Beam Position Monitors (RFBPM) in the accelerator ring, the front ends of the APS-U will have three diagnostic components devoted to maintaining orbit control. Beam stability will rely on two unique components that will detect X-Ray Fluorescence (XRF): the first XBPM (XBPM1) and the Intensity Monitor (IM1). The second XBPM (XBPM2) will use photoemission current to help maintain beam stability. The XBPM1 is the initial source of feedback control during user operation. The IM1 and XBPM2 are secondary devices that provide complementary data during user operation. The IM1 provides intensity measurements while a photon shutter is closed and is used to calibrate the XBPM1. The XBPM2 is not in the orbit feedback loop and is mainly used to assess feedback performance. The layout for the devices is shown in simplified form in Figure 1.

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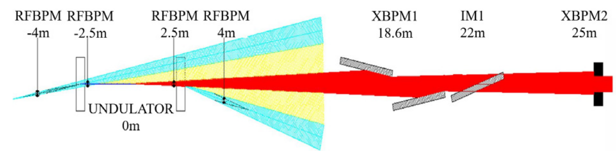

Figure 1: Layout of XBPM system.

FIRST X-RAY BEAM POSITION MONITOR (XBPM1)

The XBPM1 for the high heat load front ends (HHLFE) for the APS-U [1] uses pinhole optics and an array of silicon PIN photodiodes to monitor both vertical and horizontal displacement of the X-Ray beam as the beam is absorbed by two grazing incident insertion device (GRID) GlidCop absorbers. The XBPM1 is called the GRID-XBPM for this reason. The HHLFE is downstream of two inline undulators. The GRID absorbers are incident with the beam at 1° and will absorb 11.5 kW during normal operation. Missteering conditions require the absorbers to be able to withstand absorbing 17 kW and for this reason, GlidCop was the necessary material for this application. A cross-section of one of the GRID masks and detectors is shown in Figure 2.

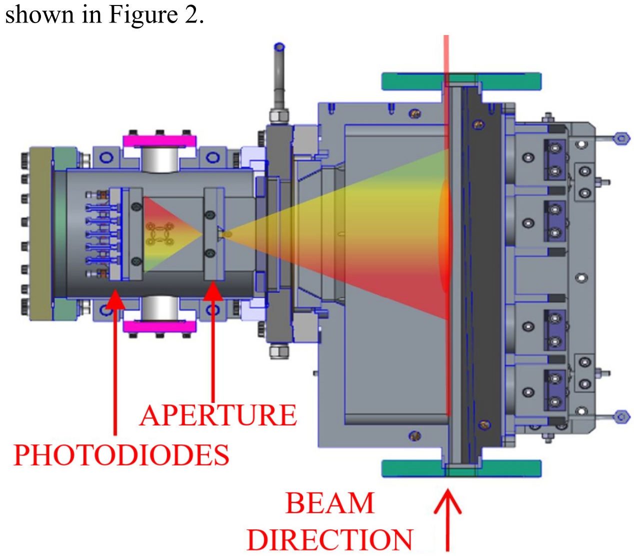

Figure 2: Cross-section of one GRID mask, with fluorescence overlay.

The unique design of the detectors is the major upgrade for this component as the GRID-XBPM style of XBPM1 has been proven effective in the current APS [2]. The detector uses an array of nine photodiodes as shown in Figure 3.

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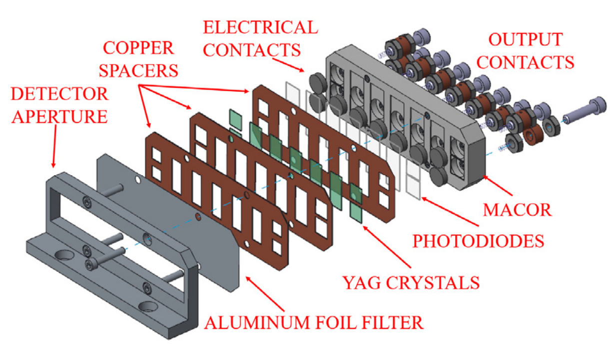

Figure 3: Detector Assembly for the GRID-XBPM.

The photodiodes are grounded to the same copper sheet to provide a basis of comparison to use for signal processing. In front of the photodiodes are Yttrium Aluminum Garnet (YAG) crystals that scintillate the XRF from the absorbers and produce visible light for the photodiodes. The photodiode lead that is not grounded is connected to an output connector, which is then connected to the feedback system.

The design of the array allows for both vertical and horizontal beam position monitoring by comparing the relative signals produced by each photodiode. Horizontal measurements are done by the middle five photodiodes and vertical measurements are done by the outer four photodiodes. As seen in Figure 2, the pinhole optics allow for upstream fluorescence on the GRID absorber to be observed by only the downstream photodiodes. By using the difference-over-sum for the signal between the upstream and downstream photodiode signal, it can be determined where on the GRID mask the beam is incident horizontally. The vertical measurement is done similarly. Figure 4 shows the layout of the photodiodes more clearly.

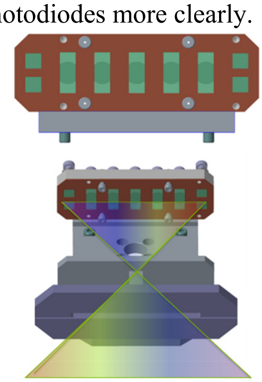

Figure 4: Front View Detector Array for the GRID-XBPM.

The GRID-XBPM will be tested in late 2018 and outlook is hopeful, as similar designs with less photodiodes have proven successful [2].

INTENSITY MONITOR (IM1)

The IM1 for the HHLFE measures XRF from a photon shutter. The full beam is absorbed by a GlidCop absorber at 1.1° when the shutter is closed. XRF reaches the upstream and downstream ends of the shutter where detectors are located. The top view of the IM1 at the beam orbit plane is shown in Figure 5.

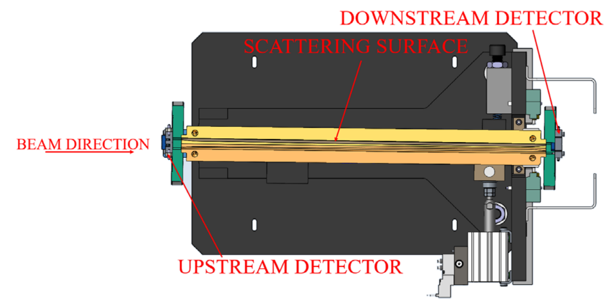

Figure 5: Cross-section of IM1 Detector System.

The detectors are single photodiodes behind aluminum filters electrically isolated from other components of the photon shutter. Detector design is shown in Figure 6.

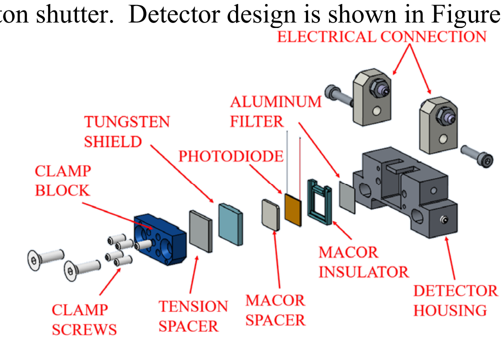

Figure 6: Detector Assembly for the IM1.

At the upstream end, a detector is placed above the nominal beam center, and at the downstream end, a detector is placed below the nominal beam center. The sum of these signals will not be dependent on the position of the undulator beam. The arrangement allows the difference-over-sum to be calculated for the two signals, which will give horizontal beam position information.

The IM1 is expected to be installed in the first upgraded front end, 28-ID, for the APS-U in late 2018. This front end will receive the current APS undulator beams but will provide test data for this type of IM1.

SECOND X-RAY BEAM POSITION MONITOR (XBPM2)

The XBPM2 design for the HHLFE is an integrated scattering mask and detector in the same unit that will ease onsite alignment. The XBPM2 uses four Invar collectors that are electrically isolated, using Macor, from the body of a GlidCop mask to determine the absolute position of the beam by collecting photoelectrons. Figure 7 shows the layout of the XBPM2.

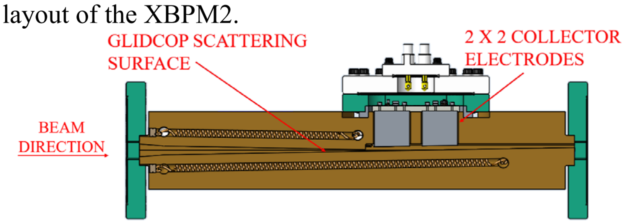

Figure 7: Cross-section of XBPM2.

Signals are expected to exceed milliamperes because of the detector's proximity to the undulator beam, as the aperture at the end of the mask is 2 mm x 2 mm. This will reduced the electronics necessary for the XBPM2 to simple

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resistors and floating power supplies. Since the collectors are metal and ceramic, the XBPM2 is expected to be radiation resistant and should require little maintenance. The detector is shown in Figure 8.

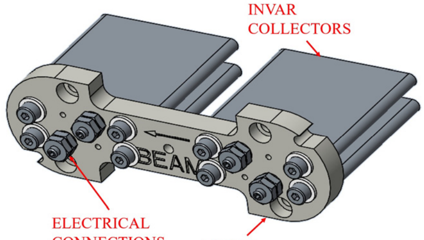

Figure 8: Photoelectron Collector for XBPM2.

The collectors are positively biased to attract photoelectrons straight away from the incident surface of the mask.

The XBPM2 is currently being tested in the APS at 27-ID with original APS undulators, and the results are very promising. High signal levels show that this design is viable.

NORMAL-INCIDENCE COMPTON SCATTERING X-RAY BEAM POSITION MONITOR (COMPTON XBPM)

An XBPM R&D project for the APS-U was a low-cost-alternative XBPM to replace the GRID-XBPM. The Normal-Incidence Compton Scattering X-Ray Beam Position Monitor (Compton XBPM) was developed and tested in mid-2017 and results are presented here.

The design includes two blades that are placed above and below the beam to absorb the halo of the beam at normal incidence. To be an effective alternative for the XBPM1, the blade material needed to be able to absorb a direct hit from the photon beam at the blade edge, absorbing half the beam in comparable conditions to the APS-U canted undulator front ends. High thermally conductive materials were chosen because of the severe condition of normal incidence. The Compton XBPM tested one chemical vapor deposition (CVD) diamond blade and one pyrolytic graphite blade as absorbers. To detect the Compton scattering from the carbon absorbers, silicon photodiode detectors and YAG scintillators were placed normal to each blade on the opposite side of the beam. A pair of photodiodes corresponded to each blade, which allowed for both horizontal and vertical beam position monitoring. A cross section is shown in Figure 9.

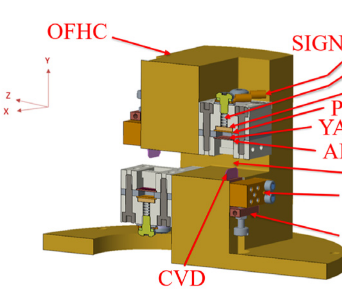

Figure 9: Cross-section of Compton XBPM.

The Compton XBPM was tested in two locations at the APS, one canted undulator beamline and one high heat load front end. The canted undulator test subjected the Compton XBPM to single undulator beam at 28 m from the source behind a beryllium window and a 3 mm x 2 mm aperture mask at 25 m. The power experienced at this location, which totaled less than 100 W was survivable for the Compton XBPM and this test gave usable results. This was a proof of concept test. For applications with relatively low power, the Compton XBPM may be a cost-effective design. During the high heat load test, which was a survivability test, dual undulators were steered directly at the blades. This test was at 20 m with no beryllium window and it simulated the power that the APS-U canted undulator front ends would produce. The test confirmed that the Compton XBPM was effective as long as the absorbers were far from the beam. When the beam was steered directly at the blades, the diamond cracked and the pyrolytic graphite sublimated. This was predicted by simulation and confirmed during the experiment. The Compton XBPM failed the survivability test.

The testing done with the Compton XBPM led to the development of the current GRID-XBPM design with undoped YAG crystals as well as determining that the Compton XBPM worked comparably to the GRID-XBPM for low power. Horizontal and vertical beam position monitoring was reliable with RMS resolution near 0.3 µm vertically. There was low bending magnet background signal-to-noise ratio of better than 30:1, which was comparable to the GRID-XBPM.

Further testing could be done to develop this technology further, but for the purposes of the APS-U, the reliable GRID-XBPM was chosen as XBPM1.

CONCLUSION

The work done to develop the XBPM system for the APS-U has built iteratively on previous designs that have been successfully used in the current APS for years. The development of array detectors will lead to interchangeable printed circuit boards instead of Macor supported designs to assist in maintenance and replacement of radiation-damaged detectors. Similar designs to what has been presented will be done for the APS-U canted undulator front ends (CUFE) and will use the technology bred from this work.

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