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DESIGN OF X-RAY BEAM POSITION MONITOR FOR HIGH HEAT LOAD FRONT ENDS OF THE ADVANCED PHOTON SOURCE UPGRADE*

S.H. Lee†, B.X. Yang, J. Mulvey, M. Ramathan
Advance Photon Source, Argonne National Laboratory, Argonne, IL 60439, USA

Abstract

Accurate and stable x-ray beam position monitors (XBPMs) are key elements in obtaining the desired user beam stability in the Advanced Photon Source (APS). Currently, the APS is upgrading its facility to increase productivity and to provide far more highly coherent and brilliant hard x-rays to beamline experiments with a new storage ring magnet lattice based on a multi-bend achromat (MBA) lattice. To improve the beam stability, one of the proposed beam diagnostics is the grazing-incidence insertion device x-ray beam position monitor (GRID-XBPM) for high heat load (HHL) front ends (FEs) at the APS. In this paper, final design of the GRID-XBPM and the high-power beam test results at beamline 27-ID-FE will be addressed.

INTRODUCTION

The APS at Argonne National Laboratory is the largest synchrotron radiation facility in the western hemisphere, providing the highest-brightness high-energy x-rays to users. To provide far more highly coherent and brilliant hard x-rays to beamline experiments, the APS upgrade (APS-U) project team is currently developing a new storage ring magnet lattice based on a multi-bend achromat (MBA) lattice, which offers small electron beam emittance, increases brightness several orders of magnitude, and approaches diffraction limits at higher photon energies. The APS-U project will put the APS on the path to continued world leadership in hard-x-ray science. To fully support the APS-U, the FEs located inside the storage ring tunnel need to be upgraded. Also, because the storage beam size will be down to several microns from one hundred micron in the horizontal plane, a major improvement in beam stability is required in order to realize the benefits of this upgrade [1]. To deliver a high degree of x-ray beam position stability to the users and to achieve the APS-U beam stability goal, the x-ray beam position tolerance and XBPM resolution requirements at 20 m from the source are listed in Table 1. To meet these values, the APS has been conducting research in developing a hard x-ray BPM that uses the 8-keV Cu K-edge x-ray fluorescence (XRF). To implement the XRF-based XBPM in place of the present photoemission-based XBPM, a grazing-incidence insertion device x-ray beam position monitor (GRID-XBPM) has been developed and its first articles were installed for tests at 27-ID and 35-ID FEs in May 2014, as seen in Fig. 1 An experimental test result with two inline undulators showed that the XBPM has approximately 30-fold improvement in rejection of bend magnet radiation background and a gap-independent calibration in one of the two dimensions as shown in Fig. 2.

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† shlee@aps.anl.gov

Table 1: APS–U XBPM Tolerance and XBPM Resolution Requirements (Z=20 m from the Source Point)

XBPM	Plane	RMS AC motion (0.01~1000Hz)	RMS Long-term Drift (7 days)
Position tolerance	Horizon.	5.3 µm	12.0 µm
	Vertical	3.4 µm	10.0 µm
Resolution	Horizon.	3.7 µm	8.5 µm
	Vertical	2.4 µm	7.1 µm

Figure 1: Installed GRID-XBPM at 27-ID FE (Looking upstream) [2].

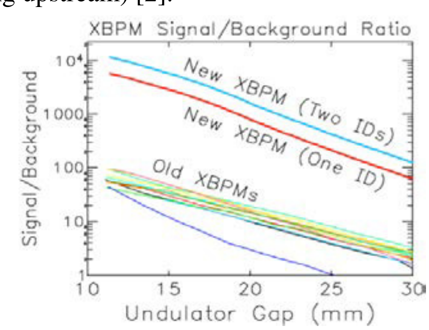

Figure 2: Ratio of undulator signal over BM background for the GRID-XBPM [2].

GRID-XBPM DESIGN

The design has been further value-engineered to make it compact. To reduce the cost, the vertical adjustment capability will be removed because the undulator gap changes are not correlated to the vertical motion of the mask. Fig. 3 shows the final design of the GRID-XBPM which is composed of two masks and two detector assembles mounted on two separate granite block for structural and temperature stability with a translation motion stage. This stage can translate the mask and detector assembly horizontally during machine study. For detecting the XRF signals, both Si-

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PIN diode and CVD diamond can be utilized. There is a Be-window between the mask and the detector to protect the synchrotron ring vacuum during periodic maintenance of detector system. So, the detector has its own vacuum pump and will be operated under a high vacuum. To decouple the detector signal readout from the main mask's deformation due to transient thermal loads, a bellows will be integrated into the detector chamber assembly. Also, to monitor the vertical and horizontal motions of the GRID-XBPM relative to the floor, the capacitive detection system and hydraulic levelling system will be equipped to provide accurate and reliable beam position information.

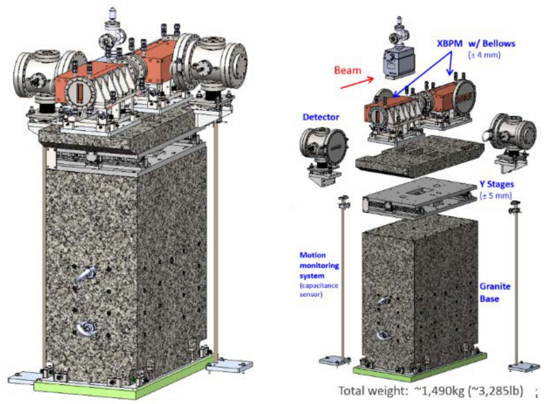


Figure 3: Final design of the GRID-XBPM and its exploded view.

Masks

The maximum total power and the maximum power density of the HHL FE for the APS-U will be limited to 19.45 kW and 453.3 kW/mrad^2 based on the operation of two inline 2.75-cm-period, 2.4-m-long undulators at k=2.44, 200 mA, 6 GeV. Based on heat load estimation [3], the angle of incidence on the active surface of the mask was determined at 1.0º (17.5 mrad) to increase the beam footprint. For the calculation of the minimum length with a grazing incidence angle of 1.0º, the dynamic range, tolerance of misalignment (±0.15 mm), and an additional 0.1 mm overlap section into the shadow at the far downstream end are considered. As shown in Fig. 4, a pre-mask is mounted on the main mask weldment with a Pyrolytic Graphite Sheet (PGS) foil for better heat transfer [4].

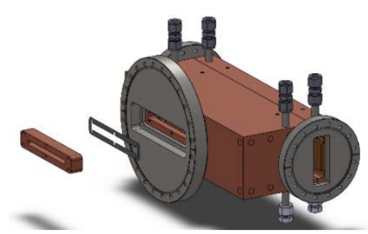
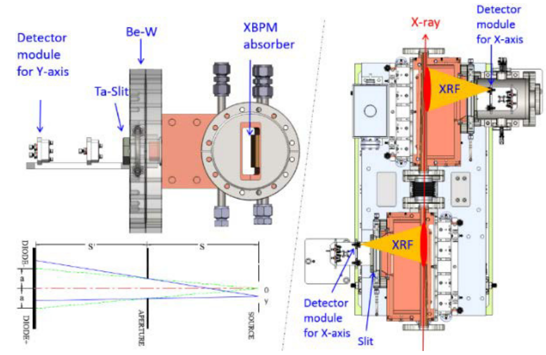


Figure 4: Recommended design of mask with PGS foil and pre-mask.

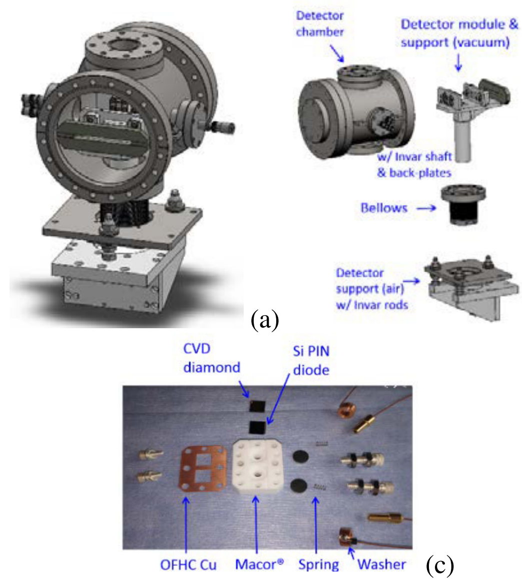
Be Windows

5.25″ x 1.0″ x 2 mm thick Beryllium sheet will be brazed to the zero-length stainless steel reducer flange of 10″ x 8″. Detector side of Be-window will be in the high vacuum (HV) and the other side will be in the ultra-high vacuum (UHV) during operation. For periodic maintenance, the detector side of Be-window will be exposed to the air.



(a) (b)

Figure 5: (a) Vertical position measurement principle (pinhole camera), (b) Horizontal position measurement principle (Integral sampling).



(a) (b) (c)

Figure 6: (a) Detector assembly, (b) its exploded view, (c) detector module with a plunger spring.

Detectors

Fig. 5 shows the XBPM position measurement principles. For the vertical position as shown in Fig. 5(a), it is possible to perform center-of-mass measurements by adding an aperture (pinhole) optics before the segment detectors. As a pinhole optics, a high Z (Tantalum) shielding material will be used to collimate the sensor's field of view to only the desired signal source footprint. For the horizontal position as shown in Fig. 5(b), it is possible to integrate the signal from each mask and compare signal intensities from two masks. Since the detector sensors will be potentially exposed to a high radiation environment to either cause drift in their response or outright failure, CVD diamond is a preferred material for reading out the intensity signals than Si-PIN diode, but the cost will be more. Detector assembly consists of detector module, its support structure with a bellows module, and vacuum chamber as

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shown in Fig. 6. To reduce radiation or thermal damage to the detector sensors, they will be kept in a holder made of Macor® machinable glass ceramics, sandwiched by a OFHC copper sheet, then pressed by a spring-loaded SST disk with an Ag-coated #10 SHC Screw.

Support Structures

Masks and detector assemblies will be mounted on the manually adjustable support structures, top and base granites with a translation stage as shown in Fig. 7.

Manual adjustment support structure Mask will be mounted on the manually adjustable support structure. G-11 thermal insulation materials are used to reduce heat transfer from the mask to the support structure. Heat transfer can be further minimized by water-cooling for better thermal stability of the structure. For alignment of the mask during assembly and installation, the support structure has the following adjustment range of motions to manually adjust the position of mask during alignment and installation.

- X-Y linear translation: ± 6 0 mm
- Rotation around x, y, z axis: ± 1.0°

Bellows To decouple the signal readout at the detector from the deformation of the mask due to transient thermal loads, a bellows module will be integrated into the detector chamber assembly. One side of the module is blocked and the other side has 4.5″ CF flange with thru holes. To meet the specification below, the bellows core should have O.D. ϕ2.75″ x I.D. ϕ2.125″ x 39 convolutions with 0.004″ ply made of AM350 SS.

- Axial stroke bellows core:
  - Extended: 2.18″
  - Compressed: 1.68″
  - Operating stroke: 0.50″
- Lateral offset bellows core:
  - Operating @ Extended: 0.25″
  - Operating @ Compressed: 0.25″
- Angular offset bellows core:
  - Operating @ Extended: 5.0°
  - Operating @ Compressed: 5.0°

Fully assembled, the bellows shall survive 10,000 cycles of maximum lateral offset at room temperature of 77°F while set at full angular offset and ±50% axial offset. The maximum axial offset will not be used as this condition but will only be present at assembly.

Translation motion stages A horizontal motion will be provided to the GRID-XBPM, which can move the mask and detector together in the horizontal direction. Most important requirement of the translation stage is of a yaw angle error for better beam position monitoring. Typical specifications are as follows;

- Yaw angle error < 3.5 arc sec (10µm/580mm ≅ 17µrad)
- Running straightness < 3.0 µm
- Step resolution (full step) 0.1 µm (2mm/2,000)
- Repeatability (open loop) < 3.0 µm
- Load capacity > 880lb (400kg)
- Designed Speed = 0.14 mm/sec
- Travel = +/-2.0 mm w/hard stop, +/-1.6 mm w/soft stop
- Total weight (design) = 360 lb (162kg)
- Size = 762 mm (L) x 457 mm (W) x 107 mm (H)

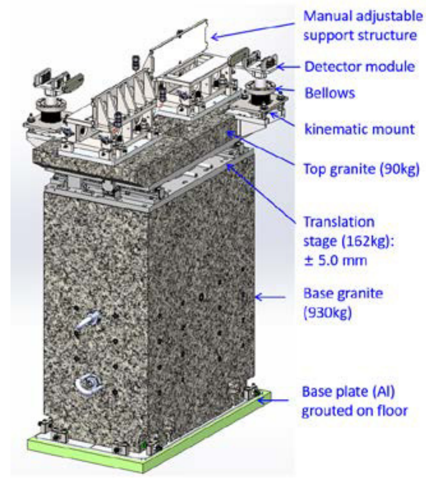

Figure 7: Support Structures.

CONCLUSION

The GRID-XBPM is one of the important components in the beam stabilization system for the APS-U. For the HHL FEs with single beam, the GRID-XBPM using XRF will be the baseline design for the APS-U FEs. With an incidence angle of 1.0 deg., it is expected that the XBPM masks will be thermally well-performed and its function will be better than the first articles installed at 27-ID and 35-ID FEs. The detector motion will be decoupled from thermal deformation of the main body and the detector vacuum will be isolated from the ring vacuum by Be-windows. The motion stage has been simplified to eliminate the vertical adjustment capability because the undulator gap changes are not correlated to the vertical motion of the mask. Thus, a compact and value-engineered design of the GRID-XBPM has been achieved for APS-U MBA FEs.

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