Development of an x-ray beam position monitor for TPS EPU beamline front ends

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Abstract. In order to develop state-of-the-art x-ray beam position monitors (XBPMs) for the Taiwan Photon Source (TPS) project, the National Synchrotron Radiation Research Center (NSRRC) and the Advance Photon Source have established a collaboration project to design and test various XBPMs for the TPS beamline front ends. One of the XBPM prototypes is dedicated to the elliptically polarized undulator (EPU) beamline front ends to be constructed at the TPS. In this paper, we present the design of the XBPM prototype. Preliminary test results for the prototype are also discussed.

1. Introduction

A prototype of a chemical vapor deposition (CVD) diamond-based x-ray beam position monitor (XBPM), dedicated to the elliptically polarized undulator (EPU) beamline front ends, has been designed and is under construction at the Advanced Photon Source (APS) for the 3-GeV, 500-mA Taiwan Photon Source (TPS) project. This work is a collaboration between Argonne National Laboratory (ANL)/APS and the Taiwan National Synchrotron Radiation Research Center (NSRRC)/TPS project [1].

The TPS is a 518-m-circumference low-emittance synchrotron storage ring under construction at the NSRRC, Taiwan. It will operate at 3 GeV with 500-mA ring current. Seven x-ray beamlines are proposed after commissioning, which is scheduled in 2015 [2]. Besides linear undulator beamlines, one tandem EPU beamline will be developed for high-resolution inelastic soft x-ray scattering experiments. Unlike a regular planar undulator, the EPU has a two-dimensional magnetic array feature. It will generate a wide range of elliptical-shaped beam power profiles. Thus the design of the x-ray beam position monitor (XBPM) becomes a challenging task.

In this prototype, a set of photoemission-type CVD diamond-based XBPMs with four inclined diamond blades has been configured to reach a compromise between the various EPU beam profiles. In addition, a set of four single-crystal synthetic diamond-based photoconductive-type XBPMs has been designed to gain extra beam center information from the fluorescence radiation generated on the front of a fixed mask downstream of the XBPM. The mechanical designs of the hybrid XBPM, as well as a preliminary x-ray test for the single-crystal diamond-based photoconductive-type detector are presented in this paper.
2. X-ray beam power distribution of the TPS EPU

2.1. Location of the EPU front-end XBPM
Like the regular planar undulator beamlines, the TPS EPU front-end XBPM is located 18.47 m from the center of the 1st undulator source and 11.78 m from the center of the 2nd undulator source. As shown in figure 1, there is a water-cooled pre-mask 918 mm upstream of the XBPM with a 23 mm(H) x 12 mm(V) output optical aperture that protects the XBPM cooling base (with a 25 mm(H) x 14 mm(V) optical aperture) from the high-power x-ray beam. At 355 mm downstream of the XBPM, a water-cooled GlidCop™ fixed mask with 14 mm(H) x 11 mm(V) output optical aperture defines the x-ray beam size delivered to the downstream beamline optics.

**Figure 1.** A side view of a 3D model of the XBPM vacuum chamber at the TPS EPU beamline front end.

2.2. X-ray beam power profile at the EPU front-end XBPM
The maximum and minimum major axes of the elliptical beam profile depend on deflection parameters along the x and y directions (Kx and Ky). Figure 2 shows the x-ray beam power profile at the EPU front-end XBPM with three typical operation conditions. With two tandem EPU48s (with 4.8-mm insertion device period length), the maximum power density at the XBPM location is 0.12 kw/mm² for a horizontal or vertical near-planar undulator condition (Kx = 0.5, Ky = 2.5 or Kx = 2.5, Ky = 0.5) and 0.067 kW/mm² for a circular condition (Kx = Ky = 2) with a ‘donut’ shape power distribution, which deposits more power to the diamond blades for the photoemission-type XBPM.

**Figure 2.** Typical x-ray beam power profile at EPU front end XBPM location with various combinations of Kx and Ky.
3. Structure design of the TPS EPU XBPM

3.1. XBPM vacuum and water-cooling system
At the TPS front ends, the EPU beamlines share most of the component designs with other regular undulator beamlines. The EPU front-end XBPM uses the same vacuum chamber, water-cooling base, and supporting structure designs as the TPS regular undulator front-end XBPM. The only differences are the hybrid monitor body subassembly specially designed for the EPU front end and its associated electronics.

3.2. The hybrid monitor body subassembly
The hybrid monitor body subassembly is mounted on the water-cooling base inside the XBPM vacuum chamber. As shown in figure 3, the subassembly consists of an oxygen-free copper (OFHC) housing, an OFHC shielding frame, a set of CVD diamond blades for the photoemission-type XBPM, and a photoconductive-type XBPM unit with four single-crystal synthetic diamond detectors.

![Figure 3. 3D models of the hybrid monitor body subassembly prototype for TPS EPU front end XBPM.](image)

3.2.1. Diamond-based x-ray photoemission monitor
As a compromise between the various EPU beam profiles and limited by cost-effective and reasonably sized CVD diamond blades, inclined diamond blades are implemented for the geometric configuration of the photoemission-type XBPM as shown in figure 4 (right). Since the hybrid monitor body is a multi-part detachable structure, it allows more accessibility in the CVD diamond blade assembly. Associated with the usage of precision fixtures, this design is able to significantly improve the geometric precision of the monitor blades assembly [3]. The four 150-µm-thick CVD diamond blades were coated with 1 µm of gold to achieve the x-ray photoemission sensing effect. To withstand the x-ray high thermal load, a comprehensive thermal analysis was applied to the photoemission-type XBPM system to ensure operational reliability [4].

![Figure 4. Side and rear views of the 3D model of the hybrid monitor body subassembly prototype for TPS EPU front end XBPM.](image)

3.2.2. Diamond x-ray photoconductive fluorescence monitor
To gain extra beam center information from the fluorescence radiation generated on the front of the fixed mask downstream of the XBPM, a single-crystal synthetic diamond-based photoconductive-type XBPM unit was mounted on the rear side of the hybrid monitor OFHC housing. As shown in figure 5 (right), the photoconductive-type XBPM unit consists of an OFHC base plate and four detector subunits seen in figure 5 (left). Each of...
the single-crystal synthetic diamond plates measures 4.5 mm x 4.5 mm x 0.15 mm. They are manufactured by Element-6\textsuperscript{TM} with N < 5 ppb electronic grade. Two 4-mm-diameter circular 1-micron-thick aluminum dots were coated on both faces of the diamond plate to create Ohm contact with the detector. Two machinable ceramic insulators were used in the clamping structure to apply a bias voltage on the diamond detector and readout the photoconductive current.

![Figure 5.](image)

**Figure 5.** Left: a 3D model of a single crystal synthetic diamond detector subunit. Middle: a photograph for the diamond detector subunit tested at TLS. Right: a 3D model of the photoconductive-type XBPM unit for TPS EPU front end.

4. Preliminary test

In October, 2011, two single-crystal synthetic diamond-based photoconductive detectors were designed and assembled at the APS. A preliminary test was performed at the Taiwan Light Source beamline18B1 x-ray micro-machining experimental station with white x-ray beam on November 29, 2011. A 69-nA photoconductive current was observed with 18 volts bias voltage on the 0.15-mm-thick diamond detector. Figure 5 (middle) is a photograph of the diamond detector tested at TLS.

5. Discussions

We presented the design of a hybrid XBPM prototype for the TPS EPU beamline front end. The prototype includes a set of photoemission-type CVD diamond-based XBPMs with four inclined diamond blades and a set of four single-crystal synthetic diamond-based photoconductive-type XBPMs to gain extra beam center information from downstream fixed mask fluorescence x-rays. Further x-ray tests of the hybrid XBPM prototype are planned.

The initial conservative thermal analysis shows a maximum 500°C temperature rise on the photoemission diamond blade when EPU deflection parameters are Ky = 4 and Kx = 2.64 \cite{4}. Although experimental results showed that the diamond blades could survive a more than 600°C temperature rise \cite{5}, many options are being studied to reduce the temperature rise: reduce the pre-mask and XBPM aperture size; increase the cooling length of the photoemission diamond blades; and enhancing the cooling efficiency.

6. References

\begin{enumerate}
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