PROGRESS TOWARD A HARD X-RAY INSERTION DEVICE BEAM POSITION MONITOR AT THE ADVANCED PHOTON SOURCE*

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Abstract

Long-term pointing stability at synchrotron light sources using conventional rf-based particle beam position monitoring is limited by the mechanical stability of the pickup electrode assembly. Photoemission-based photon beam position monitors for insertion device beams suffer from stray radiation backgrounds and other gap-dependent systematic errors. To achieve the goal of 500-nanoradian peak-to-peak pointing stability over a one-week period, the development of a photon beam position detector sensitive only to hard x-rays (> several keV) using copper x-ray fluorescence has been initiated. Initial results and future plans are presented.

INTRODUCTION

At the Advanced Photon Source (APS), a significant effort has been put into the development of ultraviolet (UV) photon beam position monitors (BPMs) for both bending magnet and insertion device (ID) beamlines [1,2]. Use of these monitors has been instrumental in the achievement of submicroradian-scale long-term pointing stability. Because they are sensitive to UV radiation, however, non-negligible residual systematic errors caused by stray bending magnet radiation affect the signals for ID photon BPMs.

To further improve ID beamline stability, an effort to develop beam position monitors that are sensitive only to hard x-rays was initiated in 2005. A spare vacuum vessel at APS beamline 19-ID was instrumented with water-cooled mounting plates, translation stages, and electrical feedthroughs to test a number of different concepts [3,4,5]. This vacuum vessel is located approximately 52 meters downstream of an ID source point, allowing low-power tests with hard x-ray beams to be conducted, with sensitivity to extremely small steering errors, owing to the long lever arm. A rectangular 2.1 × 4.2 mm aperture is located approximately 1 meter upstream of the detector mount.

EXPERIMENTAL ARRANGEMENT

Shown in Figure 1 is a diagram of one experimental arrangement used for the APS experiments. The x-ray source used for the tests was a standard APS undulator A with a 3.3-cm period, and first harmonic tunable over an x-ray energy range from 4 to 14 keV. After passing through the 2.1 mm vertical × 4.2 mm horizontal beam-defining aperture, the x-ray beam passed through a set of retractable beryllium filters, used as low-pass filters that allow only hard x-rays to proceed to the copper target. A slit / detector subassembly was placed immediately upstream of the target. The slit material for this particular experiment was tungsten, and the slit size was approximately 50 microns in the vertical direction. The detectors used were PIN diodes, each shielded by a 1-mm thick electrically grounded beryllium sheet primarily to stop back-scattered soft radiation, photoelectrons, and ions from corrupting the signals. The target was made of copper and was mounted on a horizontal translation stage together with the slit / detectors assembly. This allowed for the possibility of retracting the target to the horizontal fringes of the x-ray beam, providing a nonintercepting operation mode. A second pair of detectors were similarly placed above and below the undulator beam centerline, but displaced horizontally to the opposite side of the beam from the first pair.

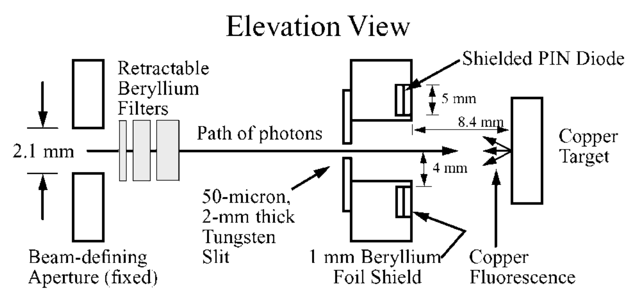

Figure 1: Experimental arrangement for x-ray beam profile measurements.

Shown in Figure 2 is a photograph of the vacuum enclosure prior to installation of the detector subassembly, indicating the placement of the water-cooled mounting plates and movable beryllium filter assembly.

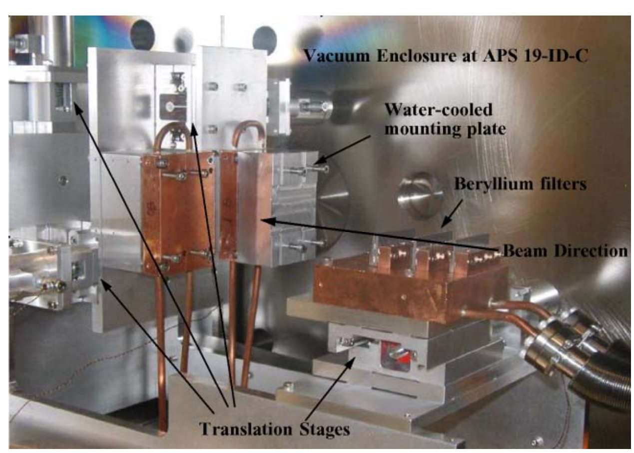

Figure 2: Photograph of vacuum enclosure internals.

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EXPERIMENTAL RESULTS

The primary purpose of the apparatus shown in Figure 1 was to determine the effective vertical beam profile of the x-ray beam. Copper is known to emit x-ray fluorescence isotropically at photon energies near 8 keV when excited by a polychromatic (white) hard x-ray source such as an undulator. Placing the detectors upstream of the target has the additional advantage of avoiding anisotropic effects like diffraction and scattering in the forward direction. The effective transverse profile results from a convolution of the undulator spectrum with the x-ray emission / absorption properties of the target, the filtering properties of the beryllium, and the sensitivity of the detectors. It is essential to determine the effective beam profile to optimize the parameters of a hard photon beam position monitor design for use with white beams.

Because the effective vertical white beam size for all measurements to date is significantly larger than the beam-defining aperture (sized to the monochromatic beam), the best method for determining the profile was to perform a vertical sweep of the particle beam's angle through the insertion device using an asymmetric local closed-orbit distortion, or bump. RF beam position monitors, mounted both upstream and downstream of the small-aperture insertion device vacuum chamber, together with four steering correctors were used to effect the bump. Shown in Figure 3 are data collected in this manner. Along the horizontal axis is the vertical x-ray beam position at the detector location, obtained from the rf BPMs by multiplying the bump angle by the 52-meter source-detector distance. The individual diode signals were first normalized by dividing by the stored beam current, about 20 mA, and then summed. The separate curves correspond to different insertion device gap values.

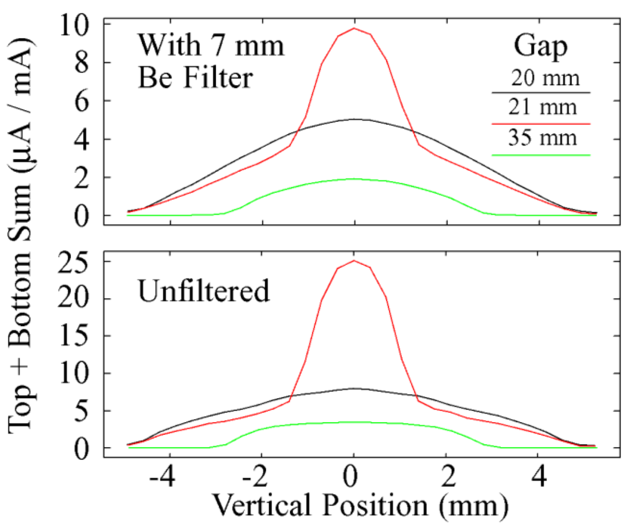

Figure 3: Experimental results of the x-ray beam profile measurements using a 50-micron slit.

The significance of the dramatic change in character between gap values of 20 and 21 mm has to do with the fact that the undulator first harmonic energy at 21 mm is high enough to eject copper K-shell electrons, while only a small fraction of the fundamental harmonic photons have enough energy at 20 mm, even though the total x-ray power is actually higher at smaller gap. The binding energy of the most tightly bound electrons in copper is 8.98 keV, while the first undulator harmonic energy is 8.97 keV at a 20-mm gap and 9.58 keV at 21 mm. Once ionized, copper emits fluorescent photons with energy very near 8 keV. The effect of the filter is an overall smoothing of the profiles in addition to a reduction in the contrast between the 21- vs. 20-mm gap curves.

For the discussion and measurements to follow, the 50 micron slit was omitted, reverting the 2.1-mm beam-defining aperture back into what its name suggests. In the monochromatic incarnation of the hard x-ray BPM [3], where the beam size is much smaller than the beam-defining aperture, a simple difference over sum calculation comparing top to bottom diode signals provides a sensitive measure of vertical photon beam position, derivable from simple geometric considerations. Given the large beam sizes of Figure 3, an indirect approach was used to infer the difference over sum position sensitivity that would have resulted in the absence of the 2.1-mm vertical aperture. In fact, a 4.5-mm vertical aperture is located at approximately 25 meters from the source, which amounts to a 9.3-mm effective aperture when projected to the 52-meter detector location, large enough to accept most of the x-ray power. A series of vertical sweeps was conducted, with the beam-defining aperture displaced vertically by an amount equal to its size between each sweep. Data from four sweeps of this type were summed, the result being the equivalent of a single sweep with the 2.1-mm aperture absent.

For the later measurements, the copper target was replaced with a 200-micron-thick CVD diamond disk with an 87-Angstrom coating of copper deposited on the downstream side. The idea here was to work toward a target that could survive at very high power associated with small insertion device gaps, since most of the x-rays are transmitted through the diamond, which also has excellent heat conductivity. The diamond disk was mounted using an aluminum clamp with a vertical opening size of 7.9 mm, which is smaller than the 9.3-mm projection of the upstream 4.5-mm aperture.

Shown in Figure 4 are the results for the top and bottom signals, normalized to the amount of stored beam current, which was about 10 mA here. The two curves in each frame correspond to insertion device gaps of 20 and 21 mm, respectively. The effect of the copper is considerably muted here, visible as a slight bump in the peak values for the unfiltered case, and nearly washed out when 7 mm of beryllium filters were inserted. The data of Figure 4 is redisplayed in Figure 5 in terms of $\Delta / \Sigma = (T-B)/(T+B)$ and $\Sigma = T+B$ values.

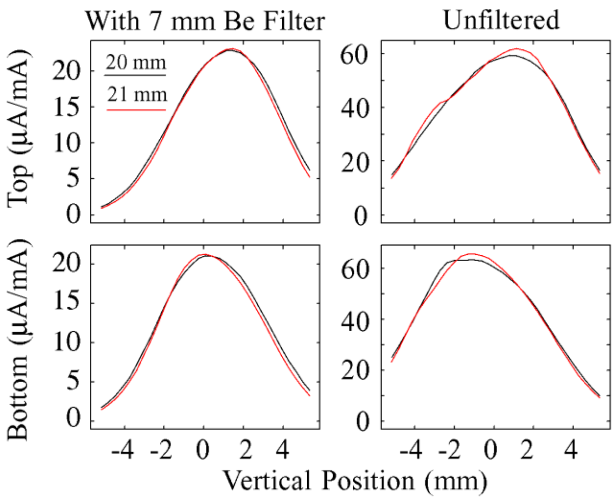

Figure 4: Diode response to vertical sweeps using a copper-coated diamond target and 7.9-mm effective vertical aperture size.

Here we see something approximating a linear response to beam position in the Δ / Σ signal, which could not be seen from any single sweep with the 2.1-mm aperture. In addition to being about 5% narrower, the sum signal for the filtered 21-mm gap case is seen to be slightly shifted relative to that for 20 mm by about 60 microns, from a Gaussian fit. This may be a real effect, since field errors internal to the insertion device can result in the photon beam and average particle beam trajectories not coinciding at the few-microradian level.

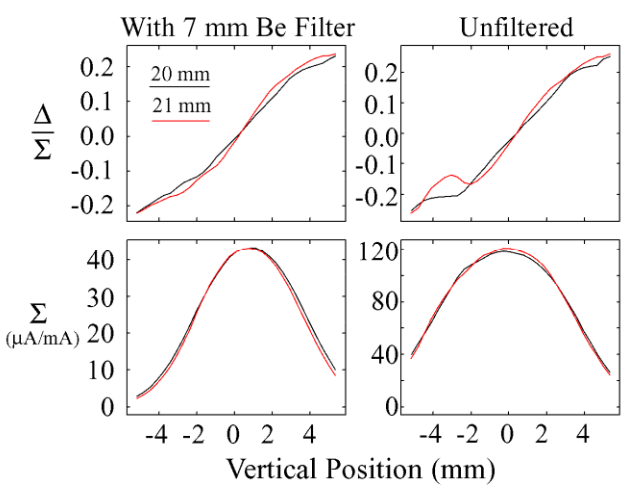

Figure 5. Δ / Σ and Σ response to vertical sweeps using a copper-coated diamond target and 7.9-mm effective vertical aperture size.

DISCUSSION

One of the main conclusions to our studies to date is the fact that a large fraction of the hard x-rays generated by an undulator at the APS do not in fact survive the beam defining aperture and are thus available for monitoring without impacting beamline operation. It is apparent from Figure 3 that at least as many photons fall outside of the 2.1-mm beam-defining aperture as inside, and for most gaps the fraction is more like three or four to one outside vs. inside.

When discussing x-ray beam stability at the 200-nanoradian level, it is essential to define the datum relative to which the x-ray trajectory is to be measured. One sensible definition of the x-ray beamline is the line connecting the center of the insertion device vacuum chamber at the source with the center of a critical aperture in the beamline. All APS beamlines have an aperture in their first optical enclosure at about 25 meters downstream from the center of the insertion device straight section. These apertures generally have dimensions of 2 mm vertical by 3 mm horizontal, or 4.5 mm by 4.5 mm for the original front ends.

The next development step will be to build a retractable high-power hard x-ray flux monitor to be placed immediately downstream of the 2- or 4.5-mm fixed beamline aperture. A geometry similar to Figure 1 sans the slit, mounted on a moveable translation stage and using a copper-coated diamond target and an array of diodes to be summed as a measure of flux is envisioned. Steering corrections would then be based on a flux optimization. The amount of copper will likely have to be increased to enhance the copper fluorescence. This device will be valuable for verifying alignment at the start of x-ray operating periods following extended maintenance and after weekly machine studies.

As a further step, a nondestructive device could be designed to intercept up to half of the beam without affecting the core of the beam. This device could be placed in the beamline front end upstream of critical beamline apertures, and could be cross referenced to the flux monitor just described to compensate for electronic or any other systematic position offsets. The challenge here will be the placement of target material so as to maximize sensitivity while minimizing gap-dependent systematic errors, which must be maintained at the few-micron level.

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