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MECHANICAL CONVERSION OF A VERTICALLY REFLECTING ARTIFICIAL CHANNEL-CUT MONOCHROMATOR TO HORIZONTALLY REFLECTING*

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Abstract

The mechanical conversion of a high-resolution artificial channel-cut monochromator (ACCM) from a vertically reflecting orientation to a horizontally reflecting orientation is presented. The ACCM was originally commissioned for the 8-ID-I beamline at the Advanced Photon Source (APS), Argonne National Laboratory [1, 2]. The ACCM was intentionally designed at commission to have the potential to be reoriented to the horizontal direction. After nearly a decade of operation in the vertical orientation the ACCM was rotated to the horizontal orientation. The details of the design which allowed this conversion and the preparation steps needed to assure the continued performance of the ACCM will be discussed.

INTRODUCTION

An ultra-high-vacuum double crystal monochromator (DCM) was previously designed for the 8-ID-I beamline at the Advanced Photon Source [1]. The DCM was designed to meet the same stability performance as a single channel-cut crystal using an overconstrained weak-link mechanism for positioning alignment of the second crystal [3]. In addition, features were incorporated into the design for the potential conversion of the vertically reflecting geometry to horizontally reflecting. This paper will discuss the mechanical conversion of the DCM from vertical to horizontal reflecting geometry and the optical results.

MECHANICAL CONVERSION

The original vertical orientation can be seen in Fig. 1(a-b). For the conversion to work the entire vacuum tank was designed so that when rotated 90° about the x-ray beam path (Fig. 1(a)) the crystal assembly would be at the same height. The support frame was designed with this in mind, which can be seen in Fig. 1(b), and the table was also designed with a hole through the top plate for clearance of the main Bragg rotation stage flange. Rotation of the DCM was done in the end station with little modification and the final horizontal orientation can be seen in Fig. 1(c). Internal components were kept in place during the rotation and only the x-ray vacuum lines, cooling lines, and electrical components were detached. Modifications included new supports for the ion pumps shown in Fig. 1(c), and two internal support straps, Fig. 2, for the water cooling lines. The straps were installed to reduce the strain on the connection points due to gravity. All crystal mounts, stages, and supports needed no modification for the new orientation.

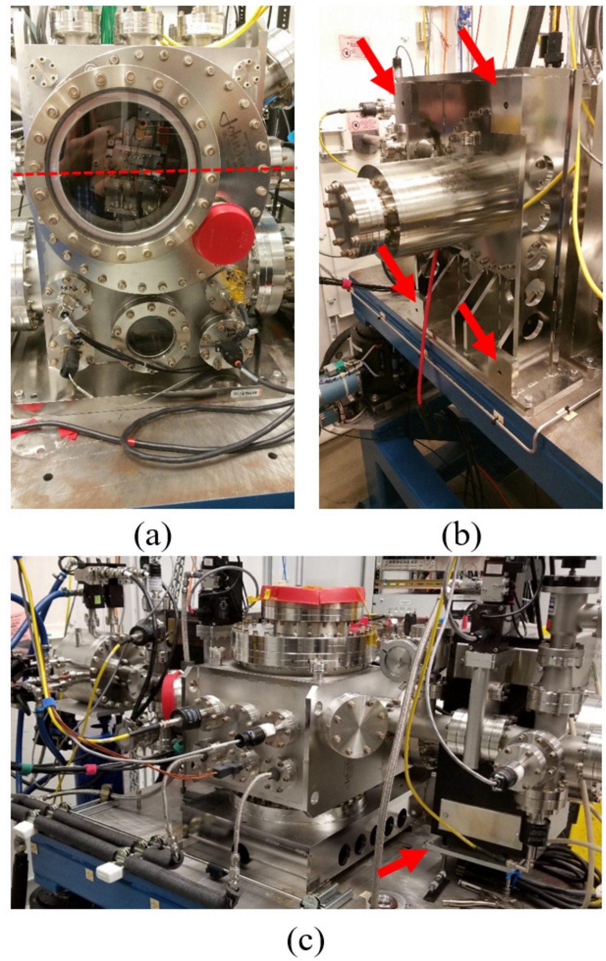

Figure 1: (a) Front view of DCM in vertical orientation with a dashed line representing x-ray path. (b) Back view of DCM showing new mounting surfaces (red arrows) for horizontal orientation. (c) Isometric view of DCM in the new horizontal orientation with red arrows showing new ion pump supports.

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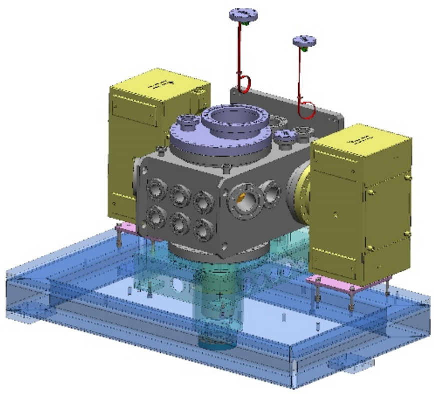

Figure 2: Model of the DCM in horizontal orientation showing the support straps for the cooling lines mounted to the back of vacuum flanges.

OPTICAL CONVERSION OF DCM

The electron beam source size (σ) in the current third generation storage rings is highly asymmetric with a vertical source size of ~10 µm and the horizontal source size being higher by more than an order of magnitude. As a result, the transverse coherence lengths at a longitudinal distance R from the source and for a wavelength λ is defined as, λR/σ. At the X-ray Photon Correlation Spectroscopy (XPCS) beamline 8-ID-I at the APS, the vertical and the horizontal transverse coherence lengths are ~150 µm and 7 µm respectively at a distance of 65 m from the source where the monochromator is located. For coherent scattering experiments, it is imperative to utilize the entire transverse coherence area of the beam. Additionally, for XPCS experiments, there is another level of signal to noise optimization [4] that is involved which requires the angular speckle size (diffraction limited scattering from the sample) to match the solid angle subtended by the pixel. For the state-of-the-art pixel array detectors (PADs), the pixel size is typically in the range of 50-75 µm. In order to fulfill this condition, the beam size at the sample should be in the order of 1-10 µm for a sample to detector distance at 8-ID-I of 4 m.

It is well known that the thermal load of a polychromatic synchrotron x-ray beam incident on the first crystal of a double crystal monochromator induces significant thermal bumps leading to distortion of the crystal surface. This distortion results in a broadening of the rocking curve leading to a loss in the reflectivity. Additionally, this also causes significant wave front distortion which negatively impacts the functioning of downstream optical components such as focusing optics.

Previously, a detailed thermal analysis of this monochromator was carried out to understand the effect of the thermal bump [5] on the focal length of the downstream focusing optics based on a Beryllium Compound Refractive Lens (CRL). Thermal analysis verified the experimental observations that the thermally deformed first crystal acts as a lens creating a virtual source that is much closer to the crystal (ca. 1.5 m) than the real source (ca. 65 m) thereby increasing the focal distance of the CRL assembly by as much as 100% from the theoretical 2 m to an experimentally observed ca. 4.5 m.

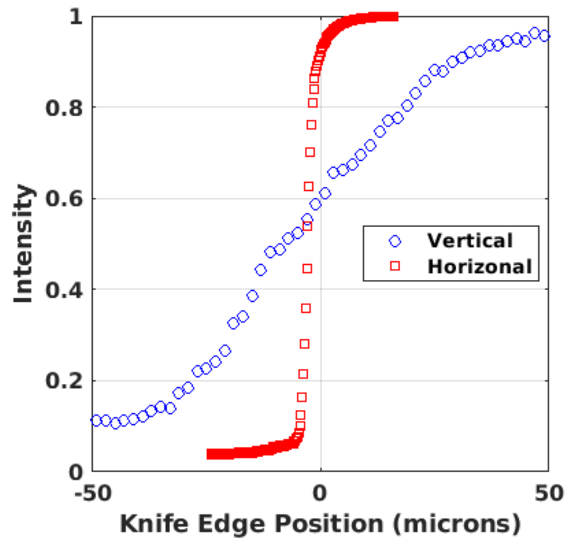

Figure 3: Knife edge scan of the vertically focused beam with the monochromator in the vertical versus the horizontal diffraction geometry.

While it is possible to mitigate the thermally induced distortions by cryogenic cooling for a Silicon monochromator to a regime of zero thermal expansion, the same is non-trivial for Germanium as the zero thermal expansion occurs at ca. 50 K. Since such a mitigation was beyond the scope of the beamline in its current state, we embarked on flipping the orientation of the monochromator to be horizontally diffracting from the original vertical scattering geometry. The monochromator was originally designed by taking this option into consideration [1].

This also aligns well with the fact that the transverse coherence length of the x-ray beam in the horizontal direction is far more forgiving than in the vertical which allows us to mitigate the thermally induced distortions without going to the extreme of cryogenic cooling. The effect of the flipping of the monochromator on the focusing is shown below. Figure 3 shows the knife edge scan through the focused x-ray beam under both orientations of the monochromator. Figure 4 shows the derivative of the knife edge scans yielding the focal spot sizes. The horizontal orientation yields a focal length and a focal spot size that matches the theoretically estimated values based on ray tracing. Figure 5 shows the knife edge scan and its derivative in the case of the horizontal orientation of the monochromator.

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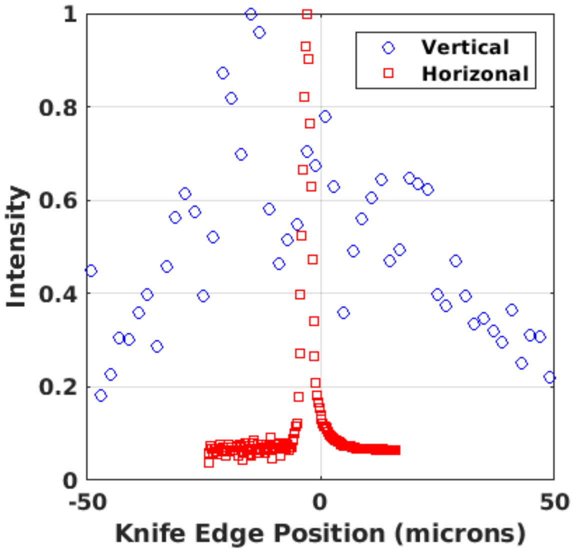

Figure 4. Derivative of the knife edge scan of the vertically focused beam with the monochromator in the vertical versus the horizontal diffraction geometry.

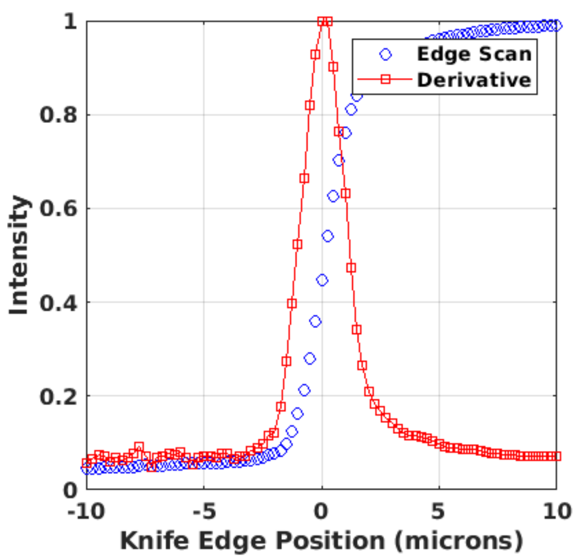

Figure 5: Knife edge scan along with the derivative showing the theoretical focus size of the vertically focused beam with the monochromator in the horizontal diffraction geometry.

CONCLUSION

Previously, a high stability DCM was designed to operate in both vertical and horizontal reflection geometry. It was originally installed at the 8-ID-I beamline at the APS in the vertical orientation. A thermal analysis of the DCM found that a thermal bump was having negative effects on the downstream optical components. Instead of using cryogenic cooling to create a non-zero thermal expansion it was decided to flip the DCM to a horizontally reflecting geometry, which would take advantage of the more forgiving transverse coherence length of the x-ray beam in the horizontal direction.

Changing the orientation of the DCM was successfully completed. Mechanically, only slight modifications were required, which included internal support straps for cooling lines and new ion pump supports. Optically, the horizontal orientation was found to improve the focus. The focal length and focal spot size matched theoretical ray tracing values.

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