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Development of a Double Crystal Monochromator

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Abstract. A high-precision water-cooled, small offset, double crystal monochromator has been developed for the Advanced Photon Source (APS) UNICAT Sector 34 beamline. The design incorporates the supports and gravity feed water cooling of two diamond or silicon crystals correctly positioned about a common rotation axis so that the incident and diffracted beam do not walk off the edges of the crystals within the energy range 6-15KeV (30° <q<11. 6°). In the 34ID implementation, the first crystal sees unfocussed pink beam from an undulator. The second crystal has a ±5° motorized tilt motion around an axis parallel to its face and around the beam direction. In this paper preliminary measurement data obtained from Advanced Photon Source and the detail of the instrument design are presented.

INTRODUCTION

The high power associated with the x-ray beams generated by the third generation synchrotron radiation facilities has created new challenges in the design of the beamline components that intercept the x-ray beams. The challenge is especially critical in the design of the monochromators, which must provide acceptable performance under the thermal load of the x-ray beams. Research activities in the development of monochromators for more stable and less complicated beamlines has led to examination of many aspects of the monochromators' design. Dr. Paul Fuoss developed the techniques to design the first and second crystal so close to each other that the x-ray beam walks over the second crystal. This resulted in fewer moving parts inside the vacuum chamber and helped reduce design complexity. In this paper, we describe the design and features of a new monochromator that has only one moving part inside the chamber, and we provide a preliminary study of the design and characterization aspects of a diamond crystal.

MONOCHROMATOR DESIGN

The overall philosophy of the design is to keep to a minimum the number of essential motions of the crystals. This minimizes the opportunities for instabilities, vibrations and drift. Crystal translation axes are therefore avoided altogether by using a small offset of just 2 mm between the parallel crystal faces. The resulting beam offset is below 4 mm (for symmetric reflections) and this varies by a fraction of a millimeter over the entire energy range, typically 6 to 15keV. This variation is not normally noticeable in an experiment.

The only motion necessary to be placed in-vacuum is a single crystal tilt. Because of the small offset, it is unnecessary to use independent tilts ("chi") on both crystals. The primary drive motions for both crystals are passed through the vacuum wall via differentially pumped seals. The novel use of coaxial drives means that it is the differential theta motion that is controlled ("delta-theta"). Energy is scanned by a single motor so the crystal pair moves as a channel cut. This leads to very stable tracking of the energy over wide ranges as we describe in this paper. The use of a delta-theta configuration with a narrow range also means it can be heavily geared down for fine adjustment. This also avoids the problem of crashing the crystals when the offset is so small. The design was created using parametric solid models as shown in figure 1. Finite Element Analysis were conducted on several critical parts to determine the possible deflection under different load and heat constraints.

FIGURE 1. Complete design generated using parametric solid models

The main structural component of the monochromator is the Huber 420 rotator, mounted vertically as shown in figure 2. To the non-rotating part of this is mounted a main body assembly which contains the differential pumping ports, a flange to mate with the tank, and bearings and seals for the common crystal rotator spool which passes through it. This common crystal rotator passes through the main rotator and is attached to its rotating part. Also mounted here is the first crystal rotator. When its motor is run, a screw jack is operated which moves a roller assembly up and down. This roller assembly bears against the angled side of the long free arm, which, with the short free arm, forms a clamp around the first crystal spool. The first crystal spool rotates on bearings inside the common rotator. When the rollers run down, the first crystal rotates and the angle of reflection decreases. When the rollers run up, springs which link the fixed screw jack and motor mounting bracket to the long free arm, cause opposite rotation, and the incident angle increases.

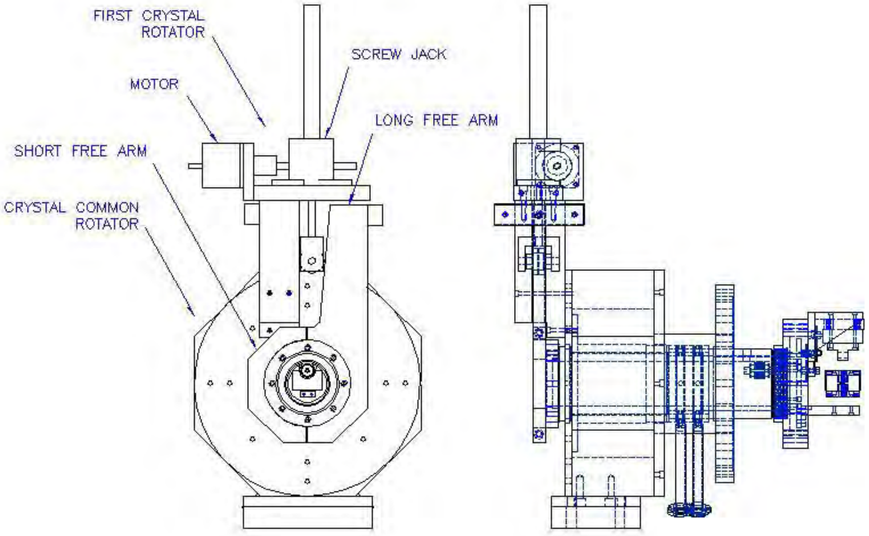


FIGURE 2. The main structural component of the monochromator

First crystal holder. This is a copper block excavated under the crystal and cooled by a continuous water tube starting and ending outside the vacuum. This tube features sections with wave-like bends to accommodate rotation of the crystal holder relative to the tubing entrance/exit flange.

Second crystal holder. This tilts ±5° by being attached to a small vacuum-compatible tilt stage driven by an arrangement of miniature gears, shafts and couplings connected to a motorized feedthrough as shown in figure 3. A short manual horizontal adjustment is also incorporated. Both holders incorporate a matrix of very small tapped holes for attachment of the crystals.

Compton shield. This is attached to the second crystal holder to absorb parasitic radiation emitted from the first crystal. It is cooled by a tube virtually identical to that on the first crystal holder. Because of the very small area through which these tubes must pass, and their proximity to each other, the four wave-like areas mentioned above are staggered so they can nest together without interference.

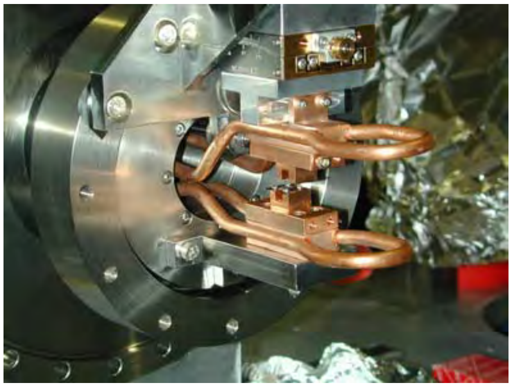


FIGURE 3. Shows water cooling tubes and crystal mounts.

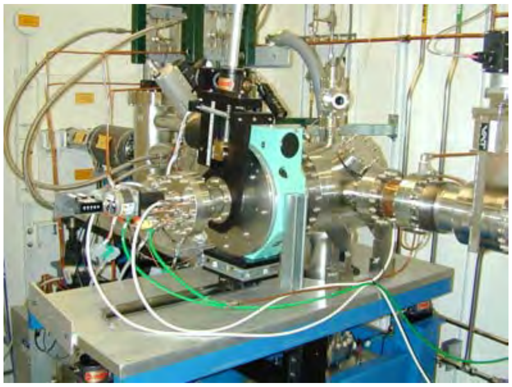


FIGURE 4. Complete system shows the stand and the monochromator stands.

Feedthrough flange. This incorporates numerous ports for electrical connections and the second crystal tilt motor, and holes for passage of the four water cooling tubing ends as shown in figure 4.

Tank. It surrounds the crystal holders and has vacuum flanges for connecting to the monochrometer body, the pump, beam in and out, view port and utility. Its mounting feet incorporate T-slots with setscrews for small manual position adjustment.

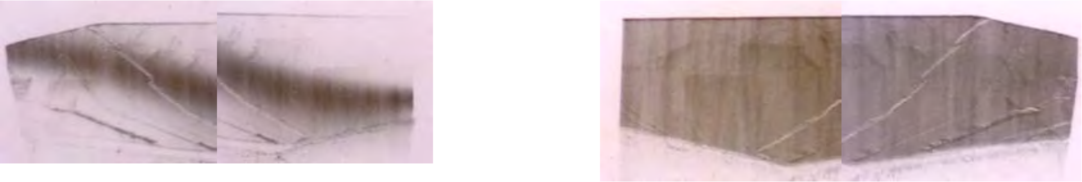
Fixed horizontal entrance aperture. This protects the crystal holders from a mis-steered beam. It is made from Glidcop, an explosion-bonded to stainless steel and contains water-cooling channels and fittings.

Motorized 20 mm vertical height adjustment of the entire monochrometer/tank/pump assembly. This is a welded three-legged stand made from four-inch square tubing. On top of this are three screw jacks driven by a single stepper motor via a driveshaft and gearbox. These jacks support an aluminum plate with a large round cutout for pump attachment. To this plate are attached the tank and a length of rail on which the body of the monochromator slides for easy removal from the tank.

Gravity Feed Cooling System. In order to reduce vibrations of the crystals induced by the cooling water flow, a low pressure, closed loop system was constructed. Water is stored in a 40 l stainless steel tank approximately 1.5 m above the monochromator and is gravity fed through separate lines for each of the two crystals. The water is collected in a large polypropylene tank beneath the monochromator and a sump pump periodically returns the water to the steel storage tank

Rocking Curve Measurements

The completed monochromator was tested in hutch 34-ID-B at the APS, providing a monochromatic beam that was monitored with an ion chamber in hutch 34-ID-C. Synthetic Diamond (111) crystals (Sumitomo) of approximate dimension 9x5x0.5 mm were attached to the copper mounting blocks. Two #2-56 screws held tantalum straps across each end of the crystals. A strip of indium was used between the copper and the crystal to provide an extended area for thermal contact. It was found by x-ray topography that the crystals were easily strained as shown in figure 5, so the clamping screws were loosened afterwards until they were just finger-tight. The final positions of the crystals were set with a lateral offset of 7.5 mm (along the beam) and a vertical offset of 2.5 mm. This allowed tuning of the energy over the required 6-15keV range while keeping the beam reasonably centered and with only a fraction of a millimeter change in vertical displacement.



Second crystal, as previously mounted

Second crystal, after loosening clamping screws

FIGURE 5. – X-ray topography of second crystal.

The rocking curve was measured by scanning the delta-theta motion that changes the angle of the second crystal relative to the first. The rocking curve width corresponded to about 0.1 mm of motion of the screw-jack wedge-drive, or about 200 steps on the motor. This was found to be sufficiently geared-down for routine tuning and very little backlash was observed, once the standard motor-backlash correction was employed. The tilt motion (chi) provided smooth horizontal beam steering with relatively little coupling to the delta-theta motion. The chi motion could be scanned, but a small residual backlash effect was obtained, perhaps arising from the gear chain; even though this could probably be corrected, it was not found to be inconvenient.

The great advantage of the simple design is the resulting stability. No feedback system was required to keep the monochromator tuned up. Some downward drift of the intensity was detected, which required re-optimization of delta-theta approximately every 12 to 24 hours. From a "cold" start, the relative motion moved by almost one rocking-curve-width in the first hour, but not significantly afterwards. Because of the relatively good stability, we did not benefit enormously from operation of APS in "top-up" mode, as other groups have found.

Wide-ranging energy scans could be performed routinely, as shown in Figure 6. The spectrum of APS undulator "A" at sector 34 was measured with an ion chamber for three different settings of the "taper." This measurement is used to verify that the taper is calibrated correctly in our installation. The calibrated undulator "gap" was set to 8.0keV, but the peak in the spectrum was found to be at 7.9keV because of the angular integration over the horizontal emission cone of the undulator. For this measurement, 1 mm vertical and 0.25 mm horizontal slits were used in front of the beam-splitting mirror [1], which is located 26 m from the source. The mirror is a liquid-nitrogen-cooled block of Si coated with Pt [1]. The monochromator was located at 46 m.

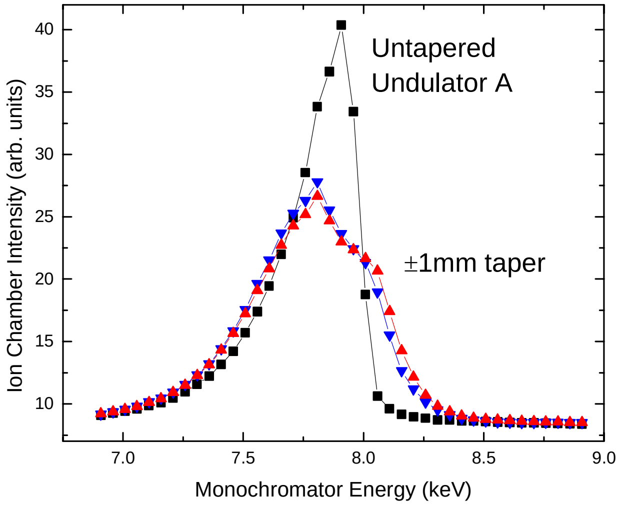


FIGURE 6. Spectrum of APS undulator "A" at sector 34 measured in a scan of the single energy drive motor. Three different settings of the undulator "taper" are shown.

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[1] "Beam Splitting Mirror for Advanced Photon Source Sector 34" C. A. Benson and I. K. Robinson, AIP Conference Series Eleventh US National Conference on Synchrotron radiation Instrumentation, ed P. Pianetta et. al. CP521 230-233 (2000)