REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 73, NUMBER 3 MARCH 2002

Design and performance of a stable first crystal mount for a cryogenically cooled Si monochromator at the Advanced Photon Source

E. M.Dufresne,[a] D. A. Arms S. B. Dierker,[b] and R. Clarke
Department of Physics, University of Michigan, Ann Arbor, Michigan 48109-1120

Y. Yacoby
Racah Institute of Physics, Hebrew University, Jerusalem, Israel 91904

John Pitney, Bob MacHarrie, and Ron Pindak
Bell Labs, Lucent Technologies, Murray Hill, New Jersey 07974-0636

(Presented on 23 August 2001)

We present a new design for mounting a cryogenically cooled Si crystal which gives greatly improved beam stability. The design has been successfully implemented at the University of Michigan, Howard University, Bell Laboratories-Lucent Technologies Collaborative Access Team (MHATT-CAT) 7ID Beamline of the Advanced Photon Source. Before the installation of the new crystal mount, our Si (lll) cryogenically cooled monochromator was sensitive to the pressure fluctuations of the liquid nitrogen coolant, such that the angle of incidence on the first crystal varied linearly with the applied pressure in the cooling lines, causing beam motion of about 250 μm, 60 m from the source. The key element of the design is a symmetrically positioned cooling manifold which balances the forces caused by pressure fluctuations. With this new mount, the typical beam stability is now about 10 μm, comparable to the source stability. © *2002 American Institute of Physics.* [DOI: 10.1063/1.1423630]

Third generation sources such as the Advanced Photon Source (APS) provide x-ray beams with beam position stability on the order of 10 μm, and beam steering stability on the order of 0.1 μrad. Typical optical elements and experimental setups are, respectively, 30 and 60 m from the source, thus, to preserve the source position stability, the monochromator incident angle must be stable to within 10 μm/(2 $\times$30 m)$\approx$0.2 μrad. Thermal drifts or unbalanced mechanical forces originating from cooling fluids can cause angular movements of several μrad, thus stable mechanical and thermally insulated mounts are essential to provide beam position stability.

On the insertion device beamline 7ID of MHATT-CAT, we have built a fixed offset double crystal monochromator following a proven APS design.[1] The first Si (lll) crystal is directly cooled by liquid nitrogen (LN_2). This nitrogen is fed by a closed loop Oxford cryocooler. In the original design of the first crystal mount, we have found that the beam flux was nearly completely lost during a periodic refill of the LN_2 cryocooler. This fill typically lasts about 15 min. During the fill, warm gas from the LN_2 feed line comes in the Dewar that houses the pump, and disturbs the closed loop pressure by typically 2 psi. Once liquid flows in the Dewar, the intensity recovers. This loss of flux implies that the two Si (lll) crystals were misaligned by an angle comparable to the Darwin half width of 15 μrad. This experience is consistent with other APS installations of the cryogenically cooled monochromator. For example, Alkire, Rosenbaum, and Evans mention beam position fluctuations caused by pressure fluctuations in their cooling lines.[2]

Since we suspected our first crystal mount to be sensitive to pressure fluctuations, we describe below the technique used to diagnose the cause of beam intensity fluctuations, and to remedy them. This technique uses tilt sensors to monitor the tilt angle pressure response. We then describe a new design of a first crystal mount which has improved dramatically the stability of our undulator monochromatic beam. We conclude with some additional comments on upgrades which have further improved the beam stability.

We performed tests without x rays and with the crystal at room temperature using two tiltsensors to test how the pressure in the crystal coolant lines affects the tilt of the first crystal. The tiltsensors used provide sufficent angular resolution to measure 0.1 μrad shifts.[3] The tilt sensors were mounted perpendicular to each other on the top surface of the first crystal. We pressurized the LN_2 reservoir and cooling lines with dry nitrogen gas and measured the resulting tilt in θ_B and χ of the first crystal. The cryocooler pressure sensor was used to record the applied pressure.

Figure 1 shows the angular tilt versus the applied pressure for θ and χ before implementing the new crystal mount. Typically after a first pressurization and depressurization cycle, the curves were quite reproducible. Although some hysteresis is present, we measure a reproducible, linear dependence of both θ_B and χ on pressure. The slopes in Fig. 1 are 14 and 21 μrad/psi for θ and χ, respectively. The fluctuations in the closed loop pressure during normal operations are about 0.3 psi, producing a 4 μrad change in theta, thus 8 μrad in two theta. These fluctuations are caused by a heater circuit turning on and off every 20 s to keep the pressure

---

[a] Electronic mail: 1 dufresne@umich.edu

[b] Also at the National Synchrotron Light Source Brookhaven National Lab, Upton, NY 11973-5000

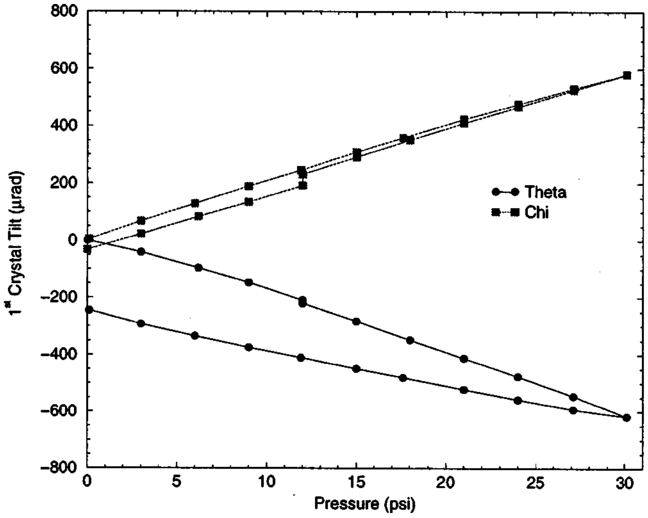

FIG. 1. Tilt angles vs applied pressure prior to upgrade.

constant. This angular tilt is small compared to the Darwin width of 29.2 μrad, but it produces a 240 μm vertical beam translation 30 m downstream. During an automatic fill of the LN$_2$ reservoir, the pressure typically changes by about 2 psi over the course of about 15 min, during which the x-ray intensity vanishes. Prior to the modification, a pressure change of 2 psi produces a tilt in theta of 27 μrad, well outside the Darwin half width of about 15 μrad. Hence, the beam is lost. So, the tilt versus pressure measurements are completely consistent with our earlier observations on the x-ray beam.

The second crystal is mounted independently from the first crystal directly onto the Huber circle.[1] To make sure that the Huber would not transfer pressure forces on the second crystal, we also performed a pressurization test but found no measurable angular shift of the second crystal to a 20 psi pressurization. The pressure sensitivity lies solely with the first crystal.

Figure 2 shows a side view of the new first crystal mount of our double crystal monochromator. The beam propagation direction is into the page. The Si (lll) single crystal is held by three bolts between two Invar plates. Cooling channels were bored through the crystal, allowing LN$_2$ to flow transverse to the beam.[4] A standard indium C-ring seal provides for a leak-tight cryogenic seal.[4,5] The crystal is held firmly by a thick Invar plate which is also bored with cooling channels and connected to the LN$_2$ lines. This cold Invar plate is mounted on a dovetail slide, thermally insulated from it by vacuum compatible G-10 posts. Three pairs of G-10 posts attach the plate to the female dovetail slide in three perpendicular directions, and provide a very stiff anchorage for the Si crystal. The dovetail slide is used to align the first crystal in the center of rotation of an in-vacuum Huber rotation stage that sets simultaneously the first and second crystal of our monochromator Bragg angles.[1] Once on center, the dovetail is secured by two set screws.

The slide is mounted on a coarse rotation mount with a ±5° range that allows the first crystal angle to be aligned with respect to the second crystal mount. Once in position, the stage is secured by three bolts onto the back plate. No provision was made for a chi misalignment at this point. We rely on precise machining of all the plates to prevent any misalignment in chi. It is possible that the In seal would cause a chi angle misalignment of more than 0.1° because it is hard to keep the two Invar plates parallel to each other. While sealing the crystal, one must try to keep the Invar plates and crystal surface perpendicular to each other. Nevertheless, after assembly, it was found that chi was horizontal to within 0.1°. The whole assembly is bolted onto the Huber one circle.

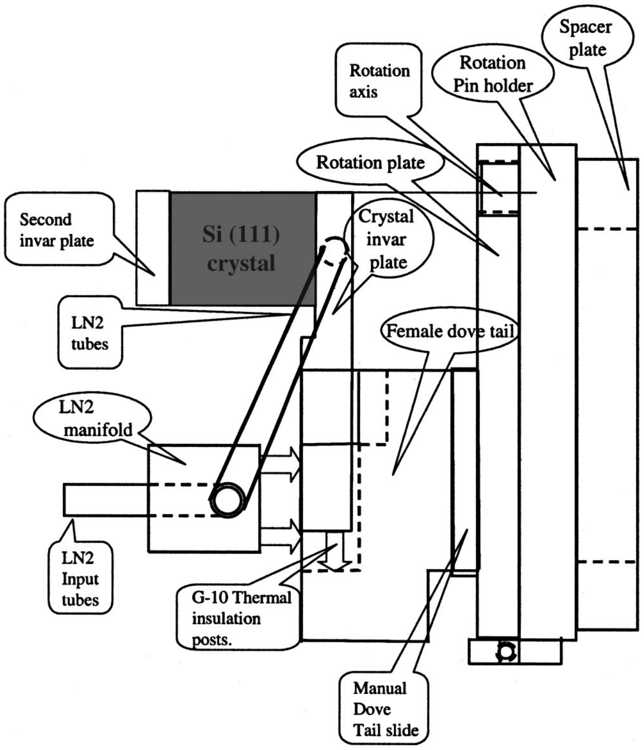

FIG. 2. Side view of the new crystal design.

The LN$_2$ enters the assembly through an Invar cooling manifold (see Fig. 3). The manifold is itself mounted on the

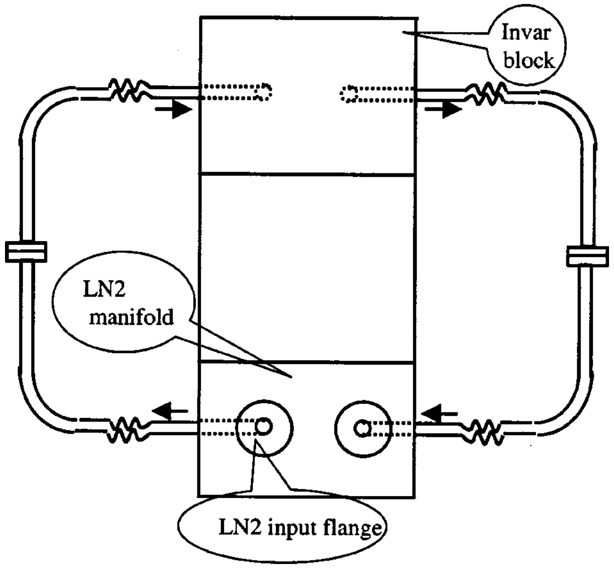

FIG. 3. Front view of the new crystal design.

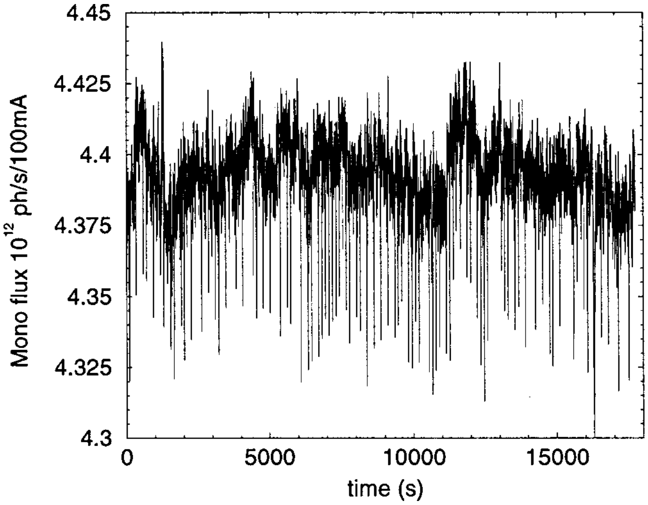

FIG. 4. Time series during top-up operation of the APS. The sudden dips are due to top-up injections.

female dovetail, and thermally insulated from it by four G-10 posts. All the forces due to pressure fluctuations are transferred to the solidly held manifold, and thus not transferred directly to the first crystal. Furthermore, when the first crystal rotates to change Bragg energy, forces from the motions of the cooling lines are not transferred directly to the crystal. This manifold should help with energy scans of the monochromator.

The details of the cooling lines are shown in a front view in Fig. 3. Most importantly, the flow directions were chosen to balance the forces on the first crystal due to pressure changes. Bellows and flanges were added to help with the assembly. The bellows allow for thermal contraction of the cooling lines. In Fig. 3, the LN_2 flows out of the page through the Invar crystal plate into the Si crystal (not shown here) and returns in the page, again balancing forces on the crystal. After installation of the new crystal mount in the monochromator tank, we performed a new measurement of the tilt dependence on pressure. The Bragg angle theta now only deflects by (0.2 μrad/psi) which is a factor of 48 more stable than previously. This test proves the mechanical stability of the new mount.

We tested the flux stability with the new monochromator set to diffract 10.0 keV x rays. The white beam slits were set to 0.4×0.4 mm^2. In the beamline, the white beam slits are at 26.5 m, the monochromator at 30 m, and an ion chamber 35.5 m from the source records the monochromatic flux. Figure 4 shows the monochromatic flux versus time for 5 h during top-up operation of the APS. The top-up operation was interrupted temporarily at $t=6273$ s, and the beam decayed from 102.05 to 100.65 mA until 7127 s when top-up was restarted. Then the full current was ramped up and restored by $t=7942$ s. The intensity is stable to 0.3% rms! This is excellent. As expected, the beam intensity drops by up to $=1.7\%$ during a top-up fill because the injection process perturbs the orbit. Although the cryocooler refilled during this time series, no significant changes in the intensity were noted. Recent measurements of the beam position 50 m from the source show that the beam position shifts typically by 10 μm over several hours. The new first crystal mount is now far more stable than before the upgrade.

We plan in future improvements to implement feedback on beam position provided by an x-ray beam position monitor (BPM) that we built following a design of Alkire, Rosenbaum, and Evans.[2] The x-ray BPM allows for position sensitivity of a few μm. Since the installation of the new mount, we have also installed a 2.54-cm-diameter N_2 gas return line connected to the vent line of the Oxford cryocooler. Compared to the original 1.2-cm-diameter line, this new line provides four times the throughput of warm gas, and thus reduces the thermal and pressure disturbance in the recirculating LN_2 closed loop when the cryocooler refills its N_2 supply every 3 h or so. Furthermore we have added a vacuum jacketed line to the input line of the cryocooler which has reduced the fill time and again the pressure disturbance on the cryocooler. All these changes have greatly improved the pressure stability of the cryocooler and thus the mechanical and angular stability of the first crystal.

We thank Tim Nurushev for his help during the diagnostic phase of this project. We are also thankful to the technical staff at Hebrew University, Argonne National Lab Central shop, the APS machine shop, and Optics Fabrication Lab who were instrumental in the completion of this project. Operation of the MHATT-CAT Sector 7 beamlines at the Advanced Photon Source was supported by DOE Grant No. DE-FG02-99ER45743. Use of the Advanced Photon Source was supported by the U.S. Department of Energy, Basic Energy Sciences, Office of Energy Research, under Contract No. W-31-109-ENG-38.

[1] M. Ramanathan, M. A. Beno, G. S. Knapp, G. Jennings, P. L. Cowan, and P. A. Montano, Rev. Sci. Instrum. **66**, 2191 (1995).

[2] R. W. Alkire, G. Rosenbaum, and G. Evans, J. Synchrotron Radiat. **7**, 61 (2000).

[3] Applied Geomechanics Inc., 1336 Brommer St., Santa Cruz, CA 95062, (831) 462-2801.

[4] G. S. Knapp, C. S. Rogers, M. A. Beno, C. L. Wiley, G. Jennings, and P. L. Cowan, Rev. Sci. Instrum. **66**, 2138 (1995).

[5] C. S. Rogers, D. M. Mills, W.-K. Lee, G. S. Knapp, J. Holmberg, A. Freund, M. Wolff, M. Rossat, M. Hanfland, and H. Yamaoka, Rev. Sci. Instrum. **66**, 3494 (1995).