A Rotational Stage Using Overconstrained Weak-Link Mechanism for NIST USAXS Instrument at the UNICAT 33-ID Experimental Station

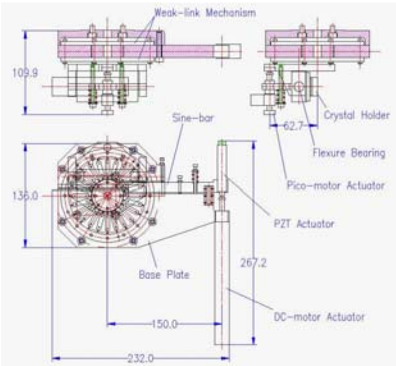
Deming Shu[1], Jan Ilavsky[2], Thomas S. Toellner[1], and Esen E. Alp[1]

[1] Experimental Facilities Division, Advanced Photon Source
Argonne National Laboratory, Argonne, IL 60439, USA

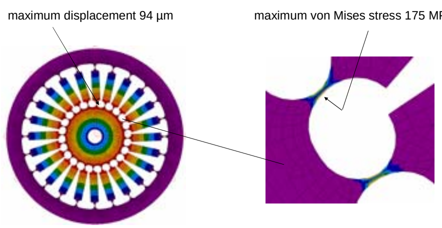
[2] National Institute of Standards and Technology, Washington DC, USA, and
Purdue University, West Lafayette, IN, USA

Abstract

We have designed and constructed a high-precision high-stability rotational stage for the National Institute of Standards and Technology (NIST) ultra-small-angle x-ray scattering instrument at the Advanced Photon Source (APS) UNICAT 33-ID beamline experimental station.
The stage includes a PZT actuator, a Pico-motor actuator and a DC-motor actuator for the crystal holder fine adjustment. An overconstrained weak-link mechanism provides high structure stiffness and stability. Preliminary experimental applications with this new rotational stage showed a significant system stability improvement.

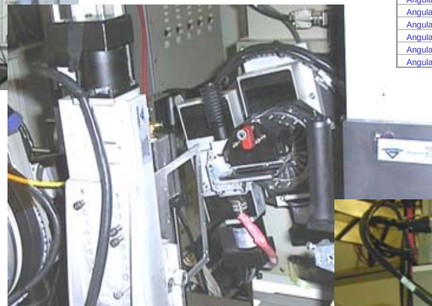


The rotational stage consists of two sub-assemblies: a base structure and a crystal holder. The base structure includes a compact sine-bar driving mechanism for the crystal pitch alignment, which is the key component of the whole structure. There are two groups of stacked thin metal weak-link structures mounted on each side of the base plate. A sine-bar is installed on the center of the planar rotary shaft for the crystal pitch alignment. Two linear driver are mounted on the base structure serially to drive the sine-bar. The rough adjustment is performed by a PI DC-motor actuator with a 50-nm step size. A PI closed-loop controlled PZT with strain gauge position sensor provides 1-nm resolution for the pitch fine alignment. A pair of commercial flexure bearing is mounted on the crystal holder, and a Picomotor driven structure provides the roll alignment for the crystal.

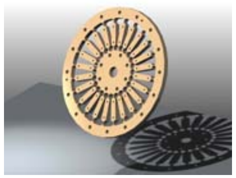


A finite element simulation for the wheel-shaped weak-link displacement under a 0.89-Nm torsion load. The left side shows the distribution of displacement, and the right side shows the distribution of stress in an enlarged zone.

UNICAT USAXS experimental station



Photograph of the rotational stage for USAXS instrument

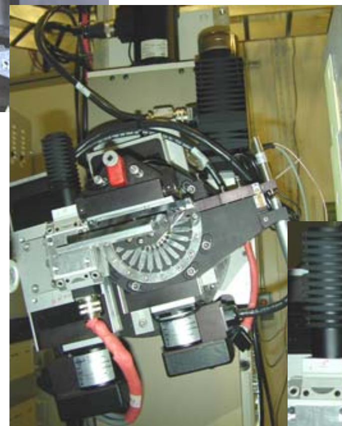


3-D model of the overconstrained weak-link mechanism

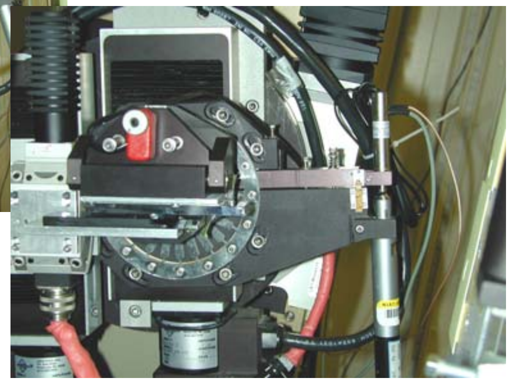
TABLE 1. Design specifications for the rotational stage for NIST USAXS instrument	
Maximum Overall Dimension	267 mm x 232 mm x 110 mm
Main Shaft Diameter	10 mm
Mounting Plate SIze	136 mm x 136 mm
Crystal Holder Size	25 mm x 100 mm
Number of Angular Alignment Axes	2
Angular Alignment Resolution (Pitch)	50 nrad
Angular Alignment Resolution (Roll)	600 nrad
Angular Alignment Stability (Pitch)	Drift less than 25 nrad per hour
Angular Alignment Stability (Roll)	Drift less than 100 nrad per hour
Angular Alignment Range (Pitch)	0.6 degree
Angular Alignment Range (Roll)	2 degree

Photograph of the rotational stage for USAXS instrument

To optimize the system stiffness, we have chosen overconstrained mechanisms in this design. The precision of the modern photochemical machining process using lithography techniques makes it possible to construct a strain-free (or strain-limited) overconstrained mechanism on the thin metal sheet. By stacking these thin metal weak-link sheets with align-pins, we can construct a solid complex weak-link structure for a reasonable cost. In this design, 250-µm-thick stainless steel sheets were used. Each group consists of twenty weak-link sheets. A 0.6-degree adjustment range was reached, which agreed with the finite element analysis result. A finite element simulation for the wheel-shaped weak-link displacement under a 0.89-Nm torsion load has been performed. In this case, the maximum displacement on the weak-link is 94 µm, which corresponds to a 0.25-degree angular motion on the planar shaft, and the maximum stress in the weak region is 175 MPa, which is 72 % of the yield stress as defined by von Mises criteria.



Photograph of the rotational stage for USAXS instrument



Photograph of the rotational stage for USAXS instrument

References

[1] D. Shu, T. Toellner, and E. E. Alp, Novel Miniature Multi-Axis Driving Structure with Nanometer Sensitivity for Artificial Channel-Cut Crystals, Synchrotron Radiation Instrumentation: Eleventh US National Conference, ed. P. Pianetta, Am. Inst. Physics, Conf. Proceedings vol 521 (2000) 219

[2] D. Shu, T. S. Toellner, and E. E. Alp, Modular Overconstrained Weak-Link Mechanism for Ultraprecision Motion Control, Nucl. Instrum. and Methods A 467-468, 771-774 (2001)

Acknowledgment

We acknowledge help from Messrs. Daniel Nocher, and Roger Ranay of the APS. The UNICAT facility at the APS is supported by the Univ of Illinois at Urbana-Champaign, Materials Research Laboratory (U.S. DOE, the State of Illinois-IBHE-HECA, and the NSF), the Oak Ridge National Laboratory (U.S. DOE under contract with UT-Battelle LLC), the NIST (U.S. Department of Commerce) and UOP LLC. The APS is supported by the U.S. DOE, Basic Energy Sciences, Office of Science under contract No. W-31-109-ENG-38.