Nanopositioning Design for X-ray Nanofocusing with K-B Mirrors and MLLs at the APS

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Abstract:

Hard x-ray nanofocusing optics are required in several new Advanced Photon Source (APS) Upgrade beamline construction projects, such as the In Situ X-ray Nanoprobe (ISN) and Sub-micron 3-D Diffraction (S3DD) beamlines. The ISN beamline is aimed at high-resolution imaging, spectroscopy, and tomography of energy systems and materials at a spatial resolution of 20-50 nm (baseline) with photon energies between 4 keV and 30 keV. The 3-D microdiffraction beamline is aimed at a spatial resolution of sub-50-300 nm with hard x-rays. The ISN instrument will also provide capability in variable temperature, flow of gases and fluids, and applied electrical fields, towards the study of properties of materials and devices under in situ conditions, as well as materials fabrication and device operation [1]. Nanopositioning techniques present a significant opportunity to support the state-of-the-art x-ray nanofocusing optics at the APS Upgrade project. Preliminary precision optomechanical designs for x-ray nanofocusing with Kirkpatrick-Baez (K-B) mirrors and multilayer Laue lenses (MLLs) at the APS are presented in this paper.

1-Introduction

The APS has developed the hard x-ray nanoprobe beamline at APS Sector 26, which has been operated, in partnership with the Center for Nanoscale Materials (CNM), since 2008. This system covers an energy range of 3-30 keV, and utilizes diffraction, fluorescence, and full-field transmission imaging to enable the study of nanoscale materials and devices. With zone plate optics, the nanoprobe has to date achieved a spatial resolution of 40-nm in scanning mode and 30-nm in full-field mode [1-3]. The high spatial resolution is enabled by combination of a high-resolution positioning system based on flexural stages, and high accuracy provided by laser interferometer-based encoders.

Based on the experiences gained from the CNM/APS hard x-ray nanoprobe design, construction, and operation, further efforts have been made to develop new precision positioning stages for APS users and for the new ISN and S3DD beamlines for the APS Upgrade project [4]. To focus x-rays with large bandpass to a spot size of 50 nm, elliptically figured K-B mirror optics will be applied for the nanoprobe instrument. Zone plates or MLLs will also be used to focus x-rays with small bandpass to a spatial resolution of 20 nm or below. Both K-B mirror optics and MLLs optics are capable of providing high focusing efficiency, between 30% and 80% at high photon energies.

Preliminary precision optomechanical designs for x-ray nanofocusing with Kirkpatrick-Baez (K-B) mirrors and multilayer Laue lenses (MLLs) at the APS are presented in this paper.

2-Nanopositioning system design for x-ray nanofocusing with nested K-B mirrors

High-stiffness rotary weak-link mechanisms based on stacked thin-metal sheets, as shown in Figure 1, were first developed for the APS high-energy-resolution beamline 3-ID [5,6] and are commercially available today [7]. More than 50 sets of such rotary weak-link mechanisms have been made for APS users. Applications include high-energy-resolution monochromators for inelastic x-ray scattering, x-ray analyzers for ultra-small-angle scattering, and diffracted-beam crystal analyzers for powder-diffraction experiments [8-11]. The laminar structure is configured and manufactured by chemical etching and lithography techniques. The precision and stability of this mechanism allowed us to align or adjust an assembly of crystals to achieve the same performance as that of a single channel-cut crystal. Their typical angular positioning resolution is 10-30 nrad with a travel range of up to 1.2 degrees [12].

Figure 1. A photograph of the APS high-stiffness rotary weak-link mechanisms.

To apply these rotary weak-link mechanisms to vertical axis and tip-tilting configurations, linear weak-link modules have been added into a new flexural stage system for high-precision K-B mirror manipulating as shown in Figure 2. The prototype of the two-dimensional tip-tilting stage system is designed for a novel nested prefigured elliptical mirror system (Montel x-ray mirror system) to push the performance of polychromatic microdiffraction far beyond current levels at APS Sector 34 [13]. The test results will help design an ultra-stable mirror-based x-ray nanofocusing system for the new ISN and S3DD beamlines for the APS Upgrade project.

The two-dimensional tip-tilting flexural stage system comprises a vertical-axis rotary weak-link top stage and a horizontal-axis tip-tilting weak-link base stage. Six linear weak-link modules are mounted on the sides of the base plate and top plate, orthogonal to the rotary weak-link plan, and act as a vertical stiffener for the vertical axis [13]. With this new design, 2-kg or higher vertical load capacity is achievable. The design specifications for the APS Z8-53 two-dimensional tip-tilting flexural stage system are listed in Table 1.

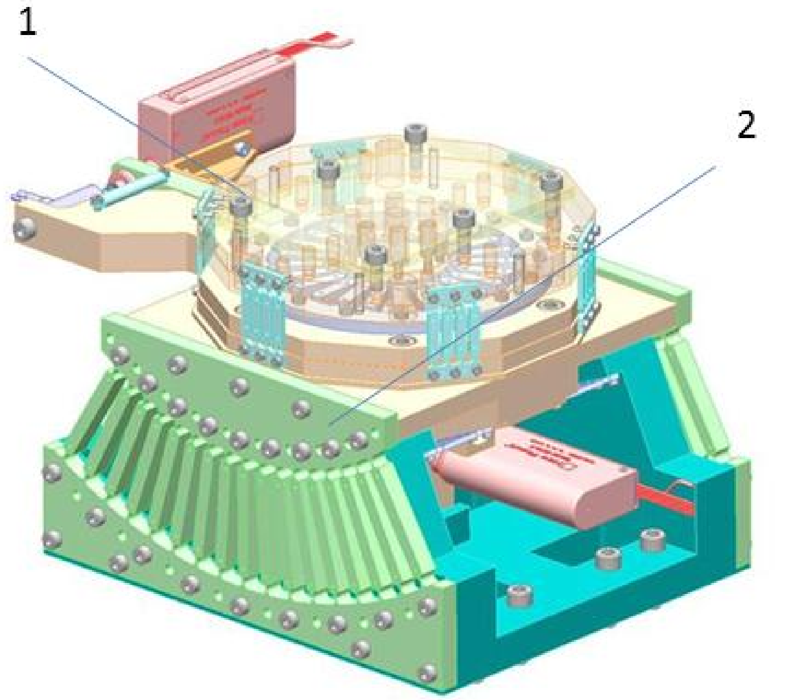


Figure 2. A 3-D model of the two-dimensional tip-tilting flexural stage system: (1) Vertical-axis rotary weak-link top stage; (2) Horizontal-axis tip-tilting weak-link base stage.

Table 1. APS Z8-53 Design Specifications

	Horizontal-axis tip-tilting base stage	**Vertical-axis rotary top stage**
Normal load capacity (kg)	5	2
Driver type	PZT and Picomotor	PZT and Picomotor
Encoder type	Strain sensor and linear grating encoder	Strain sensor and linear grating encoder
Angular travel range (mrad)	26	26
Min. incremental motion (nrad)	10	10
Overall dimension (mm)	212 (L) x 184 (W) x 108 (H)	236 (L) x 158 (W) x 50 (H)

3-Nanopositioning system design for x-ray nanofocusing with MLLs

The first prototype of precision multi-dimensional alignment apparatus for 2-D MLL x-ray focusing, designed and constructed for an MLL test bed at APS beamline 26-ID in 2008 [14], demonstrated the focusing capability of hard x-rays to a 2-D focus of 25 nm horizontal x 27 nm vertical FWHM at a photon energy of 12 keV, and of 25 nm horizontal x 40 nm vertical FWHM at a photon energy of 19.52 keV [15]. Carried out by a collaboration between Argonne and Brookhaven National Laboratory (BNL) scientists and engineers, a second MLL test bed was designed at the Argonne in 2010 for the National Synchrotron Light Source-II (NSLS-II) nanopositioning development project at BNL. The aim is to achieve NSLS-II's R&D goals for achieving 10-nm focusing of hard x-rays [16].

Figure 3 shows a 3-D model of the multidimensional alignment apparatus for x-ray MLLs with nanometer-scale 2-D focusing. The alignment apparatus consists of two groups of stages to align two MLLs precisely with respect to each other in a total of eight degrees of freedom. The upstream MLL lens is mounted on the lower group of stages that provides three translational and two angular precision adjustments. The downstream MLL lens is mounted on the upper group of stages that controls two translational and one rotational degree of motion precisely. Figures 4 and 5 are photographs of the upper and lower groups of positioning stages.

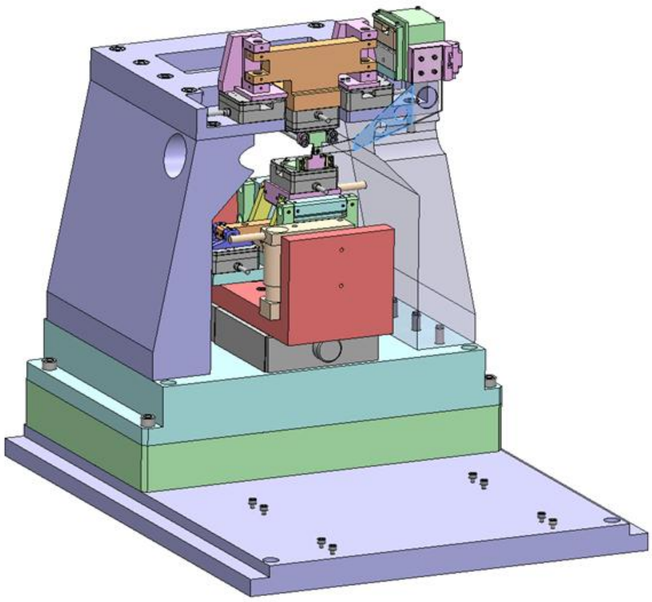
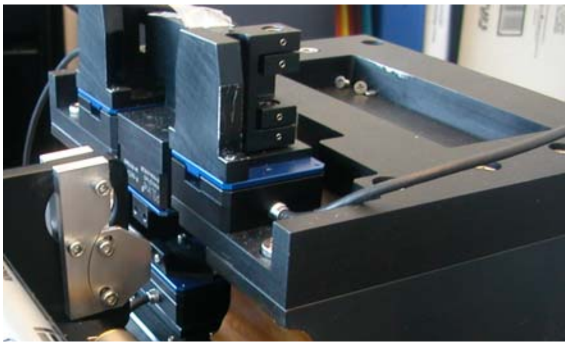


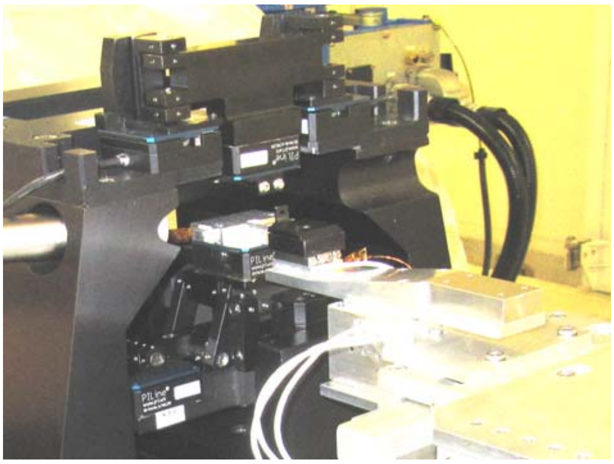
Figure 3. A 3-D model of the multidimensional alignment apparatus for x-ray MLLs with nanometer-scale 2-D focusing.

Figure 6 shows the second MLL test bed installed at a long imaging beamline experimental station (I13L) at the Diamond Light Source (DLS), UK. It will be used as an initial platform for further nanofocusing developments in collaboration with the NSLS-II, APS, and DLS staff [17].



Figures 4. The upper groups of positioning stages.

Figures 5. The lower groups of positioning stages.



Figures 6. The second MLL test-bed installed at a long imaging beamline experimental station (I13L) at the Diamond Light Source (DLS), UK.

4-Summary

Progress has been made to develop precision optomechanical structures for x-ray nanofocusing with K-B mirrors and MLLs at the APS. Nanopositioning techniques present a significant opportunity to support the state-of-the-art x-ray nanofocusing optics for APS users and for the new ISN and S3DD beamlines for the APS Upgrade project.

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