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MODULAR NANOPOSITIONING FLEXURE STAGES DEVELOPMENT FOR APS UPGRADE K-B MIRROR NANOFOCUSING OPTICS*

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Abstract

Kirkpatrick and Baez (K-B) mirror-based nanofocusing optics [1] will be applied to many beamlines endstation instruments for the APS-Upgrade (APS-U) project. Precision nanopositioning stages with nanometer-scale linear positioning resolution and nanoradian-scale angular stability are needed as alignment apparatuses for the K-B mirror hard X-ray nanofocusing optics. For instance, at the APS-U 19-ID-E In Situ Nanoprobe beamline endstation [2], to maintain stability of a 20-nm focal spot on the sample, nanofocusing K-B mirror system with 5-nrad angular stability is required. Similar angular resolution and stability are also required for APS-U 9-ID CSSI, APS-U 34-ID ATOMIC and other beamline endstation instruments [3, 4]. Modular nanopositioning flexure stages have been developed for the K-B mirror nanofocusing optics, which includes: linear vertical and horizontal flexure stages, tip-tilting flexure stages, and flexure mirror benders for bendable nanofocusing K-B mirrors, to overcome the performance limitations of precision ball-bearing-based or roller-bearing-based stage systems. The mechanical design and applications are described in this paper.

INTRODUCTION

The Advanced Photon Source (APS) at Argonne National Laboratory (ANL) is scheduled to undergo a massive upgrade that will replace the current electron storage ring with a new Multi-Bend-Achromat (MBA) reverse bent lattice model. X-rays generated by the upgraded APS will be up to 500 times brighter than those created by the current APS. Nine new feature beamlines and enhancements to many existing beamlines will be completed to enable many new exciting scientific research and development capabilities. A total of 12 pairs of K-B nanofocusing mirror systems, including 8 pairs of prefigured mirrors and 4 pairs of bendable mirrors, will be designed and constructed for the APS-U project.

To overcome the performance limitations of precision ball-bearing-based or roller-bearing-based stage systems, precision flexure nanopositioning stages with nanometer-scale linear positioning resolution and nanoradian-scale angular stability are developed at the APS to use as alignment apparatuses for the K-B mirror hard X-ray nanofocusing optics [5]. These modular stages are designed based on the experiences gained from the flexure stages APS developed for high resolution monochromators [6-10], and especially, for the K-B mirror alignment apparatus for APS 34-ID-E sub-micron 3-D Diffraction experimental station [11, 12]. Laminar weak-link mechanisms [13-15] are applied as a motion guiding structure for the flexure stages. The planar-shape weak-link laminar structure is configured and manufactured by chemical etching and lithography techniques with high-stiffness and high-precision.

As shown in Fig. 1, a typical K-B mirror optics for hard x-ray micro- or nano- focusing is a two-mirror system. Placed orthogonal to each other, each mirror is responsible for a single direction focusing and focused to the same focal spot [5]. With assistance of manual alignment processes prior to the x-ray alignment, the motorized manipulations for the K-B mirrors alignment can be minimized for the linear motion axes X_h, Y_v, and angular tilting motion axes A_{xv}, A_{yh}. In many in-vacuum setup, the orthogonality and distance between the two mirrors are also need to be aligned under X-ray.

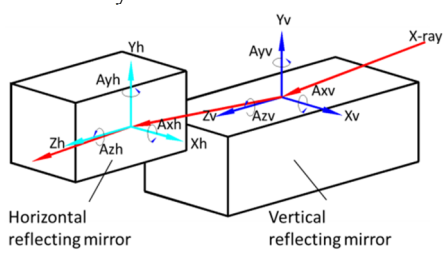

Figure 1: Schematic diagram of the K-B mirror hard X-ray nanofocusing optics.

STAGES DESIGN ENHANCEMENT

Several design enhancements are made for the modular K-B mirror stages for the APS-Upgrade project, which include:

- Designed linear flexure stages with optional extended travel range.
- Designed flexures linkage mechanisms with two vertical or horizontal linear flexure stages to perform linear and angular adjustment for longer mirrors.
- Designed motorized flexure stages for orthogonality adjustment.
- Equipped capacitive sensor for all linear and tip-tilt flexure stages as an option.

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- Ultra-High-Vacuum (UHV) compatibility option is available for both linear and tip-tilt flexure stages.
- Options for bendable K-B mirrors.

Figure 2 shows a photograph of the new laminar weak-link linear motion guiding mechanisms for APS T8-49v02 UHV-compatible vertical flexure stage with 1-nm positioning resolution and 1-mm travel range. The load capacity of the Picomotor™/PZT-driven stage is 10-kg. As shown in Fig. 3, the new T8-48v04 horizontal flexure stage is UHV-compatible with 1-nm positioning resolution, 1-mm travel range, and 4-kg load capacity. A 3D model is shown in Fig. 4 to illustrate a flexures linkage mechanism for a 400-mm-long vertical reflecting mirror alignment apparatus. With two vertical linear flexure stages, it can perform a minimum vertical displacement of 1 nm, and a pitch adjustment in nanoradian scale.

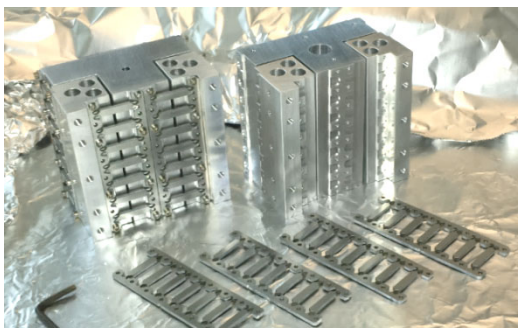

Figure 2: Photograph of the APS T8-49v02 vertical flexure stage weak-link guiding mechanisms.

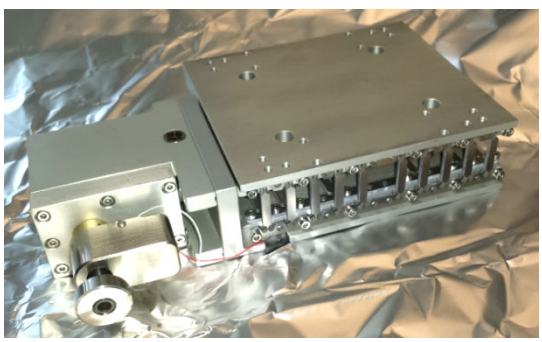

Figure 3: Photograph of the APS T8-48v04 UHV-compatible horizontal flexure stage.

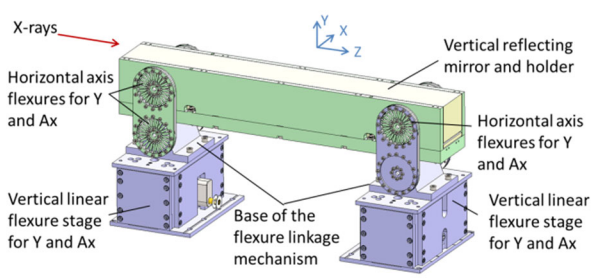

Figure 4: 3D model of the APS UHV-compatible flexures linkage mechanism for a 400-mm-long vertical reflecting mirror alignment apparatus.

APPLICATION CONFIGURATIONS

Short K-B Mirrors in a Mini-UHV-Chamber

A Mini-UHV-Chamber has been developed at the APS 34-ID-E for nanofocusing K-B mirrors with vertical reflecting mirror length of 65 – 100 mm, and horizontal reflecting mirror length of 25 – 40 mm. The Mini-UHV-Chamber is mounted on the top of a multidimensional flexure stage system with four flexure stages for x-ray nanofocusing with focal spot in the sub-50-nanometer scale as shown in Fig. 5 [5].

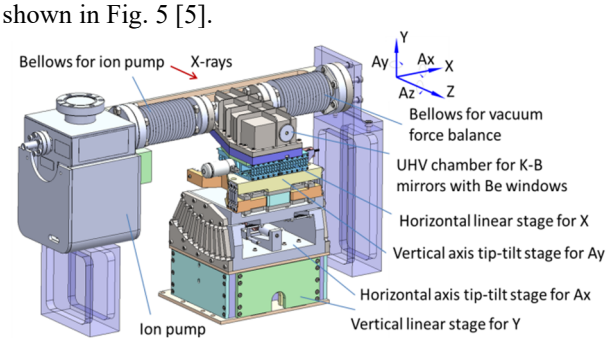

Figure 5: 3D model of the 34-ID-E Mini-UHV-Chamber with multidimensional flexure stage system.

Short or Medium K-B Mirrors in Helium

As a compact/cost-effective solution, nanofocusing K-B mirrors with vertical reflecting mirror length of 65 – 200 mm, and horizontal reflecting mirror length of 45 – 100 mm can be mounted on separate flexure stage groups on a base with gantry structure as shown in Fig. 6 [16].

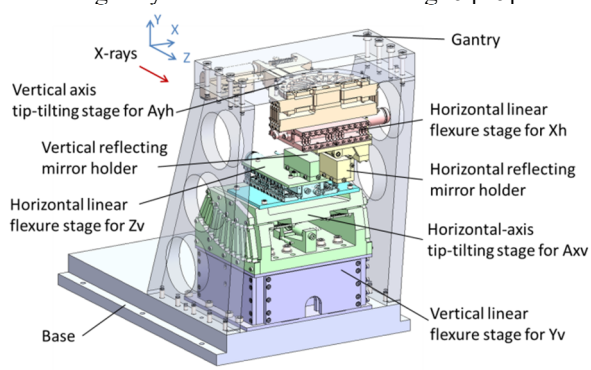

Figure 6: 3D model of the 32-ID nanofocusing K-B mirrors with separate flexure stage groups on a base with gantry structure.

Short or Medium K-B Mirrors in UHV

Short or medium K-B mirrors can also be mounted on separate flexure stage groups in a UHV chamber with or without gantry structure to fit with the instrument space. Figure 7 shows a pair of nanoforcusing K-B mirrors with a vertical reflecting mirror length of 150 mm, and a horizontal reflecting mirror length of 100 mm for the APS-U 7-ID-D Multi Modal Imaging and Diffraction (MMID) instrument. Both stage groups for vertical and horizontal mirrors are mounted on the same base in UHV.

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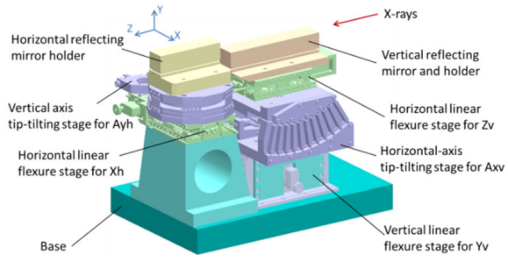


Figure 7: 3D model of the 7-ID-D nanofocusing K-B mirrors with flexure stage groups on same base in UHV.

Long Prefigured K-B Mirrors in UHV

For a nanofocusing K-B mirror with length longer than 200 mm, flexures linkage mechanism driven differentially by two linear flexure stages can perform better angular positioning resolution and stability. Figure 8 shows the design of K-B mirror stage system for APS-U 19-ID-E In-Situ Nanoprobe (ISN) instrument [2] with vertical reflecting mirror length of 404 mm, and horizontal reflecting mirror length of 129 mm. The design aim is to achieve 1 nm and 5 nrad positioning resolution for x-ray nanofocusing with focal spot ~20 nm with integrated laser interferometer and capacitive sensors. Figure 9 shows the design of K-B mirror stage system for APS-U 4-ID-G Polarization Modulation Spectroscopy (POLAR) instrument with vertical reflecting mirror length of 328 mm, and horizontal reflecting mirror length of 147 mm. Commercial motorized coarse stages are used to switch between multiple mirror coating strips.

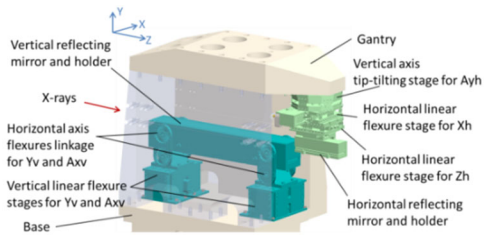


Figure 8: 3D model of the 19-ID-E ISN K-B mirrors with stage groups on a base with gantry structure in UHV.

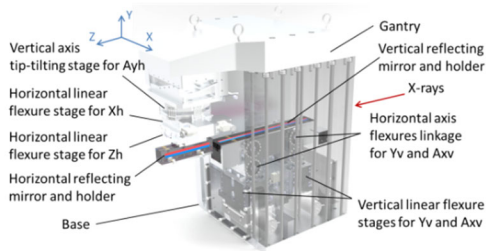


Figure 9: 3D model of the 4-ID-G ISN K-B mirrors with stage groups on a base with gantry structure in UHV.

Long Bendable K-B Mirrors in UHV

The APS modular nanopositioning flexure stages also support the applications with APS bendable K-B mirrors [17, 18]. As shown in Fig. 10, the K-B mirror stage system for APS-U 9-ID-D Coherent Surface Scattering (CSSI) instrument [3] includes two APS developed flexure mirror benders with vertical reflecting mirror length of 300 mm, and horizontal reflecting mirror length of 180 mm.

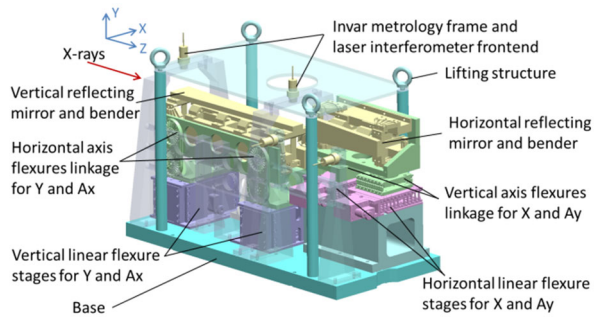


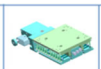
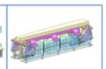
Figure 10: 3D model of the 9-ID-D nanofocusing K-B mirrors with flexure stage groups on the same UHV base.

The flexure stage group for both vertical and horizontal mirror benders are mounted on the same Invar base with Invar metrology frames for laser interferometer fiber optics frontends in UHV. The design goal of this bendable K-B mirror stage system is to provide variable x-ray focal spot with angular beam stability better than 20 nrad.

SUMMARY

Modular nanopositioning stages with nanometer-scale linear positioning resolution and nanoradian-scale angular stability are developed for the K-B mirror hard X-ray nanofocusing optics. Preliminary test results for the APS 32-ID flexure stages showed nanometer-scale linear positioning resolution with nanoradian-scale angular stability [16]. Table 1 summarized UHV-compatible modular nanopositioning stages to be applied for the K-B mirror hard X-ray nanofocusing optics for APS-U project.

Table 1: Applications of the UHV-Compatible Modular Nanopositioning Flexure Stages for APS-U Project

UHV Flexure Stages Linkages Benders	 H Stage T8-48v04	 V Stage T8-49v02	 Ay Stage T7-52	 Linkage Z7-61	 Bender Z7-70
APS-U 4-ID-G POLAR	Qty. 2	Qty. 2	Qty. 1	Qty. 1 With adj.	
APS-U 4-ID-H POLAR	Qty. 2	Qty. 2	Qty. 1	Qty. 1 With adj.	
APS-U 7-ID-D MMID	Qty. 1	Qty. 1	Qty. 1		
APS-U 8-ID-E XPCS	Qty. 2	Qty. 2		Qty. 1 With adj.	Qty. 2 With adj.
APS-U 9-ID-D CSSI	Qty. 2	Qty. 2		Qty. 1 With adj.	Qty. 2 With adj.
APS-U 19-ID-E ISN	Qty. 2	Qty. 2	Qty. 1	Qty. 1 With adj.	
APS-U 34-ID-F ATOMIC	Qty. 2	Qty. 2		Qty. 1 With adj.	Qty. 2 With adj.

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