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PROGRESS OF NANO-POSITIONING DESIGN FOR THE COHERENT SURFACE SCATTERING IMAGING INSTRUMENT

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Abstract

As part of the Advanced Photon Source Upgrade (APS-U) project, the Coherent Surface Scattering Imaging (CSSI) [1] instrument is currently being developed. One of the most important components of the CSSI instrument at the 9-ID beamline of the APS-U, the Kirkpatrick-Baez (K-B) mirror system, will focus hard X-rays to a diffraction-limited size of 500 nanometers at a working distance of 550 mm. High angular stability (19 nrad for the horizontal mirror and 14 nrad for the vertical mirror) is specified not just for the focused beamsize but, more importantly, to ensure the beam stability at the detector position that is up to 24 m from the K-B mirrors. A large sample-to-detector distance (up to 23 m), one of the beamline's unique features for achieving a sufficient coherent-imaging spatial over-sampling, requires sample angular stability of 50 nrad. In CSSI scattering geometry, the vertically placed sample reflects X-rays in the horizontal direction at an extremely shallow angle. The design includes two high-precision rotary stages for sample pitch (vertical axis) and yaw (horizontal axis). The current design of instrument's nano-positioning stages [2] and metrology required to satisfy the stability and positioning requirements are discussed in this paper.

INTRODUCTION

Motivation

The instrument will use coherent X-ray scattering for non-destructive, in-situ structure characterization with high three-dimensional resolution and high temporal resolution. This will allow for the investigation of self-assembly of mesoscale structures at surfaces at interfaces, as well as three-dimensional surface nano-patterning and nano-fabrication.

Large Sample to detector distance (up to 23m) is needed to achieve speckle oversampling. Figure 1 shows a schematic of the instrument, K-B mirrors, and the detector. The X-ray beam is shown in red and the horizontally scattered beam as it travels to the detector is in orange.

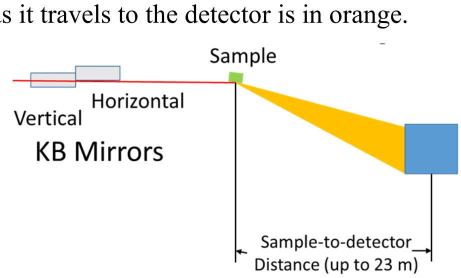

Figure 1: Instrument schematic: Not to scale.

Samples must be scanned with five (5) degrees of freedom (3 linear directions and 2 rotary directions: sample pitch and sample yaw [axis normal to sample surface]).

Technical Approach

To meet the stability and positioning requirements the design makes use of precision commercial stages, custom weak-link laminar flexure stages, and a metrology systems.

Weak-link laminar flexures are used to overcome limitations of ball-/cross-roller bearing stages. Resulting in minimal motion error and high repeatablilty of motion [2].

Four (4) different metrology frames using capacitive sensors and laser interferometers to achieve positioning and stability requirements. The KB mirror nanopositioning stages measured by a metrology frame with four (4) laser interferometers. The sample nanopositioning stages have three (3) metrology frames. One (1) capacitive sensor based metrology for both rotation scanning stages. The other frame with both capacitive sensors and laser interferometers is used to measure linear scanning stage motion errrors.

INSTRUMENT LAYOUT

The CSSI Instrument consists of five (5) major components as shown in Fig. 2:

- Granite air-bearing stages for aligning K-B mirrors and sample to the Beam
- Ultra-high Vacuum Chambers for K-B mirrors
- High vacuum chamber for samples
- Kirkpatrick–Baez mirrors with alignment apparatuses and laser interferometer metrology.
- Sample nanopositioning stages and metrology frames

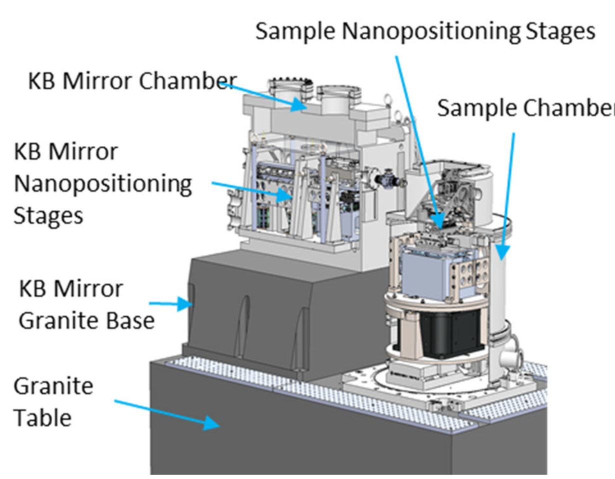

Figure 2: 3D model of the APS CSSI instrument.

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FLEXURE STAGES FOR K-B MIRROR SYSTEM

The K-B mirror components are shown in Fig. 3. Two (2) bendable mirrors are used for nanofocusing. One reflecting the beam vertically and the other for horizontally. As seen in Fig. 4 the bending mechanism consists of a lever arms driven by a piezo actuators. Laminar weak-link flexure guided are used for precision bending.

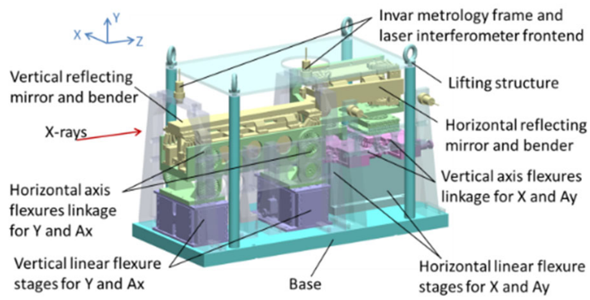

Figure 3: 3D model of the flexure stages system for K-B mirrir alignment.

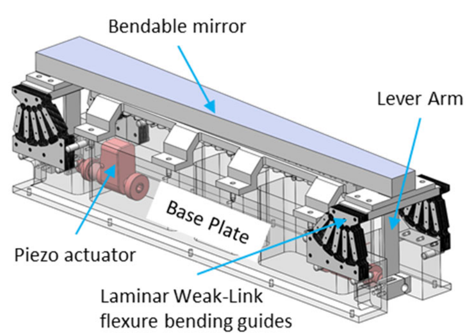

Figure 4: 3D model of KB mirror flexure bending mechanism.

The vertical and horizontal mirrors each utilize weak-link flexures are utilized for aligning the mirrors. The alignment apparatuses consist of two (2) linear weak-link flexure stages and passive weak-link flexures allowing for linear and angular adujustments (see Fig. 5):

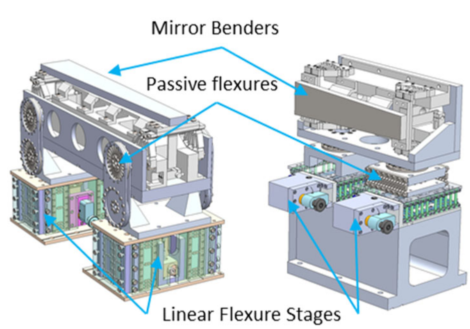

Figure 5: 3D model of horizontal and vertical KB alignment apperatuses.

STAGE SYSTEM FOR SAMPLE MANIPULATION AND SCANING

The sample manipulation and scanning stages are shown in schematic form in Fig. 6. The Sample motion is divided into 5 groups. Group 0 is the granite support table for the instrument. Group 1 is for sample alignment and positioning. Groupl 2 are the sample scanning stages. Groupl 3 are stages to correct sample orientation errors. Group 4 are stages to position a point of interest on the sample with respect to the scanning stages.

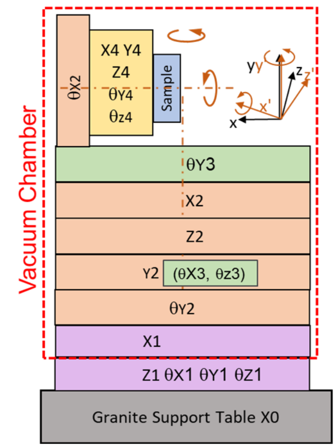

Figure 6: Schematic view of sample stages.

Figure 7 shows a cutout 3D view of the all the sample stages and metrology frames. The sample scanning, correction, and point of interest positiong stages will be discussed further in this section.

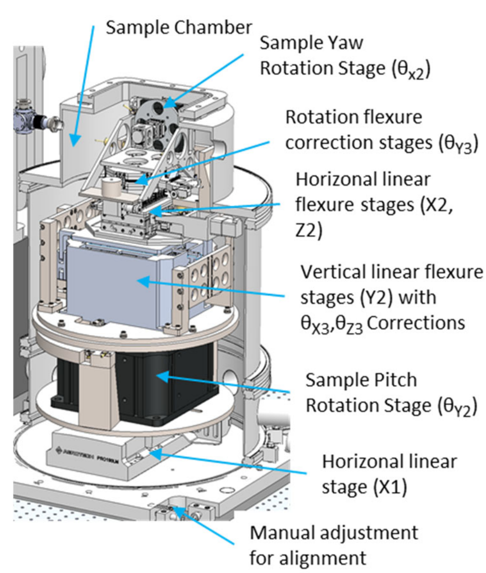

Figure 7: 3D model of the sample stages system.

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Sample Scanning and Correcting Stages

The custom flexure stages for scanning and correction are shown in Fig. 8:

1. horizontal stage: flexure bearing stage with centimeter-level travel range with nanometer minimum incremental motion (MIM) [3].
2. Horizontal stage: Piezo driven flexure stage with travel range of 1 mm and nanometer-level MIM [4].
3. Vertical stage: flexure bearing stage with centimeter-level travel rang and nanometer level MIM. With piezo accuators to correct any tilt errors.
4. Rotation Correction: flexure stage sample pitch with a travel range < 1^{o} and MIM of tens of nano-radians [2].

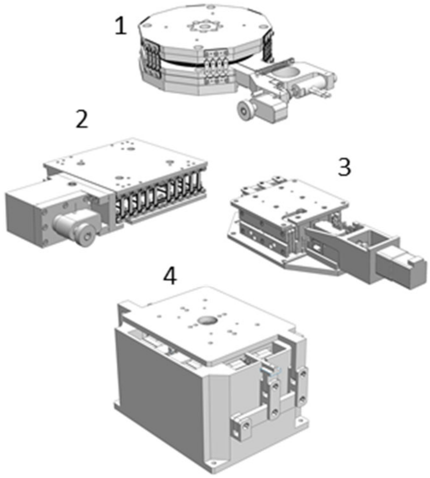
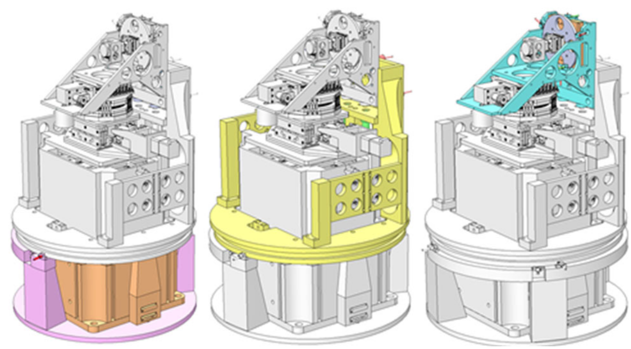


Figure 8: Custom flexure stages for sample scanning and sample.

SAMPLE METROLOGY SYSTEMS

The rotation metrology (shown in Fig. 9) use six (6) channels each of capacitive sensors. The sensors are mounted to an Invar® frame and target a polished aluminum disc. By calibrating the system [5] axial and radial errors can be measured on the nanometer level and tilt errors in the 10s of nanoradians.

The linear stage metrology (Fig. 9) consists of an Invar® frame and three (3) collimated laser interferometers heads with mirrored targets and three (3) capacitive sensors. Linear errors measured at 10s of nanometers and angular errors to 100-200 nanoradians.



(a) *(b)* *(c)*

Figure 9: 3D model of the capacitive sensor metrology for scanning rotation stages (a) sample pitch stage metrology (b) linear sample scanning stages (c) sample yaw stage metrology.

SUMMARY

Nanopositioning stages for KB focusing and aligning and for sample scanning and orientation correction. Most of these stages are laminar weak-leak flexure stages allowing the design to meet the stability and poisoning requirements of the APS Upgrade project featured CSSI beamline.

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