Mechanical Design of a New Precision Alignment Apparatus for Compact X-ray Compound Refractive Lens Manipulator

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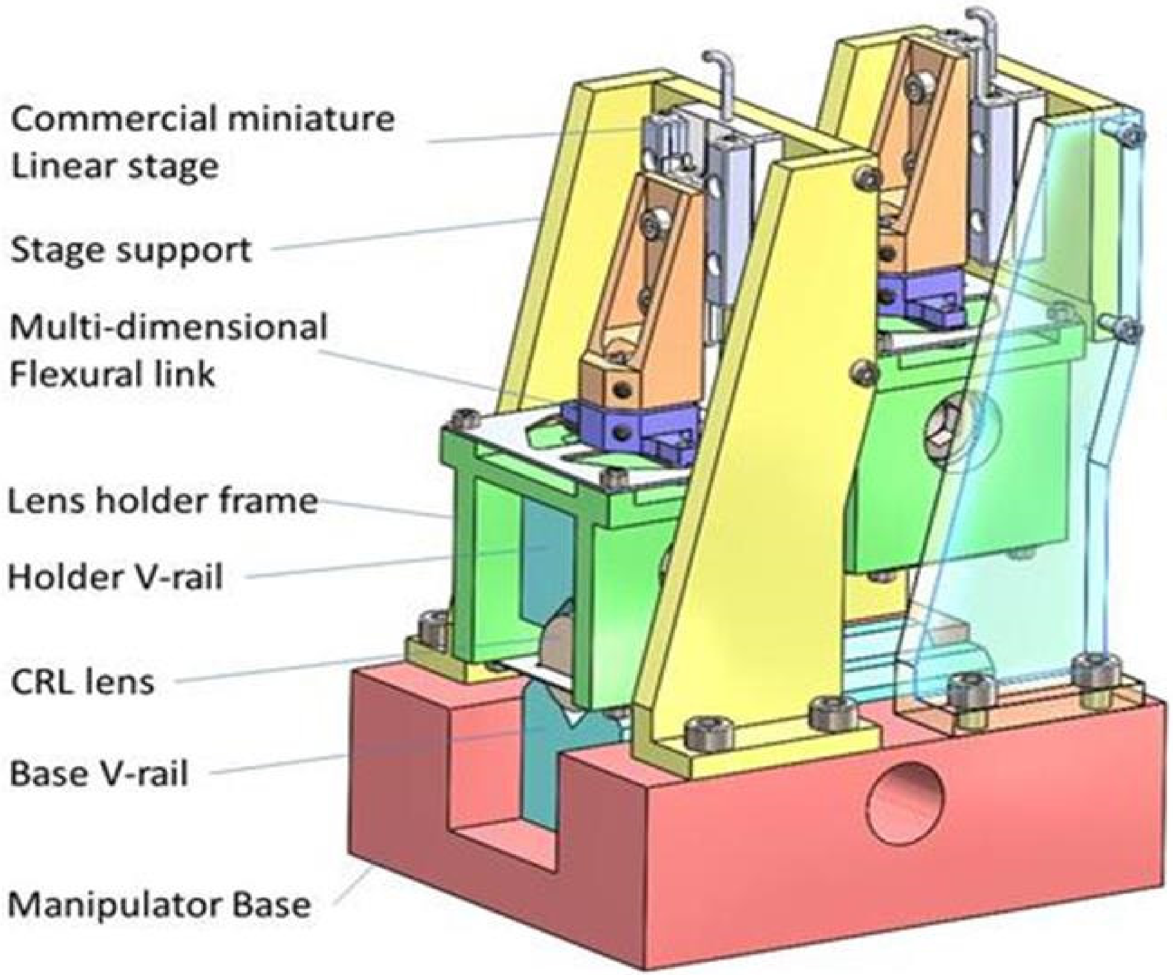
Introduction

- Dark-field imaging of multi-scale structures is a novel full-field imaging modality. It uses Bragg peaks to reconstruct 3D distribution of mesoscopic and microscopic structures that govern the behavior of functional materials, in particular, thermodynamic phase transitions in magnetic systems.
- At the heart of this new microscopy technique is a CRL-based x-ray objective lens with an easily adjustable focal length to isolate any region of interest, typically in the energy range of 5-100 keV or higher, with high precision positional and angular reproducibility.
- Since the x-ray CRL manipulator system for this technique will be implemented on a high-resolution diffractometer detector arm that rotates during diffraction studies, compactness and system stability, along with the ability to change focal length (“zooming”), became key design requirements for this new CRL manipulator system.

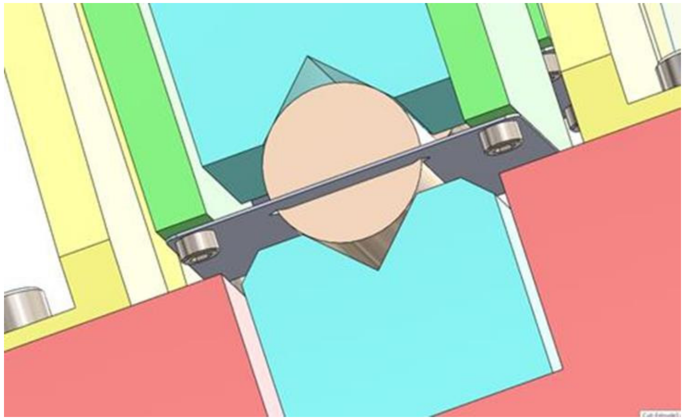
Proof-of-Principle Prototype

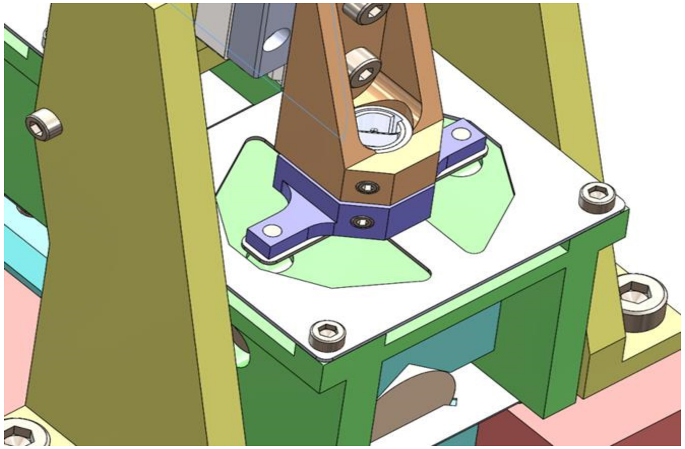
The prototype is using commercial high precision linear roller bearing V-rail as a reference base. It includes a base subassembly with stage support and a base V-rail, a lens holder V-rail with lens holder frame subassembly, a commercial miniature piezo-driven linear stage (SmarAct™ 1720s), and a multi-dimensional flexural link subassembly.

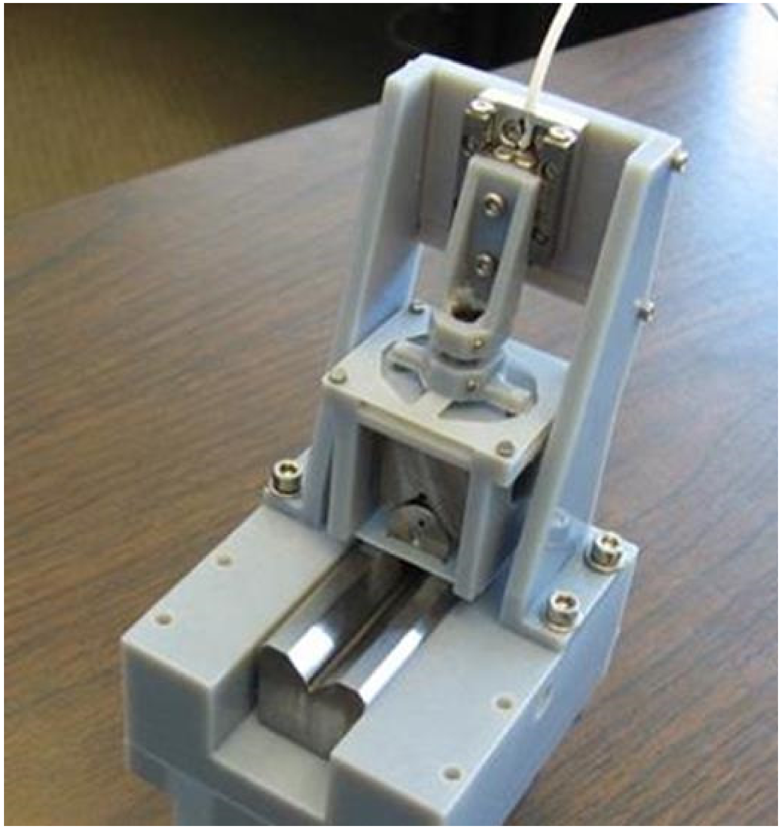


Proof-of-Principle Prototype

- A group of eight CRL is confined by a thin metal lens confiner, which is mounted on the bottom of the lens holder frame. A short linear bearing V-rail is mounted in the lens holder frame as the top half of the lens alignment structure.
- At the linear stages lower limit position, the flexural link subassembly provides multi-dimensional flexibility to ensure the CRL group to be fully aligned between the lens holder V-rail and the base V-rail.

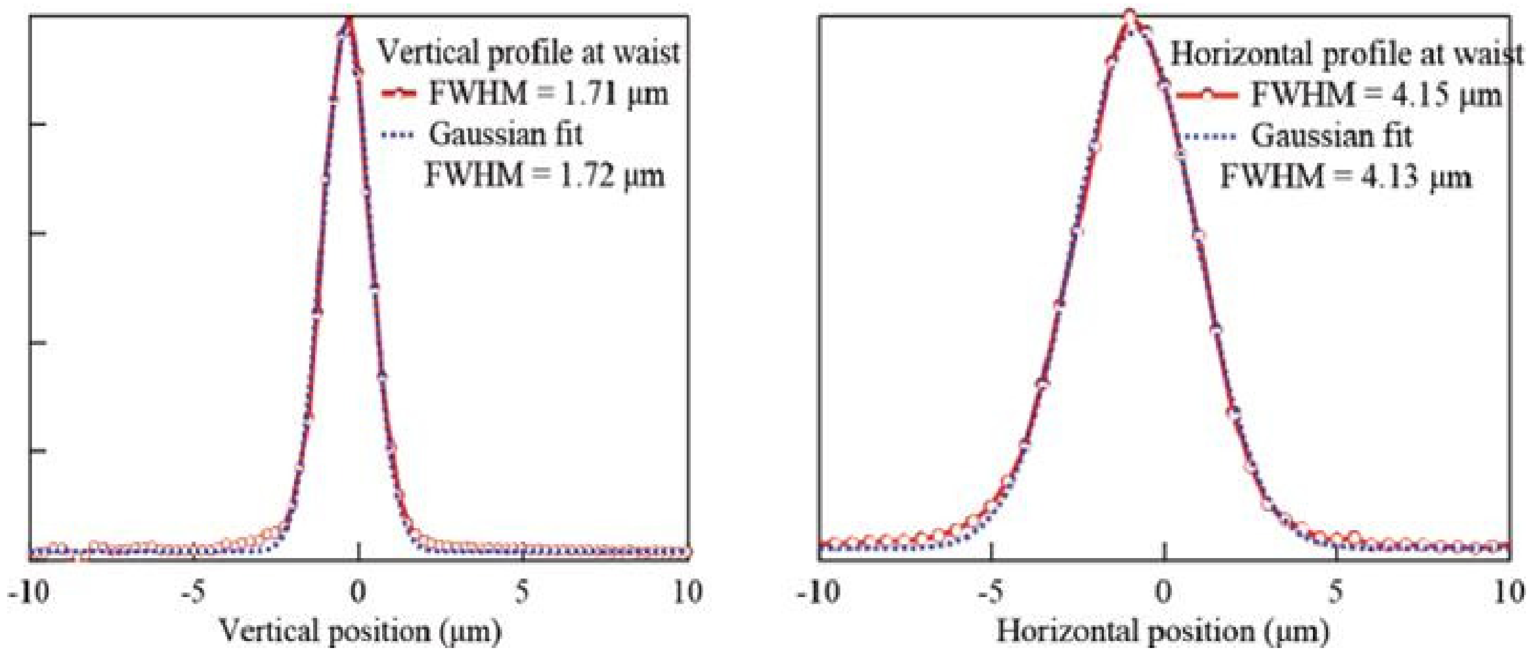




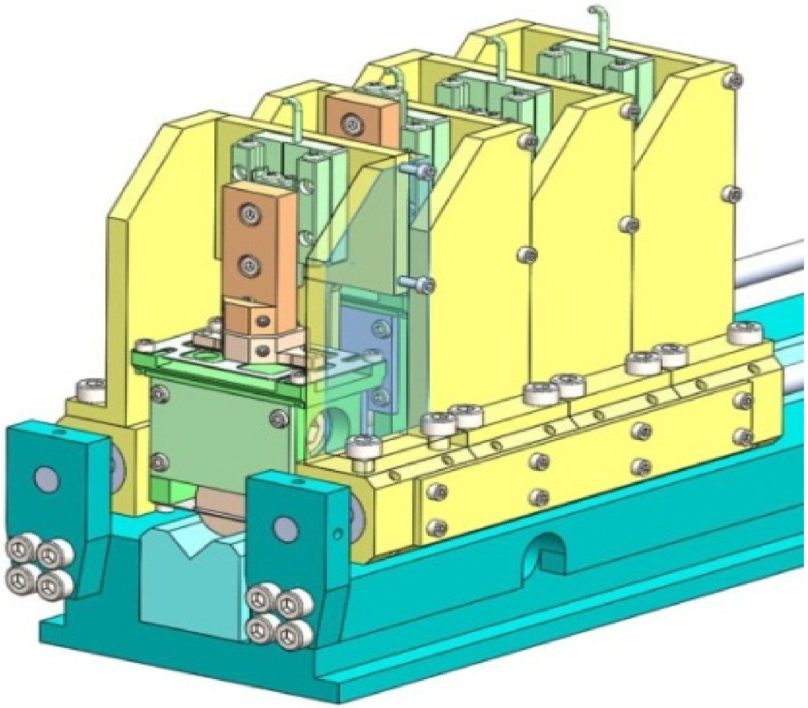


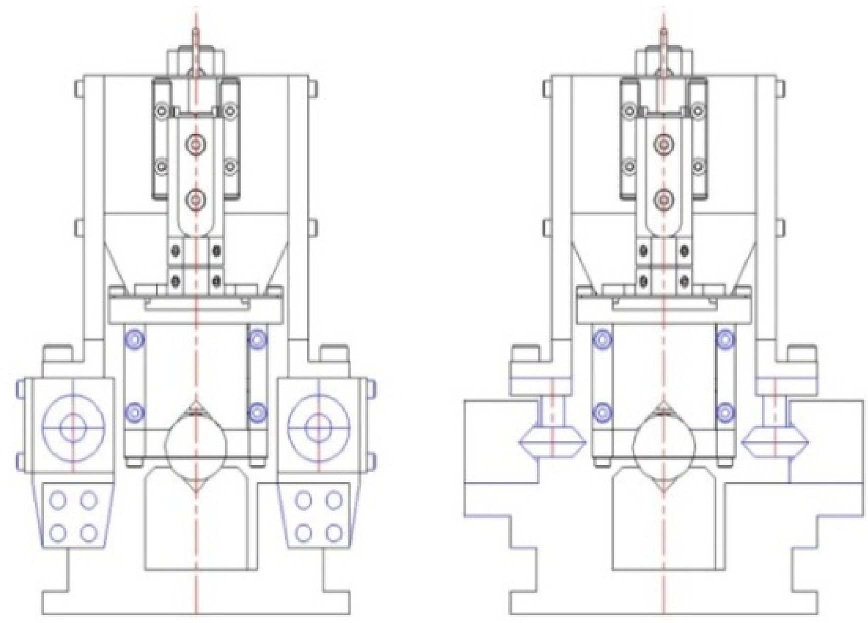
X-ray Test for the Proof-of-Principle Prototype

- A proof-of-principle prototype for the compact x-ray CRL manipulator has been manufactured with 3D-printing technique. It is designed to hold a group of eight 2-D parabolic beryllium CRL lenses with 50 micron radius of curvature from RXOPTICS™.
- The 2D-lenses have a circular frame with a diameter of 12 mm and a thickness of 2 mm for each lens. The x-ray test was performed at the APS 1-BM beamline using an 8 keV beam. The measured focal size of the lens stack is 4.1x1.7 μm^2 FWHM at 589 mm downstream of the lens stack.
- The total transmission of the stack is 36% within the 390×390 μm^2 aperture, which gives a gain of ~8000.



Design of the Compact Manipulator for 16-mm CRL Lens Stack

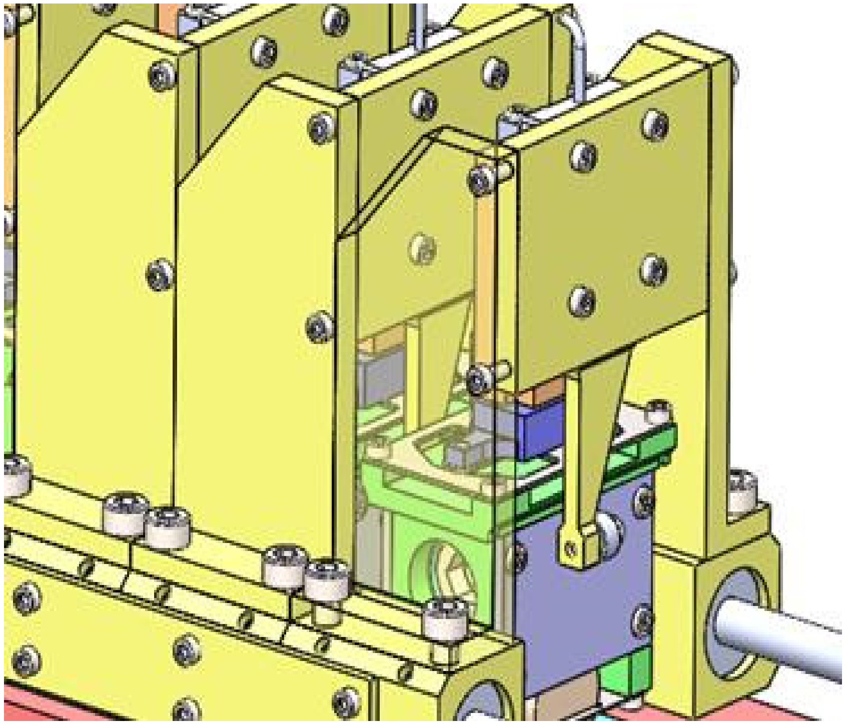


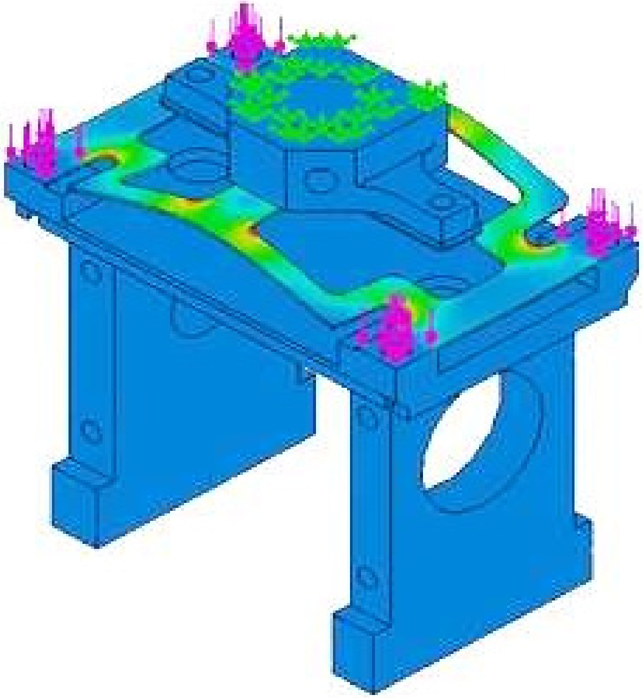


- Based on the experiences gained from the proof-of-principle prototype, a compact manipulator APS Y9-5101 for 16-mm CRL lens stack was designed using commercial miniature piezo-driven linear stage, such as SmarAct™ 1720s, as a lens manipulating driver.
- A group of four Y9-5101 CRL manipulators are mounted on a pair of linear guiding rails and linked together as a unit to be driven by a manual or motorized linear motion driver for focal length adjustment.
- Since the manipulator precision alignment structure is based on the commercial high precision V-rail, a regular linear guiding system can be used for the focal length adjustment. Two options of the linear guiding system are designed for the focal length adjustment.

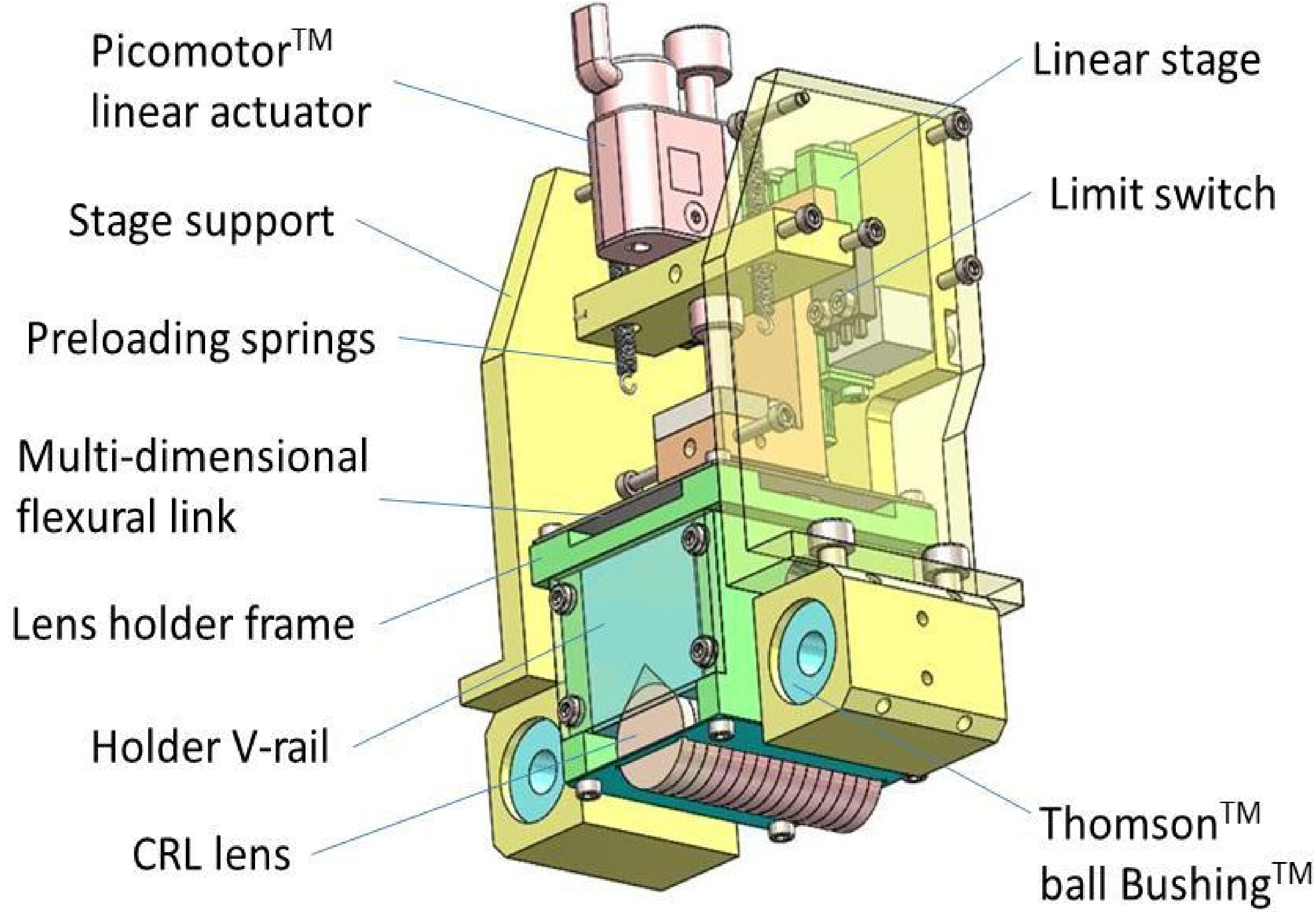
Design of the Compact Manipulator for 16-mm CRL Lens Stack

- To accommodate to the operation conditions on a diffractometer detector arm that may rotate in horizontal as well as vertical planes during diffraction studies, a micro-bearing has been added on the stage support structure to confine the vertical tilting range of the flexural link subassembly.
- A 3D FEA model for the flexural link subassembly of the Y9-5101 CRL manipulator has been built. The results showed that the maximum Von-Mises stresses on the 250 micron thick flexural link with various operation conditions are well below the material yield stress for 17-7-PH stainless steel.





Design of the Compact Manipulator for 32-mm CRL Lens Stack

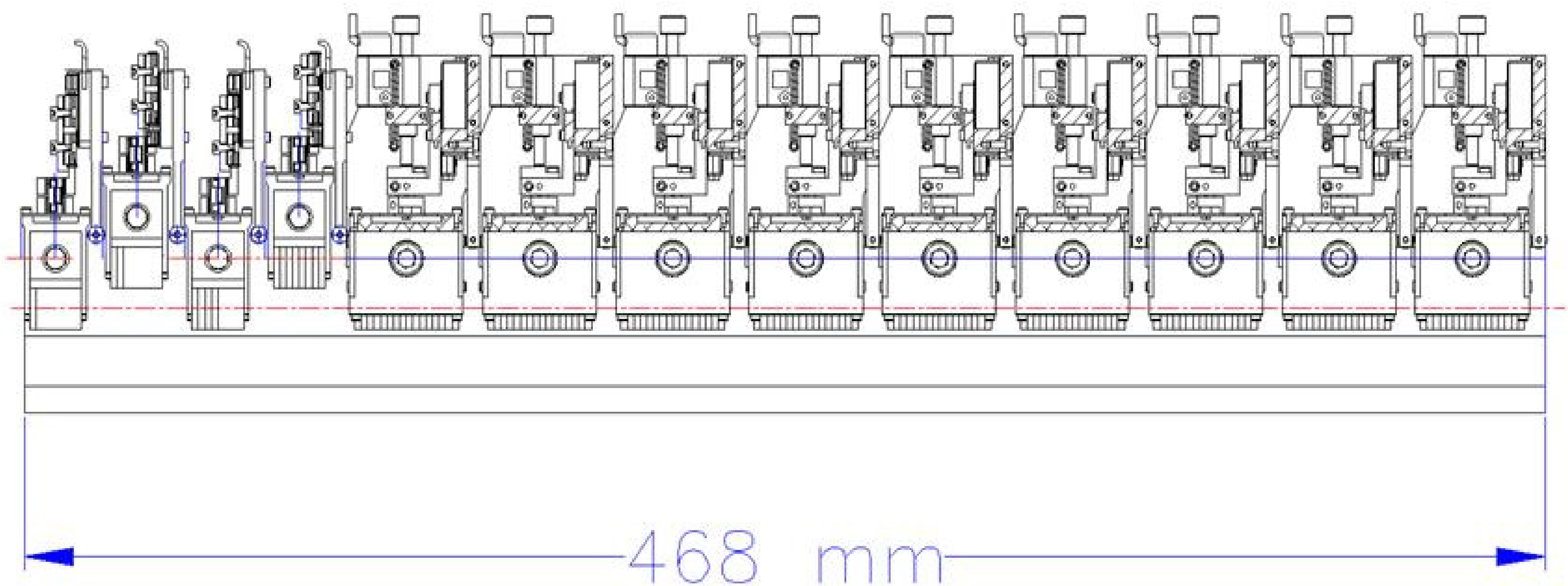


To manipulate CRL lens stack with longer total length, a compact manipulator APS Y9-5102 for 32-mm CRL lens stack was designed using commercial piezo-driven linear actuator, such as Picomotor™ 8353, as a lens manipulating driver with maximum axial driving force of 13 N.

The manipulators integration flexibility

A 3D model of a combination of four Y9-5101 and one Y9-5102 manipulators for a total of 48 CRL to be mounted on a Thomson^{TM} rail system with 140-mm travel range for focal length adjustment on a high-resolution diffractometer detector arm for dark-field imaging application.

The manipulators integration flexibility



- A schematic diagram for a combination of four Y9-5101 and nine Y9-5102 manipulators for a total of 159 CRL with an overall manipulators dimension of 468-mm.
- The 1+2+4+8+16x9 CRL lenses arrangement provides the flexibility to select any number between 0 – 159 for the numbers of CRLs to be aligned into the x-ray beam.

Summary

- The mechanical designs of a new precision alignment apparatus for compact x-ray CRL manipulator system are presented in this paper.
- This CRL manipulator system is specially designed for dark-field imaging of multi-scale structures at the APS.
- It is suitable to be implemented on a high-resolution diffractometer detector arm that rotates during diffraction studies with limited load capacity.
- A prototype for proof-of-principle has been built and tested at the APS with promising results.
- The compact modular designed CRL manipulators are compatible with high-vacuum (HV) or ultra-high-vacuum (UHV) operation conditions.
- The manipulators integration flexibility provides wide range of applications for synchrotron radiation instrumentation.

Acknowledgment

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