Mechanical Design and Development of Compact Linear Nanopositioning Flexure Stages with Centimeter-Level Travel Range and Nanometer-Level Resolution

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- Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement
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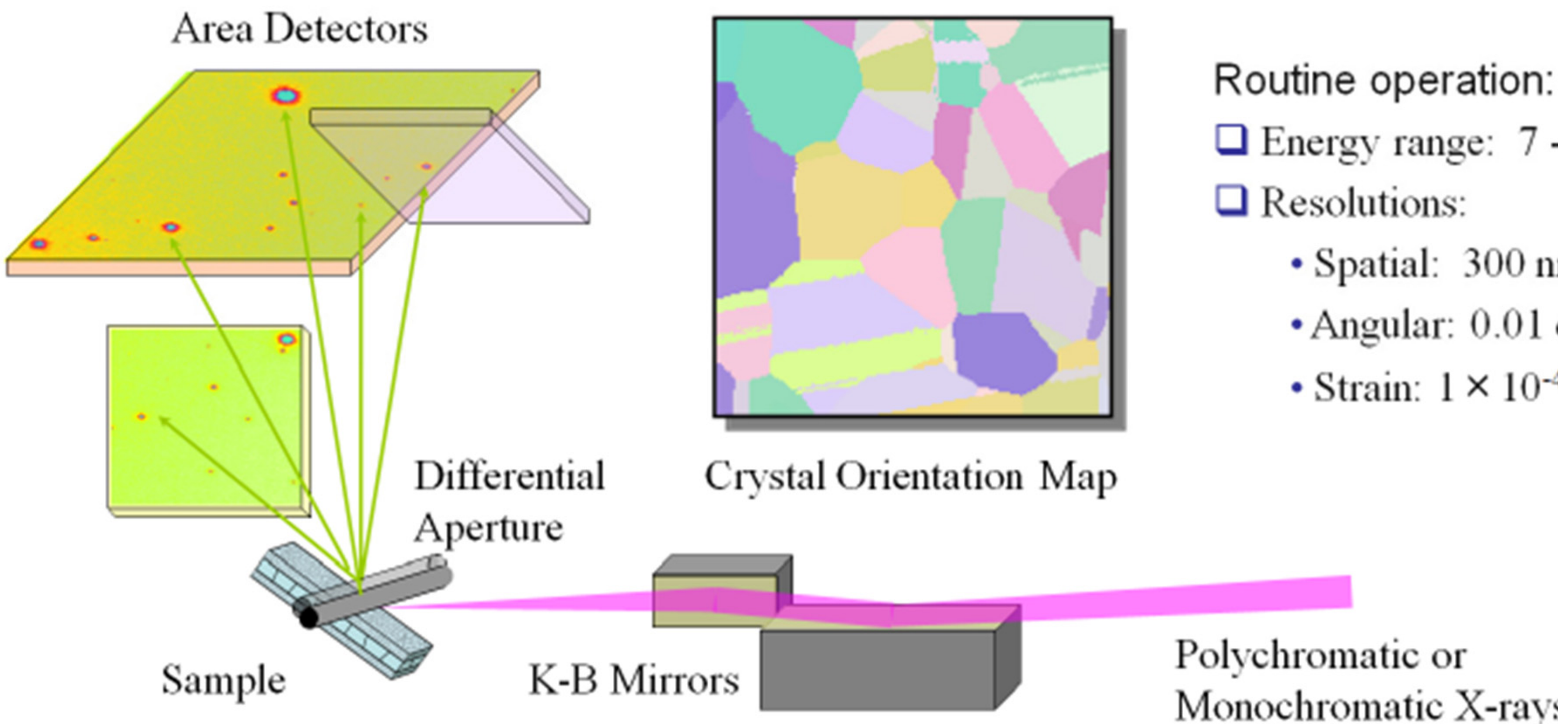
- Summary

Introduction

- Nanopositioning techniques present an important capability to support the state-of-the-art synchrotron radiation instrumentation research for the APS operations and upgrade project.
- X-ray Laue Diffraction 3D Microscopy developed at 34-ID beamline in the APS has been a unique and powerful tool for spatially-resolved structural studies at sub-micron level for materials science [3]. A precision linear stage is needed to perform a wire scan as a differential aperture for the 3-D diffraction microscope.
- The wire scan motion is usually localized in a very short specific travel range after an initial large travel range alignment. Localized wear of the linear bearing stage, which causes an unrepeatable defect in the linear motion straightness of trajectory is always an issue for the results of the 3-D x-ray diffraction microscope.

Introduction

- With advanced focusing mirror optics and depth-resolving technique, focused polychromatic or monochromatic x-ray beams can be used to determine the local phases of crystalline materials, the local crystal orientation and therefore the grain and phase boundary structure, and the local defect distribution including elastic and plastic strains.



Routine operation:

- ❑ Energy range: 7 - 30 keV
- ❑ Resolutions:
  - Spatial: 300 nm
  - Angular: 0.01 degree
  - Strain: 1×10^{-4}

W. Liu et al, XRM-2010

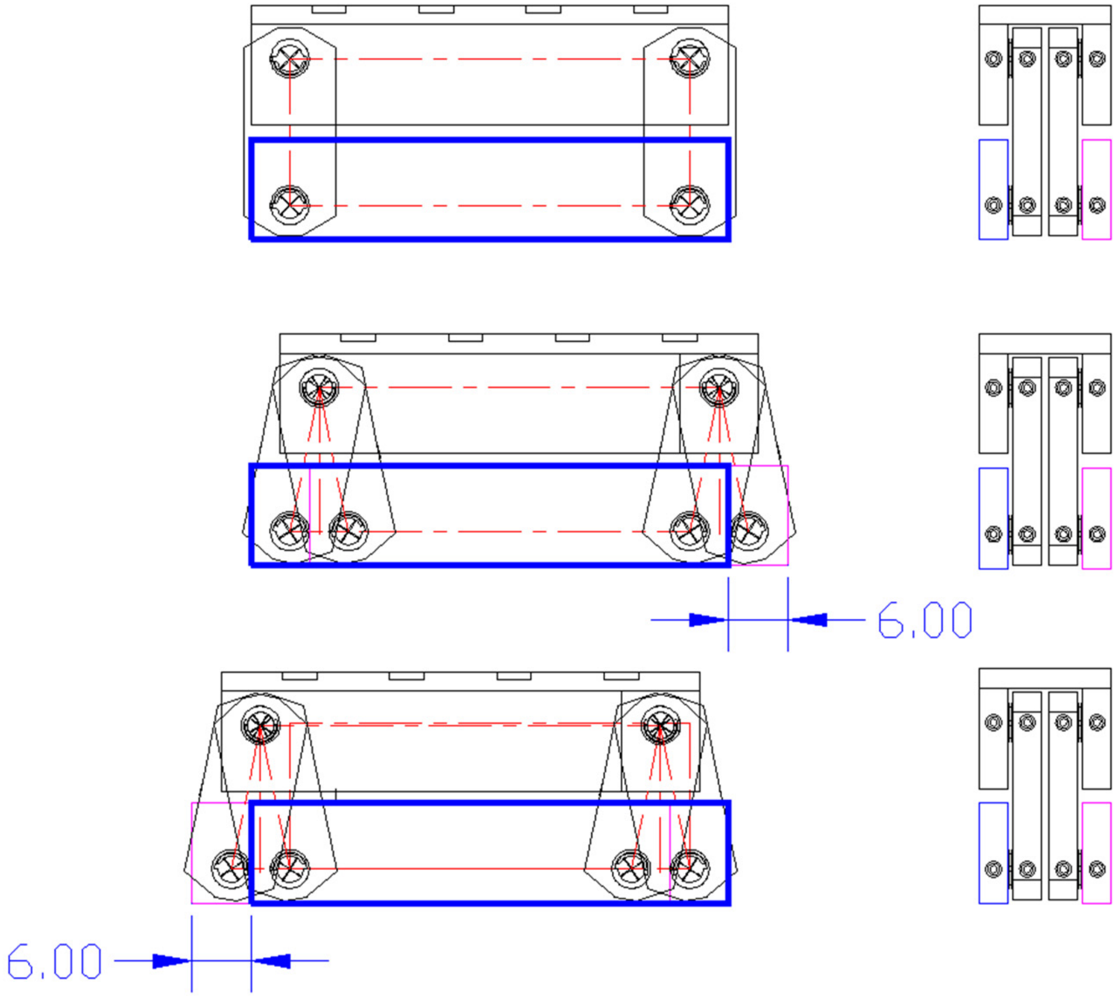
Introduction

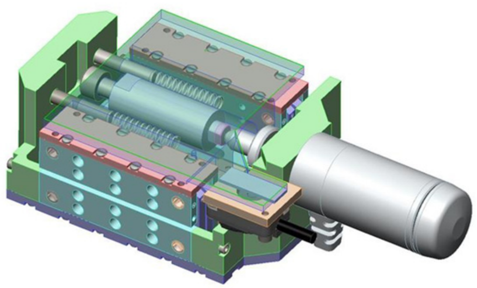
- To improve the linear motion performance and durability of the wire scan stage, a compact flexural-pivot-based precision linear stage APS T8-54 has been designed and constructed at the APS to replace the existing bearing-based linear stage for wire scan using deformation-compensated flexural pivot mechanisms.
- Based on the experiences gained from the initial operation of the T8-54 flexure stage at the APS sector 34, a few design enhancements have been made to further improve the performance of the T8-54 stage.
- These design enhancements have also been implemented in the new compact flexure stage design for scanning sample stages at the APS sector 2.

Introduction

The deformation compensated flexural linear guiding unit for APS T8-52

The basic parallel mechanism includes seven elements linked by eight commercial flexural pivots:
two parallel bars;
four I-link bars;
and one U-shaped middle bar sub-assembly.





[1] U.S. Patent granted No. 8,957,567, D. Shu, S. Kearney, and C. Preissner, 2015.
[2] D. Shu et al, J. Phys. Conf. Ser. 425 212011(2013).

Introduction

The deformation compensated flexural linear guiding unit

C-Flex Bearings
Standard Material Properties

Sleeves:

416 stainless steel (AMS 5610L Type II)

Springs and Cores:

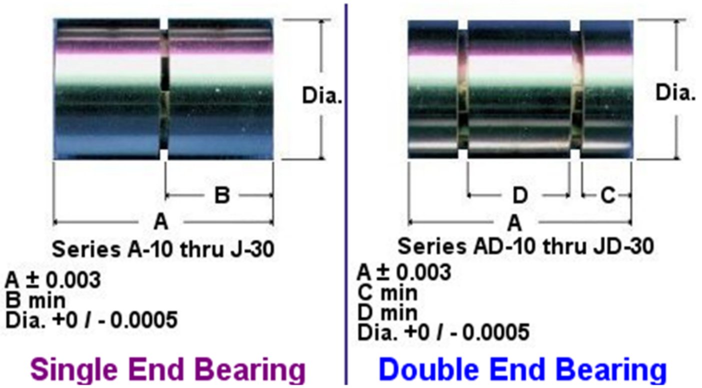
410 stainless steel (AMS 5504M)
420 stainless steel (AMS 5506F)
Braze Alloy: AMS 4765
Hardness: 46 - 56 Rc

Spring Material Properties:

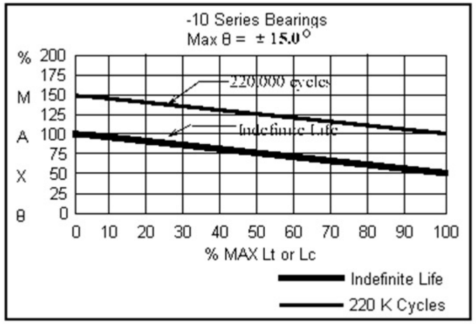
Fatigue Strength: 75,000 psi
Ultimate Tensile Strength: 294,000 psi
Modulus of Elasticity: 29,000,000 psi
ASTM Grain Size: #6 or finer

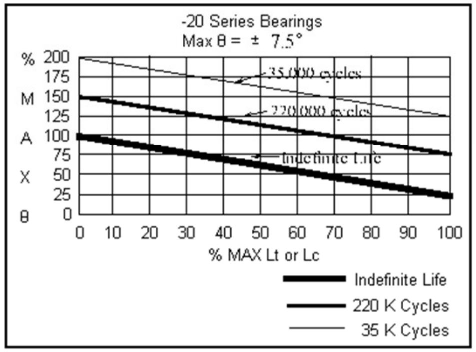
http://www.c-flex.com.

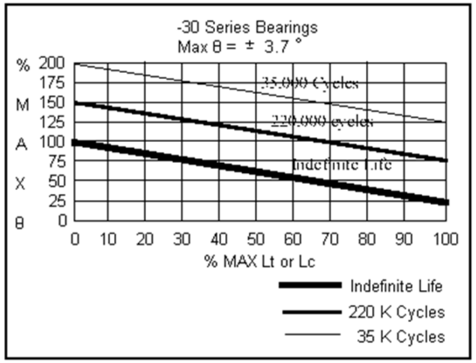
C-Flex Information On Bearings



C-Flex Bearings
Life Projections







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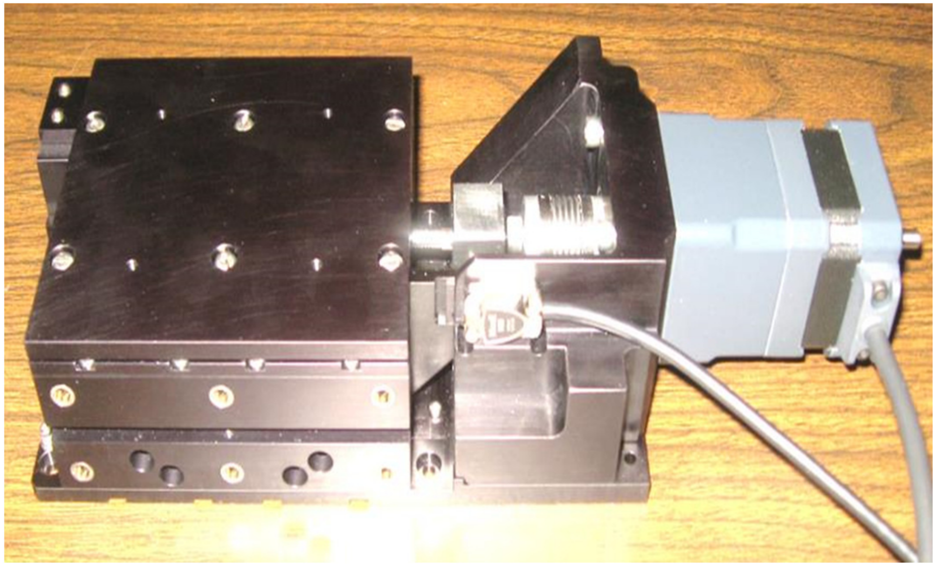
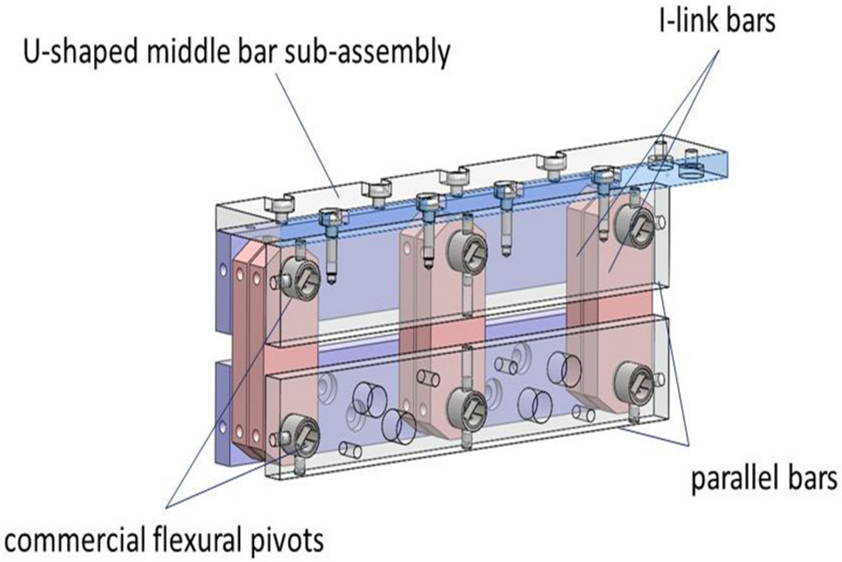


Photograph of the original APS T8-54 linear flexure stage for wire scan as a differential aperture for the 3-D diffraction microscope at the APS sector 34.

A 3-D model of the basic deformation compensated linear guiding mechanism for T8-54 linear flexural stage.



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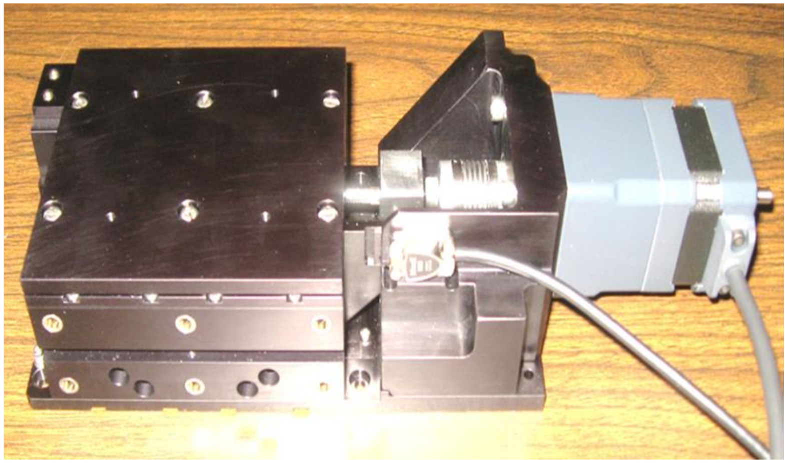
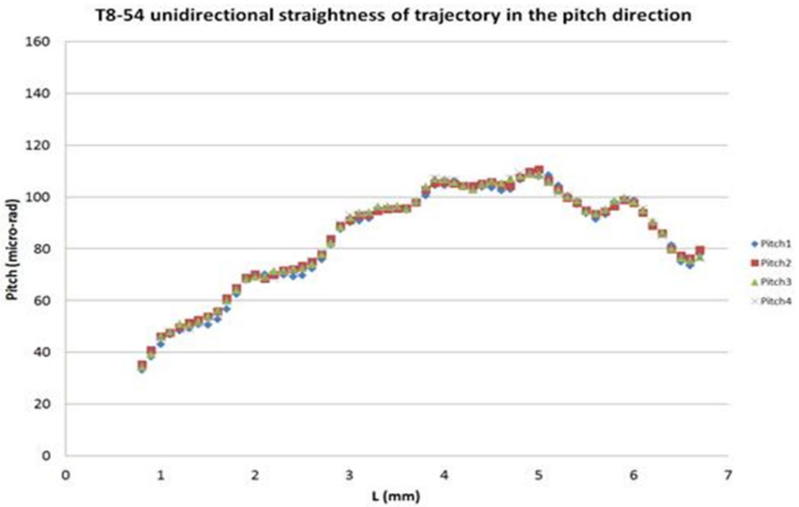
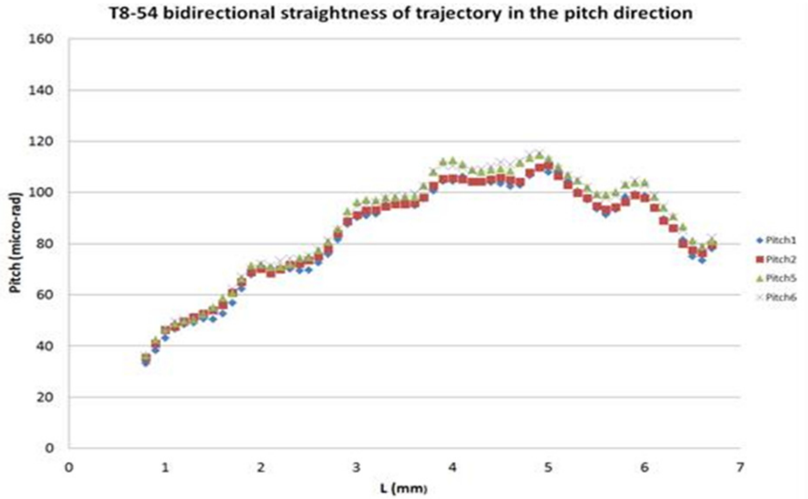
[5] D. Shu, W. Liu, S. Kearney, J. Anton, and J. Z. Tischler, Proceedings of SPIE-2015, Optomechanical Engineering conference, 9573-28, San Diego, CA, Aug. 2015.

Introduction







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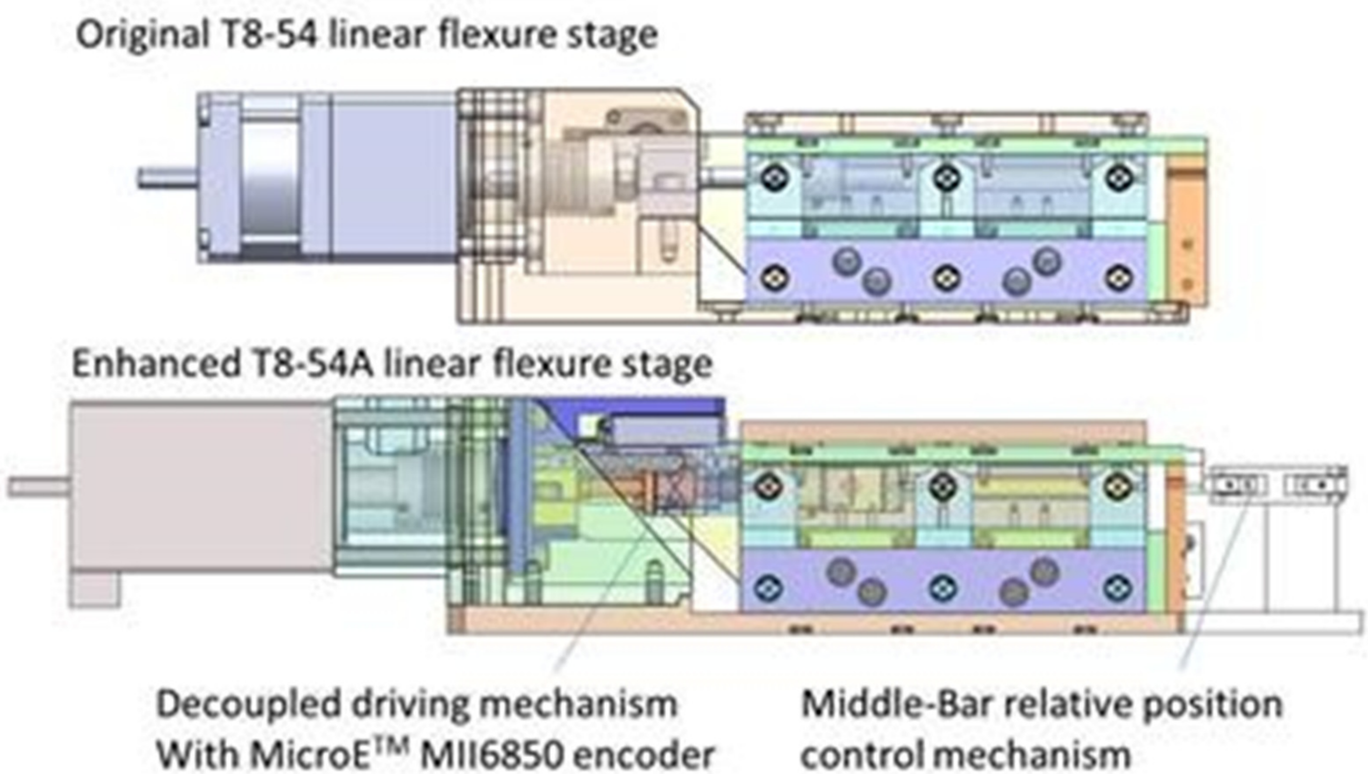
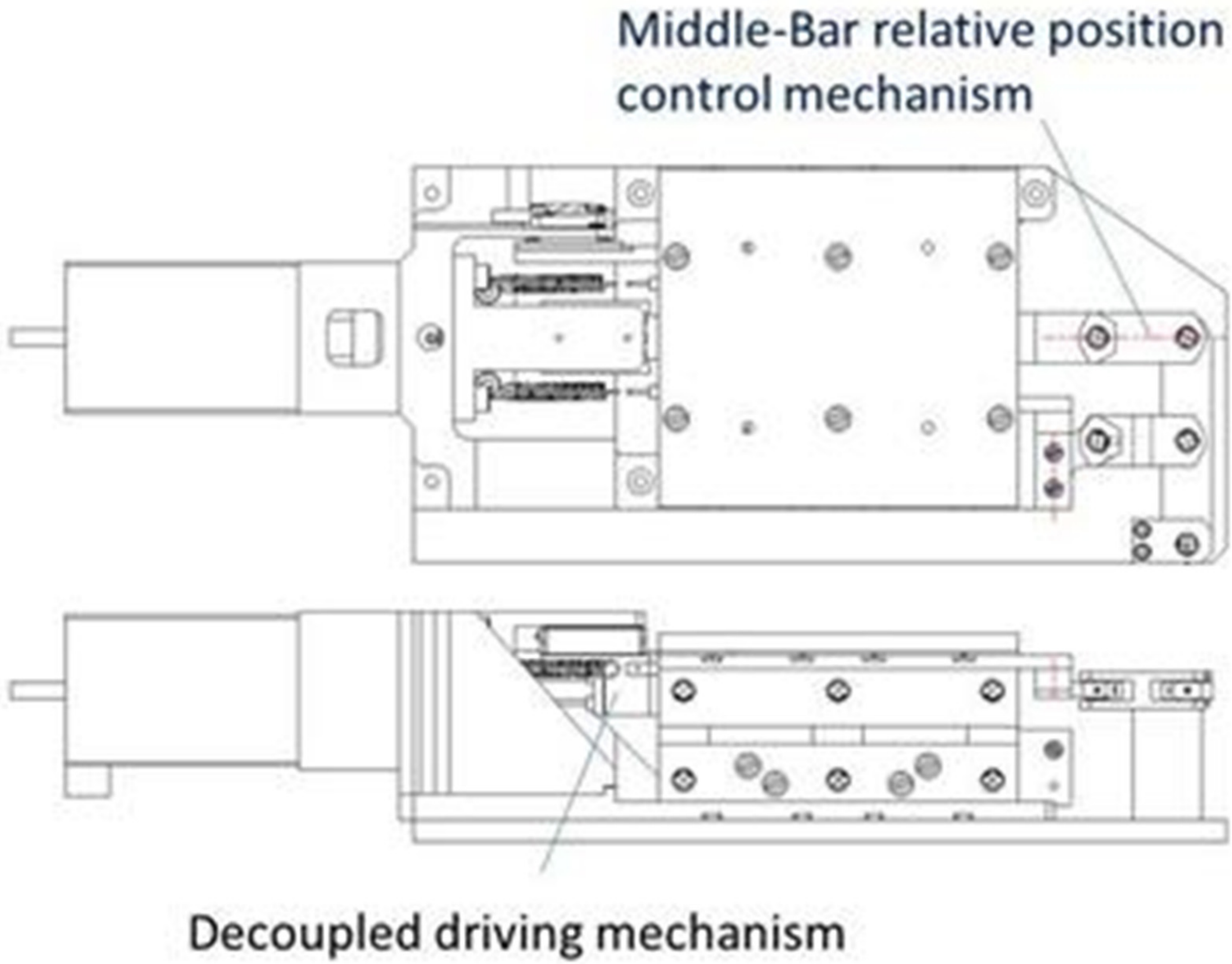
Design Enhancement for APS T8-54A Flexure Stage



- A new decoupled driving mechanism with MicroE^{TM} MII6850 encoder replaced the original direct driving mechanism with MicroE^{TM} M3500si encoder to reduce the stage's straightness of trajectory error caused by the ball screw direct driving mechanism and the grating encoder interpreter's error.
- A new middle-Bar relative position control mechanism [6] has been added to the stage's structure to enhance the stiffness of the flexure linear guiding mechanism.

[6] D. Shu, W. Liu, S. Kearney, J. Anton, B. Lai, J. Maser1, C. Roehrig, and J. Z. Tischler, U.S. Patent application in progress for ANL-IN-16-125, 2016.

Design Enhancement for APS T8-54A Flexure Stage



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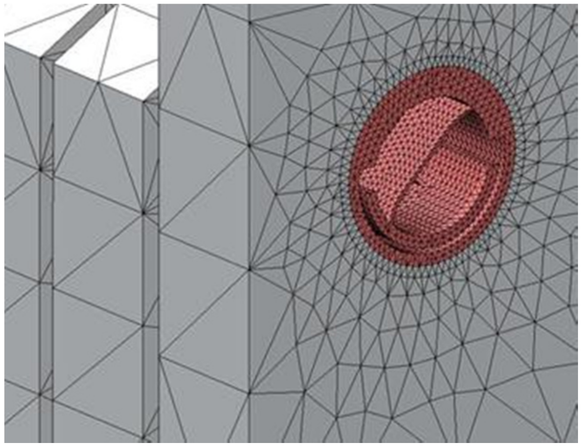
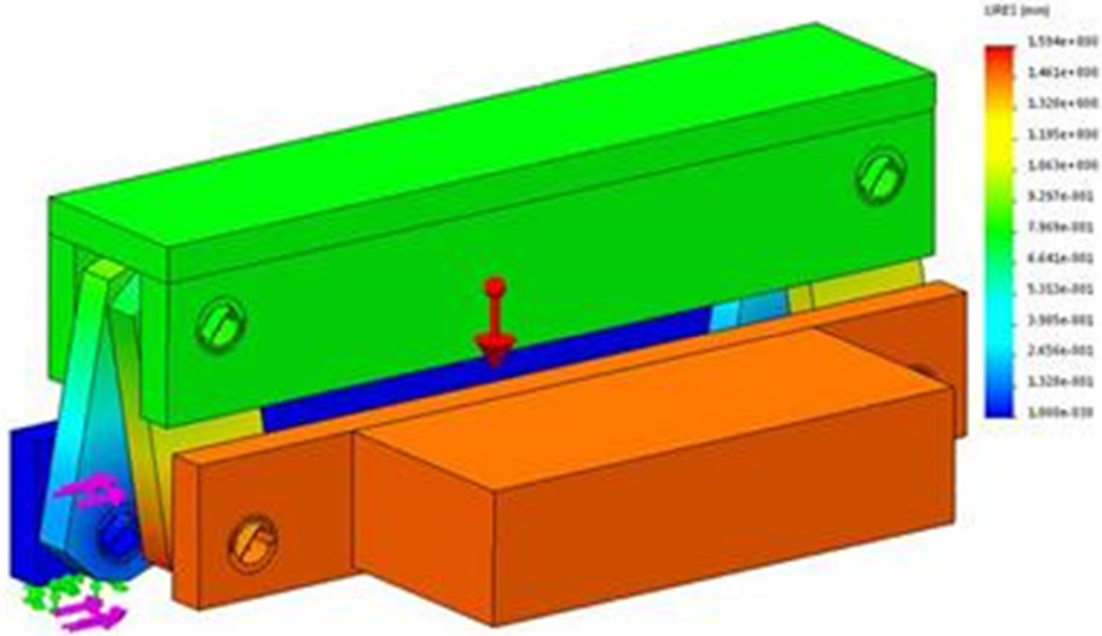
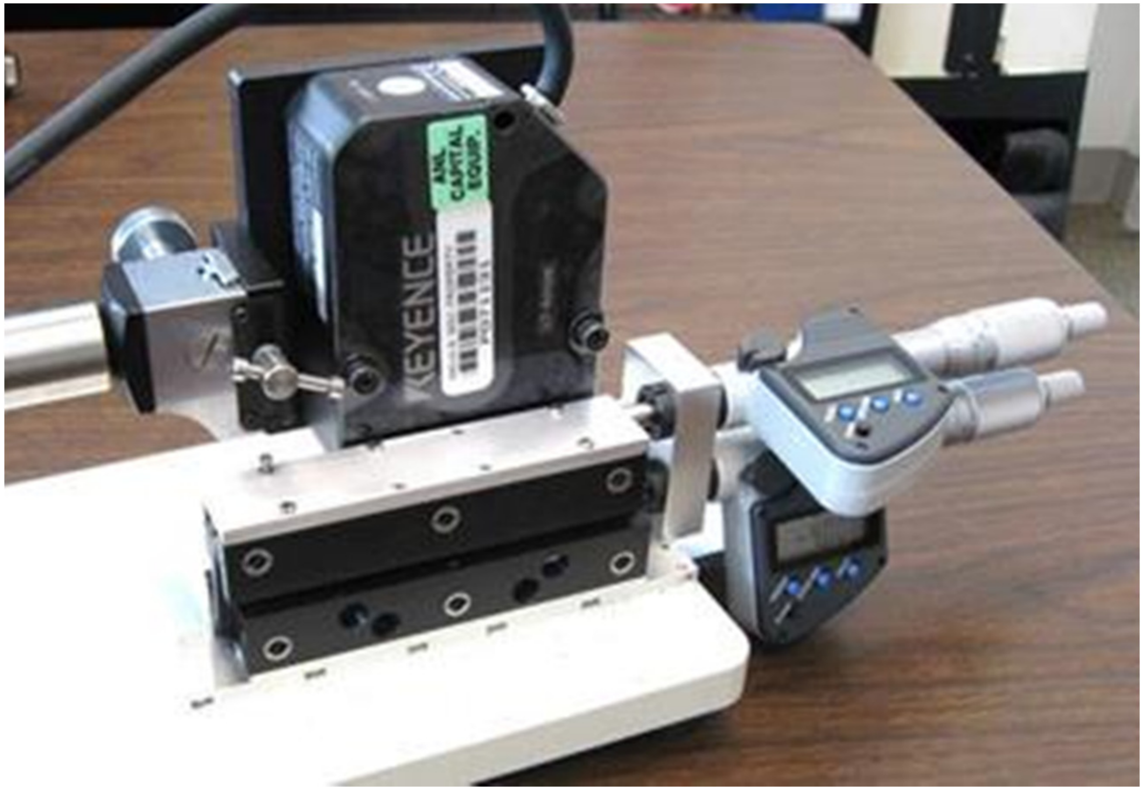
Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement





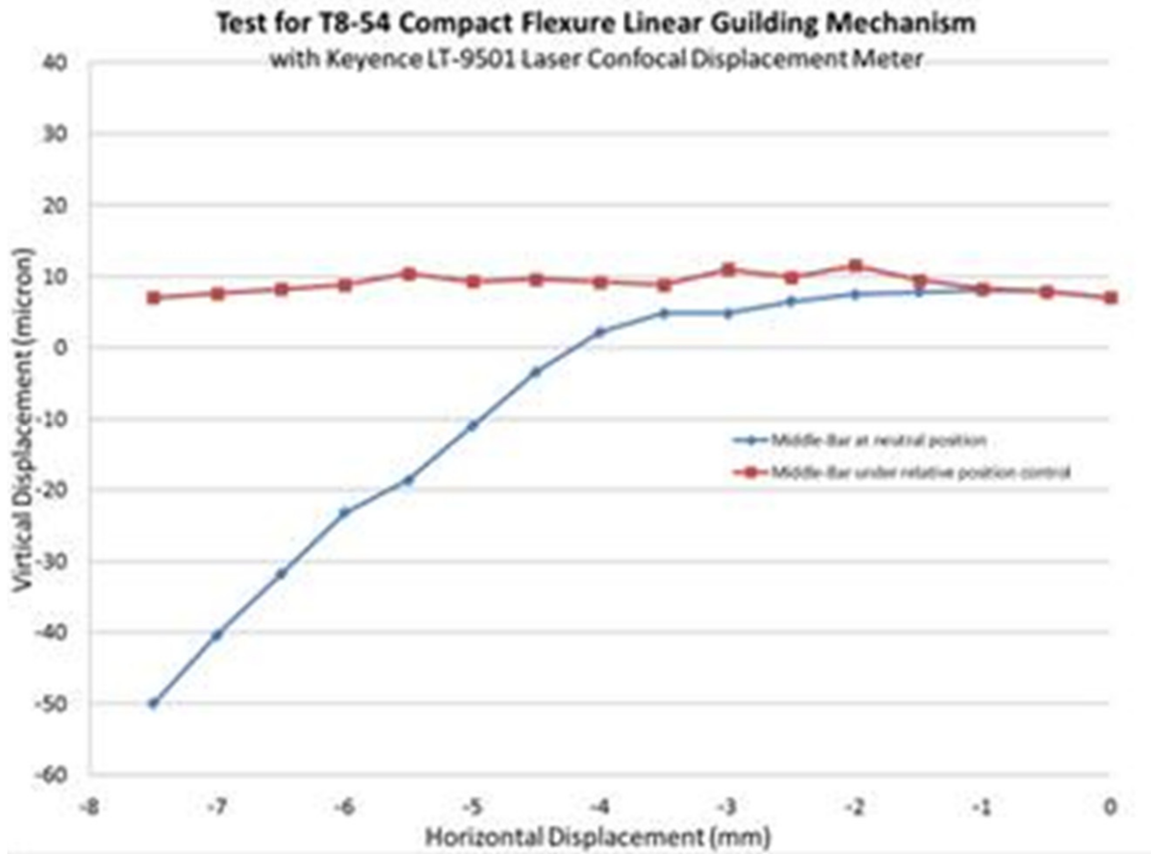
- Preliminary finite element analysis (FEA) started with a single flexure linear guiding mechanism to simulate the effectiveness of the middle-Bar relative position control mechanism.
- A proof-of-principle experiment has also demonstrated a promising result with reasonable agreement with the FEA results.

Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement



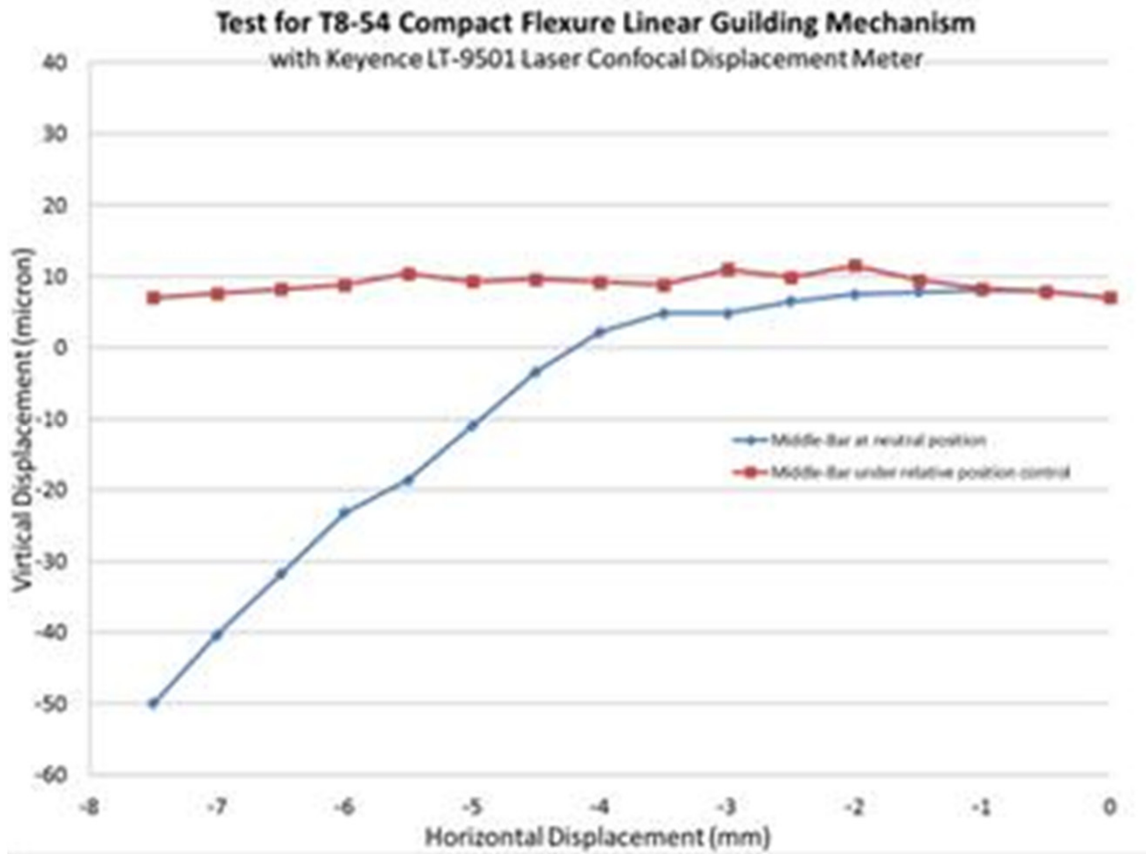
- Preliminary test is also started with a single T8-54A flexure linear guiding mechanism with the middle-Bar relative position control.
- The relative horizontal positions of the carriage and the middle-bar of the guiding mechanism are positioned by two digital micrometers.
- A Keyence™ LT-9501 laser confocal displacement meter is used to measure the stage's parasitical vertical displacement.

Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement



The results showed that the stage's parasitical vertical motion is reduced to the level of ~1 micron rms over the 8 mm horizontal travel range while the middle-bar's relative horizontal position is controlled at a theoretical 1:2 position with carriage.

Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement



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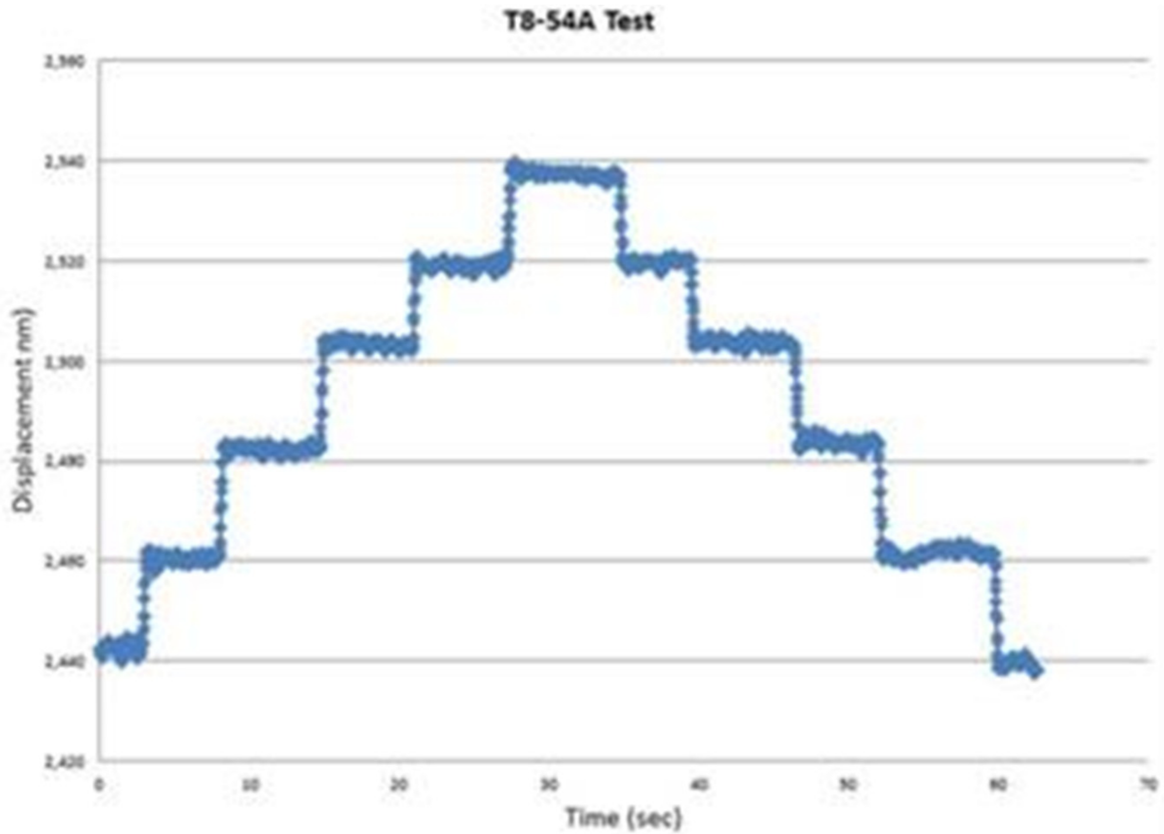
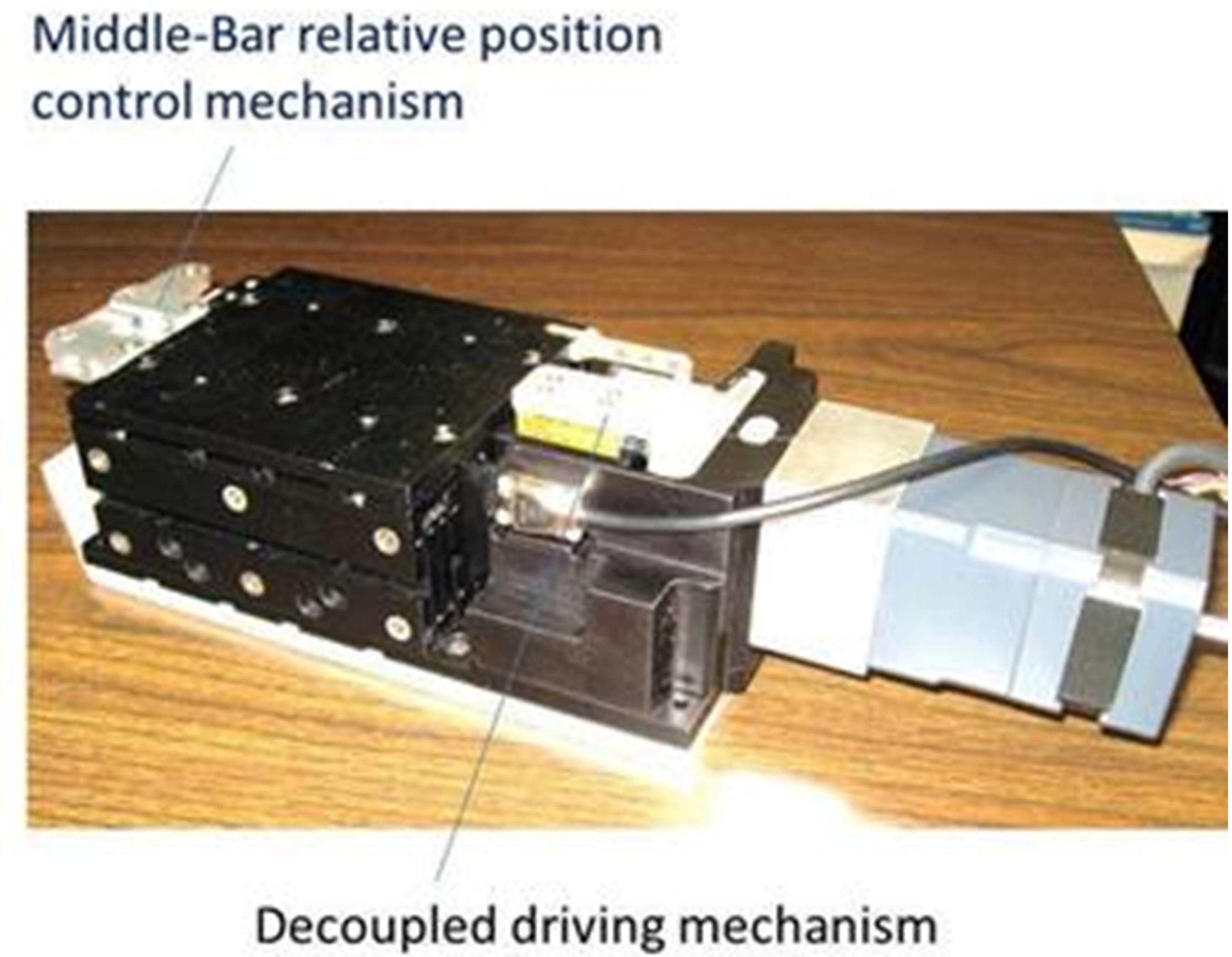
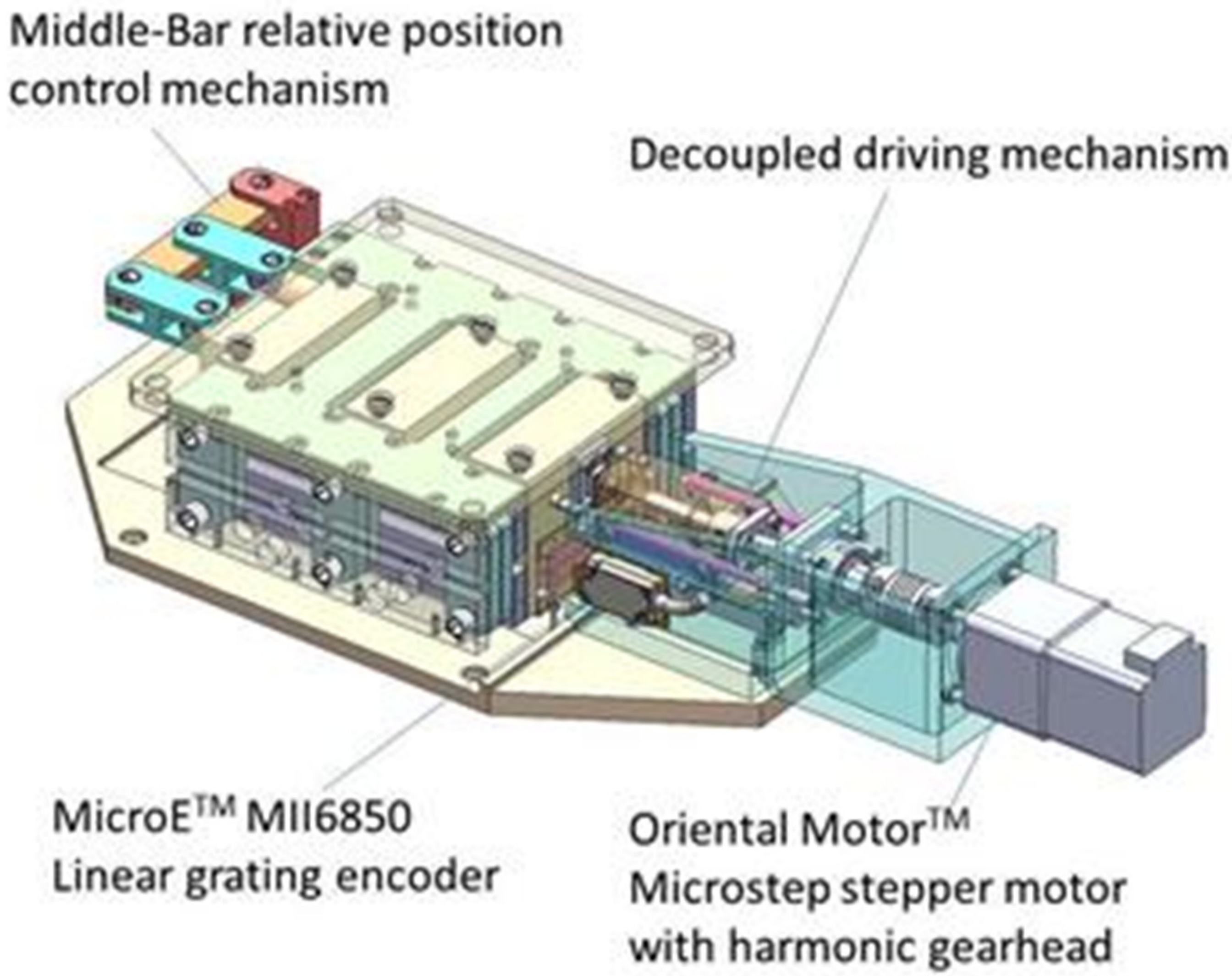


As expected, the flexure linear guiding mechanism has a nanometer-level positioning capability. The flexure stage's positioning sensitivity is limited by its driving mechanism. We have tested the decoupled driving mechanism with 20 nm steps with Attocube™ FPS3010 laser interferometer.

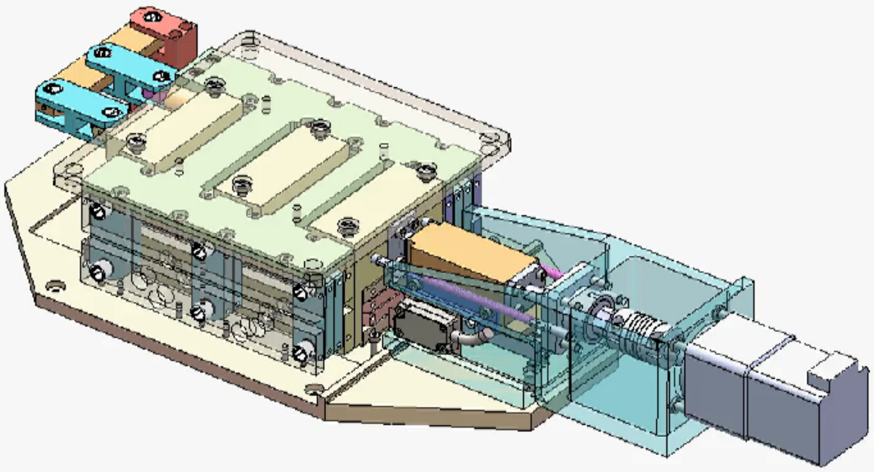
Preliminary Analyses and Proof-of-Principle Test for the T8-54A Design Enhancement



Design of APS T8-56 Compact Linear Horizontal Flexure Stage



Design of APS T8-56 Compact Linear Horizontal Flexure Stage



Summary

- The mechanical design and finite element analysis of the updated APS T8-54 and T8-56 flexural stages, as well as preliminary mechanical test results are presented in this paper.

- Comprehensive mechanical tests for T8-54A with laser interferometer system are in progress.

Acknowledgment

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Thank You for Your Attention