



Canadian Light Source *Centre canadien de rayonnement synchrotron*

A Novel Mirror Manipulator Design and the Prototype Test



1. Introduction

- A High precision, high resolution and stable mirror manipulator plays a very important role In a beamline.
- Lots of different mirror manipulators were designed and are serving in beamlines. Especially, Hexapod mirror manipulators get impressive improvement in recent years.
- However, I personally feel they are not so perfect.
- The intension of the new mirror manipulator introduced here is trying to keep the advantages of both Hexapod manipulator and traditional manipulator and avoid their deficiency.

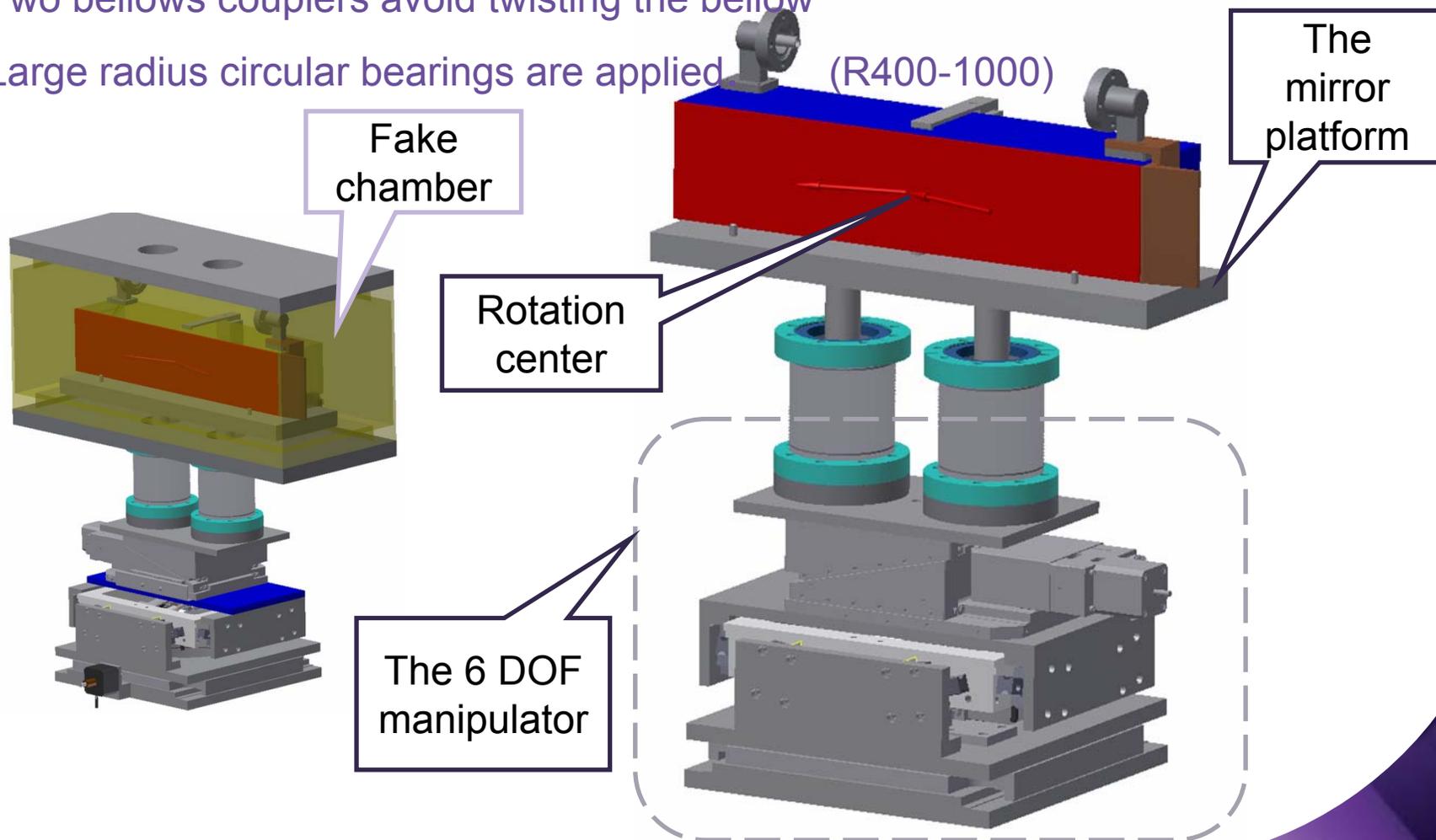


2. THE MANIPULATOR

It is interchangeable with Hexapod mirror manipulator

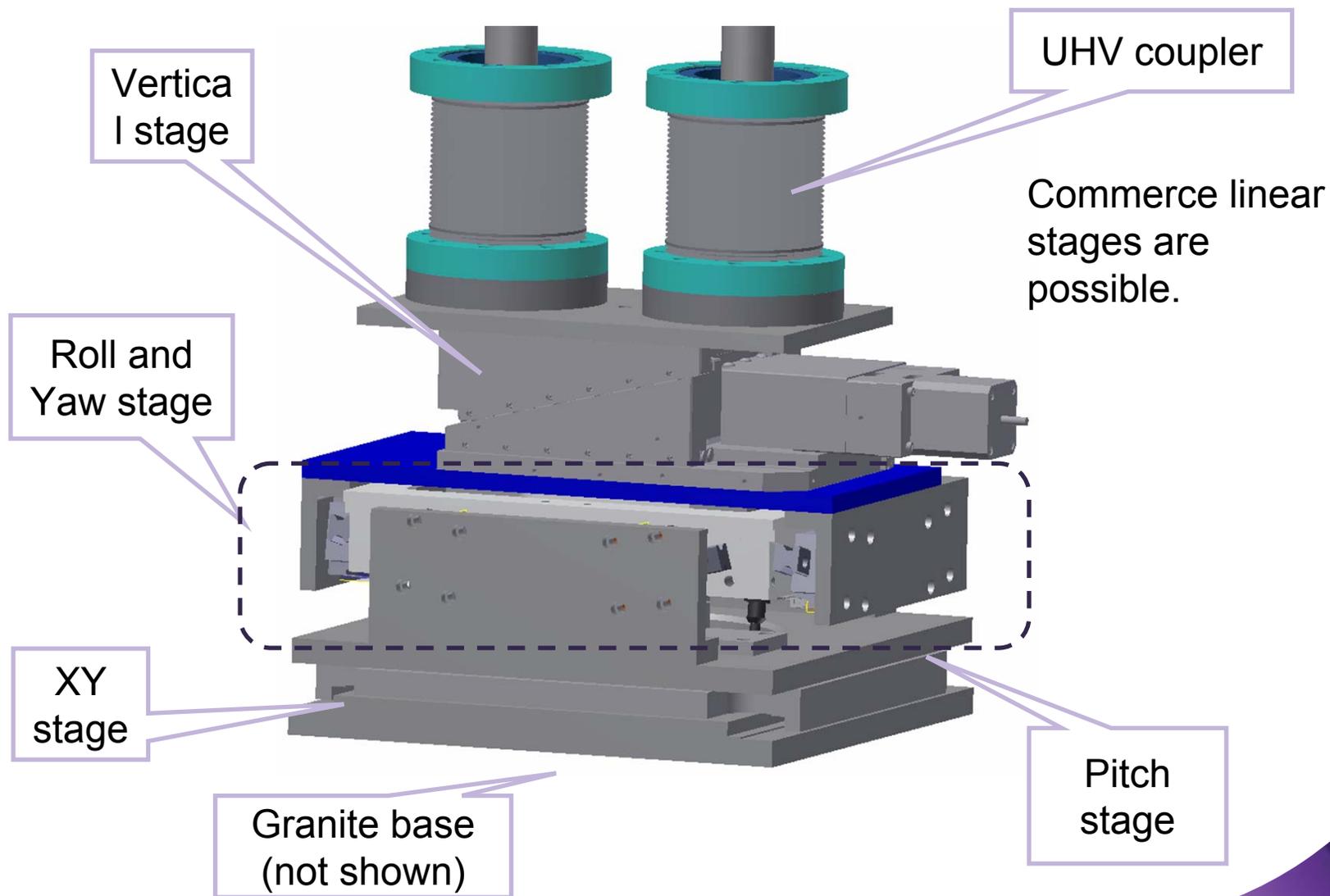
Two bellows couplers avoid twisting the bellow

Large radius circular bearings are applied (R400-1000)



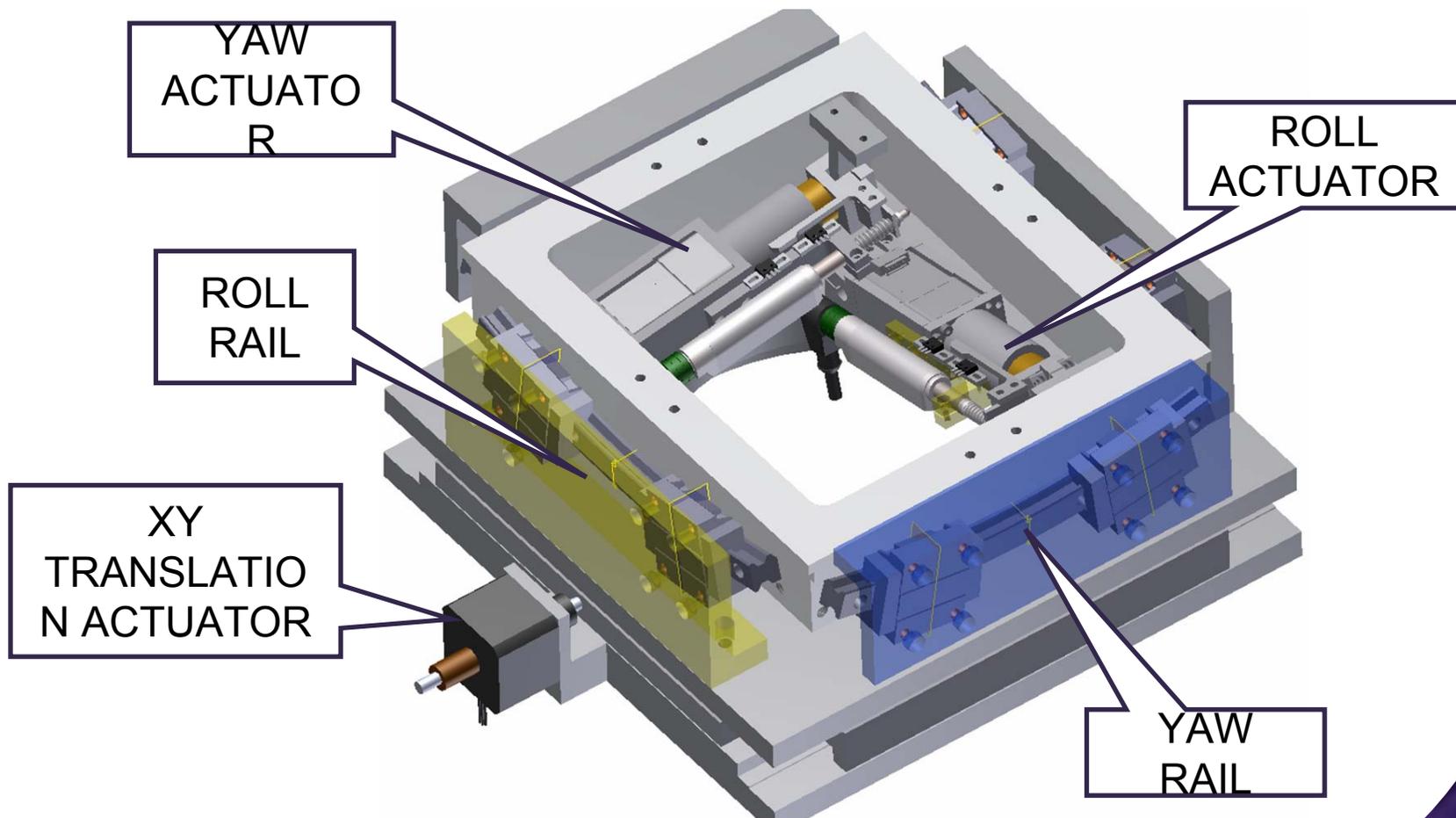


2.1 Configuration



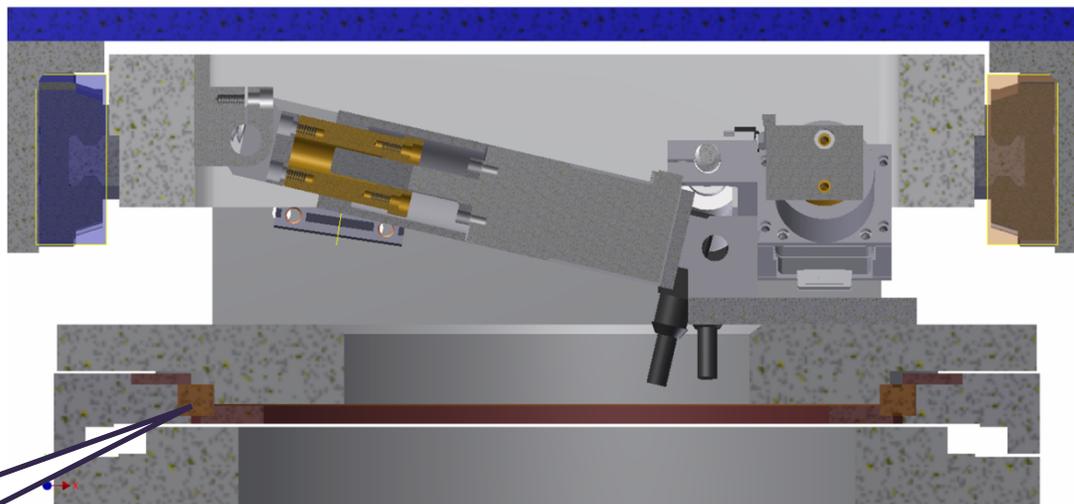


2.2 ROTATION ACTUATING & GUIDING

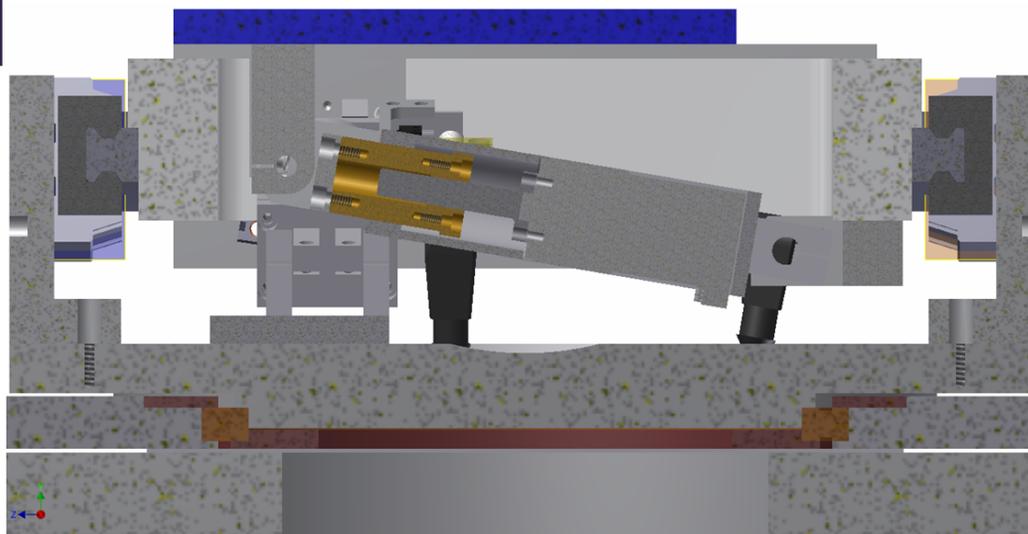




2.2 ROTATION ACTUATING & GUIDING



PITCH
BEARING





2.3 Features

- 1) The degrees of freedom (DOFs) could be chosen based on the mirror manipulating requirements. When the mirror only needs 3 DOFs, it can be assembled to 3 DOFs manipulator to save cost and increase stability. When it has 6 DOFs, it functions exactly like a Hexapod.
- 2) Comparing to Hexapod, it does not need positioning software. Each actuator exactly controls one degree of freedom. The six degrees of freedom are independent. Further more, it is easy to directly limit these three motions.
- 3) It has high resolution and repeatability. (long actuating arm)
- 4) With small driving units it can manipulate heavy mirrors. (the loads perpendicular to the actuating direction)
- 5) The manipulator could be de-coupled from the mirror chamber and be seated on a granite table independently.
- 6) The three rotation axes intersect to one point and this point can be adjusted vertically and horizontally or be fixed to the optical center no matter the mirror do what kinds of linear motions. (If a linear stage is under the rotation stages, its motion changes the rotation center. If a linear stage is upper the rotation stages, it moves the mirror, but will not change the rotation center)



2.4 ROTATION ACTUATING

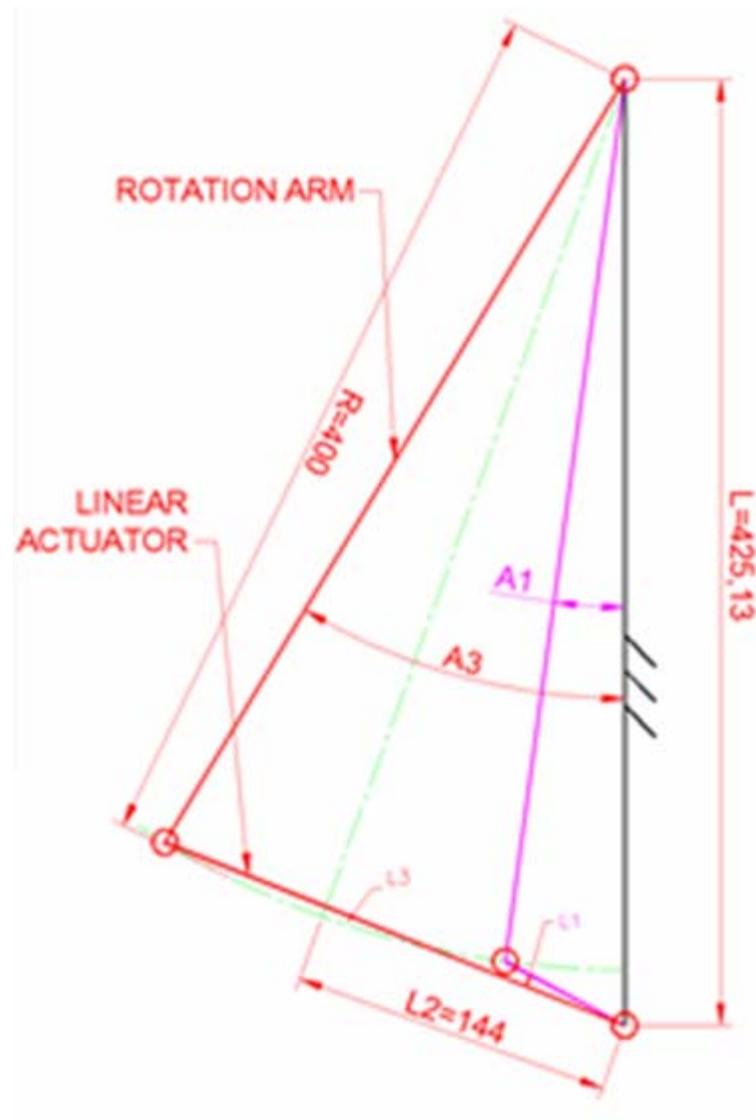
Like the three linear motions, the three rotations are also driven by linear actuators. The right drawing shows relation. (ΔL is the actuator length changing)

$$A_0 = \sin^{-1} \frac{L_2}{\sqrt{R^2 + L_2^2}}$$

$$A_1 = \cos^{-1} \frac{2R^2 + L_2^2 - (L_2 + \Delta L)^2}{2R \sqrt{R^2 + L_2^2}} - A_0$$

$$A_p = \Delta L / R \quad (\text{linear relation})$$

$$R_a = 2.5 \frac{P}{R} \quad (\text{mrad/half step})$$

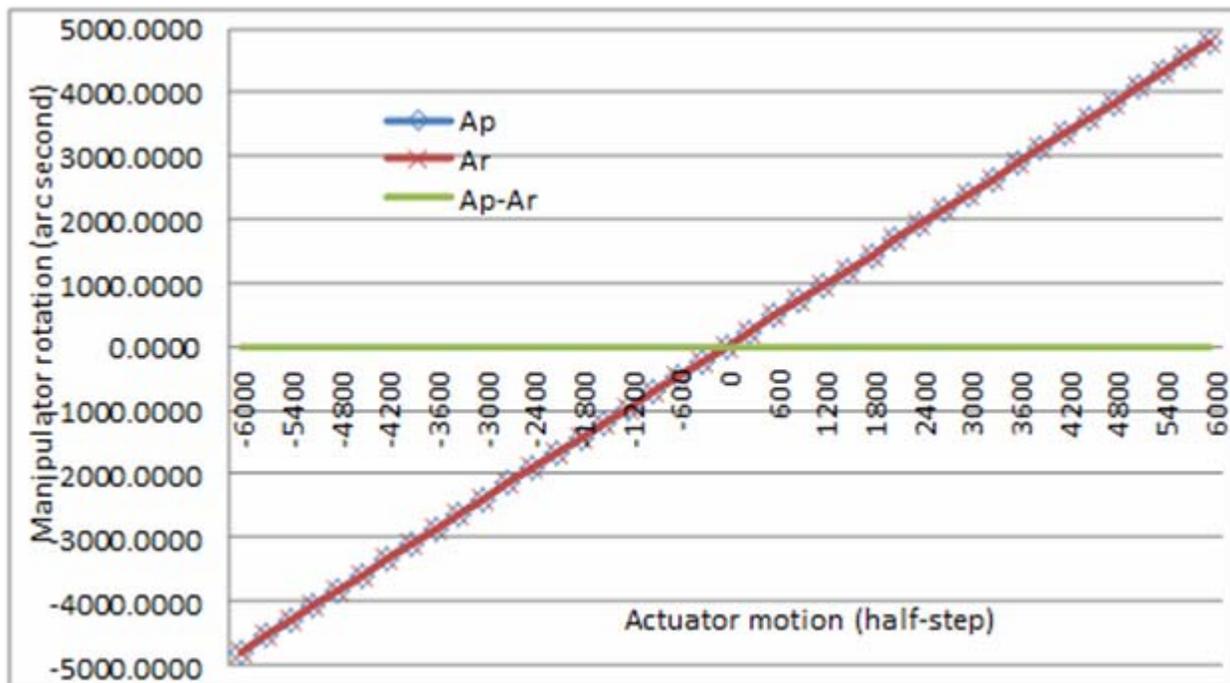




The difference between real rotation angle A_r and proximate rotation angle A_p

When the actuator length changing ΔL is presented by the motor motion steps, The relation between the angle changing and linear motor steps is shown in the following diagram. $A_r=1^\circ$, $A_r-A_p=0.1891$ arc seconds (9.17×10^{-4} mrad). (Resolution is 0.8 arc seconds/half-step)

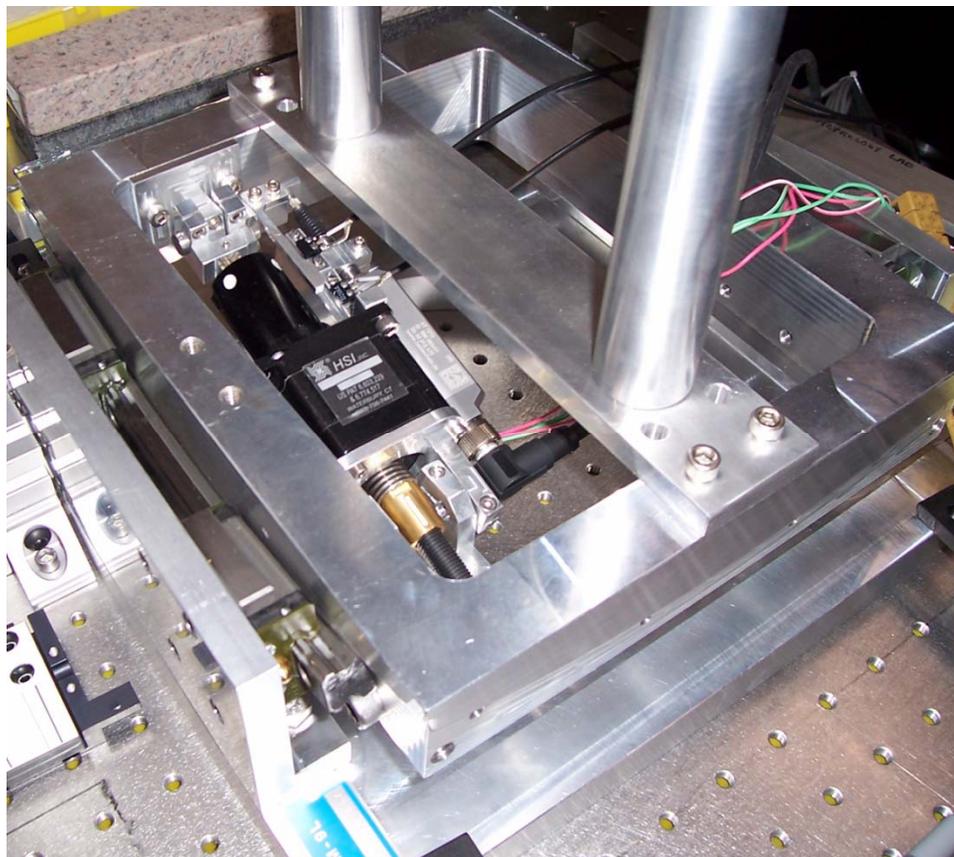
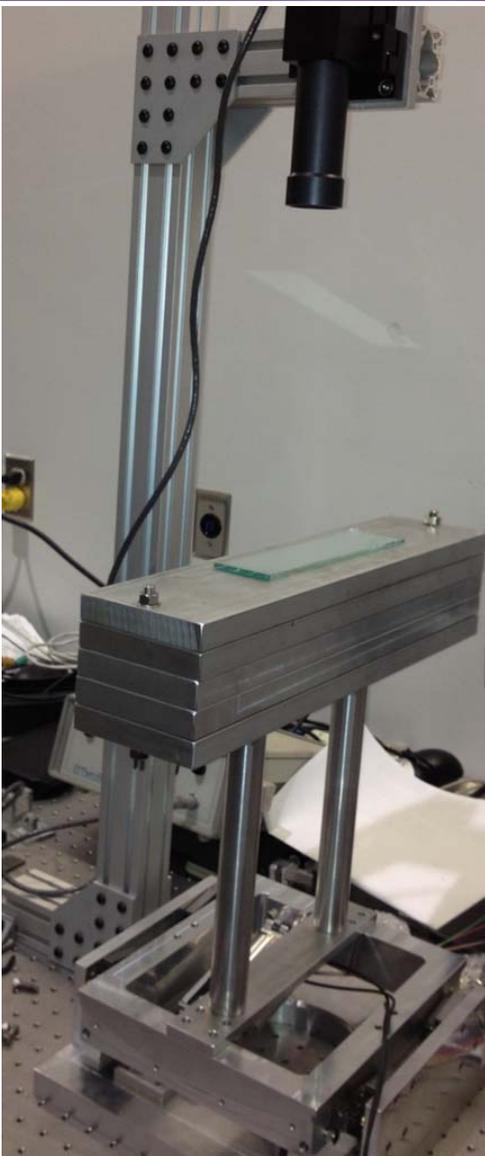
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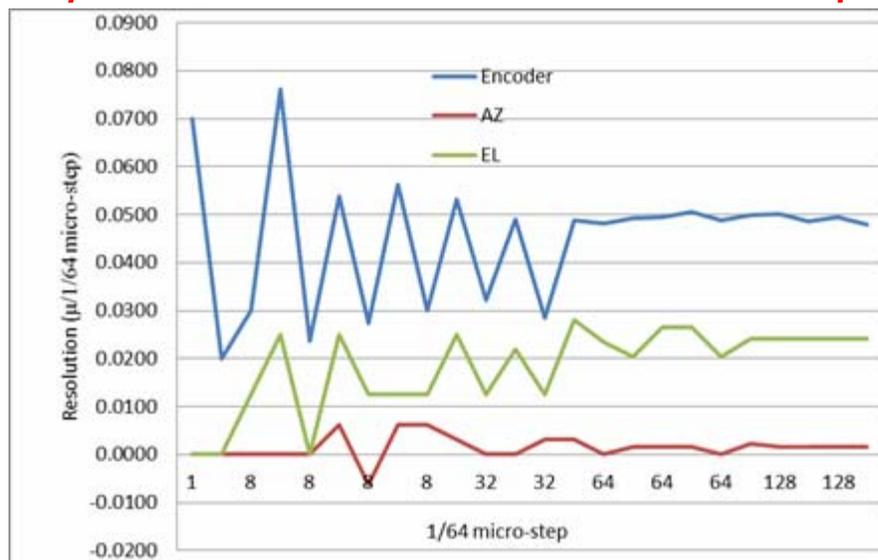
3. PROTOTYPE AND TEST





3.2 The resolution at micro driving

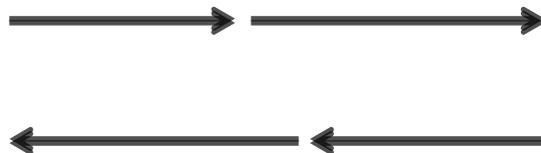
In the second test, the linear stepping motor was driven in 1/64 micro-step. The test was set driving the motor at one micro-step, 8 micro-steps, 32 micro-steps and 64 micro-steps. The **average resolution is 0.05 μ /micro-step in linear or 0.024 arc second/micro-step**. The tested result shows when the motor is driven in 1/64, 1/8 full step, the motion is not stable. When the actuator is driven in half or more than half step, the motion gets even. *High resolution cannot depend on micro driving. If higher resolution is required, the actuator need to be equipped with a harmonic gearhead.*





3.2 Backlash and repeatability test

The linear actuator stepping motor was driven in 1/64 micro-step. The manipulator was commanded to walk in +N, -N, -N, +N step cycle. N is the number of micro steps, and it was changed from 100, 200, 300, 400, 500, 1000, 3000, 7000, 10000, 13000, 16000, 19000, 22000. In one cycle, 2 backlash values and one position error can be tested. **The average linear backlash is 2.9 micron. The angular backlash is 0.0107 mrad (2.2 arc seconds). The position error is between -0.75 to 0.78 micron in linear, and -0.7 to 0.6 arc seconds (-0.0034 to 0.0029 mrad) in angular.**





4. Conclusion

1) Some preliminary design work was done and a prototype was tested. More R&D work and a real application are necessary. It will be used on CLS FAR IR beamline M2 mirror manipulating.

2) Three factors decide the performance of the manipulator. They are the flexure pivot bearing, the linear actuators and the linear & circular guide rails. The current technology has no issue with these three requirements, but cooperation from industry is required to produce compact and high performance linear actuators and large radius cross roller circular bearings.



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Thank you!