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A SUBNANOMETER LINEAR DISPLACEMENT ACTUATOR

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Abstract

With the development of synchrotron radiation technology, an actuator with sub-nanometer resolution, 100 N driving force, and compatible with ultra-high vacuum environment is required. To achieve synchrotron radiation micro-nano focusing with adjustment resolution of sub-nanometer and high-precision rotation at the nano-arc level, most of the commercial piezoelectric actuators are difficult to meet the requirements of resolution and driving force at the same time. The flexure-based compound bridge-type hinge has the characteristic of amplifying or reducing the input displacement by a certain multiple, and can be used in an ultra-high vacuum environment. According to this characteristic, the bridge-type composite flexible hinge can be combined with commercial piezoelectric actuators, to design a new actuator with sub-nanometer resolution and a driving force of 100 N. This poster mainly presents the principle of the new actuator, the design of the prototype and the preliminary test results of its resolution, stroke.

INTRODUCTION

Flexure-based compliant mechanisms are wildly used due to their positive merits including free of backlash and friction, vacuum compatibility, and can achieve high-resolution motion. But the final resolution the mechanism can achieved is limited not only by flexure-based structure but also limited by the actuators.

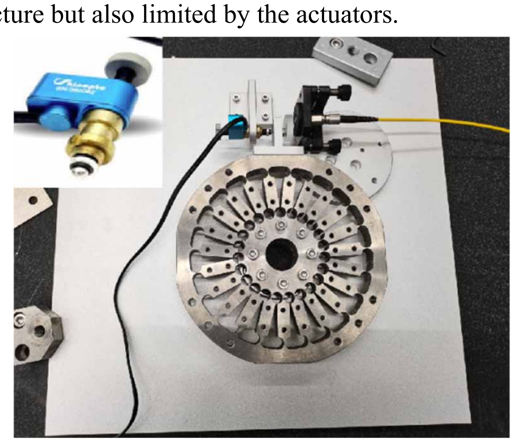

Figure 1: Preliminary resolution test of a weak-link mechanism.

As shown in Fig. 1, for example. When we use a domestic piezoelectric actuator to driven a weak-link mechanism [1] to measure the minimum angular resolution of the weak-link mechanism. The radius of the wheel-shaped flexible hinge is 200 mm. And the angular resolution we got finally is about 120 nrad, the result is limited by the minimum step size of the piezoelectric actuator (about 15 nm). So we need an actuator with smaller minimum step size if we want to achieve a higher angular resolution.

SOLUTION AND CALCULATION

To achieve higher resolution at lower cost, a compound bridge-type hinge [2] is chosen as a pantograph mechanism to achieve smaller minimum step size by scaling down the step size of the piezoelectric actuator we have. Figure 2 shows the schematic diagram of the compound bridge type hinge, as can be seen from the figure, the bridge-type composite flexible hinge has four ends A, B, C, and D. When we fix end C and apply opposite thrust to ends B and D, end A will move along the x direction relative to end C. direction displacement.

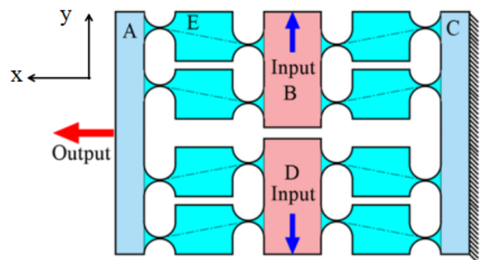

Figure 2: The schematic diagram of the compound bridge- type hinge.

In order to more accurately analyze the relationship between the relative displacement of ends B and D and the relative displacement of ends A and D, One-quarter of the model shown in Fig. 2 is taken for theoretical analysis, as shown in Fig. 3.

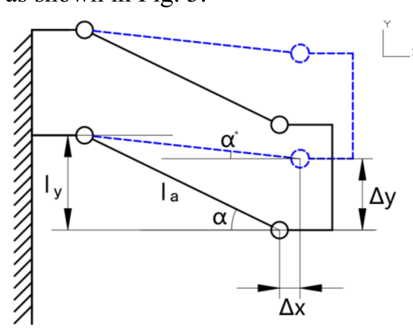

Figure 3: Simplified analysis of bridge-type composite hinge model.

In Fig. 3, l_y represents the distance (eccentricity) between the two ends of the hinge structure E in the y direction, l_a represents the arm length of the hinge structure (the length of the dotted line in Fig. 2), and α represents the angle between the arm length and the horizontal direction.

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Refer to Figs. 2 and 3, when a certain force is applied to ends B and D to cause a certain displacement Δy along the y direction, according to the geometric relationship in Fig. 3, ends B and D will produce a certain parasitic displacement Δx in y direction. We can establish the relationship between the parameters l_y, l_a, α and Δx, Δy :

$$\begin{aligned} l_a cos\alpha + \Delta x &= l_a cos\alpha^* \\ l_a \ \sin\alpha - \Delta y &= l_a sin\alpha^* \end{aligned} , \tag{1}$$

where:

$$\alpha = \text{arcs}\left(\frac{l_y}{l_a}\right) . \tag{2}$$

Eliminate parameter α^*:

$$\Delta y = l_a sin\alpha - \sqrt{l_a{}^2 sin^2\alpha - \Delta x^2 - 2 l_a cos\alpha \Delta x} . \tag{3}$$

Then we can get the relationship between the multiples of the input displacement Δy and the output displacement Δx:

$$A = \frac{\Delta y}{\Delta x} = l_a sin\alpha - \sqrt{\frac{l_a{}^2 sin^2\alpha - \Delta x^2 - 2 l_a \Delta x cos\alpha}{\Delta x}} . \tag{4}$$

That is, through the bridge-type composite flexible hinge structure shown in Fig. 2, with terminals B and D as input terminals and A as the output terminal, the displacement of the input terminal can be reduced by A times and output from terminal A.

It can be seen from the formula that the displacement scaling factor A is ultimately related to l_y and l_a, so the displacement scaling factor of the bridge composite flexible hinge can be adjusted by changing the value of l_y, as shown in Fig. 4.

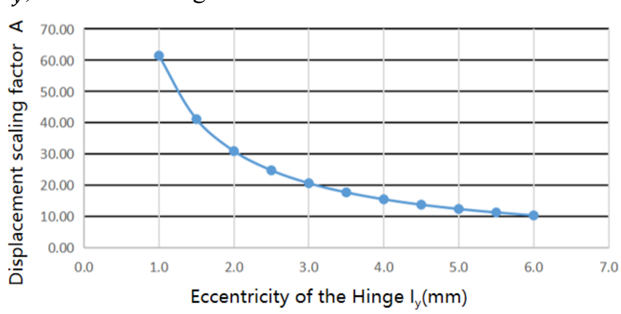

Figure 4: The relationship between l_y and A.

MECHANICAL DESIGN OF THE ACTUATOR

Figure 5(a) shows a sub-nanometer displacement actuator based on a compound bridge-type hinge design. The piezoelectric actuator is fixed on the D end of the bridge-type composite flexible hinge, so that it can push the B end. Due to the interaction of forces, the piezoelectric actuator exerts equal magnitude and direction on the B and D ends of the bridge-type composite flexible hinge. Opposite driving force, resulting in input displacement. In order to enhance the lateral stiffness of the bridge-type composite flexible hinge, a lateral hinge is designed at its output end to support and constrain the degrees of freedom except the driving direction. Figure 5(b) shows a hierarchical composite actuator with a piezoelectric actuator as a coarse adjustment stage and a sub-nanometer displacement actuator as a fine adjustment stage.

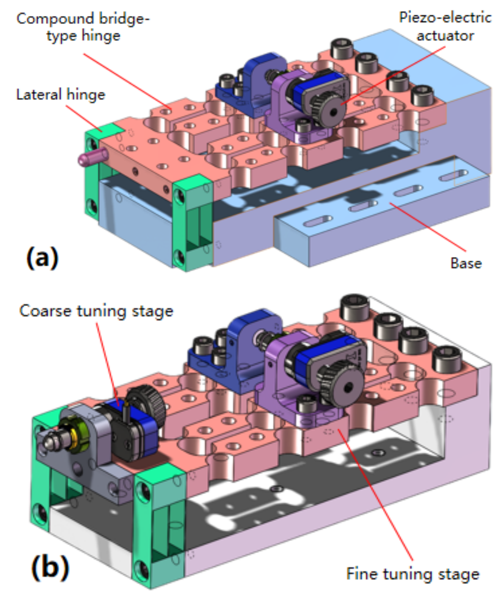

Figure 5: The mechanical design of the actuator.

EXPERIMENT AND RESULT

A prototype machine was produced for testing based on the design in Fig. 5. As shown in Fig. 6, a laser interferometer was used to measure the displacement of the input end and the output end to calculate the actual displacement scaling factor of the prototype machine.

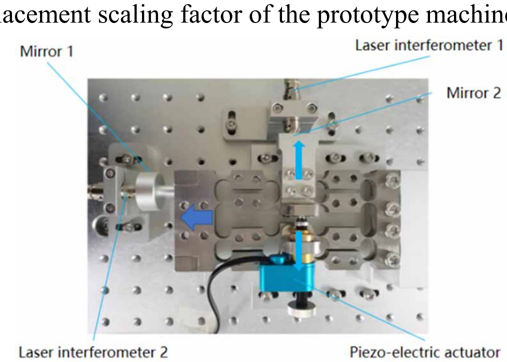

Figure 6: Minimum resolution test for the prototype.

We also drove the piezoelectric actuator with a step value of 1 to test the minimum resolution that can be achieved at the output end of the prototype machine in this case. The measured minimum resolution result at the output end is shown in Fig. 7. The experimentally measured displacement scaling factor of the prototype is about 40. Combined with the measured minimum resolution of the prototype of 0.35 nm, it can be calculated backwards that the step displacement of the piezoelectric actuator in 1 step is about 14 nm, which is the same as the measurement in Fig. 1. The step

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displacement of the piezoelectric actuator is consistent with 1 step.

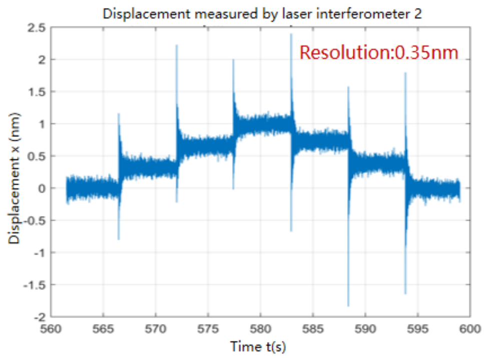

Figure 7: Minimum resolution test results.

On the basis of the prototype machine in Fig. 5(a), a piezoelectric actuator is added as a coarse adjustment stage to form the composite actuator shown in Fig. 5(b), which is used to drive the weak-link mechanism, as shown in Fig. 8. We place three different types of laser interferometers on the weak-link mechanism to measure the minimum angular resolution that the mechanism can achieve.

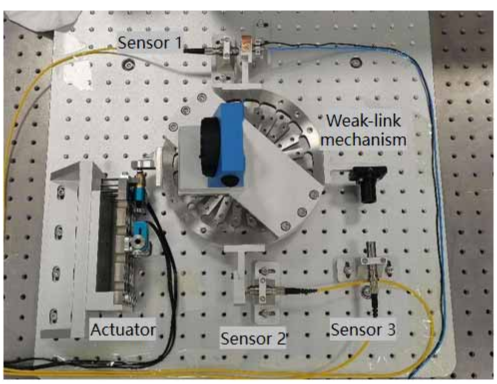

Figure 8: Angular resolution test device.

Figure 9 shows the measurement results of one of the laser interferometers. The measured minimum angular resolution of the weak-link mechanism is about 3.5 nrad. Combined with the magnification of the driver (40 times), it is exactly the same as the direct piezoelectric actuator in Fig. 1. The angular resolution measured by the sensor driver is consistent, further proving the reliability of the prototype.

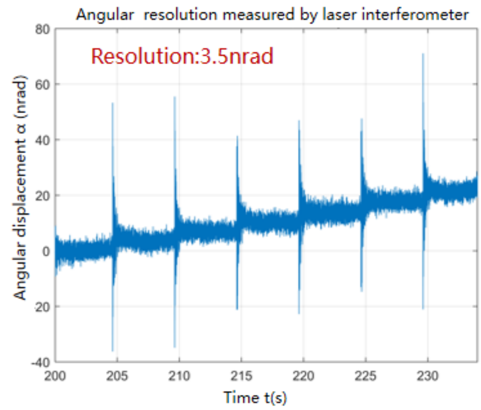

Figure 9: Measurement results from one of the laser interferometers.

CONCLUSION

This poster briefly proposes a method to achieve sub-nanometer displacement actuation at a lower cost and shows preliminary experimental results of the prototype produced. Due to time constraints, relevant tests on the driving force and stability of the driver will be carried out later.

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