PRECISION MECHANICAL DESIGN OF A MINIATURE DYNAMIC MIRROR BENDER FOR THE SSRF BEAMLINE UPGRADE PROJECT

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Abstract

Dynamic mirror benders which enable high precision figuring of planar substrates for x-ray focusing are widely used as conventional optical equipment in various synchrotron radiation beamlines. Especially, in cases for x-ray focusing optics coated with multilayers in a Kirkpatrick-Baez (K-B) configuration [1] as the final focusing elements immediately upstream of the sample, the dynamic mirror benders provide high precision figuring to allow the mirror figure to be tuned to optimize the focusing at different incidence angles to cover a wide energy range [2].

Recently, collaboration between Argonne National Laboratory and Shanghai Institute of Applied Physics has produced designs of a new miniature dynamic mirror bender using Argonne's laminar nanopositioning flexure technique [3-5] for the beamline upgrade project at the Shanghai Synchrotron Radiation Facility (SSRF). The mechanical design and finite element analyses of the miniature dynamic mirror bender are described in this paper.

INTRODUCTION

The SSRF is a 3.5 GeV third generation synchrotron radiation source. Currently, there are sixteen more beamlines under design and construction stage for the SSRF Phase-II beamline construction project. Both SSRF and Advanced Photon Source (APS) have a keen interest in the development of novel K-B mirror mount stages for synchrotron radiation applications. As a part of Argonne Strategic Partnership Project (SPP) (formerly known as work for others or WFO project), collaboration between Argonne National Laboratory and Shanghai Institute of Applied Physics has produced designs of a new miniature dynamic mirror bender using Argonne's laminar nanopositioning flexure technique for the beamline upgrade project at the SSRF. The motivation of the new design is to develop a compact, cost-effective flexure mirror bender with high stability.

TEST MIRROR FOR PROTOTYPE

Figure 1 shows a schematic diagram of a silicon test mirror for the new miniature dynamic bender prototype. The 90 mm long silicon mirror has an effective optical length of 66 mm and thickness of 5.5 mm. The width of the mirror is designed to perform the optical figuring of the mirror under bending [6]. With a dynamic mirror bender, which is capable to provide bent moment tuneable between 0.35 N·m to 0.71 N·m, the elliptical mirror figure radiuses are tuneable between of curvatures of 24 m–88 m to 12 m-44 m.

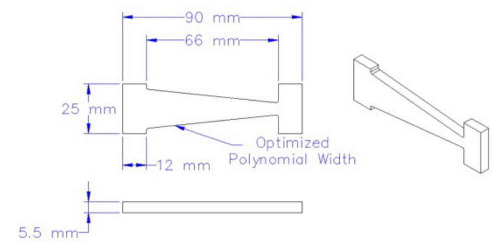

Figure 1: Schematic diagram of a silicon test mirror for the new miniature dynamic bender.

DESIGN OF THE MIRROR BENDER

Based on the type of bending actuators, the miniature dynamic mirror bender is designed with two configurations: the open-loop control configuration with Newport™ Picomotor™ actuators and the closed-loop control configuration with Newport™ NPM-140 piezo micrometer adapter [7]. Both design configurations use the same flexure bending mechanism module.

Mirror Bender with Newport™ Picomotor™ Actuators

The miniature dynamic mirror bender for open-loop control configuration consists of a base; a pair of laminar flexure mechanism modules; a pair of bending arms; and two Newport™ Picomotor™ 8301 actuators. The silicon mirror is bonded to a pair of adapters to connect with the bender as shown in Figure 2.

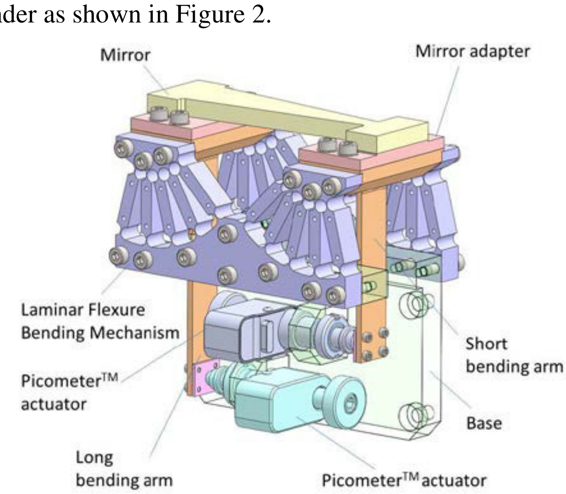

Figure 2: 3-D model of the miniature dynamic mirror bender with Newport™ Picomotor™ 8301Actuators for open-loop control configuration.

Since the Picomotor™ 8301 piezo linear actuator has a limited 22 N axial load capacity, similar to the ESRF mirror bender design [2], the bender has a longer bending arm to provide the necessary bending moment. The elastic deformation of the bending arm also provides an extended bending resolution.

Mirror Bender with Newport™ NPM-140 Piezo Micrometer Adapter

With Newport™ NPM-140 piezo micrometer adapter's 100 N axial load capacity and nanometer-scale positioning resolution [7], the dynamic mirror bender's closed-loop control configuration also has a more compact design with shorter bending arm. As shown in Figure 3, the closed-loop control configuration consists of a base; a pair of laminar flexure mechanism modules; a pair of bending arms; a Newport™ NPM-140 piezo micrometer adapter with 140 micron travel range for the long bending arm, and two manual adjusters for both long and short bending arms. Figure 4 shows a comparison between the two configurations of the dynamic mirror bender design.

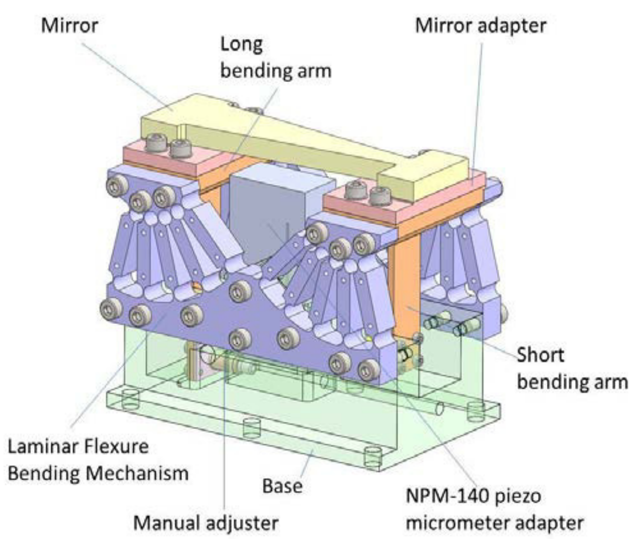

Figure 3: 3-D model of the miniature dynamic mirror bender with Newport™ NPM-140 piezo micrometer adapter for closed-loop control configuration.

Design of Laminar Flexure Bending Mechanism

The flexure bending mechanism module is constructed with stacks of thin metal weak-link sheets which are manufactured using photochemical machining processes with lithography techniques [4]. The module is a solid laminar bonded complex structure designed for ultrahigh positioning sensitivity and stability performance.

Figure 5 shows a 3-D model of the laminar flexure bending mechanism module. It is a combination of two individual tip-tilting flexural guiding structures. The 8-mm-thick bonded module consists of forty layers of 200-micron-thick photochemical machined single weak-link sheet. The weak-link sheet material could be 17-7 PH stainless steel (for lager dynamic range) or Invar-36 (for better thermal stability).

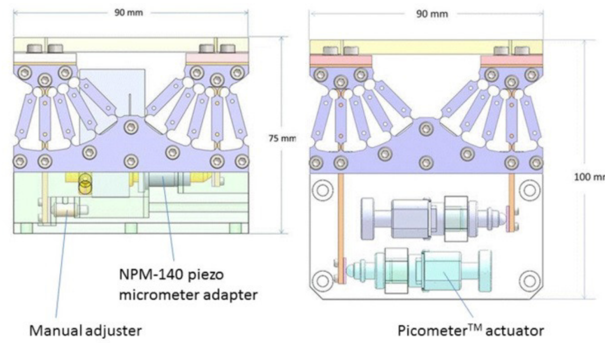

Figure 4: A side view for comparison between the two configurations of the dynamic mirror bender design. The configuration with NewportTM NPM-140 piezo micrometer adapter shows a 25% overall height reduction.

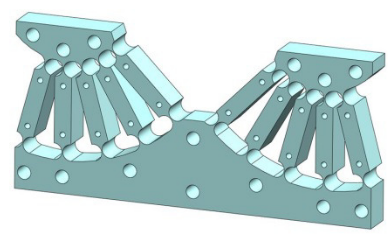

Figure 5: 3-D model of the 8-mm-thick laminar flexure bending mechanism module. It is a combination of two individual tip-tilting flexural guiding structures.

PROTOTYPE FOR FINITE ELEMENT ANALYSIS AND PRELIMINARY TEST

As shown in Figure 6, 7 and 8, finite element analysis (FEA) results for the Z7-5006 dynamic mirror bender prototype with open-loop control configuration show that, with a 15.1 N load applied to the short bending arm and a 11.4 N load applied to the long bending arm (to simulate a bent moment of ~1 N·m), the maximum Von-Mises stress on the 8-mm-thick weak-link modules reaches ~109 MPa, which is only less than 10% of the material yield stress for 17-7-PH stainless steel. The maximum displacement of the long bending arm is ~0.97 mm. The maximum displacement of the short bending arm is ~0.57 mm.

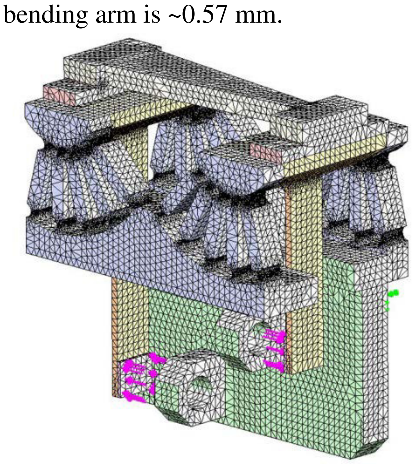

Figure 6: 3-D model of the flexure bending mechanism with solid mesh for FEA.

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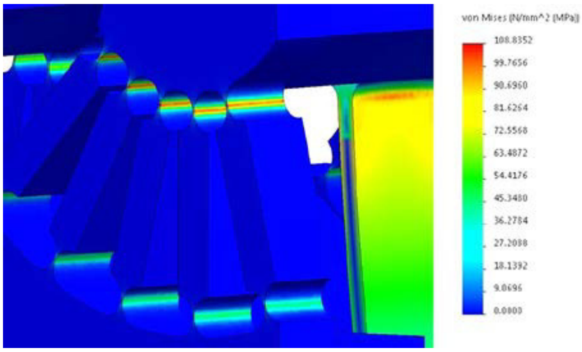

Figure 7: 3-D model of the flexure bending mechanism shows the maximum Von-Mises stress on the 8-mm-thick weak-link modules reaches ~109 MPa.

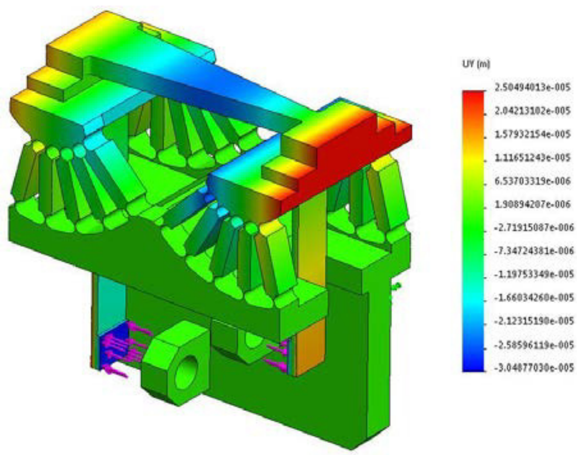

Figure 8: 3-D model of the flexure bending mechanism shows the maximum displacement of the long bending arm is ~0.97 mm, and the maximum displacement of the short bending arm is ~0.57 mm.

A prototype of the miniature dynamic mirror bender Z7-5006 with closed-loop control configuration has been designed and constructed for preliminary mechanical and optical tests. As shown in Figures 9 and 10, an aluminium alloy dummy mirror with mirror adapter is mounted on the dynamic mirror bender for mechanical assembly test. The flexure bending mechanism module is constructed with 17-7 PH stainless steel sheet. The material used for the short and long bending arms is Invar-36. The prototype's base is made from aluminium alloy.

In Figures 9 and 10, the temporary linkages between the two individual tip-tilting flexural guiding structures in the module have not been removed yet.

SUMMARY

The mechanical design of a miniature dynamic mirror bender with open-loop control and closed-loop control configurations for beamline upgrade project at the SSRF are presented in this paper. FEA results have shown that the mechanical design of the Z7-5006 prototype bender is capable of meeting design requirements for the SSRF 90-mm-long test mirror. Table 1 summarizes the design specifications of the Z7-5006 prototype miniature dynamic mirror bender. Mechanical test with laser interferometer is in progress. The results will be presented in a separate paper later.

Table 1: Design Specifications of the Z7-5006 Prototype Miniature Dynamic Mirror Bender

Z7-5006 dynamic mirror bender (open-loop control configuration)	
Overall dimensions (mm)	90 (L) x 62 (W) x 100 (H)
Normal load capacity (kg)	0.1
Driver type	Newport™ Picomotor™ linear actuator
Driver encoder type	N/A
Driver axial load capacity (N)	22
Driver min. incremental (nm)	20
Manual adjustment option	Yes
Tuneable bent moment (N·m)	0.2 - 1
Z7-5006 dynamic mirror bender (closed-loop control configuration)	
Overall dimensions (mm)	90 (L) x 62 (W) x 75 (H)
Normal load capacity (kg)	0.1
Driver type	Newport™ NPM-140 piezo micrometer adapter with closed-loop control option
Driver encoder type	strain-guage
Driver axial load capacity (N)	100
Driver closed-loop travel range (micron)	140
Driver min. incremental (nm)	1
Manual adjustment option	Yes Tuneable bent
moment (N·m)	0.2 - 1

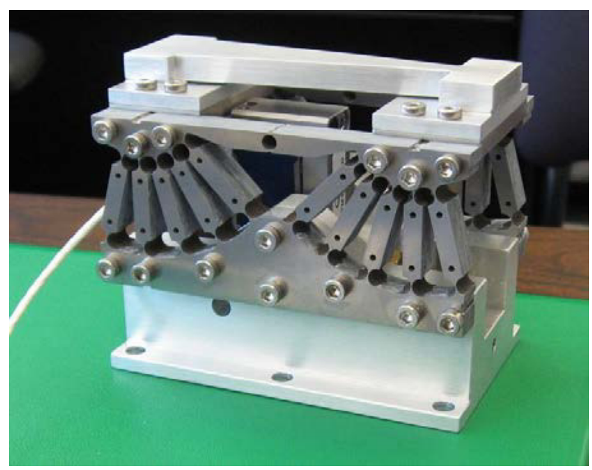

Figure 9: Photograph of the Z7-5006 prototype dynamic mirror bender with closed-loop control configuration.

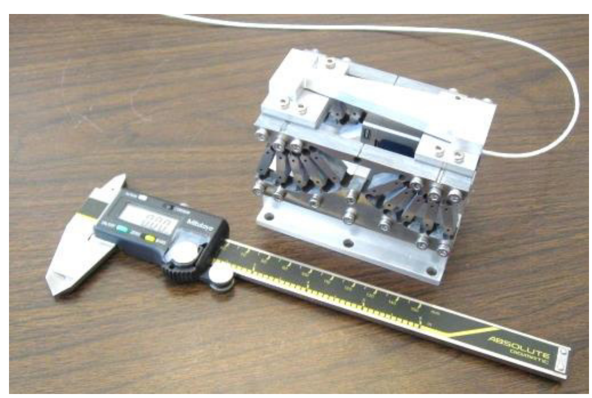

Figure 10: Photograph of the Z7-5006 prototype dynamic mirror bender with closed-loop control configuration.

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