Design of a Monolithic Aspherical Mirror Bender for an Active Grating

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Abstract

A novel monolithic bender was designed for an active bendable polynomial grating. The grating was proposed to increase the resolution of the CEM design used in the Dragon type beamlines of the SRRC. The grating can eliminate the defocus and coma aberrations to yield a theoretically ultra high resolution. The bender was designed with an almost fixed center point after bending, and a low height to fit requirements of installation. Two PZT actuators are used to bend the bender to an adjustable third order polynomial surface profile and meet the grating adjusting rage specification. After a series of FEM analyses to optimize the design, a prototype bender was fabricated and tested to achieve satisfactory results. This paper presents in detail the design and analysis processes.

Keywords: beamline, active grating, mirror bender, FEM

1. Introduction

Higher resolution is now an important issue to improve the experiment quality among the synchrotron radiation applications [1,2]. There are many efforts exerted on this topic [3-5]. In SRRC, an active bendable grating was proposed to enhance the quality of the CEM design used in the Dragon type beamlines. By using an optimized third order polynomial surface profile, it has the potential to raise the resolution 10 times theoretically [6].

It is familiar to use mechanism with actuators to bend mirror substrate to a desired shape. A prototype had been fabricated and tested at first attempt [7]. Though it shows good surface quality, there is two major drawbacks limited it to be a grating and these drawbacks are also seen in other mirror designs. One is the tall height (85mm). It demands large chamber and is not easy to install with other adjusting mechanism. The other is the center point will move when bended, since the fixed point is on the two sides in this kind of design [7,8]. An additional adjusting mechanism will be essential during bending range.

In order to avoid these drawbacks, a new compact bender with the features of polynomial surface, low profile and nearly fixed center position was designed through linkage analysis and optimized by FEM software (ANSYS). Prototypes were fabricated and tested. The results shows good conditions and will be ruled to be gratings.

2. Design and analysis

2.1 Main Structure Design and Analysis

It demands two control parameters $C_{2,opt}$ and $C_{3,opt}$ to produce a polynomial surface ($y=C_{2,opt}x^2+C_{3,opt}x^3$), the basic concept of the new design was to use two actuators to meet the requirements of polynomial surface, nearly fixed center area and low height (50 mm).

┌──┐–like shape is a popular and successful type mechanism for bending mirror. At primary concept, it was still adopted. When pushing the side legs to bend, the mirror plate will be concaved. There should be linkages to lift up the legs to maintain the position of the center area. Besides, the linkages should be outside the legs and attached to a base foundation since low height is another criteria. Considering unequal couple bending, other linkages are added to the legs at upper position to apply firmly support. The concept linkage design is as in Fig. 1. The DOF (degree of freedom) is calculated to be –1 and approves that the design is capable of unequal couple bending.

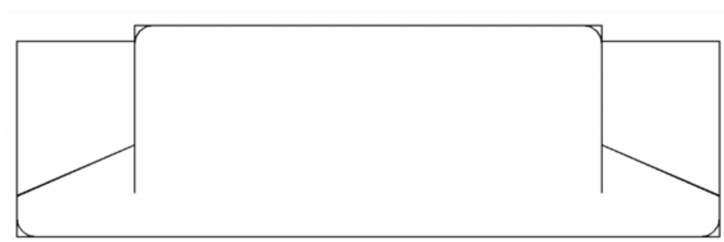

Fig. 1: The concept linkage design.

The detailed design was started according to the size spec of the active grating that is 180 mm feasible length, 40mm width, and 50 mm height, bending range up to 27 m radius of curvature at least. The flexure hinge type joints with two PI 245-50 vacuum compatible PZT actuators are adopted based on the consideration of high precision, compact, and minimizing assembling error.

The bending should occur mainly at the mirror plate. The thickness of mirror plate should less than the legs and was defined to be 10 mm on the consideration of polishing. Let the thickness of the side legs be 17.5 mm including 2.5 mm hinge hole radius. The hinges links legs and lifting linkages were placed 30 mm below the mirror surface and 40mm of the other lifting linkage hinges which link the supporting base. The supporting linkages are placed 3 mm below the mirror surface in order easy to glue the mirror plate and polish. The bending plate length inside the legs was set to 200 mm to cover the 180 mm feasible length. Then the major size parameters to be determined were the length and angular of the lifting linkages and the thickness of the hinges.

The length and angular of the lifting linkages can be roughly calculated from the displacement of hinge joint after bended as in Fig. 2. For a 27 m curvature bending, the center position of the mirror surface fixed, the altitude lifting δ is about 0.25 mm and horizontal displacement δ_x is about 0.11 mm. The length l_0 and angular θ of the lifting linkages can be roughly calculated to be 22.86 mm and 23.6 degree. A primary design with roughly dimensions was established for FEM analysis to optimize the angular of the lifting linkages and the thickness of the hinges as in Fig. 3.

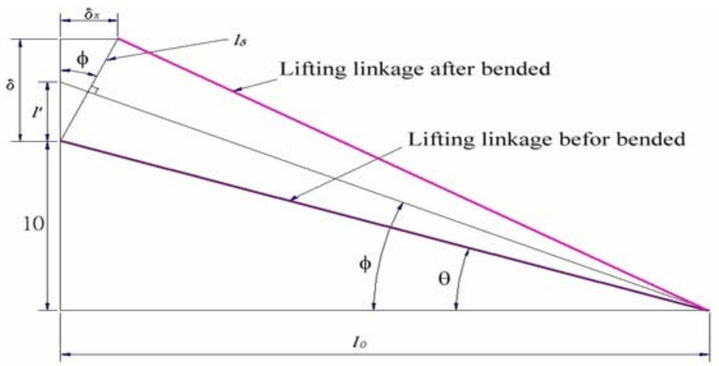

Fig. 2: Lifting linkage displacement analysis

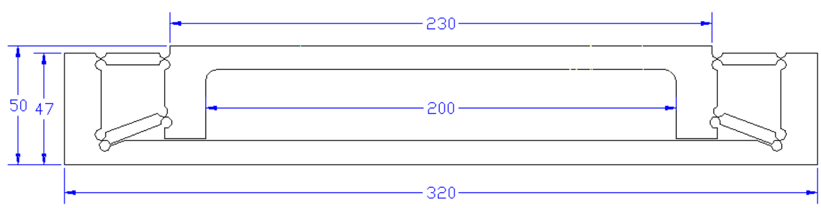

Fig. 3: A primary bender design with roughly dimensions

The material for the bender body is 17-4 PH stainless steel because of the high strength after hardening and stability after thermally cycle to –196°C and 200°C [9]. From the optimization of FEM analysis (ANSYS), the thickness of the hinges is 0.3 mm and the angular of the lifting linkages is 20.7 degree for monolithic type (electro-less Nichol plating). A little modification of the angular of the lifting linkages should be made for glued type mirror plates. It is 20.3 degree for 3 mm ULE (7mm 17-4PH), and 20.7 degree for 5 mm Si (7 mm 17-4PH).

As in Fig. 4, with 100 kgw force applied at both side legs, the displacement of the center area of the surface is only about 1.7 µm, the radius of curvature is 22 m and the largest concentration stress is 55 kg/cm^2 about half the linear limitation. The simulation results satisfied the requirements of the active grating.

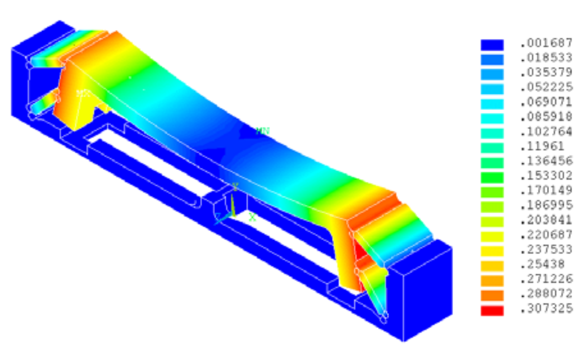

Fig. 4: Bending simulation under 100 kgw force applied at both side legs, unit: mm.

Also, the unequal force bending was simulated. Fig. 5 shows the fitting results of the centerline of the mirror plate under 40 kgw and 37 kgw different bending force what is about the rage of real application.

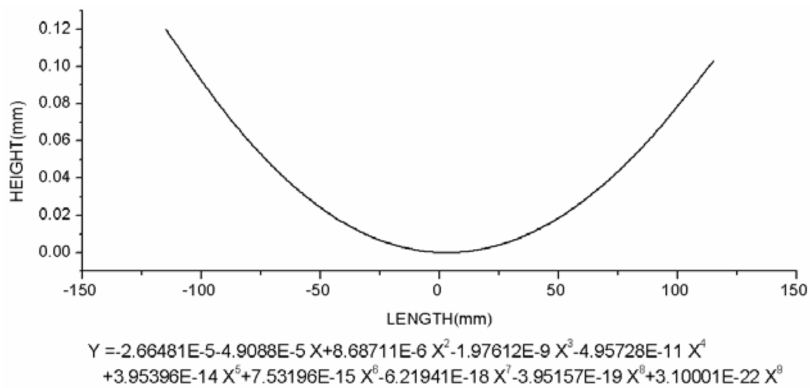

Fig. 5: The fitting results of the centerline of the mirror plate under 40 and 37 kgw different bending force.

2.2 Actuator Sub-assemblage Design and Analysis

Since the side legs will be lifting when bended by the actuators, the connecting parts between actuators and legs will be lifting with the legs also. The actuator sub-assemblage was designed as in Fig. 6. With center connecting part fixed with the supporting base of the bender, the actuators will also rotate slightly when bending. The connecting parts are also whit hinge type joints. The side legs connecting parts are of plate type hinge and the center connecting part is of cylindrical type to minimize the affection of assemblage error. The thickness of the hinge joints was also optimized by FEM analysis, 0.5 mm for the plate type and 3 mm for the cylindrical type.

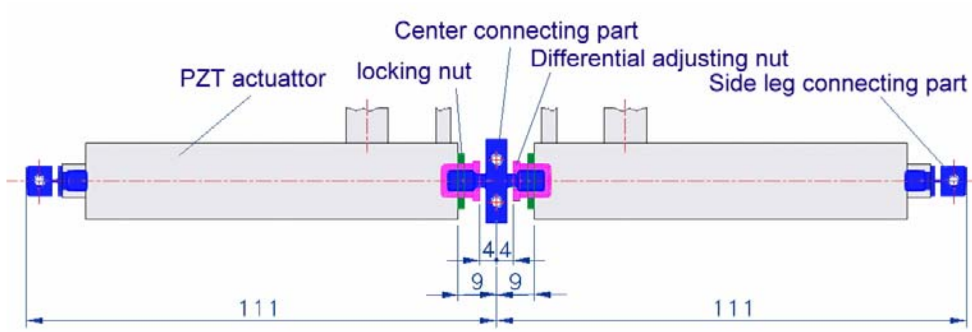

Fig. 6 The actuator sub-assemblage of the bender.

*2.3 **E**nvironment Consideration*

- Vacuum

There were gas leakages designed between all connecting parts for ultra-high vacuum compatible.

- Heat load

The estimated heat load in beamline application is 1.5W at most. There will be temperature rising above 20 degree C if the heat is transferred only through the supporting base in vacuum from simulation. Connecting screw holes are set on the bending legs for heat load conducted away in installation.

From simulation, only the highest temperature is different, the temperature distribution along the surface is almost the same for different heat conducting rate of the heat dissipation assemblage. It is feasible to combine the result for a compensation to derive the polynomial parameters.

2.4 Final Bender Design for an Active Grating

From all the above design consideration and optimization, the final bender design for an active grating with the spec of grating is as shown in Fig. 7.

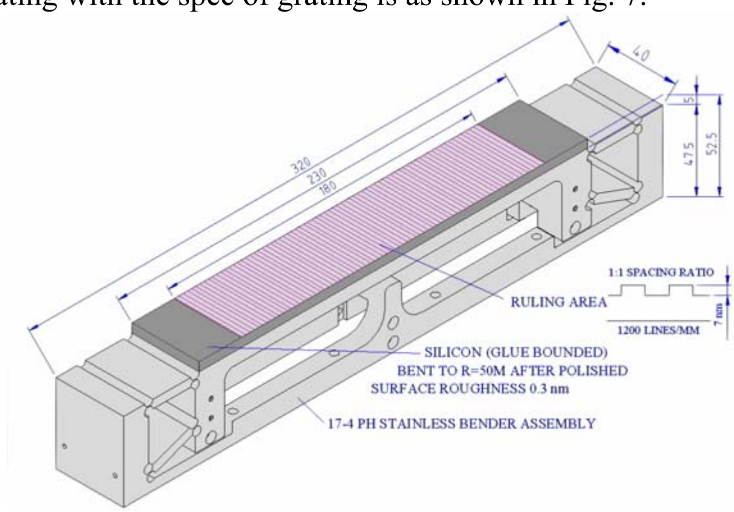

Fig. 7: The final bender design for an active grating with the spec of grating.

3. Fabrication and Test

The fabrication processes are pre-working, H900 hardening, fine machining, cleaning, thermal cycle treatment, mirror plate gluing (or electroless nickel plating), polishing (grating ruling) and assembling. A prototype with ULE plate glued was fabricated for test as in Fig. 8. By adjusting the differential screw, the testing prototype was pre-bended to a curvature about 72 m radius. A series of tests and measurements were carried out on the prototype to examine the bender design.

The slope error was measured to be 2.7 μrad RMS in 180mm length and 1.5 μrad RMS in 150 mm length. There is side effect due to bending legs on both sides and congruent to the analysis result. The roughness of the prototype is 6-10 angstroms due to local vendor capacity. If the roughness could be better, the slope error should be less than 1 μrad RMS in 150 mm length. The side effect can also be eliminated through pre-bending polishing.

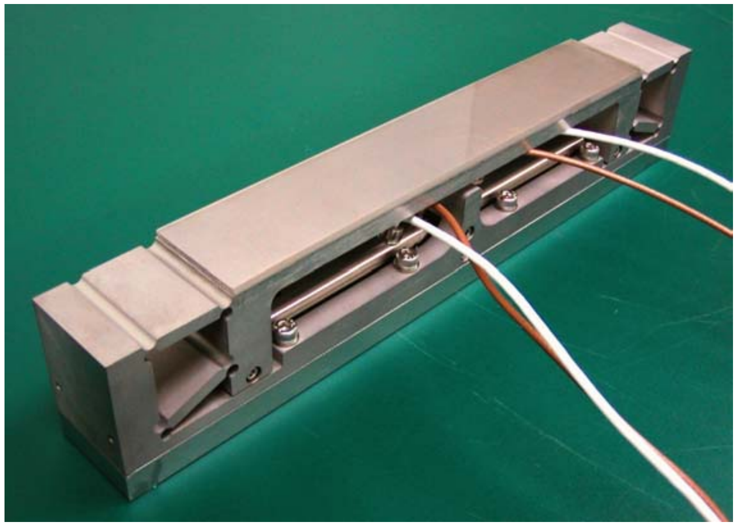

Fig. 8: The testing prototype after assembled.

The range can be chosen with the differential adjusting crew nut to be from flat to 55 meter radius or from 72 meter radius to 35 meter radius. The tested prototype adjusting range of C_2 and C_3 is shown in Fig. 9. The largest center displacement in the range is about –1.6 μm and indicates that it will less than -0.5 μm in real application.

The stability for a sudden adjustment (from 72 m to 50 m) is 0.3% in radius change after an hour and the repeatability is less than 0.1% after a series adjustment being made or temperature rising. Also, the vibration situation of the PZT actuators was tested. There are no obvious amplitude change and frequency peaks detected between servo control on and off.

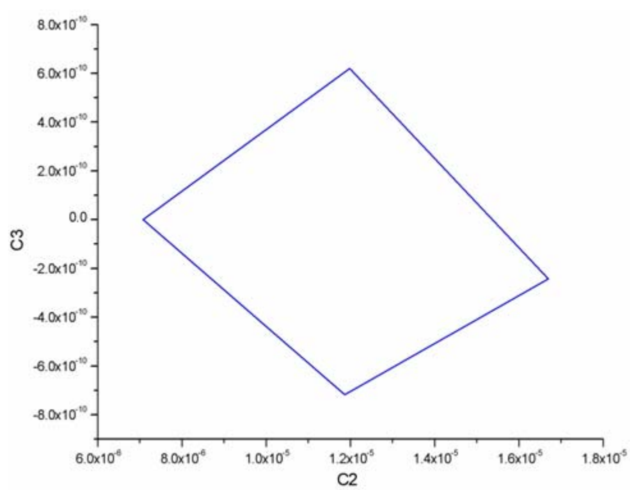

Fig. 9: The adjusting range of C_2 and C_3 for the polynomial surface profile $y=C_2x^2+C_3x^3$, unit:mm.

4. Conclusion and Discussion

A novel monolithic bender for an active polynomial grating had been designed and fabricated in SRRC through the mechanism synthesis and analysis and with the aid of FEM analysis. This type of bender has the features of nearly fixed center point after bending and with 50 mm low height. It is capable of large bending range from flat to 20 m-radius curvature. By adapting unequal couple, it can be bent to an adjustable 3rd order polynomial surface profile in order to cancel the defocus and coma aberrations.

A series of tests and measurements were carried out on prototypes to examine the bender design. The result shows good conditions and meets the requirements of the active grating. The good stability and repeatability of the testing prototype indicates that good hardening and thermally cycle treatment are important and effective at the fabrication processes.

Though this bender design is originally proposed for the active grating, it can be adopted for bendable polynomial mirrors. According to the mirror size to analyze and optimize the dimensions of the linkages, the main structure can be accomplished. The actuators can also adopt other than PZT actuators in different applications.

5. References

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