CHARACTERISTICS OF MECHANICALLY-BENT-SHAPED MIRROR FOR SOFT X-RAY

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Abstract

The characteristics of "Arm Method" mechanically-bent-shaped mirror has been evaluated by equipping on the BL-27SU beamline of SPring-8. For forcusing the SOR light on the sample position, the mirror surface should be an asymmetrically bent elliptic shape. The "Arm Method" mirror bender is a device to give bending moments to the mirror with using shaft rigidity by pulling the arm shafts. This mirror bender is designed to change the curvature of 50(W)x540(L)x25(T)mm3 Si mirror down to approximately 400m radius. By adding different moments on either side of the mirror, it is possible to make the mirror off-axis pseudo elliptical shape. After measuring the slope error by using LTP, the bender has been installed on the beamline. The beam profile on the focal plane has been measured by stepping a pinhole photodiode detector along the axis perpendicular to the SOR light. Also the effect of the "double tubing" cooling system has been investigated. As the result. we have obtained good reproducibility, stability, and holdness of the bender.

1. Introduction

A large number of "Arm Method" mirror benders have been supplied to SPring-8 and KEK/PF, in which the bender is a device to give bending moment to a plane mirror by pulling arm shafts situated parallel to the mirror surface. We have already reported (1-3) the evaluation of the performance of the bender by measuring the curvatures and slope errors of the symmetrically bent mirror using LTP(Long Trace Profiler,Ocean Optics,Inc.,LTP II) owned by SPring-8, and concluded that this had very good performance on the stability, reproducibility, and firmness. Also the slope errors of the mirror coursed by bender were fairly small.

In the present work, our main aim has been to apply the bender to the BL-27SU beamline of SPring-8, and investigate that forcusing behavior at the sample position. For this purpose, we have performed following calculations and measurements.

(1) Calculation of mirror shape and slope errors when adding stress to the shaft.
(2) Measurement of slope errors of the elliptically bent mirror surface by LTP.
(3) Measurement of beam profile at the forcused point using the BL-27SU beamline.
(4) Measurement of reproducibility and holdness of the mirror bender.

2. "Arm Method" Mirror Bender

As shown in Fig.1, the "Arm method" mirror bender used in the present work is designed to produce arbitrary magnitude of the curvature by asymmetrically pulling two stainless-steel arm shafts equipped on both the ends of the mirror. The driving mechanism consists of feed

screws, worm gears and stepping motors, shown in Fig. 2. In the preceding works on LTP measurement, we used 6mm diameter stainless rods to bend the mirror, and minimum curvature of 900m was achieved. On the other hand, since the mirror should be elliptically and asymmetrically bent to 400m curvature to fit the optical ray out of the beamline, two 8mm diameter stainless steel rods were equipped instead of 6 mm ones. Thus, this kind of bender is able to control the amount of curvature by changing the diameters of the shafts.

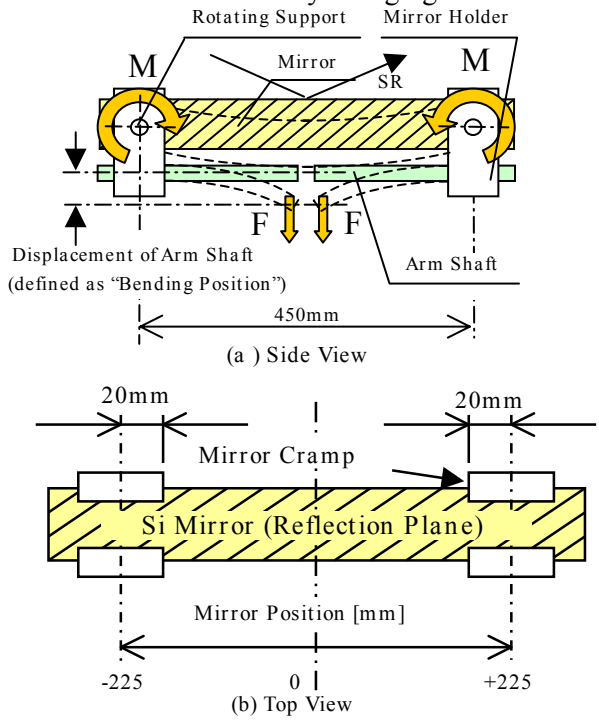


Figure 1: Principle of "Arm Method" Mirror Bender Mechanism.

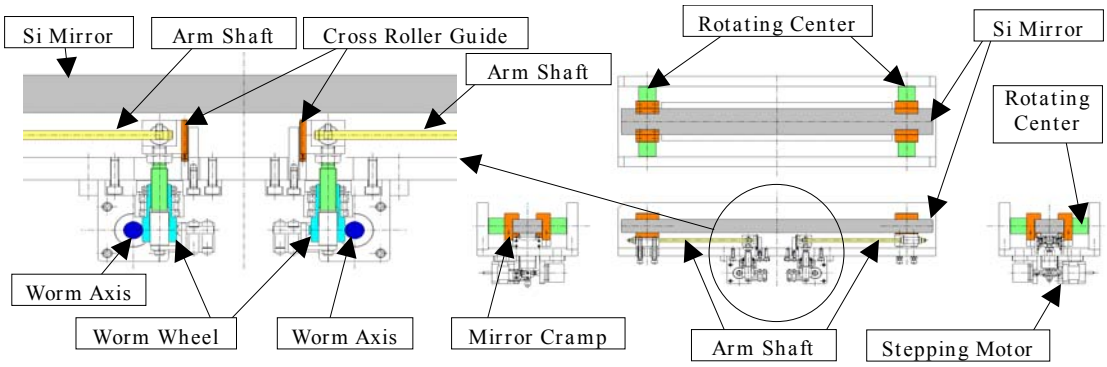


Figure 2: Structure of "Arm Method" Mirror Bender Mechanism.

In order to control the curvature in vacuum, stresses produced by different stepping motors are added to the individual arm shafts. Dimension of the plane mirror made of silicon is 540mm(L)x50mm(W)x25mm(T) and the minimal curvature designed is 400m. The merit using the stepping motor is that the generated torque in a static condition is so high that it can hold the arm shafts firmly. Also the combination of the feed screws and the worm gears is able to precisely control the curvature by a single step movement of the motor. Also the driving mechanism becomes so compact to install in narrow space of the vacuum chamber.

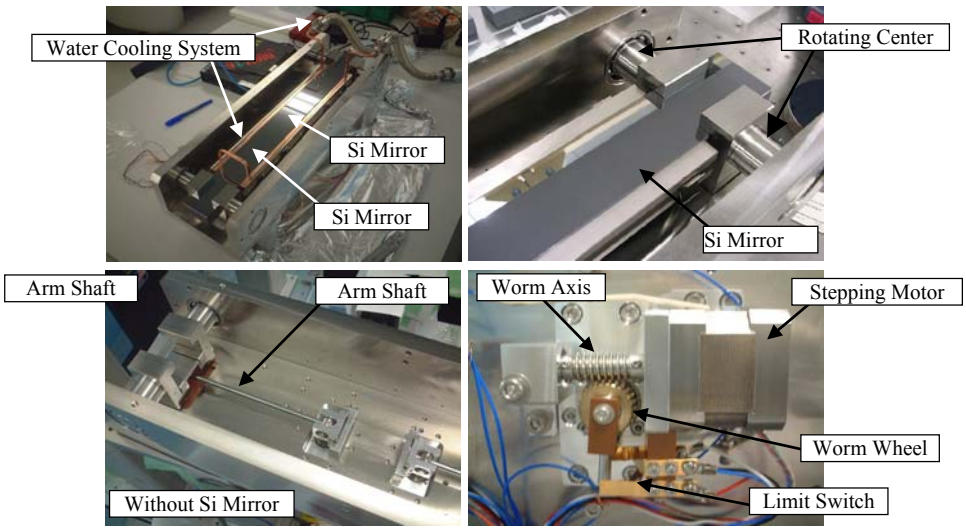


Figure 3: "Arm Method" Mirror Bender.

3. Measurement of Curvature of Elliptically Bent Mirror by LTP

Fig.4 shows the curvature of the mirror suited to the BL-27SU beamline of SPring-8. The necessary moments added to the shafts to obtain the desired mirror shape are calculated by a least squares method to fit to curvatures at local mirror positions using two equations given in Fig. 4. Fig.5 shows the differences between the calculated and the desired slopes and sags. The rms slope error is 0.42μrad.

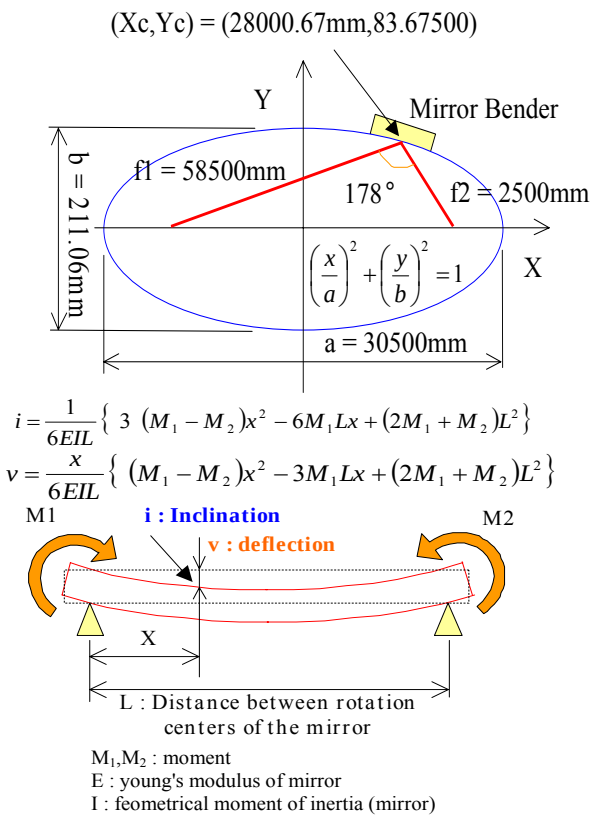
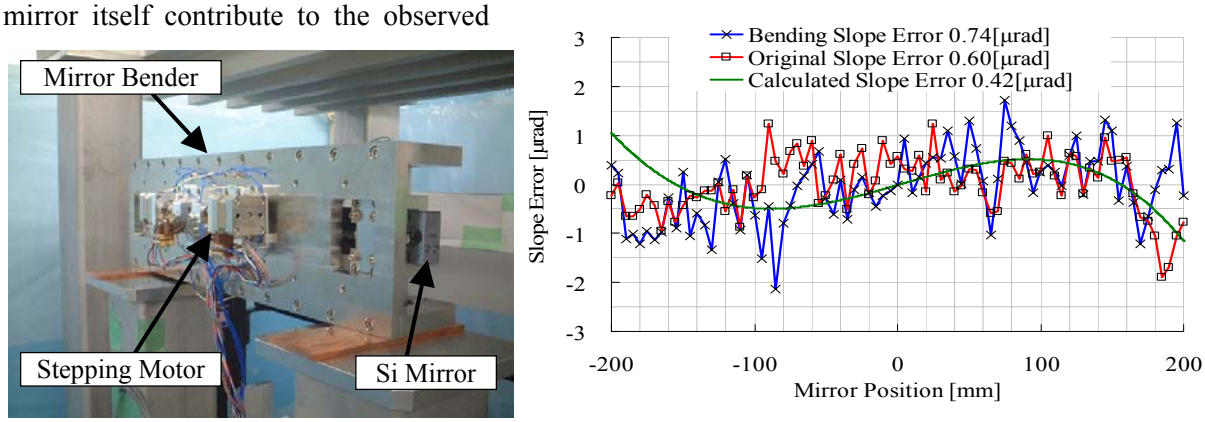


Figure 4: Calculation of Theoretical Value.

Figure 5: Differences between Calculated and Desired Value.

Since the mirror is installed to horizontal direction in the BL-27SU beamline, the measurement of LTP was performed with this direction. The result is shown in Fig. 6. Although the rms slope error obtained is 0.74μrad, the original local slope errors of mirror itself contribute to the observed



slope errors. Subtracting the original local slope errors from the measured ones, the resultant rms slope error is reduced to 0.42μrad.

Figure 6: Experimental Setup and Measurement Results of LTP on Elliptically-bent-shapedd Mirror.

Table 1: Measurement Results of LTP on Elliptically-bent-shapedd Mirror.

		Calculated	Measurmed	Original
M1	mm	7.47	7.90	
	Step	97112	102700	
M2	mm	9.69	10.73	
	Step	126002	139500	
Slope Error	urad	0.42	0.74	0.60

4. "Double Tubing" Water Cooling System

In order to focus the light stably at the sample point for long time, it is desirable to maintain a constant temperature of the mirror precisely. The sources of perturbations to the temperature in operation are the heats from the SR light and the electric current supplied to the stepping motors in vacuum. To prevent the effect of these incoming heats, so called "double tubing" water cooling system is equipped to the mirror holder.

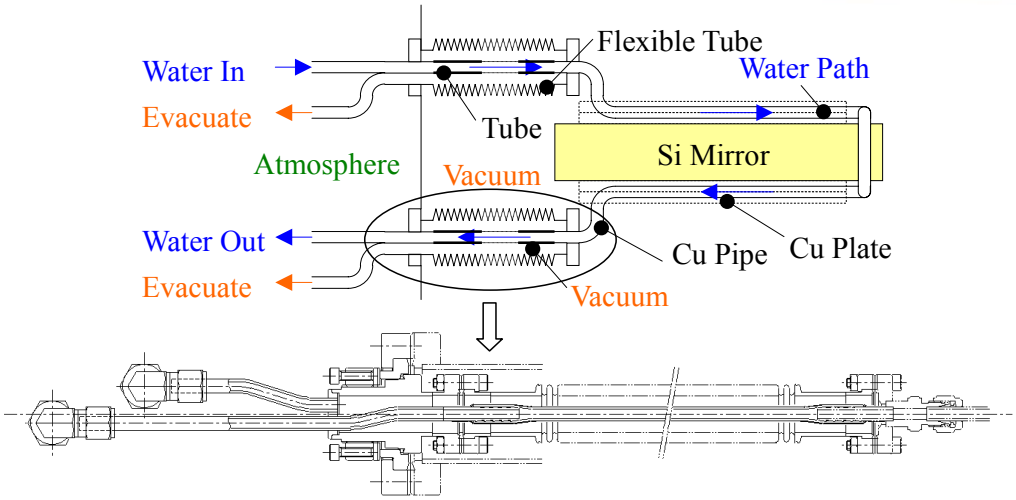


Figure 7: Principle of "Double Tubing" Water Cooling system.

Usually, the water cooling system consists of flexible tubes or copper pipes. But, this kind of cooling system has a demerit that unnecessary forces through the cooling pipes are added to the mirror holder, due to the differential pressure between the vacuum and high pressure water in using flexible tubes. Also copper pipes prodused additional forces to the holder because of their hardness. On the other hand, the double tubing system adopted has an advantage that the differential pressure between the flexible tube and the vacuum is almost negligible, because the space between two pipes is evacuated to nearly vacuum. The cooling water flows inside the inner tubes which are made of soft silicon rubber. Moreover, the outer pipes are made of "Supper Bellows", which have smaller spring constant (now patent pending). In conclusion, the stress to the mirror holder through the cooling pipes is able to be neglected.

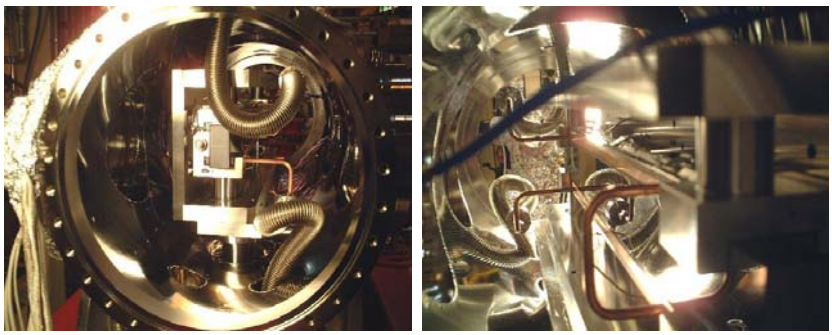


Figure 8: "Double Tubing" Water Cooling system in Mirror Chamber.

5. Measurement of Microfocusing Performance using SPring-8 BL27SU

Fig. 9 shows a schematic layout of the microfocusing optics and the BL27SU beamline of SPring-8. Soft X-ray radiation from undulator is directed towards the front-end X-Y slits which are positioned at 27m from the light source and open up to 3.0mm(horizontal)x0.3mm(vertical). After horizontally reflecting from the plane pre-mirror following the front-end slits, there are another X-Y slits which are widely opened not to restrict the beam light. The elliptically bent cylinder mirror is situated at 58.5 m from the source, which focuses the light beam to an one-dimensional (horizontal) μ-spot. The profile and two dimensional distribution of the μ-spot were obtained by stepping a pinhole photodiode detector with a pinhole diameter of 10μm along the horizontal and vertical axes on the focal plane, which was situated at 2.5 m from the bent mirror. Consequently, demagnification ratio of optics is 2.5m/58.5m=1/23.4. Since the source size of the undulator is 758μm, the ideal beam width at the focal point is estimated to be 32.4μm.

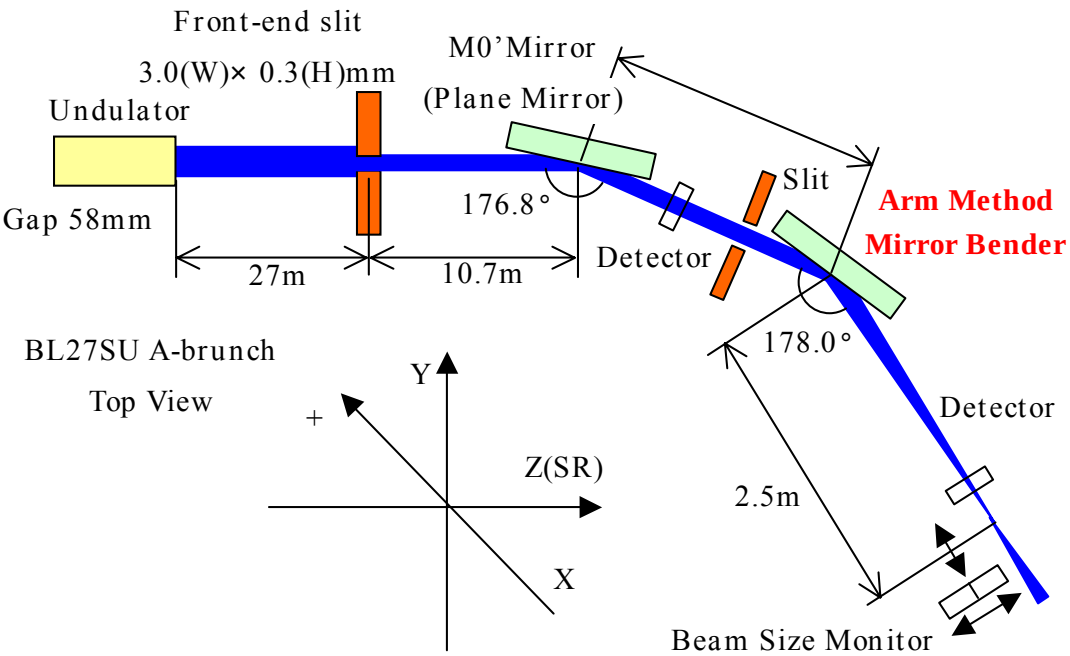


Figure 9: BL27SU A-brunch.

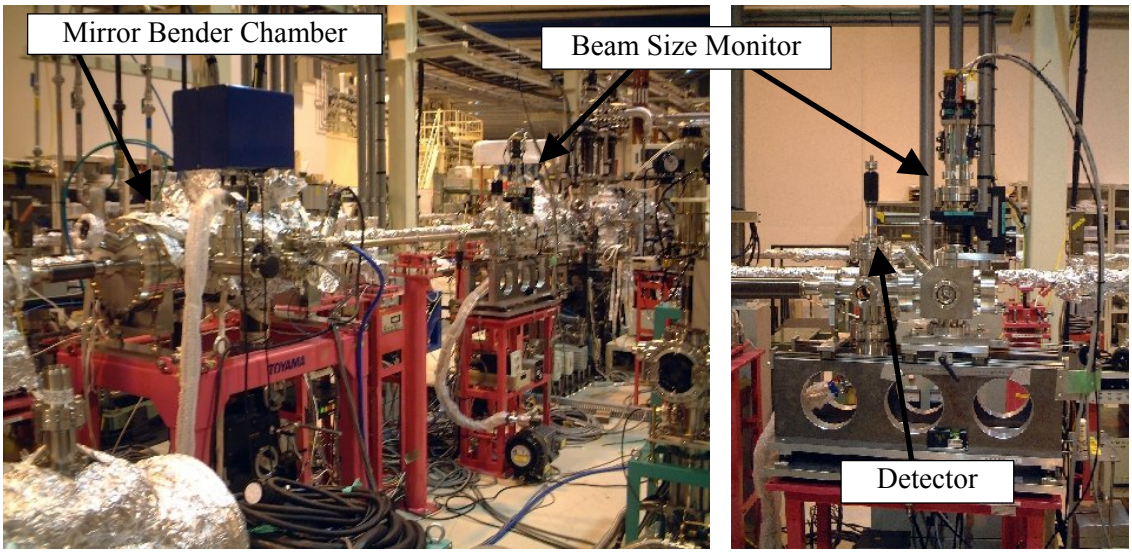


Figure 10: Mirror Bender Chamber and Beam Size Monitor.

5.1. Measured Beam Profiles

Fig.11 shows measured beam profiles on planes positioned from 2450mm to 2550mm by 25 mm step with constant stresses added to the shafts. The narrowest beam width and the biggest peak intensity are obtained at 2500mm position, which is the designed focal point. With separating from the focal plane, the peak intensities become weaker, and the beam profiles become more different from the Gaussian pattern.

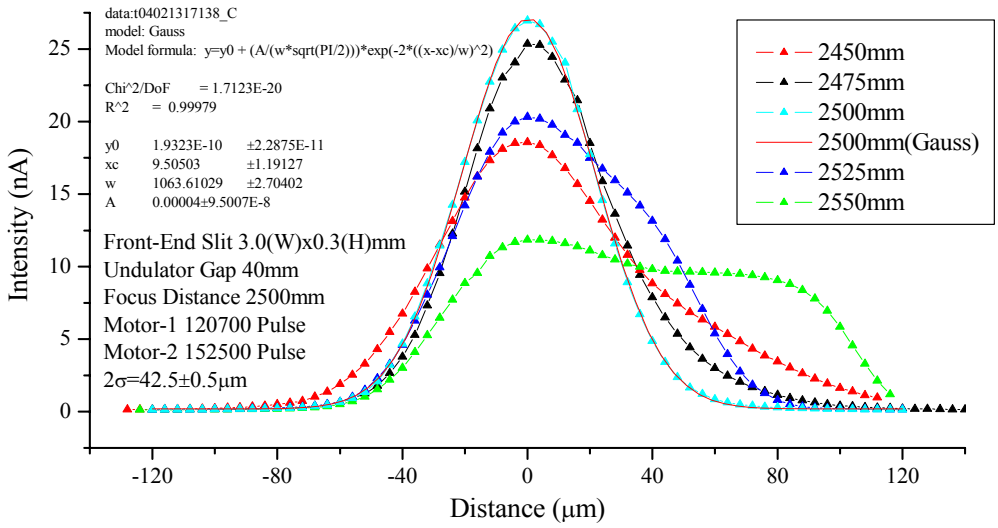


Figure 11: Beam Profiles in each distance.

The measured and calculated beam profiles along the horizontal direction at the focal plane are shown in Fig.12, where calculated one is obtained by a least squares fit to Gaussian pattern. The agreement of these two profiles is very good. The beam width defined as twice of the standard deviation is 42.3±0.07μm, which is larger than the estimated beam width of 32.4μm. The reason of this discrepancy is not clear, but by adjusting the moments applied to both arms, it could be possible to get smaller focusing size.

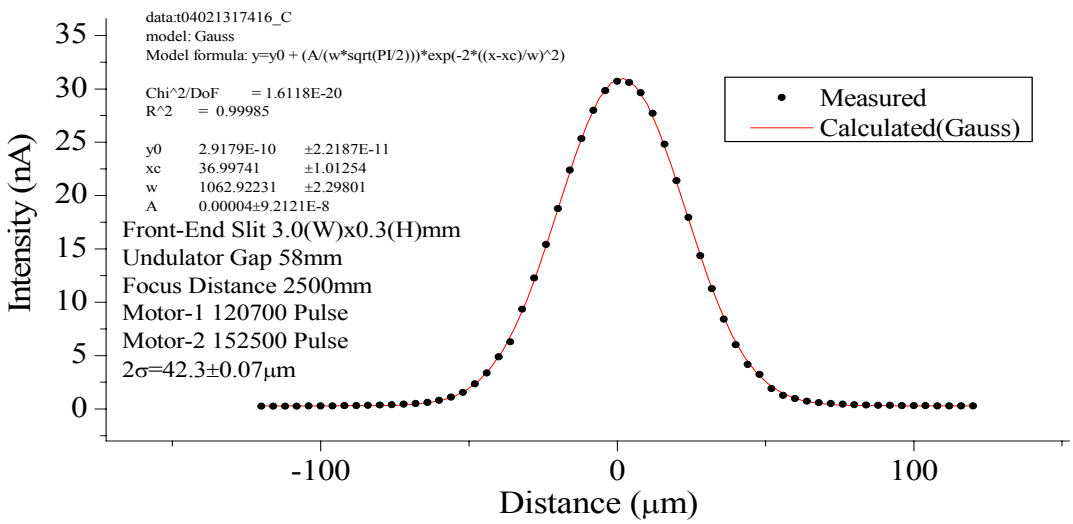


Figure 12: Comparison between Measured and Calculated Beam Profiles.

5.2. Reproducibility

The result of reproducibility is shown in Fig. 13 and Table 2. In these measurements, after changing the counts of pulses of the stepping motors to the arbitrary counts, they are returned to the original counts. The profiles of five measurements agree very well, and the rms

deviation is 0.22μm, which is about 0.5 % of the beam width. Judging from these results, the mechanism of "Arm Method" mirror bender reproduces the curvature of mirror very well.

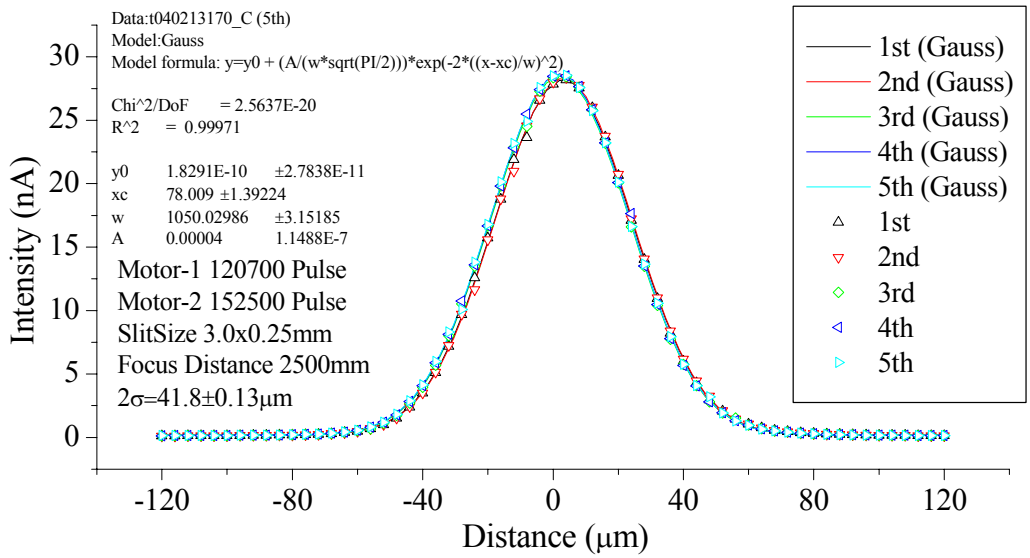


Figure 13: Reproducibility.

Table 2: Reproducibility.

	1st	2nd	3rd	4th	5th	Ave.
2σ (μm)	42.2 ±0.12	42.1 ±0.11	42 ±0.12	41.6 ±0.13	41.8 ±0.13	41.93 ±0.22

5.3. Stability

Fig. 14 shows schematic drawings of the mirror and the mirror bender with thermocupples for the temperature during measurment of the forcusing profile on the sample position. Fig. 15 shows the variations of beam widths, beam distances, and peak intensities during maintaining the counts of pulse of stepping motors with and without the water flowing, where distance means the peak position of the profile. These results show that the "Double Tubing" water cooling system works well and the stability of the curvature of the bent mirror is quite good.

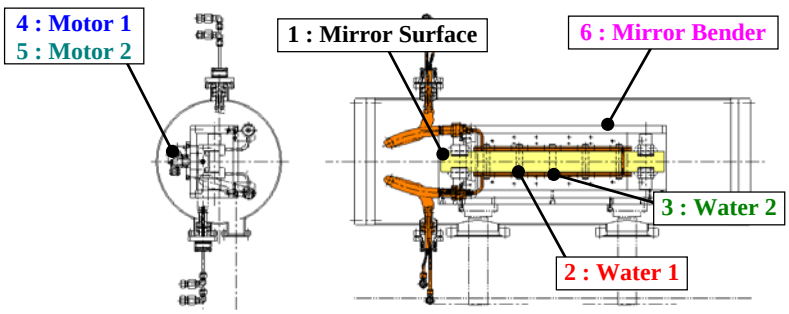
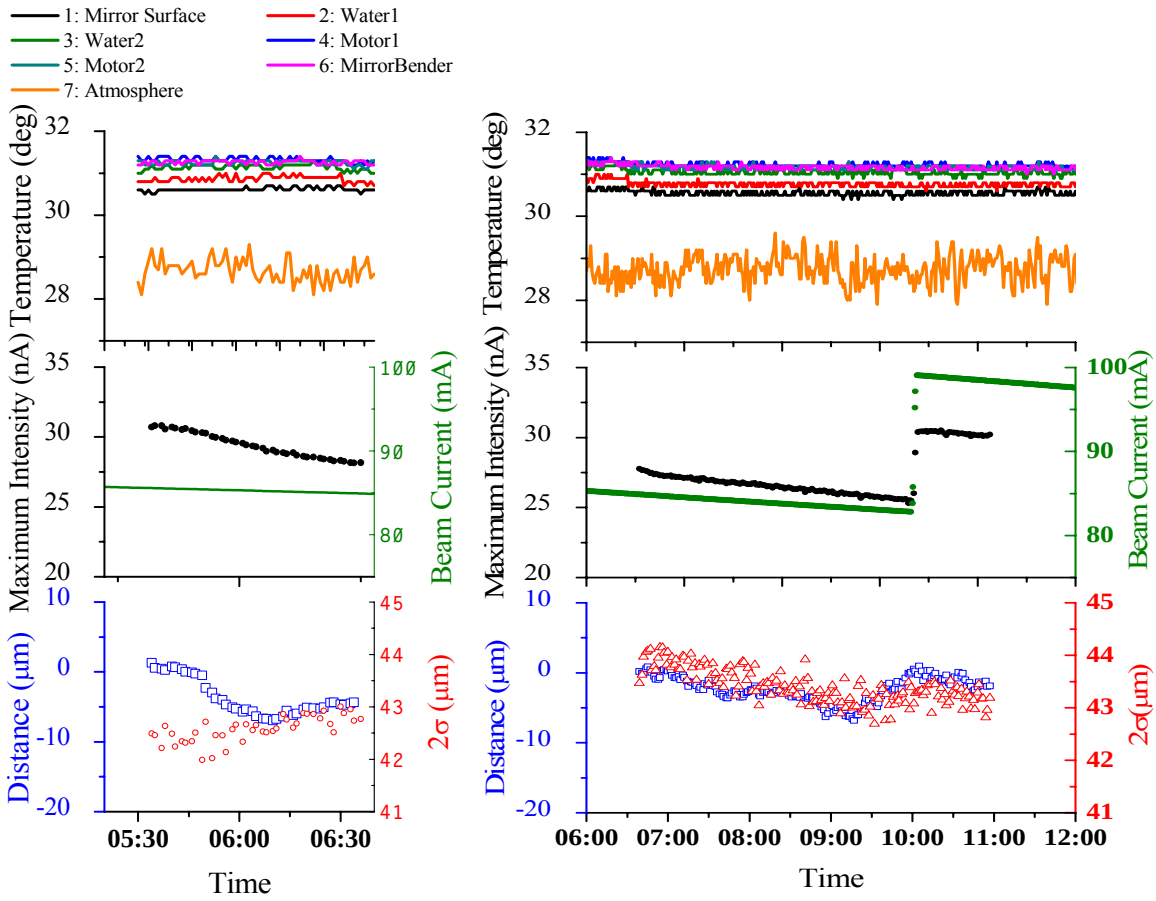


Figure 14: Attachment Position of Thermocupple



(a) without Water-cooling (b) with Water-cooling

Figure 15: Stability.

6. Conclusion

Installed in the BL27SU beamline of SPring-8, the optical system of the "Arm Method" mirror bender has been tested on its performance by measuring the profile at the focal point. The focusing property, reproducibility and maintenance of the mirror bender have been concluded to be very good.

Next beam time experiments scheduled from 14-th of June and 6-th of July are planed to get smaller beam size by lengthening the distance between the source and the benders. Also, to get two-dimensional spot, another bending mirror is set to perpendicular direction to this bender.

7. References

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