Characteristics of Mechanically-Bent-Shaped Mirror

N. Kamachi*, K. Endo*, H. Ohasi # and T. Ishikawa†

*TOYAMA Co.,Ltd., 4-13-16 Hibarigaoka, Zama-shi, Kanagawa 228-0003, Japan
Phone: +81-46-253-1412; Fax: +81-46-253-1412
E-mail: kamachi@toyama-jp.com
SPring-8/JASRI, Kouto 1-1-1, Mikazuki, Hyogo 679-5148, Japan
†SPring-8/RIKEN, Kouto 1-1-1, Mikazuki, Hyogo 679-5148, Japan

Abstract

The experimental apparatus to test the characteristics of mechanically-bent-shaped mirror for x-ray optics was prepared and tested. The applied mirror bender was Toyama's own developed one [1], and many of the similar type of the mechanisms had been being used in SPring-8 [2] as well as KEK/PF in Japan. And, we performed a series of the actual measurement by using a LTP II (Long Trace Profilometer) [3] at SPring-8. The items to be tested were: 1) difference from ideal curvature, 2) reproducibility of bent radius in each trial, 3) time-dependent stability, 4) temperature influence, 5) gravity influence, and 6) influence by the side cooling system. These testing are still under way and their results should be discussed later. However, the conclusion so far is that the reproducibility and the stability seem to be good enough for the normal use as x-ray reflecting mirrors, although the bent-shaped curvature is sensitive to the disturbance elements.

Keywords: mrror bender, x-ray optics, LTP II

1. Introduction

Recently, mirror bending mechanisms to be applied to x-ray optics have been widely used, and their requirements are getting higher and higher in accordance with the progress in performance of both the experimental technique and the insertion device. In Japan, several generations of this kind of mirror bending mechanisms had been developed, and some of them have been successfully applied [1,2]. However, only a few data to measure directly the bent-shaped surface curvature has been presented, because the mechanically-bent-shaped mirror with its mechanism is not so easy to put on the conventional measuring instrument.

We, this time, assembled the compact mirror bending setup for experimentation and measured the direct profile of the bent surface. The adopted mechanism was "arm method" developed by Toyama Co., Ltd., and as a measuring instrument "Long Trace Profilometer (LTP II) [3] " owned by SPring-8 was used.

In this paper, the data on the following subjects are reported and discussed:

1) Difference from ideal curvature
2) Reproducibility of bent radius in each trial
3) Time-dependent stability
4) Temperature influence
5) Gravity influence
6) Influence by the side cooling system

2. Experimental Method

2.1 Mechanism of Mirror Bender

The principle of the adopted mirror bending mechanism is shown in Fig.1. This mechanism is developed by Toyama Co., Ltd. and named "arm method". A mirror is cramped at both ends by the mirror holders which are rotatable when the moment for bending is loaded. The mirror holder has an arm shaft to load the bending force. In Fig. 1, the bending force is directed downward to rotate the mirror holder to bend the mirror into concave. The actual configuration of the mechanism is shown in Fig. 2.

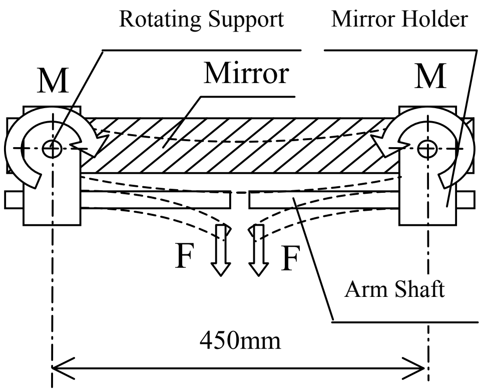

Fig. 1: Principle of "Arm Method" mirror bending mechanism.

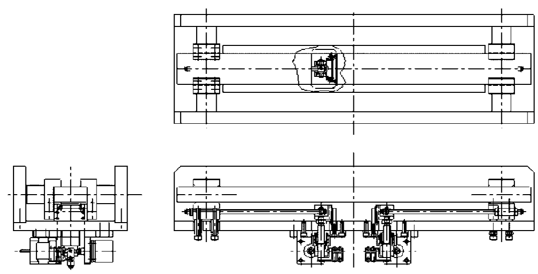

Fig. 2: Configuration of mirror bending mechanism actually applied.

2.2 Experimental Setup

As measurement tool, a Long Trace Profilometer (LTP II) was applied, which was developed by Continental Optical Corp. as "a non-contact optical profiling instrument, designed to measure the absolute surface figure and mid-frequence errors of flat, spherical, and aspherical surfaces of up to 1000 mm in length or diameter" [3].

A mirror used for the test was a plane silicon mirror with dimensions of 540 mm(L) × 50 mm(W) × 25 mm(T), the slope error of which was measured initially as 1.6μrad on the optical bench of LTP II with facing upward.

The experimental setup is shown in Fig. 3. The mirror was mounted on the bending mechanism basically with facing upward. This setup was placed in a clean room where temperature was controlled precisely.

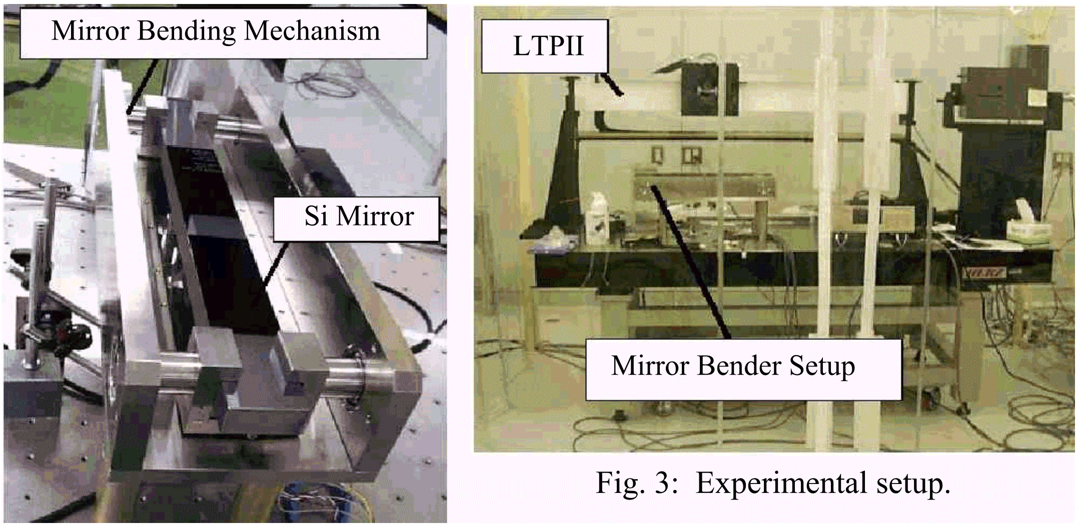

Fig. 3: Experimental setup.

3. Measurement and Results

3.1 Difference from Ideal Curvature and Reproducibility of Bent Radius in Each Trial

The measurement started after leaving the setup as it was at least over one night in a clean room to make its temperature stable at the ambient temperature. The temperature fluctuated approximately within 0.5°C every day. However, the temperature fluctuation in each measurement, which took about 5 minutes, could be kept within 0.1°C. In each trial, the displacement data of the mirror surface along the longitudinal direction were measured by LTP II.

As the first experiment, bending radius and its reproducibility was tested. The data were obtained three times at the different nine moment conditions, namely 0.0 mm to 8.0 mm at every 1.0 mm pitch in the linear driving stage to load the bending force, which correspond to 0.00 kgf-m (no load) and 1.17 kgf-m, respectively. The results are summarized in Fig. 4.

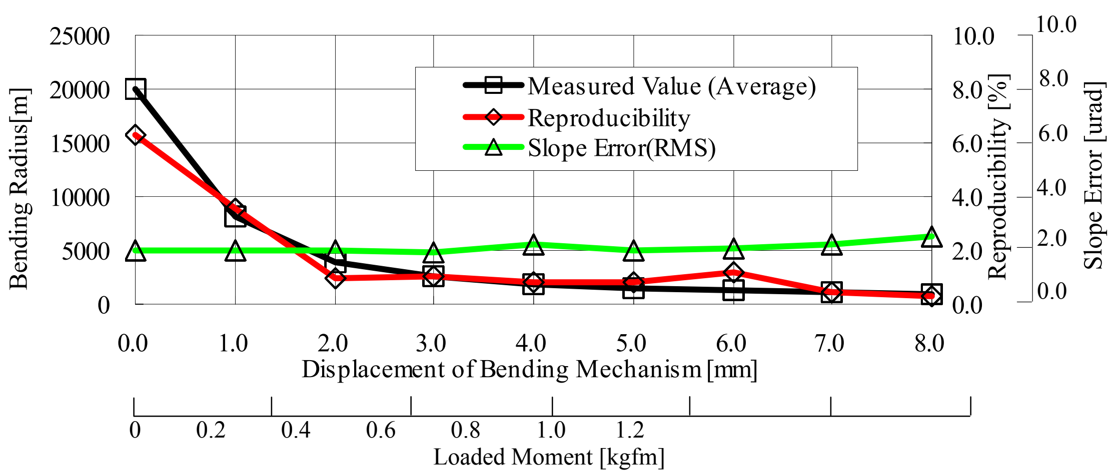

Fig. 4: Bending radius, reproducibility and slope error of bending mechanism.

The changes in bending radius look very smooth. And, the slope error (RMS value) seems to be almost consistent without regard to the bending radius keeping approximately 2 μrad. The reason why the value at no moment position (2.0 μrad) was different from the original slope error (1.6 μrad) is thought to be the influence to cramp the mirror at both ends.

Figure 5 shows the height profile and the slope error when the mirror was bent at 8.0 mm position of the driving stage. The lateral axis represents the distance from one rotation center of the mechanism. And, the scanning range of LTP II was set between 20 mm and 430 mm cutting off each cramping part as shown in the figure.

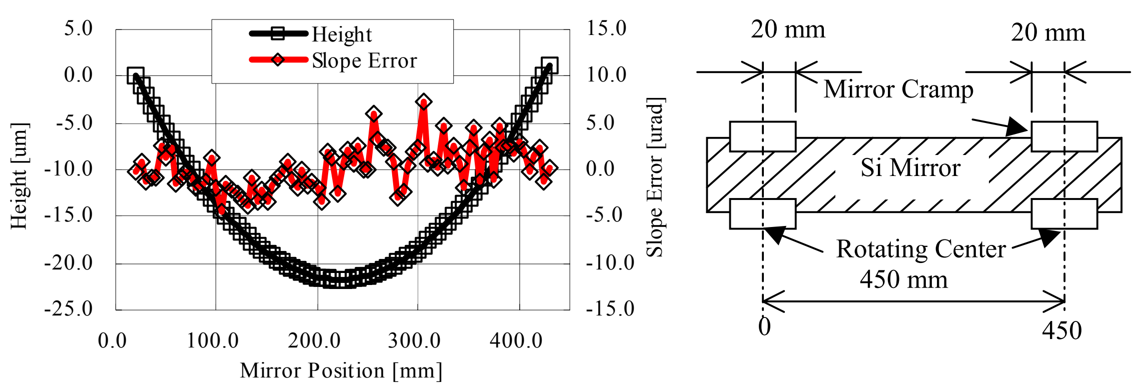

Fig. 5: Height profile and slope error of bending mechanism at 8.0 mm position (loaded moment:1.174 kgfm).

3.2 *Time-Dependent Stability and Temperature Influence*

To check the time-dependent stability of the system, the mirror had been kept bending for 24 hours in the same conditions as the previous test. Figures 6 and 7 show the results of the bending radius and the slope error with the ambient temperature data of the clean room.

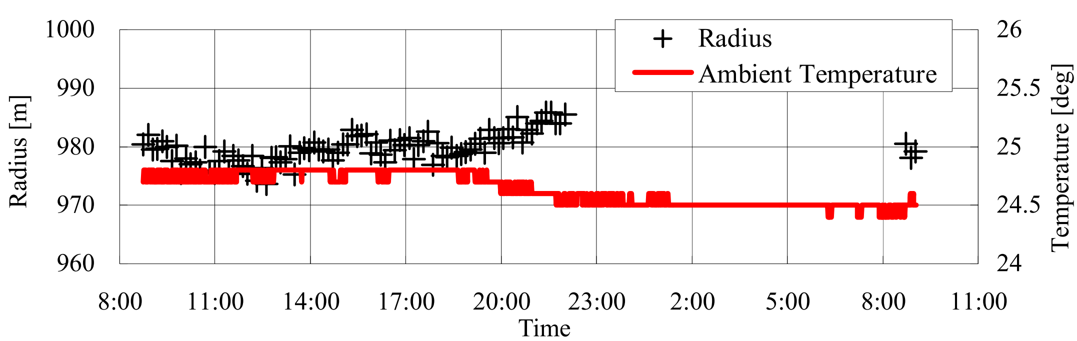

Fig. 6: Bending radius changes in 24 hours.

As seen from the figures, the temperature had been stable in the daytime until 19:00 and fell down 0.3 to 0.4°C in the evening and been stable again in the midnight. From Fig. 6, we can see that the bending radius kept stability within the range of 980 m

± 0.5% in the daytime when the temperature had been stable. Besides, corresponding to the temperature down, the bending radius changed but recovered in the morning when the temperature went up again. The same phenomenon is observed for the slope error in Fig. 7. These phenomena are supposed to be caused by the difference of the thermal expansion of each part of the bending system including the mirror itself. However, further studies should be made to clear this subject because the stability of LTP II system has not yet been confirmed.

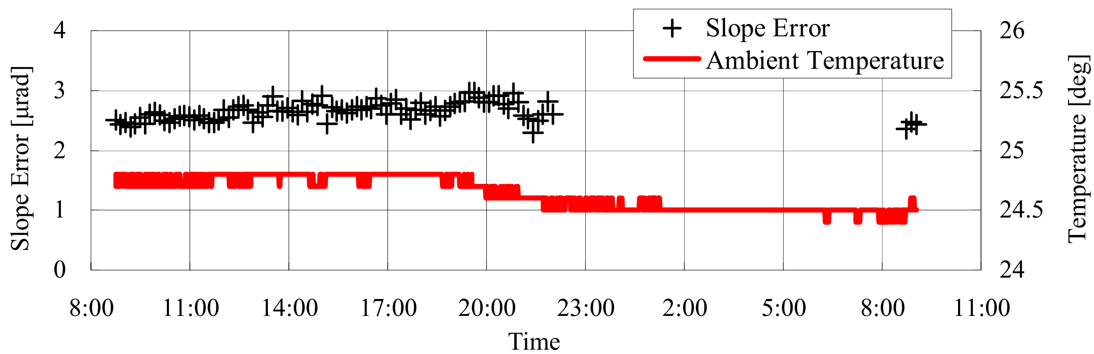

Fig. 7: Slope error changes in 24 hours.

3.3 *Gravity Influence*

Another measurement had been carried out in the same conditions as the previous tests except the surface direction of the mirror, which was set facing sideward as shown in Fig. 8.

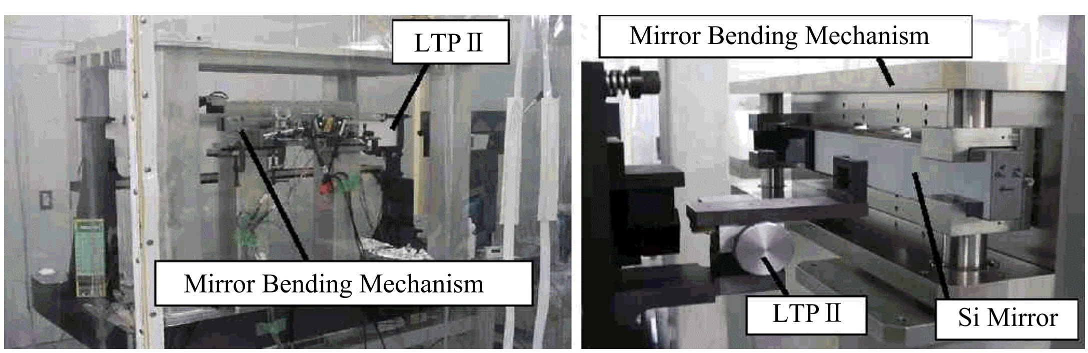

Fig. 8: Measurement setup.

The comparison of the bent-mirror radius in the bending direction of facing-upward and facing-sideward is shown in Fig. 9, where the measured deviation value is defined as just the difference of the two data. Besides, the theoretical value is calculated on the assumption that all the differences between two cases come from only the gravity influence by the weight of the mirror itself. The test result shows that the gravity influence can be observed, however, the measured deviation values cannot always fit with the theoretical ones.

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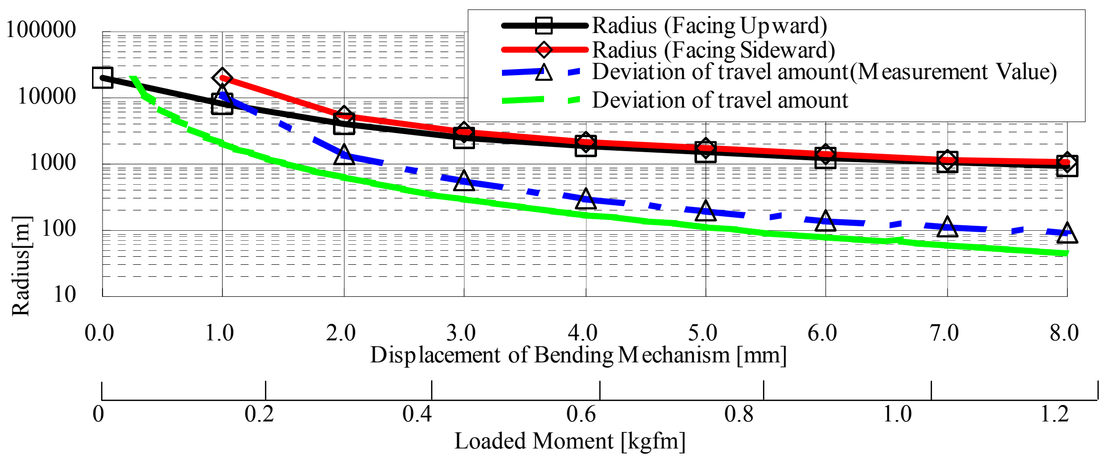

Fig. 9: Comparison of radius in upward / sideward bending.

Figure 10 gives the data comparison of the reproducibility and the slope error of two different facing directions. The tendency of the reproducibility data looks similar. But, in the high-moment range, the bent-mirror of facing-sideward direction seems better in reproducibility. Besides, the slope error (RMS value) of the facing-sideward bent-mirror is found to be better than that of the facing-upward one. It seems to originate from the difference of the initial values, which are 1.6 μrad (facing-upward) and 0.49 μrad (facing-sideward).

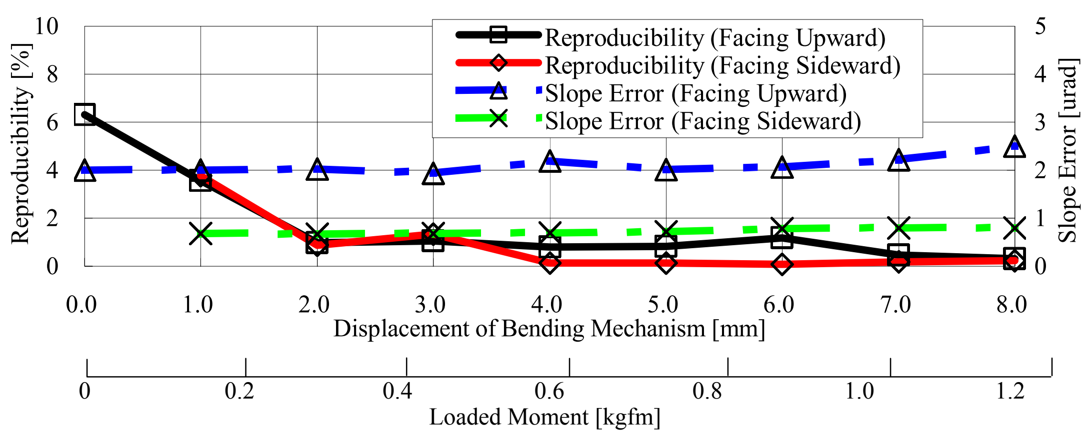

Fig. 10: Reproducibility and slope error (RMS) in upward / sideward bending.

The comparisons of the height profile and the slope error of two different facing directions at 8.0 mm position of the driving stage are shown in Fig. 11. The data of the facing-sideward bent-mirror are understood to be better.

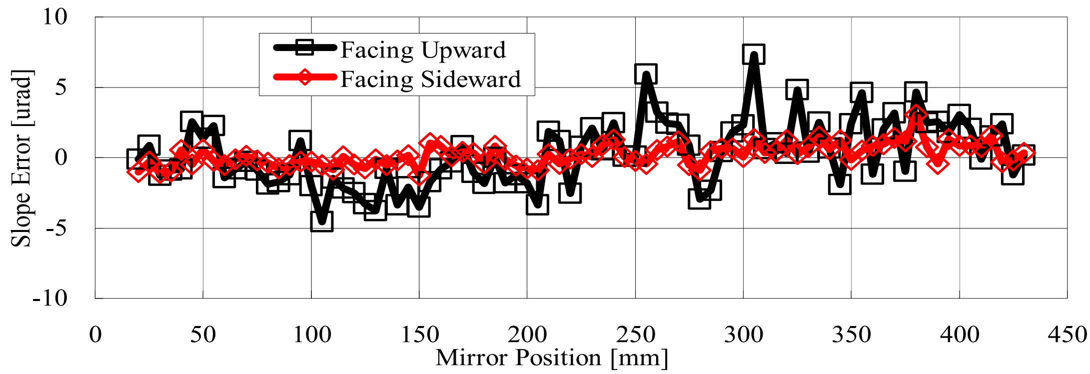

Fig. 11: Height profile and slope error of bending mechanism at 8.0 mm position (loaded moment: 1.174 kgfm).

3.4 *Influence by Side Cooling System*

As a final test in this series, the influence of the side water-cooling plate onto the characteristic of the bent-surface was measured. On the both sides of the mirror, the dummy water-cooling plates made of stainless steel were touched by the spring cramps as shown in Figs. 12 and 13. In this test, the mirror was fixed facing upward on LTP II system.

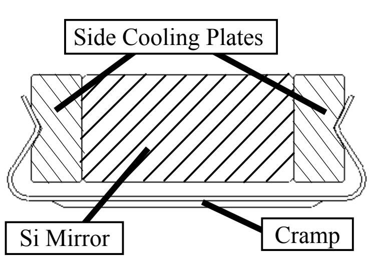

Fig. 12: Side cooling plates and cramps.

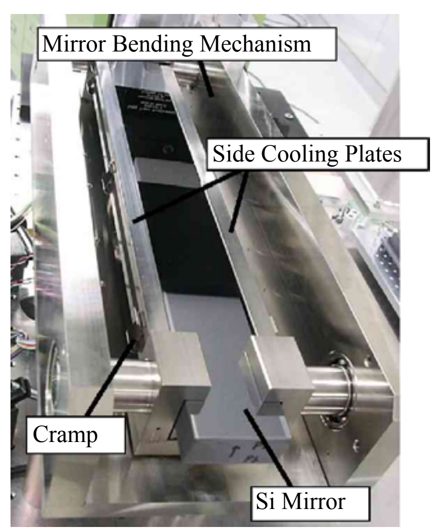

Fig. 13: Photograph of side cooling plates and cramps.

The measurement was done in variations of the number of the cramps (with 3 pcs, 4 pcs, and 5 pcs, respectively). The comparisons between with and without cooling plates are shown for bending radius (Fig. 14), reproducibility (Fig. 15), and slope error (Fig. 16).

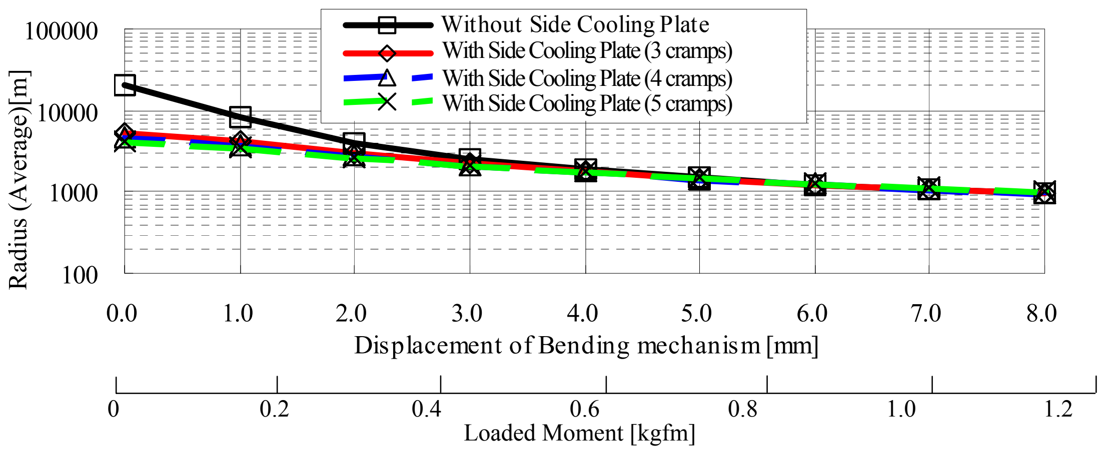

Fig. 14: Bending radius of bending mechanism with/without side cooling plate.

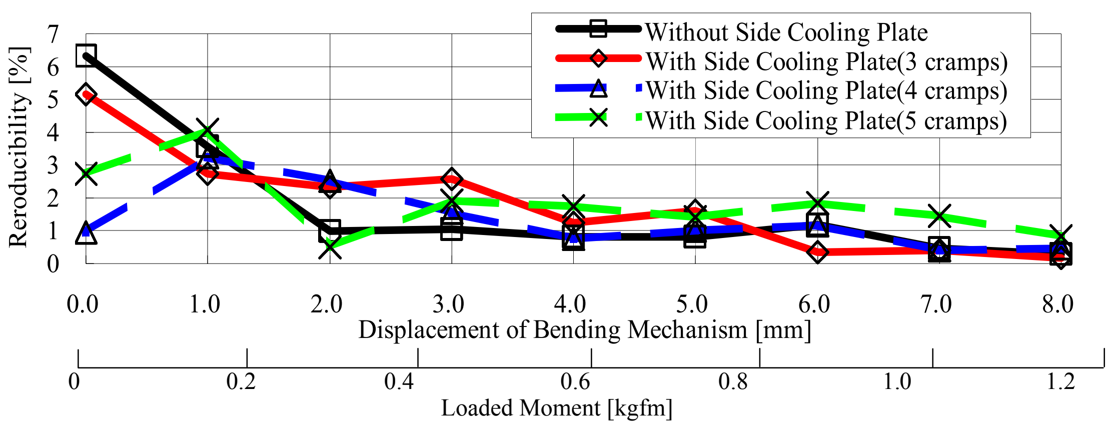

Fig. 15: Reproducibility of bending mechanism with/without side cooling plate.

When no moment was loaded, the bending radius data with cooling plates attached were found to be smaller compared to those without cooling plates. This can be explained that the mirror has a certain curvature at the initial state by the weight of the cooling plates in addition to the mirror itself. As the bending radius got smaller, however, the deviation between with and without cooling plates became small.

The friction between the mirror and the cooling plates might become stronger as the increase of the cramps to prevent the mirror from bending. However, the deviation is thought to be not so noticeable.

Although there was little relationship between the slope error and the bending force, however, the slope error was observed to get worse as increasing the number of the cramps.

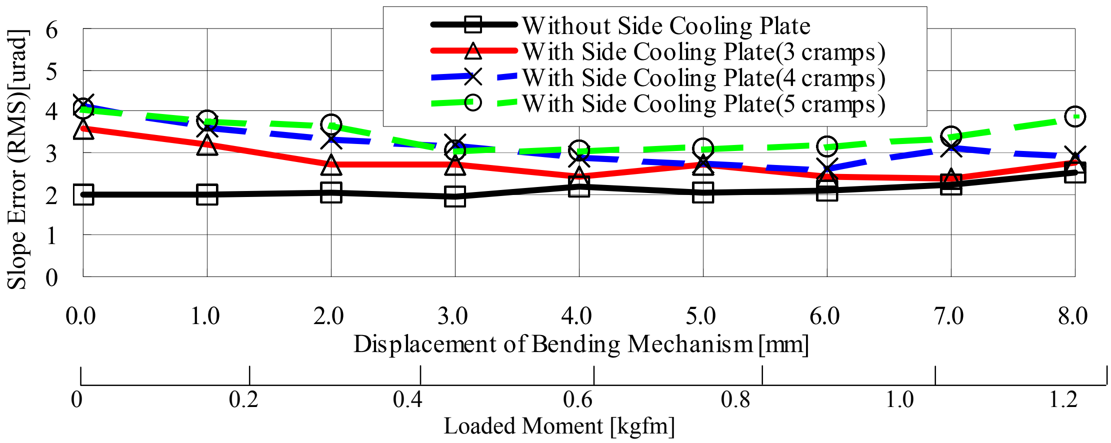

Fig. 16: Slope error (RMS) of bending mechanism with/without side cooling plate.

4. Conclusions

Although several subjects still remain to be clarified, through the present study it was shown that every important item like slope error, reproducibility and stability of the mechanically-bent-shaped mirror by Toyama's "arm method" was placed within the tolerable range for the normal application to x-ray optics. However, further studies should be performed regarding the influences of the disturbance elements upon their sensitivities.

5. Acknowledgments

This work was carried out using LTP II which was owned by Coherent X-Ray optics Laboratory in SPring-8.

6. References

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