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Note	

Microstitching interferometer and relative angle determinable stitching interferometer for half-meter-long X-ray mirror

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ABSTRACT

A surface profiler system with a high accuracy of the order of nanometers has been developed for a half-meter-long X-ray mirror. This system is based on microstitching interferometer (MSI) and relative angle determinable stitching interferometer (RADSI). Using elastic hinges and linear actuators, we designed the 5-axis- and 6-axis stages for the MSI and RADSI, respectively, for the half-meter-long X-ray mirror. A test mirror of length 0.5 m was used to measure the height accuracy (1.4 nm in rms) and lateral resolution (36 μm) of the proposed system.

Keywords: X-ray, synchrotron radiation, mirror, stitching interferometer

1. INTRODUCTION

In 3rd generation synchrotron radiation facilities, significant improvement in the quality of X-ray mirrors [1-3] has accelerated their advanced applications such as scanning X-ray microscopy by focusing the X-ray probe. Furthermore, high-quality mirrors are gaining importance in tailoring of coherent X-rays in the emerging 4th generation light sources [4]. Recently, an ultra-smooth, high-precision X-ray mirror with a height (peak-to-valley) accuracy of 1 nm was developed by the combination of both numerically controlled elastic emission machining (NC-EEM) [5] and two types of stitching interferometry, microstitching interferometry (MSI) [6] and relative angle determinable stitching interferometry (RADSI) [7]. The evaluation technique realized height accuracies of the order of sub-nanometers and lateral resolutions higher than 20μm, which are required for total-reflection mirrors for coherent hard X-rays. The Kirkpatrick-Baez focusing system [8] using the fabricated mirrors exhibited diffraction-limited focusing properties even in hard x-ray region [9]. The observed profiles were in good agreement with the optically calculated results from the surface profiles, which were measured by a combination of these interferometers.

However, the size of the mirror was restricted to 100mm×5mm, mainly due to the measuring range of MSI and RADSI. A larger mirror has a variety of potential applications in synchrotron radiation optics. Hence, we have developed a surface profiler based on MSI and RADSI for the half-meter-long mirror. The measuring area expands to 500mm×50mm. We also designed 5- and 6-axis stages for MSI and RADSI, respectively. The elastic hinges and linear actuators were adopted for achieving high stability and high precision. In order to process a large number of measurement points the speed of positioning and analysis was enhanced.

2. MICROSTITCHING INTERFEROMETER FOR HALF-METER-LONG MIRROR

An MSI for the half-meter-long mirror comprises a microscopic interferometer head, 5-axis stages, and their controllers. A photograph of the system is shown in Fig. 1. The interferometer head (ZYGO Corp., NewView 5000) has a view area of 5.76 mm × 4.32 mm with a spatial resolution of 0.036 mm. In order to maintain a stitching angle error of

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less than 1 × 10^{-7} rad, a constant focus distance of less than 1μm must be maintained while measuring the height on the entire surface of a mirror [6].The mirror is set on a two-dimensional tilt and elevation stage, which can be horizontally scanned, as shown in Fig. 2, and is automatically aligned to maintain the focus distance within a single dark fringe interval of approximately 0.15 μm. An interference fringe image is monitored and the measurements are performed in the following sequence;

(1) A captured fringe image is binarized to detect the edge.

(2) The stage is tilted to the correct slope of the mirror, which is determined by the slope of the fringe edge.

(3) The stage is elevated slightly to adjust the focus of the fringe image and to obtain the null fringe.

(4) After tuning the light intensity the surface profile is measured.

(5) The stage is horizontally driven toward the preset direction for the preset interval.

(6) Return to (1)

For the microstitching of the half-meter-long mirror more than 180 sequences are repeated. The improvements of environmental instabilities such as the vibration of the system, temperature fluctuations, and index fluctuations in the optical path are important to perform highly accurate measurements.

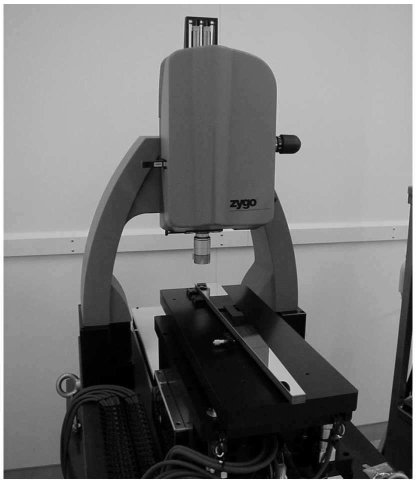

Fig. 1. Photograph of the MSI for the half-meter-long mirror. The 5-axis stage is placed under a microscopic interferometer head (Zygo Corp., NewView 5000). A test trapezoidal mirror of length 540mm is set on the stage.

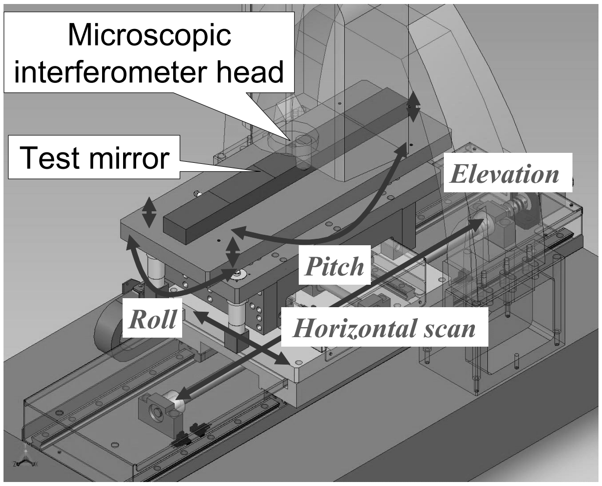

Fig. 2. Schematic view of the 5-axis stage of the MSI for the half-meter-long mirror. The stage can be tilted and elevated by three linear actuators and can be horizontally scanned by two stepper motors.

3. RELATIVE ANGLE DETERMINABLE STITCHING INTERFEROMETER FOR HALF-METER-LONG MIRROR

A RADSI provides compensation for integrated angle errors while microstitching then entire surface [6-7]. The RADSI for the half-meter-long mirror, which is shown in Fig. 3, comprises a Fizeau interferometer (Zygo Corp., GPI XP-HR) with a transmitted reference plane of diameter 200 mm, 6-axis stages, and their controllers.

A test mirror and a reference mirror of length 100mm are placed on each stage under the transmission flat of the Fizeau interferometer, as shown in Fig. 4. All stages can be moved up and down for the easy installation of mirrors. The relative stitching angles of the test mirror are determined from the tilt angles of which a flat reference is simultaneously measured with the acquisition of the surface profile in a shot, as shown in Fig.5. The tilt angles are calculated on the basis of the surface profiles of a reference without plane correction. For this purpose, the attitude control of these mirrors is important.

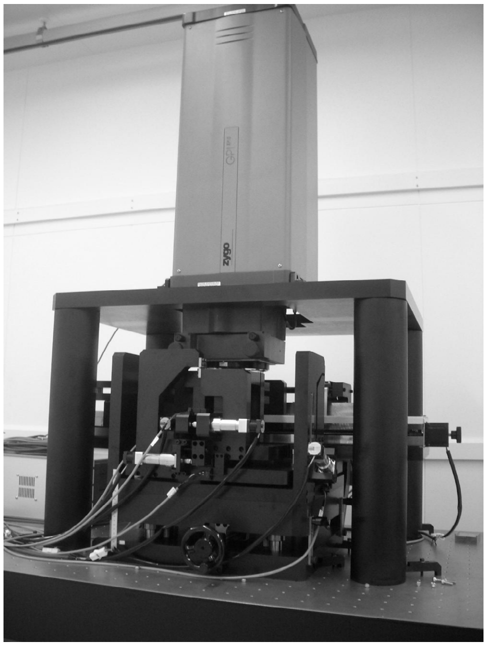

Fig. 3. Photograph of the RADSI for the half-meter-long mirror. The 6-axis stages for the half-meter-long mirror are placed under the Fizeau interferometer (Zygo Corp., GPI XP-HR) with a transmitted reference plane of diameter 200 mm, supported by four pillars on a passive damping stage.

Fig. 4. Photograph of the right-side view of the image in Fig. 3. A test mirror of length 540 mm and a reference mirror of length 100mm are placed on each stage under the Fizeau interferometer.

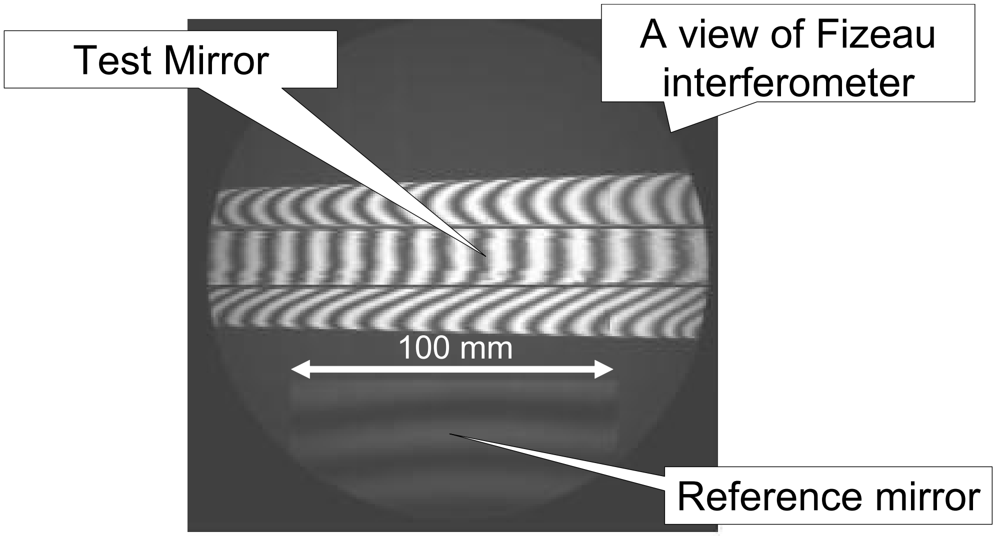

Fig. 5. Image of the interference fringes in the RADSI. The upper and lower fringes are formed on a test trapezoidal mirror and reference mirror, respectively. The polished area of the test mirror is 10-mm wide at the center of the mirror.

Figure 6 shows a schematic view of the 6-axis stage of the RADSI for the half-meter-long mirror. A reference mirror is adjusted to decrease the density of the interference fringes by independently adjusting the pitch and roll rotations of the posture of the test mirror. Both the reference (R) and test (T) mirrors are placed on the common base, which can be tilted; therefore a constant relative angle can be maintained between both the mirrors while conducting stitching measurement in one view of the Fizeau interferometer. After the acquisition of the surface profiles from one view, the test mirror is translated to measure the adjacent shots with the overlapping area independent of the posture of the reference mirror. The stages should be capable of realizing smooth and accurate motions with 0.5 m of travel and at angles up to +/–5º with resolutions higher than 1×10^{-6} rad. The elastic hinge–based mechanical design facilitates these rotations with high stability and high precision. Liner actuators within a semi-closed looped control are used for the fine angular positioning of these stages.

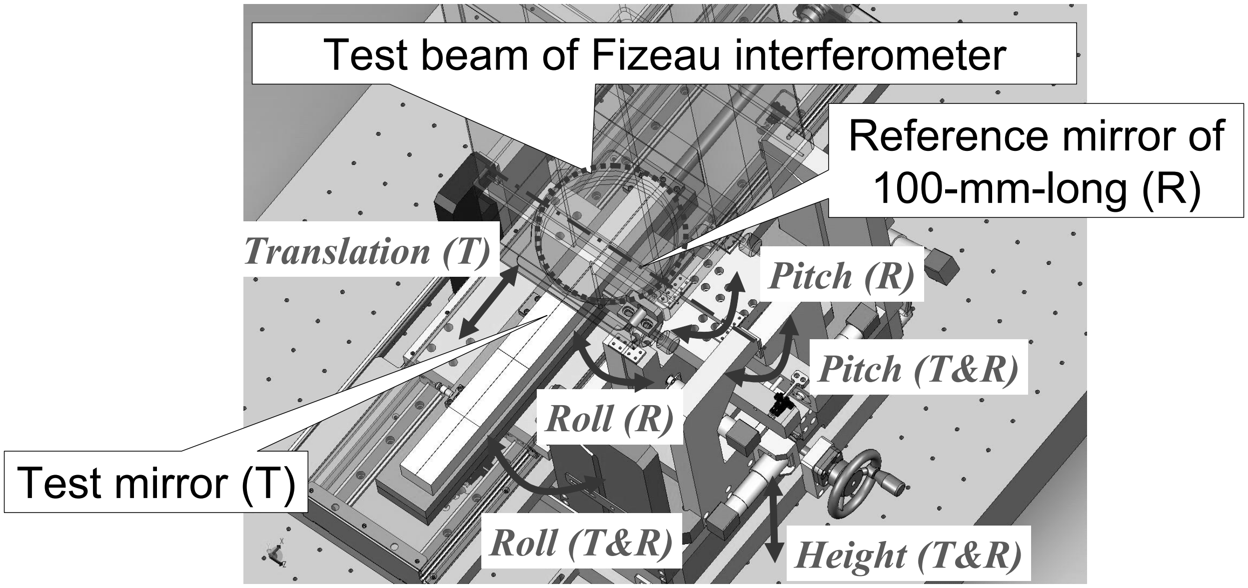

Fig. 6. Schematic view of the 6-axis stage of the RADSI for the half-meter-long mirror. A test mirror (T) can be translated in the longitudinal direction. A reference mirror (R) can be adjusted to decrease the density of the interference fringes by pitch and roll rotations. Both the mirrors (T and R) can be tilted on the same stage during the stitching measurement. The hinge–based mechanical design facilitates these rotations with high stability and high precision.

4. EVALUATION OF STITCHING INTERFEROMETERS FOR HALF-METER-LONG MIRROR

4.1 Evaluation of system errors on MSI and RADSI

In order to evaluate system errors, images of the residual height of the overlapping area between the neighboring shots in the microstitching measurement and the relative angle determinable stitching measurement are illustrated in Fig. 7 and Fig. 8, respectively. The overlapping areas in the area of each shot measured using MSI and RADSI are 5.76 mm (X) × 1.62 mm (Y) in 5.76 mm (X) × 4.32 mm (Y) and 7.2 mm (X) × 48.6 mm (Y) in 7.2 mm (X) × 99 mm (Y), respectively. Each shot was measured in the neighboring area on a 540–mm–long test mirror. Each value in the figures represents the residual height in rms. The residual height indicates the system error, including both the figure error of the reference surface and the stitching errors. The results indicate that the total measurement accuracy for a 0.5–m–long mirror is higher than 1.4 nm in rms.

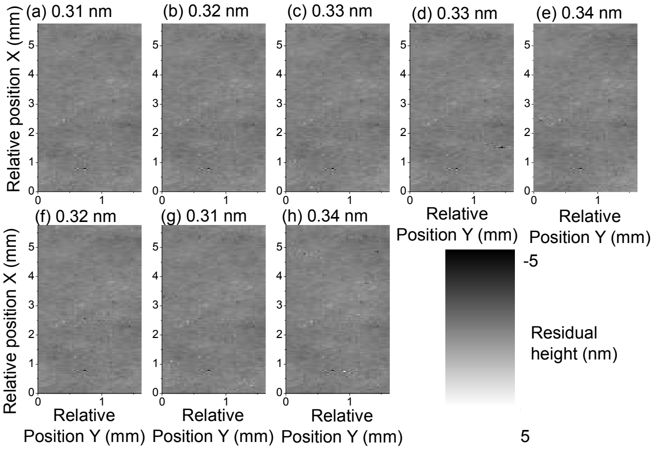

Fig. 7. The residual height of the overlapping area between the neighboring shots obtained in the microstitching measurements. Each figure shows the residual height of the overlapping area of 5.76 mm (X) × 1.62mm (Y) in each shot area of 5.76 mm (X) × 4.32 mm (Y) measured at neighboring positions. (a), (b)…, and (f) show the residual height between the 1st and 2nd, 2nd and 3rd…, and 184th and 185th, respectively. Each value in the figure represents the residual height in rms.

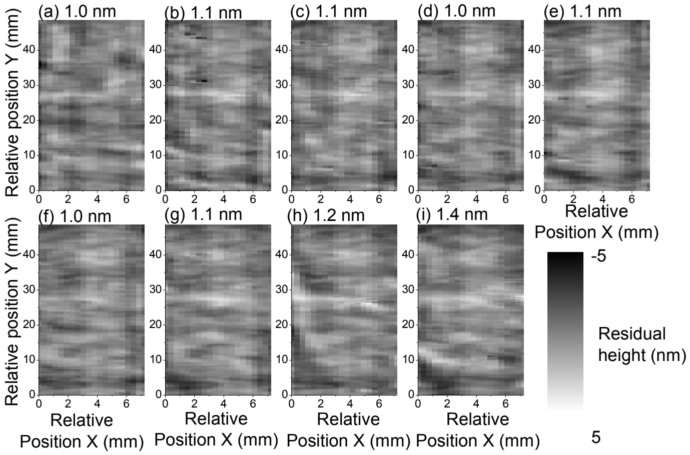

Fig. 8. The residual height on overlapping area between neighboring shots by relative angle determinable stitching measurements. Each figure shows residual height of overlapping area of 7.2 mm (X) × 48.6 mm (Y) in each shot area of 7.2 mm (X) × 99 mm (Y) measured at neighboring position. (a), (b)…(i) show the residual height between 1st and 2nd shots, 2nd and 3rd shots …, 9th and 10th shots, respectively. Each value in figure shows the residual height in r.m.s..

4.2 Result obtained for a test trapezoidal mirror of length 540 mm

A test trapezoidal mirror of length 540mm and thickness 13mm was measured using MSI and RADSI for the half–meter–long mirror. Figure 9 shows the high-pass-filtered (HPF) height profiles of the test mirror measured using MSI (dotted lines) and RADSI (solid lines). The cutoff for the HPF is 2.5 mm in both the profiles. The distinguishable shapes are in agreement with the height profiles measured using MSI and RADSI near both the edges of the mirror, as shown in Figs. 9 (b) and (c). This indicates the successful coordination with pixels in each interferometer. As a result, the height map of the test mirror is incorporated in both the profiles of MSI and RADSI as illustrated in Fig. 10. Figures 10 (b) and (c) show the longitudinal and lateral profiles at the center of the mirror, respectively.

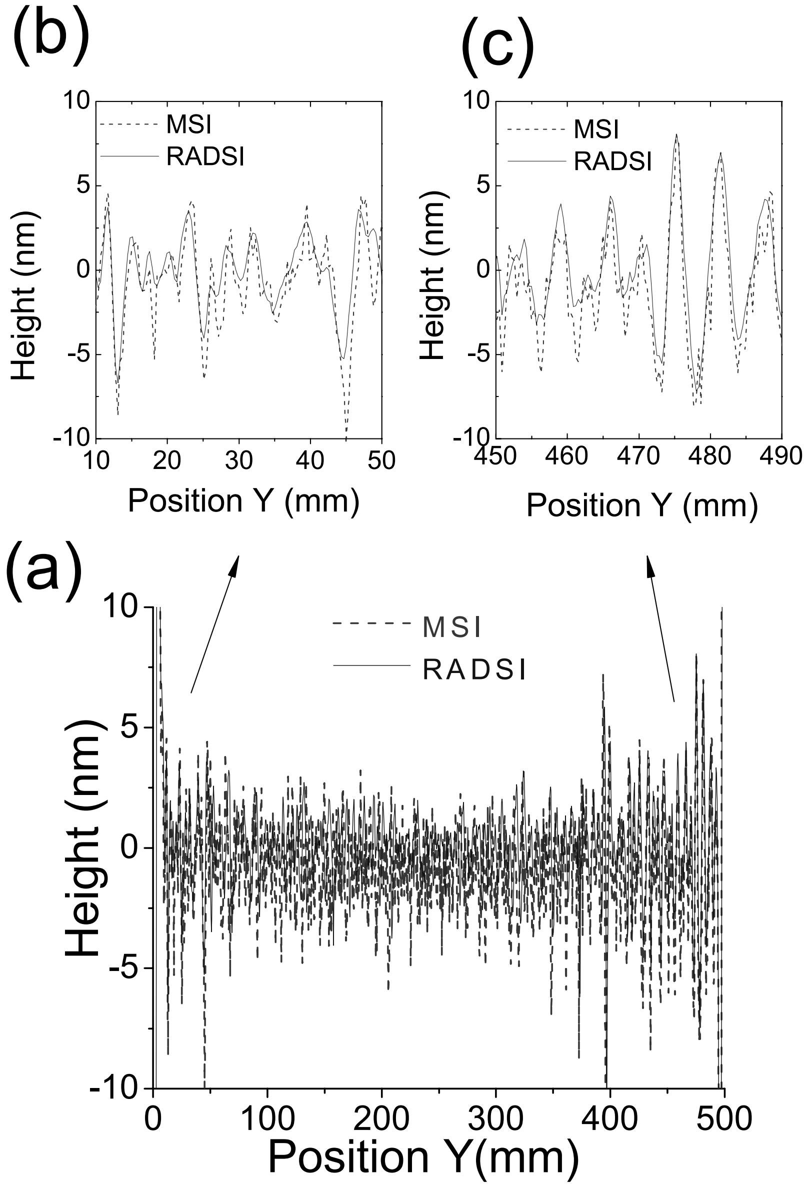

Fig. 9. High-pass-filtered (HPF) height profiles at the center of the 540-mm-long test mirror measured using MSI (dotted lines) and RADSI (solid lines). The cutoff for the HPF is 2.5 mm in both the profiles. Further, (b) and (c) show the magnified views of the left and right sides in (a), respectively.

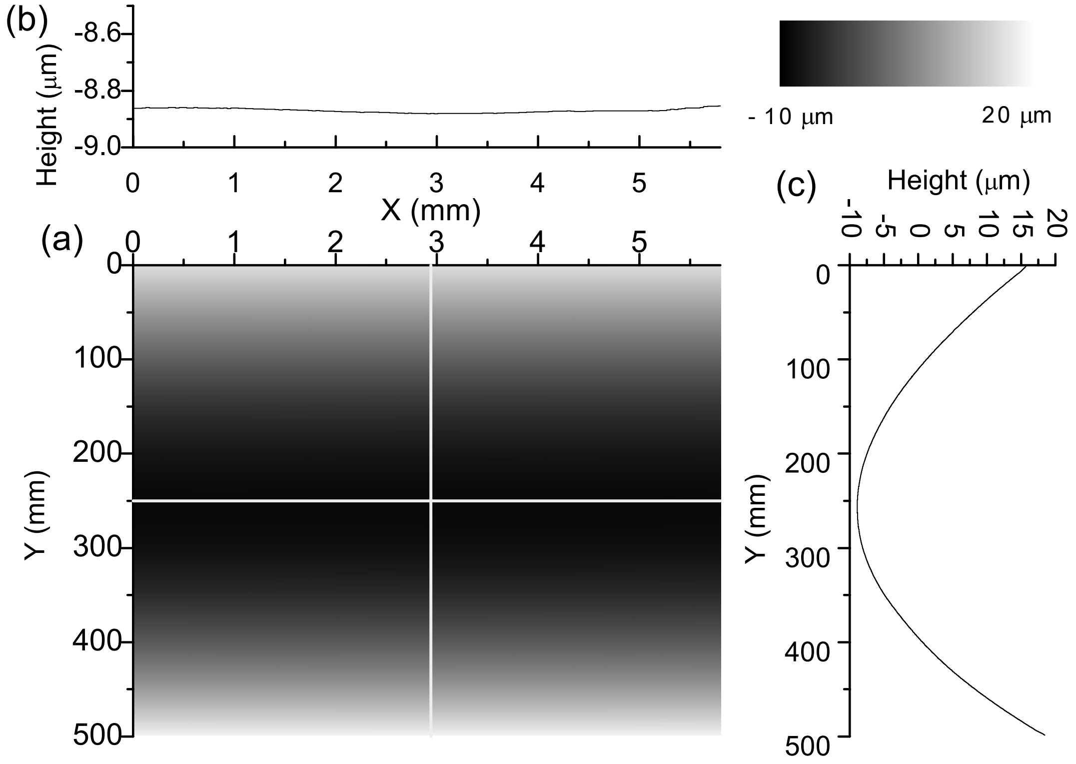

Fig. 10. (a) Height map of the test trapezoidal mirror of length 540 mm incorporated in the results of both MSI and RADSI. Further, (b) and (c) show the longitudinal and lateral profiles at the center of the mirror, respectively.

5. SUMMARY

We developed an MSI and RADSI for a half-meter-long X-ray mirror. The available area of measurement expands to 500 mm × 50 mm. Further, 5- and 6-axis stages were designed for MSI and RADSI, respectively. Elastic hinges and linear actuators were adopted to realize high stability and high precision. The developed interferometers demonstrated the ability to measure the surface profiles of a 0.5-m-long mirror with accuracy higher than 1.4 nm rms.

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