Nanometer Profile Measurement of Large Aspheric Optical Surface by Scanning Deflectometry with Rotation Devices - Development of Three Dimensional Measuring Facility and Experiment

Muzheng Xiao, Satomi Jujo, Satoru Takahashi, Kiyoshi Takamasu
The University of Tokyo, Japan

xiaomuzheng@nanolab.t.u-tokyo.ac.jp

Abstract

Large aspheric optical surfaces with high accuracy are widely used in huge telescopes and large X-ray facilities. Profile measurement methods with uncertainty less than one hundred nanometers are strongly required for those accurate surfaces. Scanning deflectometry methods have been used for flatness measurement with sub-nanometer uncertainty. However, the limited measuring range makes it unavailable for optical surface with large angle change. In this paper, we have proposed new methods for large aspheric optical surfaces with large angle change. Rotation devices are used for the enlargement of autocollimator measuring range and methods are proposed for the elimination of pitch error of linear scanning stage. Then a three dimensional measuring machine based on pitch angle pre-measurement method is developed for axial symmetric optical surface measurement. Pitch angle of linear stage is measured before the measurement of the sample surfaces and used for compensation to the angle data of sample surfaces. The repeatability of profile measurement result is less than 30 nanometres.

1. Principle

Large aspheric optical surfaces are widely used in ELTs (extremely large telescope) and X-ray facilities [1] [2]. Many interferometric methods are developed for aspheric surface measurement. However, there is still much problem left for them. For example, it is necessary to use reference surfaces with extremely high accuracy using interferometric methods. Standard aspheric optical wavefront is also difficult to produce. The shape of measurable aspheric surfaces is limited using interferometric methods.

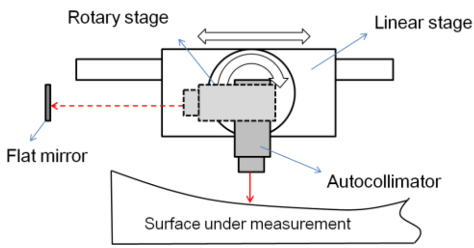

Fig. 1 Principle of improved scanning deflectometry method

In this paper, we have proposed a new method based on scanning deflectometry method as shown in Fig. 1. An autocollimator is fixed on a linear stage to scan the angle change of the sample surface normal. For the enlargement of the autocollimator measuring range, a motorized rotary stage is fixed between the linear stage and the autocollimator. When the detected angle from autocollimator is going to exceed the measuring range of the autocollimator, the rotary stage turns a certain angle to fit the sample surface normal. Then the detected angle returns into the measuring range. Using this rotation translation, the measuring range of the autocollimator is enlarged. A flat mirror is fixed vertically to the linear stage scanning direction. Before the measurement of sample surface, the autocollimator is turned parallel to the scanning direction and by the flat mirror reflection and the angle change is measured while the linear stage scans. The pitch error of the linear stage is then measured. After the scanning of sample surface angle change, the pitch angle measured is used for compensation to the measured angle data.

2. Data processing methods

The rotation angle of rotary stage is needed for the angle data connection and the according position calculation. In this paper, the rotation angle detection is calculated from the autocollimator measured angle.

Because the rotated angle is supposed to be an angle on the order of several hundreds of micro-radians, we can assume the circle arc length is the same as the circle arc length. As a result, the relationship between the rotation angle and detected angle change by autocollimator is calculated as Eq. 1[3].

$$\alpha = \frac{R}{R-D}\beta \tag{1}$$

Where, α is the autocollimator rotated angle and β is the detected angle change by autocollimator between the angle measured before the rotation and the angle measured after the rotation. R is the curvature radius of the surface in the rotated part. And D is the distance between rotation center of rotary stage and sample surface. Because of the rotation of the autocollimator, the angle data detected is interrupted. To calculate the profile data, the angle data should be connected first. The connected angel is calculated by the sum of raw angle data, the pitch angle data of linear stage and rotated angle data with Eq. 2.

$$A_i = \sum a_i + \sum \alpha_j + A_{pitch} \tag{2}$$

Where, A_i is the connected angle data; a_i is raw angle data; α_j is the rotated angle data; A_{pitch} is the pitch angle data of linear stage. Finally, after making numerical integration of connected angle data, the profile data is calculated.

3. Experiment

As shown in Fig. 2, a three dimensional measurement experimental setup is built. We did experiments to measure a concave mirror. The linear stage scans the centre of the mirror in 40 mm length and repeat scanning after the rotary stage turning 10 arc-deg. At last the whole mirror surface is scanned by 36 lines. And the measured profile data is shown in Fig. 3(a). The repeated experiment is done for 5 times. And Fig. 3(b) shows the standard deviation on rotation stage on the position of zero arc-deg and 180 arc-deg, and the position of 90 arc-deg and 270 arc-deg is shown in Fig. 3(c).

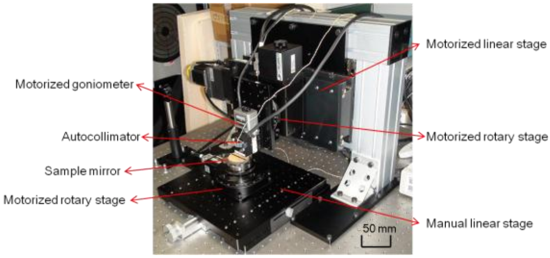

Fig. 2 Three dimensional measuring facility for large aspheric optical surface

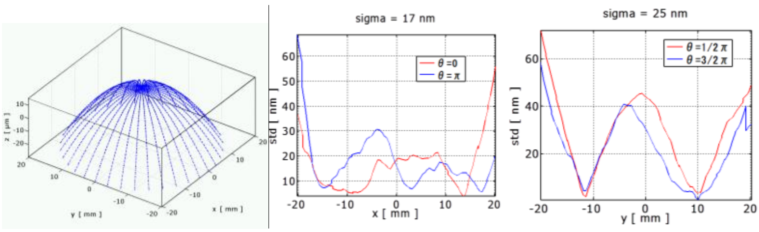

Fig. 3 Measurement result of a concave mirror. (a) Profile result with 36 lines.
(b) Standard deviation on the position of zero arc-deg and 180 arc-deg.
(c) Standard deviation on the position of 90 arc-deg and 270 arc-deg

From the repeated experiment result, we know that the average of standard deviation is less than 30 nanometers. The measured result will be compared with interferometric method in future work.

References:

[1] E D. The European Very Large Telescope (VLT) project, Endeavour. 11 (1987) 149-155.
[2] Y Senba, H Kishimoto, H Ohashi, H Yumoto, T Zeschke, F Siewert, et al. Upgrade of long trace profiler for characterization of high-precision X-ray mirrors at SPring-8, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment. 616 (2010) 237-240.
[3] M Xiao, S Jujo, S Takahashi, K Takamasu. Nanometer profile measurement of large aspheric optical surface by scanning deflectometry with rotatable devices: Uncertainty propagation analysis and experiments, Precis Eng. 36 (2012) 91-96.