euspen's 21st International Conference & Exhibition, Copenhagen, DK, June 2021
www.euspen.eu

Measurement of aspheric mirror by non-contact three dimensional nano-profiler using normal vector tracing method

Mikiya Ikuchi[1], Kota Hashimoto[1], Takeshi Ashizawa[2], and Katsuyoshi Endo[2]

[1]Department of Precision Science and Technology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan
[2]Research Center for Ultra-Precision Science and Technology, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan

m-ikuchi@div1.upst.eng.osaka-u.ac.jp

Abstract
Recently, optical elements with a free-form surface have been required in various fields. To manufacture such optical elements, a measurement method is required that can measure the absolute three-dimensional surface profile of such optical elements within nanometer precision. Therefore, we are developing non-contact three dimensional nano-profiler using normal vector tracing method. In this study, we measured an aspheric mirror surface by this method and estimated the uncertainty of measurement result.

Keywords: Metrology, Three-dimensional Profiler, Form error, Free-form, Optical element, Uncertainty, Absolute measurement

1. Introduction

Recently, optical elements having a free-form surface has been required in various fields such as semiconductor production technology, etc[1]. To produce such optical elements, a measurement method is required that can measure the absolute three-dimensional surface profile of such optical elements within nanometer precision. As conventional method for the surface form measurement, coordinate-measuring-machine (CMM) and phase shift interferometer are mainly used. However, it is difficult to measure the absolute three-dimensional surface form of free-form optical elements by phase shift interferometer because it requires a reference surface[2]. Also, high precision CMM needs metrology frames[3]. This means that it is difficult to measure such optical element surfaces within nanometer precision, without contact, and with traceability.

Therefore, we are developing the non-contact three dimensional nano-profiler using normal vector tracing method. This method can measure the absolute three-dimensional surface profile without any reference surfaces or metrology frames. In this study, we measured aspheric mirror by this method and estimated the uncertainty under several assumption.

2. Measurement principle

In this method, the sample surface normal vector is detected based on using the straightness of the laser and the highly accurate angle detection of the goniometer [4, 5]. The normal vector is equivalent to the slope of the sample surface. So, the three- dimensional surface form of the sample surface can be obtained by integrating the slope of the sample surface. Fig. 1 shows the schematic diagram of the non-contact three dimensional nano-profiler which we have developed. The non-contact three dimensional nano-profiler consists of an optical unit and a sample unit. The optical unit has two rotation stages, one linear stage, and an optical head. On the optical head, a laser light source and a quadrant photodiode (QPD) estimated detector, are mounted with a polarizing beam splitter (PBS). On the other hand, the sample unit has two rotation stages and two linear stages and a sample holder. When measuring a sample, the laser is projected on each point of the sample surface. At that time, assuming that the sample has the designed form, the five axes are numerically controlled so that the incident beam is normal to sample surface, and optical pass length is constant. If the sample has designed form, the reflected light will return to the center of the QPD. However, the actual reflected light deviates from the center of the QPD because the sample has different surface from designed form due to the form error. So, this deviation is detected as a QPD signal. The normal vector and coordinates at each point on the sample surface can be obtained from QPD signals and the outputs of the encoder for each axis. The normal vector is equivalent to slope of sample surface. So, we obtained sample form by integrating slope of each point. In this way, it is possible to measure the absolute three-dimensional surface profile without a reference surface [6].

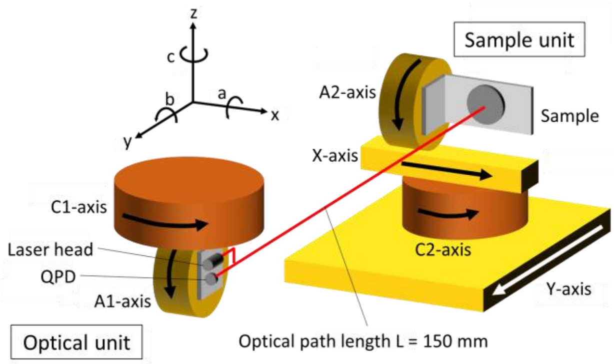

Figure. 1 The non-contact three dimensional nano-profiler

3. Measurement of aspheric mirror

In this study, we measured an aspheric mirror ten times by raster-scanning the laser horizontally in a range of 20.1 mm x 20.1 mm with a scan pitch of 0.1 mm. Fig. 2 shows the average of form error for ten measurements. Concentric form error is found from Fig. 2. This form error is considered to be caused by the cutting process during manufacturing sample. The form error is 29.8 nm PV, and 5.0 nm RMS. Next, we evaluated the repeatability of the form measurements, as shown in Fig. 3 The repeatability (standard deviation) is 0.271 nm($\sigma_{average}$), and we achieved the goal of less than 1 nm.

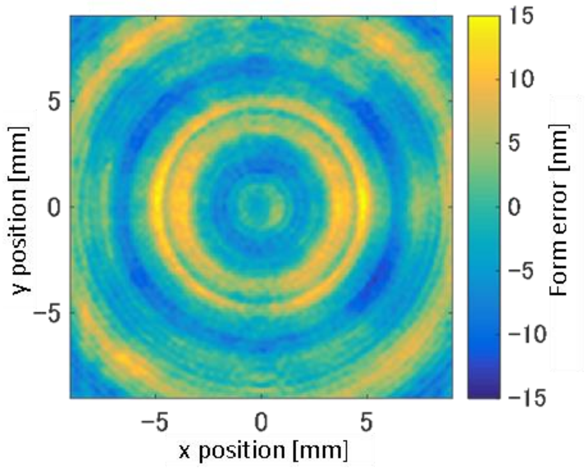

Figure. 2 Form error (average of ten measurements)

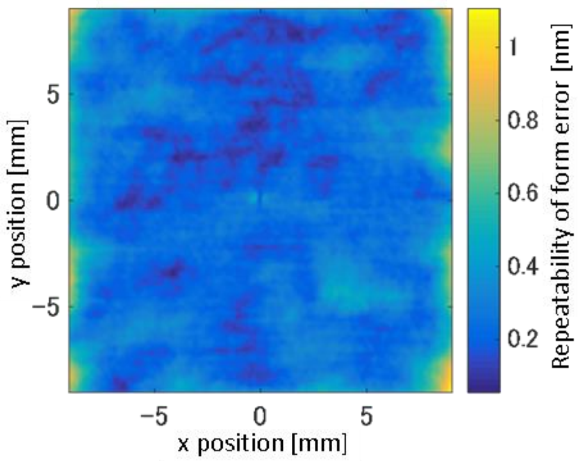

Figure.3 Repeatability of the form error

4. Estimating uncertainty

Finally, we estimated the uncertainty of this measurement. In this method, we can calculate the uncertainty of measurement by simulating the influence of all error factors on the measurement result and measuring the amount of error. Table. 1 shows the error budget table which shows uncertainty due to each error factor and combined uncertainty. In this report, the value 2σ when coverage factor k=2 is defined the measurement uncertainty. Repeatability is evaluated by experiments (see Figure 3). Systematic error factors include assembly error, motion error, and encoder reading error. The assembly error was estimated from the results of previous experiments and goal value of uncertainty of optical lengh measurement. The motion error was estimated from the measured values. Encoder reading error was calculated from the measurement value[7]. As a result, the uncertainty of this measurement was estimated to be 4.8 nm, and we may achieve the goal of less than 10 nm.

Table 1 The error budget table

Error factor	Std. Uncertainty
Repeatability	0.271 nm
Systematic error	
Assembly error	1.22 nm
Motion error	2.03 nm
Encoder reading error	0.415 nm
Combined Uncertainty (2σ)	4.8 nm

5. Conclusion

In this study, we measured aspheric mirror, and estimated uncertainty of this measurement. The form error is 29.8 nm PV, and 5.0 nm RMS. The repeatability (standard deviation) is 0.271 nm($\sigma_{average}$), and we achieved the goal of less than 1 nm. Also, the uncertainty of this measurement was estimated to be 4.8 nm, and it was shown that we may achieve the goal of less than 10 nm.

References

[1] Zhen Cao, Yanqiu Li and Fei Liu 2013 Opt. Eng. **52(12)** 125102
[2] Jeon J W and Joo K N 2019 *Sensors* **19(23)** 5298
[3] Huang Q, Wu K, Wang C, Li R, Fan K C, and Fei Y 2016 *Appl. Sci.* **6(4)** 97
[4] Usuki K, Kitayama T, Matsumura H, Kojima T, Uchikoshi J, Higashi Y and Endo K 2013 *Nanoscale Res. Lett.* **8** 231
[5] Kudo R, Kitayama T, Tokuta Y, Shiraji H, Nakano M, Yamamura K, and Endo K 2017 *Opt. Lasers Eng.* **98** 159-162
[6] Kitayama T, Tonaru D, Matsumura H, Uchikoshi J, Higashi Y, and Endo K 2012 *Key Eng. Mater.* **516** 606-611
[7] Hashimoto K, Ashizawa T, Ikuchi M, and Endo K 2020 *SPIE Proceedings* **11492** 1149206