Non-contact absolute internal distance measurement between two mirrors by using a low-coherence tandem interferometer with optical prism mechanism (1st Report)

The University of Tokyo Agustinus WINARNO, Hirokazu MATSUMOTO, Satoru TAKASHASHI, Kiyoshi TAKAMASU
Osaka University Takao KITAYAMA, Ryota KUDO, Katsuyoshi ENDO

High-accuracy free form surface and aspherical mirrors are significant in many fields such as lithography applications, digital camera, etc.

A novel profiler using normal vector tracing method can measure the aspherical mirrors without the use of a reference surface. To achieve a high accuracy of the measurement, it is highly demanded to precisely measure the internal distance between a mirror to be measured and a quadrant photodiode (QPD).

This paper is the first report of a new optical measurement method for measuring internal distance between two plane mirrors by using a low-coherence tandem interferometer that will be applied for nanoprofiler. In order to observe interference fringes, the optical path difference of the scanning interferometer is adjusted to be the same with the optical path of the second interferometer, which is the internal distance between two mirrors. The internal distance of 100 mm has been measured within a standard deviation of 60 nm.

1. Introduction

High-accuracy free form surface and aspherical mirrors are highly demanded in the optical projection systems for lithography application. A novel nanoprofiler using normal vector tracing method that can measure the aspherical mirrors without the use of a reference surface has been proposed [1]. To achieve a better accuracy of the measurement by evaluating the assembly errors, it is highly demanded to precisely measure the internal distance between a sample surface and a quadrant photodiode (QPD) by using an absolute measurement method.

A new optical measurement method for measuring internal distance between two plane mirrors by using a low-coherence tandem interferometer that will be applied for nanoprofiler is proposed. A tandem low-coherence interferometric method is adopted in this study [2,3]. Scanning and probing interferometers were connected by a single-mode optical fiber to perform tandem low-coherence interferometer. As a result, the internal distance between two mirrors could be remotely measured.

2. Principle

The main characteristic of low-coherence tandem interferometer is that interference fringes can be observed only when the optical path differences of probing and scanning interferometers are equal. Therefore, the Michelson-type scanning interferometer with Super Luminescent-light Diode source (SLD; ASLD-CWDM-3-FA; Amonics), which functions as an optical path compensation interferometer, was set up to generate low-coherence interference fringes. A schematic of experimental setup is given in Fig. 1. The scanning interferometer is equipped with He-Ne length measuring system (ML100; Renishaw) for measuring distance between two low-coherence fringe patterns. Low-coherence light with a center wavelength of 1544 nm is first introduced to the scanning interferometer. After passing through the single mode optical fiber, a beam from the scanning interferometer is introduced to beam splitter (RM1) which functions as a reference mirror. One part of the beam is reflected back into the circulator (CIR2) and another part of beam is divided in to two by prism (BS4). The two parts of the divided beam are thus directed to the mirror M1 and M2. Finally, a photo-detector (2001; New Focus) collects the beams reflected from the mirrors and reference mirror. The optical paths in probing interferometer are shown in Fig.2. In order to measure the internal distance between two mirrors (L), length of L1 and L2 are measured.

\[ L_1 = 2(A_1 + A_2 + B_1 + B_2) \] .................................(1)

\[ L_2 = 2(A_1 + A_2 + 2B_1 + 2B_2 + C_1 + C_2) \] .................................(2)

\[ L_1 - L_2 = 2(B_1 + C_1 + B_2 + C_2) \] .................................(3)

The internal distance before correction is expressed by Eq. (4).

\[ (L_2 - L_1)/2 = B_1 + C_1 + B_2 + C_2 \] .................................(4)

A correction value C is added in to Eq. 4 as a correction due to the refractive index difference between air and prism. Therefore, the length of L after correction is express in Eq.5.

\[ L_1 + (L_1 - L_2)/2 = B_1 + C_1 + B_2 + C_2 + C \] .................................(5)

Fig. 1 Schematic diagram of experimental setup
The correction value C is calculated by measuring a gauge block as reference length. Because $L_1$ and $L_2$ are known values and L is equal to the length of gauge block, therefore C can be calculated by using Eq. (5).

$$L = \frac{(L_2 - L_1)}{2} + C$$  

The excess fraction method has been applied for measuring the length of gauge blocks instead of internal distance between two mirrors. We considered that the error of measurement could be easily evaluated by measuring a gauge block before performing an actual application. Two short gauge blocks were wrung on measuring surfaces of the gauge block (grade 1) to be measured in order to make internal distance as shown in Fig.2. At first, a 25 mm of gauge block was set in the probing interferometer. Pair of low-coherence interference fringes that correspond to the length of $2L_1$ or $2L_2$ are generated when the length of optical interference between two interferometers is equal, that is $2L_1$ or $2L_2$. Therefore, a half of the length between two fringe patterns is equal to $L_1$ or $L_2$ that is precisely measured by the He-Ne length measuring system. Because L is equal to the length of the gauge block, that is 25 mm, the correction value C can be calculated by using Eq.5. Without changing the setting, the 100 mm gauge block has been measured. The excess fraction method has been applied for measuring the length of the gauge block[4]. The experiment was performed in the air-uncontrolled experimental room. The temperature, humidity and pressure are 21.7 °C, 31 %, 1017.2 hPa, respectively.

Result of preliminary experiment is shown in Table 1. The result in Table 1 shows that the preliminary experiments achieved standard deviation of measurement better than 60 nm. The average value of 100 mm gauge block is 202 nm from the nominal value. The average value is within the tolerance of deviation length ($\pm 0.8 \mu$m). Accuracy of temperature measurement gives contribution to the uncertainty of thermal expansion coefficient and temperature difference from standard temperature (20 °C). Uncertainty of temperature measurement at 21.7 °C is estimated to be 111 nm [3].

Table 1. Result of preliminary experiment (Unit: mm)

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<tr>
<th>Nominal Size</th>
<th>25 mm</th>
<th>100 mm</th>
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<td>100.000268 100.000268</td>
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Standard deviation 0.000054 0.000038

4. Conclusion and future works

Experiment on a new optical measurement method for measuring internal distance between two plane mirrors has been performed. We demonstrated a measurement of 25 mm and 100 mm gauge blocks by using the proposed method with standard deviation of 60 nm. The result shows that the proposed method is reliable and this technique can be applied for measuring the internal distance between a mirror to be measured and a QPD for nanoprobe. For improving the measurement accuracy, some improvements are considered such as replacing the prism and measuring a gauge block with zero thermal expansion coefficients as a reference length.

5. Acknowledgement

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6. References