Roughness Analysis Method of Polarization Lateral Shearing Interferometry

Hyo Mi Park[1], Luke D. Mayer[2], Daewook Kim[2] and Ki-Nam Joo[1,#]

1 Department of Photonic Engineering, Chosun University, 10, Chosundae 1-gil, Dong-gu, Gwangju, 61452, South Korea
2 James Wyant College of Optical Sciences, University of Arizona, 1630 E. University Blvd, Tucson, Arizona, 85721, USA
Corresponding Author / Email: knjoo@chosun.ac.kr, TEL: +82-62-230-7549

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In this investigation, we propose a snapshot roughness measurement method based on the measurement result of a polarization lateral shearing interferometer. The proposed method can calculate various roughness parameters from a sheared interferogram without any sophisticated surface reconstruction algorithms. In addition, a compact polarization lateral shearing unit with a polarization camera is designed to simultaneously obtain four phase-shifted interferograms by a single acquisition. To generate two laterally-sheared wavefronts, we use a polarization grating and a flat mirror, which can be adaptable to the typical imaging system. Moreover, it is very insensitive to vibration because it measures the interference signal generated based on self-interference and analyzes the roughness of the single image. The measured results were compared in the experiments with those of a white light scanning interferometer, and the proposed roughness measurement method was experimentally verified.

NOMENCLATURE

s = lateral shearing amount
ΔW_x = the surface of gradient vectors at every interval of s along x-direction
W_s = the partially integrated surface map
X_k = the k-th surface column vector

1. Introduction

Traditionally, surface roughness has been measured by a contact stylus probe to obtain the line profile of the surface [1]. By defining the arithmetic mean roughness (Ra), the root mean square (RMS) roughness (Rq), the peak to valley roughness (Rz), etc., the form and the waviness of the line profile are removed, and the parameters are calculated to characterize the surface. However, the contact method can damage the surface and requires a long measurement time to measure the roughness of a surface. On the other hand, optical techniques such as phase-shifting interferometry, coherence scanning interferometry, and confocal microscopy, which can obtain the surface profile without lateral scanning have been adopted in roughness measurements to estimate the surface roughness parameters [2]. Because most optical techniques depend on axial scanning to obtain the surface profile, however, they are sensitive to environmental conditions.

In this investigation, we propose an attractive snapshot roughness measurement method based on the measurement result of a lateral shearing interferometer. The proposed method can calculate roughness parameters from a sheared interferogram without sophisticated surface reconstruction algorithms.

2. Principle

As shown in Fig. 1, the lateral shearing interferometer (LSI) in this investigation consists of two polarization gratings (PG) to generate two laterally-sheared wavefronts and a polarization camera (PCMOS) to simultaneously obtain four phase-shifted interferograms from a single image [3]. Then, it can immediately obtain the wavefront gradient map to be used for the roughness calculation.

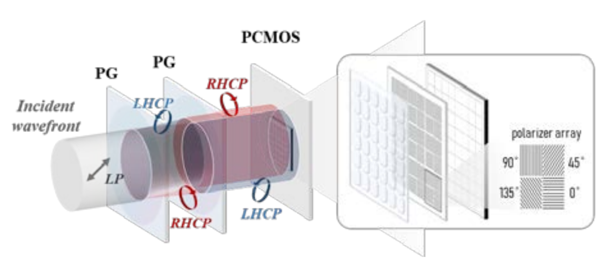

Fig. 1 Optical configuration of the polarization lateral shearing interferometry

Because the lateral shearing interferogram is based on the difference between two laterally shared surface heights, in fact, the surface height can be partially reconstructed, which leads to the roughness parameter calculation. As shown in Fig. 2, ΔW_x measured by LSI indicates the height differences between the original surface column vectors (X_k) along with the lateral shearing amount of s along the x-direction and can be expressed as a matrix form of

$$\Delta W_x = [(X_{s+1} - X_1) \ \dots \ (X_{2s+1} - X_{s+1}) \ \dots \ (X_{3s+1} - X_{2s+1}) \ \dots] \quad (1)$$

When only the results of the surface gradient vectors (X_{k+s}-X_k) at every interval of s are selected and accumulated as shown in Fig. 2, then, the surface (W_s) at the interval of s can be partially restored as

$$W_s = [(X_{s+1} - X_1) \ (X_{2s+1} - X_1) \ (X_{3s+1} - X_1) \ \dots] \quad (2)$$

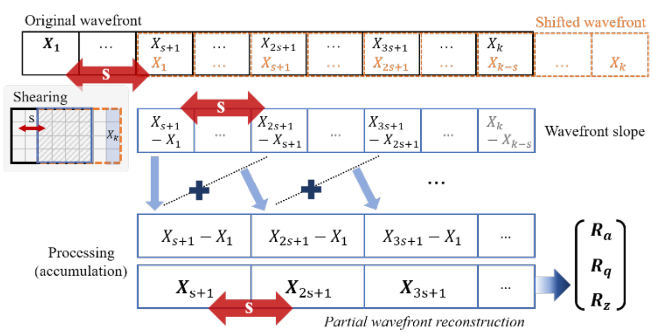

Fig. 2 Partial wavefront reconstruction by using a wavefront slope in the x-direction

Subsequently, the roughness parameters such as R_a, R_q, and R_z, etc. can be calculated from the reconstructed surface if the effect of X_1 can be negligible compared to the roughness values. Theoretically, the whole surface cannot be fully reconstructed owing to the unknown first column vector (X_1), but every horizontal line profile with the interval of s can be obtained as shown in Fig. 2 because the common X_1 values can be removed at every horizontal line. Even though this partial integration method cannot reconstruct the original surface and calculate the surface roughness parameters, therefore, it can provide lots of roughness parameter sets for lines at once, and their mean values can be equivalent to the surface roughness parameters.

3. Experimental results

The snapshot roughness measurement system was constructed, to validate the performances of the roughness analysis method. In addition, to verify the proposed roughness analysis method, the same specimens were measured with a white light scanning interferometer (WLSI) for comparison. Figure 3 shows the results of a flat mirror and the roughness standard specimens with R_a =20 nm and R_a =30 nm for each system. The roughness parameters such as R_a, R_q, and R_z obtained by the proposed methods were very close to the counterparts of the WLSI. The R_a values from the proposed method and the WLSI were also matched to the specifications of the roughness standards. To estimate the repeatability of the sensor, on the other hand, 10 consecutive measurements were implemented, and their standard deviations were calculated. As a result, the repeatability for every parameter was less than 0.1 nm.

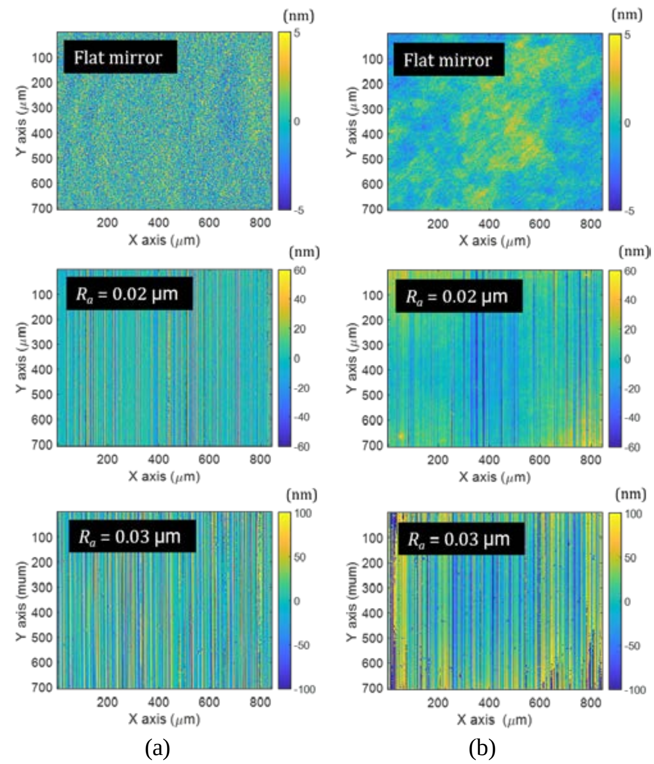

Fig. 3 (a) Surface gradient maps obtained by LSI and (b) surface measured by a white light scanning interferometer with a flat mirror, roughness standard specimens

4. Conclusions

We proposed an interesting snapshot roughness measurement method based on the measurement result of a lateral shearing interferometer in this investigation. By the polarization nature of the polarization grating, a polarization camera can directly obtain the phase map with two orthogonally polarized wavefronts, which are laterally sheared. The proposed method can simply calculate roughness parameters from a sheared interferogram. The measured results were compared in the experiments with those of a white light scanning interferometer, and the proposed roughness measurement method was experimentally verified.

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