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Surface figure measurements using geometric phase shearing interferometer

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Abstract
In this investigation, we propose a simple radial shearing interferometer using geometric phase lenses. We focus on the analytic approach for surface figure measurements based on the shearing interferometry using the properties of GPLs, and the system instrumentation and characterization with theoretical and experimental concerns. The proposed interferometer in this investigation consists of GPLs to generate two radially-sheared wavefronts and a polarization pixelated camera to simultaneously obtain four phase-shifted interferograms from a single image. In the experiments, the measured results were compared with those of a conventional method, and the proposed interferometer was experimentally verified.

Keywords: geometric phase lens, radial shearing interferometer, wavefront sensing, wavefront reconstruction

1. Introduction

A radial shearing interferometer (RSI) has the benefit to measure the surface figure of the specimen with a single radially-sheared interferogram. Especially, a cyclic radial shearing interferometer (CRSI) has the advantages of common paths between two sheared beams, the immunity of vibrations and high system stability [1]. However, RSI has the following restrictions to be applied for measuring various surfaces. First, the radial shearing ratio is almost fixed without any significant optical configuration change such as the replacement of optical components and the use of a sophisticated zoom lens system [2]. The second limitation of RSI is that the optical configuration is quite bulky and complicated [1,2]. Furthermore, the snapshot measurement is needed to observe the surface figures in real time manufacturing process.

In this investigation, we propose a simple radial shearing interferometer using a geometric phase lens (GPL) pair. Previously, a geometric phase optical component has been introduced to be applied in interferometry, but it only provided the theoretical basics without the further considerations related to surface figure measurements and the characterization of the method [3]. We focus on the analytic approach for surface figure metrology based on the properties of the GPL, and the system instrumentation and characterization with theoretical and experimental concerns.

2. Principle

The RSI in this investigation consists of a GPL pair to generate two radially-sheared wavefronts and a polarization pixelated camera (PCMOS) to simultaneously obtain four phase-shifted interferograms from a single image as shown in Fig. 1. An arbitrary wavefront corresponding to the surface figure of the specimen is incident to the radial shearing part, which uses a GPL pair, and two radially-sheared wavefronts are generated. Typically, a collimated right-handed circular polarized (*RHP*) beam is focused by a single GPL, and its polarization status is converted into left-handed circular polarized (*LHP*) while it is vice versa for an *LHP* beam. When a collimated linearly polarized (*LP*) beam is incident to the GPL, therefore, it can be divided into two beams; a focused beam and its conjugated diverging beam as shown in Fig. 2(a). If another identical GPL is used again, furthermore, both of the focused and the diverging beams can be converted into semi-collimated beams, which are radially sheared as shown in Fig. 2(b).

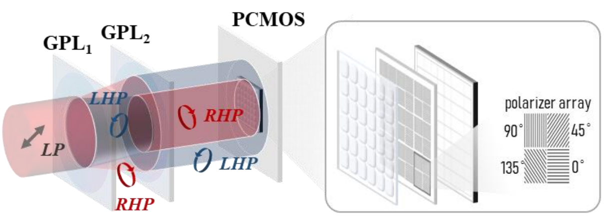

Figure 1. Schematic of a radial shearing interferometer based on a geometric phase lens pair; GPL, geometric phase lens; PCMOS, polarization pixelated camera; LP, linear polarization; *LHP*, left-handed circular polarized; *RHP*, right-handed circular polarized. The inset describes an inner polarizer array of the PCMOS.

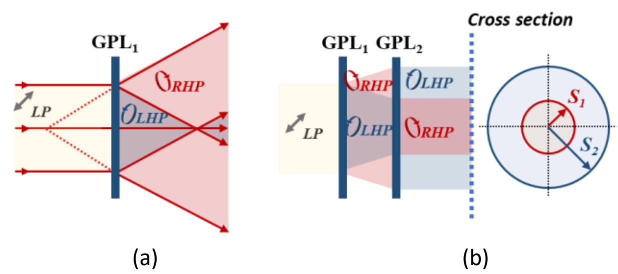

Figure 2. (a) a focused beam and its conjugated diverging beam by a GPL and (b) two radially sheared beams by a GPL pair.

In order to mathematically describe this radial shearing by the GPL pair, the ray transfer matrices can be used, and radial shearing ratio (s) is derived as

$$s = \frac{(f+d)}{(f-d)} \quad (1)$$

where *f* is the focal length of a GPL, and *d* is the distance between two GPLs much smaller than *f*. As known in Eq.(1), *s* can be adjusted by simply changing *d*.

In the meantime, the polarization states of two wavefronts are orthogonal with each other based on this polarization characteristics of a GPL, e.g. one is *RHP* and the other is *LHP*. Then, two circularly polarized beams are combined by the polarization array inside of the PCMOS, which can generate four phase-shifted interferograms at once [4]. By using the spatial phase shifting technique, the phase map is simply calculated from the interferograms, and finally the surface figure of the specimen can be obtained by the wavefront reconstruction algorithm [5,6].

3. Experimental results

For the feasibility test, concave mirrors with several radius of curvatures (ROCs) were measured. Two commercial GPLs with a 75 mm focal length from Edmund Optics were used, and an infinity corrected microscope with a 2x objective with a PCMOS from Lucid Vison Labs was adopted to obtain the four phase-shifted interferograms. Then, the phase maps were calculated using four phase-shifted interferograms, and the surface figures of the mirrors were able to be reconstructed by the modal algorithm based on the regression technique with Zernike polynomials of radial order of four. As the result, the surface figures was obtained as concave shown in Fig. 3, and their ROCs were 38.0 mm, 50.0 mm, 100.6 mm, 150.9 mm, 198.7 mm, respectively, close to the manufactured specification of the target as shown in Table 1.

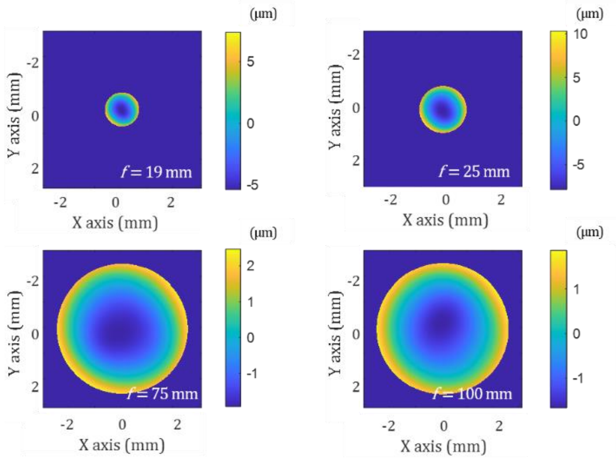

Figure 3. Surface figure measurement results of concave mirrors.

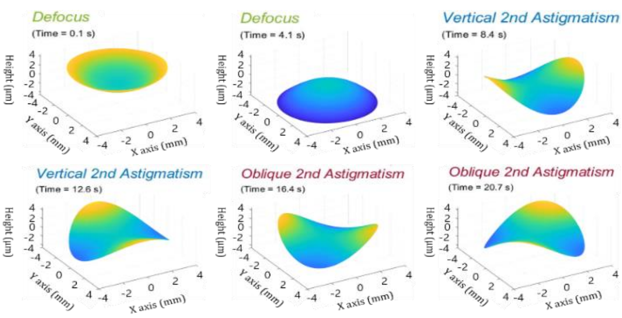

Figure 4. Snapshot measurement results of reconstructed DM shapes with the duration of 0.1 s.

To further verify the dynamic performance of the proposed interferometer, several types of wavefront aberrations generated by a deformable mirror were also measured. To monitor the variation of the DM shape, it was continuously switched between applying several different Zernike aberrations as shown in Fig. 4. For this experiment, the interferometer measured each wavefront within a 0.1s time interval. The measurement speed is determined solely by the frame rate of the PCMOS, as no additional temporal procedures are needed to complete reconstruction.

Table 1 Summary of ROC measurment results of concave mirrors

Focal length of concave mirror (mm)	Designed ROC (mm)	Measured ROC (mm)
f=19	38	38.0
f=25	50	50.0
f=50	100	100.6
f=75	150	150.9
f=100	200	198.7

4. Conclusion

To summarize, we proposed a radial shearing interferometer based on a geometric phase lens pair in this investigation. By the polarization nature of the geometric phase lens, a polarization pixelated camera can directly obtain the phase map with two orthogonally polarized wavefronts, which are radially sheared. In the experiments, several concave mirrors were measured to experimentally verify the proposed interferometer. In order to evaluate the dynamic performance, the variation of deformable mirror shapes were also monitored with 0.1 s.

References

[1] D Bian, D H Kim, B G Kim, L D Yu, K-N Joo and S W Kim 2020 Appl. Opt. **59** 9067-9074

[2] T Ling, D Liu, Y Y Yang, L Sun, C Tian and Y B Shen 2013 Opt. Lett. **38** 2493-2495

[3] L A Alemán-Castaneda, B Piccirillo, E Santamato, L Marrucci and M A Alonso 2019 Optica **6** 396-399

[4] M Novak, J Millerd, N Brock, M N Morris, J Hayes and J Wyant 2005 Appl. Opt. **44** 6861

[5] W H Southwell 1980 J. Opt. Soc. Am. **70**(8) 998-1006

[6] C Tian, X Chen, and S Liu 2016 Opt. Express **24** 3572–3583