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Radial Shearing Interferometer for Reconstruction of Wavefront by Fringe Modeling

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A perfect aspherical lens design significantly enhances the performance of an imaging system. However, the trend of device miniaturization makes this surface measurement becomes a challenge. In this study, a novel waviness profile metrology method for an aspheric surface is proposed by fringe modeling of a radial shearing interferometer (RSI) to reconstruct a wavefront. An RSI experiment is conducted with a small shearing amount to minimize the asphericity and a dynamic interferometer using a polarizing camera is combined to obtain the wavefront by the phase-shifting technique. Fringe modeling of the interferometer is realized by Ray-tracing software and the wavefront is extracted to compare with the respective wavefront in the experiment. The parameters of modeling are optimized iteratively with a good wavefront agreement between modeling and experiment to obtain a testing surface. The waviness surface profile expects to achieve the nanometer scale and this potential method is powerful for applying to surface metrology as a new measurement standard.

NOMENCLATURE

I = fringe (interferogram)
ϕ = wavefront phase
$\boldsymbol{E}$ = wavefront in the experiment
$\boldsymbol{M}$ = wavefront in the modeling
ε = limited value

1. Introduction

An ingenious aspherical design can effectively control aberrations, produce high performance, and reduce complexity to an optical system. By virtue of the randomness and variety of this surface, high accuracy measuring is always a challenge for any optical engineering, and system calibration is extremely important to minimize unexpected aberrations. The radial shearing interferometer [1] (RSI) is known as one of the most powerful tools for wavefront testing due to the reference-free property.

A rectangular cyclic RSI is defined by a cube polarizing beam splitter (PBS) and three mirrors M_1, M_2, and M_3 as a figure 1. A wavefront under test with random polarization will be defined at 45^o via linear polarization (LP); the two orthogonal polarizing red and blue beams are split after PBS marked P (0^o) and P (90^o), respectively. The RSI configuration is built with different focal lengths ($L_2 > L_1$) of lenses to produce the difference in beam size of output beams to create the shearing amount. A quarter-wave plate (QWP) is placed right after the output of the interferometer with 45^o to transfer vertical and horizontal linear polarizations into right and left circular polarization, respectively which is used as the material for a spatial phase-shifting on the camera. The two output beams interfere at their superposition with the reference-free which reduced asphericity by the shearing amount. Dynamic interferometer using the polarizing camera takes 4 interferograms and wavefront is analyzed by the phase-shifting technique.

Fringe modeling is established to extract a wavefront and compared it with the experimental wavefront to find the corresponding configuration of the modeling being set up in the experiment. In this study, we performed wavefront comparison by iterative optimization for a waviness aspheric profile in non-null testing based on RSI configuration.

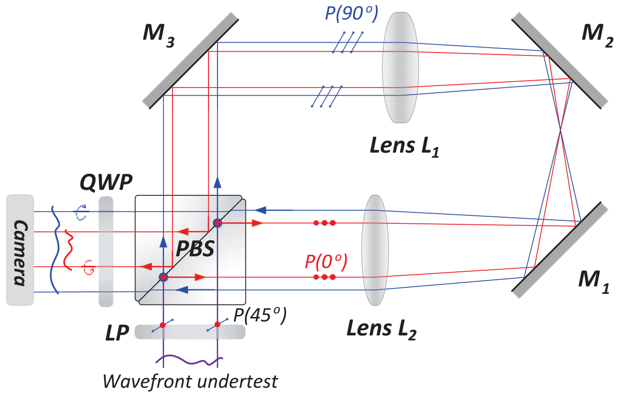
2. Method

An experimental setup is conducted as shown in figure 1 using a low coherence light source (center wavelength 830 nm), the polarizing camera collects 4 fringes (I_1, I_2, I_3, I_4) in a single shot which is 90^o phase difference as follows:

$$I_1(x,y) = I'(x,y) + I''(x,y)\, cos[\phi(x,y) + 0] \quad (1)$$

$$I_2(x,y) = I'(x,y) + I''(x,y)\, cos\left[\phi(x,y) + \frac{\pi}{2}\right] \quad (2)$$

$$I_3(x,y) = I'(x,y) + I''(x,y)\, cos[\phi(x,y) + \pi] \quad (3)$$



$$I_4(x,y) = I'(x,y) + I''(x,y)\, cos\left[\phi(x,y) + \frac{3\pi}{2}\right] \quad (4)$$

Fig. 1 Schematic of the polarization radial shearing interferometer for aspheric surface testing.

The low noise interferograms are extracted and the 4-bucket phase-shifting technique is applied thoroughly to figure out the wrapped wavefront phase expressed in equation (5)

$$\phi(x,y) = tan^{-1}\left(\frac{I_4 - I_2}{I_1 - I_3}\right) \quad (5)$$

This wavefront phase is discontinuous wavefront in a period of 2π, and it through an unwrapping process to be a continuous wavefront phase. A thirty-seven terms Zernike polynomial is used to represent and eliminates the unexpected aberration to obtain the symmetric wavefront error (***E***).

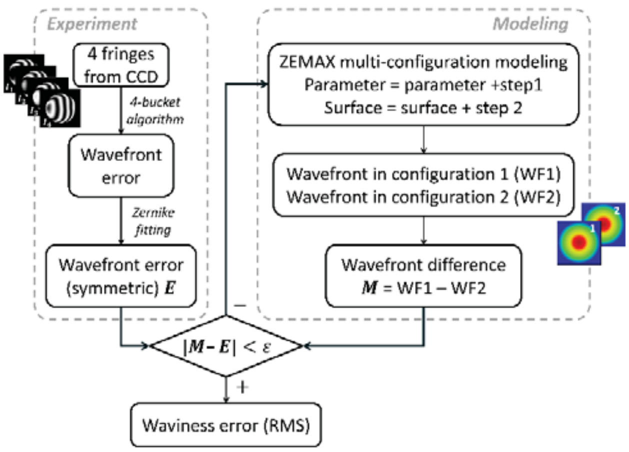


Fig. 2 Flowchart of the iterative optimization process.

The modeling of the system is realized by Ray-tracing software (ZEMAX) with two individual configurations to represent measurement and reference arms. The wavefront difference (***M***) of the two configurations is optimized and compared with the wavefront error in the experiment (***E***). The wavefronts comparison process is performed iteratively to obtain a perfect agreement between modeling and experiment. Figure 2 shows a flowchart of the iterative optimization process, optical constraints (parameters), and surface coefficients (surface) in modeling are optimized to find an exact representative configuration in the experiment. The wavefront comparison in the experiment (***E***) and modeling (***M***) is continuous in progress until achieving the limit value (ε) to find the reasonable waviness surface error. The iterative optimization method figures out the misalignment, retrace error, and the coefficient of even aspheric coefficients of the measurement target which express the surface waviness.

3. Conclusions

We express a novel and potential method not only in aspheric measurement but also effective in optical system calibration. If a standard spherical mirror is used as a target for an interferometer system calibration. Then the optical constraints are fixed and proceed an aspheric measurement with the surface coefficient, which is optimized, a high accuracy aspheric surface profile is effectively measured. The method shows great potential in optical metrology across many different optical configurations and promises to become the new measurement standard.

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