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Multi-directional lateral shearing interferometer based on rotatable prism pairs

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ABSTRACT

The common camera lens usually includes the spherical glass/plastic lens and aspheric glass/plastic lens. However, spherical/aspheric shape measurement is still a key problem in the process of optical lens fabrication. At present, the in-process measurement of spherical/aspheric shape is conducted mainly by the probe-contacting method. But after a long time, its probe could be scratched severely and cause some big errors. Laser shearing interferometry is a good substitute to some degree. Nevertheless, it is not convenient for general shearing interferometer to carry out the in-process measurement because it is only suitable for certain kind of spherical/aspheric with respect to aperture or asperity. Here a new lateral shearing interferometer is proposed to solve the described problems. It is based on two Jamin plates and rotatable prism pairs which are used not only for shearing displacement and direction, but also for fringe period and tilt degree, in order to meet requirements of various spherical/aspheric shapes or asperities. The new interferometer features a simple optical structure and two symmetric light paths, which makes its system with minimal error. The relation between shearing displacement, fringe period and prism angle of rotation is given in this paper. And the error source is primarily from the manufacture errors of prisms and plates. The final experiments show that one can achieve good-quality fringe patterns according to the requirement of measurement, concerning the shearing direction, shearing displacement, fringe period, tilt degree, etc.

1. Introduction

Spherical/aspheric lens is the main element of optical system, but the measurement of spherical/aspheric shape is still difficult to realize, especially aspheric one. The aspheric lens can correct the aberrations and improve the imaging quality of the optical system. Because of its fine characteristics, the aspheric lens is widely used in the modern optical design [1]. But unfortunately, the in-process aspheric measurement has failed to keep pace with the optical design and fabrication technology [2]. At present, the in-process measurement of spherical/aspheric shape is conducted mainly by the probe-contacting method. But after a long time, its probe could be scratched severely and cause some big errors [3]. So the optical (laser) measurement method is preferred during the process of spherical/aspheric lens or lens mould. The present optical measurement method could be primarily divided into null testing and shearing interferometric testing. The null testing has superior precision but requires a unique null optic [4], which dramatically increases the complexity and cost. The shearing interferometry [5,6] can test lots of aspheric surfaces, as long as their large dynamic rang is not exceeded. Although the shearing interferometry is flexible for aspheric measurement, in principle, the real experimental setup is not convenient to be adjusted according to the requirements of different aspheric shapes, especially for lateral shearing interferometer. Because it needs to combine the two orthogonal fringe patterns to form the final shape for lateral shearing interferometer, a flexible experimental setup should be developed to meet the change of shearing direction, even as well as fringe period, tilt degree and shearing displacement. Therefore, a new scheme of lateral shearing interferometer is proposed, which is simply based on two optical plates and two rotatable prism pairs. Two plates form a symmetric optical structure, which ensures an aplanatic interferometry in order to minimize the system error. Rotatable prism

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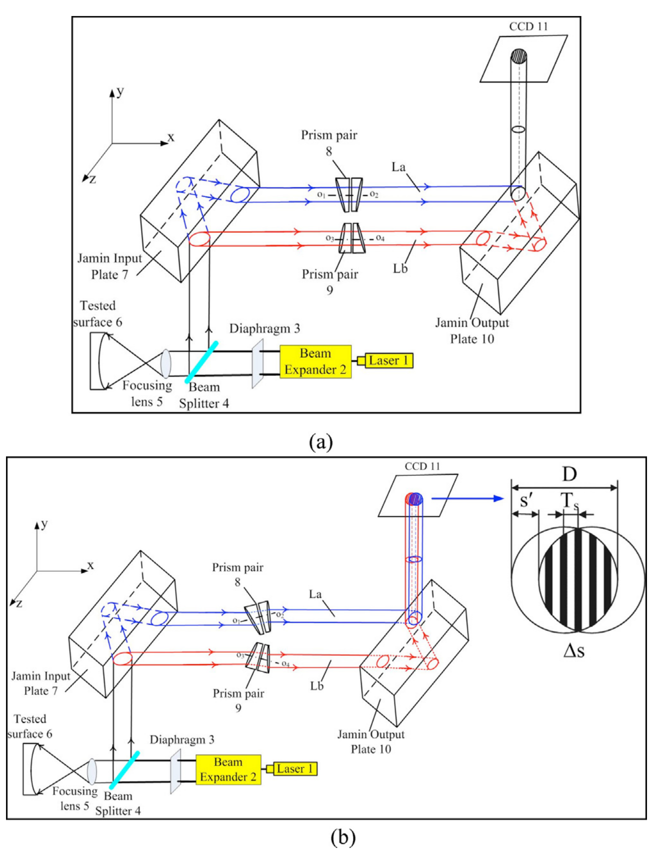
pair could be used not only to adjust the shearing displacement and direction, but also to change fringe period and tilt degree depending on the requirements of various spherical/aspheric shapes or asperities. In Section 2, the relation between shearing displacement, fringe period and prism angle of rotation is given. Section 3 shows the experimental results of various shearing interferometric states and error analysis. And some conclusions are provided in Section 4.

2. Principles

Fig. 1 shows the basic diagram of Jamin carrier-frequency interferometer, which is based on the two prism pairs with a minute angle α. The incident light is parallel to the axis of prism pair. The laser from laser machine 1 is expanded by beam expander 2, and passes through diaphragm 3. Then it is transmitted by beam splitter 4 and focusing lens 5, and enters the tested surface 6. The light beam is reflected by tested surface 6 and passes through the focusing lens 5 again. Afterwards, it is reflected by beam splitter 4 and enters the first optical plate (Jamin Input Plate 7). The light beam is divided into two parts (light path La and Lb) by front and back faces of the plate, and prism pairs 8 and 9 are put into light La and Lb, respectively. The light beams after prism pairs are reflected by front and back faces of the second plate (Jamin output Plate 10) again. The two beams after Plate 10 meet together to form the final interferometric fringes, which are imaged onto CCD 11. In Fig. 1a, light La and Lb are parallel to the optical axis o_1–o_2 and o_3–o_4, respectively. Moreover, the prism angle is very small, i.e., much less than 1°, so it means that the incident angle of light Θ is proximately regarded as 0 for prism pair. As for a single prism, shown in Fig. 2, the light



(b)

Fig. 1. Scheme diagram of interferometer: (a) Jamin carrier frequency interferometer; (b) Jamin lateral shearing interferometer with carrier frequency.

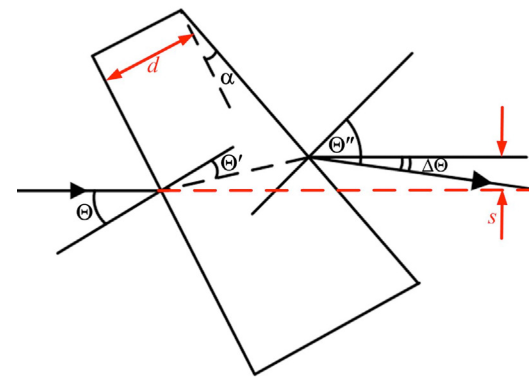


Fig. 2. Deflection state of light after prism.

lateral movement s and deflection angle $\Delta\Theta$ could be denoted as Eqs. (1) and (2) [7]:

$$s = d \cdot \left(\sin\Theta - \frac{\sin 2\Theta}{2\sqrt{n^2 - \sin^2\Theta}} \right), \tag{1}$$

$$\Delta\Theta = \left(\frac{\sqrt{n^2 - \sin^2\Theta}}{\cos\Theta} - 1 \right) \cdot \alpha, \tag{2}$$

where d is thickness of prism and n is the refractive index.

As for the prism pair of Fig. 1a, $\Theta = 0$, so the light lateral movement $s' = 2s = 0$, and the deflection angle δ is also dependent on the rotation angle (θ_1, θ_2) of each prism. Moreover, δ is different from $\Delta\Theta$, which is denoted [8] as Eq. (3):

$$\delta = 2(n-1)\alpha \cos\left(\frac{\theta_1 - \theta_2}{2} \right), \tag{3}$$

and azimuth angle ϕ is

$$\phi = \frac{\theta_1 + \theta_2}{2}. \tag{4}$$

Therefore, in Fig. 1a, the interferometer is not a shearing one because the shearing displacement $\Delta s = 2s'$ is 0. The fringe patterns (fringe period T_δ) shown on CCD are caused only by the deflection angle δ, and

$$T_\delta = \frac{\lambda}{2\sin\delta} \approx \frac{\lambda}{2\delta} = \frac{\lambda}{4(n-1)\alpha\cos[(\theta_1 - \theta_2)/2]}, \tag{5}$$

where λ is the laser wavelength. As for Fig. 1b, there are two cases shown in Fig. 3a and b, which show that two prism pairs are tilted with angle of Θ around axes z and y, respectively.

So the light incident angle Θ will lead to the shearing displacement of $\Delta s = 2s \neq 0$ as well as different deflection angle δ and azimuth angle ϕ. Here δ and ϕ not only depend on the light incident angle Θ and the prism angle α, but also on the rotation angles (θ_1, θ_2) of prism, which could be denoted [8] in spherical coordinates by Eqs. (6) and (7):

$$\begin{aligned} \delta = \cos^{-1}\{ & \cos\theta \sin\varphi \left[\cos\theta_2 \sin\varphi_2 \cos(\theta_{22} + \delta_2) \right. \\ & \left. + \sin\theta_2 \cos\varphi_2 \right] + \sin\varphi \sin\theta \sin(\theta_{22} + \delta_2) \\ & + \cos\varphi[\cos\theta_2 \cos\varphi_2 - \sin\varphi_2 \cos(\theta_{22} + \delta_2) \sin\theta_2]\}, \end{aligned} \tag{6}$$

$$\begin{aligned} & \phi = \frac{-\sin\varphi_2 \cos(\theta_{22}+\delta_2)\sin\theta_2 + \cos\theta_2 \cos\varphi_2}{\sqrt{1 - \sin^2\varphi_2 \sin^2(\theta_{22}+\delta_2)}}), \quad \sin^2\varphi_2 \sin^2(\theta_{22}+\delta_2) \neq 1, \\ & \phi = 0, \quad \sin^2\varphi_2 \sin^2(\theta_{22}+\delta_2) = 1. \end{aligned} \tag{7}$$