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Aspherical mirror online testing using phase retrieval with stitching

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ABSTRACT

We present a method to online testing aspherical mirror using phase retrieval with stitching. The principle of online testing is shown. The mechanism to online testing is designed and we demonstrate the kinematic analysis of this mechanism. The mathematical model of stitching method in phase retrieval is established. In simulations we prove the correctness and the validity of this method.

1. Introduction

The big aperture optical mirrors are widely used in various optical systems. The machining and measuring of these mirrors have become the main block. In the process of these mirrors, for the big dimension, big volume and huge weight, there is imminent needed a method to provide online testing. The requirement of this technique as follows: (1) inherently tolerant of vibration effects; (2) high resolution in horizontal orientation; and (3) high testing precision.

Currently we mostly use interferometer to test optical mirror for the high precision. But this technique demands a vibrationless measuring condition which cannot be easy reached. Afterward the anti-vibration interferometer is invented, such as 4D interferometer and ESDI interferometer. However the equipment is usually much expensive and huge dimension which may be not fit to online testing. Furthermore for the aspherical mirror interferometer is usually no use.

We present the phase retrieval with stitching to online testing aspherical mirror. Phase retrieval is wieldy used in wavefront measurement for the advantage as follows: (1) simple arrangements; (2) inherently tolerant of vibration effects; (3) without retracing error. It requires only simple intensity measurements collected by CCD array at the field of interest [1–3]. These features of phase retrieval are consistent with the demand of online testing. However, the range of the tested mirror is limited by the f/# of tested mirror which can be released by a stitching method. These methods make a promise in online testing aspherical mirror.

Related work has been done in the X-ray imaging field to improve the robustness of image reconstruction by phase retrieval. In these fields, the intensity measurements are usually collected in far-field which makes the longitudinal displacement of the detector cannot provide suitable diversity for robust phase reconstructions. So the transverse translation diversity is presented [4–9]. Some workers apply this technique to wavefront measurement and they have measured a transmitted wavefront [10]. But for online testing aspherical mirror, there are few works presented. In this paper we present an approach to online testing aspherical mirror using our stitching algorithm in phase retrieval.

Section 2 is the method to online testing aspherical mirror with phase retrieval by stitching. The stitching algorithm is demonstrated in Section 3. And we conclude in Section 4.

2. The method to online testing aspherical mirror

2.1. The principle of online testing

The phase retrieval with stitching algorithm can be applied to online testing a concave aspherical mirror. The sketch map of online testing with the phase retrieval by stitching algorithm is shown in Fig. 1. The left map is the measurement of the central position and the right map is the measurement of the off-axis position. The testing principle is: He–Ne laser produces the collimation beam which is changed into a spherical wavefront by the expander. Firstly the beam illuminates the central position of the tested mirror and the CCD camera can receive the intensity pattern of the central position. Then the beam is moved to the off-axis position by the *Y* rotation-axis, the *X* translation-axis and the *Z* translation-axis. And the corresponding intensity patterns will be caught.

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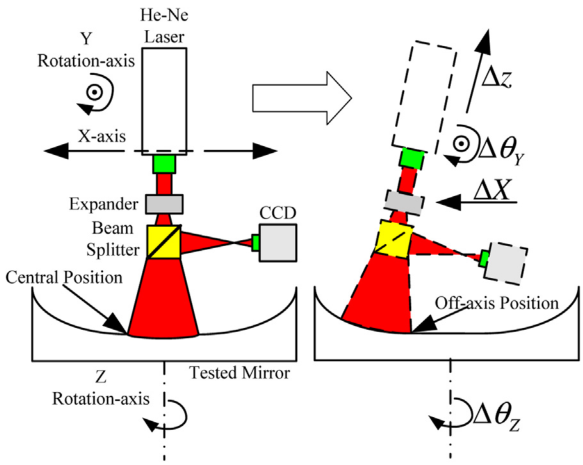

Fig. 1. Sketch map of online testing with the phase retrieval by stitching algorithm.

There are approximately four steps to online testing as follows: (1) the optical path alignment. The alignment is composed by two parts, alignment between the light source and the tested mirror and alignment between CCD the camera and the tested mirror; (2) online testing the central position. We save the intensity patterns emitting from the central position; (3) online testing the off-axis position. We also store these intensity patterns emitting from the off-axis position; (4) reconstruct the surface figure error of tested mirror by stitching algorithm.

2.2. The mechanism to online testing

The mechanism to online testing is designed in Fig. 2. The movement of the mechanism can be divided into two types. The one is the adjusting movement. The other is the aligning movement. On condition the tested mirror is axial symmetry, the adjusting movement will include *Y*-rotation, *Z*-rotation, *X*-translation and *Z*-translation and the adjusting movement will be composed by the adjustment of He–Ne laser and the adjustment of CCD camera.

For the movement of the mechanism, the actual position usually is different from the nominal position. This difference can be described as the geometric center error and the direction error of the optical axis. These errors should be optimized by stitching algorithm.

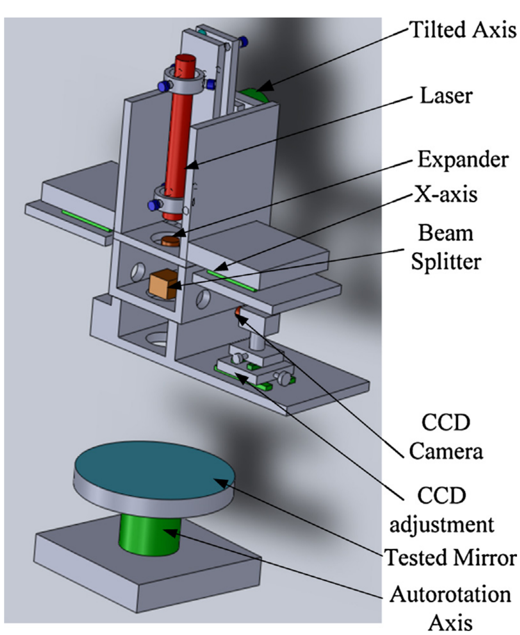

Fig. 2. The mechanism to online testing.

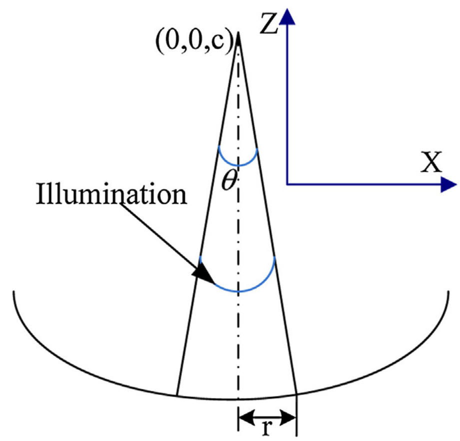

Fig. 3. Schematic showing the testing structure of central position.

2.3. The kinematic analysis

After the mechanism is designed, the illumination wavefront will be known. We assume the vertex angle of the testing beam is θ. Fig. 3 is schematic showing the testing structure of the central position. The radius of the testing area can be given by

$$r = R\sin\left(\frac{\theta}{2}\right) \tag{1}$$

where *R* is the vertex curvature radius of testing area. We let the tested mirror is paraboloid. It can be expressed as

$$X^2 + Y^2 = 2pZ \tag{2}$$

Because

$$R = p\left(1 + \frac{X_0^2}{p^2}\right)^{3/2} \tag{3}$$

where X_0 is the *X* coordinate of the central position.

When the testing area is off-axis, the testing structure is shown in Fig. 4. We denote the central position with solid line. The first dashed line is rotated from the red real line by *Y*-rotation with β angle in Fig. 4. The second dashed line is the tested off-axis position which is translated from the first dashed line by *X*-translation and

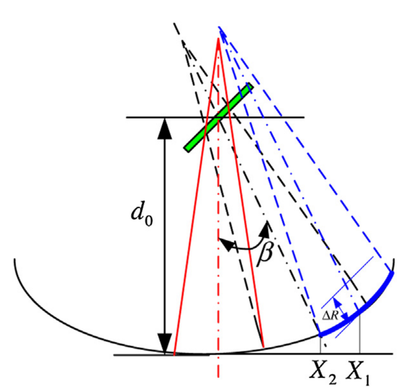

Fig. 4. The testing structure of off-axis position.