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Non-null testing for standard quadric surfaces with subaperture stitching technique

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ABSTRACT

A new method is proposed for testing standard quadric surfaces with several subapertures based on interferometry. Subapertures arrangement, best-fit sphere calculation and distortion correction about such surfaces are discussed in this paper. In addition, we provide an experimental demonstration by testing a Ø310 mm convex hyperboloid mirror. The experimental result shows that the proposed method can accomplish the testing of quadric mirrors without auxiliary compensation effectively. The analysis and proposed methods bring much to the application of non-null aspheric testing.

1. Introduction

Aspheric surfaces are widely used in a variety of optical systems to improve the imaging quality with fewer optical elements. The common methods used for testing aspheric surfaces, such as the null testing with compensator or CGH, will introduce extra errors from auxiliary optics and need a high cost. Besides, for large aperture aspheric surfaces especially convex surfaces, the aperture of neither interferometer nor the auxiliary optics is large enough to cover the full aperture of the tested surfaces. A subaperture stitching method has been developed to measure aspheric surfaces with low cost. The basic idea of subaperture stitching method is to divide the tested surface into several smaller subapertures, which can be tested with a standard interferometer. After completing the measurement of each subaperture, we get the full aperture map of the tested surface with relative stitching algorithms.

The subaperture testing method was first introduced in 1980s [1]. Many researchers have developed different stitching algorithms. Obvious improvements can be observed from the Kwon–Thunen method [2] and the simultaneous fit method [3], to the discrete phase method [4,5], the optical null technique from QED [6,7], and then to the maximum likelihood algorithm from Arizona University [8,9]. Aiming to improving the efficiency of the stitching, we proposed a kind of stitching technique to test standard quadric surfaces in non-null configuration. Advantages of the technique were claimed and verified through experiments.

In this paper, we focus on the non-null testing technique for standard quadric surfaces including the best-fit sphere calculation to each subaperture, subapertures arrangement method of the full aperture and distortion correction method. The stitching was accomplished with our previously mentioned algorithm [10]. The stitching technique has also been applied to a Ø310 mm convex hyperboloid mirror. This paper is organized as follows. In Section 2, the basic theory of stitching technique is introduced. In Section 3, we apply the above technique to the actual experiment and the relative result is introduced. The conclusion is given in Section 4.

2. Theory

2.1. Calculation of best-fit spheres for subapertures

The sag of a standard quadric surface can be expressed as [11]

$$z=\frac{c_{con}(x^2+y^2)}{1+\sqrt{1-(1+\kappa)c_{con}(x^2+y^2)}} \tag{1}$$

where c_{con} is the conic' axial curvature and κ the conic constant. For the off-axis section of rotationally symmetric surfaces, it can be

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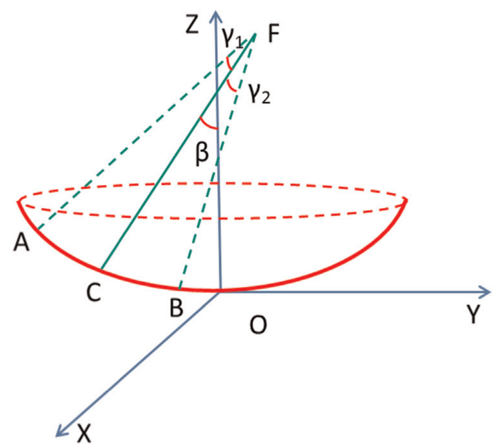

Fig. 1. Sketch of non-null testing. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

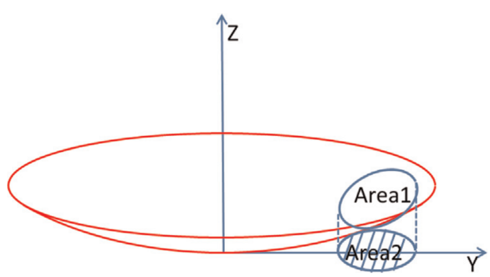

Fig. 2. Test configuration of subaperture.

regarded as part of the rotationally symmetric surface.

When calculating the best-fit sphere of a subaperture, for the sake of conciseness, we just consider the subaperture whose center is in the *Y–Z* plane shown in Fig. 1. The analysis is also adapted to the subaperture whose center is not in the *Y–Z* plane, as it can be regarded as a rotation result around the *Z* axis.

As shown in Fig. 1, the red line is the profile map of an aspherical mirror. ACB is the subaperture to be tested where point *C* (x_c, y_c, z_c) is the center of the subaperture. *F* is the center of the best-fit sphere of subaperture *ACB*. The angle between *FC* and *Z* axis is β. It is assumed that the tested area is rotationally symmetric around *FC*, which means γ_1 ($\angle AFC$) is equal to γ_2 ($\angle BFC$).

A spherical coordinate is established where *F* is the center and $\overrightarrow{FC}$ is the positive direction. A point *P* in the subaperture *ACB* can then expressed as

$$\begin{cases} x_p = r\sin\theta\cos\varphi + x_c \\ y_p = -r\cos\beta\sin\theta\sin\varphi + r\sin\beta\cos\theta - h\sin\beta + y_c \\ z_p = -r\sin\beta\sin\theta\sin\varphi - r\cos\beta\cos\theta + h\cos\beta + z_c \end{cases} \tag{2}$$

where *h* is the length of *FC*, *r* is the length of *FP*, θ and φ are the zenith angle and azimuth angle respectively.

As the point $P(x_p, y_p, z_p)$ is in the subaperture *ACB*, it meets

$$(\kappa + 1)z_p^2 - 2pz + (x_p^2 + y_p^2) = 0 \tag{3}$$

where *p* is the radius of curvature at the vertex of the aspheric mirror ($p = 1/c_{con}$).

Eq. (3) can be written as

$$Ar^2 + Br + C = 0 \tag{4}$$

where

$$\begin{cases} A = \kappa(\sin\beta\sin\theta\sin\varphi + \cos\beta\cos\theta)^2 + 1 \\ B = [-2h\kappa\sin\beta\cos\beta + (-2(\kappa+1)z_c + 2p)\sin\beta - 2y_c\cos\beta]\sin\theta\sin\varphi \\ \qquad + [-2h(\kappa\cos^2\beta + 1) + (-2(\kappa+1)z_c + 2p)\cos\beta + 2y_c\sin\beta]\cos\theta \\ C = h^2(\kappa\cos^2\beta + 1) + (2(\kappa+1)z_c - 2p)h\cos\beta - 2y_c h\sin\beta \end{cases} \tag{5}$$

r can be calculated by

$$r = \frac{\sqrt{B^2 - 4AC} - B}{2A} \tag{6}$$

and

$$\nabla r = \frac{\partial r}{\partial \rho}\hat{\rho} + \frac{\partial r}{\rho\partial\theta}\hat{\theta} + \frac{\partial r}{\rho\sin\theta\partial\varphi}\hat{\varphi} \tag{7}$$

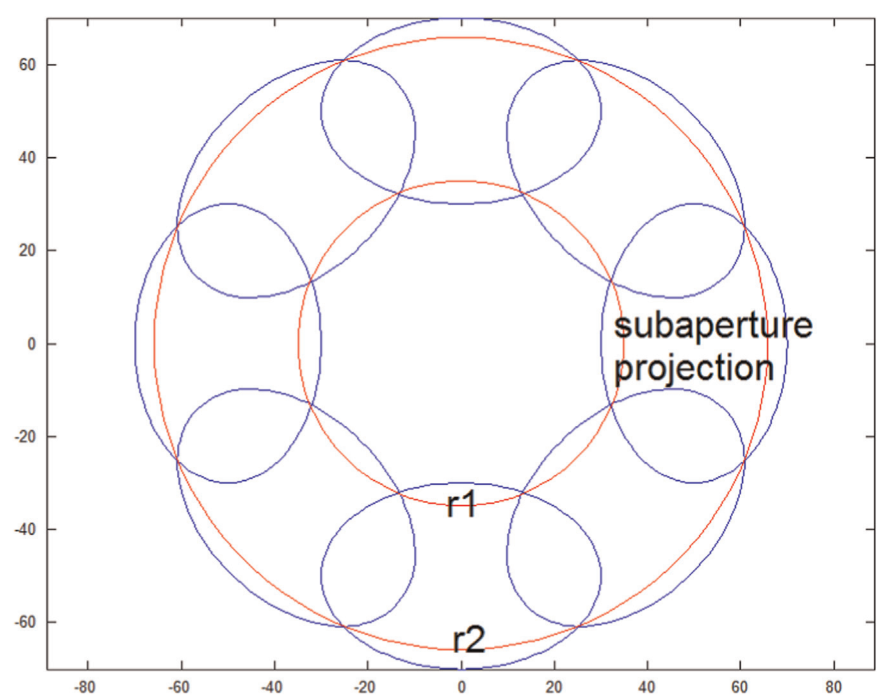

Fig. 3. Testing ring.