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A novel definition method of optical asphericity

Huilan Liu*

School of Instrument Science and Opto-electronics Engineering, Beihang University, Beijing 100083, PR China

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Abstract

In view of the fact that methods for calculating asphericity of optical aspheric surface are nonuniform, a novel definition method named least maximal error method is proposed on the basis of an analysis of the common calculating methods. It fully unifies the asphericity calculation for conicoid and high-order aspheric surface. It finds the best-fitting spherical surface, notes the maximum deviation between aspheric surface and the best-fitting spherical surface minimum, and this maximum deviation is defined as the maximal asphericity of aspheric surface. The theory of the definition method and some calculation examples are put forward. The method is suitable for computer programming and its result is accurate.

Keywords: Asphericity; Definition methods; Least maximal error method; Aspheric surface

1. Introduction

Using aspheric surface elements in optical system can correct aberrations, improve image quality, and decrease system structure. Hence, optical aspheric surfaces are widely used. The maximum asphericity is an important data in manufacturing and measuring optical aspheric surfaces. It reflects the level and difficulty of measurement [1]. In optical measurement, the maximal asphericity corresponds to maximal interference fringes grade when aspheric surface is measured using standard spherical surface. The essence or substance of asphericity is to find a best-fitting spherical surface and calculate the deviation between aspheric surface and the best-fitting spherical surface.

At present, optical asphericities are divided into conicoid asphericity and high-order aspheric surface asphericity. The definitions of asphericity are not uniform. In this paper, novel definition method named least maximal residual error method is proposed on the basis of an analysis of the common calculating methods. The principle of the definition method is clear. The method is suitable for computer programming and can be used to precisely calculate asphericity of any order axis-symmetrical optical aspheric surface.

2. Comparison of different methods

There are many definition methods of optical conicoid asphericity, e.g. approximate formula method, precise formula method and least-square fitting method [2].

Approximate formula method is usually used in the process of conicoid manufacture. The asphericity is defined as the difference between horizontal coordinates of aspheric surface and best-fitting spherical surface. The best-fitting spherical surface is the spherical surface passing through the peak and edge points of the

*Tel.: +8610 82316906.
E-mail address: liuhuilan@buaa.edu.cn.

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conicoid. This method has large error because of using approximate calculation.

Precise formula method is usually used in conicoid measurement [3]. The asphericity is defined as the difference between aspheric surface and best-fitting spherical surface along normal of the latter. This method is suitable for conicoid asphericity calculation and the result is precise.

In least-square fitting method, the choice of the best-fitting spherical surface is to make the square summation of difference with the conicoid to be the least, in the whole caliber of the conicoid. This method has good definition, but calculation is complex [4].

The asphericity calculation of high-order aspheric surface is different from that of the conicoid. High-order aspheric surface can be described in two different formats:

$$y^2 = 2R_0x - (1+K)x^2 + a_3x^3 + \cdots + a_nx^n \tag{1}$$

or

$$x = \frac{y^2}{R_0 + \sqrt{R_0^2 - (1+K)y^2}} + a_4y^4 + a_6y^6 \cdots + a_{2n}y^{2n}, \tag{2}$$

where $K = -e^2$, e is the eccentricity.

For high-order aspheric surface, there are many methods of calculating the maximum asphericity, e.g. arc height method and wave aberration method [5]. Each method has its weaknesses. In arc height method, the normal is neither that of aspheric surface nor that of best-fitting spherical surface. So this definition is not with much reason. The normal defined in wave aberration method is that of aspheric surface, which does not tally with the reality of aspheric surface manufacture and measurement. And there is approximation in calculation.

A new definition is proposed for asphericity of aspheric surface in this paper. It will be shown later that this method can unify the asphericity calculation for conicoid and high-order aspheric surface.

3. Theory of the new definition method

The new definition method is named least maximal error method. This method is based on geometry viewpoint. By finding a best-fitting spherical surface, making the maximum deviation between aspheric surface and the best-fitting spherical surface minimum, the maximum deviation is defined as the maximal asphericity of aspheric surface. The deviations are along the normal of the latter, and the deviations should be all positive [6].

The method of finding the best-fitting spherical surface and calculating the maximal asphericity can be described as the following. The aspheric surface is fixed in a coordinate system. Spherical surfaces with alterable positions and radiuses are taken into account. Deviation δ_i between each spherical surface and aspheric surface along the normal of the former is calculated, and the maximum is found. The minimum among these maximums is found, and the corresponding spherical surface is the best-fitting spherical surface. The corresponding maximal deviation $\delta_{\max}$ is the maximal asphericity of aspheric surface. As shown in Fig. 1, the peak of the aspheric surface is positioned at origin O. O′ is center of best-fitting spherical surface. The distance between origin and the center is a. R is the radius of the best-fitting spherical surface. In this method, best-fitting spherical surface defined with a and R is searched to satisfy the equation

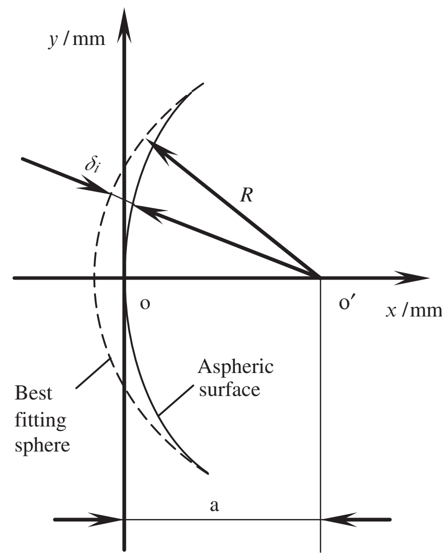

Fig. 1. Asphericity used in the least maximal error method.

$$\delta_{\max} = \left[\max\left(R - \sqrt{(x_i - a)^2 + y_i^2}\right)\right]\Big|_{\min}. \tag{3}$$

If parameter a is fixed, the center of the best-fitting spherical surface is fixed. The minimum in radical sign of the formula can be calculated. Thus, the minimal distance from point of aspheric surface to core of best-fitting spherical surface is fixed. Maximal deviation decreases as R decreases. It is obvious that, when a is close to the peak radius of the aspheric surface R_0, the least maximal deviation present to the instance that the edge point of aspheric surface and that of the best-fitting spherical surface are superposed. In this circumstance, the coordinate of the edge point of aspheric surface is (x_1, y_1). As the maximal deviation of the edge point is zero, the radius of the best-fitting spherical surface can be calculated from

$$R = \sqrt{(x_1 - a)^2 + y_1^2}. \tag{4}$$