Aspheric surface profilometry using 2^{nd} derivative of local area

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I present a method of aspheric surface profile measurement using white-light scanning interferometry. This method is based on the principle of curvature sensor which is related to the second derivative of local area under test along a line. The profile is reconstructed from the curvature data on the each point. Unlike subaperture-stiching method and slope detection method curvature sensing have strong points from a geometric point of view in measuring the aspheric surface profile. The subaperture topography is obtained by using white-light scanning interferometry to avoid the optical alignment error along an optical axis. The measurement results demonstrate that the proposed method and system is well suited for the aspheric profile measurement.

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1. Introduction

High-quality optical systems need components with optical surface whose form is close to aspheric surface. One feature of aspherization is that often it will be possible to both improve the optical performance and reduce the number of optical elements in the system. However the problem of measuring aspheric surface with high accuracy has not yet been generally solved.

As shown in Fig.1, the most obvious feature which can be measured to determine topography is the distance from a reference plane, which is 0^{th} order derivative of local area. While distance measurement has no mathematical post-processing, measurement accuracy is exposed to unavoidable errors of the stage, such as tip-tilt, nonstraigtness and non-orthogonality. Slope measuring systems are in use, and from the slope which is 1^{st} order derivative of local area the topography is calculated by integration. While it doesn't need the reference plane, measurement accuracy also depends on possible unintentional rotational error, tip-tilt motion of sensor in scanning over the surface.[1] The curvature, 2^{nd} order derivative of local area, is a very interesting measurand since it is an intrinsic property of the surface. It has the advantage that a matched adjustment is allowed. The measurand of curvature have a high reproducibility and even strong curvature, for example, of steep aspheric surfaces, are accessible. They do not need form references, i.e. prototype surface of the same extension as the surface to be measured. As they measure an intrinsic property of the local surface, whole-body motion like tilting of the artifact is not disturbing.[2]

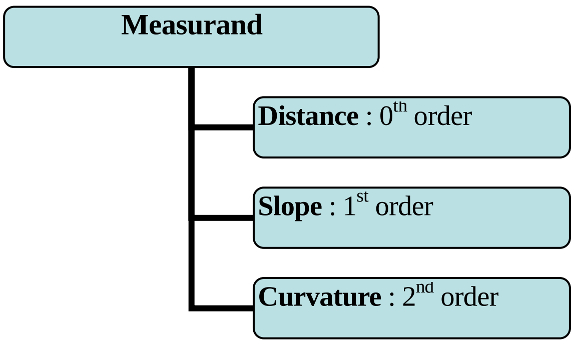

Fig. 1 Different measurands for determining topography

2. Principles of profile reconstruction

The following Frenet equations describe the relationship between the curvature k(y) and arbitrary curves z(y) in the space.[3]

$$\frac{d^2 z(y)}{dy^2} = k(y)\cdot\left[1+\left(\frac{dz(y)}{dy}\right)^2\right]^{\frac{3}{2}}$$

This is only for a one-dimensional surface section z(y) in a plane. To obtain unique solutions to these differential equations, additional conditions must be imposed, for example, initial values $z(y_0)$, $z'(y_0)$ must be specified. Let φ(y) denote the integrated curvature,

$$\varphi(y) = \int_{y_0}^{y} \kappa(\varsigma)\, d\varsigma \quad \text{and} \quad \alpha = \frac{z_0'}{\sqrt{1+z_0'^2}}$$

a constant determined by the initial value value $z'_0=z'(y_0)$. By using the integrated curvature φ(y) and the constant α the differential equ.1 is led to the following equation.[4]

$$\frac{dz(y)}{dy} = \frac{\varphi(y)+\alpha}{\sqrt{1-(\varphi(y)+\alpha)^2}}$$

Since $\varphi(y_0) = 0$ holds, this function satisfies $z'_0=z'(y_0)$. Hence, a solution to the differential equ.1 is obtained by integration of equ.2. The surface profiles can be directly reconstructed by numerical integration of the measured curvature and subsequent integration of equ.2. These results can be used to reconstruct the whole surface profile and look into the flatness of precisely machined surfaces.

3. Experimental results

The optical aspheric surface under test is the 300 diameter primary mirror which is a part of the astronomical cassegrain telescope. The radius of curvature is 1680mm, the type of surface is parabolic with k= -1.0 conic constant.

The accuracy of measurement has been assessed by comparison with a well-calibrated UA3P(Ultra Accuracy 3-D Profilometer) that is widely used for profiling aspheric surfaces and provided by Panasonic inc., Japan. As illustrated in Fig. 2, when a diagonal profile is measured across the mirror over 52mm measurement range, the maximum difference turns out to be 25.78nm, with a standard deviation of 8.47nm. The measurement range was bounded by travel length of curvature sensor which shows unstable motion out of measurement boundary because of the heavy weight of test piece.

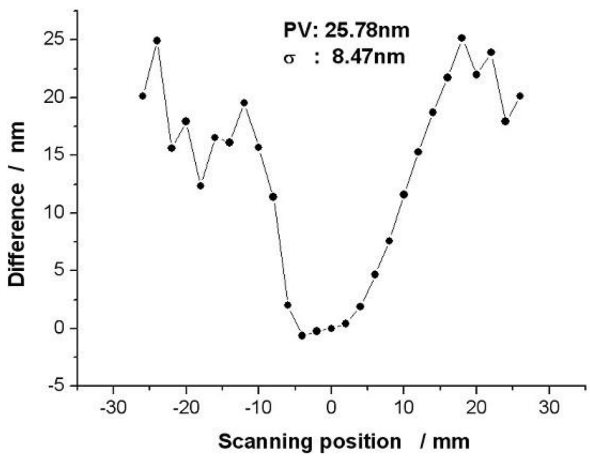

Fig. 2 Result of measurement of the aspheric mirror

4. Conclusions

For measuring aspheric surface profile, the method measuring the 2nd order derivative of subaperture has some advantages from a geometrical or mathematical point of view. The primary mirror for cassegrain type astronomical telescope, with K= -1.0 and R=1680mm, was used for testing. When the measurement results are compared with one obtained from the commercial stylus profiler, the proposed method and system turn out to be suitable for measuring the aspheric surface profile.

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