수치해석을 이용한 비구면 렌즈 설계

Aspherical Lens Design by Numerical Analysis

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Aspherical lenses are essential ingredients in reducing the sizes and the weights of optical systems. One of the most frequent purposes of employing aspherical lenses is in order to eliminate spherical aberration. It is said that one aspherical lens can be as good as 3 ~ 4 spherical lenses. Aspherical lenses have been usually designed using dedicated lens design software such as Code V and Zemax. In this method, a trial lens (i.e. refractive surface) profile having the form of an even-aspheric lens formula is assumed. Such a rotationally symmetric surface profile can be parameterized as $z = z(\rho)$, where ρ is the axial distance measured perpendicular to the rotational symmetry axis(i.e. the optical axis) and z is the distance measured along the optical axis. The surface profile is given as a sum of conic surface profile and the perturbation terms described by an even-powered polynomial terms in ρ. Then, a merit function is set-up for quantitatively measuring the quality of the lens. For example, to design a spherical aberration-free lens, spherical aberration can be taken as the merit function of the lens, and smaller the value of the merit function the better the optical quality. By systematically investigating the effects of various terms, a best combination of coefficients is obtained.

This method of aspherical lens design has limitations in the precision of the lens profile, and there are certain lens profiles that cannot be designed by such programs. We have developed a new method of designing aspherical lenses. Aspherical mirror profiles observing the law of specular reflections can be designed using numerical analysis[1]. While the law of specular reflection is observed in reflective lenses, the Snell's law of refraction is observed in refractive lenses. Despite this difference, aspherical refractive surface profile can be similarly obtained using numerical analysis. Fig. 1 is a schematic diagram of a spherical-aberration-free lens profile. The origin of the coordinate coincides with the second focal point of the lens. This rotationally symmetric surface profile can also be written as a set of two curvilinear coordinates (r, θ) in the spherical polar coordinate. In this notation, r is the radial distance from the origin to the point L on the lens surface, and θ is the zenith angle (i.e. polar angle). Then, the radial distance is given in a form of an indefinite integral:

$$r(\theta) = r(0)\exp\left[\int_0^{\theta} \frac{n_1 \sin\theta'}{n_1 \cos\theta' - n_2} d\theta'\right],$$

where n_1 and n_2 are the refractive indices for the 1st and the 2nd medium. The two variables in cylindrical coordinate can be parameterized in terms of the polar angle θ as $\rho(\theta) = r(\theta)\sin\theta$ and

$z(\theta)=r(\theta)\cos\theta$. Fig. 2 shows a schematic of a finite-conjugate spherical-aberration-free double-aspheric lens. Fig. 3 shows an exemplary lens profile and the traces of rays, where the material is assumed as optical-grade PMMA, and the wavelength of light is 633.8nm. The front-vertex focal length is taken as 50mm, and the rear-vertex focal length as 200nm, and the lens diameter as 50mm. From the Fig. 3, we could see that the exemplary lens obtained using the formula is indeed spherical aberration-free. Fig. 4 shows the photograph of fabricated prototype.

In conclusion, we have derived a new method of designing aspherical lenses using numerical analysis.

Acknowledgement

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[1] G. Kweon, K. Kim, G. Kim and H. Kim, "Folded catadioptric panoramic lens with an equidistance projection scheme", Appl. Opt. **44**, 2759-2767 (2005).

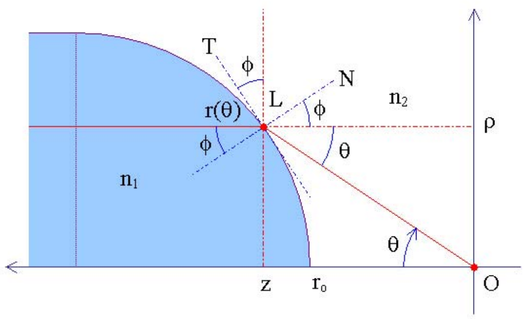

Fig. 1: Schematic diagram illustrating the profile of spherical-aberration free aspherical refractive surface.

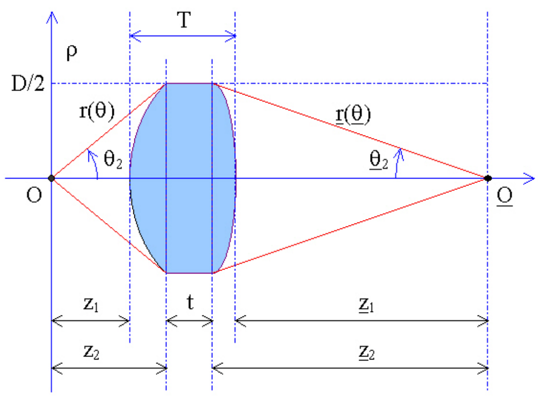

Fig. 2: Finite-conjugate double-aspheric lens free from spherical-aberrations.

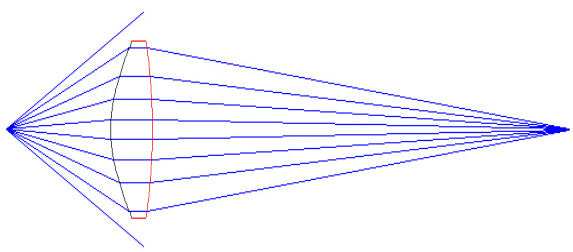

Fig. 3: Exemplary lens profile and the ray traces.

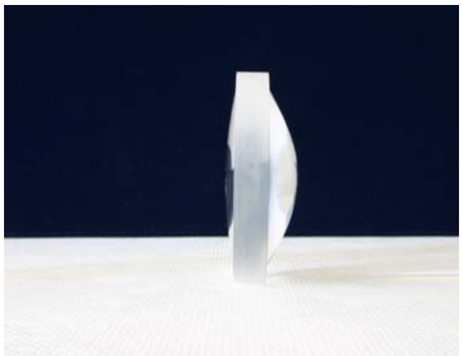

Fig. 4: Finished prototype made of PMMA.