An Integrated Solution for Compensation of Refractive Index Drop and Curve Change in High Precision Glass Molding

Fritz Klocke[1], Olaf Dambon[1], Lijuan Su[2], Fei Wang[1], Peng He[2], Gang Liu[1], Allen Y. Yi[2]
[1] *1Fraunhofer Institute for Production Technology, IP, Aachen, Germany*
[2] *Department of Integrated Systems Engineering, The Ohio State University, USA*

fritz.klocke@ipt.fraunhofer.de

Abstract

In precision glass molding, refractive index change and geometrical deviation (curve change) occurred during molding process can result in substantial amount of optical property change to the glass lenses. Previously, refractive index drop and curve change were investigated in separate studies by the authors. However, optical performance of a molded glass lens depends on both refractive index and geometry. In order to fabricate glass aspherical lenses with optimal performance, both refractive index and curve have to be considered simultaneously. This research presented an integrated compensation procedure for both refractive index and curve changes of a molded glass lens. First, group refractive index change predicted by finite element method simulation was used to provide a compensated lens design. Second, curve change of the molded aspherical glass lenses was compensated with a previously developed numerical simulation approach, which was used to modify the mold shape to compensate for thermal shrinkage of the molded glass lenses. Measurements of geometry and optical performance confirmed that the molded lenses perform as specified by the original design. It also demonstrated that finite element method assisted compensation procedure can be used to predict the final optical performance of compression molded glass components.

1 Optical Design

In order to demonstrate the compensation procedure, the design and molding of a double convex aspherical lens is presented in details such that the compensation scheme can be easily applied to other optical devices. In this research, the original design is shown in Figure 1. Glass material is P-SK 57, an optical glass designed for precision glass molding by Schott. The back focal length of this lens is 50.52054 mm, which is considered to be the original lens design.

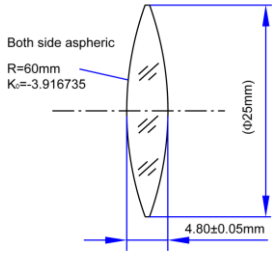

Figure 1: Geometry of the original lens design.

2 Compensation Theory

In the process of establishing the compensation scheme, both refractive index drop and geometrical deviation are modeled by finite element method (FEM). Methodologies established in previous researches were utilized in predicting final refractive index distribution and the design of the molds [1, 2]. The final optical performance of the molded lens was compensated by curve modification based on both refractive index and geometry changes predicted using FEM simulation based simulation scheme shown in Figure 2.

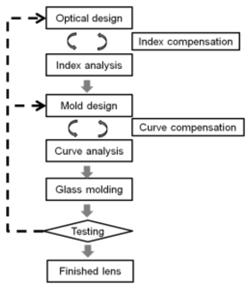

Figure 2: An integrated compensate scheme.

3 Index Prediction and Compensation

Specifically, to predict refractive index drop (distribution), the cooling process of a lens with original design shape was simulated in a 2D axisymmetric model (Figure 3). The structural relaxation behavior of the glass material during cooling was modeled by using the TNM model as in references [3, 4].

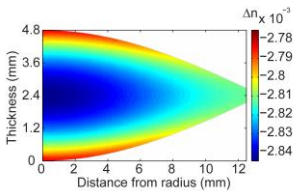

Figure 3: Prediction of refractive index change in the molded lens.

4 Geometry Prediction and Compensation

Simulation on geometrical deviation of glass molding process is simulated by using ABAQUS. Optical surface of the lens design is considered as original form for mold curvature compensation iteration. After the iterations, the calculated deviation of the lens' optical surface is represented as the red/dashed curve in Figure 4. The mold surface was machined with a small deviation shown as the blue/solid curve to compensate for this deviation on molded lenses.

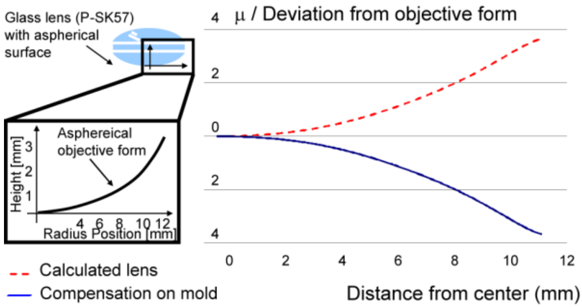

Figure 4: Curvature compensation

For the lens under test, the cooling rate was 0.84 K/s. According to the simulation model, the predicted average refractive index change is -0.003, which is considered to be typical refractive index change for the compression molded lenses from experiments [3]. As a result, the back focal length of compression molded lens with the compensate design becomes 50.53801 mm.

5 Optical Performance

If a point light source is placed in front of the molded lens the wavefront comes from the back surface of the compensated lens is simulated by ZEMAX and shown in Figure 5a. Experiments were performed to measure the wavefront coming from the molded lenses using the WaveMaster LAB. The back focal length was measured to be 50.53801 as in Figure 5b. The P-V value was measured to be 0.55 wave, the standard deviation was 0.132 wave. The measurements are within 0.4 wave of the original design P-V value.

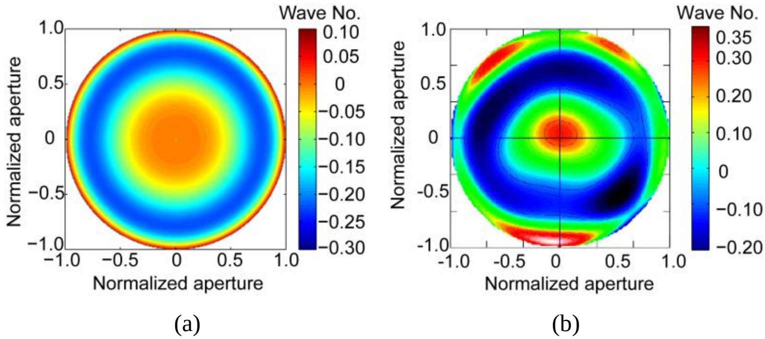

Figure 5: (a) Simulated wavefront and (b) measured wavefront of the molded lens when a point source was placed at the focal point.

Summary

For high precision glass molding, an integrated compensation scheme for both refractive index and geometry deviation was developed. In this approach, an FEM simulation based on TNM model was applied to predict index drop of the optical glass after precision molding. The predicted index value was then used to compensate for optical lens design. A case study on molding of the aspherical lens was conducted to successfully demonstrate the feasibility of the proposed manufacturing scheme.

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