Effects of striae in optical glass on optical systems – first results

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Striae are short ranged (0.1 mm … 1.0 mm) changes in the refractive index inside an optical glass: The effects of striae on the optical performance for a camera lens and a binocular lens are studied using the software ZEMAX. First results suggest glasses with striae level below 30 nm wave front deformation can be tolerated.

1 Introduction

Optics and photonics are key enabling technologies and are used in microscopes, telescopes, cameras or other optical instruments. As a matter of fact optical glasses with certain inner quality e.g. high homogeneity combined with low striae content are essential for such applications. Striae inside a glass cause a wave front deformation and thus can cause a blurring of the image.

2 Striae definition

Striae are local changes of the refractive index within optical glass with elongated shape and small width (typical size between 0.1 mm and 1.0 mm) [1], [2]. The origin of striae are local changes in the chemical composition of the glass during the melting and casting process. Striae have a slightly different glass composition and therefore different optical properties. This results in a change of the wave front passing glass if having striae, see Fig. 1.

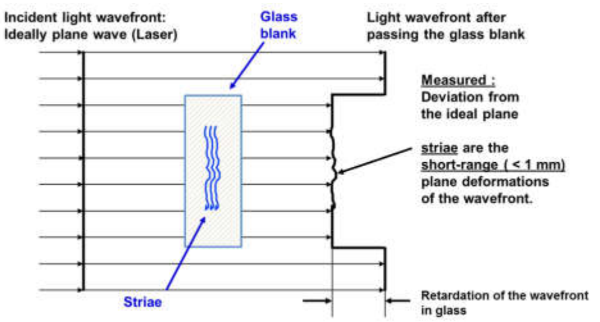

Fig. 1 *An incident plane wave distorted by striae leading to wave front deformation.*

Striae level are classified according the resulting wave front deformation see Tab. 1. Striae modeling with ZEMAX

An optical glass with refractive index n in air at (vacuum) wavelength λ_0 with a stria causes a phase difference of $\Delta\phi$. This results in an optical path difference (OPD) of **Fehler! Verweisquelle konnte nicht gefunden werden.**

$$\Delta L = \frac{\Delta\phi \cdot \lambda_0}{2\pi}. \quad (1)$$

In a thin lens approximation a OPD can be described as caused by a height variation Δh:

$$\Delta\phi = \frac{2\pi}{\lambda_0} \cdot (n-1) \cdot \Delta h \rightarrow \Delta h = \frac{\Delta L}{(n-1)}. \quad (2)$$

Striae are modelled as surface (height) variation since they result in the same effect. Two models are used a cosine shaped single stria and a build-in function [4] of periodic surface – compare with [5]. The height of the striae are adapted for different striae level according Tab. 1 and using a height variation Δh according eq. (2) and for different widths (ranging from 0.1 mm to 1.0 mm). A single stria is positioned at 2 positions: preferred at the center of the lens and at 25% of the diameter of the lens.

Striae classification (MIL 174 G)	ISO DIN 12123 (2017)	Optical path difference
A	SW 10	0 nm … 10 nm
B	SW15	10 nm … 15 nm
C	SW30	15 nm … 30 nm
D	SW60	30 nm … 60 nm

Tab. 1 *Striae classification and corresponding optical path difference*

3 Optical System selection for striae simulation

Criteria for the optical system selection were long glass path, mass product and “advanced” performance. Thus, here we show a camera lens design “Vivitar” [6] and a binocular lens design that comes with ZEMAX [7]. Further examinations can be found in [8].

The 2 lens designs can be seen in Fig. 2. The marked surfaces (called “FI”) point to the surfaces that were “equipped” with striae. Only on these most impacting surfaces straie were incorporated as a

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worst case simulation. The camera design had an effective focal length of 28.0 mm, F# = 3.0, and was designed for a film format of 24 mm x 36 mm. The binocular afocal design had an aperture of 30.0 mm, 8x magnification, and total length of 232.7 mm.

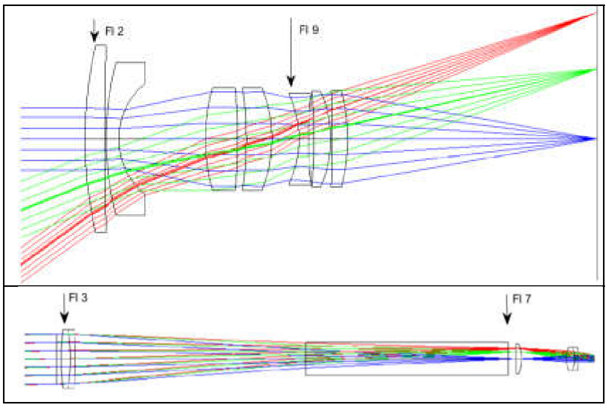

Fig. 2 *Lens designs for the striae simulations: Vivitar camera design (top) and binocular lens design (bottom).*

4 Criteria for reliable striae simulations

The striae simulations are very sensitive and need special care for reliable simulation results. For example distortion is calculated with respect to the chief ray and as soon as this ray is distorted - e.g. by a single stria in the center of a lens – the calculated values are misleading. Therefore, distortion is calculated with an external macro referencing to the "center of gravity" point. We found the following criteria for reliable striae simulations:

- a ray pencil must hit a local stria fully and the stria should be roughly in the center of the ray pencil,
- the reference should not be distorted in order to ensure the same basis (thus the principle ray should not go through the center of a stria), and
- ensure enough rays are hitting a stria, roughly more than 10 rays.

All these criteria should be fulfilled for reliable simulations.

5 Simulation results

Based on the criteria of chapter 5 only surface 2 (Fl 2) of the Vivitar camera design and surfaces 3 and 7 (Fl 3 and Fl 7) of the binocular result in reliable simulations, compare also with Fig. 2.

The performance criteria were maximum distortion and spot size for both design. In case of the camera lens also MTF was simulated [8], but not shown here. The maximum distortion of the Vivitar camera design was V = 2.4 % and for the binocular V = 1.1 %. The result of the Vivitar camera design with striae and also for the binocular for distortion is shown in Fig. 3. The limit of tolerable change in distortion was set to 2 % thus for the vivitar distortion < 4.4 % were allowed (< 3.1 % for binocular).

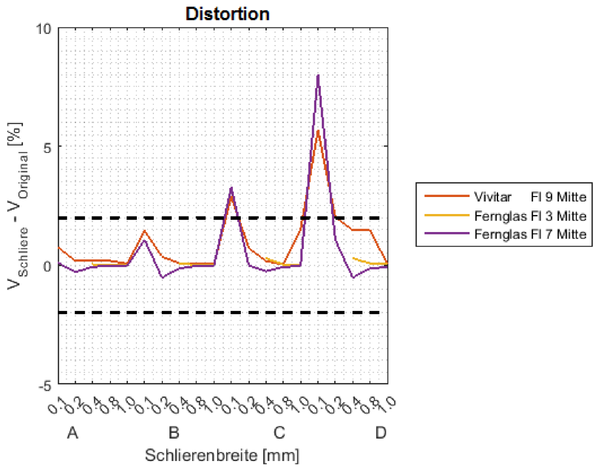

Fig. 3 *Striae simulation results for distortion. The dotted line displays the limit for tolerable distortion. The x-axis show different striae levels (namly A, B, C, D – see Tab. 1) and (!) different striae width (0.1 mm … 1.0 mm) for each striae level.*

Fig. 3 shows the most impact have short ranged striae of width of 0.1 mm. But, if the stria is below C level (with optical path difference $\Delta L < 30\,nm$ – SW30) the distortion is tolerable and below the limit.

6 Summary and outlook

Striae in optical system simulations are presented. A striae inside a glass (and thus inside a lens) cause a wave front deformation and thus can cause a blurring of the image. First results show, if the striae level is below 30 nm optical path difference (SW30 – C classification) striae have low impact regardless of its structural width. In a future work more typical sample systems should be investigated.

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