Measuring the refractive power with deflectometry in transmission

Markus C. Knauer, Claus Richter, Peter Vogt, Gerd Häusler

Institute of Optics, Information and Photonics, Max Planck Research Group, University of Erlangen-Nuremberg

mailto:mknauer@optik.uni-erlangen.de

We apply “Phase-measuring Deflectometry” to the high-precision measurement of refractive power maps in transmission. The similarities and differences compared to the reflective setup are discussed. We present measurement results for precision lenses as well as for car glass windows.

1 Introduction

“Phase-measuring Deflectometry” (PMD) meanwhile is well established for measuring specular surfaces – in reflection [1]. One application is the measurement of the so-called reflection-optics of car glass windows. This is important from an aesthetic point of view only. Now, the question was, if it is also possible to measure the security-relevant refractive power of car glass windows in transmission to provide a second, traceable method in addition to the existing methods [2]. The target accuracy was 1 mD for a distance Δx of 3 mm (Fig. 1). This corresponds to a wave aberration of 1 nm only.

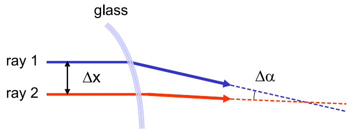

Fig. 1 *For car glass windows the refractive power is defined as $D := \Delta\alpha/\Delta x$. $\Delta\alpha$ is the angle between two rays that have been parallel before the transmission through the car window glass and had a distance of Δx.*

2 Principle

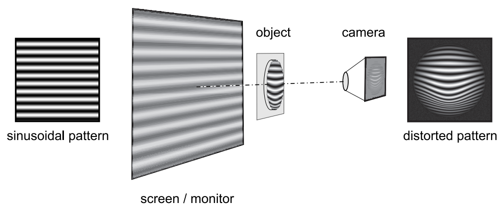

Fig. 2 *The main components of the system are a screen for pattern generation and an observing camera.*

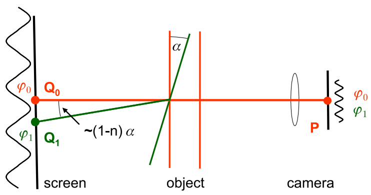

Fig. 3 *The measured phase (offset) depends on the local prismatic action of the object under test.*

The basic principle is very similar to that in reflection (Fig. 2). In reflection, the primary measurand is the local slope of the surface. In transmission, the primary measurand is the local prismatic action (Fig. 3).

3 Calibration and evaluation

The calibration of the system is comparable to that in reflection [3]. However, there is one big advantage: We do not need a planar calibration mirror. The “reference” measurement can be performed simply by removing the sample from the setup.

The definition of the refractive power in Fig. 1 presumes parallel rays. Possible solutions would be a telecentric observation or a very large observation distance. For weak lenses we also can apply a closer, diverging observation and calculate the effect the object would have on parallel rays. The curvature of the transmitted wavefront then can be calculated analogously to the calculation of the curvature of surfaces [4].

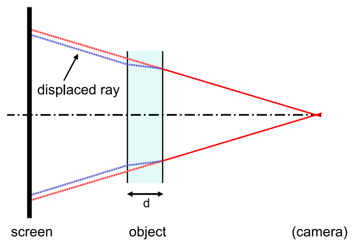

Fig. 4 *The diverging observation causes a ray displacement that depends on the thickness of the object and the angle of the ray of vision.*

When re-normalizing the results to parallel rays, some effects have to be considered. For example the thickness of the object has to be known and compensated for (Fig. 4). For the actual laboratory setup, the resulting error without compensation is about 0.7 mD/mm. Another effect is the change of the refractive power for tilted lenses. However, the explanation of the compensation algorithm would go beyond the scope of this article.

In addition to the effects of the transmissive measurement, there is also the ambiguity common to all deflectometric systems concerning the height and slope measurement. Because of the geometry of the transmissive system an inaccurate estimation of the position of the object only yields very small errors in the resulting curvature (Fig. 5).

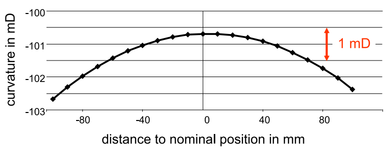

***Fig. 5** An inaccurate position of the object yields a small offset in the resulting curvature.*

4 Results

Fig. 6 and Fig. 7 display the measurement of two precision lenses, certified by the National Physical Laboratory (UK). The resulting mean values (lateral resolution 10 mm) correspond to the nominal values with an error better than 1 mD. The remaining waviness for a lateral resolution of 3 mm is approximately 3 mD. We measured a whole set of lenses ranging from -250 to +250 mD. The error was lower then 1 mD for all lenses (Fig. 8).

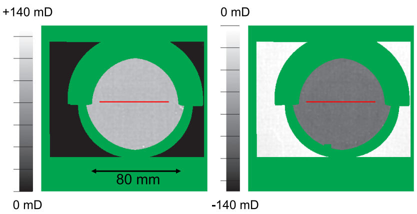

***Fig. 6** Refractive power maps of two precision lenses with +100 and -100 mD. The green parts are occlusions by the mounts and the borders of the field of measurement. The outer gray parts mark air and have the value 0 mD.*

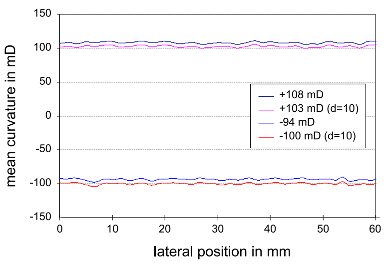

***Fig. 7** Cross sections of Fig. 6 with (d=10 mm) and without thickness compensation.*

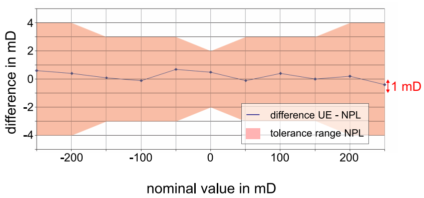

***Fig. 8** Deviation of the measured mean values from the nominal values for a whole set of precision lenses. The error is always lower than 1 mD.*

The system also was set up for the measurement of parts of windshields. It is possible to examine suspicious areas in more detail. Fig. 9 shows a typical result. It is also possible to set up much larger systems to measure large parts of glass sheets at once.

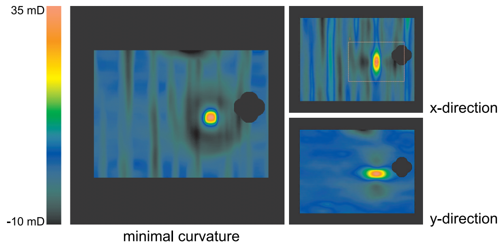

***Fig. 9** Defect on a windshield. The measurement yields the whole curvature tensor. Thus it is also possible to distinguish the so-called float drawlines (visible in the x-direction curvature map) from other defects.*

5 Summary and outlook

The actual system can be used to measure the local and mean refractive power of weak lenses with high accuracy. The system setup is very simple and robust. Thus, it is possible to use the system in a rugged industrial environment. The next step will be the extension to objects with higher refraction like eyeglass lenses (Fig. 10).

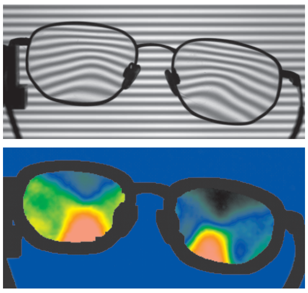

***Fig. 10** Qualitative measurement of eyeglasses.*

References

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