Can Deflectometry Work in Presence of Parasitic Reflections?

Christian Faber, Markus C. Knauer, Gerd Häusler
Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg
mailto:christian.faber@physik.uni-erlangen.de

At present, deflectometric measurements of transparent objects suffer from one severe limitation: Due to parasitic reflections at the rear side of the specimen, conventional phase evaluation approaches are no longer applicable. We present and compare three different options to overcome this problem.

1 Introduction

Phase Measuring Deflectometry (PMD) is a meanwhile established technique for optical measurements of specular freeform surfaces [1, 2]. The basic principle is depicted in the left part of Fig. 1. An extended light source (screen) is observed via the object's surface. The actual carrier of information is the particular geometrical location on the screen from where a given point on the object surfcace reflects light into a known observation pupil. From this information the surface slope can be inferred.
This source location commonly is encoded in the phase of a shifted sinusoidal illumination pattern, allowing for accurate localisation even with pixelated spatial light modulators. However, when being applied to transparent objects, the additional reflection at the rear side of the object often renders standard phase measuring approaches impossible.

The current practice is to prepare the objects under test by roughening or blackening their rear sides prior to measurement. As this is possible only for laboratory applications and not within a production environment, new solutions without affecting the integrity of the test piece are necessary.

2 Model

Figure 1 illustrates that the unsolicited rear side reflection entails an incoherent superposition of *two* signals in each given observation point, one originating from the actual source location of interest ("transmitter"), the second one from a different location on the screen ("jamming station").

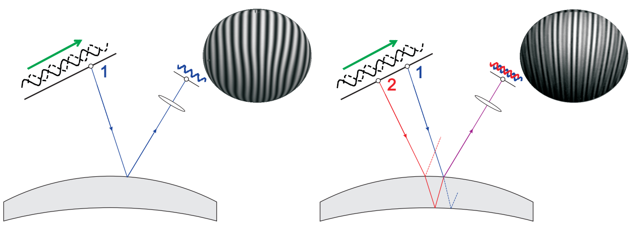

Fig. 1 *Superposition of front- and rear side signal.*
1: screen location of the "transmitter"
2: screen location of the "jamming station"

3 Approaches

There are three different ways to approach this problem:

3.1 Avoiding the problem by suppressing the reflex from the rear side

This can be achieved by changing the physical setting so that the object under test is not transparent anymore — e. g. by using an ultraviolet light source. However, this poses high technical challenges, as there are no suitable spatial light modulators readily available in the required spectral range.

3.2 Preventing the superposition by a proper spatial separation of the signals

Figure 2 illustrates this concept. Unfortunately, to ensure that transmitter and jamming station are not sending their signals at the same time, a rough estimate of their respective locations on the screen must be at hand at the time of measurement. This requires a quantitative prior knowledge of the specimen under test. Moreover, for thin and/or weak lenses the spatial separation of these screen regions may not be sufficient.

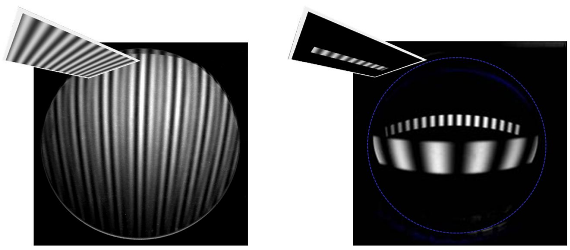

Fig. 2 *Spatial separation of front- and rear side signal. Inlays depict the corresponding illumination patterns on the screen.*

One way to deal with these drawbacks is to take this approach to the limit, illuminating only *one isolated line at a time* on the screen during a *scanning process* (see Fig. 3). We call this "line-shift approach". In this case, no prior knowledge about the object geometry is required and an (almost) full-field evaluation becomes possible. Only the (roughly "one-dimensional") regions on the object where the line images of the front- and rear side reflections intersect (and thus still superimpose) cannot be evaluated. These regions will be referred to as "*pathologic curves*".

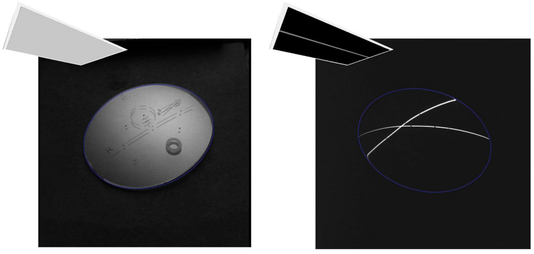

Fig. 3 *Illuminating the object with a single line. Inlays depict the corresponding illumination patterns on the screen.*

Unfortunately, for practical use, the line on the screen has to be chosen sufficiently wide and 'smooth' to avoid sampling artefacts. This implicates that the pathologic curve can become quite "broad". Although different camera locations, object orientations and/or line directions entail *different* pathologic curves on the object, these commonly do not vary enough to get rid of this limitation in practice.

3.3 Unmixing *the signals algorithmically afterwards by solving an inverse problem*

Concerning the third approach, the signal in a given observation pixel emerging from the incoherent superposition of front- and rear side reflex is given by:

$$\begin{aligned} I_{12}(\varphi_s) &= \bar{I}_1 + M_1 \cos(\varphi_1 - \varphi_s) + \\ &\quad \bar{I}_2 + M_2 \cos(\varphi_2 - \varphi_s) \\ &= \bar{I}_{12} + M_{12} \cos(\varphi_{12} - \varphi_s) \end{aligned} \quad (1)$$

with detected intensity I_{12}, stepping phase φ_s, mean intensities $\bar{I}_1$ and $\bar{I}_2$ for front- and rear side signal and respective modulations M_1, M_2 and phases φ_1, φ_2. The "mixed" quantities $\bar{I}_{12}$, M_{12} and φ_{12} denoting the corresponding parameters of the combined signal can be calculated from the measured data directly by standard phase shifting algorithms. The task is to recover the original phases φ_1 and φ_2 carrying the information of interest. As this model contains six unknown parameters, it is obvious that more than three different measured intensities are required to do so.

We were able to show that by an appropriate variation of the fringe period of the sinusoidal pattern, the information sought-after can actually be retrieved. We call this "multifrequency approach".

4 Results

All three approaches allow for the measurement of transparent specular objects without prior preparation of the rear surface. While the UV-approach requires considerable technical (and thus economical) expenses, both the line-shift and the multifrequency approach can be implemented without effort on the setup side. This has been demonstrated based on the example of refractive power measurements for progressive eyeglass lenses. The results are shown in Fig. 4 and Fig. 5.

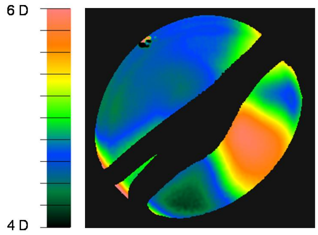

Fig. 4 *Refractive power of a progressive eyeglass lens measured with the line-shift approach. The rear side of the object has* not *been prepared to avoid reflection.*

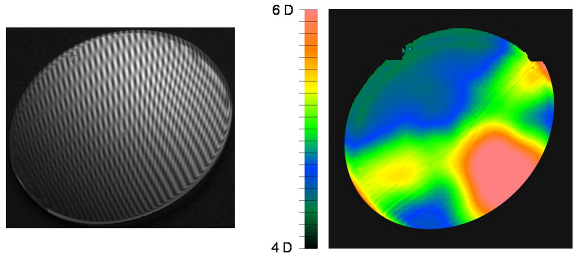

Fig. 5 *Refractive power of a progressive eyeglass lens measured with multifrequency technique. The rear side of the object has* not *been prepared. The left side shows a corresponding raw data image.*

As the pathologic regions occuring in the line-shift approach can become quite large, the multifrequency solution is preferred. Moreover, this approach is also favourable as far as information efficiency is concerned.

5 Summary and Outlook

It has been shown that deflectometric measurements can be carried out for transparent objects without prior roughening or blackening their rear surface. The next steps will be to improve the image quality by a suitable extension of the applied model and to minimize the number of the recorded raw data images in order to speed up the measurement process.

References

[1] M. C. Knauer, J. Kaminski, and G. Häusler, "Phase Measuring Deflectometry: a new approach to measure specular free-form surfaces", Proc. SPIE 5457, pp. 366–376 (2004).

[2] M. C. Knauer, C. Richter, O. Hýbl, J. Kaminski, C. Faber and G. Häusler, "Deflektometrie macht der Interferometrie Konkurrenz", tm – Technisches Messen, 76, pp. 175-181 (2009)

We thank the 'Bayerische Forschungsstiftung' for the financial support of the Project 748-07.