Improved Combined Diffractive Optical Elements for quasi absolute testing of Aspherics

Gufran Khan, Klaus Mantel, Norbert Lindlein, and Johannes Schwider

Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg
Staudtstr. 7/B2, 91058, Erlangen

mailto:gkhan@optik.uni-erlangen.de

We present a three position quasi absolute test for aspherics by using Combined Diffractive Optical Elements (Combo-DOEs). We discuss the effects of DOE's substrate quality on the accuracy of the proposed calibration procedure and present an improved design of the Combo-DOE. Further, the non-rotational deviations extracted from this procedure are compared with that of N-position rotational averaging procedure and are found in good agreement.

1 Introduction

Computer Generated Holograms (CGHs), which can also be termed as Diffractive Optical Elements (DOEs), have widely been in use for the precise testing of aspherics in different interferometric setups [1]. The high accuracy measurement requires an absolute calibration of the interferometric system, including the removal of errors introduced by the null element.

Schwider [2,3] proposed a three position quasi absolute test for rotationally symmetric aspherics by using a dual wavefront DOE, which is encoded with the aspheric wavefront as well as the best fit spherical wavefront with a slight linear offset. The calibration procedure works similar to the three position test for spheres [4], as the additionally encoded spherical wavefront can be used for the cat's-eye measurement. Beyerlein et al [5] discussed the conditions for the separation of the two wavefronts using the mentioned procedure. The experimental realization of this concept by using two types of Combo-DOEs is just in print [6]. The initial results signify this technique as a potential tool for interferometric calibration in aspheric metrology. However, this procedure has a prevalent limitation, termed as "quasi-condition", which assumes that the DOE substrate and the lithographic errors are affecting both wavefronts identically. We reported an observed residual astigmatism while performing the consistency tests of this procedure [6]. In this paper we present further investigations on the sources of errors which can be responsible for the occurrence of the astigmatism in the consistency test. We focus our attention on the substrate quality and its implications on the accuracy of the procedure.

2 Measurement Principle

The three positions of the absolute measurement of a rotationally symmetric aspheric are shown in fig. 1. These positions are (1) an initial position, (2) a 180° rotated position of the aspheric under test, and (3) the cat's-eye position where a mirror has been placed at the focus of the spherical wavefront. For the first two positions, the aspheric wavefront has been used.

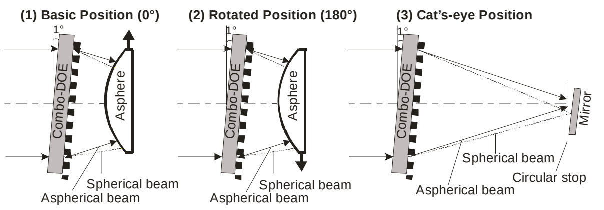

Fig. 1 *Measurement principle: Three positions for the quasi-absolute measurement of aspherical surfaces*

Design considerations of the Combo-DOE

To encode two wavefronts simultaneously, the DOE has been sliced in stripes of 50 μm size, which are alternatively assigned to the spherical and aspheric waves. To avoid back reflections from the surface of the DOE, the Combo-DOE is tilted at a 1° angle with respect to the optical axis. The spherical wavefront has an offset of 1°, which results approximately as a 2 mm linear offset in the focal plane.

There are four possibilities of the offset for the spherical wavefront as shown in fig. 2. The XY plane is the DOE plane and the offset can be along the +X, -X, +Y, and –Y directions.

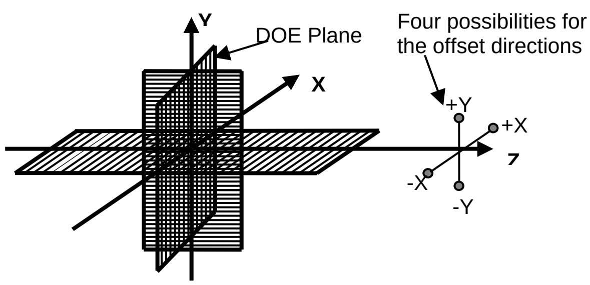

Fig. 2 *Four possibilities of the linear offset for the spherical wavefront*

Simulation studies show that any of these offset directions can be chosen irrespective of the tilt orientation of the Combo-DOE provided there are no surface deviations present in the Combo-DOE. But in the presence of a DOE deviation, it is imperative to consider the tilt direction of the Combo-DOE with respect to the offset of the spherical wavefront. The focus of the spherical wavefront should be in the direction of the surface normal, e.g. if the DOE is tilted counter clockwise around Y axis, then the offset of the spherical wavefront should be in +X direction (see fig. 2).

4 Results and Discussions

To demonstrate the principle, a phase-shifting Twyman-Green interferometric setup has been used. A rotationally symmetric convex asphere of diameter 50 mm has been chosen as a test specimen. The maximum aspheric deformation from the best fit sphere is approx. 0.25 mm (i.e. ~ 400 waves) at the edge. Using the three position procedure described in the previous section, the surface deviations of the test specimen are determined. Figure 3 (a) shows the contour plot of the absolute deviations of the surface with a contour line spacing of λ/10.

Another set of absolute deviations has been extracted while the aspheric was rotated about an angle of 90°. Though, having two sets of such absolute measurements does not give any new information about the surface errors, but nevertheless gives more insight into the consistency of the test procedure. Figure 3 (b) shows the difference between these two sets of absolute measurements, while one is rotated back by 90º to ensure the same orientation. One expects only random errors present in this difference, but a residual error in the form of astigmatism is observed.

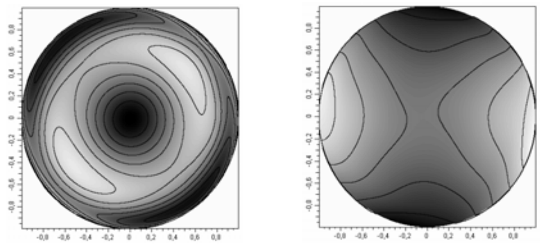

Fig. 3 *Experimental results: (a) Absolute deviations of the surface under test (b) Difference between the two absolute measurements. The contour line spacing is λ/10.*

The appearance of astigmatism in the consistency test is because the Combo-DOE was not designed by taking the orientation of the tilt into account and the orientation of the offset has been chosen incorrectly. When the Combo-DOE is optimally designed, the consistency test shows an improvement by a factor of twelve (fig. 4). Due to the non-availability of an optimally designed Combo-DOE for the aspheric at the time of writing this paper summary, the result shown in fig. 4 was achieved with an optimally designed Combo-DOE for testing a spherical surface.

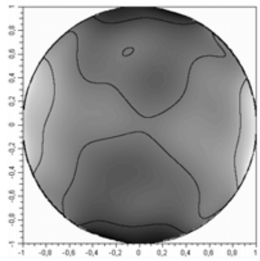

Fig. 4 *Difference between the two absolute measurements (in the case of a spherical surface) with a Combo-DOE having appropriate direction of the offset with respect to the DOE-tilt. Contour lines spacing is λ/100.*

5 Conclusion

In summary, we have presented a quasi-absolute test for rotationally symmetric aspherics, where the combined-diffractive optical elements have been used as null elements in a Twyman-Green interferometric setup. It was found that the orientation of the tilt of the Combo-DOE and the offset direction of the spherical wavefront play a critical role in the presence of substrate deviations. The consistency of the procedure is improved by an optimised design of the Combo-DOE.

References

1 J. C. Wyant, V. P. Bennett, “Using Computer Generated Holograms to Test Aspheric Wavefronts“ in *Appl. Opt*. **11**: 2833-2839 (1972)

2 J. Schwider; “Absolutprüfung von asphärischen Flächen unter Zuhilfenahme von diffraktiven Normalelementen und planen sowie sphärischen Referenzflächen”; German Patent application filed 20.06.98, Offenlegungsschrift: DE198 22 453 A1

3 J. Schwider, “Interferometric tests for aspherics“ in *Fabrication and Testing of Aspheres, A. Lindquist, M. Piscotty, and J. S. Taylor* (Editors), Vol 24 of OSA Trends in Optics and Photonics Series, Optical Society of America, Washington, D.C: 103-114 (1999)

4 A. E. Jensen, “Absolute calibration method for laser Twyman-Green wave-front testing interferometers” in *J. Opt. Soc. Am.* **63**: 1313A (1973)

5 M. Beyerlein, N. Lindlein, and J. Schwider, “Dual-wave-front computer-generated holograms for quasi-absolute testing of aspherics“ in *Appl. Opt.* **41**: 2440-2447 (2002)

6 F. Simon, G. Khan, K. Mantel, N. Lindlein, and J. Schwider, “Quasi-absolute measurement of aspheres with a combined diffractive optical element as reference” **in print** *Appl. Opt*.