Evaluation of Topography and Slope of Free-Formed Optics

R. Schmitt, D. Köllmann
Fraunhofer Institute for Production Technology IPT, Aachen, Germany

danny.koellmann@ipt.fraunhofer.de

Abstract

This paper describes the development and verification of software algorithms for the processing of comprehensive surface data with the aim of evaluating free-formed optics. Consequently, the compensation of machining errors can be achieved leading to a more efficient and reliable optic production.

1 Introduction – Adaptive Manufacturing for Complex Optics

The production of aspheres and free-formed optics currently requires several iteration steps, consisting of form measurement and corrective machining cycles in order to meet the design tolerances, because the production processes are complex and entail a wide variety of failure influences that cannot be estimated correctly beforehand. Therefore, metrology consisting of measurement system and evaluation software for the determination of surface errors is gaining importance.

2 Deflectometric Inspection of Optical Surfaces

Phase measuring deflectometry enables the non-contact and full surface measurement of optical components. The principle is to project sinusoidal fringe patterns onto a screen and to observe its reflection via the surface under test. Using well-known phase-shift algorithms allows measuring the reflection angle in each pixel of the camera and thus calculating the slope of the surface. Hence, the topography is reconstructed via integration and the curvature via derivation of the local slope. Consequently, comprehensive geometry data is available for evaluating the optical surface.

3 Processing of Measurement Data

The developed software algorithms enable analysing form and slope of the surface under test. The measurand slope provides further information about the waviness.

This permits conclusions about production parameters such as feed rate by observation of the toolmarks and about performance reductions of the optical system caused by scattered light. In order to determine topography and slope errors, the software provides functionalities such as manual coarse alignment of design and measurement data, automatic segmentation algorithms and best-fit alignment. The latter minimises the differences in height and slope (elevation and azimuth) simultaneously. The parameters for the optimisation algorithm are weighted according to their impact on the error matrix. Subsequently, the height errors are calculated in z-direction and slope errors either relatively or by determination of the deviation's value and direction.

In order to analyse the developed registration algorithm, the alignment inputs were design data and simulated measurement data. This procedure has the advantage of being able to define the deviation that is intended to result from the target-actual comparison and is therefore independent of actual manufacturing errors.

The simulated measurement data was created by modifying the original design topography using a mathematically generated deformation. Two types of deformation were applied; first, rotation-symmetric errors typical for ultra-precision grinded workpieces, and second, asymmetric deformations like non-uniform shrinkage. Afterwards, a random translation and rotation was applied on the simulated measurement data. Subsequently, the best-fit registration matched the measurement and design data, and the analysis of the result was done by calculating the difference between initial and obtained error map.

Table1: Evaluation of registration performance for rotation-symmetric errors

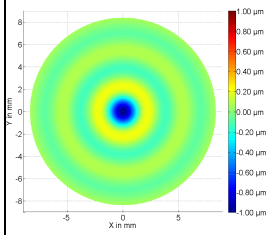
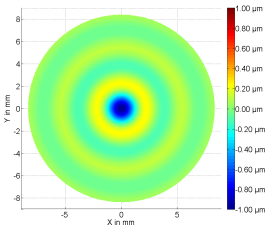
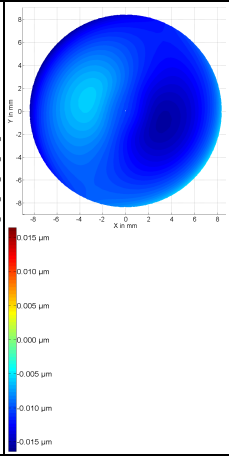
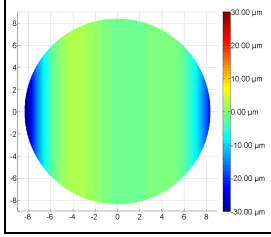
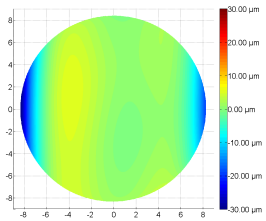
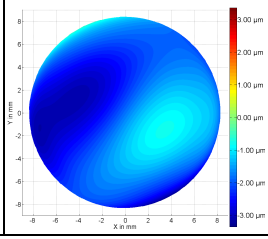
Introduced form error	Obtained error map	Difference between error maps
		

Table2: Evaluation of registration performance for asymmetric errors

Introduced form error	Obtained error map	Difference between error maps
		

The maximum deviation between the initial error map and the error map calculated by target-actual comparison after alignment was in case of rotation-symmetric errors 15 nm and 3 µm for asymmetric errors. This leads to the conclusion that for unsymmetrical errors the data segmentation is crucial for improving the target-actual comparison. Using areas with higher form accuracies within the data processing prevents that the aligning algorithms are affected by asymmetric form errors [1].

4 First Results and Outlook

Practical investigations were used to analyse the influences of different production parameters on the form accuracy within the fast-tool turning process. In a first step the impact of the feed rate was observed. For this purpose, two facet mirrors, as used for laser beam shaping, were manufactured with identical parameters except for the feed rates of 0.4 mm/min and 2.5 mm/min respectively. The error maps generated by using the novel algorithms are depicted in figure 1. They illustrate the difference in form accuracy between both specimens, which is in the range of 6 µm, due to thermal load resulting from the different machining times. The slope error map (figure 2) provides further information about the surface quality, i.e. machining marks. Result of this holistic evaluation method was identifying failures in the production process and thereby the execution of measures for improving the quality.

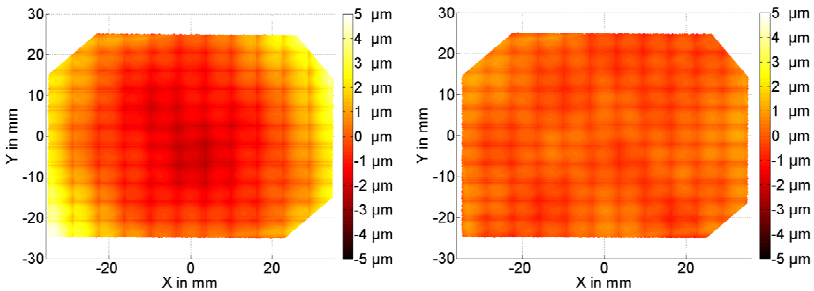


Figure 1: Error map a) facet mirror - 0.4 mm/min b) facet mirror - 2.5 mm/min

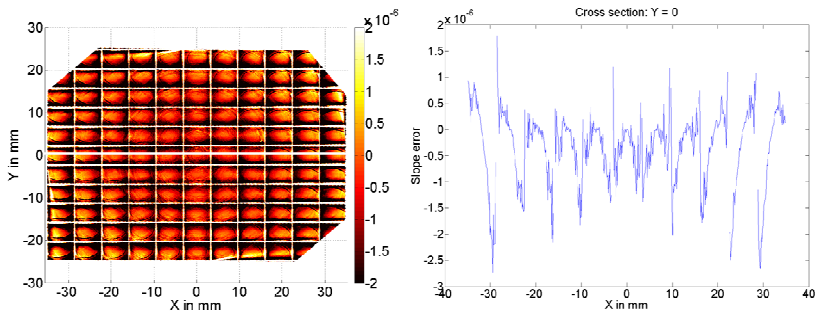


Figure 2: Slope error map with cross section

Further investigations will concentrate on improving the alignment process by using tailored data segmentation algorithms.

5 Acknowledgement

The achievements presented in this paper are the results from the EC-funded Integrated Project »Production4µ«.

The authors would like to thank the European Commission for their support that enabled the works done in the field of precision metrology and manufacturing of optical components.

References:

[1] Schmitt, R.; Brecher, C.; Köllmann, D.; Buß, C.; Manhães, M.: Segmentation and selective alignment of measurement data for optical surfaces, EOS 2009 Proceedings