Current activities towards traceable form measurements of aspheres with a tilted-wave interferometer

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Aspheres are key components of modern optical systems. However, their potential can only be utilised with high manufacturing quality, which is currently still limited by form measuring metrology. This article provides an overview of current activities of the Physikalisch-Technische Bundesanstalt (PTB) for the development of a traceable form measurement of aspheres based on a tilted-wave interferometer.

1 Introduction

Aspheres enable high-quality optical systems with less lenses while maintaining or even improving imaging quality. A reason for this is that they have more degrees of freedom compared to spherical surfaces. Therefore, imaging errors can easily be compensated for. This is why such complex lenses are becoming increasingly popular. However, their potential can only be utilized if the production quality is high, which is currently still limited by form measuring metrology. At the Physikalisch-Technische Bundesanstalt (PTB), the National Metrology Institute of Germany, a traceable reference measurement setup for the form measurement of such surfaces based on tilted-wave interferometry is under development. Tilted-wave interferometry is a promising but challenging measurement technique, since the measurement principle combines special interferometric measurements with model-based evaluation principles. Traceable measurement results with sufficiently low uncertainty are a major challenge. This contribution presents current activities at PTB to tackle this task.

2 Tilted-wave interferometry

In a tilted-wave interferometer (TWI) [1, 2, 3], a microlens array (MLA) in conjunction with a special blocking mask is utilized to generate wavefronts of varying tilt in the measurement arm illuminating the surface under test (SUT). This generates measurement data with multiple sub-interferograms (Fig. 1). By comparing simulated data generated using a model of the setup with the data measured, the form of the SUT is reconstructed. This process involves solving a non-linear, high-dimensional inverse problem. Beforehand, the model has to be adjusted to the real instrument to ensure that the model accurately replicates the actual experiment. By measuring well-known reference surfaces at more than 100 positions within the setup and comparing the measurement data to data simulated using the design model, another nonlinear, high-dimensional inverse problem is solved to adjust the model [2, 3].

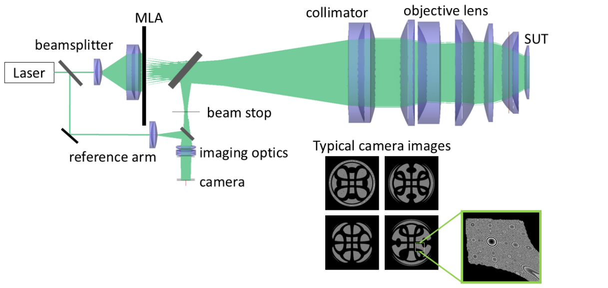

***Fig. 1** Sketch of the TWI setup together with typical camera images for an asphere (adapted from [3], CC BY 4.0).*

3 Advancements towards traceable form measurements

The development of a traceable reference measurement system based on a TWI is challenging, especially due to the embedded virtual measurements, high-dimensional nonlinear inverse problems, large amounts of data and long computing times. Nevertheless, several advancements have already been achieved during the past years: The measurement system at PTB has been developed including the data evaluation algorithms and first measurement results show good agreement with the virtual reference topography calculated from other instruments [4, 3]. Furthermore, a concept for traceability was outlined [5], sensitivity analyses have been performed, methods of experimental design were applied and virtual experiments were used to assess the main sources of uncertainty [4, 6, 7, 8].

3.1 Current activities

Concepts for a GUM-compliant uncertainty determination for such measurement systems (incl. inverse problems) are part of today's research. Within the European Partnership on Metrology (EPM)

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project "Trustworthy virtual experiments and digital twins" (22DIT01 ViDiT, vidit.ptb.de) an approximative Bayesian approach to tackle the inverse problem based on a statistical model derived from the computational model of the interferometer was developed and applied to a simplified TWI [8]. The results show strong sensitivity with respect to certain input quantities and the uncertainty of the input quantities is subject to current research.
An important source of uncertainty in aspherical form measurements in general and in TWI measurements in particular are positioning uncertainties [6, 9]. To reduce the uncertainty caused by alignment of the SUT, the improvement of absolute position information is investigated in the national research project "Absolute form-interferometry for aspheres and freeform surfaces (AbsoForm)" funded by DFG. Within this project, two different approaches are investigated to improve absolute position information: The first approach investigates an additional length measurement together with a sophisticated alignment procedure [10], while the second approach uses an internal distance measurement by applying multiple wavelength interferometry to a TWI Fizeau system [11].
Furthermore, the progress of traceable asphere metrology is also supported by the work of two competence centers: Within the PTB-internal competence center "Metrology for virtual measuring instruments (VirtMet)", recent developments in the field of virtual metrology are discussed, existing expertise is pooled and synergy effects between different applications are exploited. The competence center for Ultra Precise Surface Figuring (CC UPOB e.V., www.upob.de) regularly organizes international measurement campaigns for the form measurement of aspheres and discusses recent developments in this field. Here, PTB contributes e.g. by developing comparison methods or analyzing and comparing the measurement data [12].

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