Investigation of reference position based specimen adjustment in tilted-wave interferometry

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Tilted-wave interferometry offers a promising approach for non-null-test form measurement of aspheres and freeform surfaces. However, an ambiguity between the measured absolute surface form and specimen positioning error exists. We present a specimen adjustment strategy to ensure accurate specimen positioning and therefore reliable form measurement results in tilted-wave interferomtry.

1 Introduction

Aspheres and freeform surfaces are in high demand for their properties in compact, yet powerful optics both in high demanding scientific and comsumer applications. To aid production capabilities, tilted-wave interferometry (TWI) [1] offers fast non-null-test measurement capabilities using a model based approach. However, similar to other interferometric form measuring methods, ambiguities between the surface form deviation and the specimen position error [2] make highly-accurate measurements of the low order aberrations, especially spherical form errors, challenging. We therefore present a reference position based multi-step approach for accurately aligning the specimen position in the measurement setup with the specimen position used in the model of the interferometer.

2 Method

The alignment procedure is divided into two separate alignment steps: first, the alignment along the optical axis (z-axis) and second, the alignment of the lateral position and tilt (x, y, α, β, and γ, dependent on the specimen's degrees of freedom).

2.1 Axial specimen alignment

For the specimen alignment along the optical axis, the so-called Cat's Eye position [3] is used as an specimen independent reference position. In the Cat's Eye position, the specimen's apex is located in the focal spot of the objective lens, leading to the measured interferogram being independent of the surface form. A scheme of the optical setup of the specimen in the Cat's Eye position is given in Fig. 1 (a). To align the specimen into this position, the specimen is illuminated by light impinging from the central microlens of the microlens array [1] and the interferogram is recorded. The optical path lengths (OPLs) are extracted and the nominal OPLs are generated by simulating the OPLs using a model of the interferometer. The optical path differences (OPDs) between both are then developed into Zernike coefficients. The axial position of the specimen is varied until the *Defocus*-coefficient (Z_2^0) reaches zero. A detailed description of the method is given in [4].

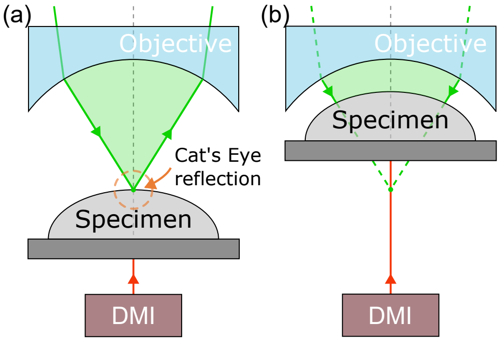

Fig. 1 *Scheme of the measurement configuration including the interferometer's objective, the specimen on the specimen stage, and a distance measuring interferometer (DMI) in (a) the Cat's Eye position and (b) the measurement position.*

2.2 Lateral specimen alignment

After the axial alignment, the specimen is moved axially into the measurement position (see Fig. 1 (b)). The axial distance is tracked with a distance measuring interferometer (DMI), which effectively references the measurement position to the Cat's Eye position. In the measurement position, the specimen is aligned with regard to its lateral position and its orientation (depending on the degrees of freedom of the specimen). For this, the microlens array is not restricted to the central microlens anymore. Therefore, typical TWI measurement data generated by differently tilted wavefronts are recorded. The difference between the measured OPLs and the OPLs of an ideal specimen without form and positioning errors is calculated (see Fig. 2). The resulting differences are caused by the form and positioning errors of the surface under test. With these data, the alignment optimization can be performed by minimizing the sum of the squared OPDs, turning it into an optimization problem.

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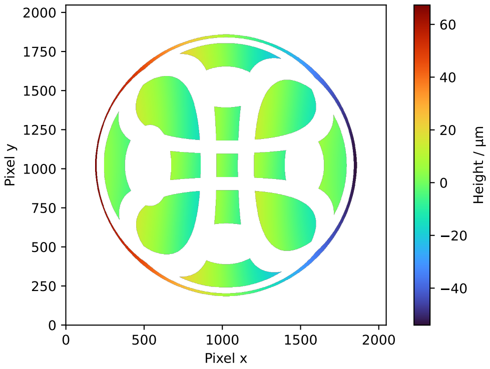

Fig. 2 *Optical path differences between measurement and simulated data of ideal specimen without form and positioning errors.*

The partial derivatives of the OPDs required for this optimization (partial derivatives of the OPDs with regard to the position and orientation of the surface) are an outcome of the simulation with the model of the interferometer [5].

3 Results

For evaluating the repeatability of the axial adjustment, various test specimens with different surface form were repeatedly brought into the Cat's Eye reference position and the specimen stage position was tracked with a DMI [4]. The short term position repeatability shows a good stability with a standard deviation in the range of a few ten nanometers (see Tab. 1)

Specimen	σ_z/nm
Asphere	27
Sphere with radius 15 mm	21
Sphere with radius 40 mm	16
Toroid	26

Tab. 1 *Standard deviation of the measured axial specimen position for repeated Cat's Eye positioning of different specimens.*

To evaluate the lateral alignment procedure using the difference between measured OPLs and simulated OPLs of the ideal specimen, a set of simulated measurement data with a specimen with varied positions along the x-axis is generated. The OPDs of the virtual measurement data and the ideal reference are calculated and the position is estimated using a linear optimization step. The result for the different specimen positions is shown in Fig. 3.

4 Conclusion

In this work, a reference-based method for specimen alignment is presented, with which the surface under test can be accurately aligned to the position used in the interferometer model within the measurement setup.

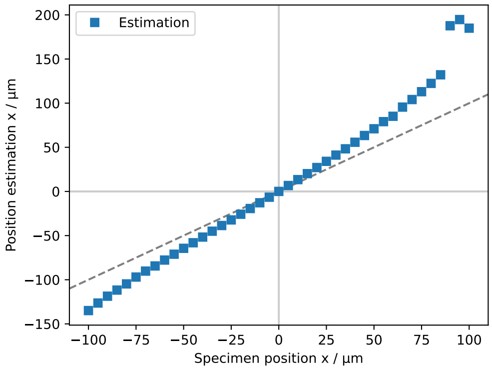

Fig. 3 *Lateral specimen position estimated in x over actual specimen position for a virtual experiment.*

The process was developed using virtual experiments and the adjustment into the Cat's Eye reference position was experimentally investigated, showing a good positioning repeatability in the order of a few tens of nanometers standard deviation. The lateral alignment procedure was tested using virtual experiments and the results show good agreement for small misalignments, which is sufficient to implement an iterative optimization procedure.

Future work will finish the implementation of the full alignment strategy and investigate the complete process in terms of repeatability. Finally, the method will be validated by measuring well-known reference specimens and the absolute distance between the Cat's Eye position and the TWI lens system will be further investigated.

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