Investigation of the positioning accuracy of the Cat's Eye as a reference position in asphere-measuring interferometry

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Abstract. Fast and accurate asphere and freeform measurements are in high demand by the optics manufacturing industry. Interferometric methods such as tilted-wave interferometry meet these demands but require accurate surface positioning of the specimen along the optical axis, since such measurements are sensitive to such positioning errors. In this work the Cat's Eye position will be investigated in terms of accuracy and repeatability as a reference position for surface positioning in tilted-wave interferometry. For this purpose, a two-regime method for specimen alignment using different optimization criteria is investigated and its repeatability is evaluated. Accurate and reproducible positioning into the Cat's Eye position together with interferometric movement tracking will allow accurate specimen positioning along the optical axis, which will significantly reduce the surface measurement errors associated with such misalignment and improve the overall measurement uncertainty.

1 Introduction

Accurate form measuring techniques for asphere and freeform surfaces are in high demand by optics manufacturing industry. Therefore, interferometric methods such as tilted-wave interferometry [1] have gained recent interest as a promising solution. However, accurate form measurement of the surface form requires accurate positioning of the specimen within the measurement system, especially along the optical axis, since such uncorrected position errors would lead to errors in the measured surface form [2, 3]. To overcome this issue, reference positions, such as the so-called "Cat's Eye" [4] position are used.

The method for aligning a specimen to the measurement position in the tilted-wave interferometer (TWI) uses a two-step process. The Cat's Eye position is used as a reference position. Since all light from the measuring interferometer of the central microlens [1] is theoretically reflected in an ideal focus spot, it is theoretically only dependent on the interferometer's optical system and independent of the specimen's surface form and therefore easy to align with high interferometric accuracy along the optical axis. Thus, it can serve as a reference for specimen positioning along the optical axis of the measurement system. From the Cat's Eye position the specimen is moved into the measurement position. The relative distance is tracked by a distance measuring interferometer (DMI). The process is shown in Figure 1.

In this work, we investigate a two-regime method for aligning a specimen along the optical axis within a TWI setup. Therefore, we explore different indicators for the interferogram of a specimen in the Cat's Eye position. Furthermore, we examine the repeatability of the alignment method into the Cat`s Eye position both by simulations and measurements.

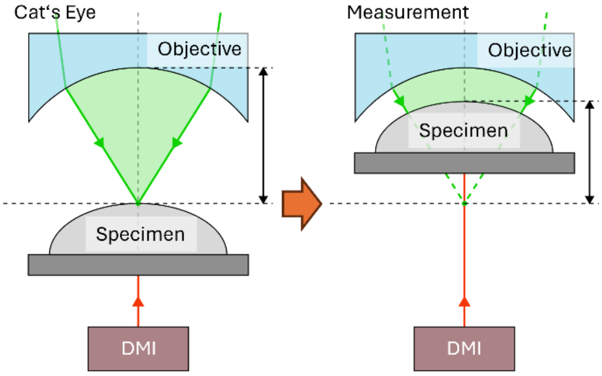

Fig. 1. Two-step specimen positioning within the TWI.

2 Method

2.1 Simulation of virtual interferograms

To develop an algorithm for specimen positioning into the Cat's Eye of the TWI, a digital twin [5] is used to generate virtual interference images. The resulting images are shown in Figure 2. Further away from the Cat's Eye, the interferogram patch has a rectangular shape, originating from a beam stop aperture, while closer to the Cat's Eye, the interferogram patch is round and the distance between the fringes gets larger the closer the specimen is to the Cat's Eye. Unlike in classical interferometry, the interference fringes in the Cat's Eye do not vanish. The

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reason is that the lens system of the object arm is optimized for several tilted wavefronts, instead of for a single wavefront, causing a not ideal focal spot. Thus, the wavefront of the reference arm and the wavefront in the Cat`s Eye reflection are not exactly matched in a TWI.

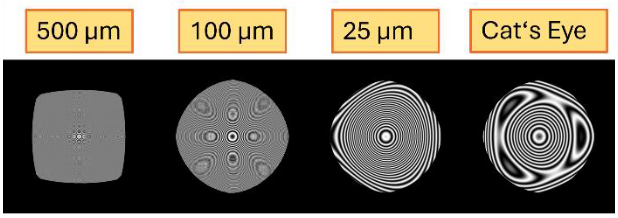

Fig. 2. Simulated TWI camera image in relation to the specimen’s distance to the Cat’s Eye position.

2.2. Position optimization criteria

For automatized positioning of a specimen in the Cat’s Eye position, the recorded interference image of the TWI is used. First, it is distinguished between a rectangular or a circular shape of the full interference patch. For a rectangular patch, the rectangle must be centred to roughly align the specimen perpendicular to the optical axis of the system. When translating the specimen towards the Cat’s Eye along the optical axis, the rectangular interference gets larger and finally transforms into a circular patch.

Using a phase reconstruction technique and phase unwrapping, the phase map of the measured interferogram is retrieved. This is compared to the phase map in the simulated Cat’s Eye position using a model of the interferometer. The z-position of the specimen is optimized to minimize the difference between both phase maps. This difference can be expressed in various ways, such as the root-mean square of the pointwise difference or the parameters of a polynomial fit e.g. Zernike fit. In Figure 3, the defocus term (Z_4, [6]) of a Zernike fit of the simulated phase difference maps is shown for various specimen topographies over their distance to the Cat’s Eye position.

2.3 Positioning and repeatability

A test specimen is inserted into the specimen stage of the TWI and moved along the optical axis until the rectangular interference patch becomes visible on the image sensor. Then, the first optimization step centres the rectangular patch perpendicular to the optical axis. In a second step, the specimen is moved along the optical axis into the regime of the circular interference patch. Here, the position along the optical axis is optimized by minimizing the phase map difference between the measured interferogram and the simulated Cat's Eye interferogram.

The process is repeated multiple times for different test specimens and optimization parameters. The final position of the Cat’s Eye optimization is tracked with the DMI, and the results are compared to evaluate the repeatability of the process.

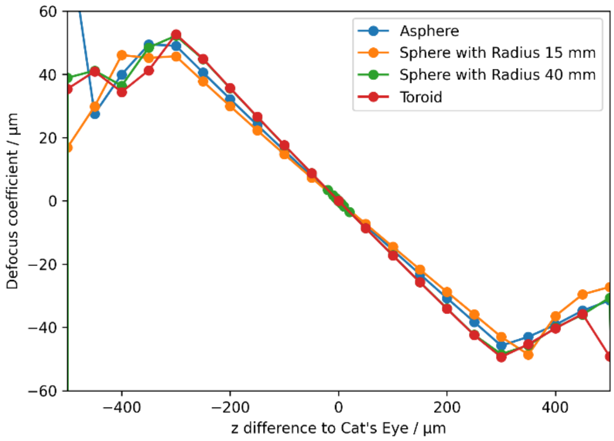

Fig. 3. Defocus of the simulated phase difference to Cat’s Eye phase in dependence of the z-position difference to the Cat`s Eye position.

3 Discussion

Accurate positioning of the specimen along the optical axis in form measuring interferometry is crucial for accurate form reconstruction. Therefore, a reliable process for specimen positioning has to be established. Using the Cat’s Eye position as a reference position is a common method in radius measuring interferometry for spherical surfaces. Knowledge of the repeatability of the Cat’s Eye position alignment in TWI will contribute to the knowledge of the positioning accuracy of the specimen in the TWI. This will contribute to establish the measurement uncertainty budget of the form measurement within the TWI.

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