Error analysis of an interferometric line-based form measuring system

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A new form measurement system enables fast measurements of arbitrarily shaped rotational symmetric specimens. A realistic model of the system has been developed which allows us to perform virtual experiments and especially to simulate the influences of main errors for different specimens. The simulations will be presented and the main error influences of the system will be discussed.

1 Introduction

The precise form measurement of nonspherical optical surfaces, e.g. aspheres, is still challenging. We have built up a new form measurement system for rotational symmetric specimens. The system is a preliminary result of a joint project funded by the Deutsche Forschungsgemeinschaft (DFG). It combines a fast line scanning interferometer with subaperture stitching and was presented at the last annual DGaO meetings [1, 2].The system is highly flexible and can be adapted to many specimen geometries. A realistic model of the system has been developed which allows us to perform virtual experiments and especially to simulate the influences of main errors for different specimens. With this model the noise of the fringes, the misalignment of the specimen, or the run-out of the movement axes can be quantified. The simulation model will be compared with real measurements to verify the model. The simulations will be presented and the main error influences of the system will be discussed.

2 Modeling of the system

The measurement system consists of a line sensor

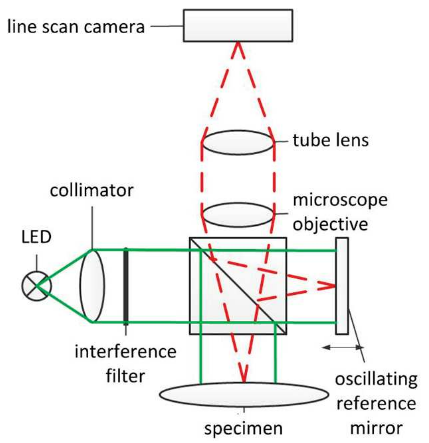

Fig. 1 *Sketch of the interferometer setup*

in a Michelson configuration with an oscillating reference mirror [3, 4] (see Fig.1).

2.1 Modeling of one oscillating period

One oscillating period of the system, which takes about 2.5 ms, can be modeled by the interference equation (see Eq. 1).

$$I(t) = I_0 \cdot \left(1 + B \cdot \cos\left(\frac{4\cdot\pi}{\lambda} \cdot z(t) + \varphi(t)\right)\right) \quad (1)$$

Additional topography errors, tilts of the specimen with respect to the sensor or motion errors and noise change the phase values (see Eq. 2).

$$\varphi(t) = \varphi_{design}(t) + \varphi_{topo}(t) + \varphi_{noise}(t) \quad (2)$$

To test the model, real topography data were used to simulate the expected interference signals $I(t)$. In a first approach, we neglected the term $\varphi_{noise}(t)$. From the simulated interference signals $I(t)$ the topography was reconstructed. The differences between the real and the reconstructed topography are within 5 nm (see Fig. 2).

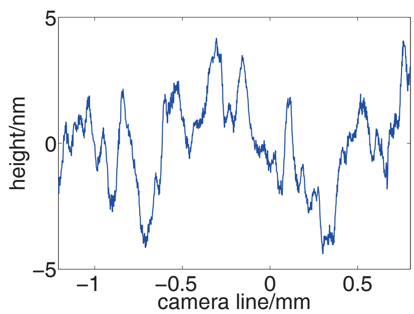

Fig. 2 *Differences between the real and the reconstructed topography*

The real topography has been measured with the system. The measured and simulated interference pattern looks almost the same (see Fig. 3).

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A detailed analysis reveals that the noise of the measured interference pattern results to topography errors in the range of 10 nm.

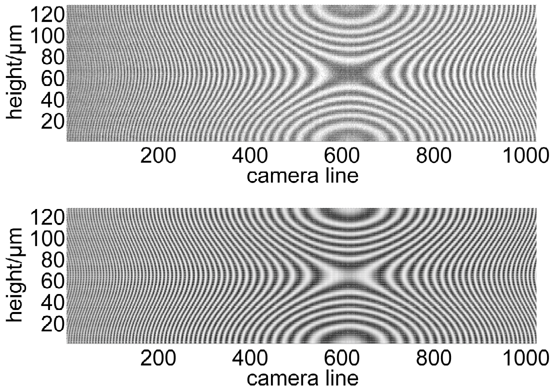

Fig. 3 *Measured and simulated interference patterns*

2.2 Modeling of one sub-aperture ring

The modeling of a complete ring scan is shown in Fig. 4. The model of the system contains a certain tilt of the specimen and some motion error. The tilt is modeled as a sinusoidal function with a PV of 30 µm that dominates the height values in scanning direction. The motion error is also modeled as a sinusoidal function but with higher frequency.

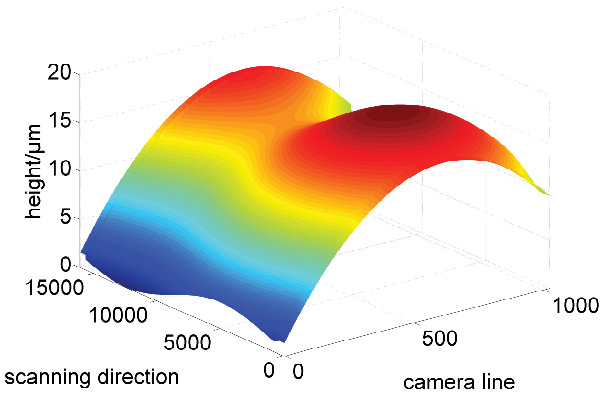

Fig. 4 *Simulated 3D height values during rotation with tilt and motion errors added*

The simulation also contains a standstill of the system to investigate the influence of noise or possible external vibrations during a measurement ring. Another simulated topography - typically for common sphere specimens - was evaluated like real measurement data. The deviation of the evaluated from the simulated topography is shown in Fig. 5. The standard deviation is about 3 nm. Since we are aiming for a measurement uncertainty of about 100 nm, the model is accurate enough.

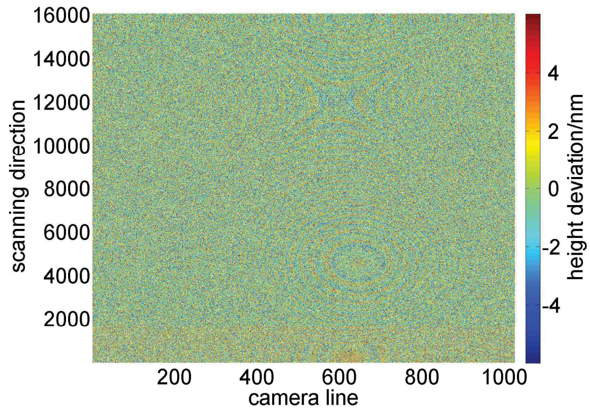

Fig. 5 *Difference between simulated and evaluated topography of one ring*

3 Summary

A model for the simulation of the line-based form measuring system has been implemented. Single rings can be simulated with motion errors and misalignment of the specimen. The model was tested by comparing simulated and measured interferences which agree within 10 nm. The model will be used for the estimation of the measurement uncertainty of the system.

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References

[1] S. Laubach, G. Ehret, H. Knell, P. Kühnhold and P. Lehmann, “Stitching streifenförmiger Subaperturen zur Formmessung”, DGaO Proceedings (2014)

[2] S. Laubach, G. Ehret, H. Knell, P. Kühnhold and P. Lehmann, “Calibration strategies for a new fast line-based form measuring system”, DGaO Proceedings (2015)

[3] S. Laubach, H. Knell, G. Ehret and P. Lehmann, “Continuous measurement of optical surfaces using a line-scan interferometer with sinusoidal path length modulation,” Optics Express **(24)**22, 29787–29798 (2014)

[4] P. Kühnhold, H. Knell, P. Lehmann, S. Laubach and G. Ehret, “Mikroskop-basierter interferometrischer Zeilensensor zum schnellen Scannen optischer Funktionsflächen”, Arbeitskreis der Hochschullehrer für Messtechnik (2014)