Characteristics of the new Deflectometric Flatness Reference at PTB

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Abstract

At PTB, a new Deflectometric Flatness Reference (DFR) system is being set up, which is designed to measure optical surfaces with an uncertainty down to the sub-nanometer range. It can be applied to specimens with dimensions of up to 1 m and masses of up to 120 kg in horizontal or vertical orientation. The design of the new instrument is supported by employing a simulation environment for measuring machines which has been developed at PTB. The mechanical and optical concept is illustrated together with the design of the DFR setup. The simulation environment and results of its application to the DFR setup are presented. Finally, conclusions with respect to the expected measurement capabilities are drawn.

1 Introduction

The topography of optical surfaces can be characterized in terms of its roughness, waviness and form which describe the topography in different spatial frequency ranges. The discrimination between these ranges depends on the lateral extension of the surface under test. This contribution focuses on the measurement of the form of nearly flat specimens with an extension of several 100 mm and spatial frequencies below 1/mm. These measurements are required, for example, for flatness references and high quality mirrors (e.g. synchrotron mirrors).

Form measurement of nearly flat surfaces with low uncertainties in the nanometer (and sub-nanometer) range can be performed by interferometric or deflectometric methods (fig. 1). At PTB, a difference deflectometric method called the 'Extended Shear Angle Difference' method (ESAD) has been successfully realized for measurements with the lowest uncertainty [1,2]. However, the ESAD setup, constructed as a prototype, suffers from rather long measuring times and from the fact that only horizontally oriented specimens can be measured. Therefore, it is now being complemented by a new instrument called the 'Deflectometric Flatness Reference' (DFR) which will enable faster and more versatile measurements.

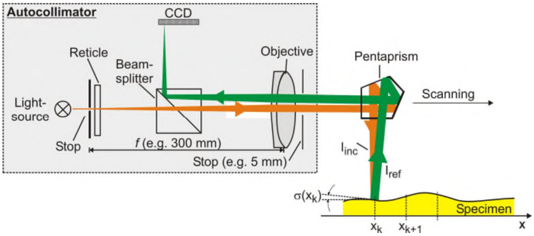


Figure 1: Principle of deflectometric form measurement using an autocollimator

2 The Deflectometric Flatness Reference system

The DFR setup is currently under construction and will be ready for the first measurements in 2010. It consists of two sub-systems. System I is designed to measure in direct deflectometric mode by applying an autocollimator and a scanning pentaprism, and in difference deflectometric mode corresponding to the ESAD principle (fig. 2). System II (fig. 3) is a complement and can measure vertical specimens without the necessity to change their orientation.

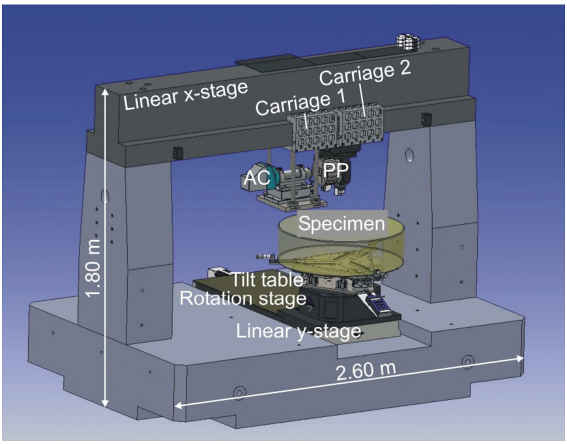


Figure 2: System I, designed primarily for horizontal specimen orientation. AC: autocollimator, PP: pentaprism or corresponding mirror device.

With these instruments, specimens with horizontal as well as vertical orientation, with dimensions of up to 1 m and masses of up to 120 kg will be measurable with the extremely low uncertainties mentioned above.

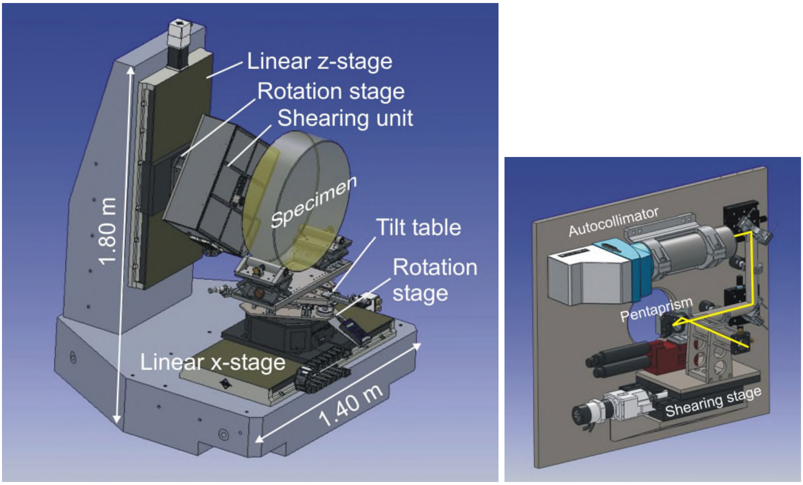


Figure 3: System II (left) and details of the shearing unit (right)

3 The simulation environment

The simulation environment emulates the measurement process and performs virtual measurements considering realistic error influences and specimen characteristics. All significant mechanical characteristics of the instrument are included in the simulation environment.

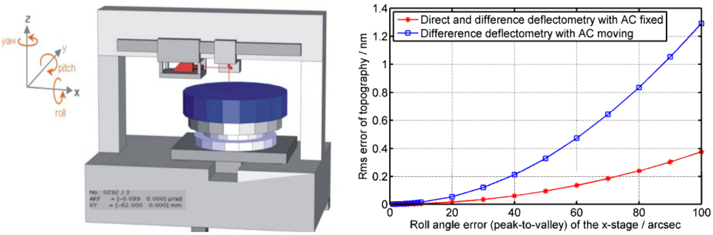
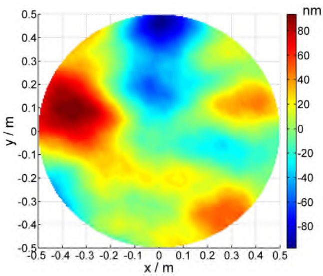


Figure 4: Model of system I implemented in the simulation environment (left) and resulting root mean square errors (rms) of the reconstructed topography in dependence on the roll angle error of the x-stage (right)

Fig. 4 shows an exemplary output of the implementation of system I with results for the root mean square error of the reconstructed topography as a function of the roll angle error of the x-stage. When the autocollimator moves, i.e. follows the pentaprism stage and is fixed only during the shearing measurement, the demands on the stage are higher than for a permanently fixed autocollimator. These simulation studies support the determination of the overall uncertainty of the instrument. At present, the influence of the optical elements is being investigated.

4 Resulting system specifications

As an example of the results from the simulation environment, the specifications necessary for the x-stage of system I are listed when a specimen as shown in fig. 5 is measured along the line with y = 0 for a topography error in the sub-nanometer range. The system under construction is confirmed by the manufacturer to achieve these specifications.



straightness	$\leq$ 5 µm
reproducibility of position	$\leq$ 0.5 µm
pitch angle	$\leq$ 3 arcsec
yaw angle	$\leq$ 3 arcsec
roll angle	$\leq$ 3 arcsec
reproducibility of angles	$\leq$ 0.5 arcsec

Fig. 5: Test topography (left) and specifications for the x-stage for sub-nanometer topography error (right)

5 Conclusion

The design of the new Deflectometric Flatness Reference for very low uncertainty flatness measurements on horizontal or vertical specimens with dimensions of up to 1 m and a weight of up to 120 kg was analyzed by a simulation environment. The simulations confirm that an uncertainty in the sub-nanometer range is achievable.

References:

[1] I. Weingärtner, M. Schulz, C. Elster, "Novel scanning technique for ultra-precise measurement of topography", Proc. SPIE 3782 (1999) 306 – 317

[2] R.D. Geckeler, I. Weingärtner, "Sub-nm Topography Measurement by Deflectometry: Flatness Standard and Wafer Nanotopography", Proc. EUSPEN (2002) 497 – 500