

Flatness Measurements with the Deflectometric Flatness Reference at PTB

G. Ehret, M. Schulz, A. Wiegmann, M. Stavridis, C. Elster
Physikalisch-Technische Bundesanstalt, Germany

Gerd.Ehret@ptb.de

Abstract

Recently, a new flatness measuring system for specimens with dimensions of up to 1 m and masses of up to 120 kg has been realised at PTB. The system, called Deflectometric Flatness Reference (DFR), consists of two sub-systems for specimens in horizontal or vertical orientation, which measures the slopes of the surfaces under test and determine from this the surface topography. The angular measurement is performed by applying a highly accurate autocollimator and a double mirror unit (DMU), which is moved along the surface under test and, thus, scans sections of the surface. The design of the instrument is based on error estimations by a simulation environment for measuring machines developed at PTB using the machine's performance data. From the results, a topography measurement uncertainty in the sub nanometre range can be deduced. Essential for this low uncertainty is the quality of the DMU. The manufacturing and the adjustment of the DMU is presented. With the new DFR system being built up, first measurements have been performed and an example will be presented.

1 Design of the new Deflectometric Flatness Reference

Optical flats of high quality are essential components in many fields of technology. To establish traceability of surface topography measurements, PTB has developed a new flatness measuring system based on optical deflectometry ('Deflectometric Flatness Reference', DFR) [1,2], which consists, due to technical reasons, of two sub-systems suited for surfaces oriented either horizontally or vertically. A two-dimensional topography can be determined from a grid of these scans. The mechanics and the optics of the DFR system have been designed to achieve uncertainties in the sub-nanometre range by using a simulation environment for measuring machines, which has been developed at PTB [1].

2 Principle and measurement modes

The specimen can be measured in three different measurement modes. One of these is the direct deflectometric mode. Another mode is the ‘Extended Shear Angle Difference’ (ESAD) mode [3], which performs difference angle measurements and has the advantage that the optical path length is almost constant by the autocollimator (AC) following the pentaprism. To improve the lateral resolution, a third principle, called ‘Exact Autocollimation Deflectometric Scanning’ (EADS, [4]) will be applied optionally. Here, at each measurement position, the specimen is tilted so that the surface under test is kept perpendicular to the scanning beam. The AC works as a null instrument and its aperture can be made small. The tilt angle is measured with an additional AC with a large aperture to yield sufficiently accurate sensor signals. Since the additional AC has a fixed distance to the specimen, the length of the optical beam path will be constant, which is also expected to result in an improved accuracy.

3 DFR setup

Figure 1 shows the two DFR sub-systems with their massive granite structures.

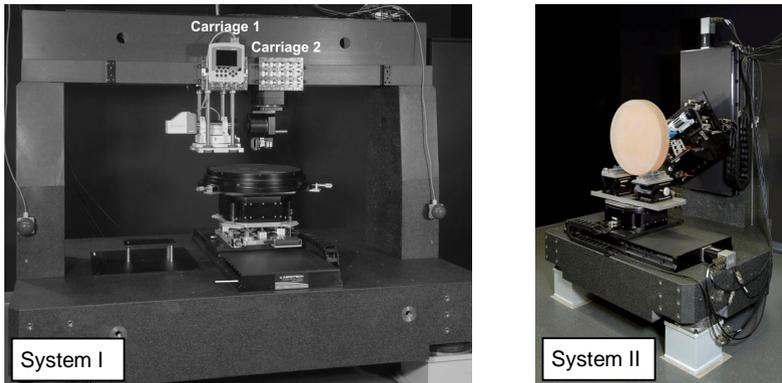


Figure 1: DFR with system I for horizontal and system II for vertical specimens

In system I, the AC at carriage 1 and the pentaprism (or double mirror unit) at carriage 2 can be moved by highly accurate air bearings. These air bearings were characterized by displacement and angle measurements. The maximum straightness deviation is below $2 \mu\text{m}$ (pv) and its repeatability below $0.2 \mu\text{m}$ for a scan length of 1 metre. The angle deviations of the pitch, the yaw and the roll angle are in the range of 1 to 3 arcsec (pv) for a scan length of 1 m. Their repeatability is always better than 0.4 arcsec. The influence of the different quantities was analysed by box plots (fig. 2).

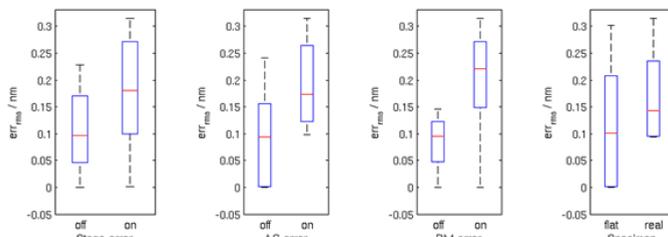


Figure 2: Box plots for an 800 mm scan showing the influence of single errors when set to zero (off) or to a realistic value (on) in the Monte Carlo error simulations

For both systems, adjustment procedures have been developed. Reproducibility tests and cross comparisons of the different operation modes are performed at present. An example of a measurement of a specimen of 500 mm diameter is shown in fig. 3.

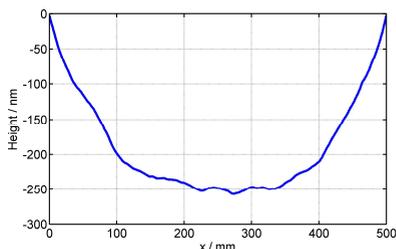
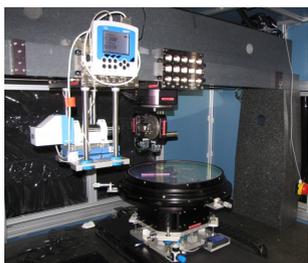


Figure 3: Exemplary measurement of a specimen ($\varnothing = 500$ mm, $m = 75$ kg)

The error simulations of the DFR system I with realistic input values showed a topography error of less than 0.5 nm for up to 800 mm specimen diameter with a peak-to-valley (pv) topography height of 200 nm in the direct deflectometric mode.

4 Manufacturing and adjustment of the double mirror system

For realization of a constant beam deflection by 90° without reflections from the entrance and exit faces, a double mirror system (DMU) with an angle of 45° between the two mirrors was manufactured from two highly reflecting mirrors of high flatness. The 1" mirrors (Si substrates with Al coating) have a flatness of better than 20 nm (pv). One of the mirrors is fixed to the body of the DMU, while the other is adjustable. For alignment, the DMU was mounted on a high quality rotary table with an AC directed to the rotation centre. First, the rotary table was adjusted so that the fixed mirror was faced by the AC (see fig. 4). Then the rotary table turned the DMU by 135° , the AC now facing the adjustable mirror, which was adjusted to give the

same reading as before. Facing only a part of the mirrors is sufficient because of the distinctive flatness of the mirrors (alternatively, the AC could be positioned above the table in the rotation axis and a small, fixed mirror in the height of the DMU could direct the light to the DMU, or the DMU could be adjusted by monitoring the 90° deflection directly). The rotary table (LT Ultra RT 300 with Heidenhain RON 886 encoder) has an accuracy of better than 0.2 arcsec. Thus, the adjustment of the DMU to better than 1 arcsec was performed. From the simulations it can be deduced that the uncertainty contribution from this internal misalignment of the DMU is negligible.



Figure 4: Internal adjustment of the DMU.

5 Outlook

The universality of the new DFR setup allows the measurement of specimens in different measurement modes. We will test, compare and determine the measurement uncertainty of these modes. Future work will focus on further improving the accuracy, e.g. by supplying thermal housings to reduce thermal effects.

References:

- [1] M. Schulz, G. Ehret, M. Stavridis, C. Elster, “Characteristics of the new Deflectometric Flatness Reference at PTB”, Proc. EUSPEN V1 pp.08 – 111, (2010)
- [2] G. Ehret, M. Schulz, M. Baier, A. Fitzenreiter: “A new optical flatness reference measurement system“, 110. DGaO, Brescia, Italy, www.dgao-proceedings.de/download/110/110_p22.pdf, (2009)
- [3] I. Weingärtner, M. Schulz, C. Elster, “Novel scanning technique for ultra-precise measurement of topography”, Proc. SPIE 3782, 306 – 317, (1999)
- [4] M. Schulz, G. Ehret, A. Fitzenreiter, “Scanning deflectometric form measurement avoiding path-dependent angle measurement errors”, J. Eur. Opt. Soc., Rapid Publ. 5, 10026-1 - 10026-4, (2010)