Difference deflectometry with coupling mirrors for flatness measurements of rough or scattering surfaces

Gerd Ehret, Michael Schulz

Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

mailto:gerd.ehret@ptb.de

Difference deflectometry is an established technique for flatness measurements of specular surfaces. We extended this technique for flatness measurements of rough or scattering surfaces and built up a demonstrator set-up.

1 Introduction

With the Extended Shear Angle Difference technique (ESAD) [1] – also named difference deflectometry – sub-nanometre uncertainties for flatness measurements of specular surfaces can be achieved [2]. This technique is also implemented in our new Deflectometric Flatness Reference systems (DFR) [3]. Since ESAD uses an autocollimator and thus requires specular surfaces, it cannot be applied directly to scattering (technical) surfaces, such as granite. This constraint can be overcome by using mirrors coupled mechanically to the surface under test. We expect to achieve uncertainties lower than those attained by commercial inclination sensors which reach sensitivities down to 1 µm/m.

2 Set-up

A scheme of the ESAD set-up for measuring the flatness of rough or scattering surfaces is shown in Fig. 1.

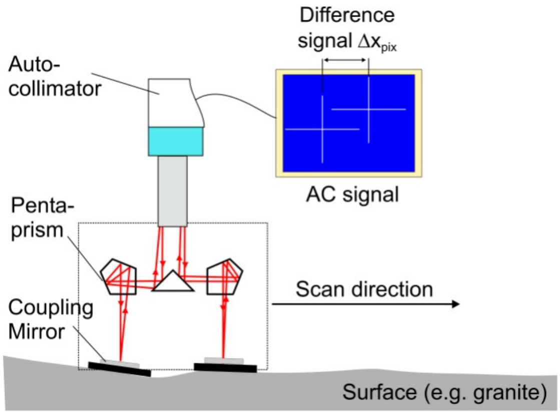


Fig. 1 *Scheme of the flatness measurement system.*

The two coupling mirrors are located in a fixed lateral distance and, thus, realize the shear. The slope differences between these two mirrors are measured with a common autocollimator (AC). A photo of the demonstrator is shown in Fig. 2.

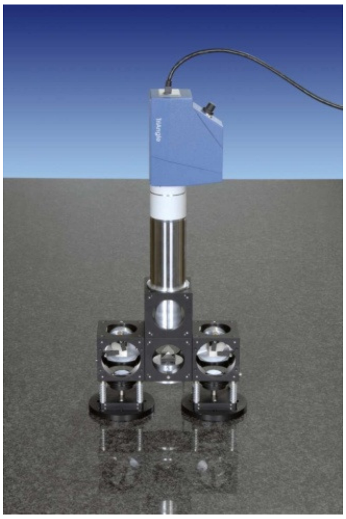


Fig. 2 *Photo of the demonstrator.*

3 Principle of difference deflectometry

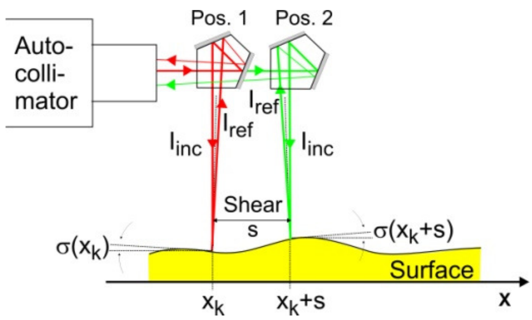


Fig. 3 *Principle of difference deflectometry.*

In difference deflectometry, the slope difference $\Delta\sigma_x(x_k)$ between two points on the surface is measured (see Fig. 3). The lateral difference between the two points – the so-called shear – is kept constant. A series of slope differences are measured, e.g. by scanning the whole measuring set-up across the sample. An exact reconstruction of the slopes σ_x is possible by using a “natural extension” and the shearing transfer function [1]. Integration of the slopes yields to the surface topography.

4 Example measurements

For the following measurements, an autocollimator with a pixel size of $\Delta x_{CCD} = 8.3 \mu m$ and a focal length of $f = 300$ mm is used. A change of the AC signal of one pixel corresponds to a change in the slope of

$$\Delta\sigma_x = 0.5 \text{ atan } (\Delta x_{CCD}/f) = 2.85 \text{ arcsec}$$

a) Point stability

The repeatability of 50 measurements at a fixed position is shown in Fig. 4. The standard deviation is 0.0055 pixel and 0.0156 arcsec respectively.

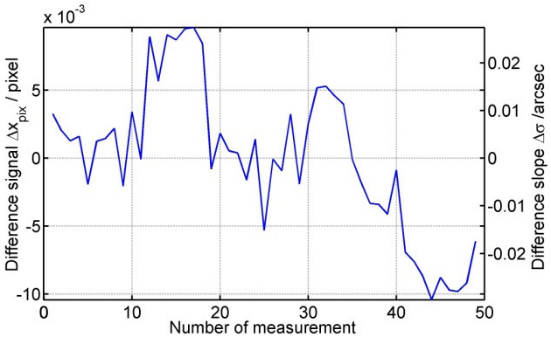
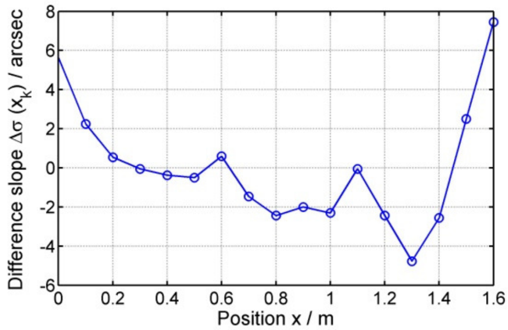


Fig. 4 *Difference signal in pixel and in arcsec.*

b) 1.6 m scan on a granite table

With the demonstrator we measured a section of 1.6 m length on a granite table. The difference slopes were measured with a scanning step of 10 cm. The measured values are shown in Fig. 5a. Using the shearing transfer function (Fig. 5b), the slopes can be calculated (Fig. 5c). The shearing transfer function is the ratio of the Fourier transform of the slope to the Fourier transform of the difference slope and is given by $T(\nu_m) = 1/(2\, i \sin(\pi\, \nu_m\, s))$ with the shear s (see Fig. 3) and the frequency ν_m. Based on the slopes in Fig 5c, the height profile of the section can be determined by integration (see Fig. 5d).

(a)



(b)
(c)
(d)

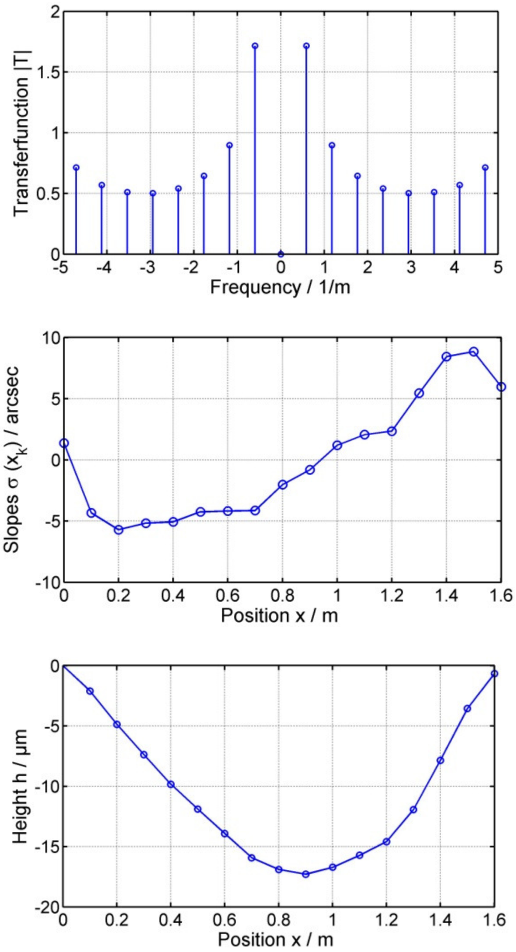


Fig. 5 *Height profile along a scanning line of a granite table measured at 17 positions over a distance of 1.6 m: (a) Difference slopes, (b) transfer function, (c) slopes, (d) heights.*

5 Conclusion and outlook

A new set-up for measuring the flatness of non specular surfaces - such as granite – was presented. Since a measurement at one position is limited only by the settling time, which can be in the ms-range, the technique enables comparably fast measurements. We expect uncertainties in the range of 0.1 µm for the resulting height profiles. The demonstrator can be developed further, especially the mechanical system. Project partners are welcome.

References

[1] C. Elster, I. Weingärtner: Solution to the Shearing problem, Applied Optics **38**(23):5024-5031 (1999)

[2] I. Weingärtner, M. Schulz, C. Elster: Novel scanning technique for ultra-precise measurement of topography, Proc. SPIE 3782, 306317 (1999)

[3] G. Ehret, M. Schulz, M. Stavridis, C. Elster: Deflectometric systems for absolute flatness measuremensts at PTB, Meas. Sci. Technol. **23** 094007 (8pp) (2012)