Traceable Multiple Sensor Systems for High-Accuracy Form Measurement

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In form metrology, scanning systems can be used successfully if large specimens are to be measured or a small lateral resolution is needed. Scanning systems with multiple sensors additionally allow the influence of random and systematic errors to be reduced. A multiple sensor concept is presented that is capable of measuring large flat or curved surfaces with high accuracy and high lateral resolution and which is traceable to the base units. Examples of measurements with a demonstrator set-up show the potential of this concept.

1 Introduction: Problems of scanning systems

The advantages of scanning systems in optical form measurement are that with suitable sensors, large specimen can be measured at moderate costs, a high lateral resolution is possible and various surface forms can be measured. For systems of distance sensors, increasing the number of sensors in the sensor head can reduce errors. While with a three-sensor system, height and tilt error of the scanning stage can be eliminated, a four-sensor system has more favorable noise propagation.

A problem that cannot be overcome with multiple distance sensors alone is the influence of systematic sensor offset errors.

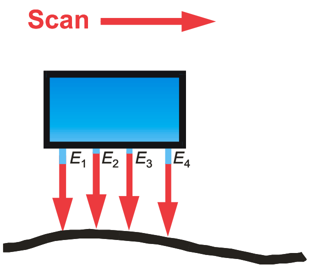

Fig. 1 *Four-sensor system with systematic sensor offset errors E_1...E_4.*

In the presence of distance sensor offset errors (fig. 1), the quadratic terms are "interchanged" between the unknowns, i.e. systematic sensor errors, the scanning stage errors and the topography.

2 Solution: Traceable Multiple Sensor system

To determine the quadratic term of the topography, corresponding to the basic curvature, additional information is necessary. It can be gained by adding an autocollimator (AC) which measures the tilt of the sensor (mirror M fixed to the sensor), see fig. 2. The system can be traced back to the base units of angle and length and is therefore called Traceable Multiple Sensor system (TMS).

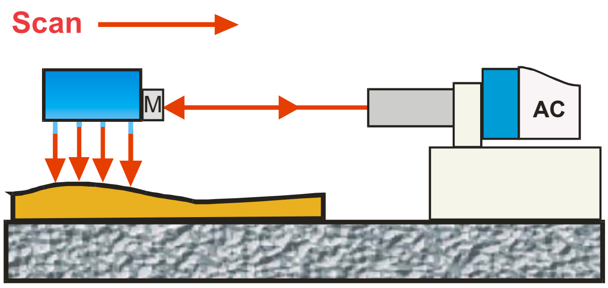

Fig. 2 *TMS system with multiple distance sensor and autocollimator as tilt sensor.*

3 Mathematical model

A mathematical model of the measuring set-up was analyzed which includes the scanning stage height and angular errors as well as the sensor offset errors. The model is indicated in fig. 3.

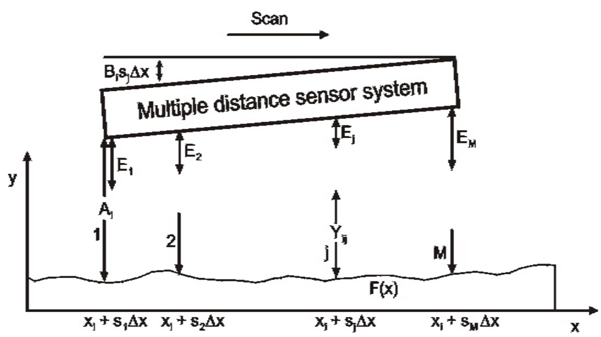

Fig. 3 *Some properties of the mathematical model. A,B: height and tilt offset at the sensor system position, E: offset error of single distance sensor, F: topography of specimen.*

The detailed description and analysis of the model is given in reference 2.

4 Experimental realization of TMS

A test set-up was realized with an autocollimator, a low-quality stage and an interferometer with 3 mm aperture, see fig. 4. The interferometer pixels were binned to 16 distance sensors.

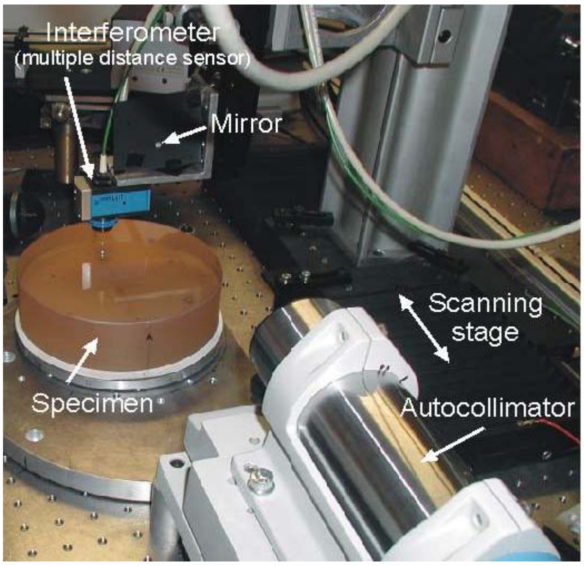

Fig. 4 *Test set-up for TMS measurements.*

5 Uncertainty of the modeled system

With realistic values for the noise of the sensors, the measurement uncertainty resulting from the model was calculated [2], see fig. 5, which is mainly below 1 nm.

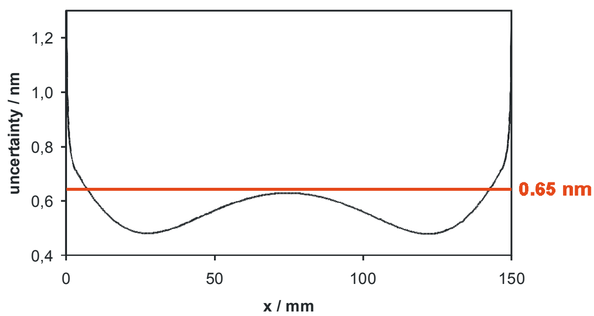

Fig. 5 *Uncertainty of a single measurement corresponding to the model. 16 sensors, 750 scan steps, sensor distance 0.2 mm (= lateral resolution). Assumed noise: distance sensors 1nm, autocollimator 0.25 nm/mm (0.05 arcsec).*

A full uncertainty analysis has to take other sources of errors into account (adjustment errors of the interferometer and of the autocollimator, lateral positioning, etc.), but from the results above it can be concluded that the TMS principle works even for a small sensor head scanning a relatively large surface.

6 Measurement example

Several surfaces have been measured with the set-up shown in fig. 4. The results for a diamond-lathed asphere with a height of 50,000 nm on an underlying flat are shown in fig. 6 as an example.

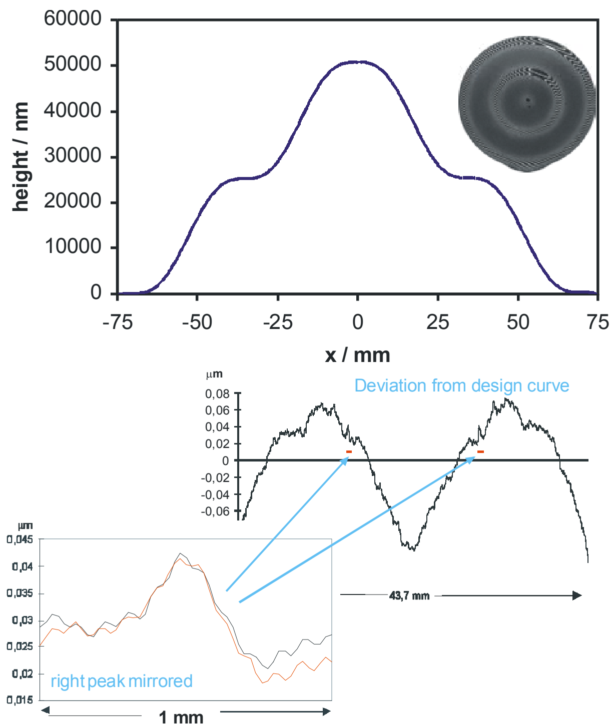

Fig. 6 *TMS measurement of a diamond-lathed surface, manufacured by PTB's Working Group 5.53 "Advanced Fabrication Technology."*

It can be seen that even the fine structures due to the lathing process are resolved, which are rotational symmetric to a large extent. This indicates the potential of the measurement technique.

Comparative measurements with other methods are envisaged. In particular, the step height between the plateaus of the specimen shown in fig. 6 could be measured with a full field Fizeau interferometer.

References

[1] I. Weingärtner, C. Elster: "System of four distance sensors for high-accuracy measurement of topography" in Prec. Eng. **28**: 164-170 (2004)

[2] C. Elster, I. Weingärtner, M. Schulz: "Coupled distance sensor systems for high-accuracy topography measurement: Accounting for scanning stage and systematic sensor errors" in Prec. Eng, in press