Measurement of Aspheric Surfaces with 3D-Deflectometry

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3D-Deflectometry provides a new very fast and accurate method for measuring aspheric surfaces. Using a high resolution two-dimensional angle sensor the local slopes of the surface are determined and the topography is reconstructed via integration. In this way various surface types can be characterized; convex and concave standard shapes as well as toric or even free form surfaces.

1 Introduction

In the production of aspheric surface testing devices which provide fast and accurate measurements of the surface topography are badly needed. Already existing non contact measurement methods as interferometry or distance sensors are only sufficient up to a small degree of asphericity. Beyond this limit measurements become extremely complex and measurement costs and time increase significantly.

Contrary to this 3D-Deflectometry provides very accurate results even for surface topographies with high asphericity in very short measurement times. No reference is needed and the measurement method is not limited to certain surface types. Convex and concave standard shapes as well as toric or even free form surfaces can be tested. There are also no constraints from surface materials as metal, glass or plastics.

2 Measurement principle and set up

In Deflectometry the local slopes of the surface under test are determined by scanning the surface with a laser and detecting the respective reflection angles of the beam. By integrating the slope data the topography can be reconstructed (Fig.1), recording the surface gradient in two dimensions even allows for 3D-reconstruction.

During measurements the sensor head is rotated around a horizontally arranged axis (θ-rotation in Fig. 2) thus predetermining a virtual reference sphere (VRS). Asphericity of the surface under test is measured as the deviation of the real surface topography from this sphere. In order to get access to the entire surface the test sample is additionally rotated around a vertical axis which has to be aligned very carefully in respect to the sensor arm axis (φ-rotation in Fig. 2). During a typical measurement sequence the sensor arm is stepped with Δθ = 0.5° while at each arm position the sample rotates a full 360° and slope data from approximately 300 sample points are recorded.

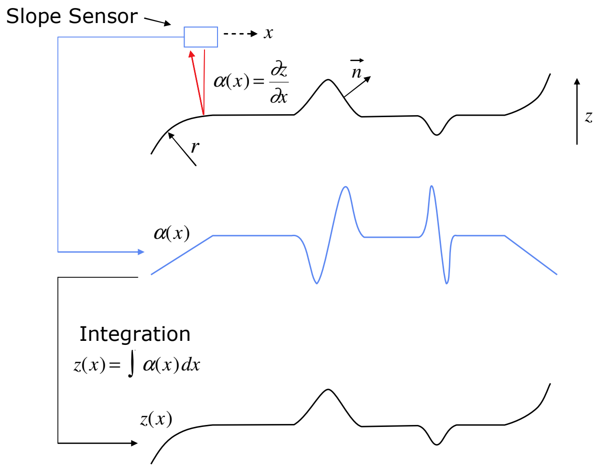

Fig. 1 *By integrating the measured slope data the surface profile can be reconstructed.*

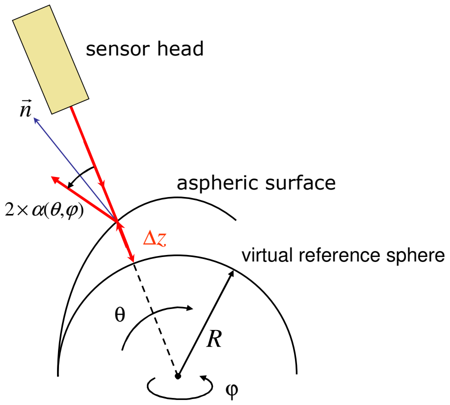

Fig. 2 *Measurement of asphericity as the deviation from a virtual reference sphere.*

The optical slope sensor consists of a diode laser which is focused onto the surface under test. A beam splitter redirects the reflected beam onto a 2-dim. Position Sensitive Detector (PSD). Here angles are measured as deviations from a null position parallel as well as perpendicular to the scan direction of the sensor head.

The sensor head has a wavelength of 635 nm and a spot size of about 30 µm (FWHM) which defines the lateral resolution of the instrument. The area of the PSD is 10 x 10 mm^2 resulting in a slope range of about ± 9° with an accuracy < 50 µrad. The reproducibility is < 1% and the measurement speed exceeds 100 Hz. Typical measurement times are less than 10 min.

Our instrument is able to measure the surface topography of test samples with Ø ≤ 100 mm and $R_{VRS} \leq 80$ mm - concave as well as convex - with a measurement resolution better than 50 nm.

3 Measurement examples

In Fig. 3 the measurement results of a steel ball are shown. The sensor arm rotation axis was adjusted so that the VRS coincided with the ball. As can be seen in Fig. 4 the surface topography deviates significantly from that of a perfect sphere. Errors are in the order of several 100 nm.

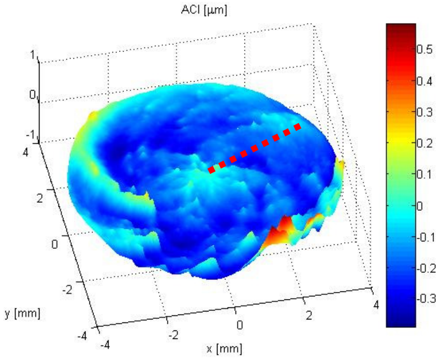

Fig. 3 3D-topography of the deviation from the VRS for a steel ball. The cross section along the dotted red line can be found in Fig. 4

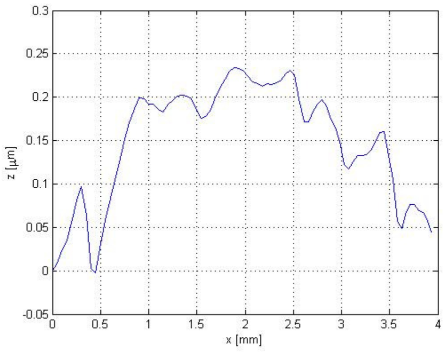

Fig. 4 Cross section of the steel ball

In a second experiment the accuracy of the instrument was tested with a reference sphere which had been measured in advance with a coordinate measurement machine. Both measurement results show a similar periodic structure in the order of a few 10 nm (Fig.5) thus demonstrating the capabilities of the new measurement method. In the additionally recorded intensity map significant damages of the surface due to the CMM measurements can be seen.

Fig. 7 displays the cross section of a large aspheric illumination lens. Only the center part of the lens is spherical while the edges become highly aspheric. Also a sine like structure superimposing the entire surface has been observed and could be analyzed.

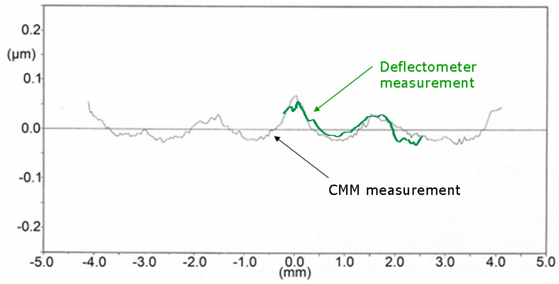

Fig. 5 Cross section of the reference sphere

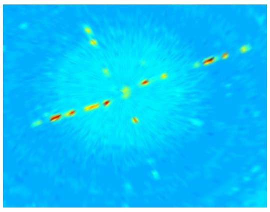

Fig. 6 Surface damages of the reference sphere due to CMM measurements

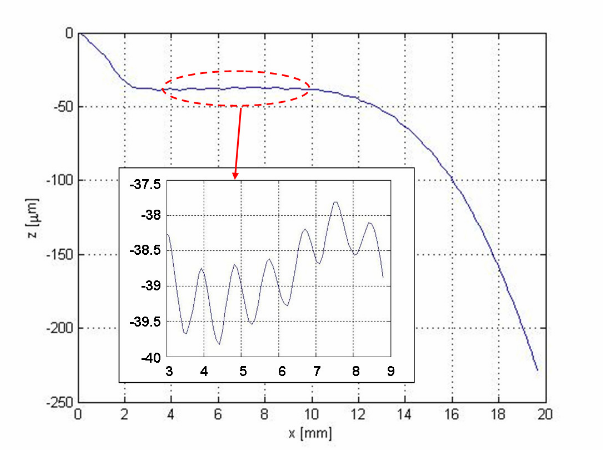

Fig. 7 Cross section of a large aspheric illumination lens (cross section starts at the center of the circular sample)

Besides the above presented measurement examples also toric- and free form surfaces have been tested and analyzed thus showing the widespread potential of the instrument.

4 Summary and outlook

Introducing 3D-Deflectometry a new measurement approach for aspheric surface topographies has been presented and first measurement examples have been shown. 3D-Deflectometry allows for fast non contact measurements with high spatial resolution covering a large asphericity range. Standard spherical as well as free form topographies can be tested with an accuracy < 1% while no additional reference is needed - thus providing a competitive alternative to conventional profiling instruments.