Comparison of ultra-precision tactile and optical profilometry freeform measurement systems

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Abstract

Ultra-precision fabrication of complex shaped optical surfaces like aspheres and freeforms for x-ray and space applications or semiconductor production equipment requires the precise assessment of surface form before and after each production step. Our ultra-precision surface manufacturing methods comprise deterministic sub-aperture techniques like ion beam figuring, plasma jet machining, or corrective polishing, which all make use of the dwell time method [1]. Thus, surface form data need to be acquired on the whole surface as an areal mapping in order to accomplish a deconvolution with the tool function yielding the dwell time distribution. In the case of aspheres and freeforms the application of interferometry may be limited due to large departures from best fitting spheres. Ultra-precision measuring systems like NOM at BESSY-II that are specially dedicated for synchrotron optics reach their limits if strongly curved surfaces with some tens of mm (radius of curvature) are to be measured. CMMs and profilometers rather provide both sufficient flexibility and accuracy to map complex surface forms, especially in a production environment.

In order to investigate the accuracy and reproducibility of the different ultra-precision measurement systems used for areal surface profiling, we conducted a measurement comparison of three optical parts on the following systems located at IOM: The ISARA 400, an ultra-precision coordinate measuring machine, scanning optical surface profiler CyberScan 350S, and D100 interferometer (Zeiss). Furthermore, the obtained results have been compared with cross sectional and areal measurements performed on external ultra-precision measurement systems such as the Nano-optic measuring machine NOM (HZB Berlin), M400 tactile CMM (Zeiss, Oberkochen), and Zygo interferometer (PTB, Braunschweig).

1. Ultra-precision surface measurement systems

1.1 ISARA 400

The ISARA400 CMM has been designed for coordinate metrology of large, complex parts with nanometer level measuring uncertainty. Three interferometric distance measuring systems are mounted in a single body metrology frame, which also holds the ultra-sensitive touch probe system. The interferometer laser beams are mutually aligned to the probe tip fulfilling the Abbe principle in 3D within the complete measuring volume. As a result, straightness errors and rotations of the three translation stages will have no first order influence on the measurement result. The 3D measuring uncertainty has been shown to be 107 nm (2σ) within the complete measuring volume of 400 x 400 x 100 mm³ [2]. Depending on point grid density measuring times can last several hours which might be acceptable for single piece or small batch fabrication.

1.2 Optical surface profiler

The optical surface profiler comprises a granite portal and a 3-axis air bearing motion, which covers a measuring volume of 350 x 350 x 200 mm³. The surface is scanned by an chromatic distance sensor mounted on the z-axis. Alternatively, a Renishaw touch probe can be attached. The residual error of the x,y-stage for the horizontal plane motion has been determined to be 27 nm after subtraction of systematic errors. The optical probe has a resolution of 3 nm. Form measurements are performed in autofocus mode where the sensor signal is held within a defined distance range and the z-axis follows the surface contour. Thus, the machine is capable of measuring rough and specular surfaces without setting up the motion scheme using a CAD model. A measuring uncertainty of 200 nm has been estimated for the complete measuring volume. The profiler provides short measurement times with high spacial resolution and sufficient accuracy at least for freeforms.

1.3 D100 interferometer

The D100 is a fast measuring interferometer with stitching options. For nearly flat synchrotron optics a number of sub-apertures have been acquired finally resulting in a full aperture surface measurement with high spatial resolution and an uncertainty of usually less than 10 nm.

2. Measurement results

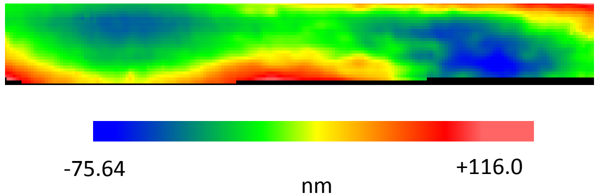

Figure 1: ISARA400 CMM mapping of a spherical mirror after best fit sphere subtraction: R = 44636 mm

The first sample was a spherical synchrotron mirror made of zerodur with radius R = 44598 mm. Figure 1 shows the surface error of the mirror obtained by ISARA400 after removing the best fit sphere. In figure 2 the center line cross section along the x-axis measured with different systems are compared. The main features of the surface shape can be identified in all measurements. The deviations in the long spatial wavelength range of approx. 20-30 nm are mainly due to different workpiece support conditions. Highest spatial measurement resolution is achieved by interferometry. ISARA surface mapping yields the lowest resolution.

Figure 3 shows the results of the surface error measurement of another aspheric synchrotron mirror along the centre line which was obtained from areal mappings for ISARA400 and Zeiss CMM M400. Since the departure from a toroidal shape is in the range of 60 µm it was not measurable by interferometer. The NOM profiler was capable to take cross section profiles, only. A very good agreement is found between ISARA400 and NOM profiler as well as Zeiss CMM M400.

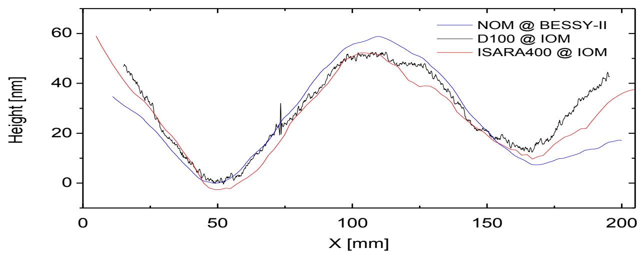

Figure 2: Comparison of center line cross section after best fit measured with NOM profiler, D100 interferometer and ISARA400 tactile ultra precision CMM.

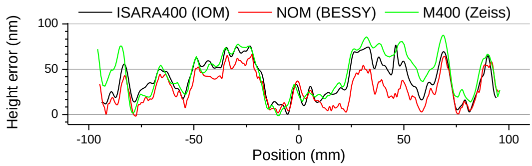

Figure 3: Comparison of surface shape error along the center line of an aspheric synchrotron mirror measured with ISARA400, NOM profiler and Zeiss CMM M400.

The third artefact is a spherical concave lens with a radius of 146.706 mm and lens diameter of 100 mm calibrated by the PTB in Braunschweig, Germany. Figure 4 shows the surface irregularities measured by interferometry at PTB and with ISARA400. Although the long wavelength error features are of similar shape and amplitude, a wavy pattern occurs in the ISARA measurement. Those mid spatial wavelength structures are due to probe tip contaminations by dust particles or lens surface contamination, which leads to wrong signals. Since the CMM point grid is much coarser than the interferometer resolution (1 mm vs. 0.2 mm) a disturbed point measurement influences the surface map much more. Thus, it is necessary to care for maximum cleanliness of surface and tactile probe tip.

a) b)

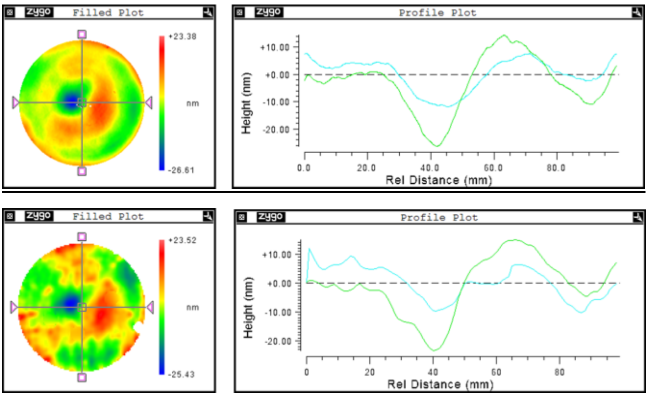

Figure 4: Surface irregularity of concave lens measured by interferometer at PTB (a) and ISARA400 at IOM (b).

References:

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[2] I. Widdershoven, et al., Journal of Physics: Conference Series **311** (2011) p. 012002