IN-PROCESS MEASUREMENT FOR PRECISION MANUFACTURING OF OPTICAL COMPONENTS

Thomas Liebrich[1], Marco Buhmann[1], Michael Marxer[2]
[1]RhySearch , [2]OST-Ostschweizer Fachhochschule

ABSTRACT
Manufacturing of optical components places the highest demands on the manufacturing processes as well as on the metrology in order to achieve typical form deviations <100 nm. The paper presents the 1D distance measurement system used and the challenges in determining its position in the machine tool coordinate system. Using a demonstrator, the achievable measurement uncertainty is estimated and the use of the measurement system as on-machine metrology system in closed-loop machining is discussed.

KEYWORDS: In-process measurement; Ultra precision; Measurement, Closed-loop machining

INTRODUCTION
Ultra-precision machining is concerned with the production of components that meet the highest requirements in terms of their deviations in form, dimensions and position. These are typically in the range <1 µm, while the achievable surface roughness is Ra <10 nm. The applications of such high-precision components are extremely diverse and range from automotive engineering to metrology, sensor technology, microtechnology or to consumer electronics. In this sense, ultra-precision machining represents a key technology, as it enables developments in a wide variety of areas, e.g. in the manufacturing of computer chips through the technological leap from optical lithography to *extreme ultra violet* (EUV) lithography.

A current trend in ultra-precision machining is the machining of freeform surfaces. These are often checked on external measuring devices, e.g. on Fizeau interferometers, for which specific reference optics are required. Especially for small lot sizes, it is therefore advantageous to measure the machined component directly on the machine tool and correct it if it is out of tolerance.

ON-MACHINE METROLOGY SYSTEM
The on-machine metrology system is based on a 1D distance measurement probe of type Hexagon HP-O, which is used on an ultra-precision turning machine (type Lt-Ultra MTC650UP), see Figure 1.

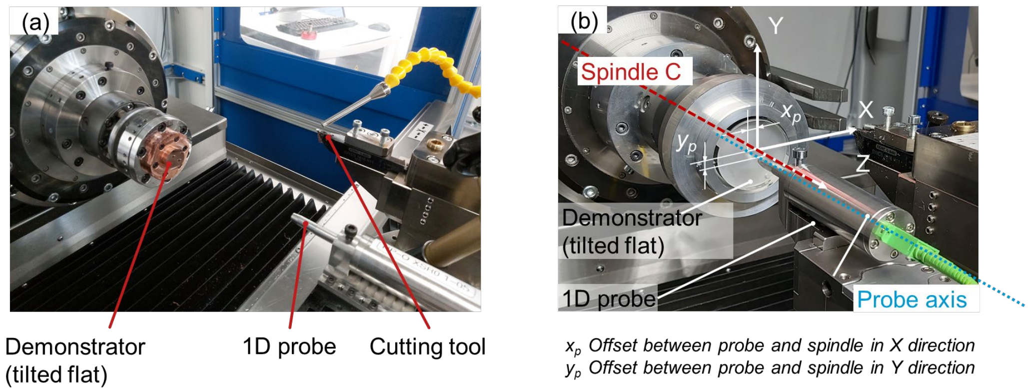

Figure 1: (a) The on-machine metrology system, integrated on an ultra-precision turning machine. (b) The probe offsets in X and Y direction with respect to the machine tool coordinate system.

The probe is based on a frequency modulated interferometric working principle, that enables absolute distance measurements up to an acceptance angle of 5°. The stated signal processing resolution is 0.9 nm, the system's maximum sampling frequency is 1 kHz. There are several challenges in setting up the metrology system:

- Determination of the position and orientation of the 1D probe with respect to the machine tool coordinate system. A new procedure, based on two steps for determining the position of the probe, is developed and validated, as discussed in [1]. As reference, an optical flat is used;
- Since machining and measuring are performed on the same machine tool, the machine tool's errors (e.g. error motions and / or location errors) must be separated from the measurement results. For this purpose, a kinematic model is set up, which allows an estimation of the measurement errors due to various influences, see [2];

- The measurement data are distances (of the 1D probe) and the axes positions of the machine tool. These must be combined and result in a point cloud, which is then filtered and processed for the calculation of the tool path, see [3].

DEMONSTRATOR CASE: MACHINING OF A TILTED FLAT

To validate the on-machine metrology system and demonstrate its performance, a tilted flat is machined and measured. The tilt angle is adapted to the used HP-O and chosen to be 5°. The advantage of a tilted flat is that it represents a freeform surface during machining, but can be easily checked on an external measuring device, e.g. a Fizeau interferometer.

Estimation of measurement uncertainty

For estimating the measurement uncertainty, following contributors are considered and combined according to GUM [4]:

- The squareness error between the spindle and the X axis of the ultra-precision turning machine;
- The straightness error of the X axis of the ultra-precision turning machine;
- The probe offsets in X and Y direction.

The result represents the PV error uncertainty, which depends on the machined geometry. For the 5° tilted flat, the PV error uncertainty is estimated to be +11.1 nm and -29.1 nm.

Closed-loop machining

The tilted flat is machined and afterwards measured using the on-machine metrology system. The measurement data are processed and the surface reconstructed [5]. A second machining – with the workpiece still in the same clamping as for the first machining – the PV error is clearly reduced from initial 1'195 nm to 141 nm, see Figure 2.

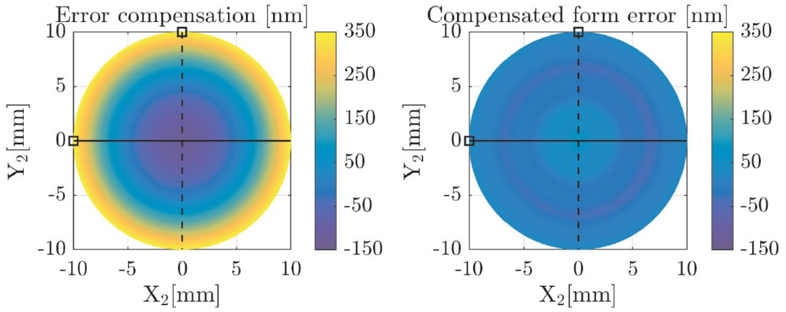

Figure 2: (a) Initial form error before the correction machining. (b) Reduced form error after the correction machining.

SUMMARY AND OUTLOOK

The presented work deals with an important topic in ultra-precision machining, namely the on-machine workpiece measurement. A new method for the determination of the sensor position is presented, which provides a significant improvement compared to the state of the art. Also, the systematic estimation of the measurement uncertainty represents an contribution, since it can be transferred to other measurement sensors or machine tool types. The validation based on a tilted flat shows the enormous influence of the environmental conditions in this extremely demanding accuracy range.

ACKNOWLEDGEMENTS

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CONTACT

* Corresponding Author: Thomas Liebrich; phone: +41 81 755 49 62; Email-address: thomas.liebrich@rhysearch.ch