Two Approaches to use Phase Measuring Deflectometry in Ultra-Precision Machine Tools

Ch. Faber[1], M. Kurz[2], Ch. Röttinger[1], E. Olesch[1], D. Domingos[2], A. Löwenstein[2], G. Häusler[1], E. Uhlmann[2]
[1]*Institute of Optics, Information, and Photonics (IOIP), University of Erlangen Nuremberg, Germany*
[2]*Institute for Machine Tools and Factory Management (IWF), TU Berlin, Germany*
kurz@iwf.tu-berlin.de

Abstract

In this paper, current results of an ongoing research project to integrate Phase Measuring Deflectometry into an ultra precision machine are discussed. Two setups for machine integrated measurements of diamond turned specular parts are presented.

1 Introduction

Ultra precision machine tools are able to manufacture optical surfaces of various shapes with a roughness of Ra < 10 nm and a form accuracy better than P-V = 0.5 µm. The goal of this project is to improve the quality of specular freeform surfaces manufactured by ultra precision Slow Slide Servo turning. For this purpose, appropriate correction cycles based on machine integrated measurements shall be applied. These measurements are conducted using the principle of Phase Measuring Deflectometry (PMD) in order to optically acquire full-field 3D topography data. Other shape measuring solutions are limited in their geometrical flexibility or based on time consuming scanning [1]. PMD is already in use for quality control of e. g. progressive eye glasses. For the machine integration, two setups have been developed – the so called “Mini PMD” which is optimized for small workpieces, and a fully integrated version covering the complete field of view required for large samples.

2 Mini PMD

Constraining the field of measurement to a diameter of D = 25 mm and limiting the maximum slope within the surface of interest to α = ± 10° allows the light source to be small and the CCD cameras to be arranged closely together. Such a setup fits into nearly all UP machine tools. The prototype has been shown in [2]. The current version is more rugged and built of solid aluminium plates for enhanced stability. In contrast to the first prototype, important aspects concerning the applicability of the device within the harsh conditions of a production environment have been taken into account. To take a single example, it is equipped with cable strain reliefs to prevent inadvertent displacement of the CCD cameras or the screen monitor while handling respectively transporting the device. As pattern generator a mini TFT monitor is used. It is clamped tightly into an aluminium frame to ensure a stable mount. In order to minimize the working distance of the cameras, a short focal length has been chosen for the imaging systems, granting the additional benefit of a robust photogrammetric calibration. Both CCD cameras are plugged to a Firewire hub also providing power for camera operation. Firewire hub and monitor are connected with a standard personal computer, the latter via USB and therefore not requiring an additional graphical interface port. Figure 1 shows the advanced Mini PMD setup with open casing for calibration purposes on the left side. For operation inside a machine tool, the casing will be closed to prevent scattered light (left side of Figure 1). The lateral resolution of the system is r = 25 µm per pixel, for a working distance of s = 120 mm. Using a calibrated flat, the measurement uncertainty of the Mini PMD in the current development stage was determined to be u = ± 250 nm.

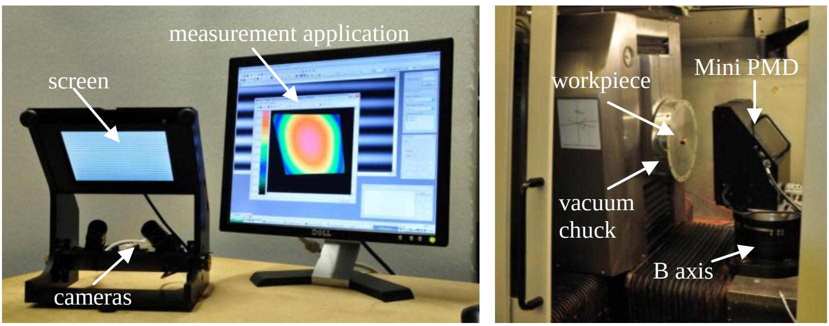


Figure 1: Mini PMD outside (left) and inside (right) an ultra precision machine tool Moore Nanotech® 350 FG from Moore Nanotechnolgy Systems, LLC, USA

Figure 2 shows a measurement result of a non-rotationally symmetric beam shaping optic machined by slow slide servo, once measured with Mini PMD within the machine tool and once measured externally with a standard whitelight interferometer. The maximum deviation between both measurements is about v = 300 nm and thus within the measurement uncertainty of the Mini PMD.

Workpiece:	Non-rotational symmetric beam shaping optic	Process:	Slow Slide Servo
Material:	E-Cu	Tool:	Natural Diamond
Diameter:	D = 20 mm	Tool radius:	r_ε = 1.5 mm
Measurement left:	Mini PMD	Feed:	f = 5 mm
Measurement right:	NewView 5010	Depth of cut:	a_p = 5 µm
		NC point distance:	w = 2°

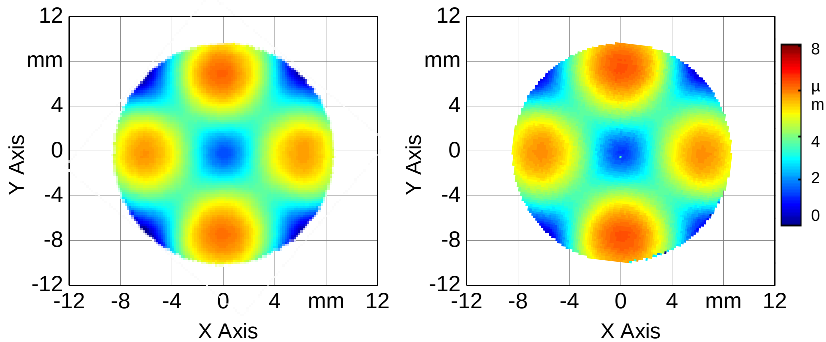


Figure 2: measurement results of a beam shaping optic acquired by Mini PMD (left) on the machine and with an external WLI ZygoLOT NewView 5010 (right)

3 Ultra precision machine tool integrated PMD

In order to expand the measurement field and to be able to measure steeper angles, the PMD setup, has to be rearranged. For the use inside the limited working space of an ultra precision machine tool, the overall dimensions of a comparable stand-alone PMD have to be reduced considerably. Thus, the approach to use the machine's C axis to reposition the workpiece between several single measurement sequences permits to decrease the size of the screen and the number of cameras needed. Figure 3 shows the realized setup in measuring respectively in standby position.

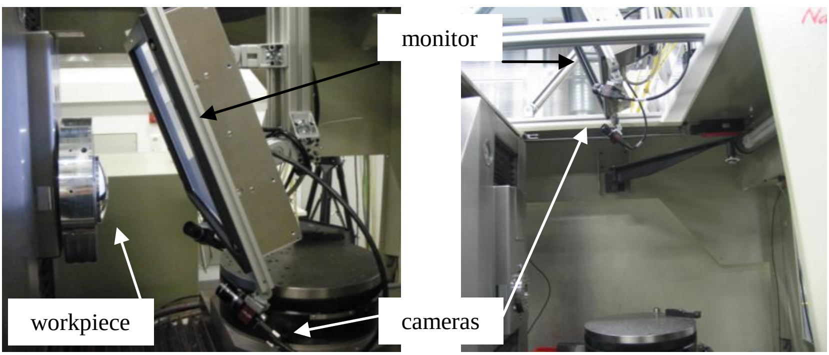
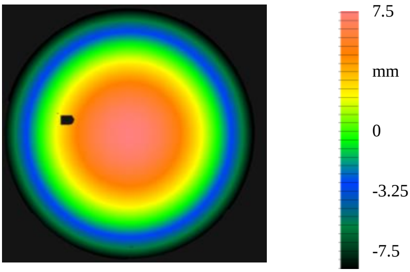


Figure 3: Fully machine integrated setup while measuring (left) and in standby (right)

By simulating the complete system with a specially developed ray traycing tool, optimum camera positions could be provided. Figure 4 shows measurement values composed by three single PMD measurements. The small black gap in the measurement values within the yellow ring is caused by a non-specular mark used for testing purposes.



PMD using a rotational axis	
20.1'' TFT Monitor, 2 Firewire cameras	
Number of rotations in-between single measurements:	N = 2
Test specimen:	Convex sphere
Radius of curvature:	R = 120 mm
Material:	Aluminium
Workpiece diameter:	D = 120 mm

Figure 4: Complete measurement of the fully machine integrated setup

4 Conclusion and Outlook

The research work presented shows a fully developed Mini PMD setup which is stable, transportable and easy to use for machine integrated measurements of small workpieces. Furthermore, an approach to support large measurement fields while simultaneously reducing the necessary installation space has been introduced. The feasibility of utilizing the rotary axis of the machine has been approved. Next steps will be to determine the realizable measurement uncertainty and the general optimization of both systems to further reduce the measurement uncertainty.

5 Acknowledgements

This research is part of the research project UH 100/71-2 and HA 1319/11-2 which is thankfully funded by the Deutsche Forschungsgemeinschaft (DFG).

References:

[1] Bichmann, R. et al.: Adaptive Fertigung mikrooptischer Bauteile mit maschinenintegrierter Messtechnik. Ergebnisbericht des BMBF-Verbundprojektes MicroAdapt. Apprimus, Aachen, 2011

[2] Uhlmann, E.; et al.: Miniaturized Phase Measuring Deflectometry Setup for Machine Integrated Measurement of Specular Surfaces. In:Proc. EUSPEN 2011.