Miniaturized Phase Measuring Deflectometry Setup for Machine Integrated Measurement of Specular Surfaces

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Abstract

This paper presents the progress of current research work on a miniaturized measurement setup based on Phase Measuring Deflectometry (PMD). It is developed and designed to optically measure specular surfaces of small workpieces within the limited installation space of ultra precision machines. The measurement setup's specifications and performance are discussed and first results of machine integrated measurements are presented.

1 Motivation

Ultra precision machine tools are able to manufacture aspheric optical surfaces with a roughness of Ra < 10 nm and a shape accuracy better than P-V = 0.5 µm [1]. To measure such specular surfaces, commonly tactile and optical measurement equipment is used. Tactile systems are stylus based profilometers or coordinate measurement machines. Stylus probes are also available as machine integrated systems in order to directly measure and correct machined surfaces while remaining mounted onto the vacuum chuck of the ultra precision machine. Unfortunately, this solution can leave unfavourable scratch marks on the surface under test. Therefore, the use of optical measurement systems is preferred. However, only a few measurement principles are actually capable of measuring specular freeforms with rather steep angles. Especially for applications in ultra precision machining, in addition to this a strong flexibility is required to be able to measure a wide range of different freeform surfaces. One measurement technique providing this capability is PMD which is used to measure e. g. progressive eye glasses [2]. But these devices are not available in a machine integrated version that meets the challenging accuracy demands of ultra precision machining. The Institute of Optics at the University of

Erlangen-Nuremberg and the Institute for Machine Tools and Factory Management (IWF) at the Technische Universität Berlin are jointly working on a research project to realize the machine integration of PMD. Covering with PMD the complete field of view for large workpieces with diameters up to D = 100 mm involves extensive modification of the machine's interior [3]. But there are many small workpieces produced with ultra precision machines which do not require setups with a large field of measurement. Examples can be found in the manufacturing of spherical or aspherical molds for small lenses or test specimen to determine the current tool offset of the turning machine. In these cases, the reduced field of measurement allows for a miniaturized setup. The approach presented in this paper aims to miniaturize the measurement setup for easy inspection of parts with diameters up to D = 20 mm, remaining clamped onto the vacuum chuck during the measurement.

2 Phase Measuring Deflectometry

Phase Measuring Deflectometry is a meanwhile established measuring technique determining the local slope of a specular object by measuring with CCD cameras how probing rays provided by a spatially extended structured light source are deflected by the object's surface [4]. The spatial and angular measurement range is determined by the geometrical configuration of the system and the size of the light source. Figure 1 shows the basic principle of PMD.

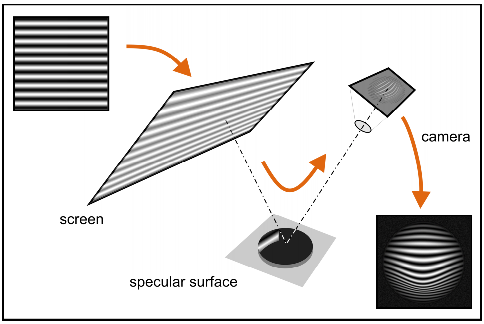
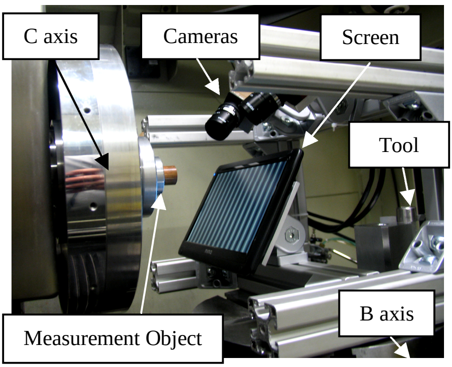


Figure 1: Principle of PMD

3 Mini-PMD

Constraining the field of measurement to D = 20 mm and limiting the maximum slope within the surface of interest to $\alpha = \pm 10°$ allows the light source to be small and the CCD cameras to be arranged closely together and near to the light source. Such a minimized setup is ready to be fit into a machine tool. For easy assembly and adjustment aluminium profiles are used for this prototype. As light source a mini TFT monitor with a screen diagonal of about d = 180 mm is used. In order to minimize the working distance of the cameras, a short focal length of f = 16 mm has been chosen for the imaging systems, granting the additional benefit of a robust photogrammetric calibration. The lateral resolution of the system is r = 28.0 µm per pixel, for a working distance of s = 120 mm. First measurements indicate a measurement accuracy with this setup of about a = 0.5 µm. The setup is small enough to be placed into a 5-axis ultra precision machining system Moore Nanotech® 350FG even with a standard tool mounted on top of the rotating table (B-axis). The system within the machine is shown in Figure 2 (left). The next version of setup will be realized without standard Al profiles and thus further minimized. Figure 2 (right side) shows the first conceptual design of such a device.



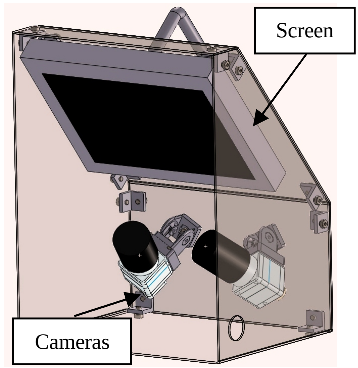


Figure 2: Mini-PMD setup on an ultra precision lathe with B axis (left) and CAD picture of a more compact next generation design (right)

Figure 3 (left) shows one of the first measurement results obtained of a non rotation-symmetrical copper part with a diameter of D = 20 mm and a sinusoidal surface with a maximum amplitude of P-V = 10 µm. The part was manufactured using Slow Slide Servo and measured directly on the machine without removing it from the vacuum chuck within about 5 min. In comparison, the off-machine measurement with a whitelight interferometer ZygoLOT NewView 5010 shown in Figure 3 (right) requires the removal of the part from the lathe and stitching. For the WLI a 2.5x objective was used, the measurement field dimensions of approx. 20 mm x 20 mm are composed of 24 single measurements of about 7.2 mm x 5.4 mm. Having the standard WLI hight resolution of about 1 nm, the measurement took about 25 min.

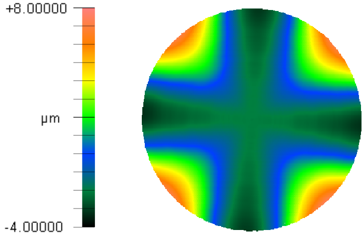
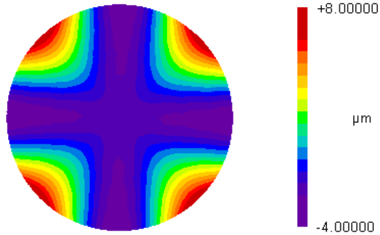
Mini PMD	Whitelight Interferometer
	

Figure 3: Height map of a Cu part with D = 20 mm and sinusoidal surface geometry measured by Mini-PMD on the machine (left) and by whitelight interferometry (right)

4 Outlook

The research work presented here shows a realized Mini-PMD setup and proves the feasibility of optical measurements within ultra precision machines. The lab prototype will be transformed into a more sophisticated setup including better handling for easy and fast machine integrated measurements, succeeded by the integration of the system into an automated correction cycle to improve the manufacturing quality of small specular surfaces.

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