Integration of Interferometry into Ultra-Precision Lathe for Tool Alignment and Surface Analysis

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Abstract

Ultra-precision diamond-machined surfaces feature form accuracies in the µm range and roughness of a few nm. To achieve such qualities, especially on such complex surfaces as free-form surfaces, it is vital to guarantee proper tool alignment. One possible method of high-end tool alignment is optical adjustments via e.g. video tool set stations combined with test cuts. This tool alignment process is currently very time-consuming. It needs several iteration steps by machining a test work-piece, measuring externally, re-clamping and re-machining. There is practically no machine-integrated measurement equipment. Therefore, maximum process reliability is not guaranteed.

To overcome these limitations Carl Zeiss Jena GmbH and FISBA OPTIK AG have equipped an ultra-precision (UP) machine with an optical measurement system. An interferometer µPhase 2HR attached to an in-house developed flexible mounting device was used. Such setups are not yet commercially available.

1 Specification and measuring setup

The tested interferometer is a Twyman-Green phase-shifting interferometer with a 632 nm laser. Multiple optics allow measurements of plane and several spherical surfaces with a numerical aperture of 0.1 – 0.71. The interferometer is equipped with a 1 megapixel camera. Freely selectable contrast conditions between 0.5% - 80% enable measurements of different materials. The rms repeatability is given as l/6500 λ, the measurement uncertainty as l/35 λ. The main advantage of the µPhase interferometer is its small size which allows measuring setups integrated within the machining center.

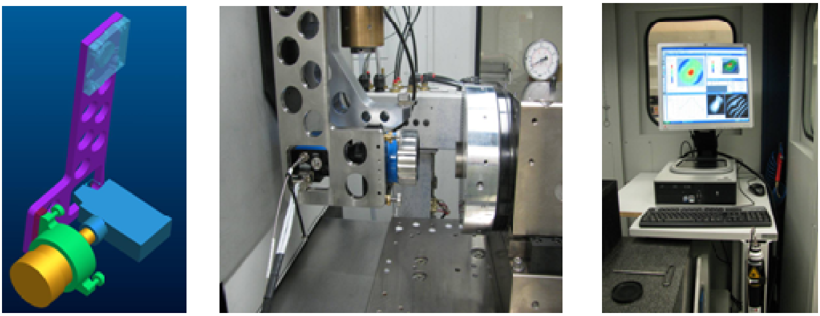


Figure 1: CAD-construction of interferometer-fixture (left), setup within UP lathe (middle) and analyzing PC incl. support construction within machining cabinet (right)

The in-house developed mounting device for the UP lathe with its quick-snap kinematical interface and 3-axis alignment components guarantees a repeatable, accurate alignment of the interferometer to the probe surface in the micrometer range. Another advantage of the small, flexible device is that the interferometer and tool holder for turning can remain in the operating range without remounting.

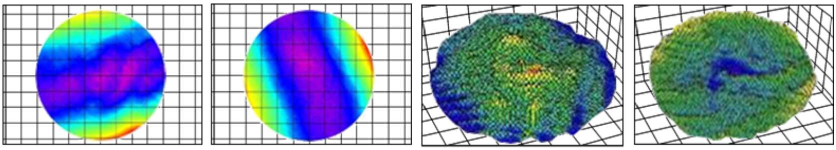
2 Measuring results

In several experiments the measurement options and limits were tested. The focus was on the calibration procedures using reference standards, the clamping influence, e.g. vacuum, and the min. measurement noise. Additional interests included measurement repeatability, the max field angle and the measurement of complex surfaces.

2.1 Calibration

Deformation-free clamping of the reference standards for the lathe setup is required to minimize measurement errors. In this setup all standards were mounted via vacuum and/or well-defined 3-point fixtures. Fig. 2 shows 2 measurements of the same vacuum mounted probe at different 90° angle orientations. The interferometer itself was calibrated in advance using a deformation-free mounted reference standard.

Several tests were done using a well known probe for both the calibration and its own surface measurement to identify the min. noise for the measurable PV and rms values. The results were PV = 10 nm - 20 nm and rms = 2 nm. Fig. 2 shows the test results using probes made of different materials such as Zerodur and aluminum.



PV	97.9 nm	97.0 nm	a)	b)
RMS	20.4 nm	20.8 nm	1.6 nm	2.4 nm

Figure 2: Deformation due to clamping and noise performance tests using (a) Zerodur probe and (b) aluminum probe

2.2 Repeatability

In addition to the min. noise, repeatability is a key objective. The interferometer specifications are ΔPV = 3.2 nm and Δrms = 0.5 nm. Because of the influences of the lathe (e.g. pumps) these values cannot be achieved. In tests with a 15x iteration loop, the min. values of PV and rms were measured to ΔPV = ±3.9 nm and Δrms = ±0.8 nm.

2.3 Complex surfaces and limits

The interferometer is designed to measure regular surfaces. The max field angle and the accuracy in measurable step heights is interesting for the measurement of more complex surfaces is. The given maximum field angle of 0.24° was verified by measuring a tilted plane. The maximum field angle achieved was 0.234°.

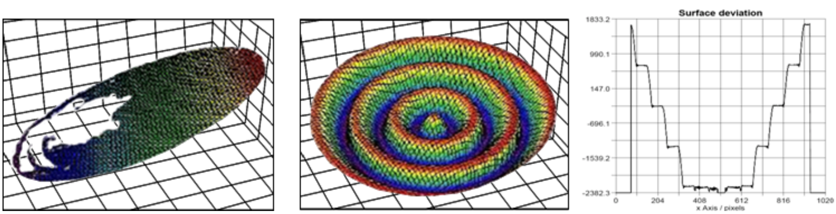
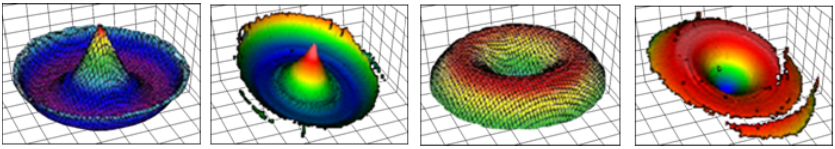


Figure 3: max field angle (left), complex surface (middle), step-height normal (right)

In order to accurately measure complex structures, e.g. fig. 3 right: steps with steep change over software settings must be taken into account, e.g. smoothing filter deactivated to measure step heights → 1 µm steps could be measured to 0.98 µm.

2.4 Tool offset

One of the benefits of using an interferometer in a lathe is the simple, process-oriented measurements of surface-deviations resulting from tool misalignments. The main advantage is the avoidance of repeated clamping/unclamping. In verification tests compared to another well-known stand-alone interferometer, the µPhase allows tool alignment with the same accuracy of less than 1 µm.



a) b) c) d)

Figure 4: Negatively misaligned tool: µPhase - (a), Fizeau interferometer (b), Posivitely misaligned tool: µPhase - (c), Fizeau interferometer (d)

3 Summary

A µPhase interferometer was integrated into an UP lathe to overcome process-oriented measurement limitations in the machining of optical surfaces. A flexible and adjustable quick-snap holder was developed and tested. Several experiments examined calibration, repeatability, tool offset measurements, measurement of complex surfaces and its limits. The machine-integrated µPhase enables measuring accuracies up to PV = 65 nm, rms = 5 nm at field angles up to 0.234°. The tool offset can be reliably calculated accurately down to < 1 µm.

Using the machine-integrated interferometer tool alignment lowers the time required by a factor of 2. The achieved results validate the possibility of measuring in optical quality with the above-mentioned setup and show the potential of optical measurements with a lathe!

References:

[1] Savio, E.; et al.: Metrology of freeform shaped parts. Annals of the CIRP, 2007.