# Application Report: µPhase® 2 HR on an Ultra-precision Lathe

## 1 Motivation

Ultra precision turning machines are often used to produce parts of optical quality, such as contact lens molds. The produced parts can be measured very precisely with an interferometer. For the measurement the parts are usually removed from the turning machine. When the measurement results show that the part needs further processing, it has to be mounted again on the machine with a quite high adjustment effort.

From this point of view it would be highly desirable to have an adequate measurement system integrated in the turning machine and measure the part without removing it from the spindle to avoid additional re-adjustment effort.

This report describes in-machine measurements with an µPhase® 2 interferometer and discusses two issues we studied. On the one hand we checked the tool offset control, on the other hand we improved the manufacturing process by determination of a correction for the cutting path.

## 2 Test setups

Within the government funded project MeTAsO[1] we were able to install a µPhase® 2 interferometer on two ultra precision turning machines of our project partners IWF TU Berlin[2] and Jenoptik-PS[3]. At the IWF the µPhase® were installed on a Moore Nanotechnoloy system, at Jenoptik-PS on a Precitech Nanoform machine.

The use of a Twyman-Green interferometer compared with a Fizeau interferometer has the great advantage that it is significantly easier to adapt the reflectivity of the reference surface to the part under test in order to get a good interference contrast. That is very important since high-reflecting surfaces are diamond-turned in most cases.

Figure 1 shows the interferometer mounted on the B-axis table of the Moore machine together with the turning tool. For the processing of the sample, the B-axis was rotated to bring the tool into working position. To align the optical axis of the interferometer with the work spindle (axis of rotation) of the lathe, the interferometer was mounted on a tilt table to provide the missing tilt axis.

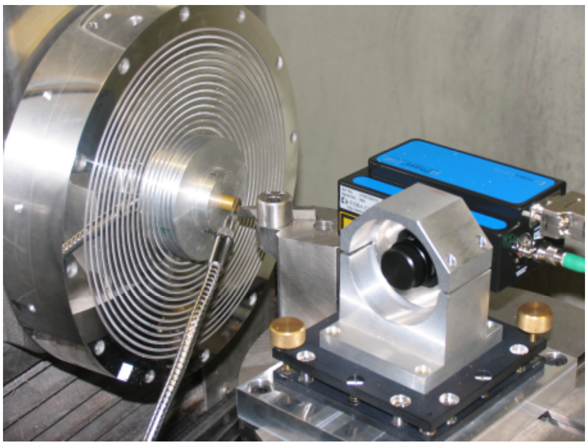

**Figure 1: µPhase 2 on Moore machine at IWF TUB**

The Precitech machine at Jenoptik-PS had two degrees of freedom less than the Moore machine at IWF. There were no B- and y-axes. Figure 2 shows the interferometer mounted on the tool table of the Precitech machine together with the turning tool. To switch between processing of the sample and measurement, the table is shifted to move the tool or the interferometer into the desired position.

[1] „Measurement Technology for Aspheric Optical components", PRO INNO II program of the German Bundesministerium für Wirtschaft und Arbeit (KF0084101WM4)

[2] Institute for Machine Tools and Factory Management, Technical University Berlin, Germany

[3] JENOPTIK Polymer Systems GmbH, Triptis, Germany

To align the optical axis of the interferometer with the work spindle (C-axis) of the lathe, the interferometer was mounted at a tilt table mounted at a y-translation to provide the missing two axes.

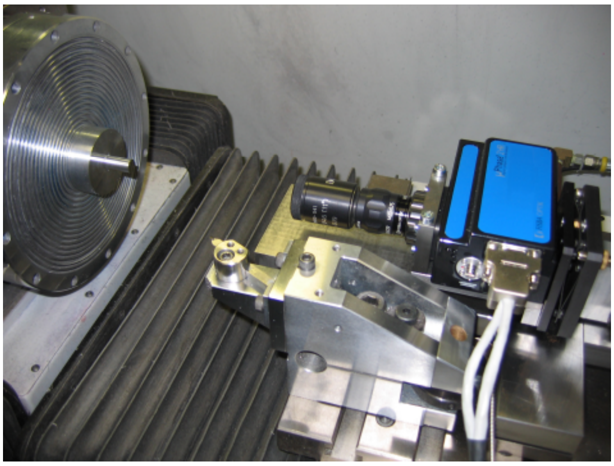

**Figure 2: µPhase 2 on Precitec machine at Jenoptik-PS**

Due to the compact and robust design of the µPhase® 2 and the relatively clean production conditions no additional protection means were necessary, except a cover for the lens. The B-axis offered an additional possibility of protection. It allows a setup where the cut tool and the measurement device are separated physically.

Once the adjustment of the interferometer was successfully done, in both cases the very high positioning accuracy of the lathe allowed a re-positioning of the µPhase® in the measurement position without any measurable deviations. Even when slowly moving the sample along the x-, y- and z-axis the interferences could be observed. But the most impressing fact was the accuracy of the C-axis rotation that allowed interferometric phase shifting measurements while the sample was spinning at 1500 rpm.

The integration of the µPhase® directly into the lathe has several advantages. Beside the fact that the interferometric measurement is contact-less, the main advantage of this setup is the integration itself. So the sample can remain on the work spindle for the measurement. That reduces the effort for production control enormously. Another advantage of the integration is the “on the fly” measurement of the sample’s shape and surface quality during the manufacturing process. The measurement results can then be used to decide whether another processing step is needed or not, or to correct the manufacturing parameter directly.

## 3 Tool Offset

Before a part can be produced, the manufacturing tool has to be adjusted according to the spindle axis. The distance of the end of the cutting path to the spindle axis of rotation is the so-called tool offset. For high-quality parts the tool offset has to be zero, i.e. the cutting path ends exactly at the axis of rotation. To determine the tool offset the central part of the manufactured part is usually analyzed visually with a microscope or a white light interferometer. The shape of the residual needle tells an experienced user how to correct the tool adjustment to minimize the tool offset. The part is remounted, overworked, removed and measured again. This is an iterative process and the cycle has to be repeated until the measurement shows no tool offset.

With an interferometric measurement the x-tool offset during manufacturing can be directly determined from the measured shape error. Depending on the cutting path error typical surface shape errors result. When the cutting path ends before (under cut) or behind (over cut) the axis of rotation, the line plot on a central cut shows a shape like an ‘M’ or ‘W’. Figure 4 shows a typical resulting ‘W’ shape.

## 4 Process Control

The production of an optical part can be seen as a process chain. Start of this chain is a specification of the desired part. At the end of the production process parts that meet the given specification are expected. Between the start and the end the production process passes a kind of control loop (more or less periodically).

Figure 3 shows this control loop.

First step is the processing of the part. Afterwards it is inspected by a measurement device. Depending on the measurement results parameter changes can be determined to correct the production process. In a closed-loop system the measurement results are used to change the production parameters automatically. The sample is overworked and measured again. This circle is repeated until the part fulfils the specifications.

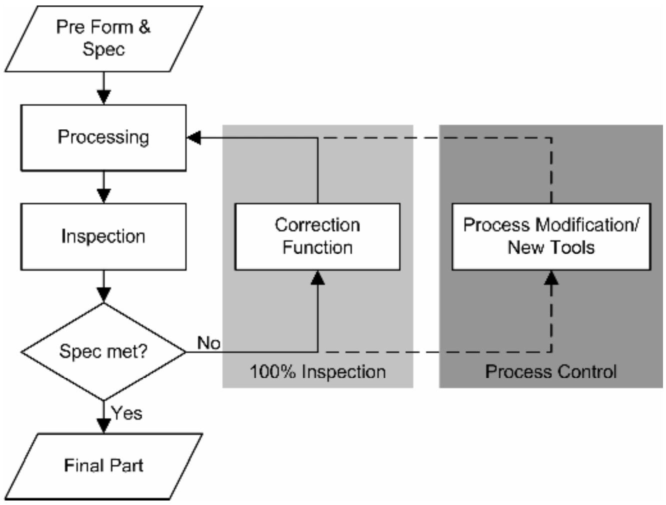


**Figure 3: Control loop**

For process control you do not do a 100% inspection. Samples are measured in regular intervals. If the samples fail the specifications the process will be stopped and modified. Important for a successful control loop is that the interface between measurement device and production machine is well defined.

For both cases, the 100% inspection and the process control, a lot of time can be saved when the measurement unit is directly integrated into the production line. This offers the possibility to directly measure the part during the production within its manufacturing mount.

# 5 Results

## 5.1 Tool Offset

Minimizing the tool offset is usually done by a measurement device externally. As described above the sample has to be removed from the work spindle, is measured, replaced on the machine and then realigned on the spindle. Some machine parameters are modified and the sample is overworked. One cycle can take a few minutes and for a minimized tool offset several iteration cycles are required, depending on the experience of the operator.

With an integrated µPhase® on the machine it is possible to measure the actual tool offset directly after the turning process. Figure 4 shows a tool offset measured by the µPhase® and calculated by the µShape™ interferometer software. While the traditional way of the tool offset correction requires several offline measurements the integrated interferometric measurement delivers the desired information in general already by the first measurement and without any additional sample adjustment.

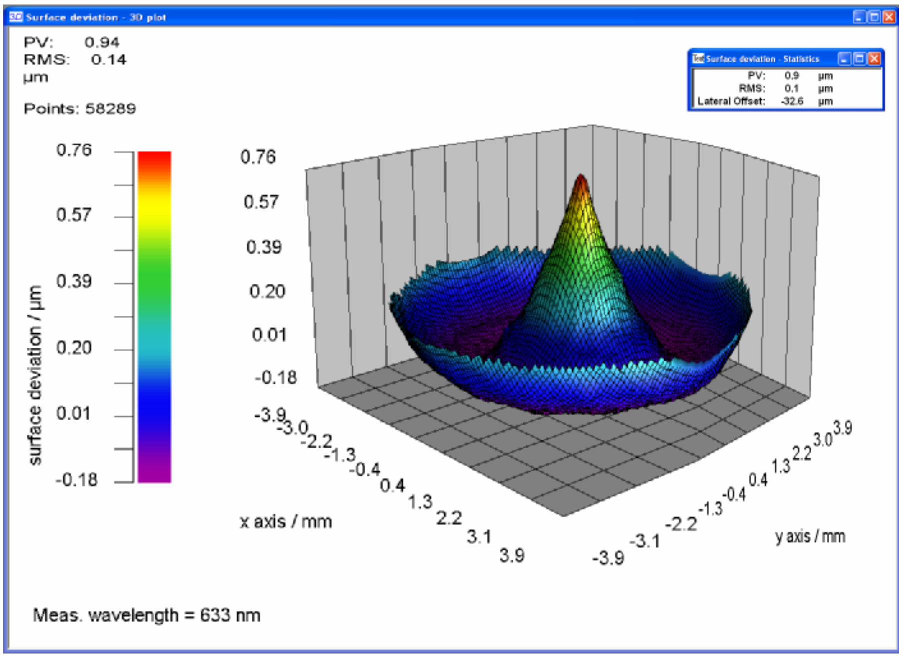


**Figure 4: Tool offset measurement with µShape™**

Furthermore we observed that the tool offset could be determined as more accurate as less the radius of curvature of the sample was. In consequence we came to the conclusion that for tool offset correction it is adequate to cut test spheres on small diameters with a small radius of curvature. So you get accurate results in a short time.

### 5.2 Process Control

To improve the quality of the production the cutting process can be corrected based on an interferometric measurement of the sample directly on the machine after the cut. Figure 5 shows two measurements demonstrating the two steps of a 100% inspection as described above.

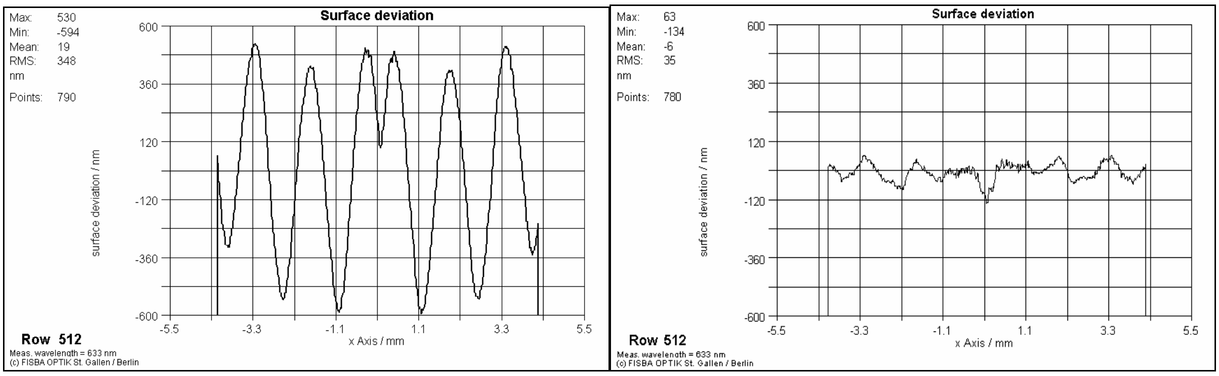


**Figure 5: left: aberration of a sphere with superimposed sine waves; right: aberration of same sphere after correction of the cutting path based on an interferometric measurement**

In the first step a sphere with a superimposed sine wave was produced. That shape stands for a badly produced sphere. It was measured with the µPhase® (left graph) and the interferometric result data are transformed into the coordinate system of the machine. They were compared with the target data of the desired sample. The difference map was fitted into a correction NC-program which calculated a corrected cutting path. The right graph shows the result of the correction: a nearly error free sample was produced. The remaining aberrations are in the range of the repeatability of the machine.

## 6 Outlook

The next step in the development would be an automated integration of the interferometric measurement into the processing workflow. The add-on module *External Interface* of the µPhase® software µShape™ offers the possibility of the control of the interferometer by the control software of the turning machine. All steps – turning, measuring, correcting – could be executed full or at least semi-automatic.

Also the tool offset determination can be further improved. For the time only the x-offset being interferometrically measured, but first investigations show that it is not influenced by a y-offset. There are optical indications that could be used for the y-offset analysis.