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Traceable profilometry with a 3D Nanopositioning Unit and zero indicating Sensors in compensation method

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Abstract. Conventional 3D profilers suffer in their traceability and accuracy from non-linearities of the 1D Sensor (optical or tactile) and different measuring principles in the scanning plane compared to the sensor axis. These problems can be overcome using a traceable calibrated 3D positioning device combined with a probing system of negligible measuring range in compensation method. Drawback: reduced dynamics, because of the necessity of accelerated movement of the object to be measured in z-direction for compensating its varying height. Sensors with negligible measuring range to be used for this approach are an optical fixed focus sensor (SIOS GmbH, Germany) and a self-made scanning tunneling sensor without piezo scanner. The integration into the nanopositioning device is made according to a multi-sensor CMM with fixed and known positions of the sensors with respect to the machine coordinate system giving the possibility of using one sensor´s data for navigating the other one. Main applications can be seen in measurement tasks where outstanding accuracy outrivals the need of high measurement speed, e.g. the calibration of step height and pitch standards for profilometry and also for SPM.

1. Measurement system and measurement principle

The measurement system used for the present work basically consists of three components:

- a 3D nanopositioning and -measuring device (SIOS GmbH)
- a fixed focus sensor based on a DVD-pickup (SIOS GmbH)
- a special STM-sensor without piezo-scanner (QFM)

Basic component is the laser interferometrically controlled 3D nanopositioning stage SIOS NMM-1 with a range of 25 mm × 25 mm × 5 mm and a resolution of 0.1 nm. The specimen carrier of this stage is a corner mirror with three perpendicular faces made from zerodur that is acting also as moving mirror of the three laser interferometers used for position measurement and closed-loop control. The virtual extension of the three laser beams coincide in one point that is also the zero position of the installed probing system (nominal probing point) preventing Abbé-errors. The corner mirror is suspended by high precision roller bearings and driven by Lorentz actuators, closed-loop controlled with a frequency of 6.25 kHz. Additionally parasitic angular movements are monitored by two angular sensors and compensated for by the driving system [1].

The wavelength of the three frequency stabilized HeNe-LASERs is calibrated against an iodine stabilized HeNe-LASER calibrated by the German NMI PTB, so traceability of the position measurements to a national wavelength standard is ensured. The manufacturer SIOS claims a volumetric positioning uncertainty of about 10 nm in the whole measurement area.

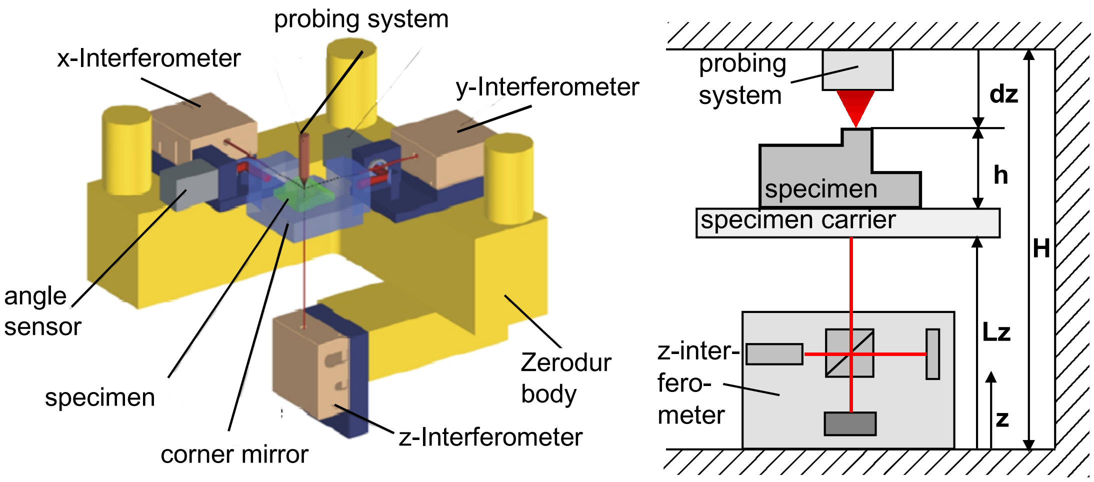

Figure 1. set-up of the SIOS NMM-1 stage (left) [1] and principle of compensation method (right)

If probing only occurs in the intersection point of the three beams, traceable measurements of work piece features are feasible without Abbé-errors. Because of dynamic influences and the position control, however, the actual probed specimen surface point will move a small measurable distance in z-direction around the nominal probing point. This distance is controlled towards a set-point of zero and also evaluated to get the local specimen height.

$$h(x,y) = H + dz(x,y) - Lz(x,y) \qquad (1)$$

where, h is the actual specimen height, Lz is the interferometer measurement value, H is the height of the system (constant), and the dz is probing system measurement value.

As dz is very small compared to the traceable measurable dimension Lz, deviations from ideal traceability remain negligible.

2. Utilized probing systems

A fixed focus sensor evaluating the focus error signal has been developed by technical university of Ilmenau [2]. This sensor is based on a conventional DVD pick-up and has already verified its performance at measurements of step height standards provided by PTB. The integration into the positioning stage is done mechanically on an invar plate being rigidly fixed to the three zerodur pillars of the metrology frame of the NMM-1. Electronic integration is done via 16 bit analog-digital converters directly connected with the DSP unit controlling the entire system. The focus sensor has a resolution below 1nm and a maximum measuring range of about 10µm. However, for the measurements shown in this paper, the measuring range has been reduced to about 200 nm in order to improve traceability.

The scanning tunneling sensor has been developed for the use on this positioning stage and only consists of a platinum-iridium probe and shielded electronics for creating a stabilized and controllable voltage, measuring the resulting tunneling current and signal conditioning, amplification and filtering. The preamplifier with fixed amplification is placed close to the probe onto the invar plate of the NMM-1 so that the way for the very low tunneling current (few nA) is only about 3 cm before transformation to a current proportional voltage signal and amplification. This is necessary to keep disturbances caused by external electric and magnetic fields as low as possible. After preamplification the signal is transferred to the tunable main amplifier to get the desired signal. The sensor output signal is a voltage between zero and -10V, proportional to the distance between probe tip and conducting surface. The absolute value for this distance cannot be derived from this signal, as the relationship between tunneling current and signal is dependent on the material of the specimen, as well as on the geometry of the probe tip. Signal transfer to the digital signal processor of the nanopositioning stage is done via the analog-digital converters of the stage. To achieve a stable enough mechanic connection, the clamp holding the probe is rigidly fixed to an isolation plate mounted onto the invar base plate of the focus sensor. The specimen is grounded by placing it onto a thin grounded plate that is fixed to the corner mirror of the NMM-1. Because of spatial restrictions it is not feasible to install both sensors exactly in the Abbé-point of the system, so small Abbé-errors may be introduced when using the STM sensor. As there is no piezo scanner, the measuring range of the sole STM sensor is very low in z-direction and virtually zero in the lateral plane. This abandons non-linearities and hysteresis effects being associated with commonly used piezo scanners [3] and makes this sensor a so called null-indicator.

With both sensors measurements in compensation method can be made. This means that all major movements and position measurements are carried out by the traceable positioning stage. The probing systems are only used to detect the distance between nominal probing point and actual probed specimen surface position for controlling it. When this distance reaches a value of zero (with a small tolerance zone where linear behaviour of the sensor can be assumed) a read out of the interferometers is triggered. With this approach the specimen topography is directly mapped by traceable equipment.

Dependent on the utilized probing system, factors influencing measurement uncertainty are the kind of probe-sample interaction, the dimensions of the zone of interaction [4] and measurement speed because of the limited dynamic properties of the positioning stage.

3. Measurement results

At the moment the STM sensor is still under testing, results derived with it will be shown in the presentation. As the STM sensor is reliant on a conducting specimen surface a tungsten carbide covered disc with a wear trace, a steel gauge block and a steel sphere of a roller bearing have been chosen for performance testing of the system. All here presented measurement results have been measured with the focus sensor and have been filtered and visualized using Matlab® 6.5.

The median filtered graph [5] of the wear trace measurement (figure 2) clearly shows three main grooves with a maximum depth of about 400 nm and some minor traces with a depth of 30-100 nm. The scanned area had a size of 400 µm × 400 µm and was sampled with a lateral resolution of 1 µm during a time of about one hour. At a measurement of the same disc with a commercial high resolution auto-focus topography measurement system (Rodenstock RM 600) the traces where hidden by the noise floor, so their depth could not be measured properly. To show that the measurable height variation is much larger than the measuring range of the sensor, a 15 mm diameter sphere from a roller bearing was measured (figure 3), clearly showing the spherical shape and a flattening at the north pole.

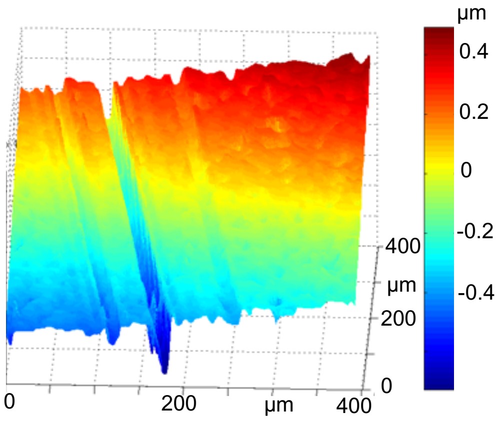

Figure 2. wear trace on tungsten carbide

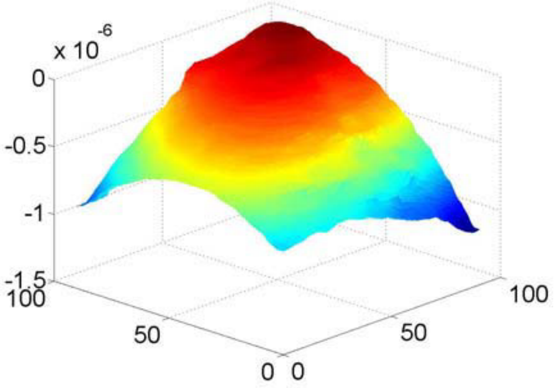

Figure 3. steel sphere from roller bearing

At the visualization of the polished gauge block surface, figure 4 (320 µm × 320 µm, lateral resolution 0.8 µm) the lapped surface structure, as well as two intersecting scratches of nearly the same depth could be extracted. The heights of the structures in that graph are below 30 nm, the inclination of the graph results from the slight tilt of the gauge block with reference to the scanning plane. Figure 5 shows a measurement of the same gauge block with an area of 2 mm × 1 mm with a lateral resolution of 10 µm. The height of the measured structures corresponds to that derived from the small area scan in between a few nanometers.

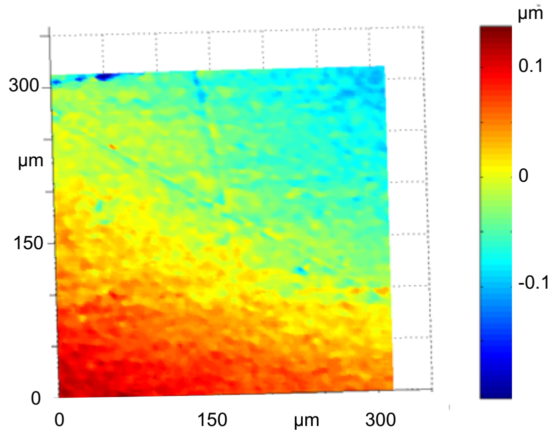

Figure 4. steel gauge block 320 µm × 320 µm

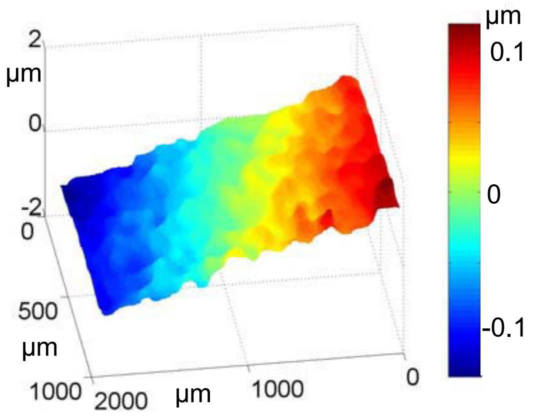

Figure 5. steel gauge block 2 mm × 1mm

4. Conclusion

With the introduced system traceable measurements with nanometer resolution in z-direction are feasible. The STM sensor under development will achieve nanometer resolution also in the lateral plane. The focus sensor is able to scan areas up to the millimeter range within 30 minutes dependent on the local spatial frequencies due to its high data acquisition rate. With the STM sensor the measurement speed will be smaller, but the spatial resolution will be higher due to smaller zone of interaction between sensor and specimen. Up to now measurements are restricted to surface slopes below 20° and low surface roughness, what is usually true at surfaces that have to be measured with nanometer resolution. In further research work the comparability of measurement results achieved with different probing systems on the same nanopositioning unit and the maximum allowable scanning speed dependent on surface quality and utilized sensor have to be investigated.

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