3-D Microprobe with Optical Detection System

F.G. Balzer, N. Dorozhovets, N. Hofmann, T. Hausotte, E. Manske, G. Jäger[1], S. Büttgenbach[2]
[1]*Ilmenau University of Technology, P.O. Box 100 565, Ilmenau, Germany*
[2]*Braunschweig University of Technology, Institute for Microtechnology. Germany*

felix.balzer@tu-ilmenau.de

Abstract

This paper introduces a novel 3-D tactile microprobe system developed at the Ilmenau University of Technology, Institute of Process Measurement and Sensor Technology. An optical detection system is used to measure the deflection of a silicone membrane and thus of the stylus.

The nanomeasuring machine NMM-1 (manufactured by SIOS Meßtechnik GmbH) [5] was used to verify the functional capability and to determine the metrological characteristics of the microprobe. Measurement resolution, linearity and repeatability were analyzed to demonstrate the suitability for measurements on microstructures.

1 Introduction

The ongoing trend of component miniaturization, which can be observed both in the laboratory and in industry, creates increasing demand for suitable measurement instruments for complex three-dimensional components. These instruments feature dimensions in the micrometer range with associated dimensional tolerances below 100 nm. Several nanopositioning and nanomeasuring machines (NPMMs) are being developed that have the appropriate capability for measuring complex microstructures [3], [4], [6], [7]. The performance of NPMMs with respect to measurement uncertainty is currently limited by the performance of the probe systems available [1]. In order to operate effectively, the microprobe systems should be able to measure a three-dimensional displacement with a higher resolution and an uncertainty well below that of the NPMM.

2 Concept of the microprobe system

The microprobe system consists of a 5 mm long stylus with a ruby ball and a silicon membrane as the damping system for the stylus and induces the measurement force.

An optical detection system shown in [2], which consists of an interferometer and a deflection measurement system, is used to measure the deflection of the membrane and thus of the stylus (see Fig. 1 (a)). It utilizes a single laser beam focused on the backside of the silicon membrane. A reflective coating is applied to enhance the reflectivity of the membrane. The reflected beam is split, with one part being detected by a deflection system using a quadrant photodiode to detect the tilt about the x- and y-axes and the other part being fed back into the interferometer for position measurement in the z-direction. The laser light source is coupled with the microprobe head using a fibre optic cable, preventing the light source heat from influencing the measurement set-up.

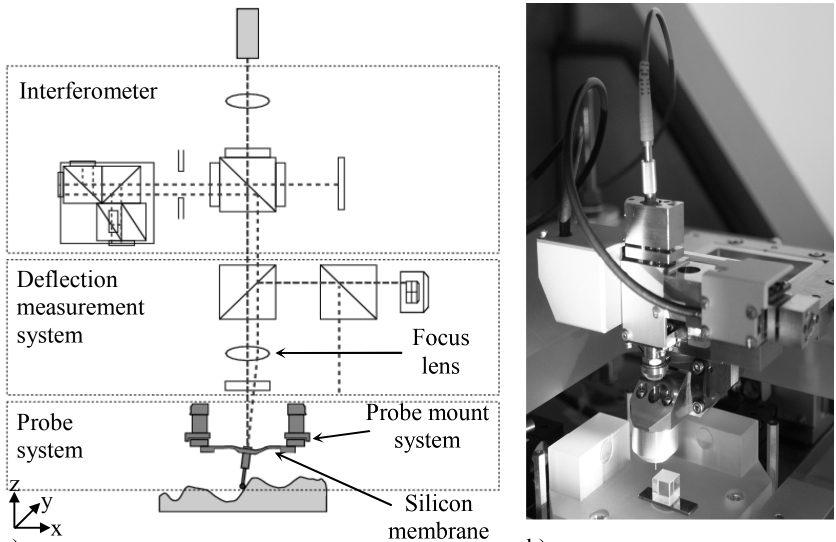


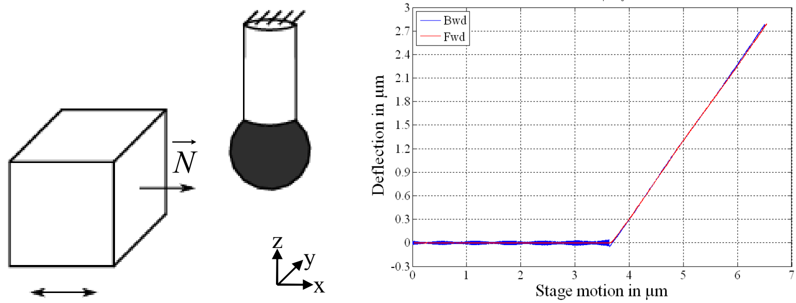
Figure 1: (a) Functional principle of the 3-D microprobe system; (b) probe system as installed in the NMM-1.

Because the membrane is only used as a damping system, no additional elements (such as piezoresistors) need to be diffused into the membrane. This has the advantage of homogeneous mechanical properties. The lack of electrical contacts allows the membrane with the attached probe stylus to be easily changed out.

The ball diameter used in the initial experiments was 0.3 mm. The probe is lightweight (equivalent mass - approximately 50 mg) and the membrane stiffness is anisotropic (about 200 N/m in xy-direction and 5200 N/m in z-direction).

3 First measurement results

The NMM-1 was used to determine the metrological characteristics. The principal set-up is shown in Fig. 2. A cube is placed on the NPMM's corner mirror and is positioned with the stage in the direction of the cube's surface normal vector. Each cube side is brought into contact with the probe, which is deflected over its measuring range. The NPMM's interferometric position values as well as the probe system's ADC values are saved simultaneously during this procedure, yielding a curve similar to that shown in Fig. 2 (b). This procedure was repeated one hundred times to determine reproducibility, linearity and resolution.



a) b)

Figure 2: (a) Principal set-up and (b) example measurement results for the x-axis

The interferometer exhibits a positioning noise of about 1.8 nm and possesses a resolution of about 0.3 nm. For a 5 mm long stylus the deflection measurement system achieves a resolution of 0.65 nm, whereas the positional noise is about 2.5 nm. Calculating one linear regression line over the one hundred measurements in each direction and subtracting this regression line from each measurement curve yields a maximum peak-to-peak value of 15 nm. The reproducibility of the force-free contact, which is calculated as the intersection point between the sensor offset value and the linear regression line, depends on the probing direction. For a lateral direction, the reproducibility is about 3.6 nm (k=2) and 5.2 nm (k=2) for the vertical direction. The contribution of hysteresis during these measurements was determined to be about 0.8 nm for a 3 µm displacement.

In order to investigate thermal drift, the microprobe system was placed in a temperature-controlled chamber with a temperature stability better than 0.2 K. The results of a 100 hour measurement yielded a temperature coefficient of approximately

76 nm/K for the microprobe system. The drift is most likely caused by adhesive layers and by differences in the coefficient of thermal expansion between the probe and the detection system.

4 Conclusion and outlook

This contribution introduced a new 3-D microprobe system with an optical detection system. It was shown that this system can be applied for typical measurement tasks in dimensional metrology, such as point measurements and scanning.

Further research will look into reducing drift and further improving repeatability by reengineering the microprobe head. The optical system must be optimized in order to achieve approximately the same resolution for both the interferometer and the deflection measurement system. Because the anisotropic stiffness of the membrane can lead to significant sensitivity changes during spherical scans, another challenge is to redesign the membrane so that its stiffness is isotropic.

References:

[1] Bos, E.: *Tactile 3D probing system for measuring MEMS with nanometer uncertainty*. Eindhoven University of Technology, 2008

[2] Dorozhovets, N.; Hausotte, T.; Hofmann, N.; Manske, E.; Jäger, G.*: Development of the interferometrical scanning probe microscope*, Proc. of SPIE, 2007

[3] Jäger, G.; Hausotte, T.; Manske, E.; Büchner, H.-J.; Mastylo, R.; Dorozhovets, N.; Füßl, R.; Grünwald, R.: *Nanometrology - Nanopositioning- and nanomeasuring machine with integrated nanoprobes*. In: Materials Science Forum (2006)

[4] Kramar, J.: *Nanometer resolution metrology with the Molecular Measuring Machine*. In: Meas. Sci. Technol. (2005)

[5] Manske, E.; Hausotte, T.; Mastylo, R.; Machleidt, T.; Jäger, G.: *New applications of the nanopositioning and nanomeasuring machine by using advanced tactile and non-tactile probes*. In: Meas. Sci. Technol. (2007)

[6] Ruijl, T.: *Ultra Precision Coordinate Measuring Machine*. Technical University Delft, 2001, PhD thesis

[7] Vermeulen, M.: *High-Precision 3D-Coordinate Measuring Machine*. Eindhoven University of Technology, 1999, PhD thesis