A High-resolution, Self-sensing and Self-actuated Probe for Micro and Nano Coordinate Metrology and Scanning Force Microscopy

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Abstract

A novel probe for micro and nano coordinate metrology as well as scanning force microscopy (SFM) was developed, featuring a fundamentally new design compared to the yet existing probes. The probe is placed in the cavity between the objective lens of an optical microscope and the object and is operated simultaneously with the optical microscope. The basic component is a longitudinally vibrating stylus attached to a big mass. The vibrating stylus is operated in a self-actuated and self-sensing mode. Thus, the motion of the probe can be directly detected electrically.

1 Introduction

A small sized ultrasonic probe has been presented earlier as a probe for coordinate measuring machines [1]. Later, this probe was operated as a scanning probe microscope [2]. But, challenges still remain, like viewing the sample while simultaneously using the tactile probe and restrictions in changing the probe (here the stylus). Also combinations of SFM heads and optical microscopes, used not only for observation but also for optical measurements, have been published before [e.g. 3]. In this research area, the detection method of the tactile probe's motion is an issue. To avoid disadvantages of optical detection methods, electrical methods were investigated. Therefore, a novel sensor head was designed based on a self-sensing and self-actuated, ultrasonic probe described in chapter 2 in more details.

Figure 1 shows an overview of the sensor head with the inserted novel probe as it is implemented in the optical path of a microscope This combination of an optical microscope with a tactile probe enables a two steps process: 1. Searching for the area of interest using the optical image and 2. precise scanning of the area of interest only.

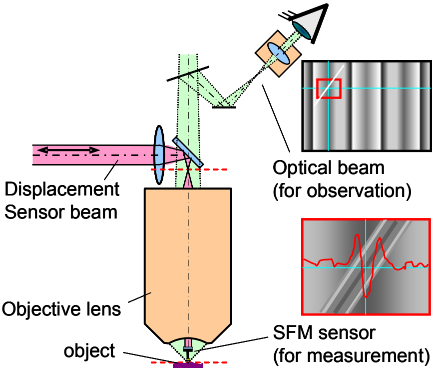

Figure 1: Principle of the complete sensor head with the probe

2 Structure and characteristics of the tactile probe

Figure 2 shows the structure of the tactile probe. It consists of three parts: an upper sensor part, a stylus part, and a supporting disc. Here the stylus is attached to the stylus plate by welding, but other methods for attachment, like soldering, are also possible. The active part of the sensor is a piezo plate, which is attached to the heavy top. The piezo plate acts as piezoelectric actuator and sensor simultaneously, thus enabling self-sensing operation. The intermediate part has a threaded bore where the stylus part is screwed in from below. This allows to remove and replace the stylus.

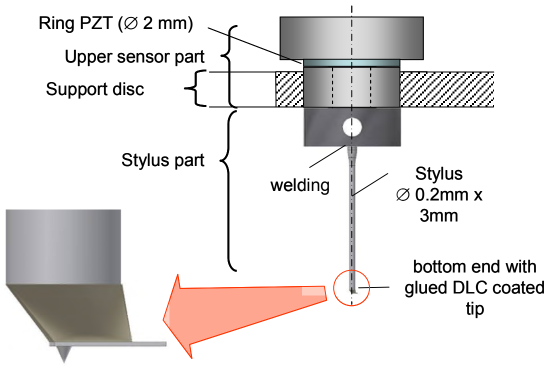

Figure 2: Structure of the tactile probe (here with a sharp tip as an example)

It is possible to attach different probing elements/tips at the end of the stylus like a sharp SFM tip, a diamond conical tip, a ruby ball, or a ball made by melting of the stylus material.

The spectral behaviour of the resonating probe has been investigated and for the geometry realized, the first longitudinal vibration mode was found to be in the order of 400 kHz, with a moderate Q factor in the range of 500. Furthermore, the high mechanical impedance of the vibrating stylus resonator results in very sensitive reactions to any tip-to-surface interaction of the probe. The measured sensitivity of the tactile probe is presented in Figure 3.

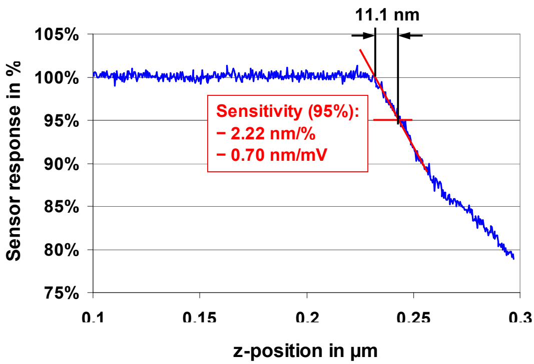

Figure 3: Sensitivity of the tactile probe

3 Measurement results using the complete sensor head

Test measurements have been performed with the complete sensor head (as sketched in Fig. 1) using the integrated z-axis actuator operated with sensor feedback control. The output voltage, shown in Figure 3, is used as control signal. In other words, the z-axis actuator keeps the vibration amplitude constant, thus the measuring force is constant during scanning. The test object is a 100 nm step height standard. The step material is SiO_2 on a Si substrate and the whole surface is chrome plated. The size of the scanned area is 100 µm x 100 µm. After establishing the SFM feedback control loop, a scanning measurement was recorded using the command data of the "Z-Position Controller" as surface data.

Although the test scan as shown in Figure 4 is an intermediate result, it is a proof of operation of the new sensor head. To achieve traceability, the measured (voltage) values were used to calibrate the system based on the certified step height values.

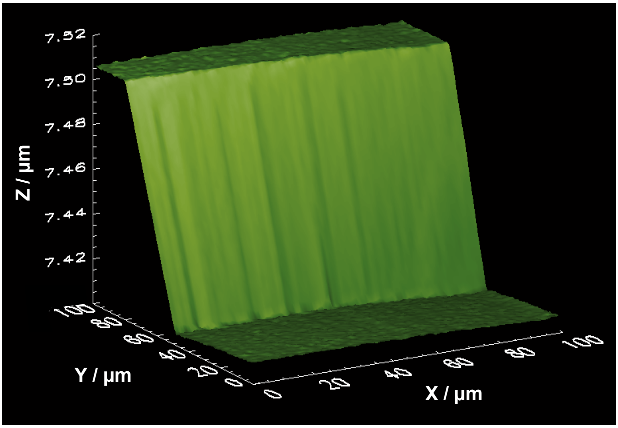

Figure 4: Test measurement

4 Conclusions

In this paper, the development of a probe for micro and nano coordinate metrology and Scanning Force Microscopy is described. The probe was designed and its characteristics were tested. It is the first representative of a new sensor family within the ultrasonic tactile sensors, employing longitudinal vibration.

The probe and z-axis actuator were combined to form a sensor head which was used to measure a calibrated step height, showing good initial results. The system allows to carry out visual observation and tactile measurements simultaneously.

Future work includes improving the traceability by installing a laser interferometer, which will measure the displacement of the probe. Furthermore, a detailed investigation of the measurement force, noise level and resolution will be performed.

References:

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