Recent Advances in 3-D Tactile Micro- and Nanometrology

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Abstract

This paper presents recent measurement results with an updated version of a 3-D microprobe with optical detection system developed earlier at the Institute of Process Measurement and Sensor Technology of the Ilmenau University of Technology [1]. This microprobe system is capable of exchanging the stylus and the deflection element separately. The nanomeasuring machine NMM-1 [2] was used for the investigation and analysis of the microprobe system. The metrological properties are presented. The functional principle of this new microprobe system includes a force-generating system to employ a vibrating mode. First results are discussed.

1 Introduction

At present the uncertainty of three-dimensional measurements on microstructures is not limited by the capabilities of nanopositioning and nanomeasuring machines (NPMMs) but by the performance of the probe systems available. Several tactile 3-D microprobe systems are under development which are capable of performing these types of measurement tasks but there are a number of unsolved problems.

Styli with probing sphere diameters below 120 µm are not commercially available but they are necessary for probing of micro-electro-mechanical systems. That is why research work has focused on micro-spherical probes machined by EDM to further reduce the tip size. But reducing the tip size is not particularly easy because interactions between the specimen surface and the probing sphere become readily apparent. On the other hand roundness deviations are a major problem. In micro- and nanometrology they are much larger than the resolution and the positioning uncertainty of the NPMM. To minimise their influence on the measurement uncertainty, they must be determined and compensated for.

Determination of radius and form of probing spheres with diameters below 1 mm is very difficult and time-consuming because the only generally successful method is the so-called three-sphere test [3]. The sphere under test must be fixed and all flexure elements have to be removed or clamped. That is why the approach of the new probe system design was to be able to exchange the stylus and the flexure elements separately. This enables the repeated use of a calibrated sphere, even if the flexure element becomes damaged.

2 Functional principle

The microprobe system consists of a measuring head and a separate probe system (see Fig. 1). Stylus deflection is detected by a single laser beam, split into two parts: one part for translation detection using an interferometer and another part used for tilt detection with a quadrant photodiode. The geometrical beam separation, which is fundamentally new in this system design, completely eliminates disruptive interference observed on the quadrant photodiode before [1]. The silicon membrane used in the previous system design has been replaced by a metal membrane, designed for isotropic probing forces.

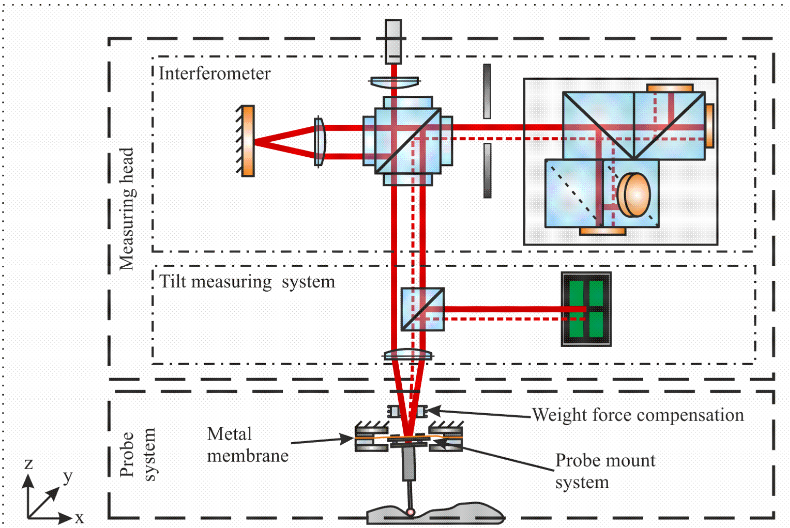

Figure 1: Functional principle

3 Measurement results

3.1 Metrological properties

For these investigations a Zerodur® cube was placed on the corner mirror of the NMM-1 (see Fig. 2). It is positioned in the direction of the cube's surface normal vector and brought into contact with the probe at a speed of 3 µm/s. The probe is deflected about 6.0 µm, whereas the optical system has a working range of about 15 µm in each direction. This procedure is repeated one hundred times.

Figure 2: Measurement set-up in the NMM-1

These measurements yield a resolution of approx. 0.3 nm for the interferometer and 0.93 nm for the tilt measuring system (using a 6 mm long stylus). Calculating the 3-D force-free contact point, the reproducibility in probing direction is nearly equal for all probing directions and is about 3.4 nm (k=2). This nearly isotropic behaviour can also be demonstrated by obtaining a directional response pattern [4]. The new membrane design shows deviations in the sensitivity coefficients of less than 4 %, probably due to assembly problems of the membrane and the kinematic probe mount system.

3.2 Scanning measurements

A new control system, based on the I++ DME specification, was implemented in the NMM-1 [5]. The I++ DME scan functions were improved and special scan functions added to allow advanced 3-D scan methods, further fulfilling the demands of scanning force microscopy and micro-coordinate measurements. These functions were used to perform sphere scans on a ruby sphere with 1 mm diameter according to DIN EN ISO 10360-4. Due to the nearly isotropic membrane behaviour, the maximum scanning speed could be increased up to about 60 µm/s.

3.3 Vibration mode

The microprobe system contains an active force-generating system (see Fig. 1). A coil and the corresponding iron core are mounted over each of the three magnets found in the kinematic probe mount system. On the one hand, adjusting the height of the cores generates weight force compensation for the plug. On the other hand, the stylus can be vibrated by powering the coils with various currents.

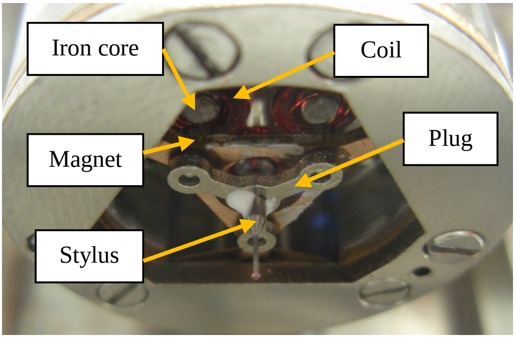

Figure 3: Weight force compensation and force-generating unit

This vibration can be realised in the measurement plane or in direction of the normal vector of the specimen surface. This vibration shall counteract the surface interaction forces between the probing sphere and the measurement surface. Initial measurements have shown no significant improvements because the vibrating frequency is not high enough due to the relative high weight of the kinematic probe mount system.

4 Conclusion and outlook

The results indicate that the microprobe system is well-suited for universal measurement tasks in micro-metrology. Further research work will focus on improving the vibration mode and on possibilities to change out the stylus. The latter task is not particularly easy because the system must be adjusted into its working range manually each time. For using an automatic plug exchange system the reproducibility of the plug position has to be improved in order to avoid manual adjustment.

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