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Fundamentals of Dynamic Sensor Positioning with Nanoscale Accuracy by an Inverse Kinematic Concept

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Summary:
A recent challenge in measurement science is the growing demand for machines allowing nanoscale positioning and measuring in large volumes. The moving stage principle typically used for these applications needs to be altered, considering the mass of the moving stage growing with the measuring volume. This paper proposes an inverted kinematic concept and discusses two approaches to the reconstruction of mirror profiles to compensate for deviations in the mirror topographies.

Keywords: metrology, interferometry, nanoscale, profile reconstruction, simulation

Introduction

Two developments in recent semiconductor production technologies lead to highly challenging requirements on measuring machines: the growing diameter of processed wafers and the diminution of the single structures and their pitches. To address this persistent trend a nano positioning and nano measuring machine (NPMM) with an inverse kinematic concept is proposed.

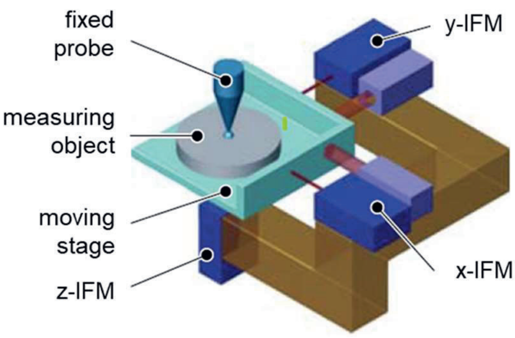

Fig. 1. Operation principle of the NPMM-200. The measuring object is placed upon the moving stage. [4]

State of the Art

The first nano measuring machine developed at the Technische Universität Ilmenau, the NMM-1 [1], has a movement range of 25 x 25 x 5 mm³. Similar to the recent trends, proposed progress formulated in the International Technology Roadmap for Semiconductors (ITRS-Roadmap) [2], had to be addressed. Therefore, the next incarnation, the NPMM-200 [3], has a measuring volume of 200 x 200 x 25 mm³ (see Fig. 1). In these machines the sensor is fixed and the movement is realized by a stage. Three interferometers (IFMs) capture the movement in the three axes x, y and z. The virtual intersection of the IFM beams is located in the contact point of the sensor on the measuring object. Hence, the Abbe principle is followed consequently which allows the NMM-1 and NPMM-200 to achieve nanoscale precision.

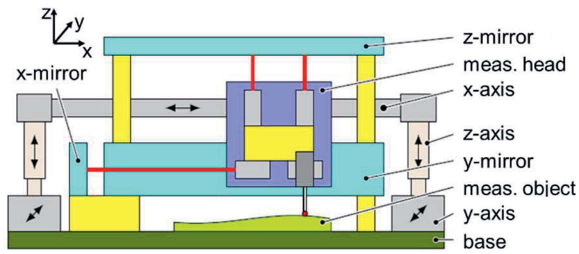

Fig. 2. Illustration of the inverse kinematic concept. The measuring head with the IFMs and the sensor is moved, whereas the mirrors are fixed and the driving system is placed outside the measuring volume. [4]

Limitations and Inverse Concept Proposal

With a proposed motion range of 700 x 700 x 100 mm³ for the next incarnation of the NPMM, the mass of the moving stage and the measuring object is estimated to be approx. 300 kg [4]. Along with the demands on the dynamics to keep measuring times in an acceptable range, the high positioning precision and the increased heat influx of more powerful propulsion systems, this leads to a conflict. In order to allow the expansion of the motion range without drastically increasing the mass to be moved, an inverse concept is proposed (see Fig. 2). Due to the realization of a lightweight measuring head (< 1 kg), the Abbe principle could no longer be strictly followed. In order to compensate for this imperfection, in every axis an additional IFM is placed, which allows to observe and control tilt errors.

Mirror Reconstruction

The inverse kinematic concept poses a novel challenge. Caused by the dimensions of the mirrors and the scanning movement of the measuring head, deviations from the ideal flat mirror profile lead to positioning errors, which need to be compensated. Since the removal of the mirrors is unfeasible, their deviation has to be examined in the mounted state. Two different approaches are analyzed. The triangulation method utilized the two IFM beams. Simplified to an one-dimensional movement along the x-axis, whereas the two IFM beams sample the z-mirror, equation (1) can be used to reconstruct the profile.

$$R(x_i) = \frac{m(x_i + {}^{d}/_{2}) - m(x_i - {}^{d}/_{2})}{d} k + C \qquad (1)$$

With m being the distance measured by the IFMs, R the contour of the mirror, d the distance between the two IFM beams, k the sampling distance and the constant C refers to a non-reconstructable straight line, which can be found via calibration. In order to test the quality of the reconstruction and to establish a tool for comparison of the reconstruction methods, topographies of different mirrors are measured with a Fizeau-IFM and the sampling and reconstruction are simulated. Results are shown in Fig. 3.

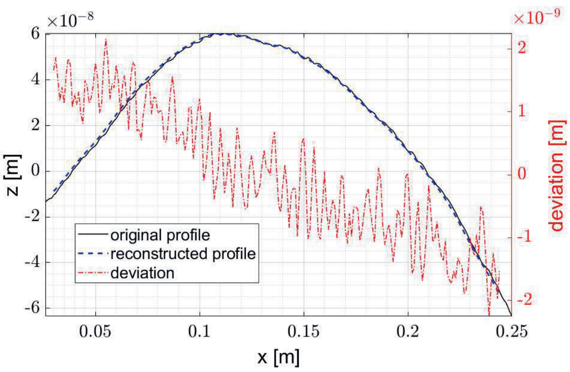

Fig. 3. Reconstruction of a mirror profile with the triangulation method.

The Traceable Multiple Sensor (TMS) method combines a system of at least two coupled distance sensors and an angular measurement system to reconstruct a 2D mirror topography and precisely separate the influences of the mirror deviation, the scanning stage error, the yaw angle and systematic errors of the distance sensors [5]. The linear actuation of the sensor head allows to generate an overestimated linear equation system by evaluating every sensor signal at overlapping positions of the sensor head. This leads to the following equation:

$$\vec{m} = A\,\vec{\vartheta} \qquad (2)$$

where $\vec{m}$ represents the measured distances and angles, A the design matrix according to the measurement strategy and $\vec{\vartheta}$ the unknown parameters. The solution of $\vec{\vartheta}$ is determined by applying the least square method. It is shown that the TMS-Method is able to measure mirror topographies with standard uncertainty below 0.25 nm and even smaller standard deviations [6].

Conclusion and Outlook

Due to large masses to be moved, the moving stage principle reaches its limits with increasing measuring volume. To overcome this constraint an inverse concept with a moving measuring head is proposed. The two discussed mirror reconstruction methods show potential to compensate for flatness mirror deviation, up to the nanoscale range. In future work a single axis demonstrator will be brought into operation in order to verify the simulation results and subsequently a three axis demonstrator will be set up.

Acknowledgments

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