Application of a novel fibre-coupled confocal sensor in a nanopositioning and nanomeasuring machine

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Abstract

This article introduces a novel fibre-coupled confocal sensor for optical, non-tactile measurement of microstructures developed at the Institute of Process Measurement and Sensor Technology. The functional principle and an analysis of its metrological properties as well as some experimental results using the NMM-1, a nanopositioning and nanomeasuring machine (NPMM) manufactured by SIOS Meßtechnik GmbH, are presented.

1 Introduction

The current challenge facing nanometrology is that there is an increasing demand for multiple-scale measurements, which refers to situations in which objects have outer dimensions in the millimetre range but contain features reaching atomic dimensions and associated tolerances in the nanometre range. To fulfil this demand, significant research is continuing all over the world to develop appropriate NPMMs. Consequently, adequate probe systems are needed which possess a resolution and an uncertainty equal or better than the parameters of the NPMM. The problem is that there are numerous measuring tasks in micro- and nanometrology but no universal probe system is currently available which is capable of performing all these measurements [1].

This contribution introduces a novel fibre-coupled confocal sensor for use in NPMMs. Confocal microscopy is a subset field of classical microscopy and a well-established optical imaging technique with regard to micro- and nanotechnology [2].

Several other sensors are known from the literature which also involve the confocal principle using a fibre coupling. However they are not suitable for the intended application because of their large geometric dimensions, insufficient resolution, heat distribution and high costs. The main development objectives have been a low cost distance measuring system, use of standard electronic components and an integration into the existing electronics unit of the NMM-1 optionally.

2 Concept of the probe system

The functional principal of the confocal sensor is shown in Fig. 1. The sensor head is fixed in position and the specimen (1) is movable along the optical axis.

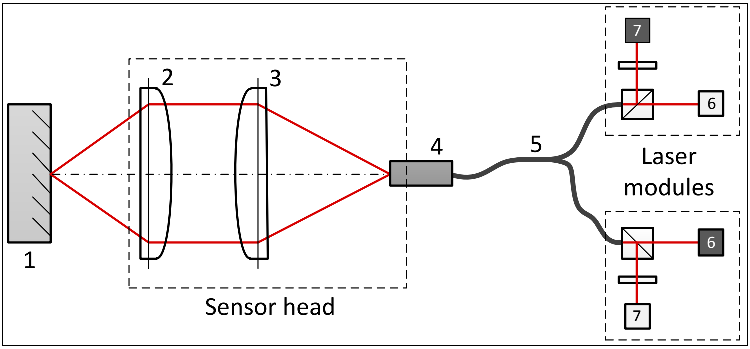


Figure 1: Functional principle, 1 movable mirror, 2 focus lens, 3 lens for collimation, 4 fibre coupling, 5 optical fibre, 6 light sources, 7 photodetectors

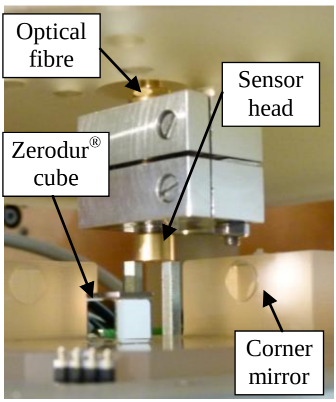
The functional principle is based on the two-wavelength method. The light of two laser diodes with slightly different wavelengths (1330 nm and 1550 nm) is coupled into a monomode fibre and transmitted to the self-designed sensor head. The latter contains a lens to collimate the divergent light coming out of the multimode fibre and a lens to focus the beam onto the specimen. The light reflected and scattered from the specimen's surface is collected by the same lenses back into the fibre and into the electronics unit. In this way, the end of the fibre acts as both the illumination and the micron-sized detection pinhole as laid out in the principle of confocal microscopy. The actual optical system design yields an approximate spot size of 4 µm mainly due to the numeric aperture of the lens and the wavelengths. This is relatively large compared to other optical sensors used for surface measurements, but for a proof of concept it was decided to be adequate because the laser diodes used are widespread in telecommunications engineering. Therefore they are not too expensive and the fibre-coupling is state of the art.

The chromatic dispersion of the focal length causes a variation of the focal distance for both wavelength. This results in a displacement between the two intensity maxima. Subtracting the signals of the two laser diodes yields a linearized difference signal similar to that in Fig. 2 b), which can be easily interpreted as a probe system signal by the actual software of the NMM-1. This enables the sensor to be calibrated and used as a measuring probe system in the NMM-1.

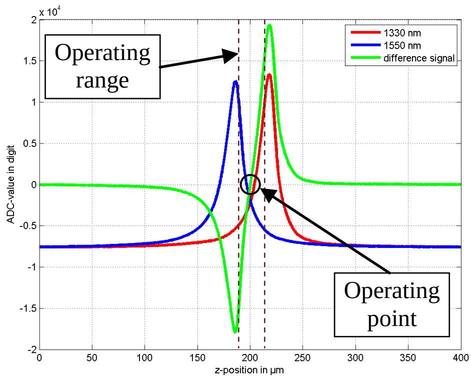
The big advantage of the fibre coupling is that the sensor head does not introduce an additional heat source into the measurement set-up. Thus, it can easily be used in applications within a temperature-controlled chamber or under vacuum conditions.

3 Measurement results

The NMM-1 available at our Institute was used to investigate the metrological properties of the sensor and to carry out the measurements. The distinctive feature of this NPMM is an Abbe-error-free alignment in the three orthogonal measurement axes. The position of the movable corner mirror, which serves as a platform for holding the specimen, is measured by three laser interferometers with a resolution of 0.1 nm [3]. In general, the positioning uncertainty in the entire measuring volume is less than 10 nm, but for a concrete measurement task the measurement values are often processed so that a smaller uncertainty is reached. The measurement set-up is shown in Fig. 2 a). A principle measurement result is shown in Fig. 2 b).



a)



b)

Figure 2: a) Confocal sensor installed in the NMM-1, b) principle measurement result

A cube made of Zerodur® with a reflective coating on its surfaces is used as specimen. The sensor head is fixed onto a Zerodur® plate used for mounting probe systems on the metrology frame of the NMM-1. The cube is moved along the optical axis of the sensor. The position values of the NMM-1 as well as the probe systems ADC values corresponding to the reflected light intensity are saved simultaneously.
The zero crossing of the difference signal is decided to be the operating point for the use as probe system. Its reproducibility has been determined in a set of 150 measurements to be about 6.9 nm (k = 2). The linearity in the working range is well below 50 nm enabling well-reproducible calibration with the NMM-1. Measurements of step height standards have to be continued to be able to compare this confocal sensor with the focus sensor which has been developed at our institute before [4].

4 Conclusion and outlook

This contribution introduced a fibre-coupled confocal sensor based on two wave-lengths for use as a low-cost optical distance measuring system, which can be used as a probing system in NPMMs. The paper focuses on the functional principle and the investigation of the metrological properties showing great potential for future work.
Measurements of microstructures and step height comparisons have to be continued. Furthermore a camera system has to be integrated to facilitate the navigation in the large measuring volume.

Acknowledgements

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References:

[1] Manske, E.; Jäger, G.; Hausotte, T.: *Prospects of multi-sensor technology for largearea applications in micro- and nanometrology*. Proc. of NCSL International Workshop & Symposium 2011, Washington
[2] Wilson, T.: Confocal microscopy. London, 1990, Academic Press
[3] Jäger, G.; Manske, E.; Hausotte, T.; Büchner, H.-J.: *The Metrological Basis and Operation of NMM-1*. Technisches Messen, 2009, Vol. 76, pages 227-34
[4] Mastylo, R.; Dontsov, D.; Manske, E.; Jäger, G.: *A focus sensor for an application in a nanopositioning and nanomeasuring machine*. Proc. of SPIE, 2005, Vol. 5856