Evaluation of periodic nonlinearities of optical interferometers by comparing two interferometers with different wavelength

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Abstract
The movement of a double-sided mirror was measured with two different interferometers aligned complying with Abbe's principle. The comparison of two interferometers with different wavelength allows a separation of their nonlinearities. Therewith the periodic nonlinearities of a novel compact Twyman-Green interferometer were determined to be smaller than ±0.2 nm.

1 Introduction

Positioning and scanning stages for atomic force microscopes often use piezoelectric transducers as actors. To overcome the nonlinearity, drift, aging and hysteresis of these transducers a position control using for example the signals of capacitive sensors is often implemented. For the realization of traceability and a minimal uncertainty at PTB a compact Twyman-Green interferometer was integrated in a metrology frame to track the movement of the stage. The uncertainty of an optical interferometer at short motion ranges is often limited by the periodic nonlinearities. Their determination was realized by a simultaneous measurement of the movement of a piezo scanner by the compact Twyman-Green interferometer and a heterodyne interferometer.

2 Twyman-Green interferometer

A HeNe laser was used as light source for the Twyman-Green interferometer under investigation. The light with a wavelength of 633 nm was transferred with a single mode fiber to the optical setup, shown in figure 1 (right-hand side). It consists only of a collimator, a plane parallel plate with a non-polarizing beam splitter (NPBS), a tilted reference mirror and a CMOS line sensor. But with this minimal amount of components it is possible to measure the displacement, its direction and the yaw angle variations of the moving mirror using a novel signal processing approach [1]. Due to the tilt of the reference mirror a fringe pattern is projected on the line sensor, whose phase variation provides information about the displacement and the shift of the peak in the frequency spectrum enables the detection of tilt variations simultaneously. This information is evaluated using a specific Fourier transformation calculated with the PC.

3 Fully differential plane-mirror interferometer

The fully differential plane-mirror interferometer, shown in figure 1 (left-hand side), used a frequency-doubled Nd:YAG laser as light source. Its light with a wavelength of 532 nm was split and afterwards frequency-shifted using two acousto-optical modulators (AOM). To drive the AOMs a two channel function generator working at 80 MHz and 78.5 MHz, which resulted in a beat frequency of 1.5 MHz, was used. The frequency shifted beams were coupled into polarization maintaining fibres to separate heat sources from the optical setup. The two spatially separated input beams passed two Glan-Thompson polarizers (GTP) to remove the second guided mode of the fibres. The optical concept of the heterodyne interferometer itself is based on plane-parallel plates. NPBSs and mirrors evaporated on the first plane-parallel plate were used to generate four parallel beams to compensate the phase variations introduced by the optical fibers, possible angle variations between the mirrors and interferometer optics and offer a minimal path difference between reference and measuring arm. The four beams with the same polarization state passed a polarizing beam splitter (PBS). They passed a quarter-wave-plate before and after their reflection by the moving and reference mirror. Then the beams were reflected at the PBS and superposed with the help of a NPBS and a mirror evaporated at another plane- parallel plate. Due to the use of two separated input beams and the prevention of ghost reflections by tilting the optical components, periodic nonlinearities were suppressed at the heterodyne interferometer. They were determined by a comparison with an x-ray interferometer to be smaller than ±10 pm [2] without any quadrature fringe correction.

The differential phase of the heterodyne signals was evaluated using a lock-in algorithm. The phase evaluation is applied, using a state-of-the-art ADC board with embedded FPGA units, to realize a phase resolution in the single digit picometer range and an acquisition rate of 48.8 kHz [3].

4 Comparison of the interferometers

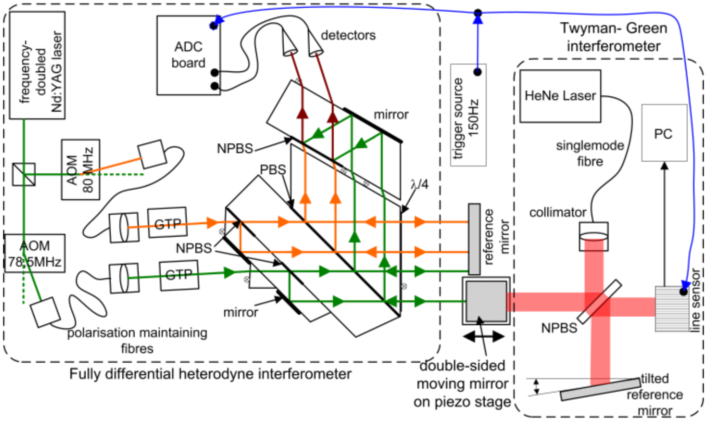

Figure 1: Setup of the different interferometer in comparison

In the comparison measurement both interferometers were placed observing Abbe's principle and tracked the movement of one common double-sided mirror fixed on a piezo scanner. For the adjustment the double-sided mirror was removed. The measuring beams of the interferometers, which both had a beam diameter of approximately 2.3 mm, were superposed at its nominal position using a diffusing screen. To minimize the influence of ghost reflections in the Twyman-Green interferometer a relative tilt of 5 mrad between the measuring beams of the interferometers was introduced. This resulted in a cosine error of 60 pm for the realized displacement of the mirror of 4.5 µm. The double-sided mirror was moved over this distance in 50 s with the piezo scanner in closed loop control using the feedback of its capacitive sensors. To minimize the influence of position noise, the data-acquisition of the different phase meters was synchronized using a common trigger. At every trigger pulse, which occurred at a rate of 150 Hz, the exposure of the line sensor was started together with data acquisition of the ADC board, which operated at a rate of 48.8 kHz, for the whole exposure time of 1.2 ms. The resulting 58 values from the heterodyne interferometer were averaged later on. Both measurement beams have a path of approximately 25 mm through air. The respective reference mirrors were arranged in such a way that the obtained dead path was minimal. To avoid the influence of air turbulences and refractive index gradients the two optical setups were placed in a temperature stabilized box.

5 Periodic nonlinearities of the interferometers

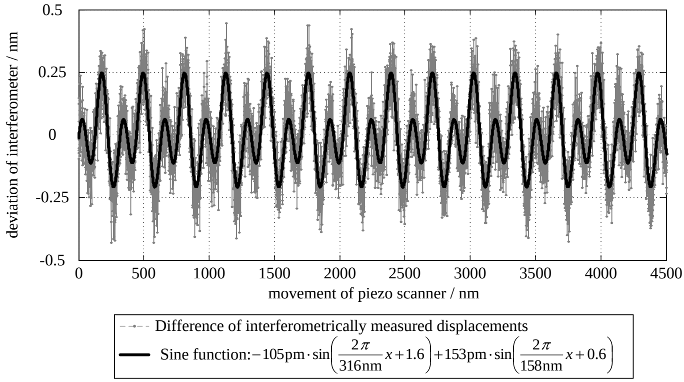

Figure 2: Deviations from a best-fit line of the difference between both interferometers

The capacitive sensors of the piezo scanner have parabolic nonlinearities in order of ±1.5 nm and a resolution of 0.1 nm, which limits their capability to determine periodic nonlinearities of the interferometers. The difference of the interferometrically measured displacements contains the periodic nonlinearities of both systems. We eliminated the influence of the cosine errors and the thermal drift, caused by the line sensor, by subtracting a best-fit line from the difference. The remaining deviations, shown in figure 2, contain, according to amplitude spectra, periodic nonlinearities with a period of 316 nm, 266 nm, 158 nm and 106 nm with the respective amplitudes of 105 pm, 6 pm, 152 pm and 27 pm. Subtracting these sine functions reduces the standard deviation of the remaining deviations to 82 pm.

References:

[1] Strube S et al, 2011, Compact field programmable gate array (FPGA)-based multi-axial interferometer for simultaneous tilt and distance measurement in the sub-nanometre range, *Meas. Sci. Technol.*, 22, 094026

[2] Weichert C et al, 2012, A heterodyne interferometer with periodic nonlinearities smaller than ±10 pm, *Meas. Sci. Technol.*, to be published

[3] Köchert P et al, 2011, A fast phasemeter for interferometeric applications with an accuracy in the picometer regime, *10th IMEKO Symposium Laser Metrology for Precision Measurement and Inspection in Industry*, Düsseldorf, VDI, 2156