Displacement Laser Interferometry with Sub-nanometer Uncertainty

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When considering interferometric displacement measurements with nanometer uncertainty over small distances (below 1mm) the measurements are influenced by periodic deviations originating from polarization mixing. In measurements with nanometer uncertainty over larger distances this error may become negligible compared to errors introduced by the refractive index changes of the medium in which the measurement takes place.

A model based on Jones matrices enables the prediction of periodic deviations originating from errors in optical alignment and polarization errors of the components of the interferometer. In order to enable the incorporation of polarization properties of components used in interferometers, different measurement setups are discussed. Measurement setups are used to measure the polarization properties of a heterodyne laser head used in the interferometer system. Based on ellipsometry a setup is realized to measure the polarization properties of the optical components of the laser interferometer.

With use of measurements carried out with these setups and the model it can be concluded that periodic deviations originating from different error sources can not be superimposed, as interaction exists which may cause partial compensation.

The correctness of the predicted periodic deviations was examined by placing an entire interferometer system on a traceable calibration setup based on a Fabry-Pérot interferometer. This system enables a calibration with an uncertainty of 0.94nm over a range of 300µm. Prior to this measurement the polarization properties of the separate components were measured to enable a good prediction of periodic deviations with the model. The measurements compared to the model revealed a standard deviation of 0.14nm for small periodic deviations and a standard deviation of 0.3nm for periodic deviations with amplitudes of several nanometers.

This Jones model combined with the setups for measurement of the polarization properties forms a practical tool which enables the designer to choose the right components and alignment tolerances for a practical setup with (sub-)nanometer uncertainty specifications.

To improve the uncertainty of existing laser interferometer systems a compensation method for heterodyne laser interferometers was investigated. It is based on phase quadrature measurement in combination with a compensation algorithm based on

Heydemann's compensation which is used frequently in homodyne interferometry. The system enables a compensation of periodic deviations with an amplitude of 8nm down to an uncertainty of 0.2nm. From measurements it appears that ghost reflections occurring in the optical system of the interferometer cannot be compensated by this method.

Regarding the refractive index of air three measurement methods were compared. The three empirical equations which can be found in literature, an absolute refractometer based on a commercial interferometer and a newly developed tracker system based on a Fabry-Pérot cavity. The tracker was tested to investigate the feasibility of the method for absolute refractometry with improved uncertainty. The developed tracker had a relative uncertainty of $8\ 10^{-10}$. The comparison revealed some temperature effects which cannot be explained yet. However the results of the comparison indicate that an absolute refractometer based on a Fabry-Pérot cavity will improve the uncertainty of refractive index measurement compared to existing methods.