# Self-calibration of non-linearities of laser interferometer and capacitive sensor combination for an interferometrically traceable AFM device


Virpi Korpelainen and Antti Lassila

Centre for Metrology and Accreditation (MIKES), P.O. Box 239, 00181 Helsinki, Finland
virpi.korpelainen@mikes.fi, antti.lassila@mikes.fi

www.mikes.fi

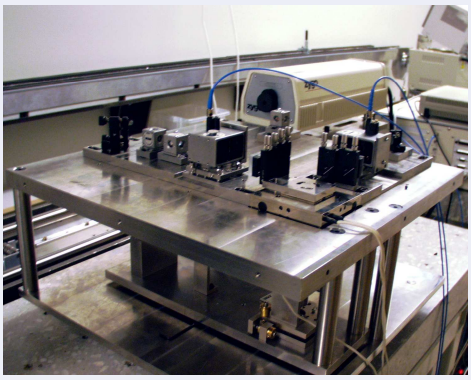

## Introduction

- During last years large investments have been directed to development and research of micromechanical and nanotechnological products
- All quantitative measurements at micro- and nanometre scale
  - in research: accuracy and reliability of results
  - in production industry: checking critical dimensions against tolerance limits

  should be traceable to the definition of the metre
- ↗ Guarantees accurate and commensurate results and high quality

- Laser interferometry is used to transfer the metre from the realisation to actual measurements .
  - In interferometric measurements at nanometre scale, one of the main uncertainty components is a periodical non-linearity of the laser interferometer [1-3]

- MIKES' metrological AFM project
  - to realise traceable scale in the nanometre region
  - to offer related calibration and measurement services
  - ➔ Straightforward source of traceability for Finnish economy and science community
  - Target uncertainty level ~1 nm with sub-nanometer resolution
  - Non-linearity of the laser interferometer is minimised by described self-calibration method

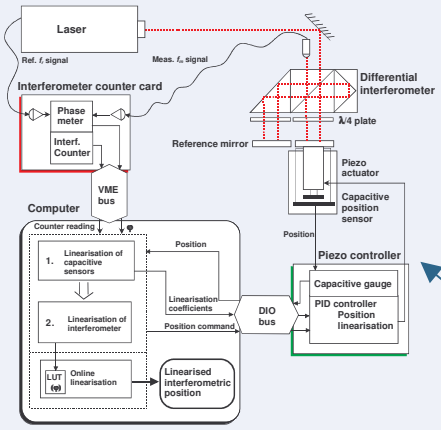


## Non-linearity of capacitive sensors

- Inherently linear devices
- Practical capacitive sensors are not ideal
- ➔ Non-periodical non-linearity
- Caused by
  - edge effects
  - plate tilt
  - flatness
  - stray capacitance

## Non-linearity of a laser interferometer

- Periodical with a period proportional to a fraction of the used wavelength
- Carefully studied [4]
- Caused by
  - elliptically or non-orthogonal polarised laser beams
  - rotational errors in the set-up
  - different transmission coefficients in the beam splitter
  - errors in phase detection
- May vary in time depending on small variations in e.g. optical alignment, ambient or material temperature or frequency of the laser
- The non-linearity may be from sub-nanometre range to a magnitude of 10 nm, depending on set-up




## Self-calibration method

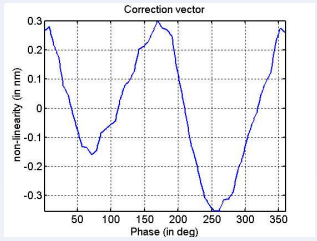
- Interferometrically traceable AFM at MIKES
  - Planned to allow simultaneous measurements of position of the scanning stage by
    - 3-D heterodyne interferometer
    - capacitive sensors
- Different natures of non-linearities the interferometer and capacitive sensors are used to eliminate both non-linearities

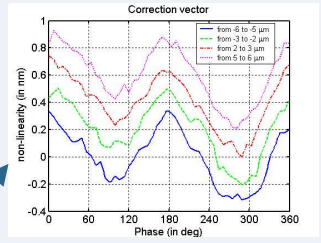
- Piezo actuator with capacitive sensors
  - Queensgate NPS-Z-15H (NPS-XY-100A)
  - Control electronics
- Laser interferometer
  - Heterodyne
  - Plane mirror interferometer
  - Differential
  - Zygo ZMI 2000
- Self-calibration scheme

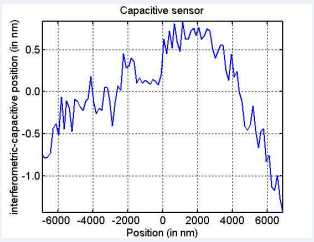
1. Non-linearity of a capacitive sensor is measured
   - by a laser interferometer
   - with step length equal to one period of the interferometer i.e. λ/4
   - Corrected with a fourth order linearisation polynome
   - Linearisation coefficients are stored in the piezo controller
2. Non-linearity of the laser interferometer is measured with sub-periodic stepping using the linearised capasitive sensor as a reference
   - Over several periods
   - Repeated a few times
   - ➔ Phase dependent non-linearity correction vector
   - Based on assumption that non-linearity of laser interferometer is similar over the total range
     - Measured in 4 different positions

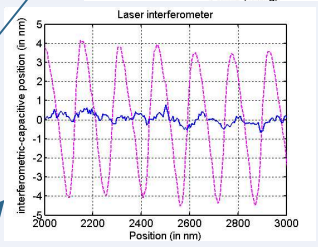
- The self-calibration can be done before each AFM measurement

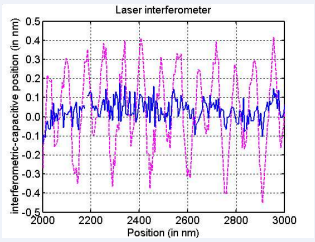
- ↗ Non-linearity of a laser interferometer can be corrected online with sub-nanometre accuracy
  - Well aligned interferometer
  - Beam splitter aligned 12° out-off-optimal




## Conclusions

- Non-linearity of the interferometers
  - affects laser interferometric distance measurements at nanometre range
- Self-calibration method developed
  - utilises different natures of non-linearities of laser interferometers and capacitive sensors
- Periodical non-linearity of laser inferferometer was reduced in worst case from 4 nm to 0.4 nm and in well aligned case from 0.4 nm to 0.1 nm
- Automated self-calibration can be repeated as often as feasible

## References


[1] N. Bobroff, 'Recent advances in displacement measuring interforometry', *Meas. Sci. Technol.*, 4 (1993) 907-926.

[2] K. Köning, R. Dixson, J. Fu, T.V. Vorburger, 'The role of periodical interferometer errors in the calibration of capacitance displacement sensors for nanometrology applications, *Meas. Sci. Technol.*, 12 (2001) 2002-2008.

[3] G. Dai, F. Pohlenz, H.-U. Danzebrink, K. Hasche, G. Wilkening, 'Improving the performance of interferometers in metrological scanning probe microscopes, *Meas. Sci. Technol.*, 15 (2004) 444-450.

[4] S.J.A.G. Cosijns, H. Haitjema, P.H.J. Schellekens, 'Modelling and verifying non-linearities in heterodyne displacement interferometry', *Precision engineering*, 26 (2002) 448-455.