PRECISION IN MEASUREMENT

SIOS Meßtechnik GmbH

Ultrastabile Laser-Interferometer:

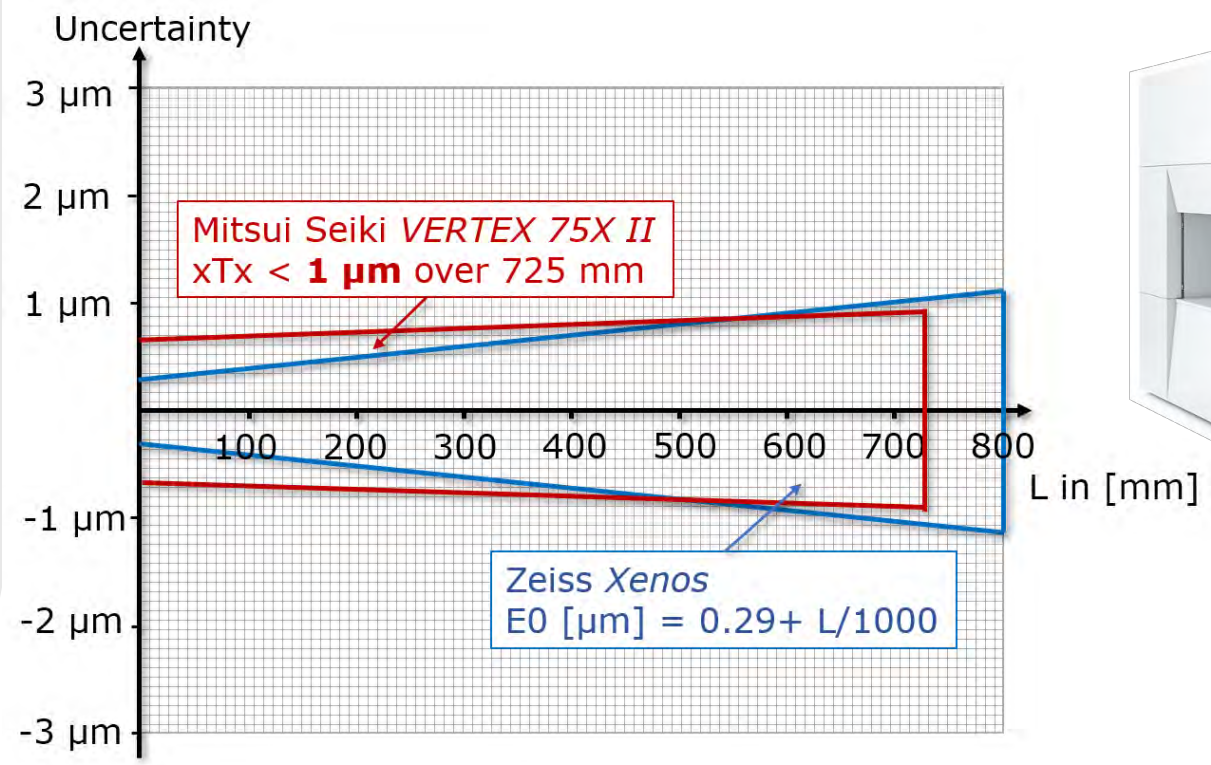
Eine Brücke zwischen Temperaturmesstechnik und laserinterferometrischer Präzisionsmesstechnik

Dr. Ralf Schüler
Leiter Entwicklung

www.sios-precision.com

Motivation

Challenges of high precision manufacturing



Source user: www.mitsuiseiki.com/products/vx750-5x.asp
www.zeiss.de/messtechnik/produkte/systeme/koordinatenmessgeraete/portalmessgeraete/xenos.html

SIOS

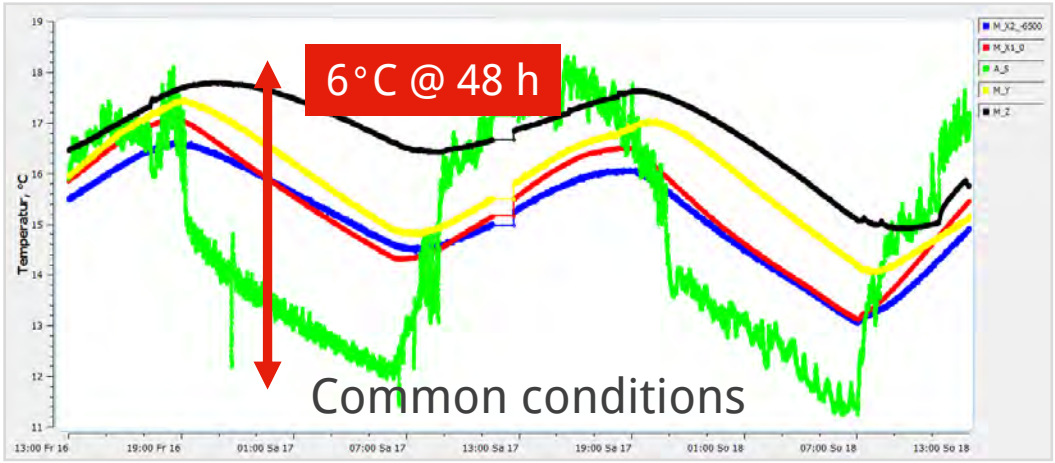
Motivation

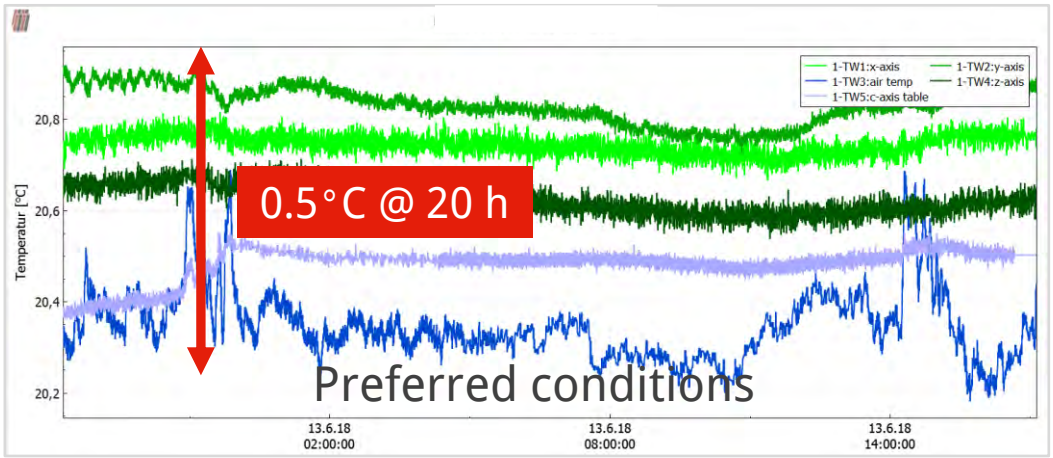
Challenges of high precision manufacturing

- leak of temperature control for machine tool and for workpiece
- different conditions for calibration and machining
- long calibration time of the machine tool

- measurement of parts directly on the machine tool (see ISO/TC 39/SC 2 proposal)
- partial calibration of the volume or parameters needed for further process

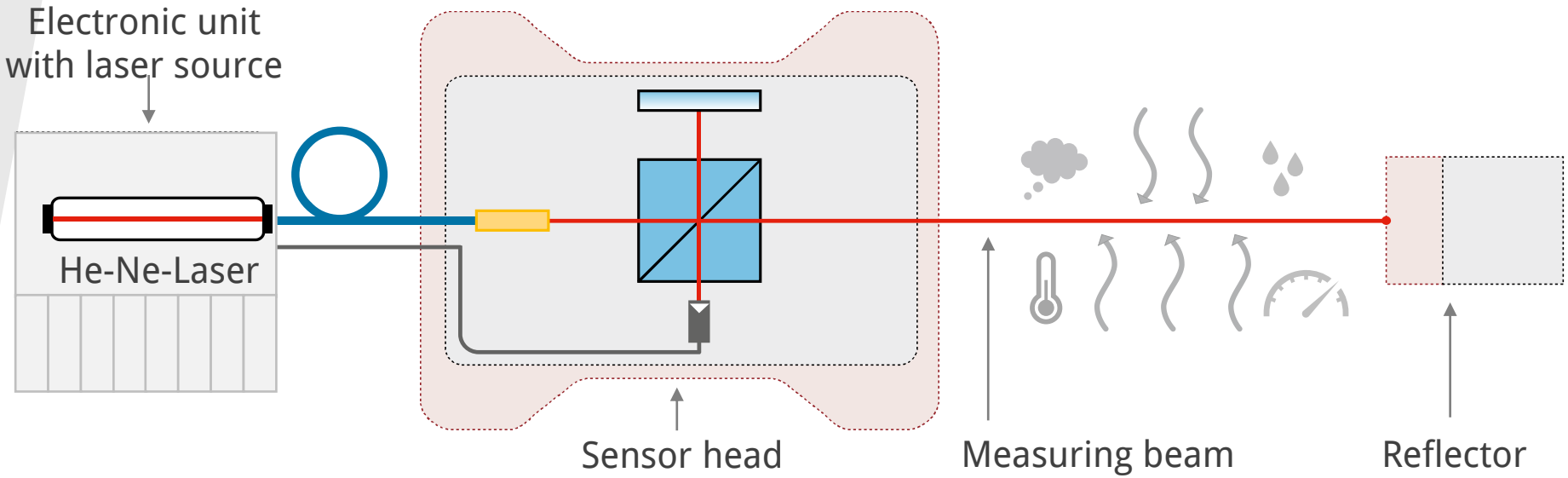
Temperature distribution





Uncertainty of Laser Interferometers

Laser wavelength as a scale of measurements



The quality of the measurements by laser interferometer in air depends on the accuracy of the definition of air refractive index along the measuring beam.

Uncertainty of Laser Interferometers

Laser wavelength in air

Laser wavelength as length measurement standard

Laser wavelength in air → $\lambda_{air} = \frac{\lambda_0}{n_{air}}$ ← Laser wavelength in vacuum

← Refractive index in air

Edlen Formula for determination of the refractive index in air

Air pressure ↓ Humidity ↓

$$(n-1)_{p,t,p_w,c} = 2.8793 \cdot 10^{-9} \frac{p}{1 + 0.003671 \cdot t} \cdot (1 + 5.33 \cdot (c - 400) \cdot 10^{-7}) - 3.7 \cdot 10^{-10} \cdot p_w$$

↑ Temperature

Uncertainty of Laser Interferometers

Laser wavelength in air

$$\Delta n/n = -0.929 \cdot 10^{-6} K^{-1} \cdot \Delta t$$

Δt - change of air temperature

If we measure at **21 °C** instead of **20 °C**, we have error of **-0.93 µm** at 1 m.

$$\Delta n/n = +2.879 \cdot 10^{-9} Pa^{-1} \cdot \Delta p$$

Δp - change of air pressure

If we measure an air pressure of **1014 hPa** instead of **1013 hPa**, we have error of **+0.27 µm** at 1 m.

$$\Delta n/n = -3.7 \cdot 10^{-10} Pa^{-1} \cdot \Delta p_W$$

Δp_W - change of water vapor pressure of the air

If we measure at **60%** instead of **50%** relative humidity, we measure **-0.09 µm** wrong.

SIOS environmental sensors and devices

Interferometers need precise environmental measurements for

- Temperature,
- Air pressure and
- Humidity

Precision Climate Measuring Station LCS

Basis System LCS-01 (wireless) and LCS-02 (wired)

- used in measuring and calibration laboratories for documentation and compensation during calibration procedure
- for monitoring precision measurements and test setups
- as module for integrating in OEM machines

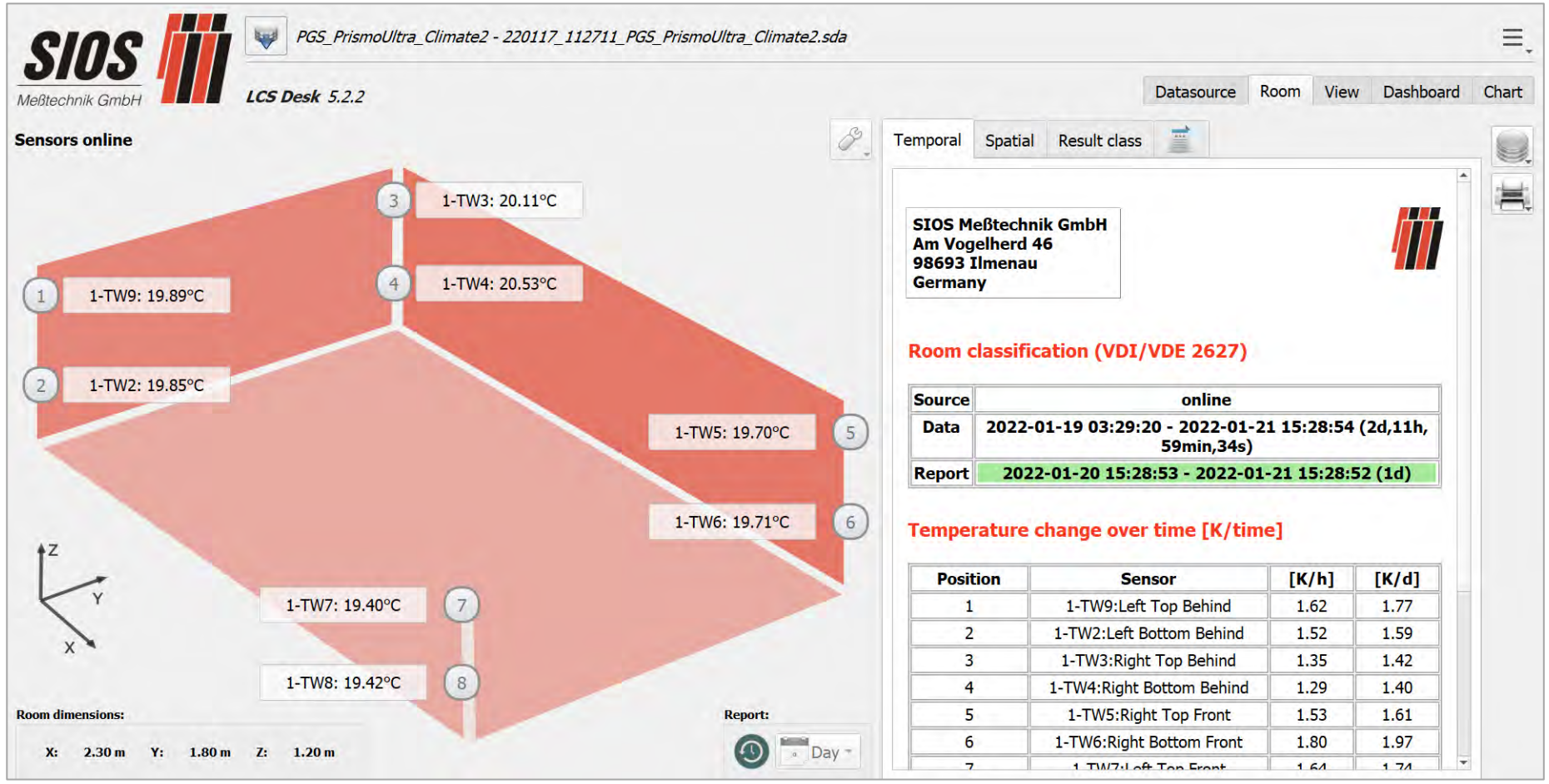
TT-01 with
air temperature sensor

WT-01 with
material temperature sensor

- 5 wired temperature sensor
- up to 15 wired Sensors with extension LCS-03
- 15 wireless temperature sensors
- 2 air pressure sensors
- 2 air humidity sensors

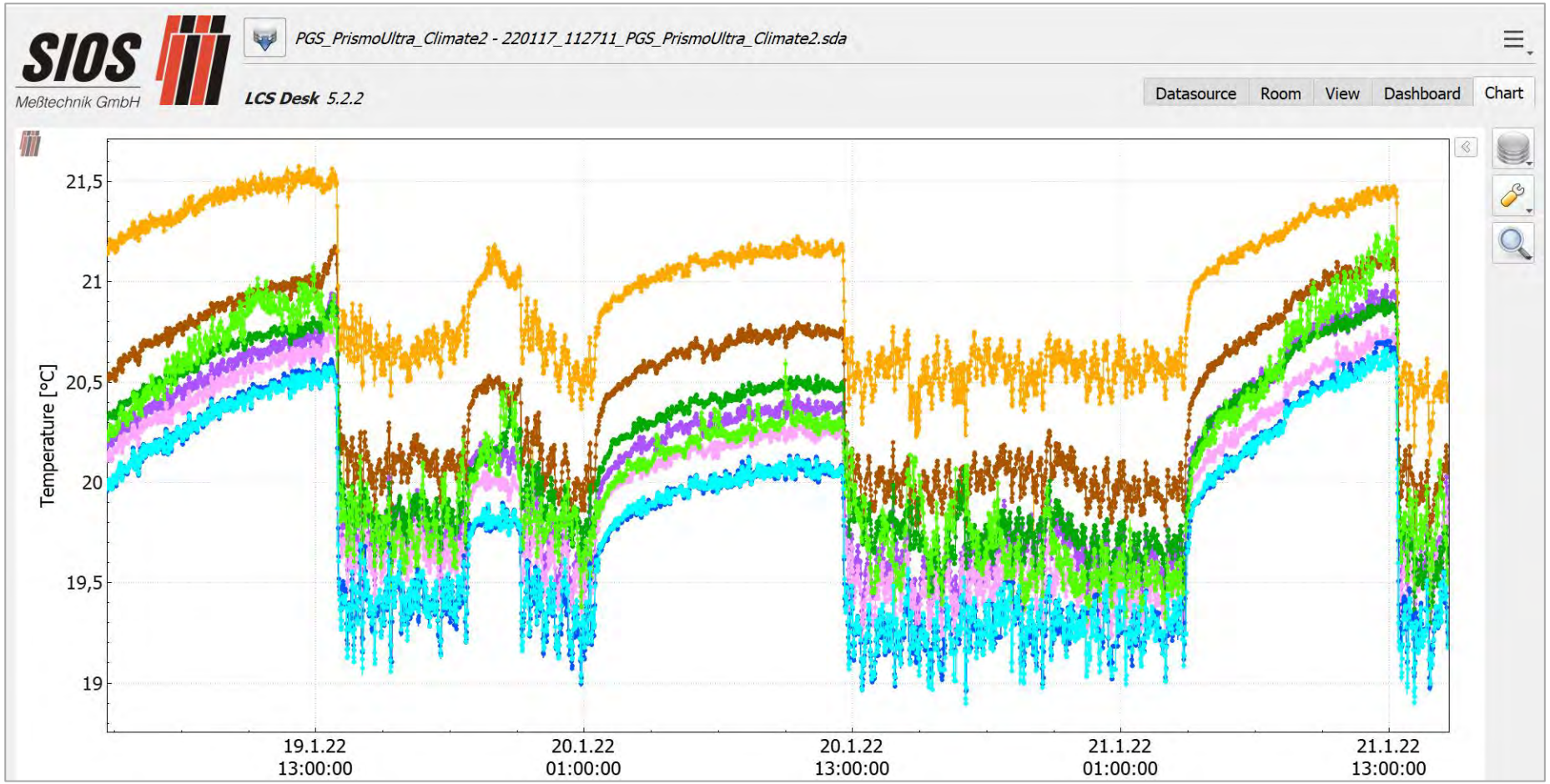
Precision Climate Measuring Station LCS

LCS Desk recording and evaluation software – live screen sensor values



Precision Climate Measuring Station LCS

LCS Desk recording and evaluation software – time-based chart screen



Precision Climate Measuring Station LCS

Application LCS Temp - evaluation system according VDI/VDE 2627

- LCS Temp is a combination of LCS-01, TT-01 or WT-01, tripods for spatial setup of sensors and software
- the measurement room classification based on VDI/VDE 2627 standard
- LCS Temp is available as wired and wireless system
- stationary and mobile version available

Precision Climate Measuring Station LCS

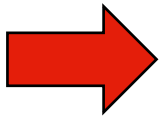
Sensor calibration – sample DAkkS certicicate

Messergebnisse
Measuring resutls

Temperatur Normal *Temperature Standard thermometer* in °C	Anzeige Prüfling *Indication calibration object* in °C	Anzeige-Korrektion *Indication correction* in K	Messunsicherheit *Measuring uncertainty* in mK
20,003	20,0032	0,000	37
18,995	18,9954	0,000	37
22,026	22,0264	0,000	37
25,027	25,0275	0,001	37
20,004	20,0040	0,000	37

Factory calibration certificate

DAkkS calibration certificate



System calibration by NMI

Precision Climate Measuring Station LCS

Sensor calibration

SIOS Meßtechnik GmbH

SIOS Factory Test Certificate

according to DIN 50 049 - 2.3 (EN 10 204)

Factory calibration certificate

Zentrum für Messen und Kalibrieren & ANALYTIK GmbH

Kalibrierschein / Calibration Certificate

DAkkS calibration certificate

PTB

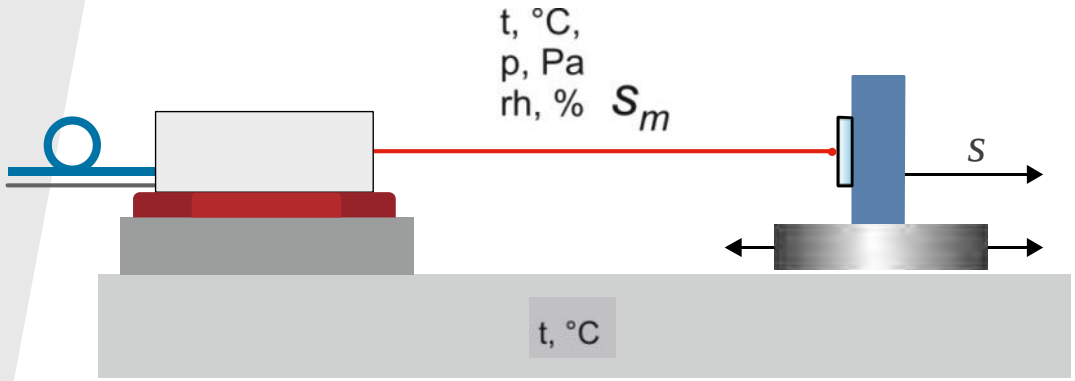
Kalibrierschein

Calibration Certificate

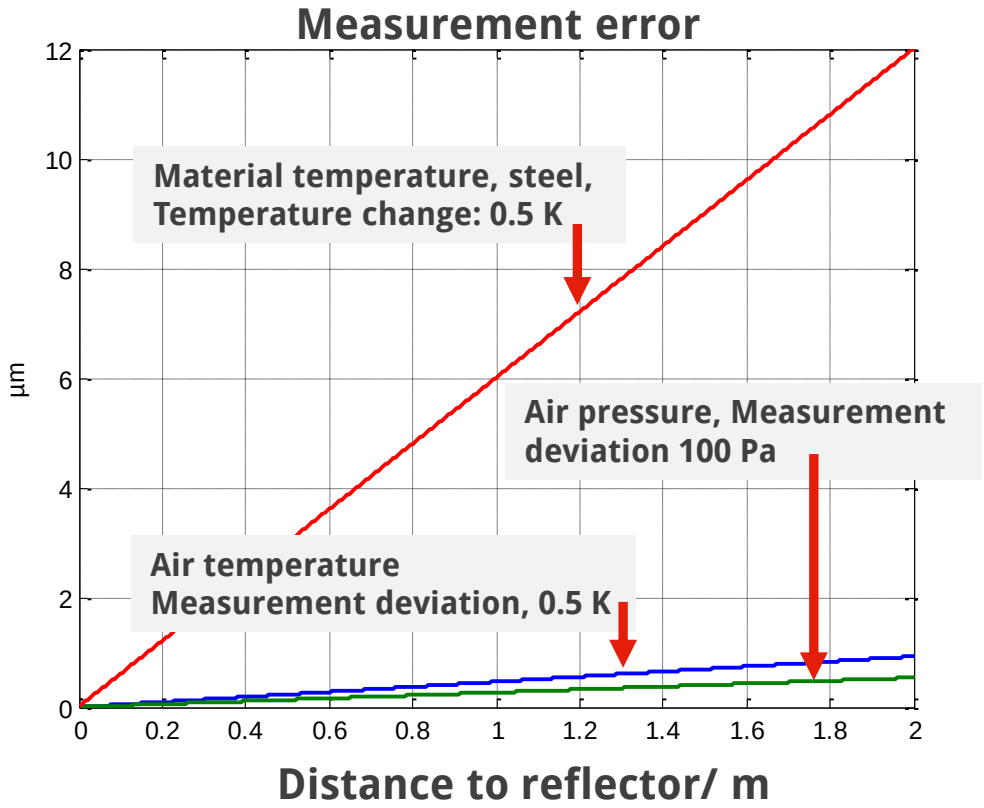
System calibration by NMI

Environmental Impacts of Laser Interferometer

Influences on the measurement setup



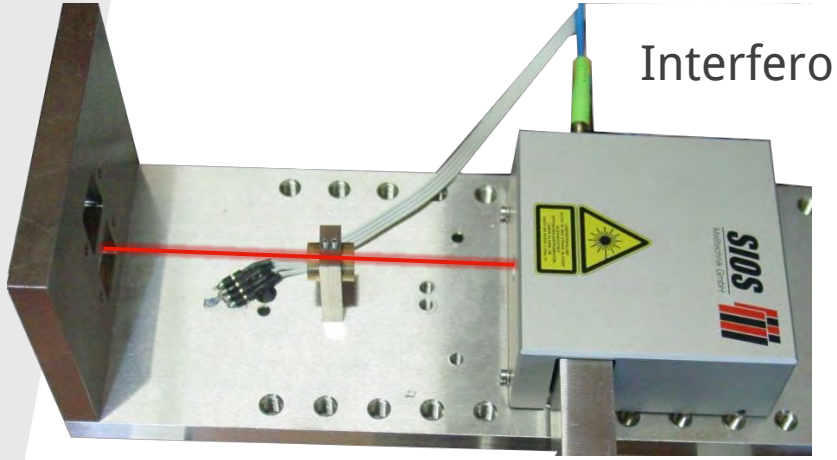
Positioning stage



Thermal stability of the setup is important for the long time measurements.

Precision Temperature Measurements

Measurement of Thermal Distribution in Materials



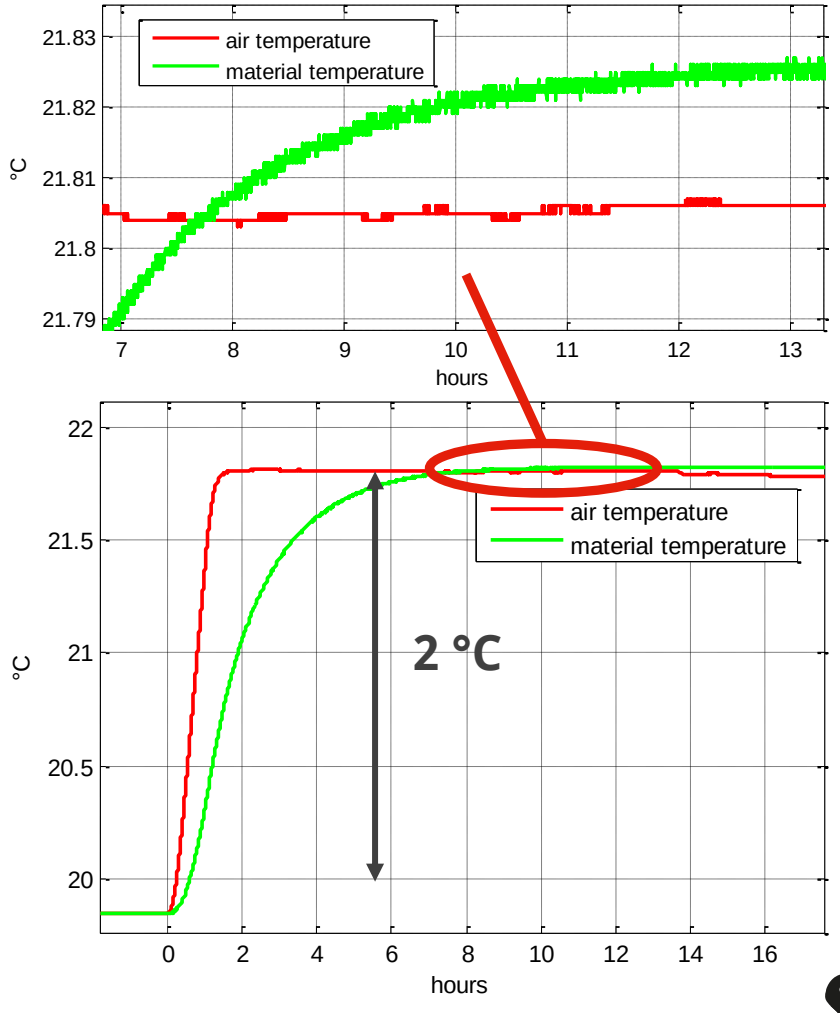
Interferometer

Fe65Ni35 Bracket, thickness **12 mm**

After a temperature change of **2 °C,**

the temperature in the measurement setup

is equalized after more than **13 hours**

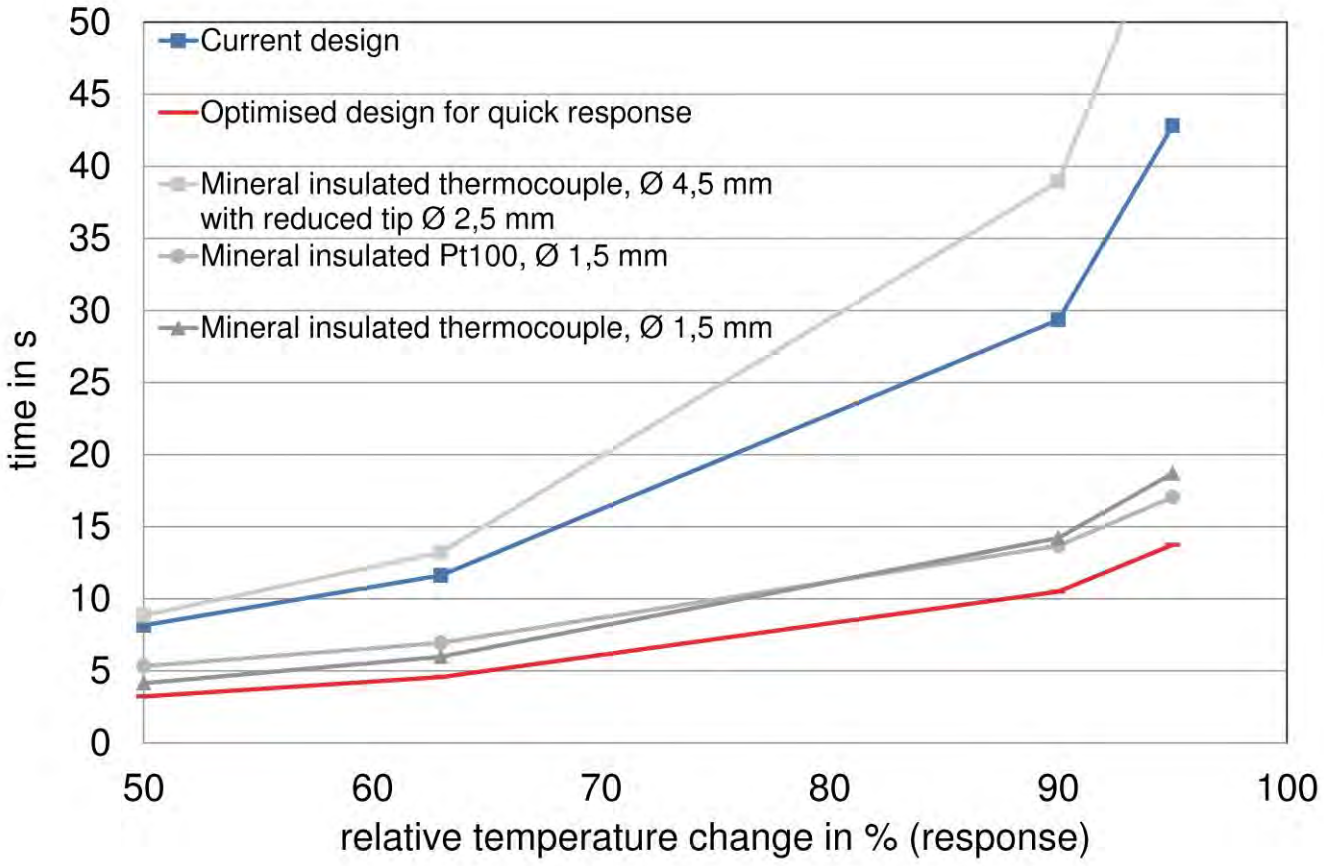


Precision Temperature Measurements

Fast air temperature sensor

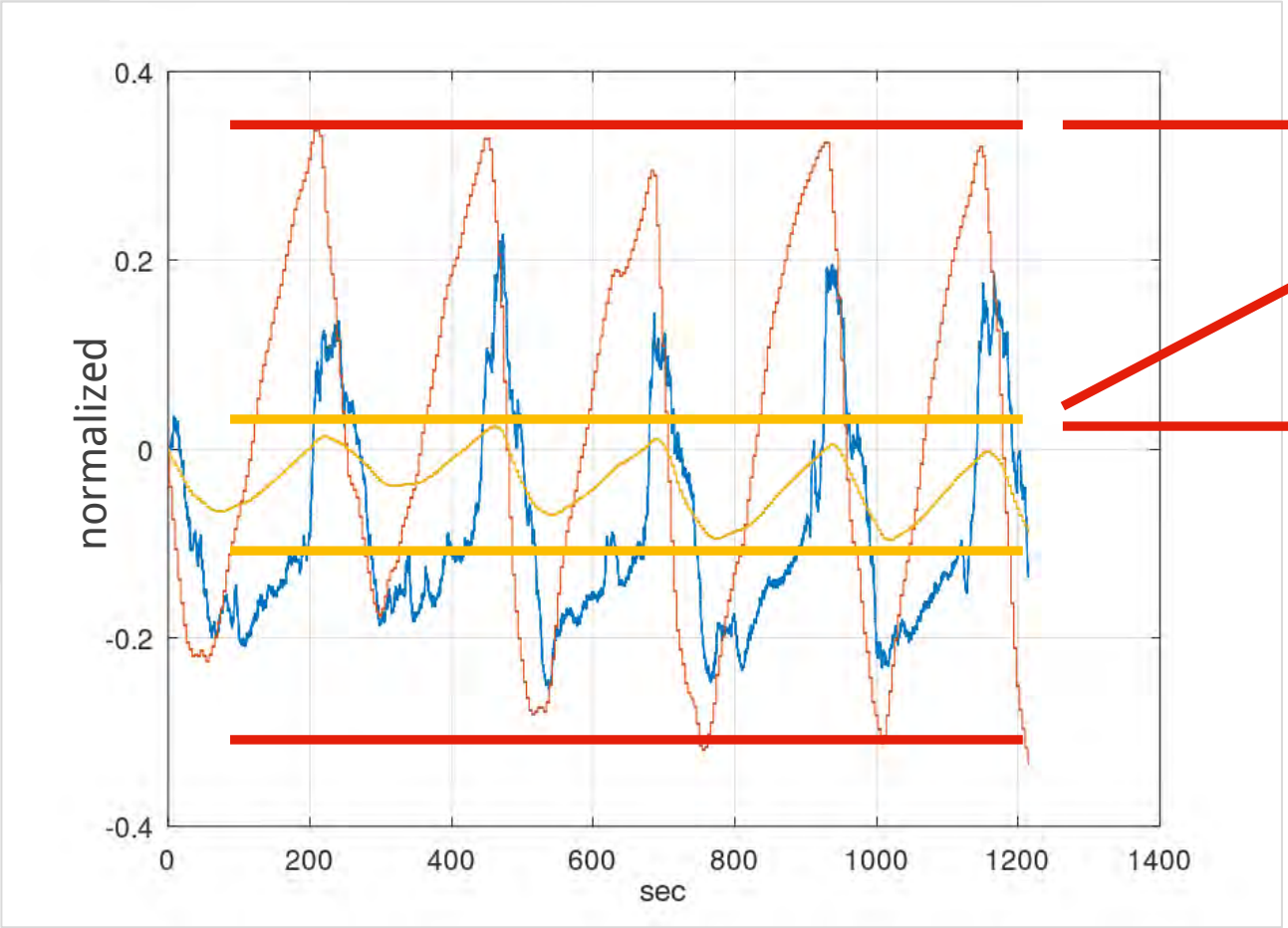
Objectivs:

Sensor which is able to follow best air temperature changes, especially in climatized rooms



Precision Temperature Measurements

Measurement of Air Temperature by Different Sensors

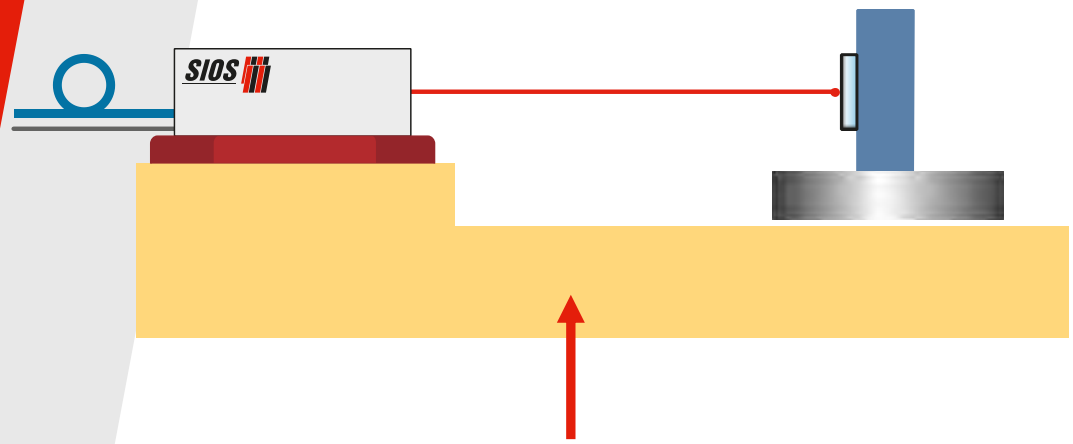


Simultaneous measurements that differ in **phase** and **amplitude**

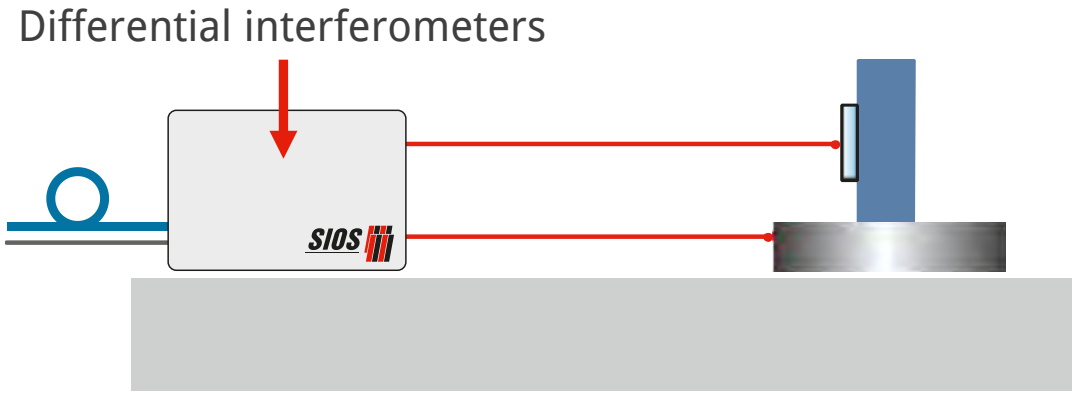
Long Term Stability Concept

Concept comparison

Thermal compensation by metrology frame

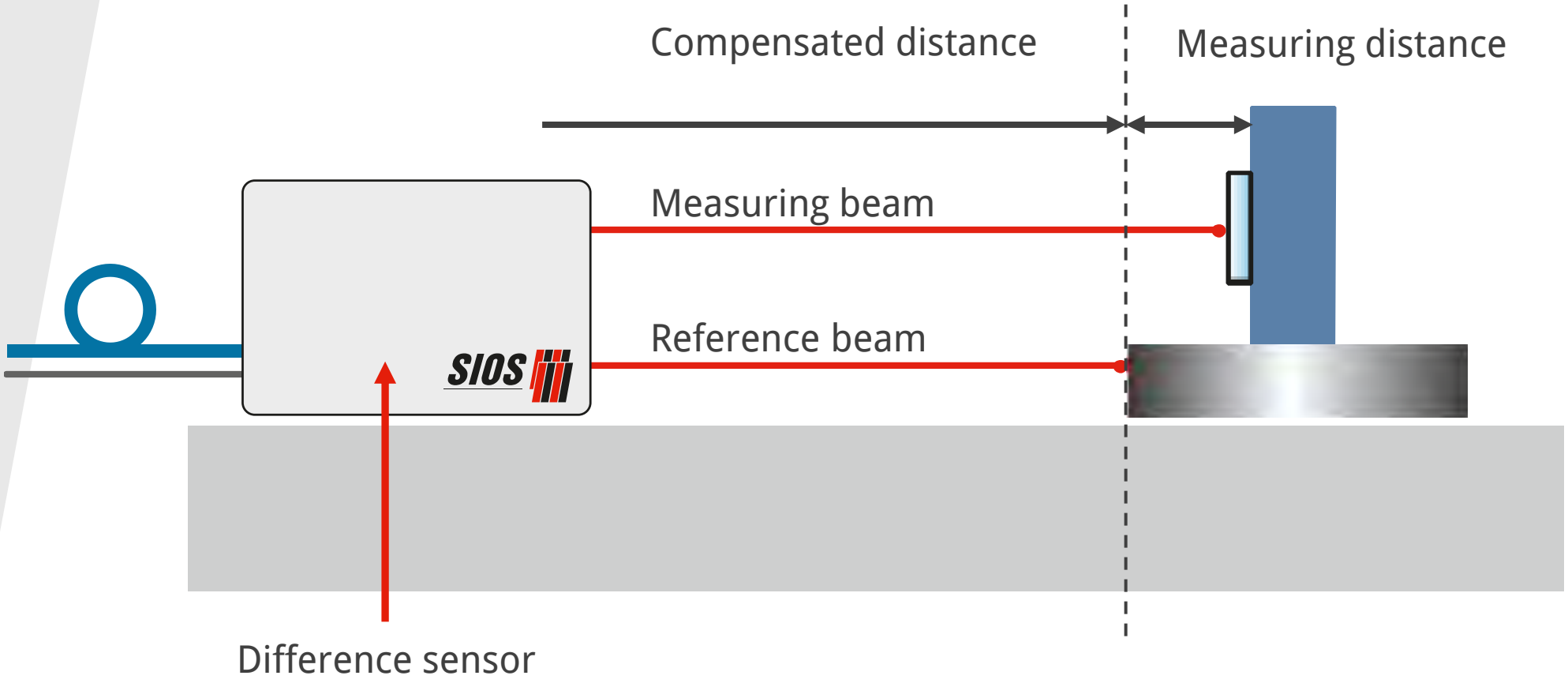


Thermal compensation by interferometer principle



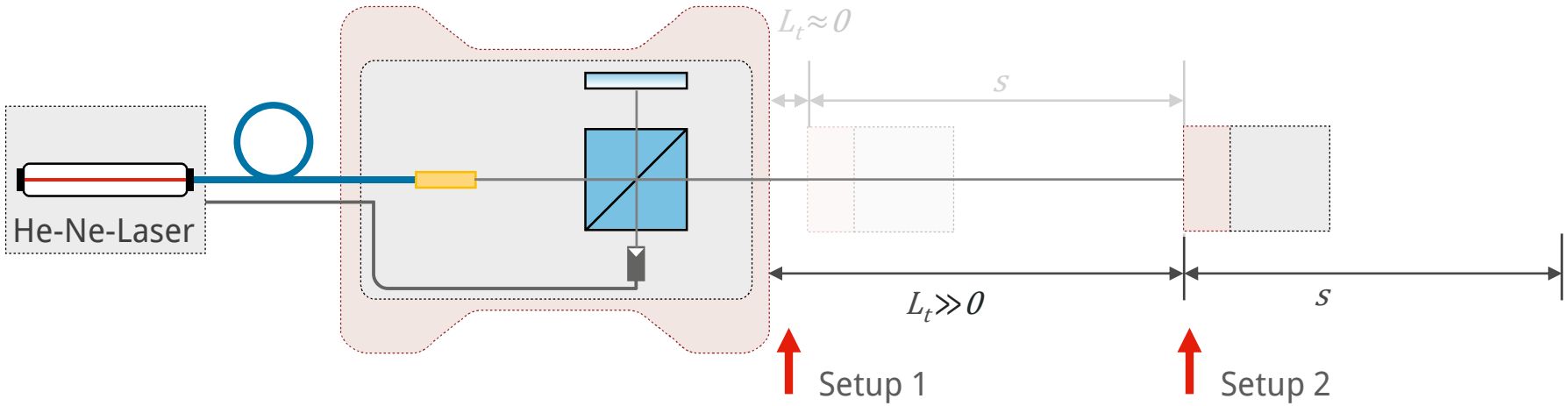
Long Term Stability Concepts

Differential Interferometer Concept



Dead Path of Laser Interferometer Setup

Dead Path Definition and Correction



Dead path of laser interferometer is a difference of lengths of measuring and reference beams in air at the **moment of setting** the interferometer value to **zero**

Dead path $L_t \approx$ **zero**, if the interferometer is set to zero at Setup 1

Dead path $L_t \gg 0$, if the interferometer is set to zero at Setup 2

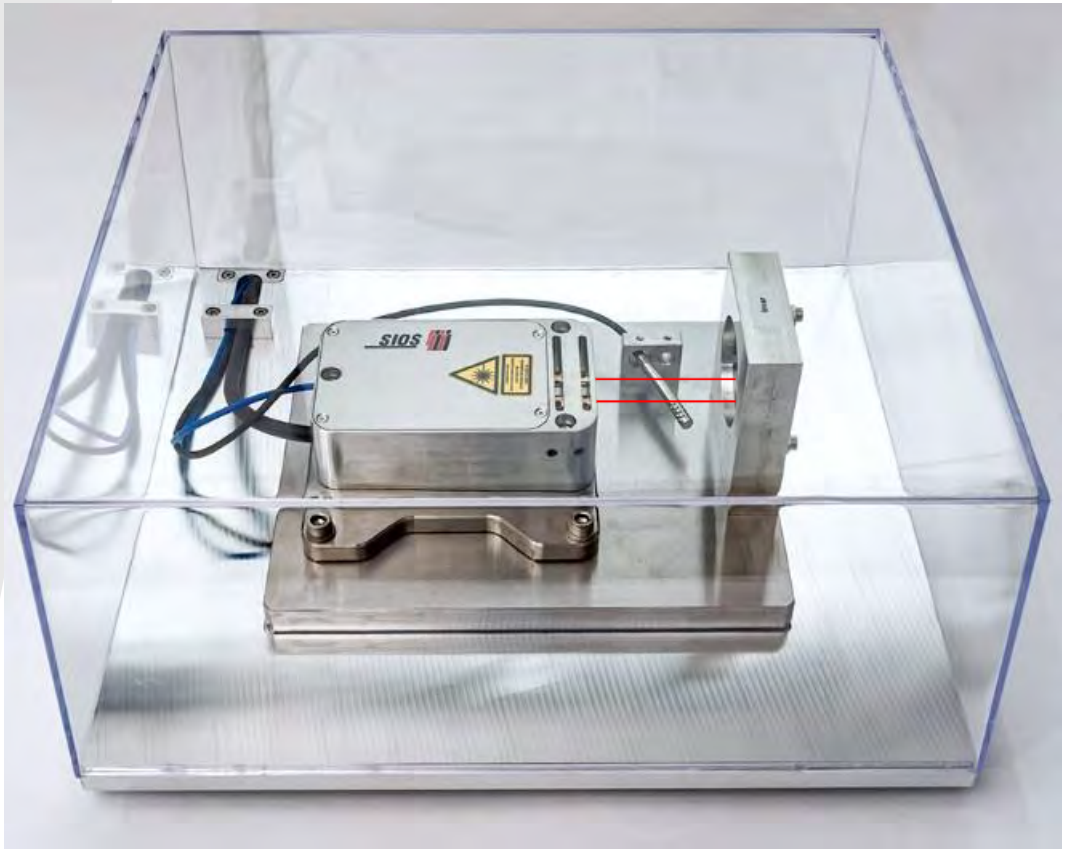
Dead path correction $L_{corr} = -L_t \cdot \left(1 - \frac{n_0}{n}\right)$

← Air refractive index at the moment of setting interferometer value to zero

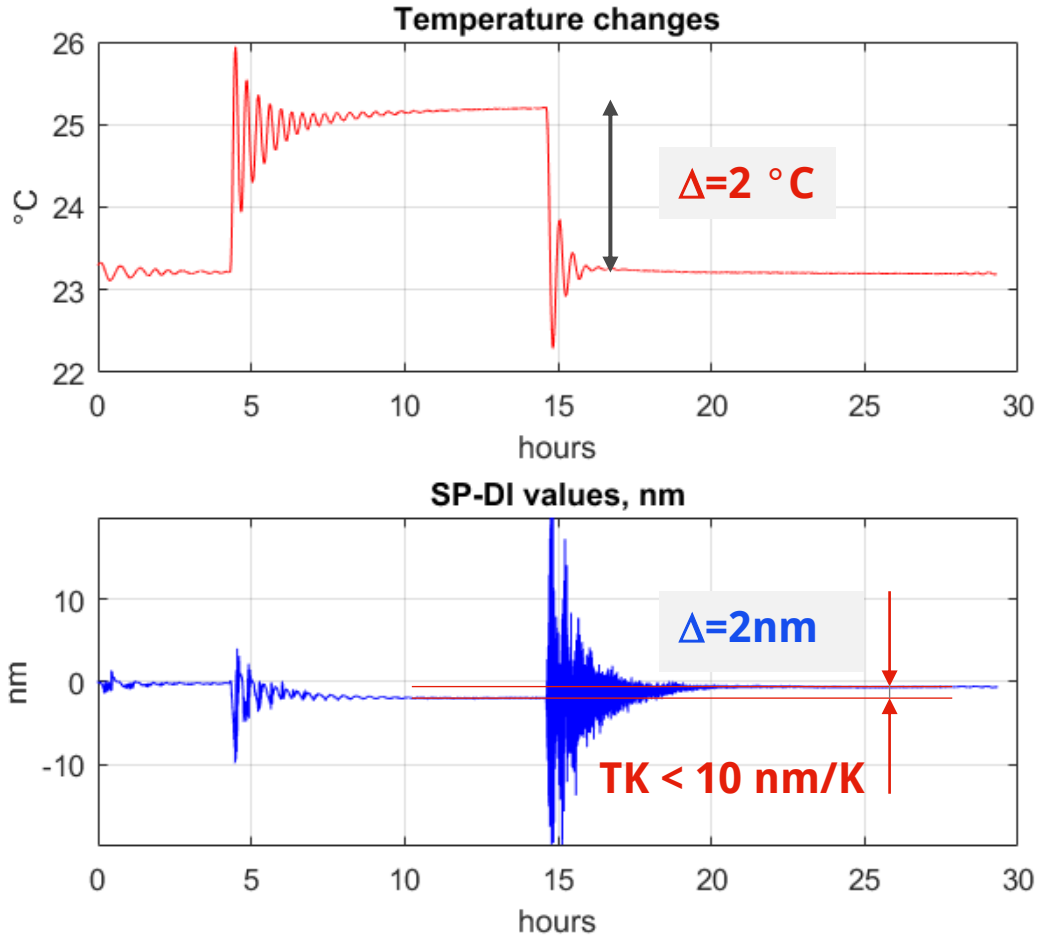
← Current air refractive index

Differential Interferometers

Lowest sensitivity to the temperature

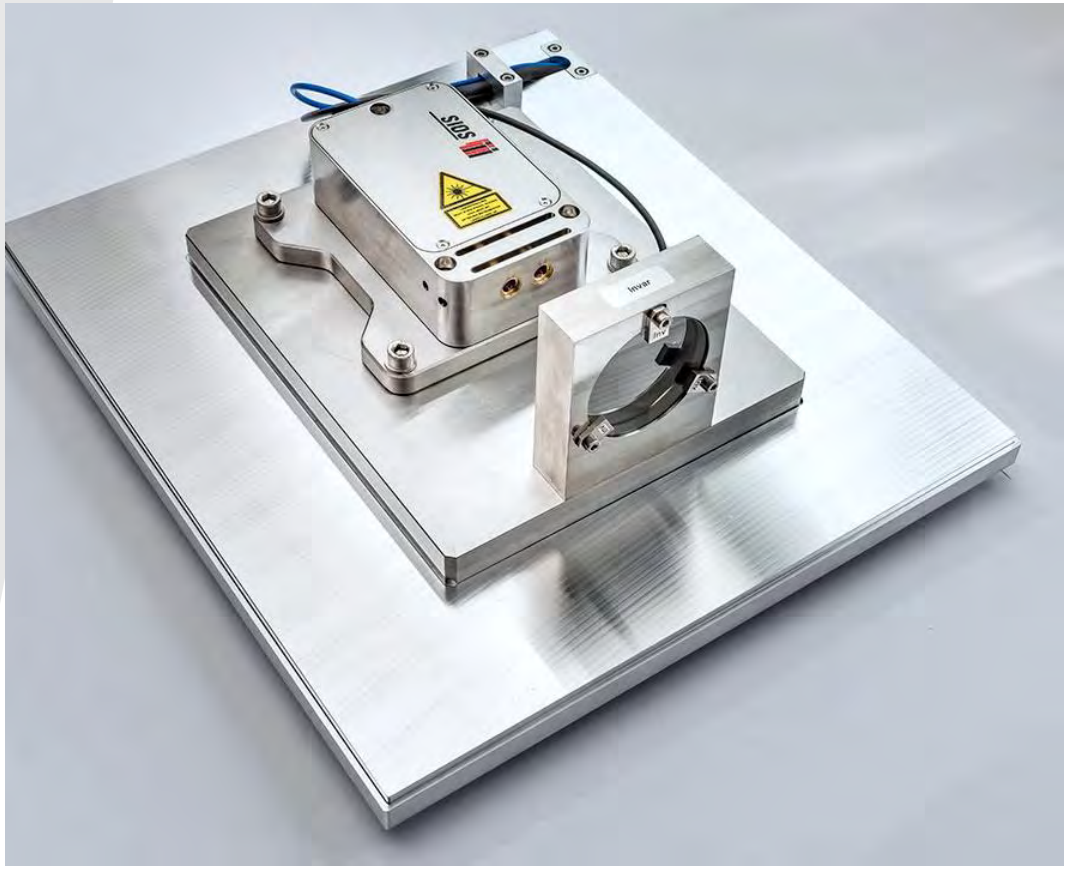


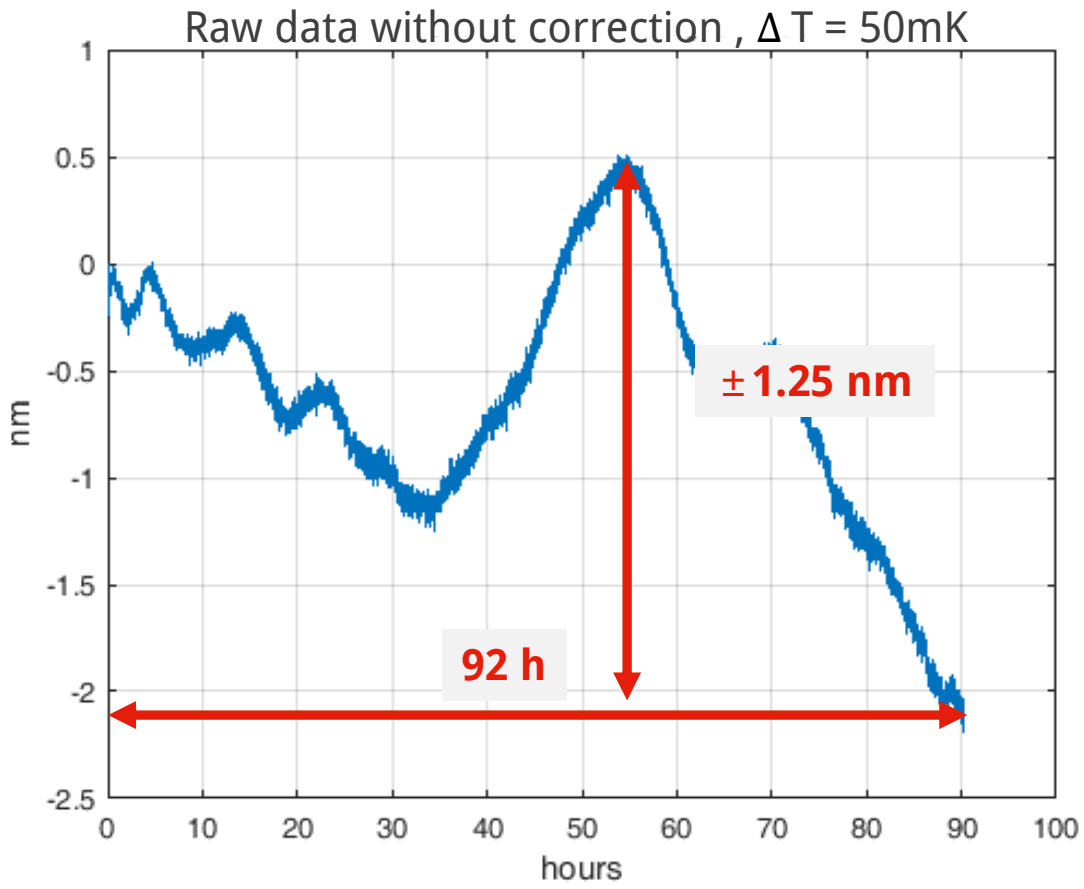
Measurement setup on Invar frame



Differential Interferometers

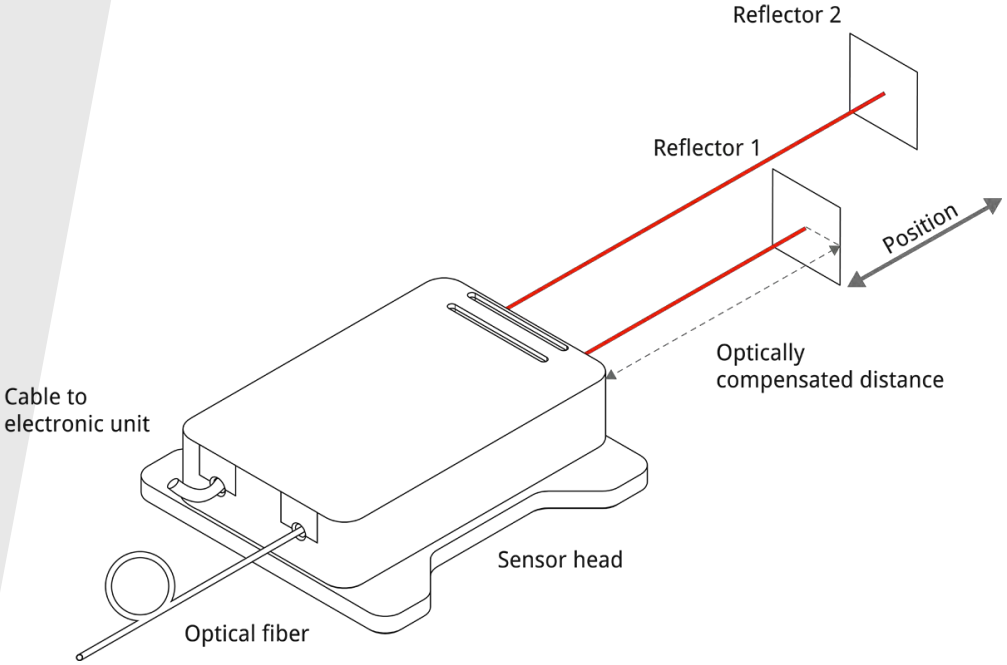
Long term stability of differential laser interferometer



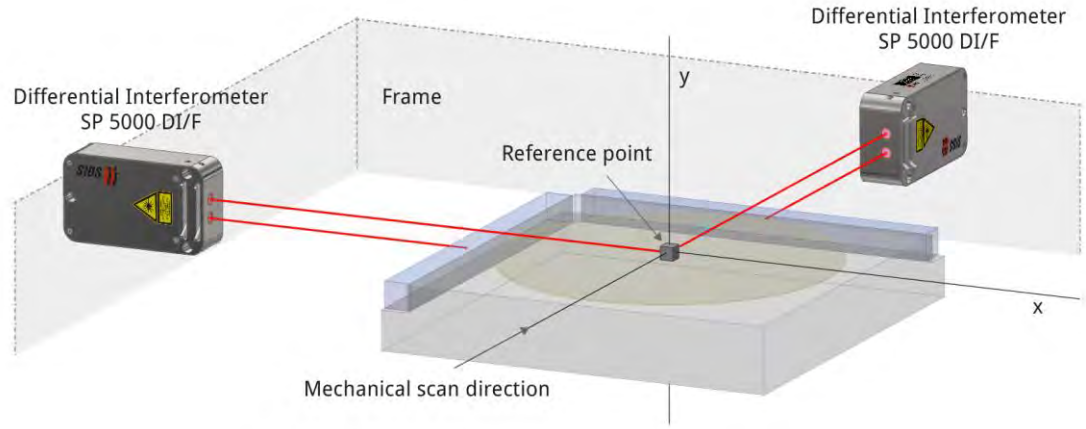


Differential Interferometers

Usage for high precision feedback control



SP 5000 DI/F

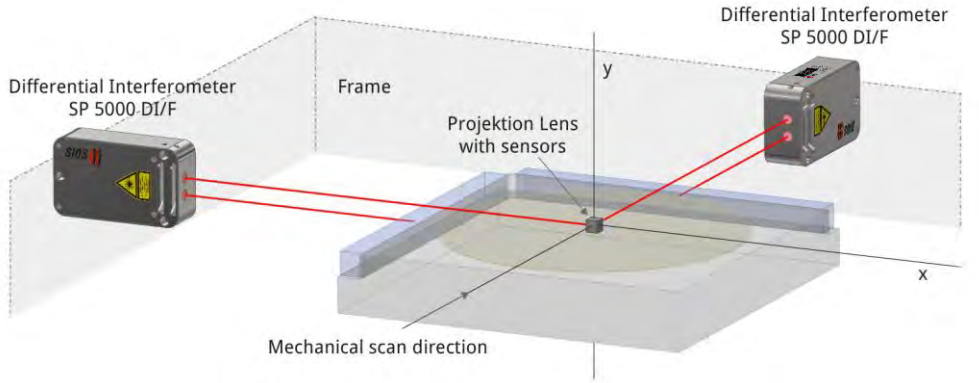


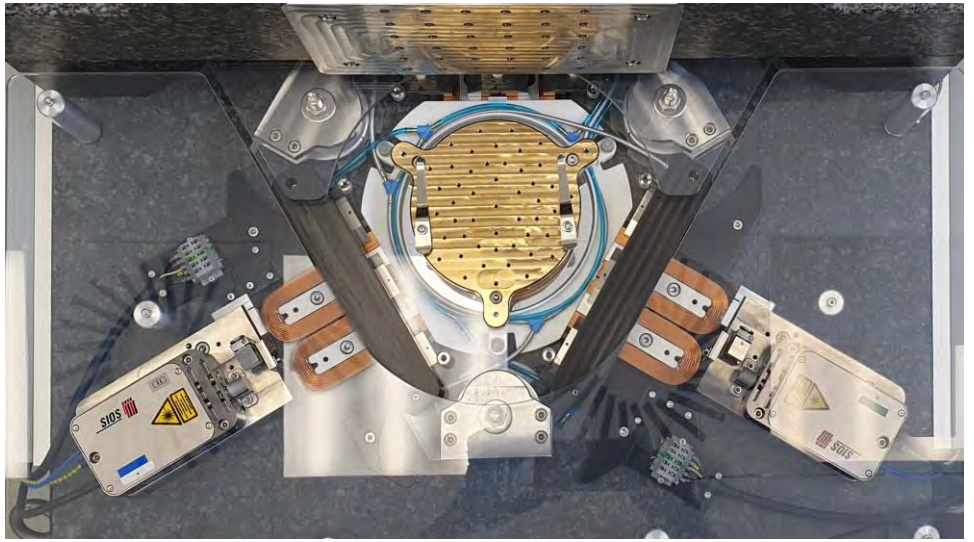
Application example

Differential Interferometers

Differential displacement measurements

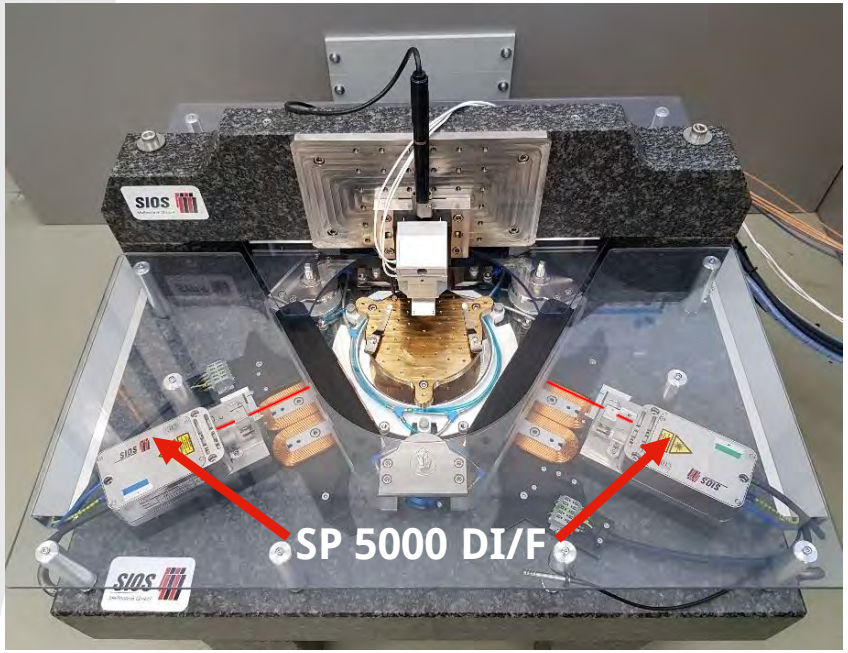
SP 5000 DI/F



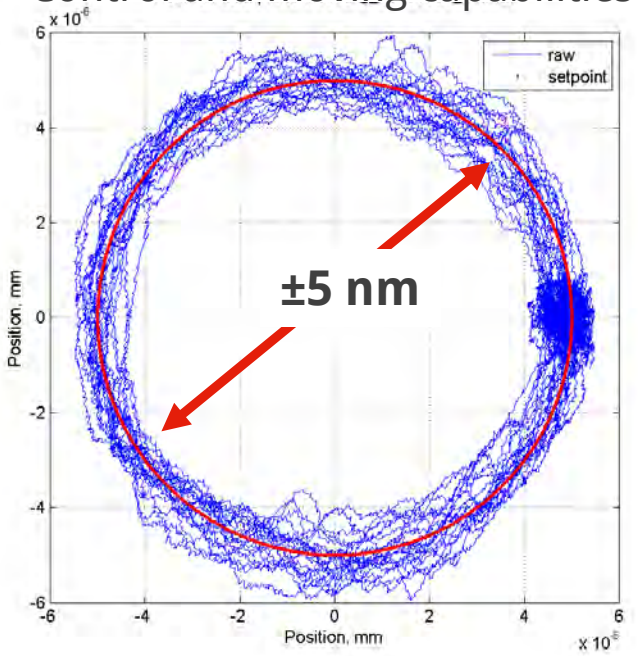


µ Positioning Platform

Positioning capabilities



Control and moving capabilities



Travel range	Ø 100 mm
Measuring resolution	0.02 nm

Ey_rms = 0.41 nm
Ex_rms = 0.29 nm

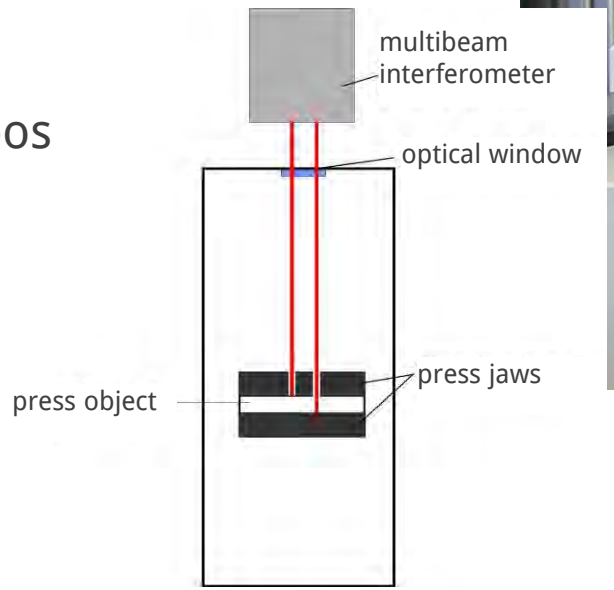
Best positioning performance for entire range

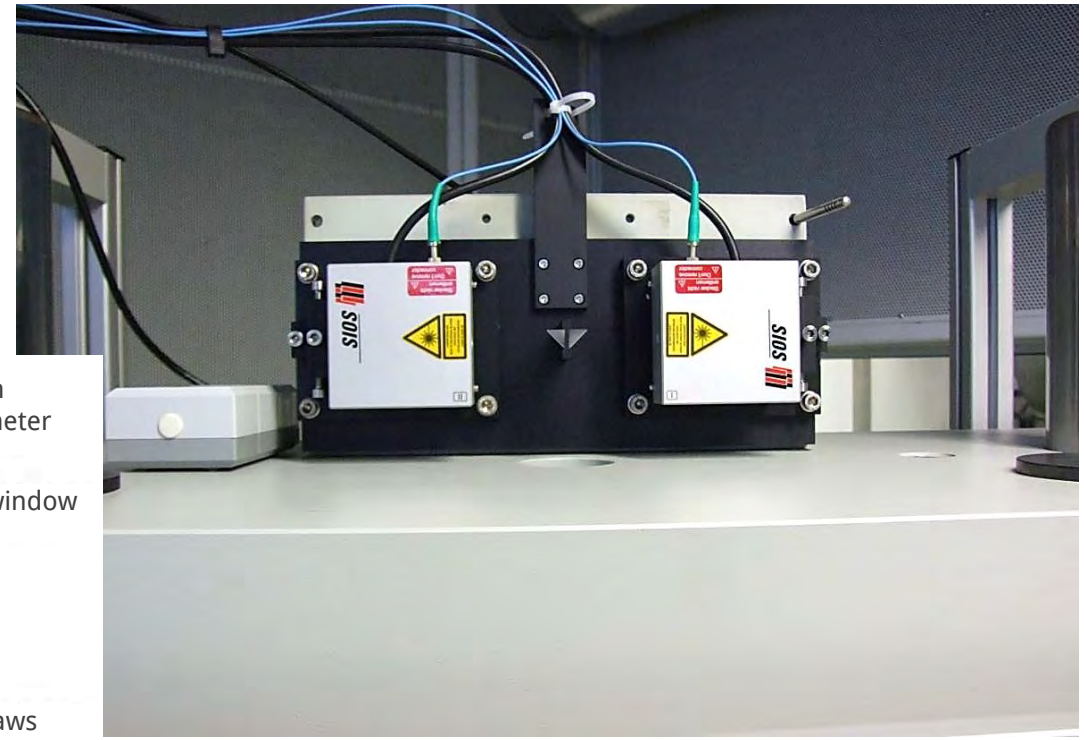
Customer Application

Differential measurement in a material testing stand

Solution

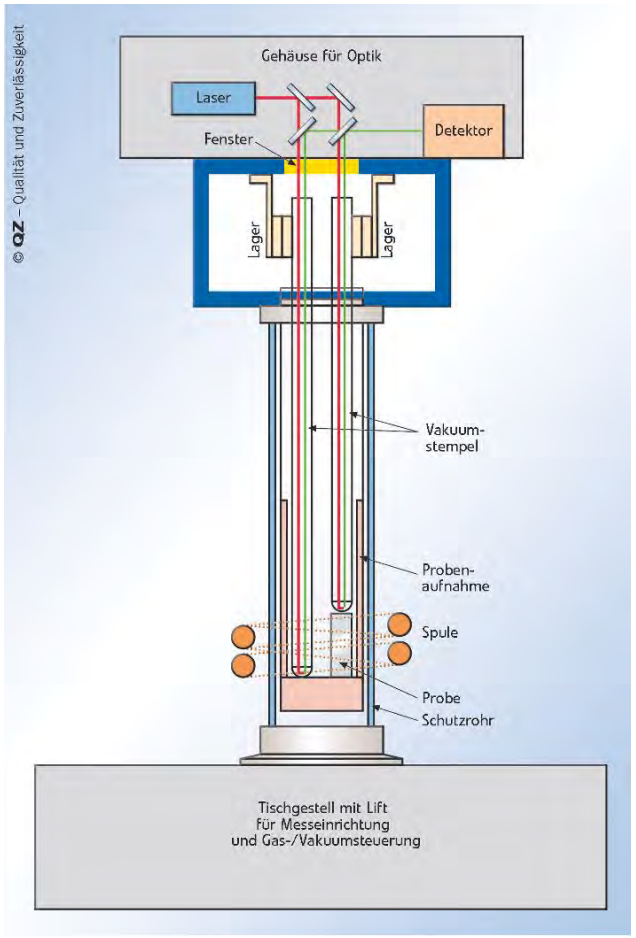
- independent adjustment of laser beams by use of two single beam sensors
- beam separation variable
- focusing of laser beams pos





Customer Application: Dilatometer

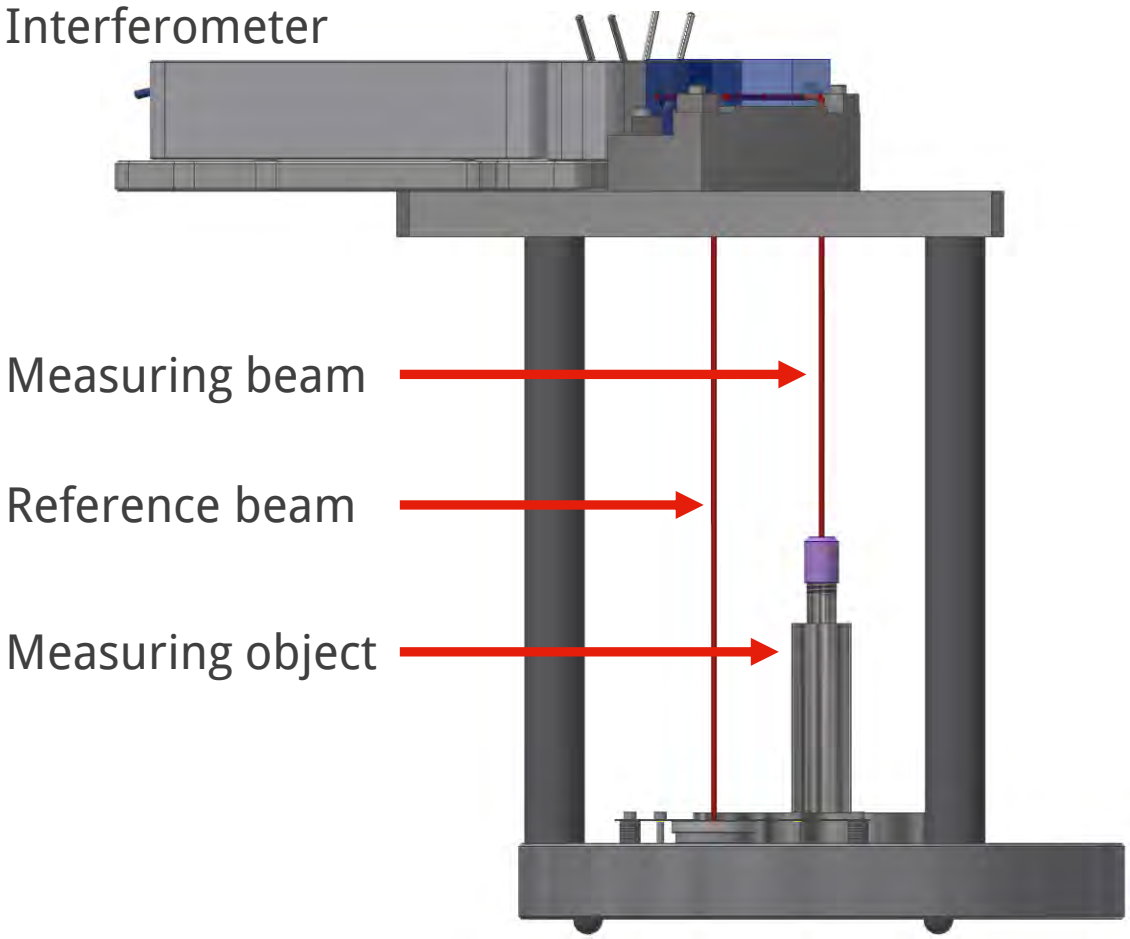
Dilatometer for measuring of the thermal expansion coefficient



Source user: Linseis Meßgeräte GmbH

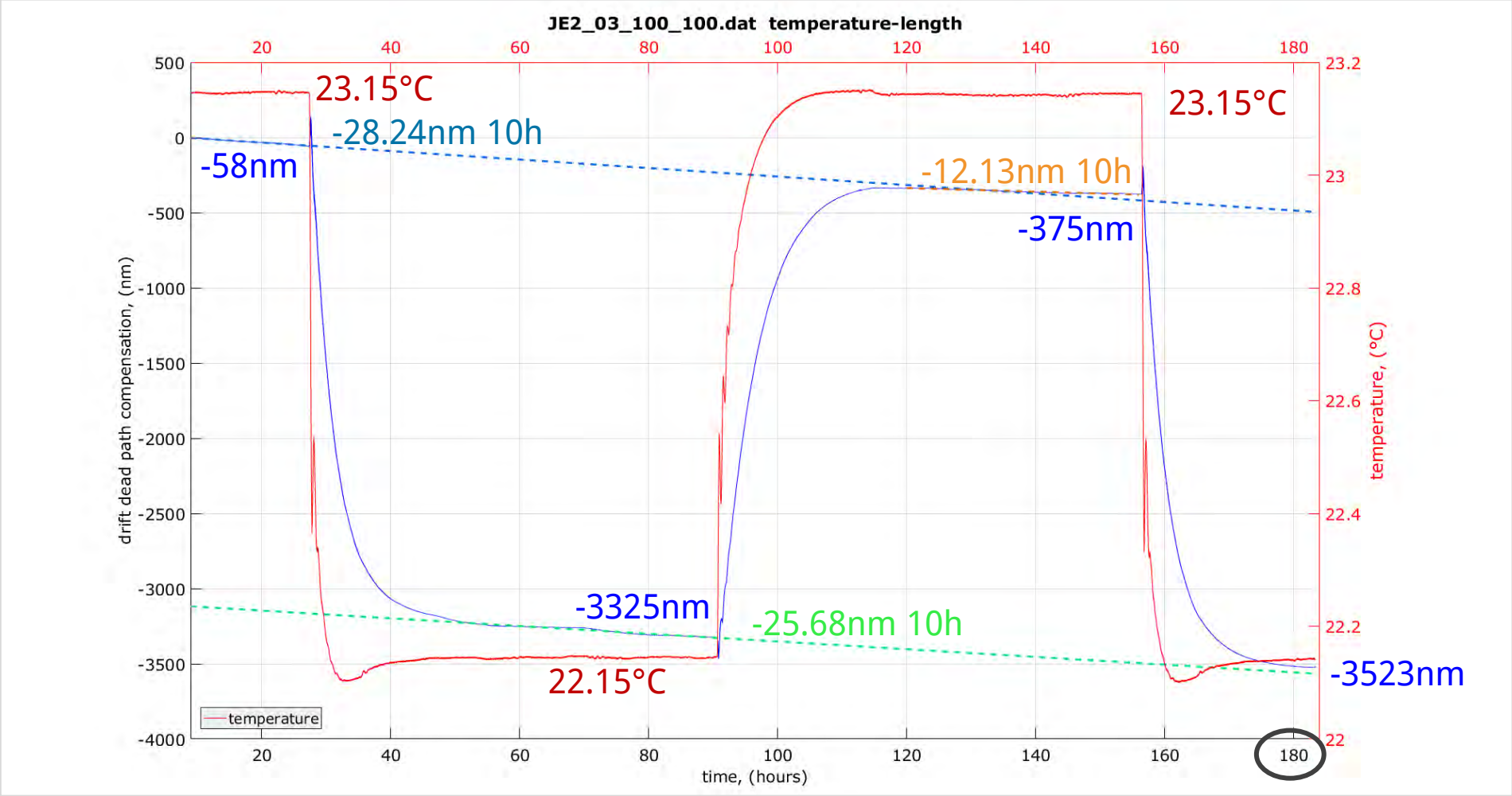
Determination of Thermal Behavior of Objects

Based on Differential Interferometer



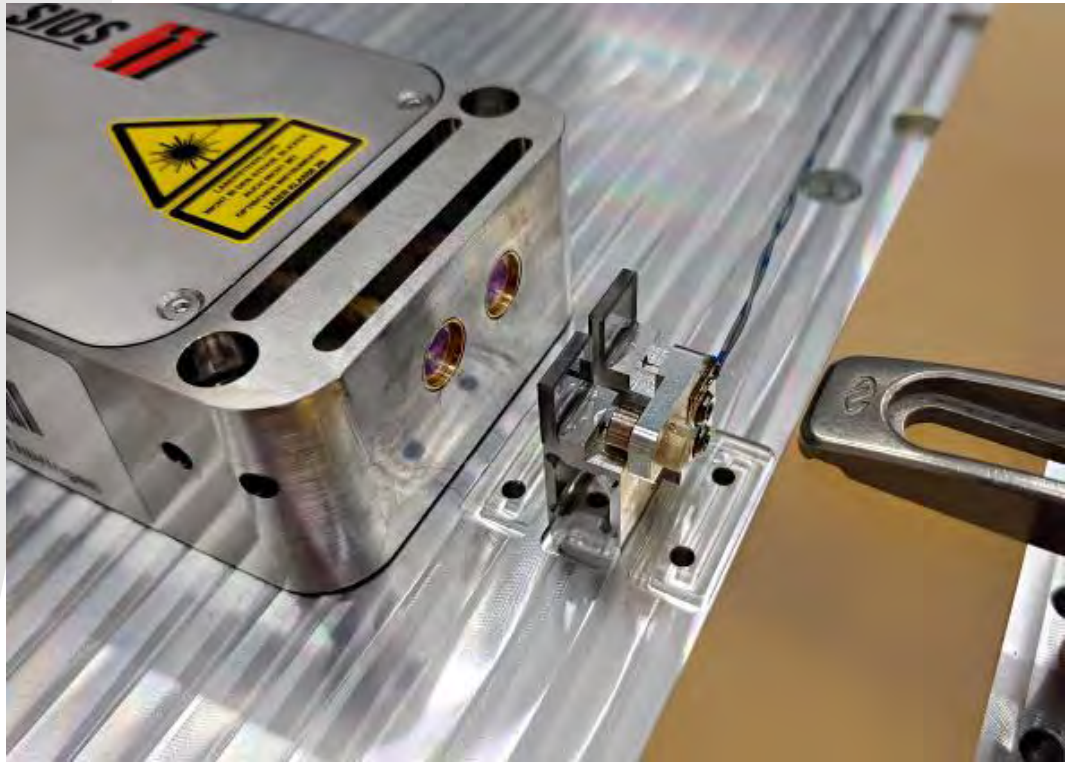
Determination of Thermal Behavior of Objects

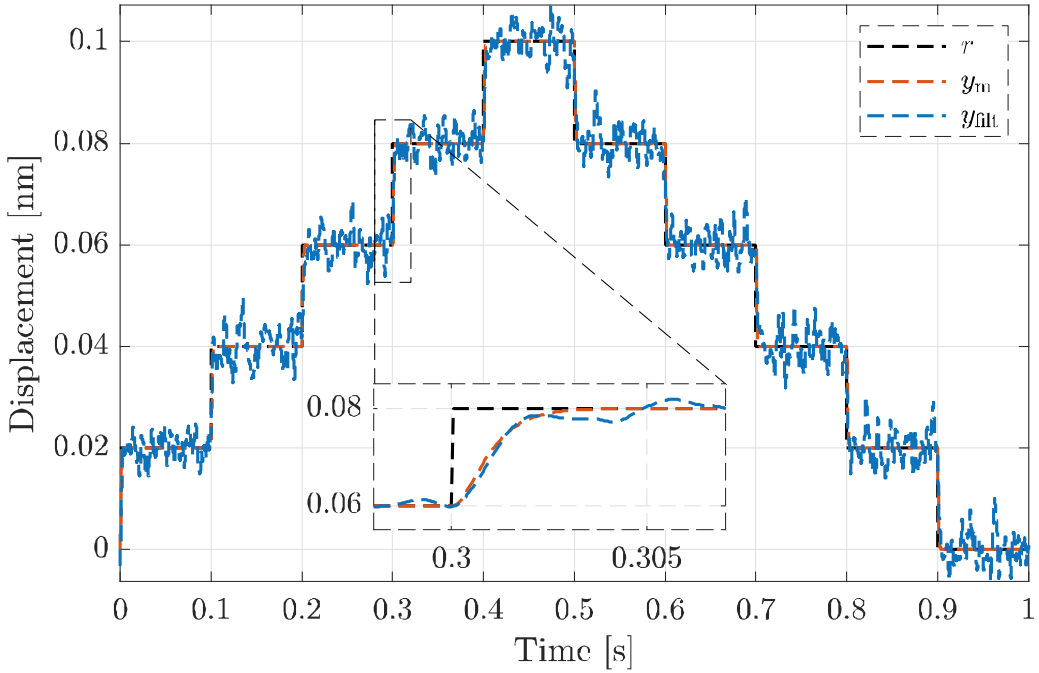
Based on Differential Interferometer



Picometer-Scale Positioning

of a linear drive system via feedforward-feedback control





Source: Picometer-Scale Positioning of a Linear Drive System via Feedforward-Feedback Control

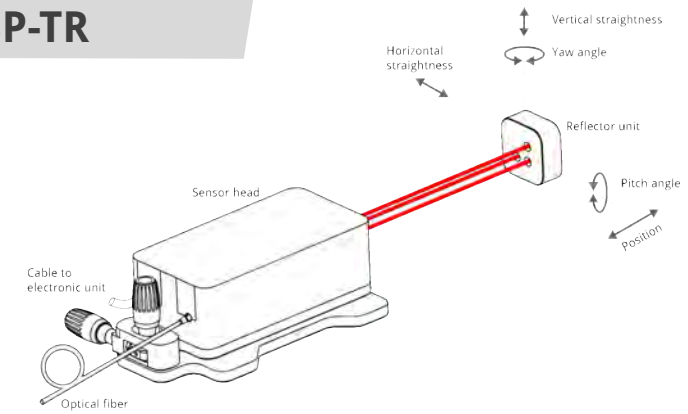
Alex S. Huaman, Michael Katzschmann, Steffen Hesse, Christoph Schaffel, Christoph Weise, Denis Dontsov, Eberhard Manske and Johann Reger

ICM 2021 International Conference of Mechatronics, Japan

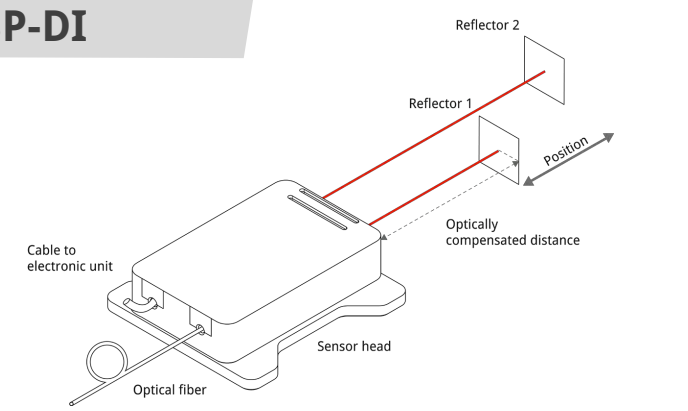
Triple-beam Differential Laser Interferometers

NEW: length, pitch and yaw by differential principle

SP-TR



SP-DI

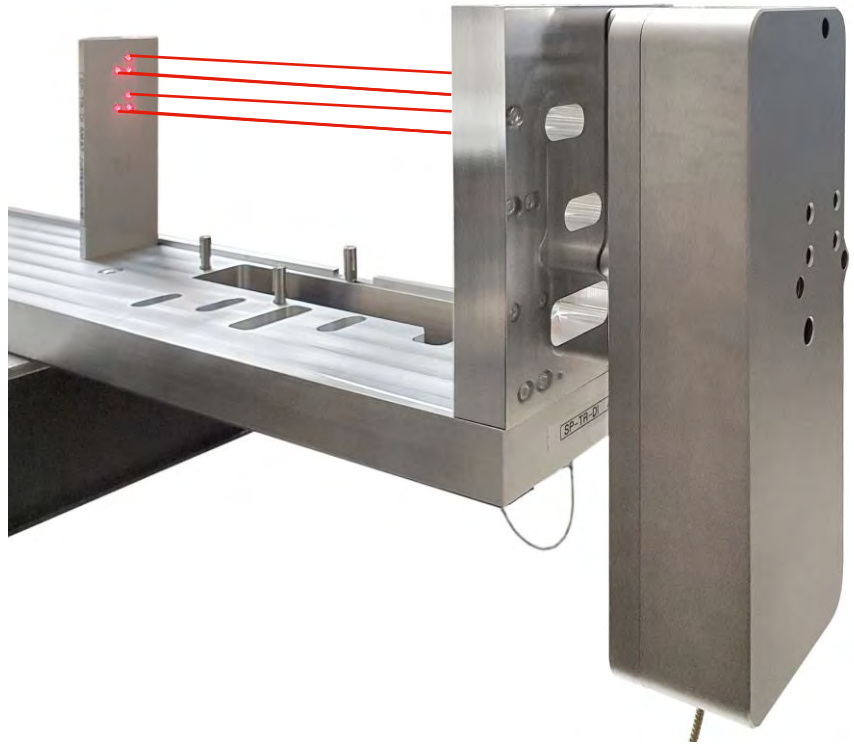


combination of

differential stability

multi-degree of freedom

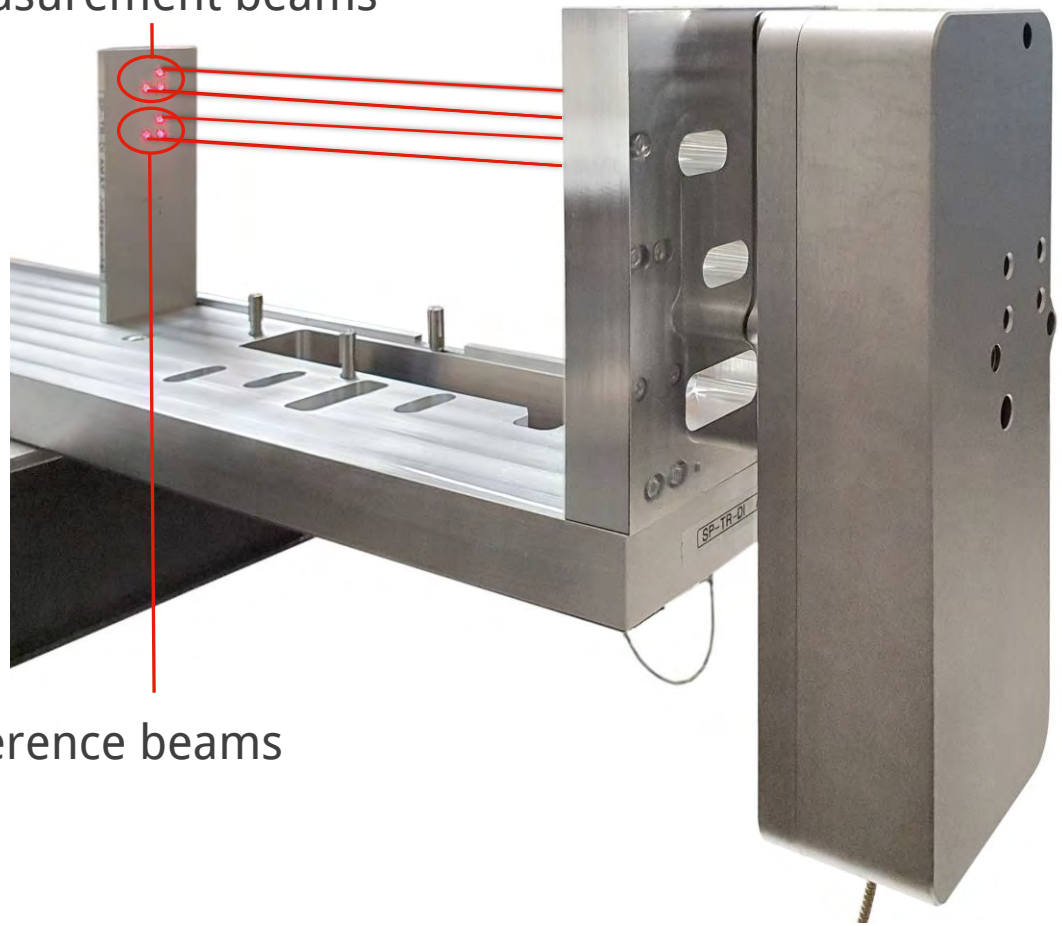
measurement



Triple-beam Differential Laser Interferometers

NEW: length, pitch and yaw by differential principle

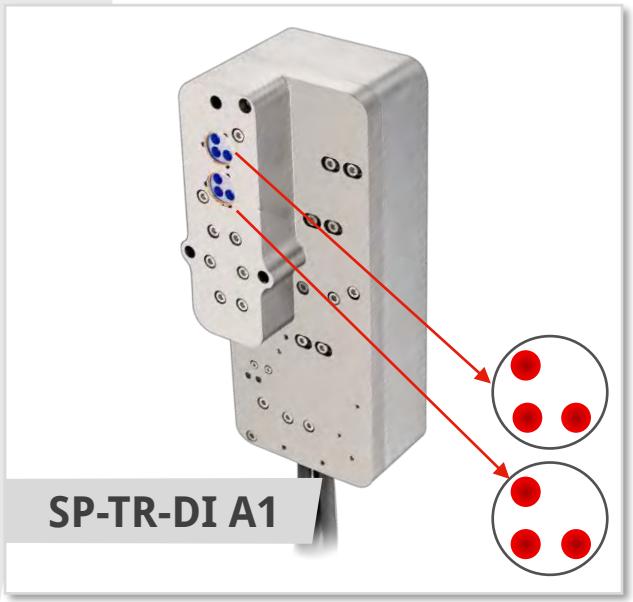
3 measurement beams



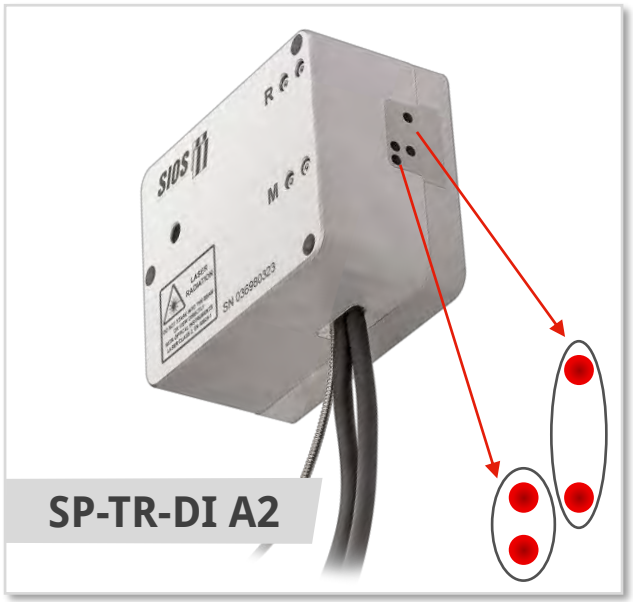
3 reference beams

Multi Beam Differential Interferometers

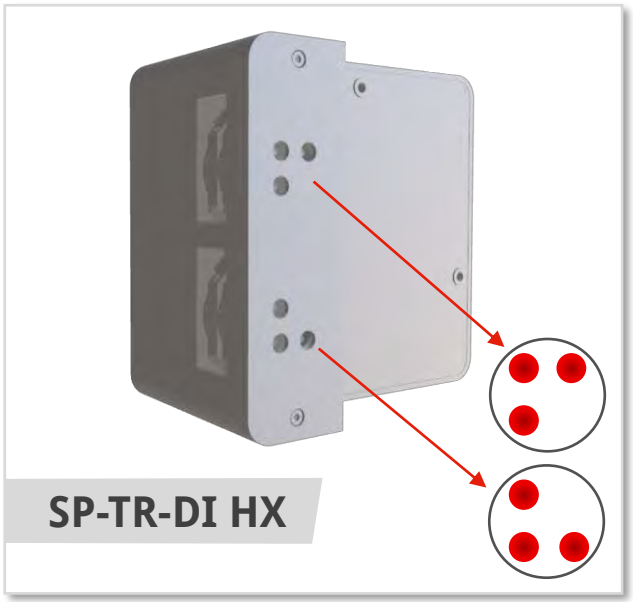
Differential length and angular measurements



- Triple beam differential
- 6 mm beam distance
- small beam footprint
- compatible to vacuum chamber



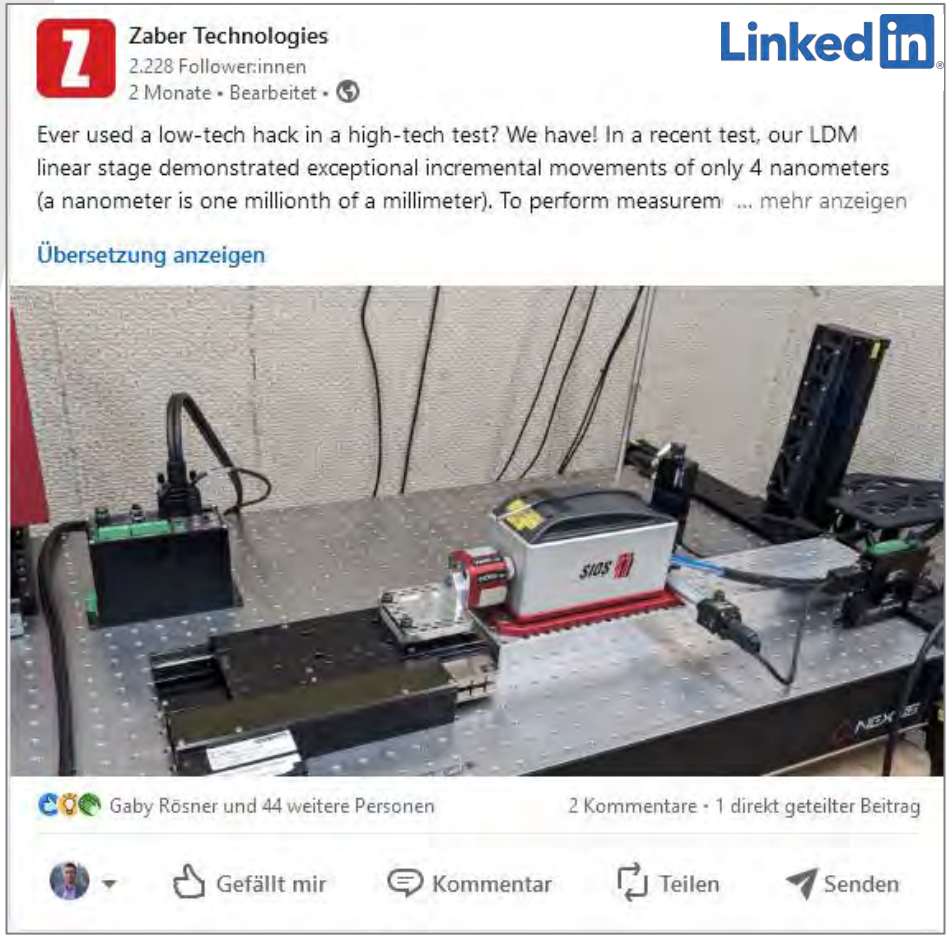
- high stable differential length measurements
- interferometric pitch angle measurements
- perfect for x-y stages



- fully differential SP-TR system
- 12 mm beam distance
- suitable for reflector applications

Low-Tech Hack by Zaber

Which factors influence highly accurate measurement results?

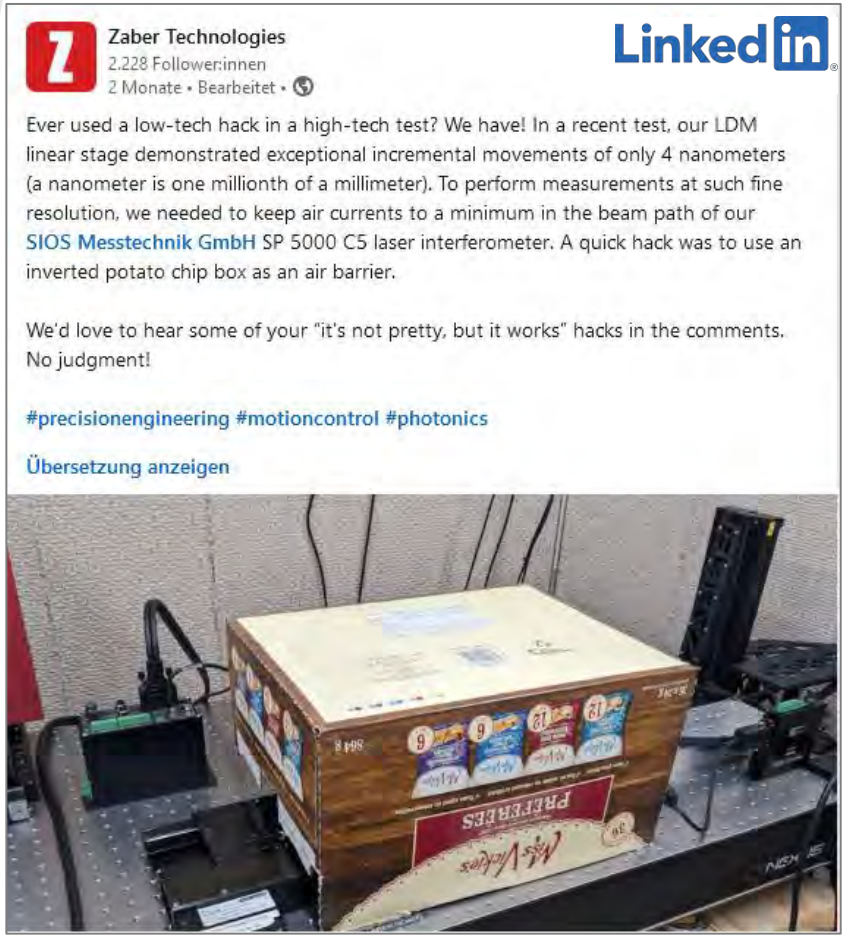


Zaber LinkedIn post looking for 4 nm positioning steps under standard lab conditions:

- measurement setup
- environmental conditions

Low-Tech Hack by Zaber

Low-tech hack for precision measurements



Zaber Technologies
2.228 Follower:innen
2 Monate • Bearbeitet •

LinkedIn

Ever used a low-tech hack in a high-tech test? We have! In a recent test, our LDM linear stage demonstrated exceptional incremental movements of only 4 nanometers (a nanometer is one millionth of a millimeter). To perform measurements at such fine resolution, we needed to keep air currents to a minimum in the beam path of our SIOS Messtechnik GmbH SP 5000 C5 laser interferometer. A quick hack was to use an inverted potato chip box as an air barrier.

We'd love to hear some of your "it's not pretty, but it works" hacks in the comments. No judgment!

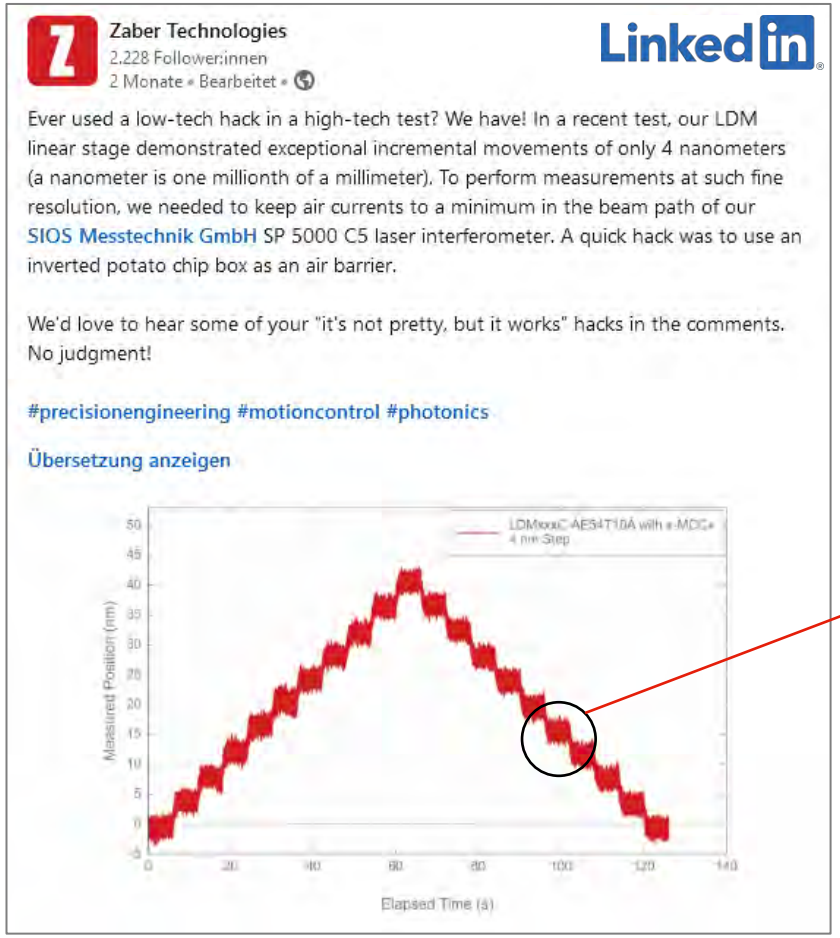
#precisionengineering #motioncontrol #photonics

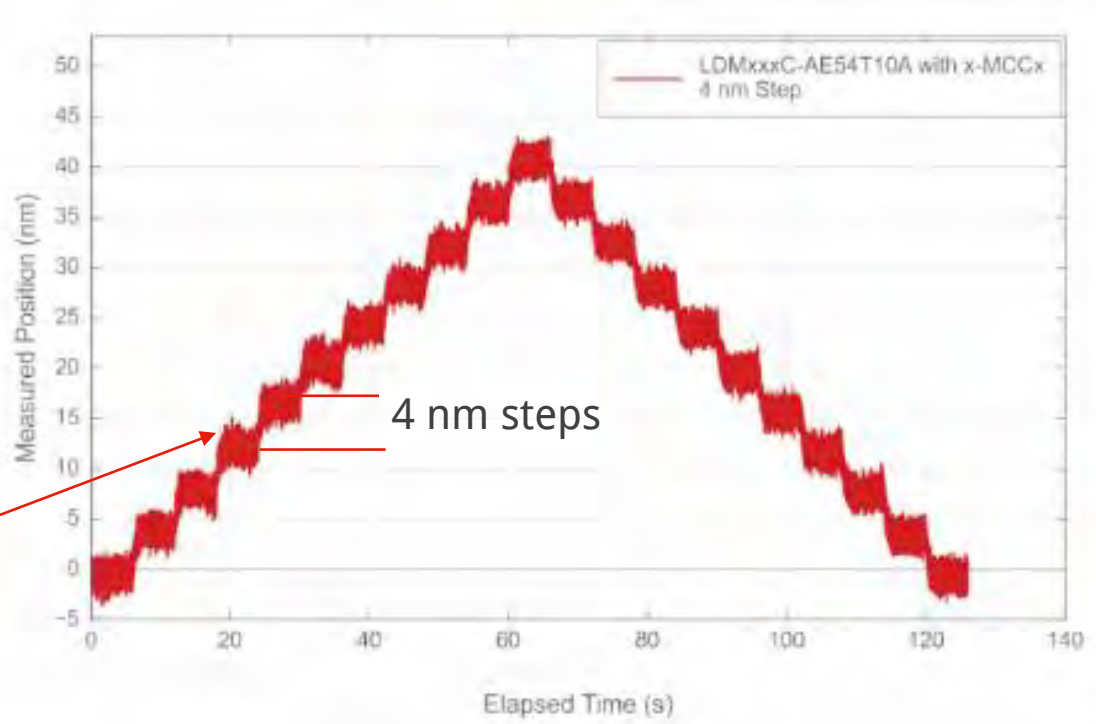
Übersetzung anzeigen

using an inverted chip box as an air barrier to quickly minimize airflow

Low-Tech Hack by Zaber

How can the influencing factors be minimized?





SIOS Meßtechnik GmbH

THANK YOU VERY MUCH FOR YOUR ATTENTION!

Dr. Ralf Schüler
Technischer Entwicklung

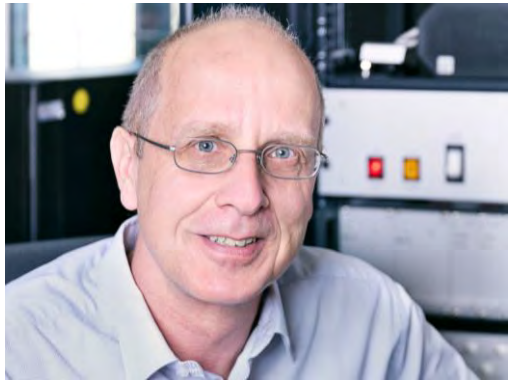
SIOS Meßtechnik GmbH

Am Vogelherd 46

98693 Ilmenau / Germany

Fon: +49 (0) 3677 64 47-39

ralf.schueler@sios.de



www.sios-precision.com

Follow Us: LinkedIn

We will keep you informed about news, dates and interesting applications from SIOS.