

PRECISION IN MEASUREMENT

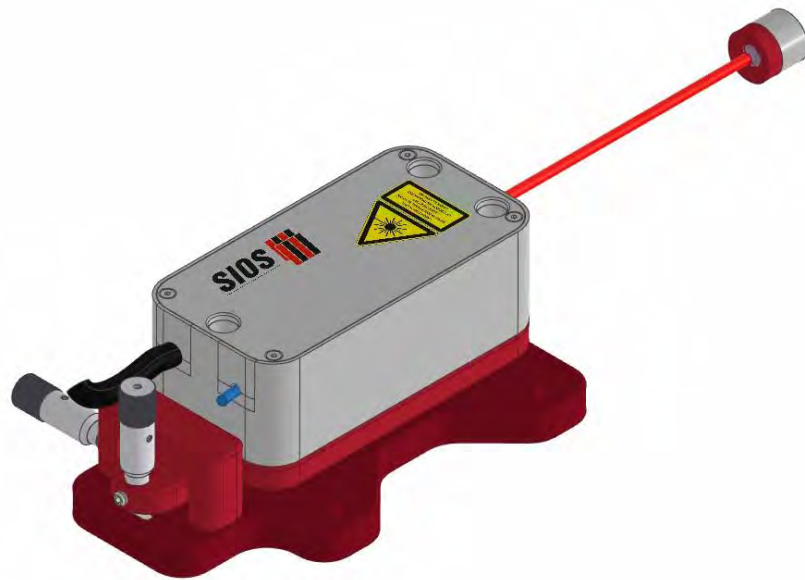


Anwendungen der Laserinterferometrie für hochpräzise dimensionelle Messaufgaben

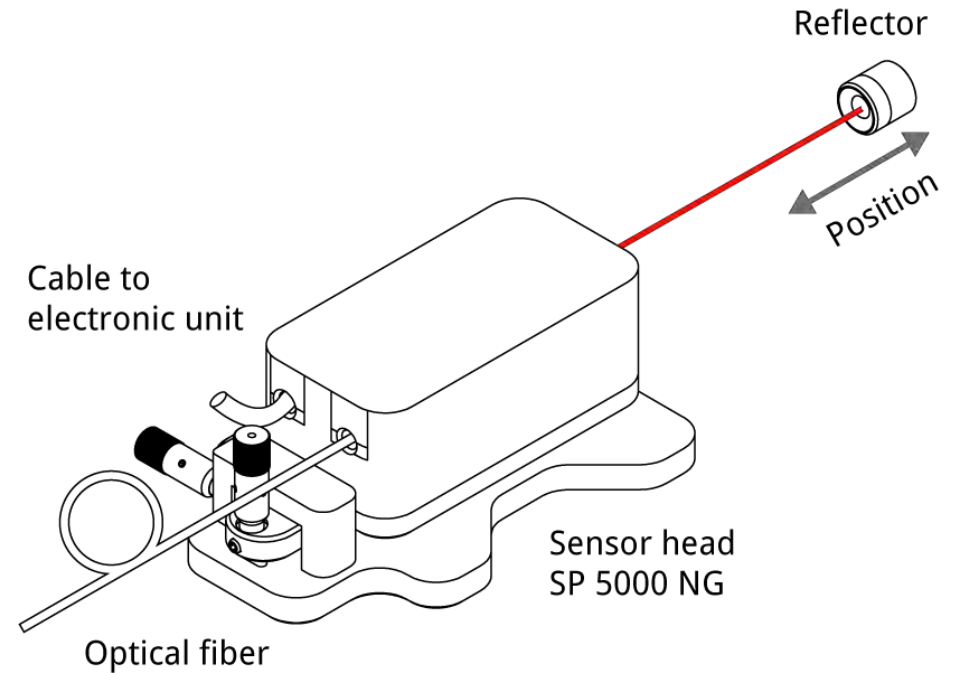
Dr. Denis Dontsov
Geschäftsführer

Single-beam Laser Interferometers

One axis displacement measuring systems



SP 5000 NG



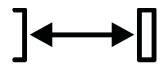

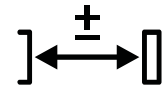
Single-beam Laser Interferometers

One axis displacement measuring systems



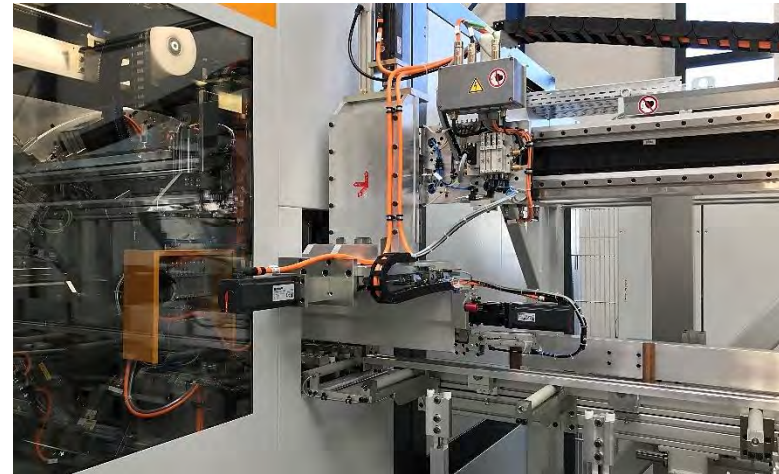
SP 15000 NG

- flexible length measuring system of highest accuracy
- highly accurate length measurements over long distances
- tilting angle of reflector maximum up to $\pm 22.5^\circ$
- easy adjustment and handling
- compact design
- extensive trigger options
- open interfaces for OEM software under Windows and Linux

 $\leq 80 \text{ m}$  5 pm  $0.1 \text{ } \mu\text{m/m}$

Single-beam Laser Interferometers

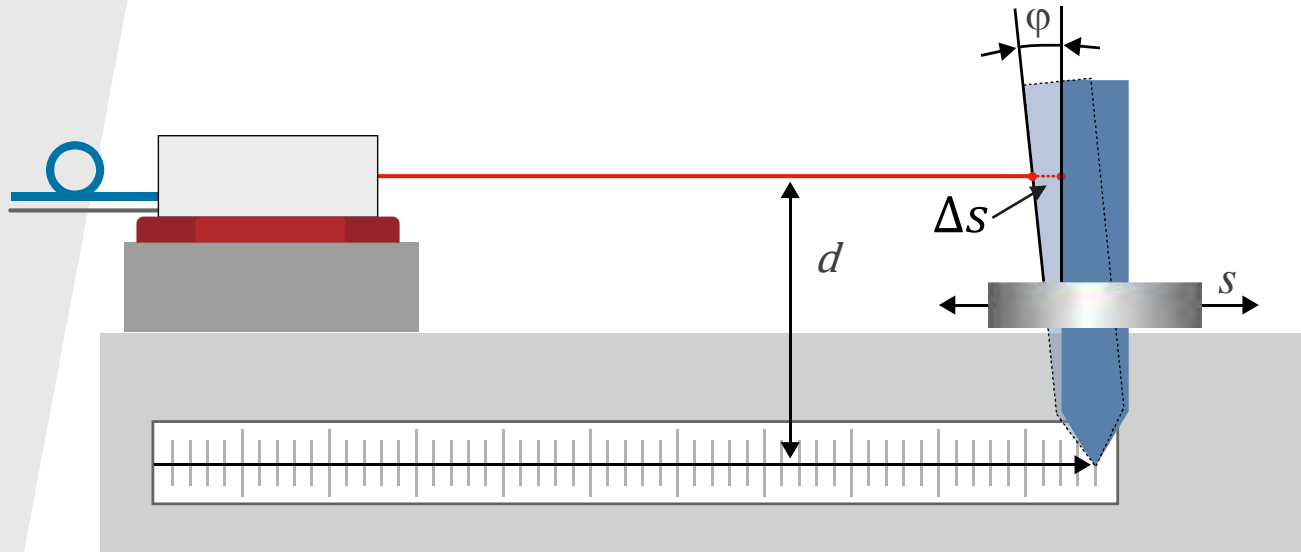
Application of SP 15000 NG in industrial environment





YZ-plane - squareness calibration – [y wz](#) / [A0Z](#)

Abbe-Error in Application



Length measuring system

$$\Delta s_{Abbe} = d \cdot \tan(\varphi)$$

d - Abbe- offset

φ - Angle

Example 1

- Abbe-offset, d 1 mm
- Dynamic mirror tilt, φ ± 8 arcsec ($\pm 39 \mu\text{rad}$)

Abbe-Error

$\pm 0.039 \mu\text{m}$

Example 2

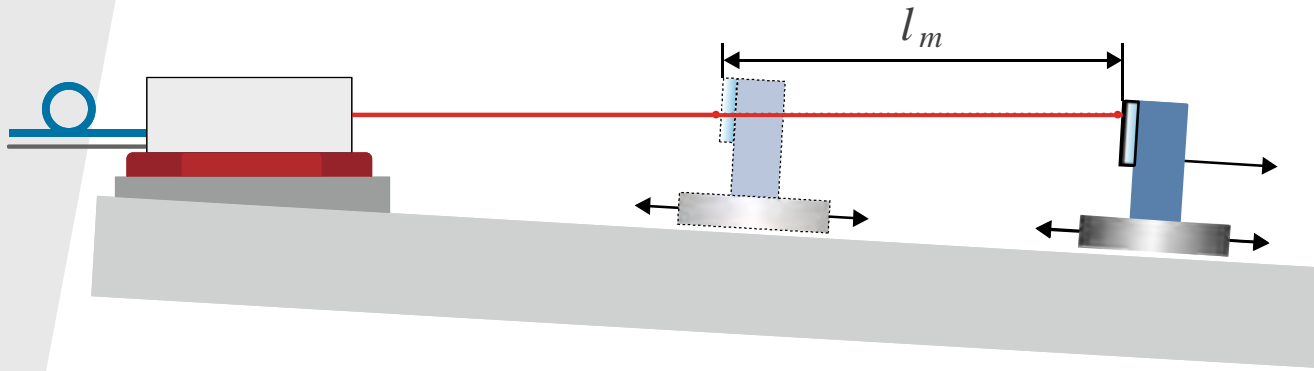
- Abbe-offset, d 50 mm
- Dynamic mirror tilt, φ ± 8 arcsec ($\pm 39 \mu\text{rad}$)

Abbe-Error

$\pm 1.9 \mu\text{m}$

Alignment-Error in Application

Direction Alignment-Error



$$\Delta l_{cos} = l_m \cdot [1 - \cos(\varphi)]$$

l_m - Measuring displacement
 φ - Angle

Example 1

- Visible beam shift at target 0.5 mm
- Movement distance 500 mm

Angle 3.4 arcmin (1 mrad)
Error 0.5 $\mu\text{m}/\text{m}$

Example 2

- Visible beam shift at target 0.5 mm
- Movement distance 50 mm

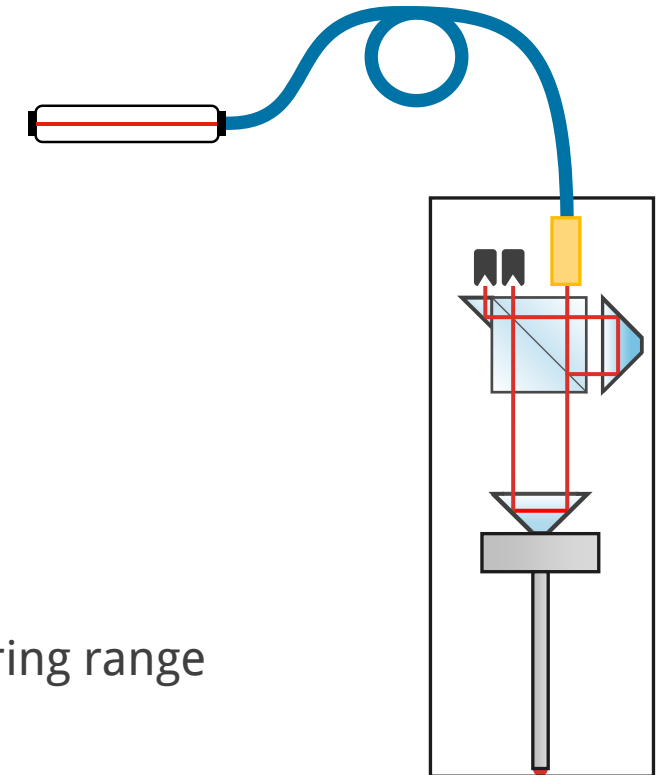
Angle 34 arcmin (10 mrad)
Error 50 $\mu\text{m}/\text{m}$

SIOS Solution

Development under consideration of error sources



- free of alignment-error
- free of Abbe-Error
- minimized death path
- constant probing force over the entire measuring range
- highest linearity $< \pm 1.2$ nm throughout the entire measuring range
- standard shaft $\varnothing 8h6$
- changeable probe tip M2.5



Uncertainty of Laser Interferometers

Uncertainty budget of air refractive index

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

Parameter	Sensitivity coefficients	Usual standard uncertainty of measurement	Contribution to the measurement uncertainty	Weighting
Air temperature (t)	$-9.3 \cdot 10^{-7} \text{ [K}^{-1}\text{]}$	$u(t) = 0.07 \text{ K}$	$-6.5 \cdot 10^{-8}$	48 %
Air pressure (p)	$+2.7 \cdot 10^{-9} \text{ [Pa}^{-1}\text{]}$	$u(p) = 29 \text{ Pa}$	$+7.8 \cdot 10^{-8}$	28 %
Partial vapor pressure (p_w)	$-3.7 \cdot 10^{-10} \text{ [Pa}^{-1}\text{]}$	$u(p_w) = 40 \text{ Pa}$	$-1.5 \cdot 10^{-8}$	10 %
CO ₂ (c)	$-1.5 \cdot 10^{-10} \text{ [ppm}^{-1}\text{]}$	$u(c) = 100 \text{ ppm}$	$-1.5 \cdot 10^{-8}$	6 %
Uncertainty of Edlen equation			$2.0 \cdot 10^{-8}$	8 %
Standard uncertainty of air refractive index			$u(n) = 0.11 \cdot 10^{-6}$	
Expanded uncertainty			$u(n) = 0.21 \cdot 10^{-6}$ ($k=2$)	

Measuring Uncertainty Budget

Example calculation

Assuming setup conditions

- measuring displacement **100 mm**
- Abbe-offset 1 mm
- Alignment-Error 30 arcsec, 145 μ rad
- dynamic mirror tilt ± 8 arcsec, ± 39 μ rad
- dead path 10 mm \pm 1 mm
- change of temperature* 0.5 $^{\circ}$ C

Parameter	Relative value	Value in nm	Description
U_laser	$2.00 \cdot 10^{-8}$	2.00	laser frequency
U_index	$1.05 \cdot 10^{-7}$	10.50	determination of the refractive index of air
U_demond		0.26	linearity error
U_Abbe		24.24	Abbe-Error
U_alignment		0.47	Alignment-Error
U_deadpath		1.59	dead path correction
U_total		26.54 nm**	

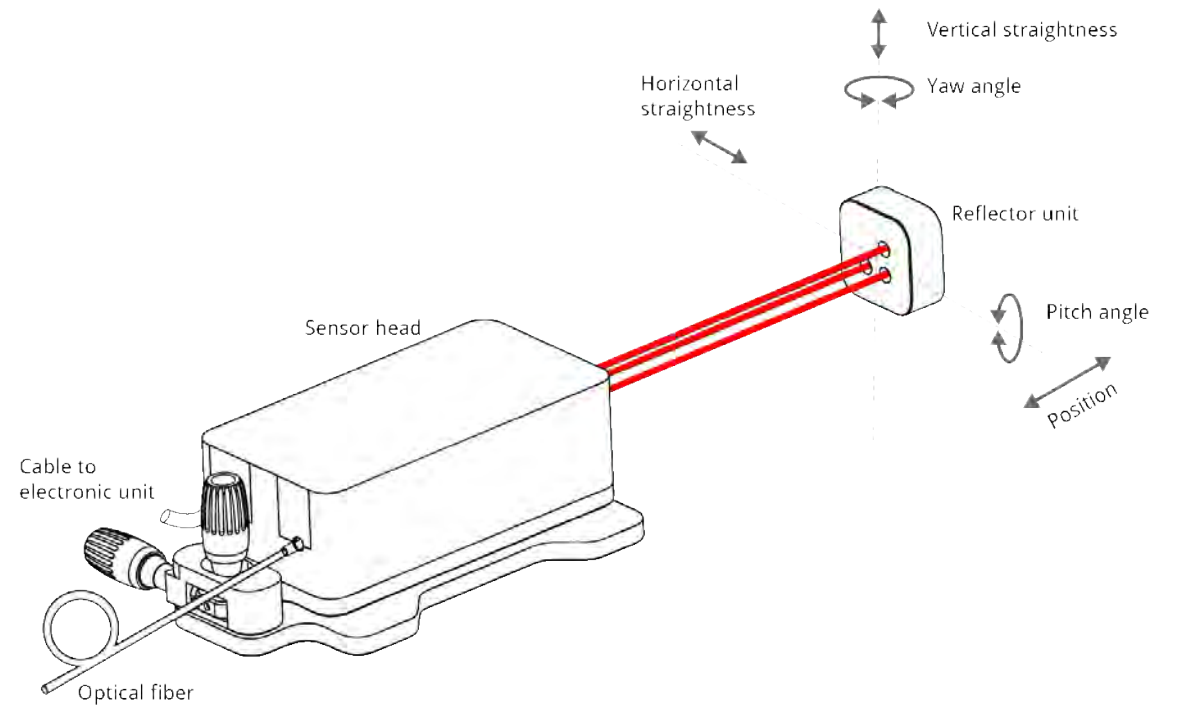
* Temperature change has been included only for dead path calculation error **Combined standard uncertainty

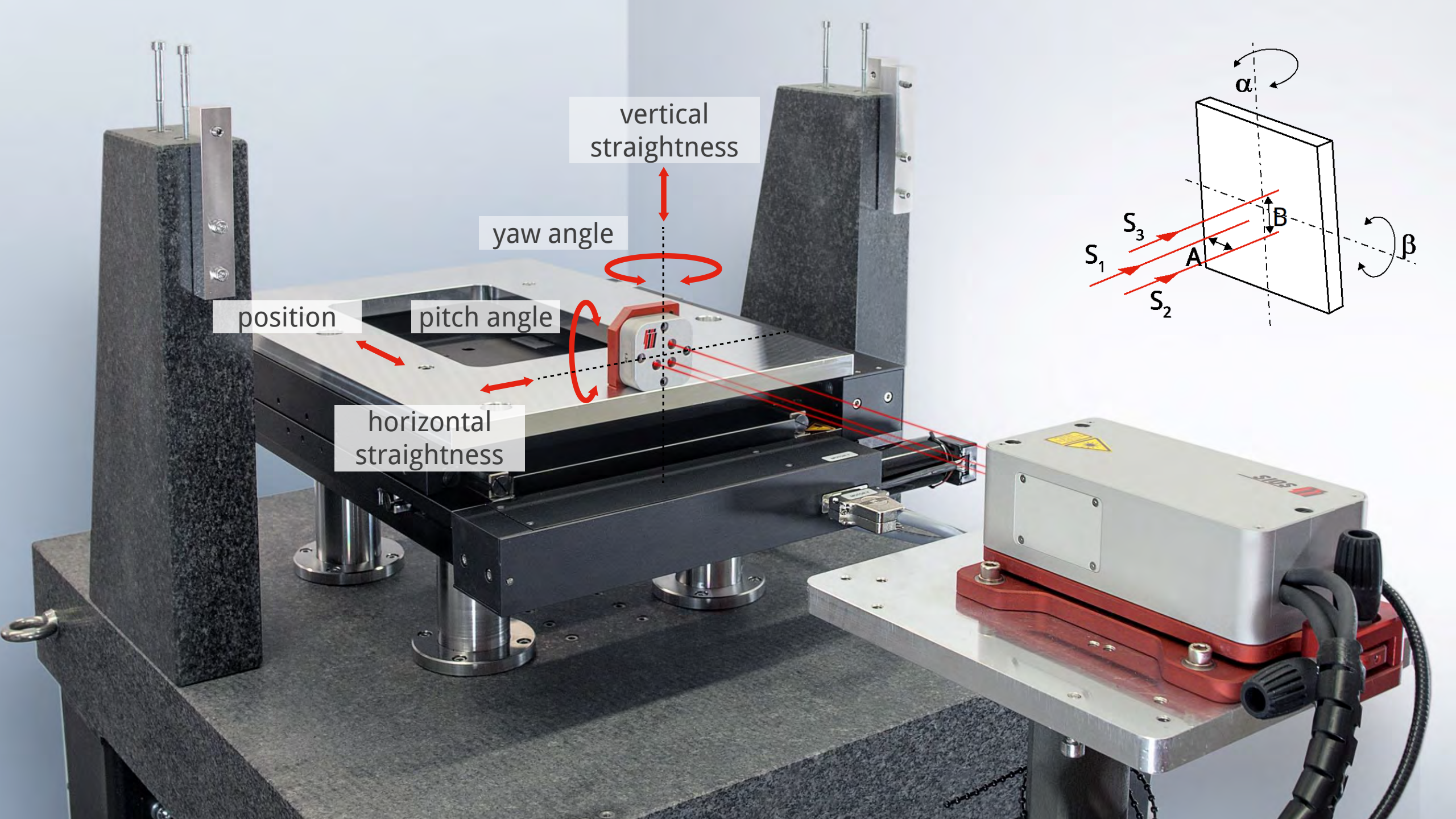
Triple-beam Laser Interferometers

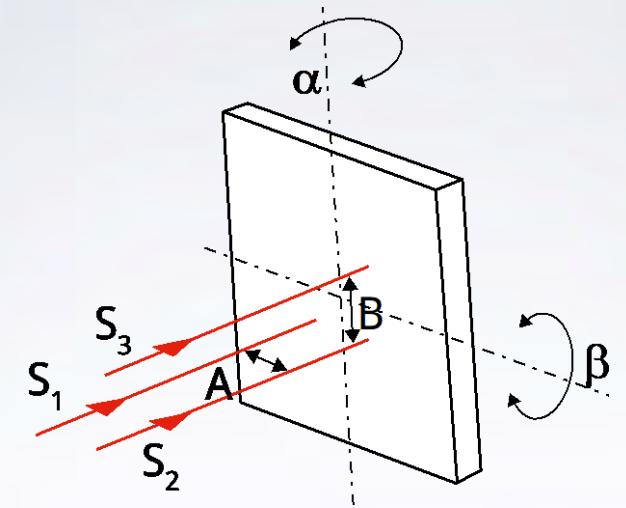
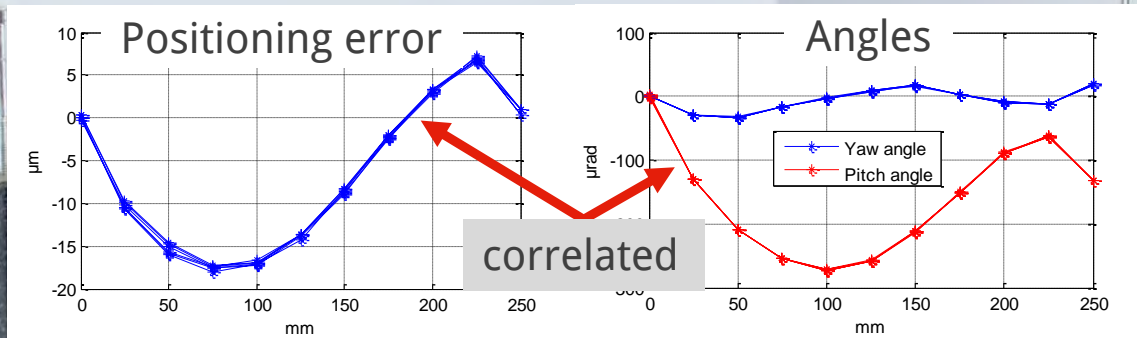
Simultaneous measurements of lengths and angles



SP 5000 TR

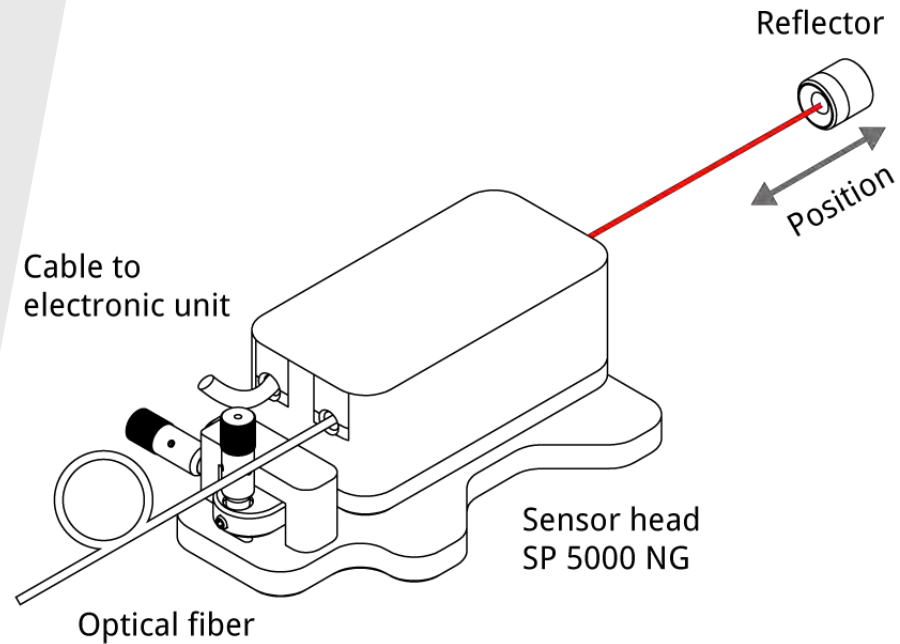




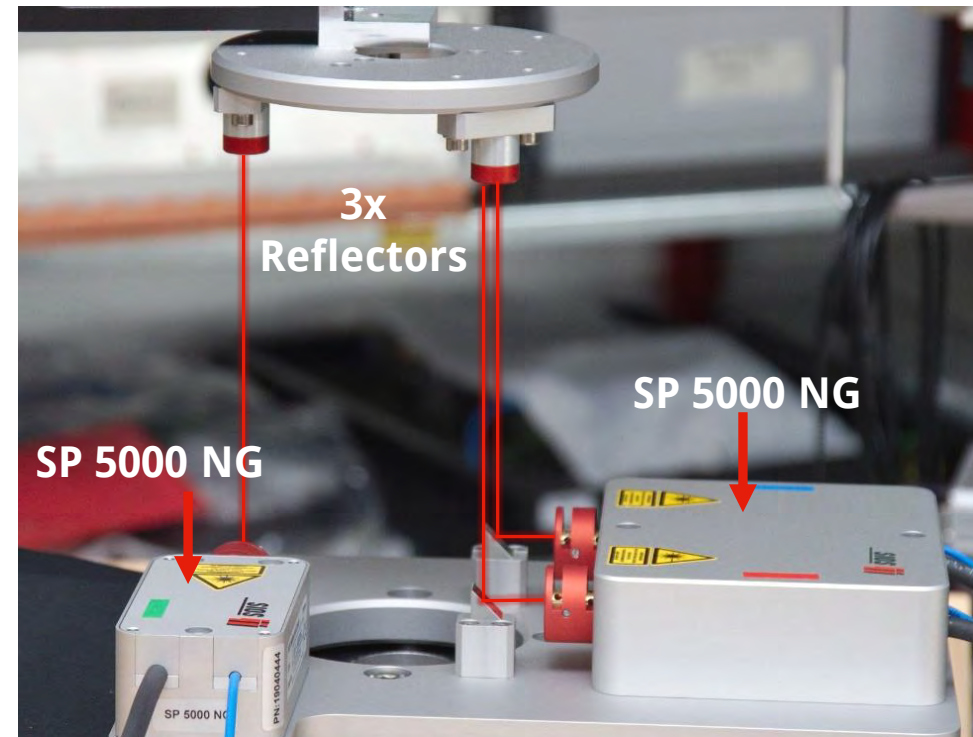


Single-beam Laser Interferometers

Universal, compact and precise



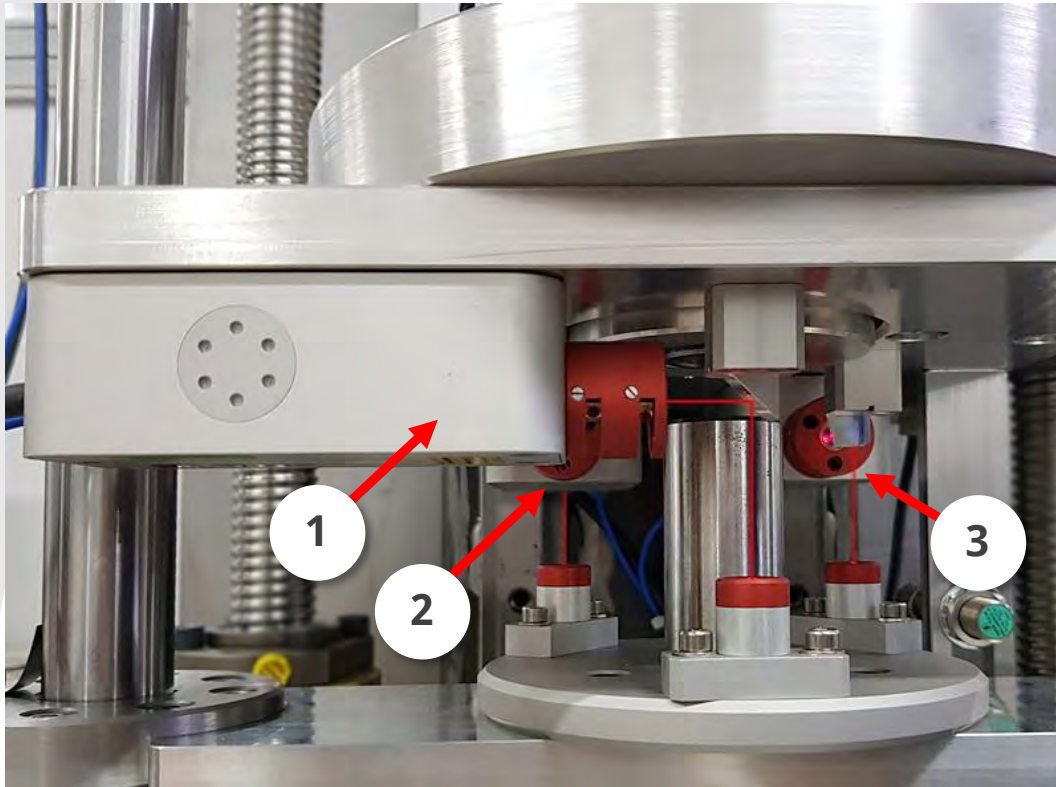
SP 5000 NG



multiple sensor arrangement
high synchronicity of data samples for $v = 3 \text{ m / s}$

Single-beam Laser Interferometers

One axis displacement measuring systems



- TÜBİTAK UME Nat. Metrology Institute, Turkey
- Project: European Metrology Programme for innovation and research
- development of a new drop mass system for calibration dynamic pressure transducers
- SIOS part: integration of three axis SP 5000 NG version
- **high dynamic application 3m/s**

Single-beam Laser Interferometers

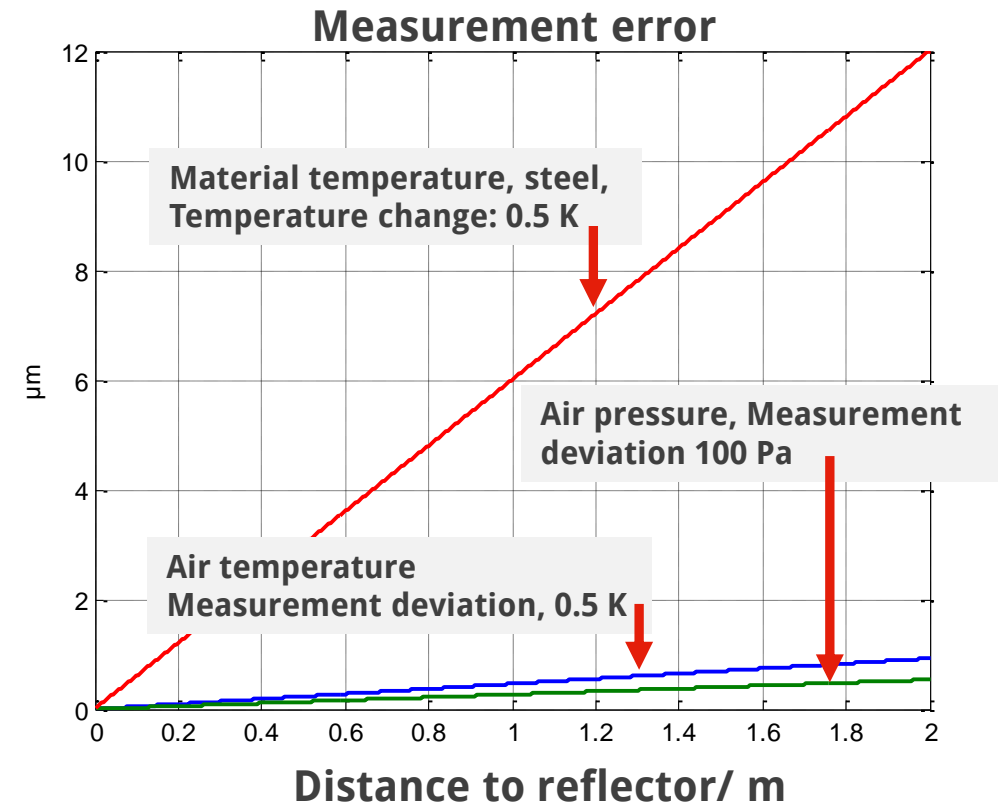
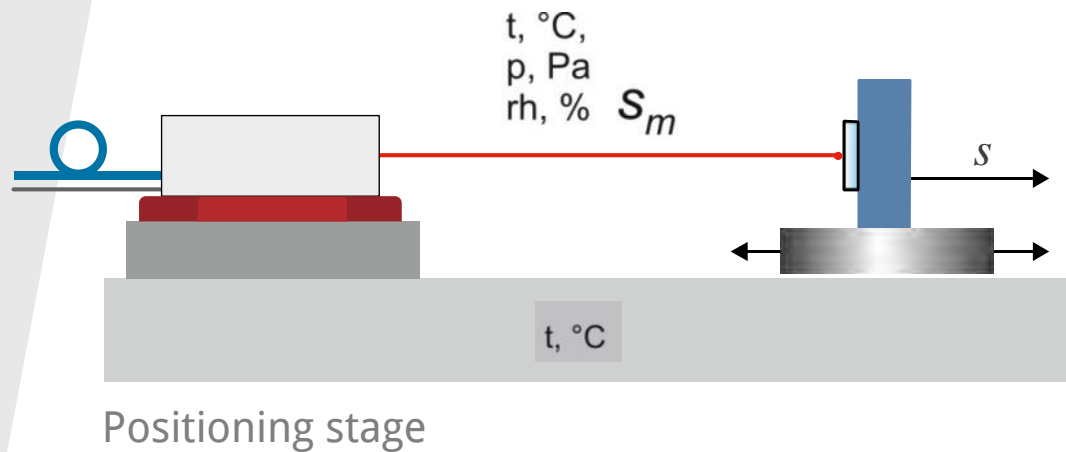
One axis displacement measuring systems



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Environmental Impacts of Laser Interferometer

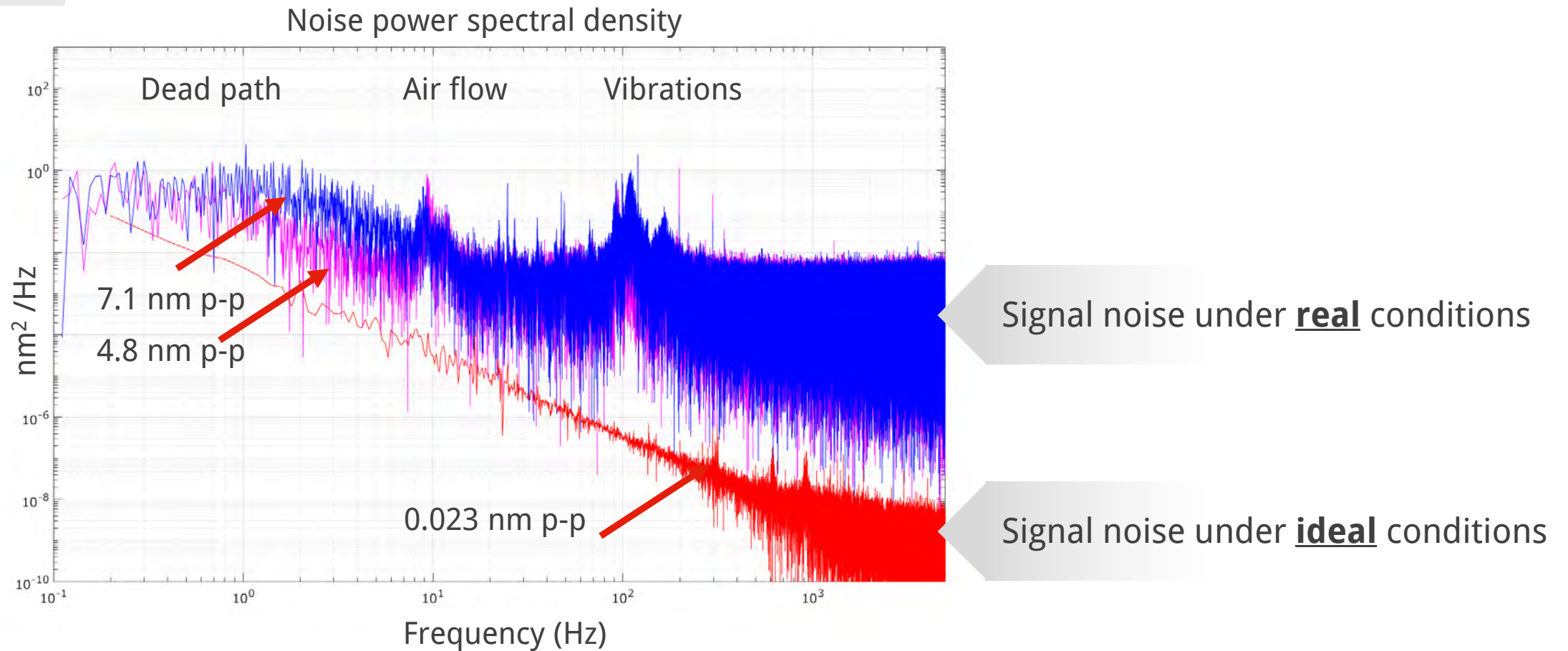
Influences on the measurement setup



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

Resolution of Laser Interferometers

Frequency and measuring conditions

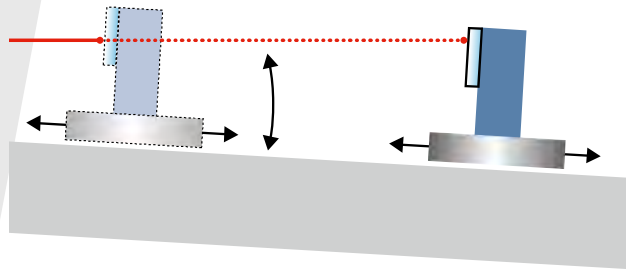


SIOS Solution

Alignment-Error



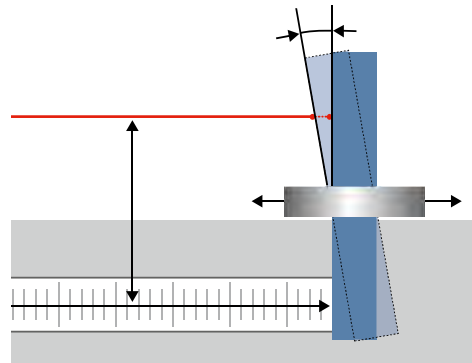
Problem



Abbe-Error



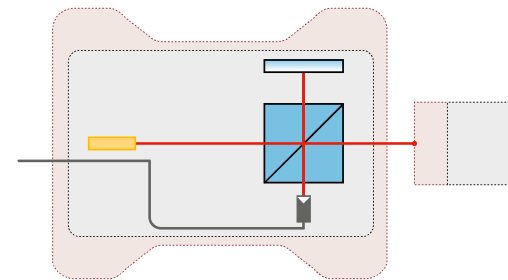
Problem



Death Path



Problem



SIOS Solution

Alignment-Error



SP Series with integrated alignment unit

Abbe-Error



SP-TR Series for simultaneous length and angle measurement to calculate abbe free measurements

Death Path



SP-DI Series for minimized death path

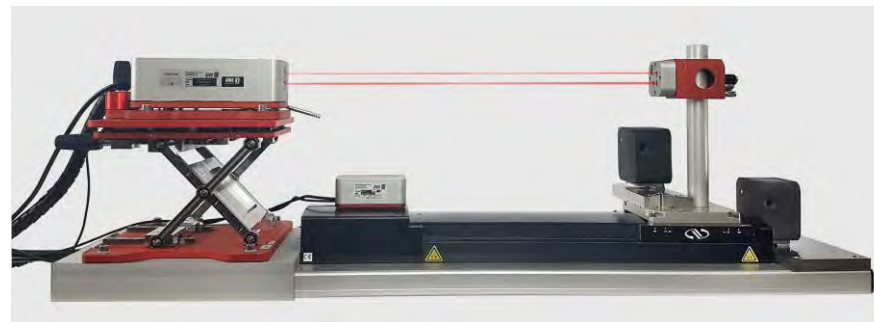
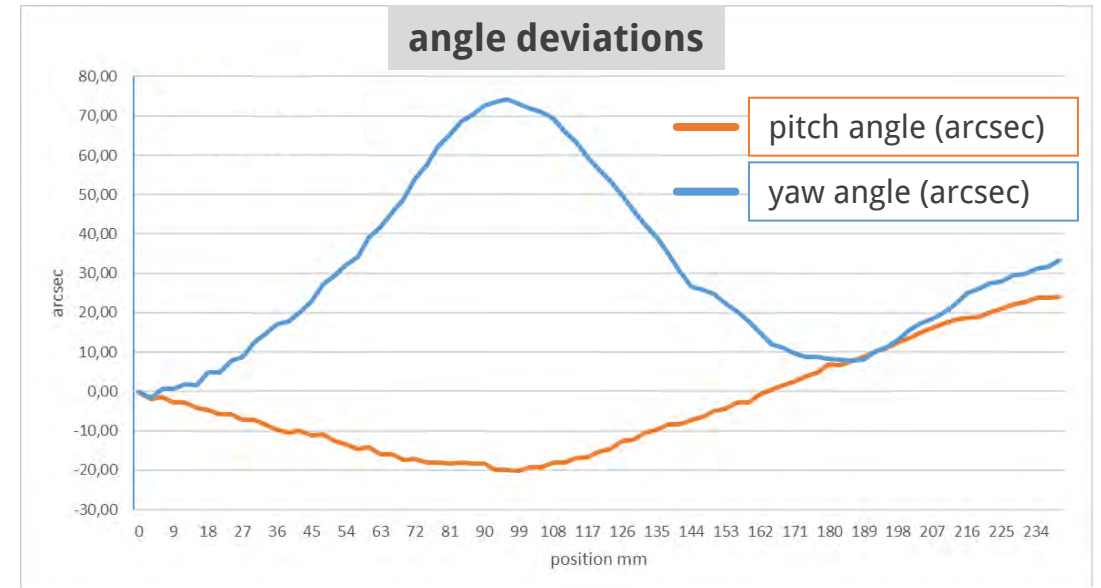
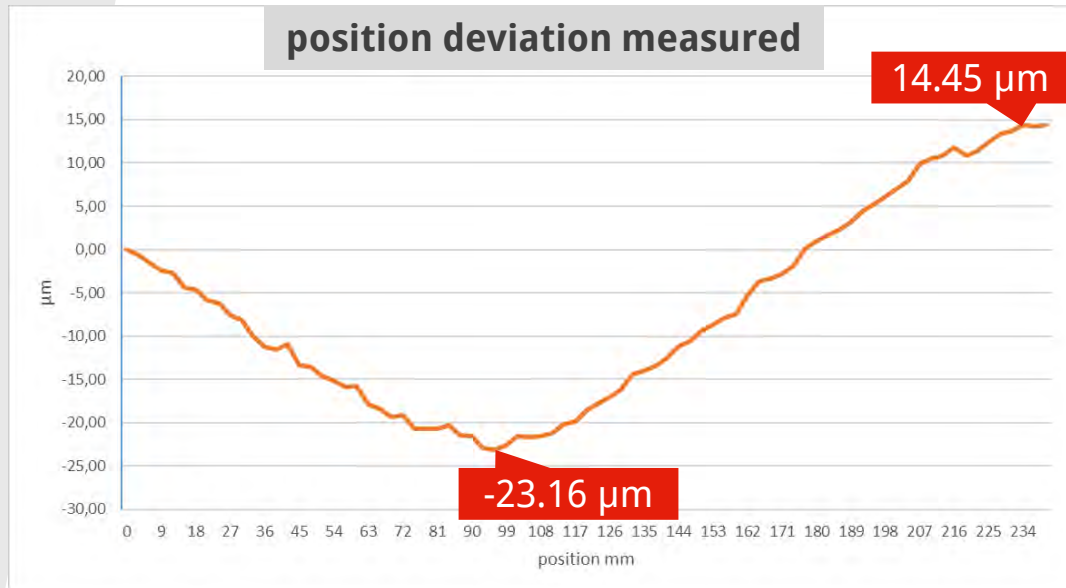
SP 5000 TR for 4 DOF

Synchronous measurement of position, pitch, yaw, roll on 132 mm height



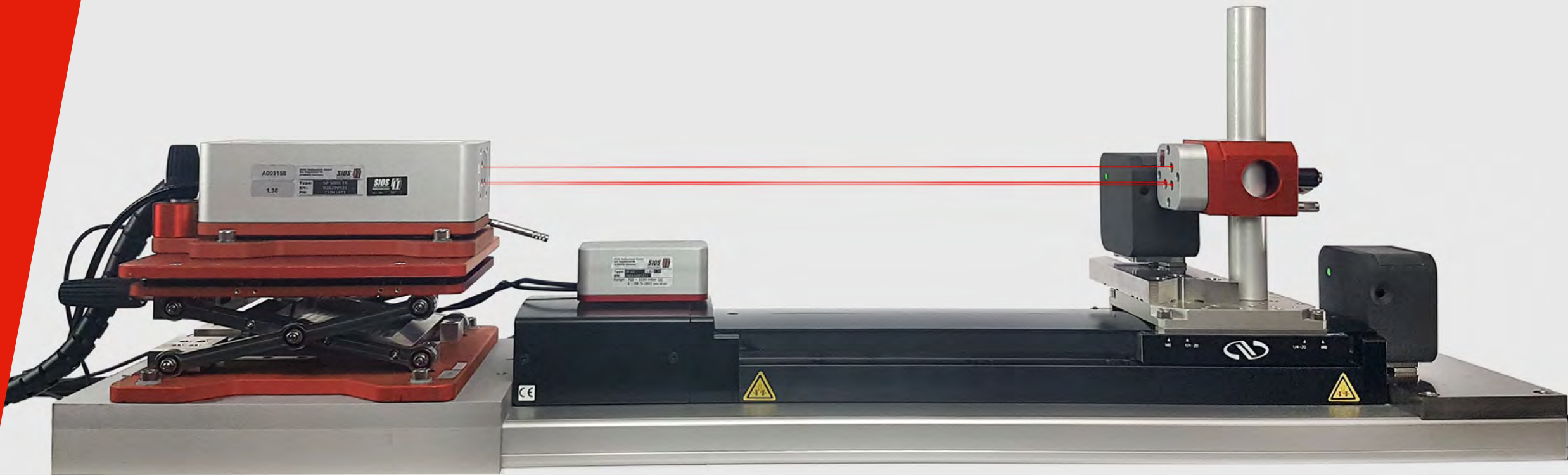
SP 5000 TR for 4 DOF

Synchronous measurement of position, pitch, yaw, roll on 132 mm height



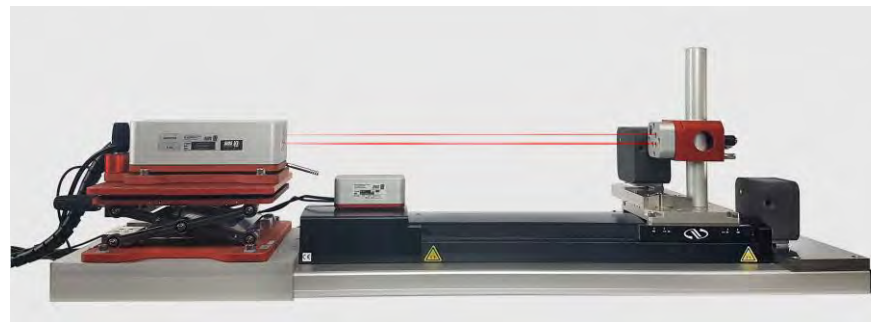
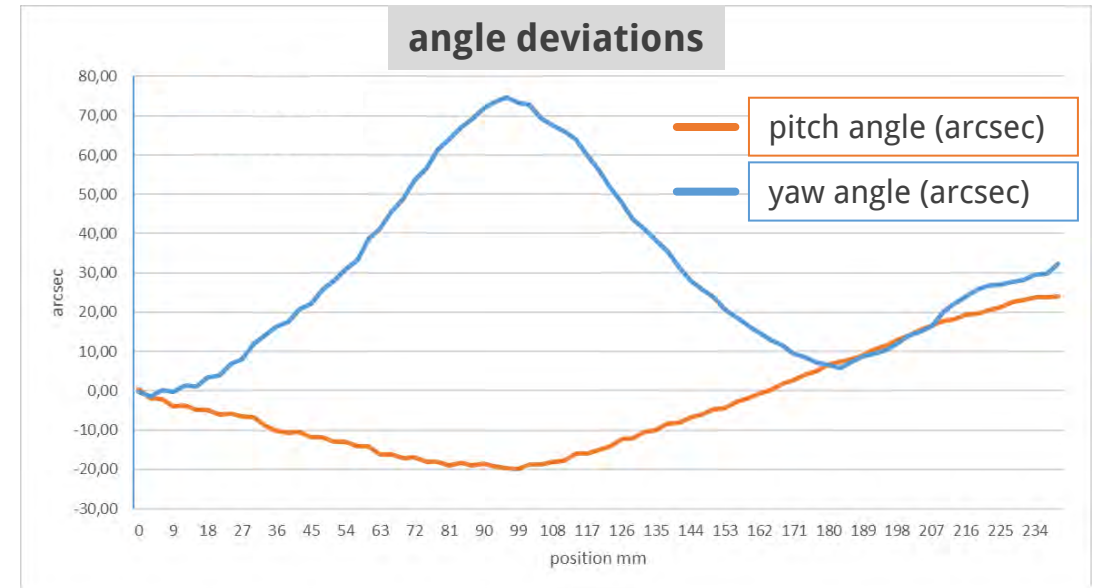
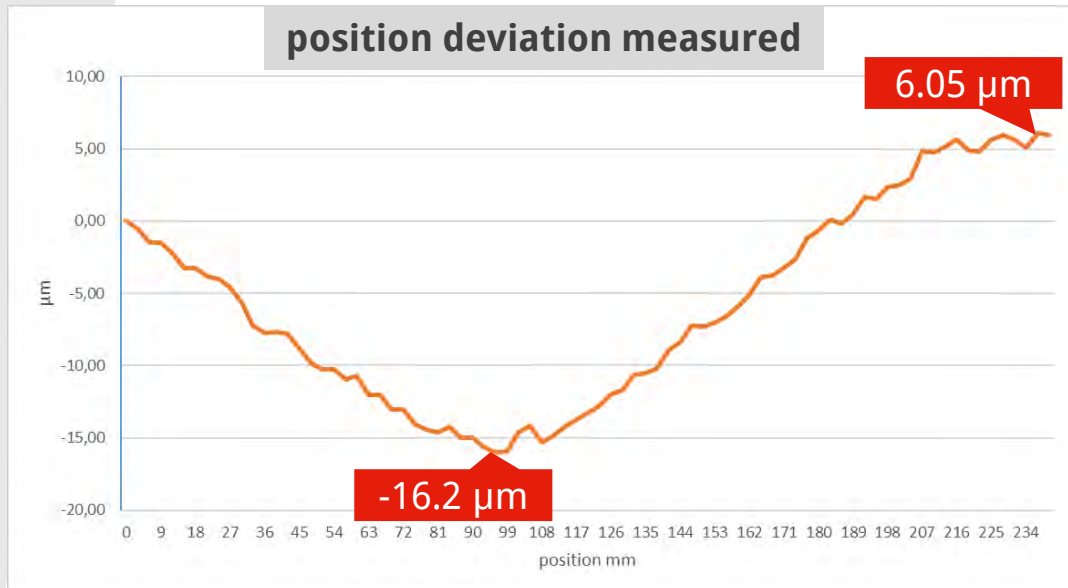
SP 5000 TR for 4 DOF

Synchronous measurement of position, pitch, yaw, roll on 62 mm height



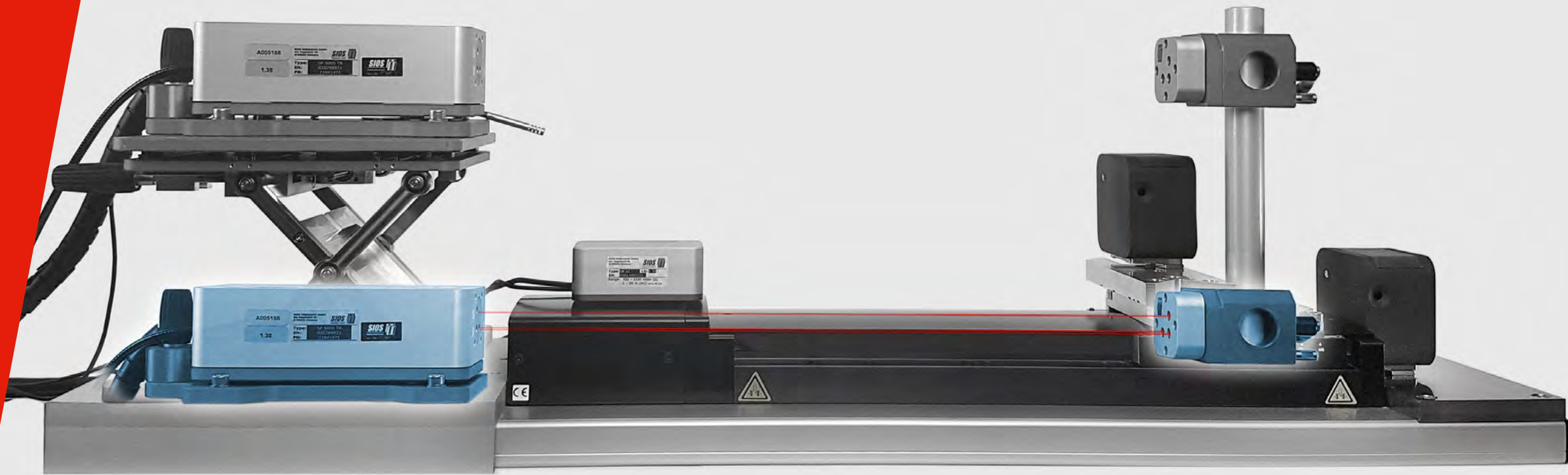
SP 5000 TR for 4 DOF

Synchronous measurement of position, pitch, yaw on 62 mm height



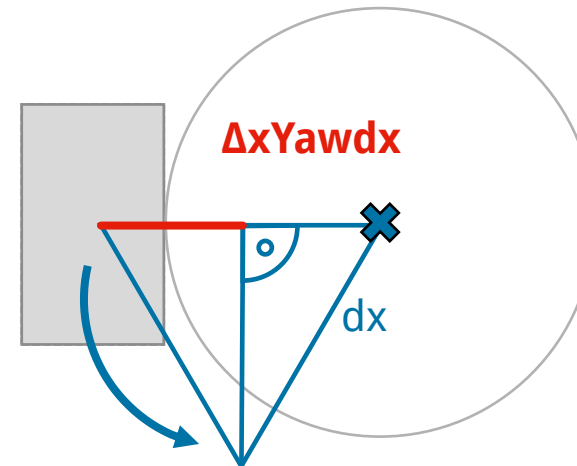
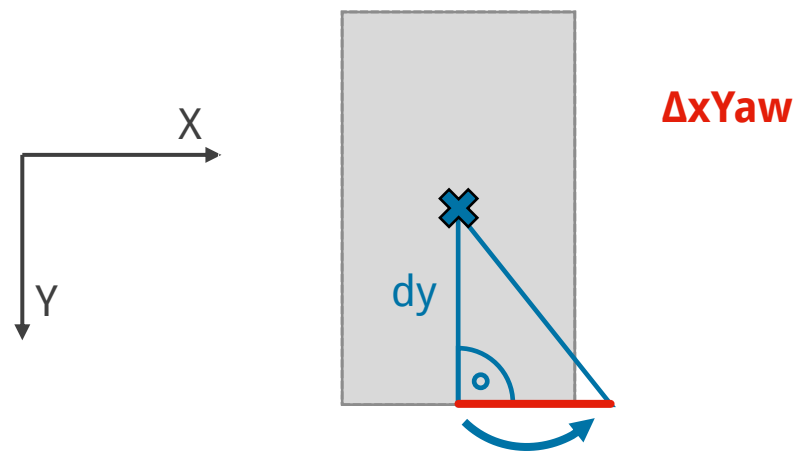
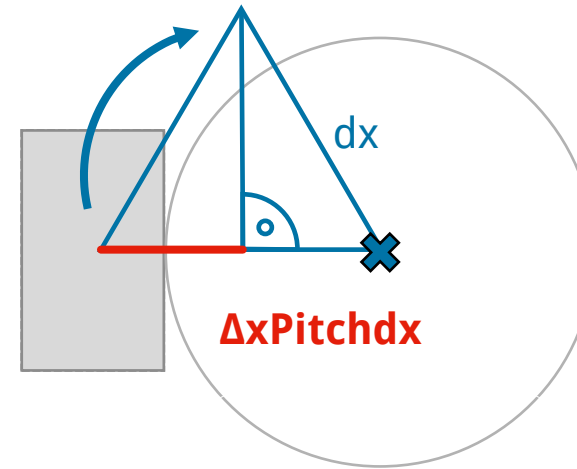
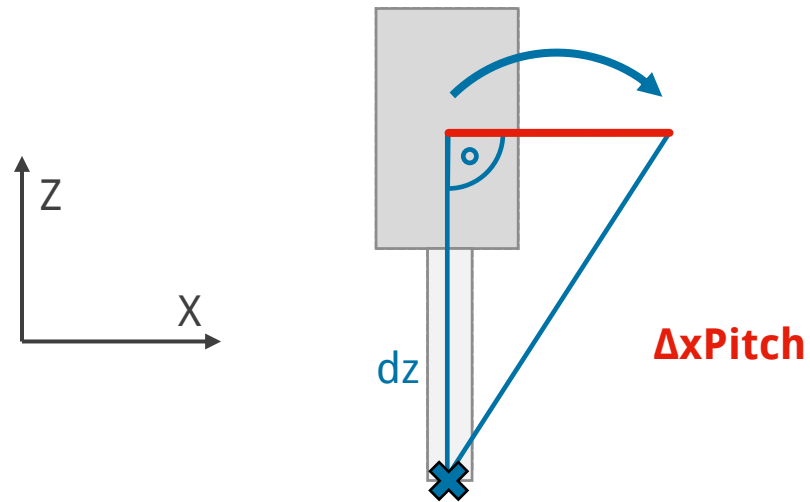
Abbe-Free Measurement

Calculating the position deviation in the center of the guide rail



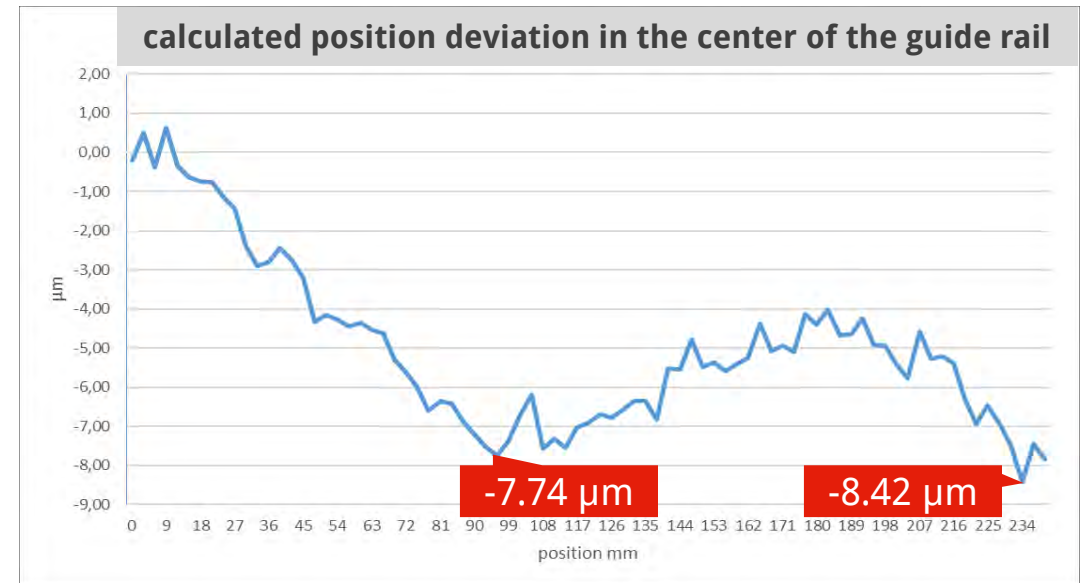
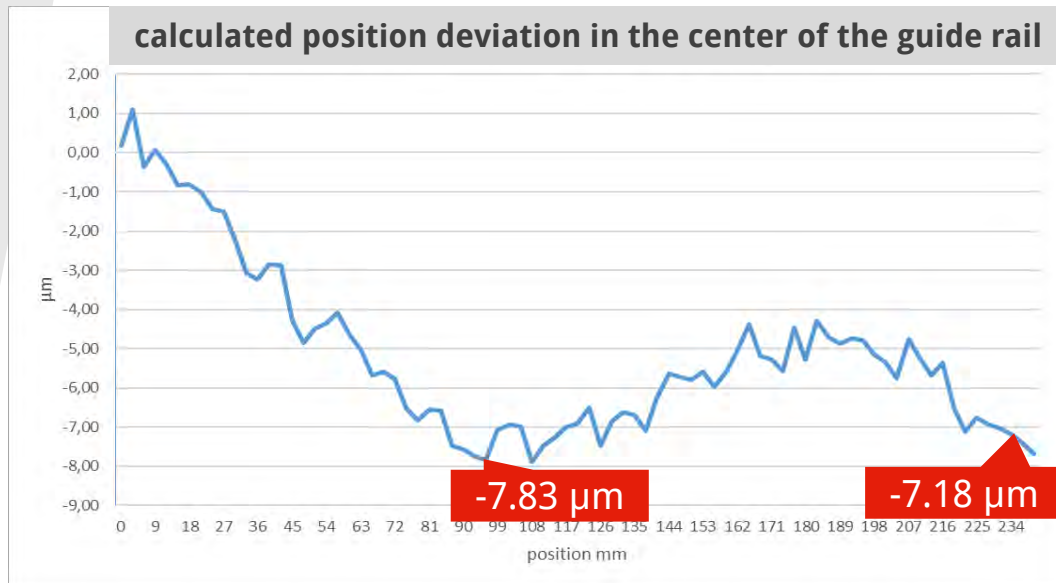
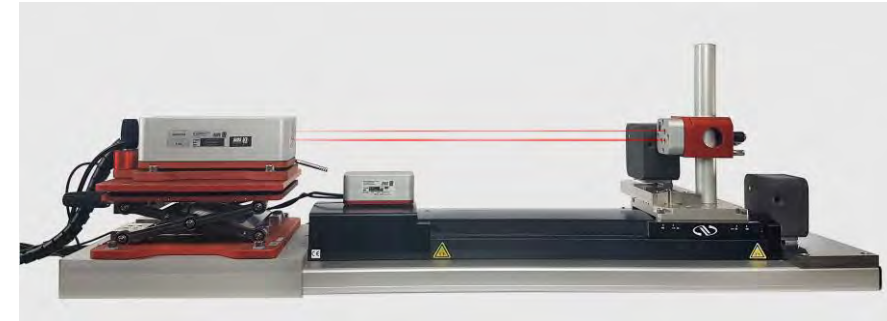
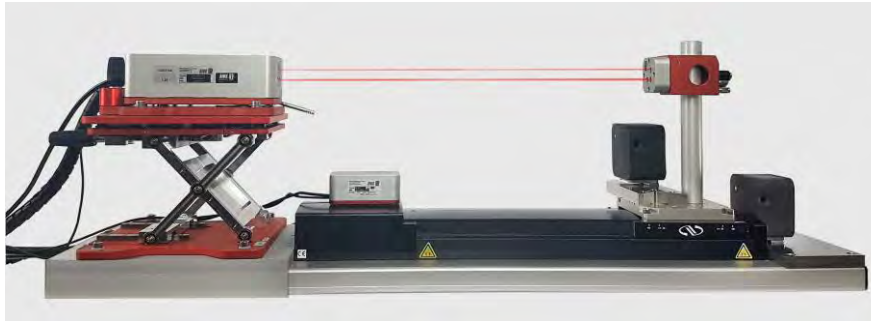
Abbe-Free Measurement

How to calculate the position deviation at the center of rotation



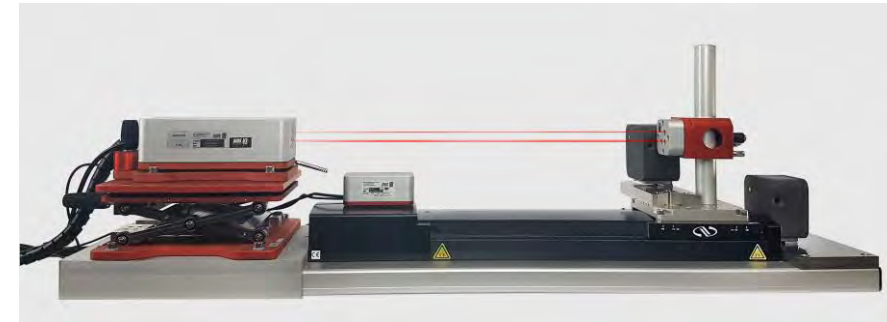
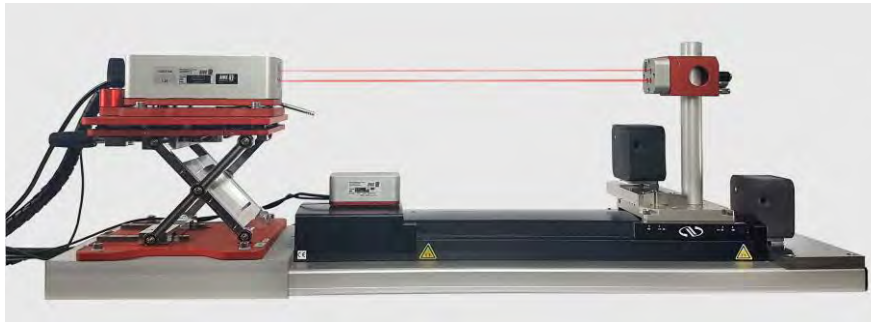
Abbe-Free Measurement

Calculated position deviation in the center of the guide rail

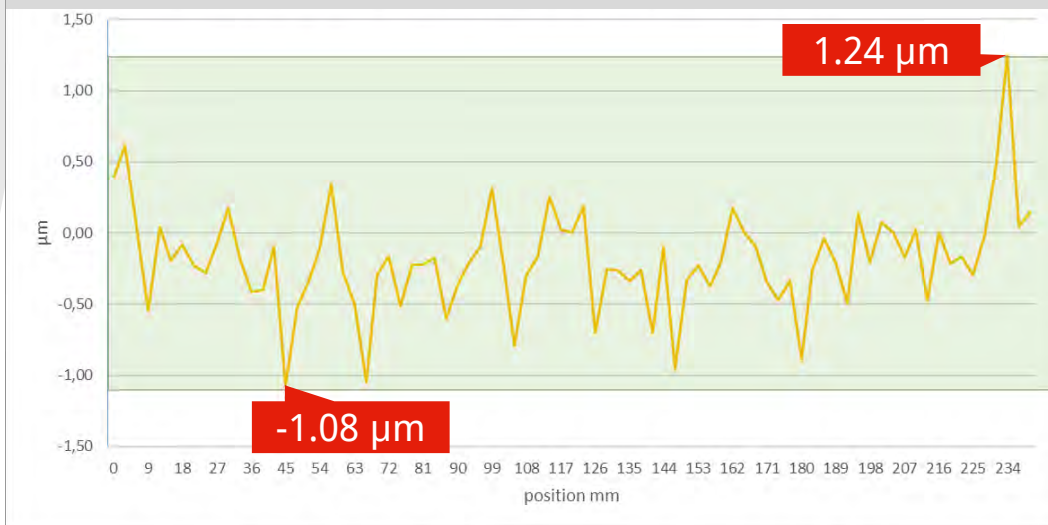


Abbe-Free Measurement

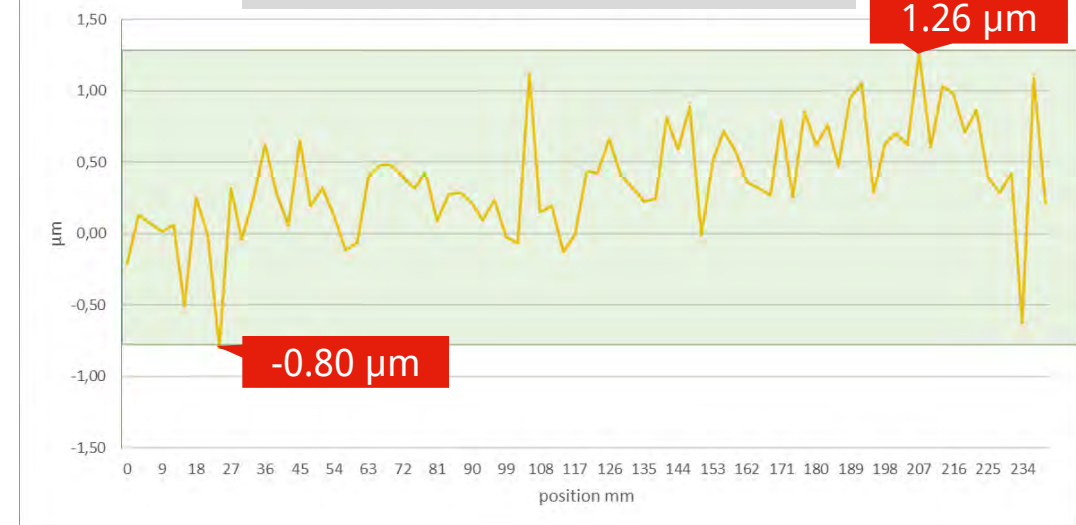
Calculated position deviation in the center of the guide rail



offset error of the calculation values between 62 mm to 132.2 mm

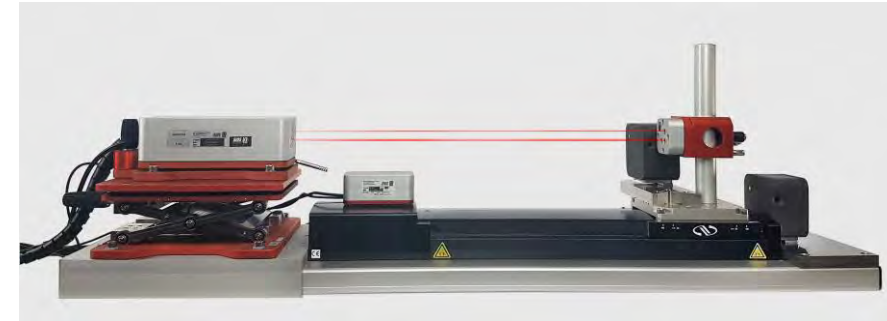
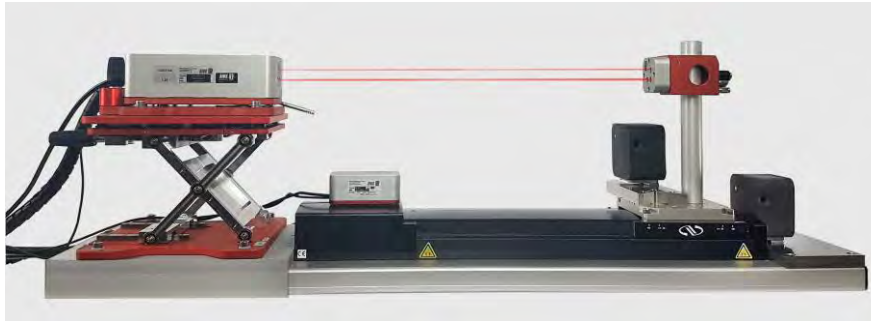


repeatability of measurement A2-A1

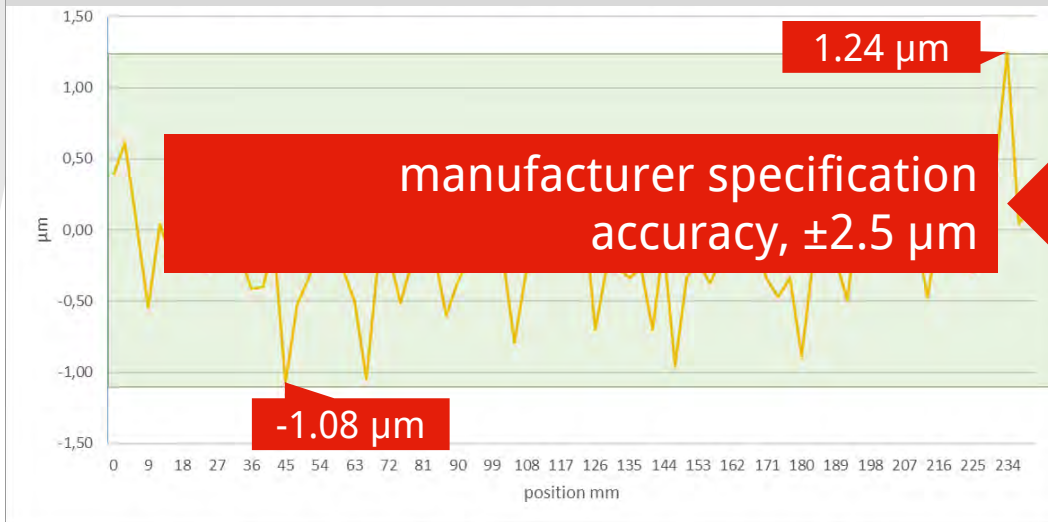


Abbe-Free Measurement

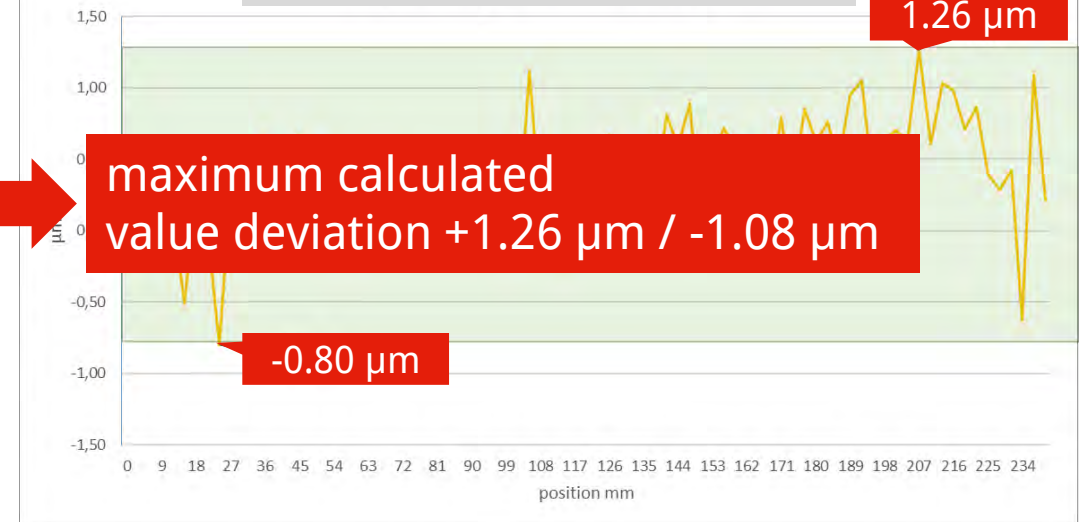
Calculated position deviation in the center of the guide rail



offset error of the calculation values between 62 mm to 132.2 mm

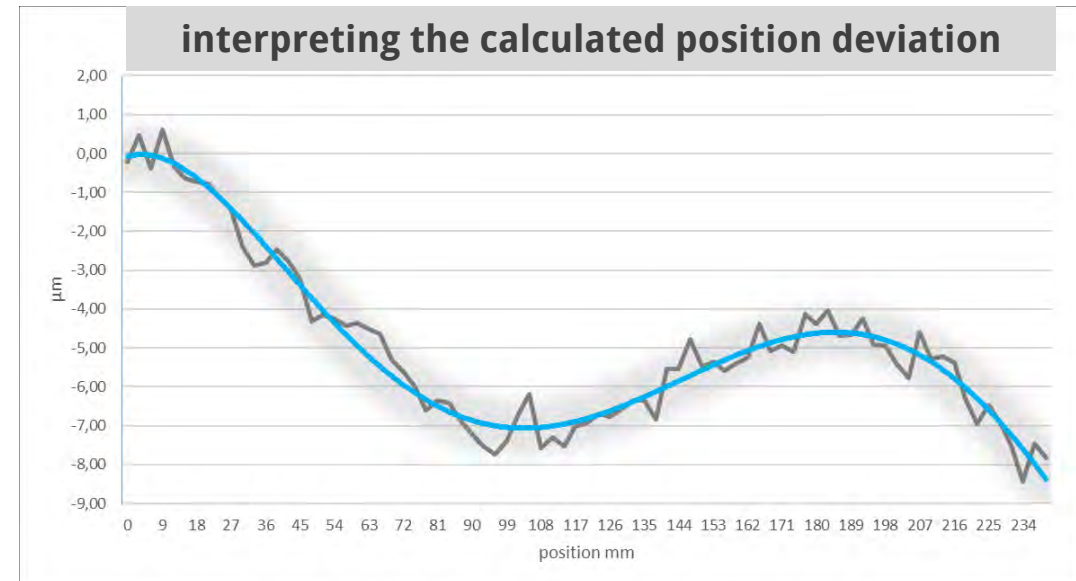
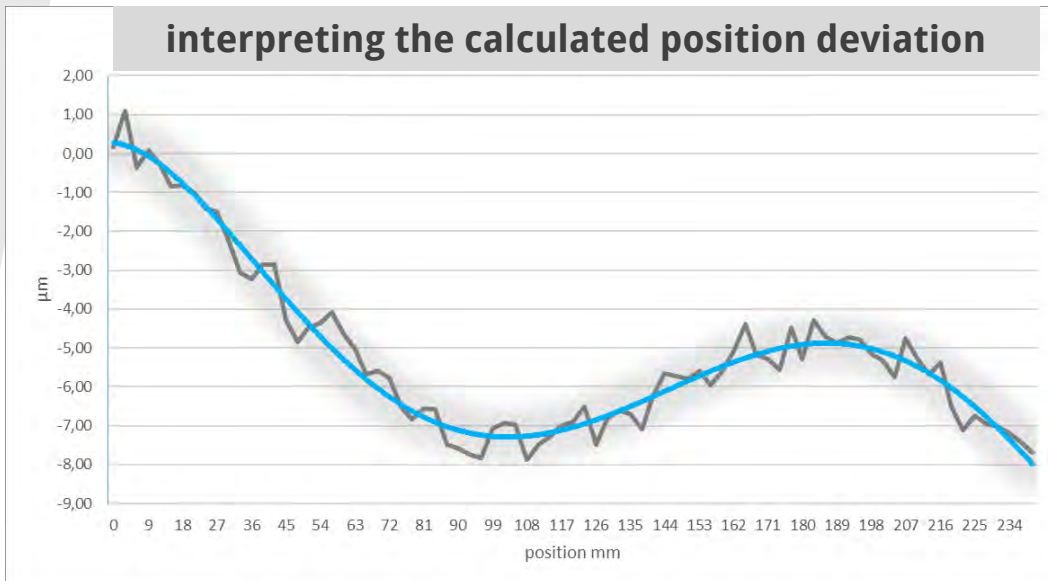
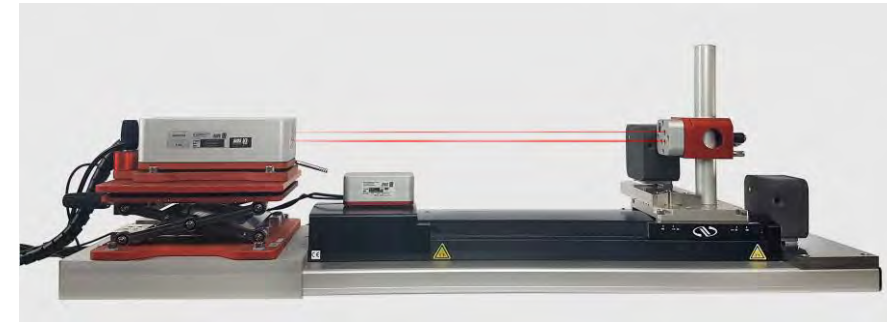
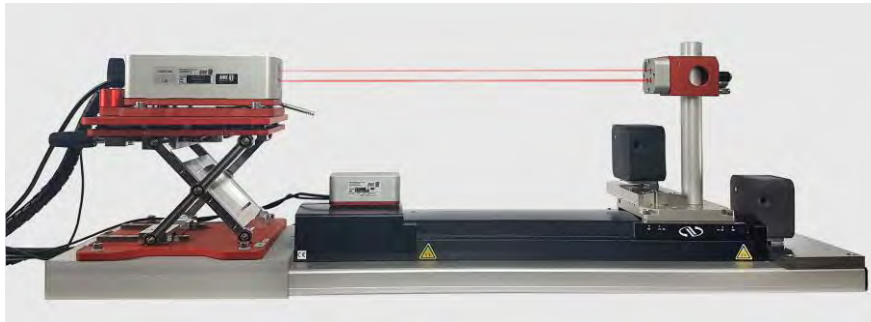


repeatability of measurement A2-A1



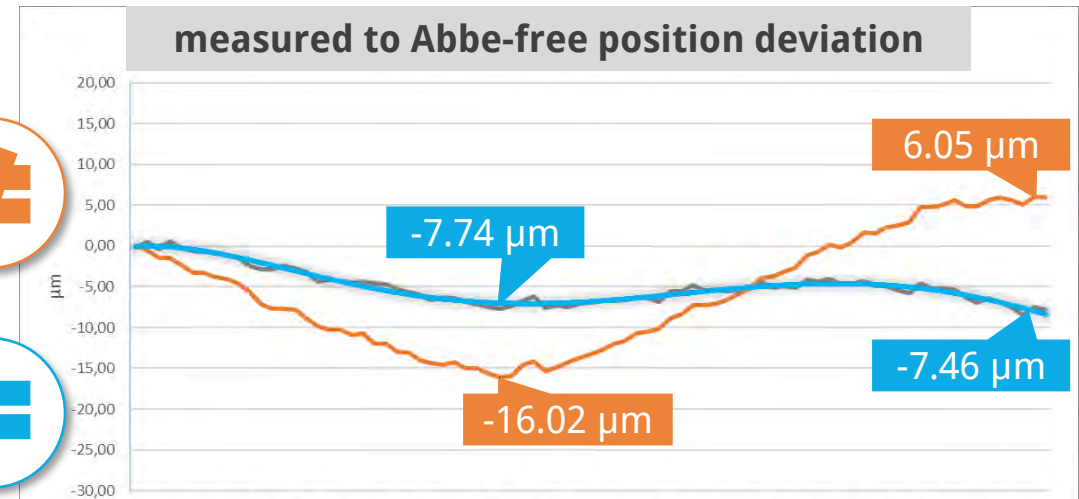
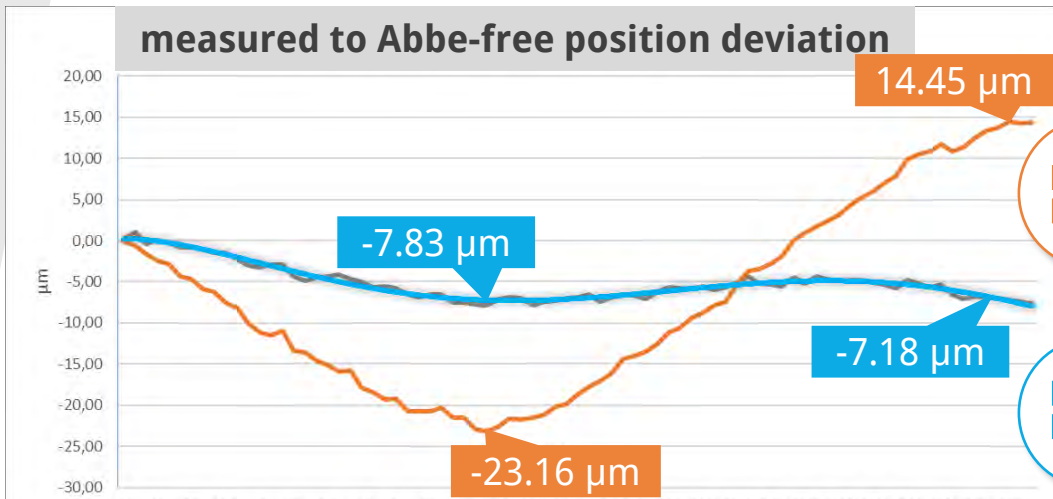
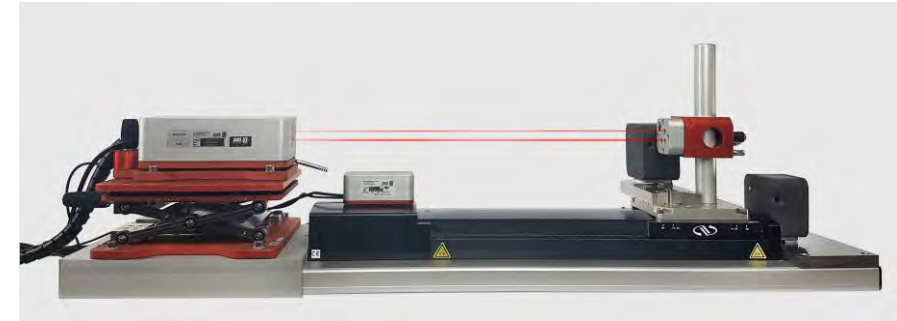
Abbe-Free Measurement

Calculated position deviation in the center of the guide rail



Abbe-Free Measurement

Calculated position deviation in the center of the guide rail



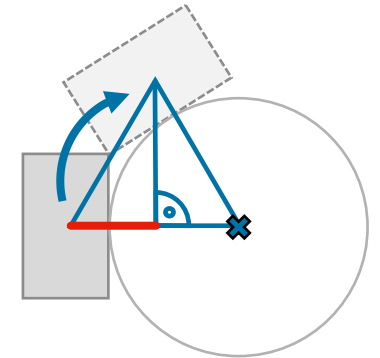
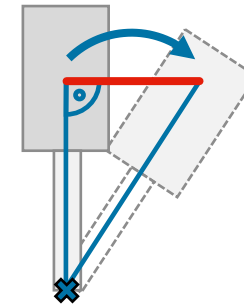
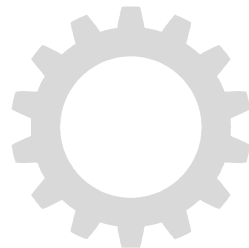
Measurements are comparable only after the calculation with angle values

SIOS Calibration Software



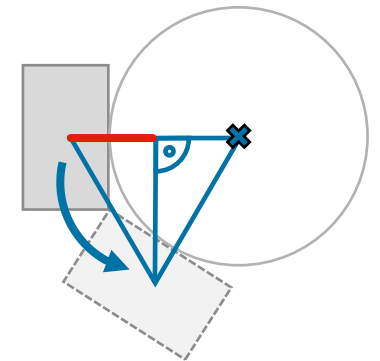
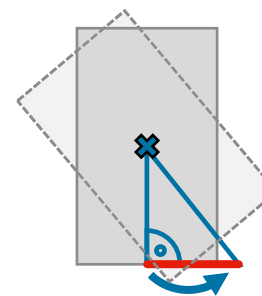
Easy and fast

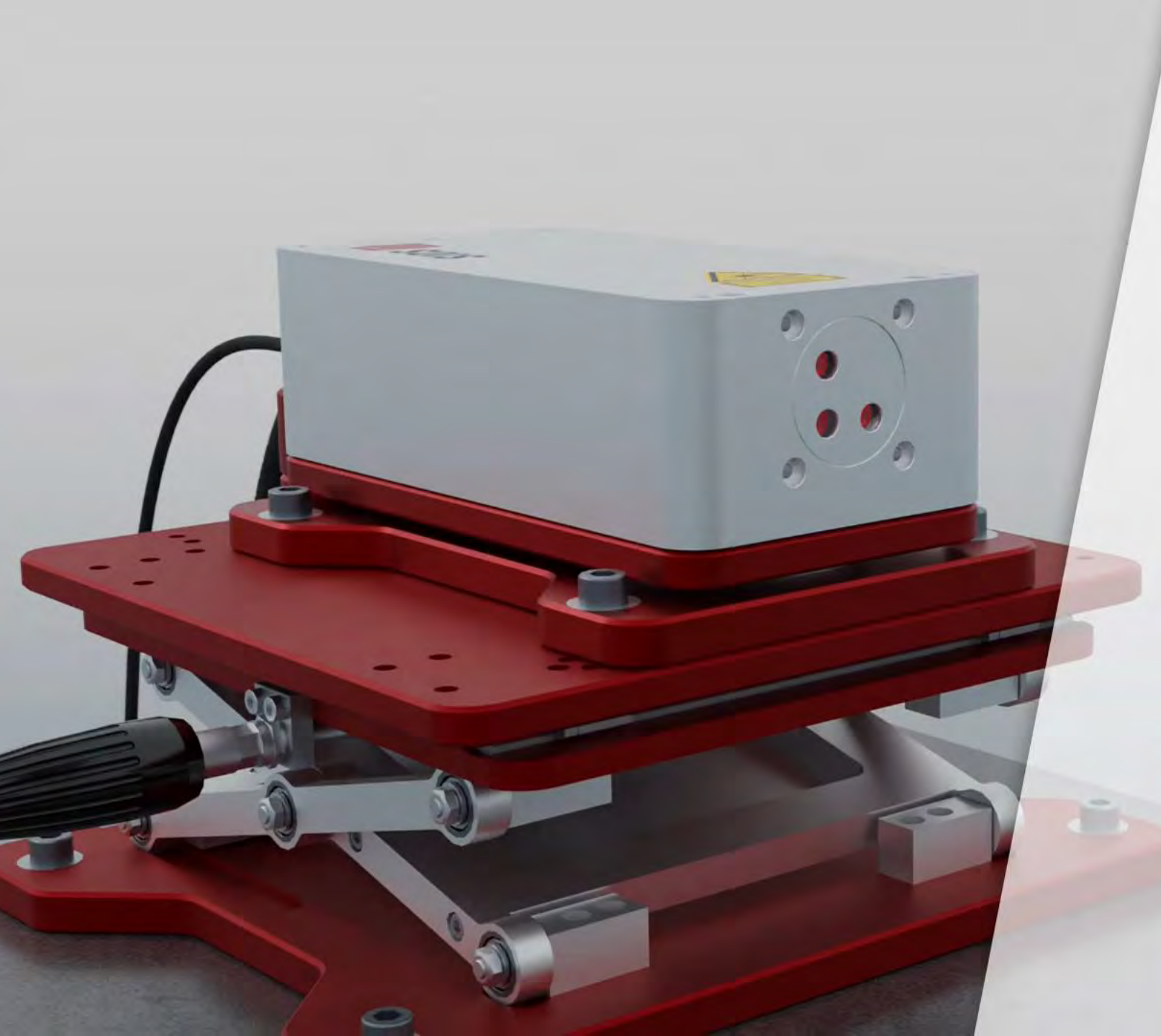
ISO & VDI compliant axis calibration
advanced data analysis ready export



Math

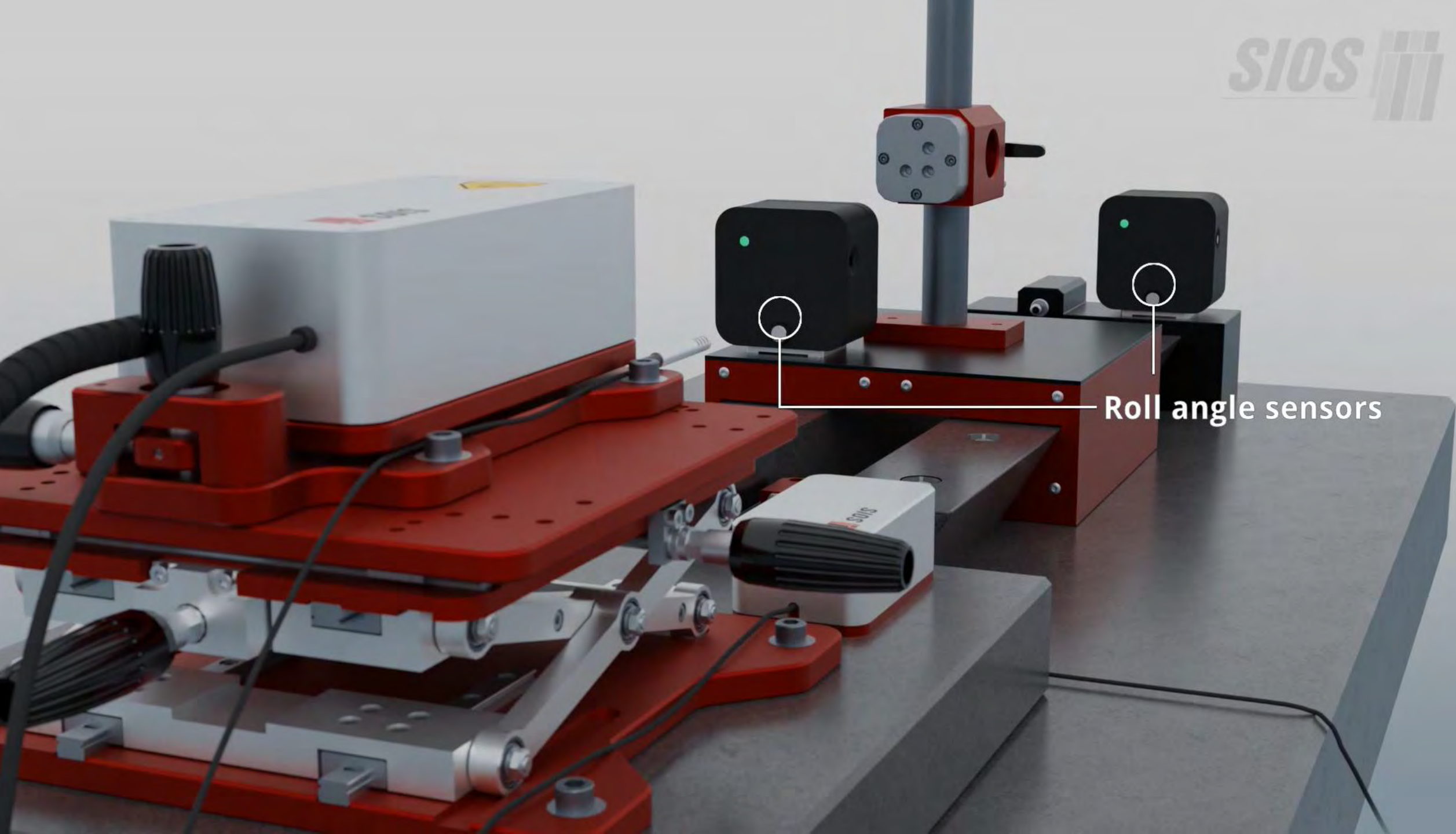
advanced data analysis e.g. in
Excel, Octave or MATLAB





Triple beam laser
interferometer

SP 5000 TR



Roll angle sensors

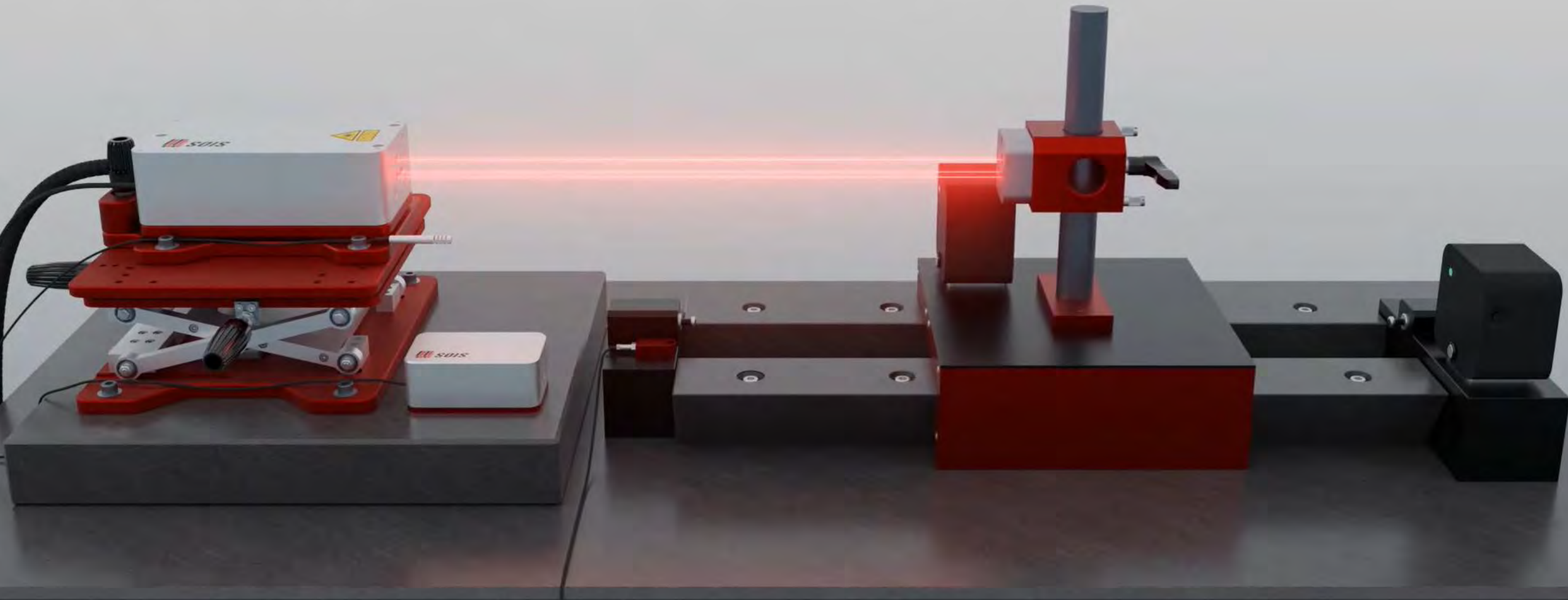
High-precision simultaneous
displacement and angle
measurement

XTX: + 55.26311 mm

XRY: + 4.50 μ rad

XRX: + 0.84 μ rad

XRZ: - 7.27 μ rad





Triple beam laser interferometer

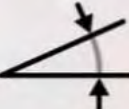
SP 5000 TR

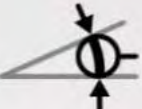
SIOS 

 up to **5 m** and more

 **20 μm**

 **0.1 $\mu\text{m}/\text{m}$**

 **$\pm 12.5^\circ$ with reflector**
 $\pm 1.5'$ with plane-mirror

 **0.002 arcsec**



SIOS Meßtechnik GmbH

THANK YOU VERY MUCH FOR YOUR ATTENTION!

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Managing Director



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