Measurement technology Group
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www.mt.uni-kassel.de

metubiq
MEASURE EVERYWHERE

Vibration-corrected coherence scanning interferometry

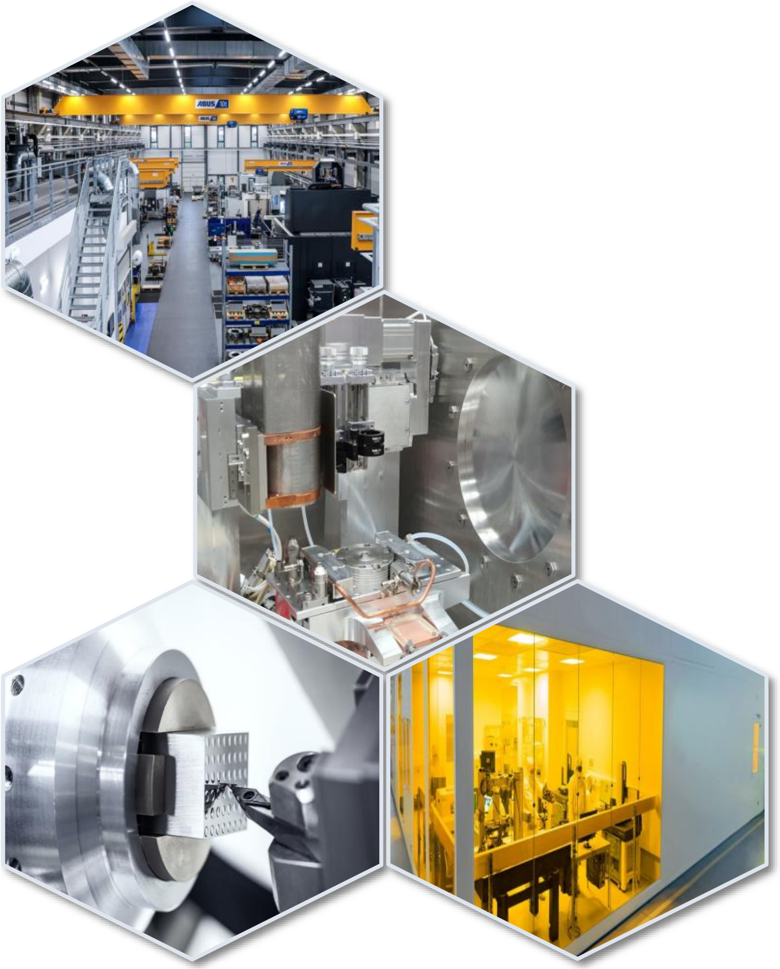
Hüseyin Serbes, Andre Stelter, Alexander Metzker und Peter Lehmann

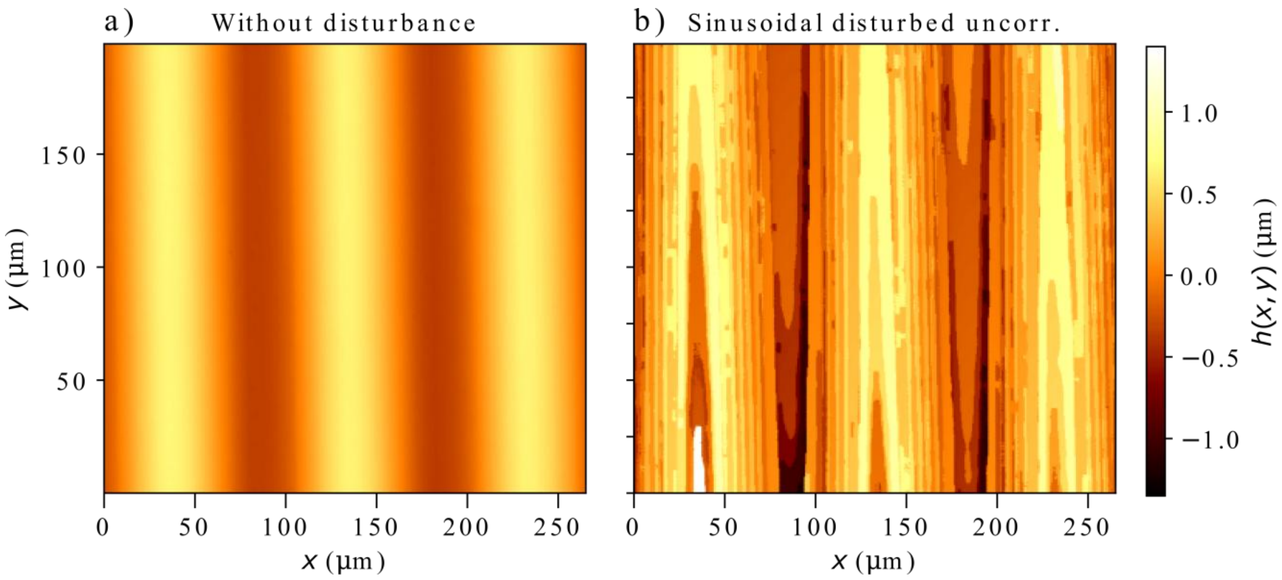
17. September 2025

3DMC 3D METROLOGY CONFERENCE

3D Metrology Conference
16. -18. September 2025, Aachen

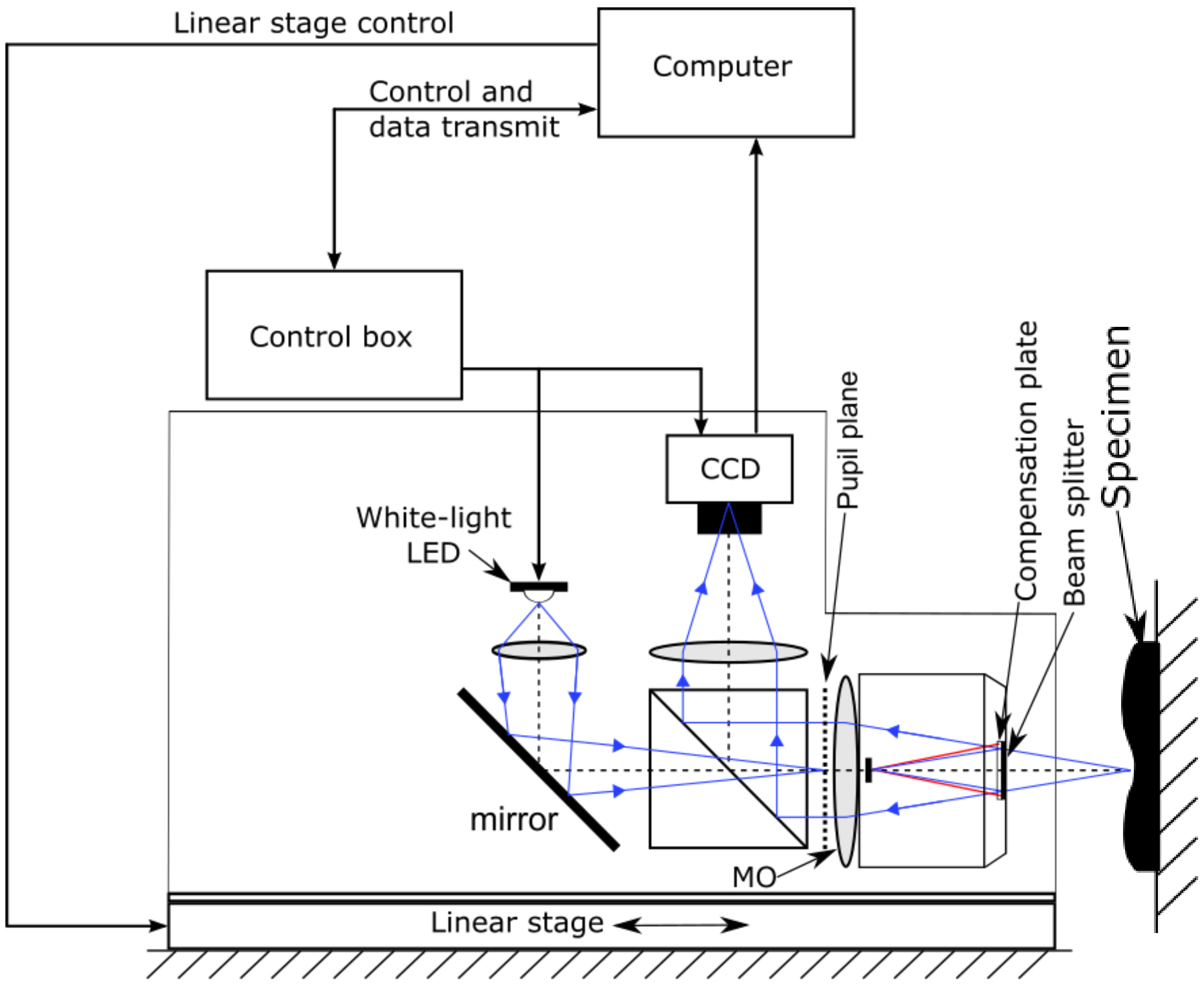
The integration of precision measurement technology into manufacturing processes is rendered unfeasible by vibrations.

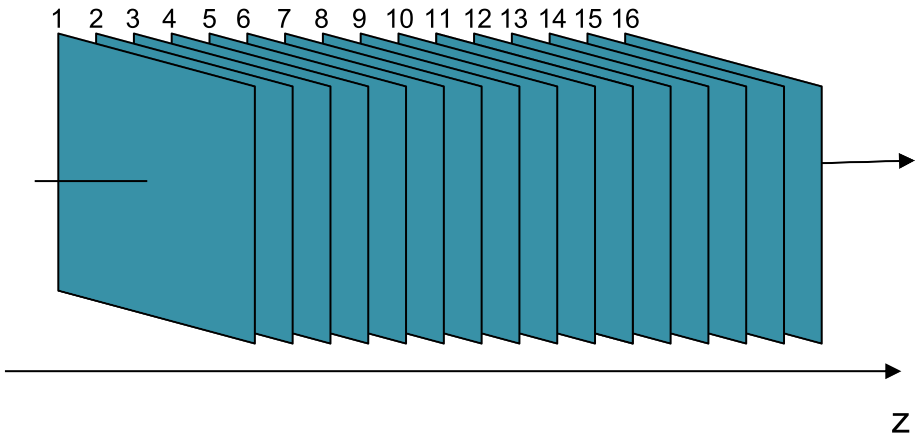


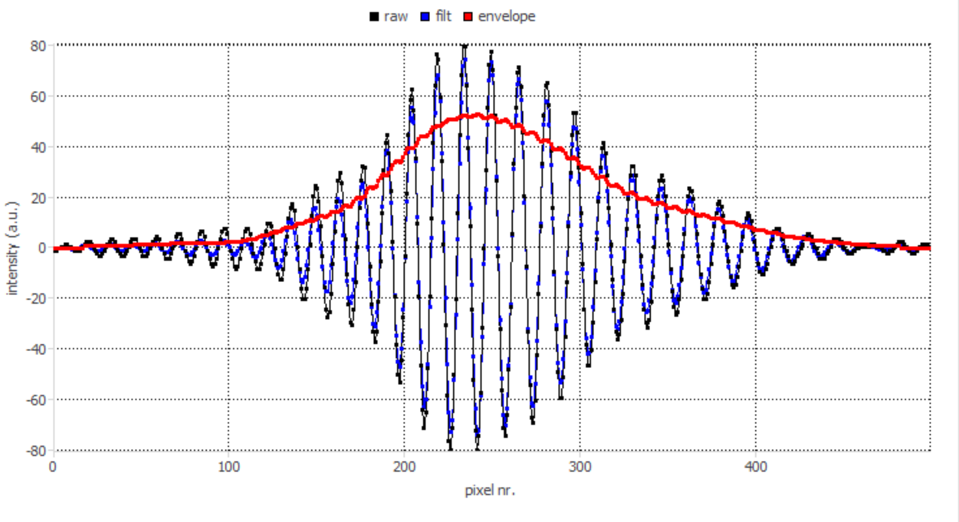


Serbes et al., *Mirau-Based CSI with Oscillating Reference Mirror for Vibration Compensation in In-Process Applications*. *Applied Sciences*. 2021; 11(20), 9642

CSI Basics

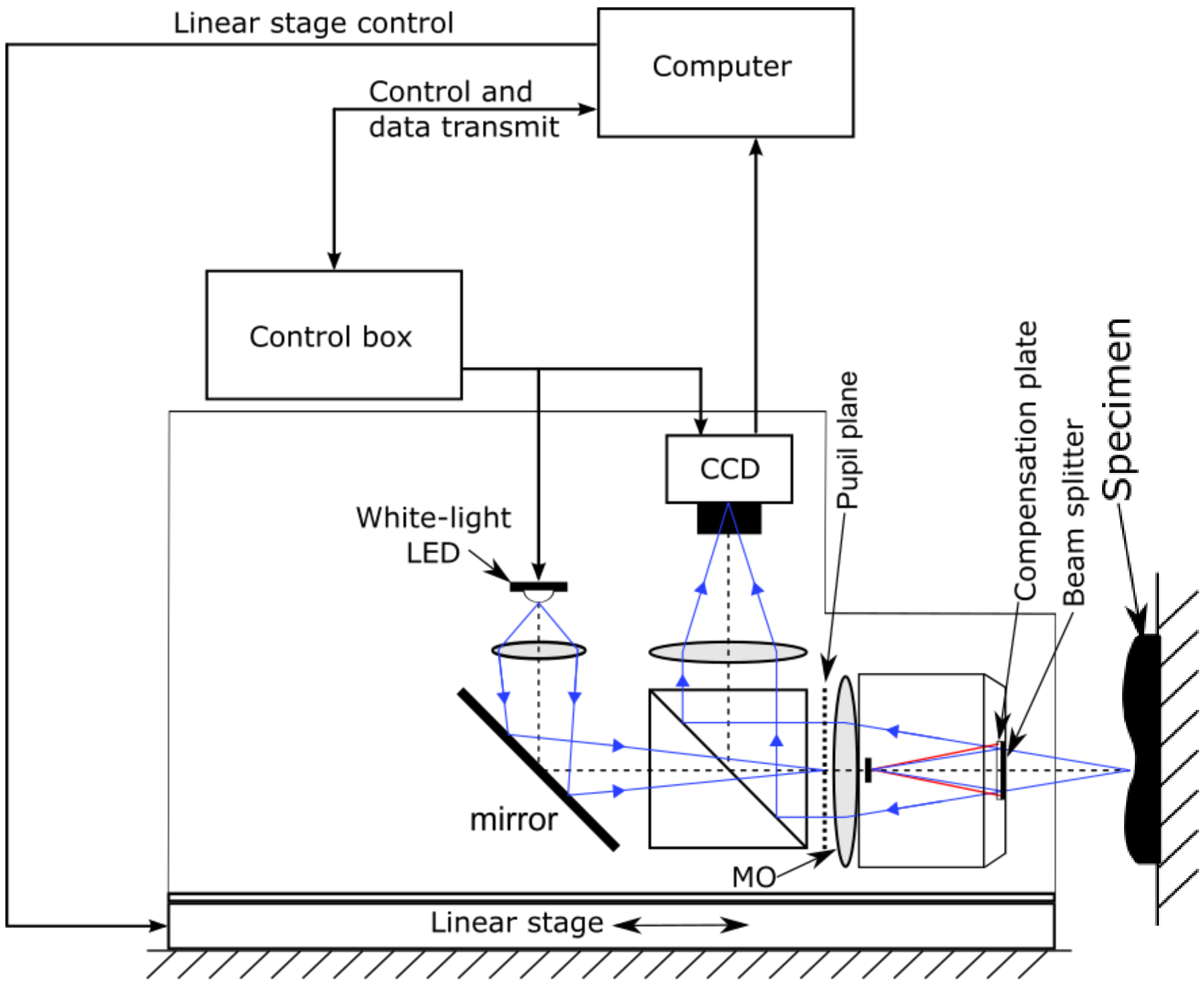


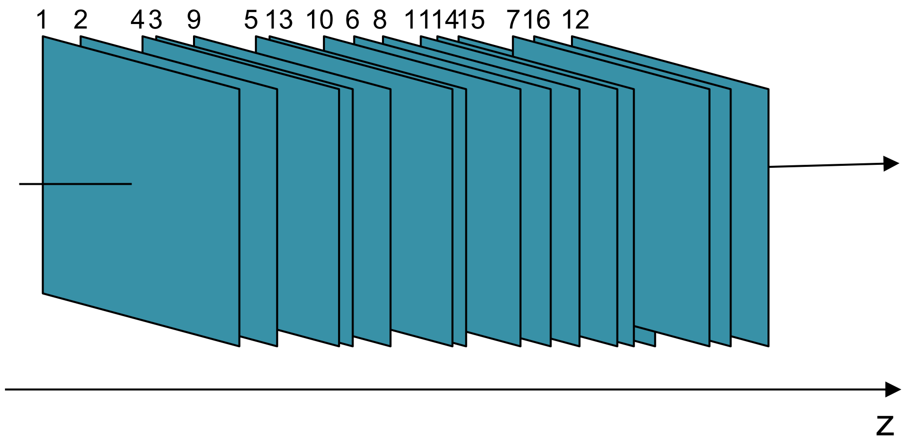


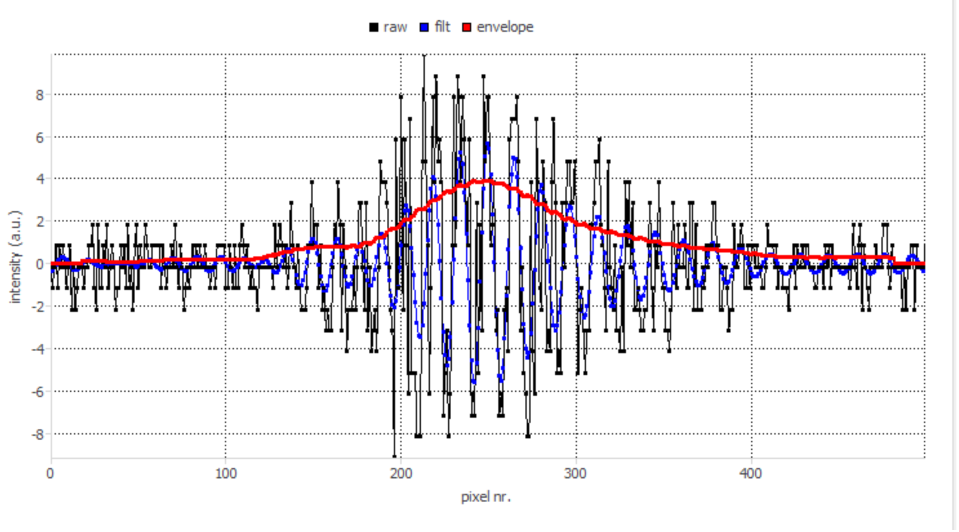


- Depth scan through continuous movement of the axial positioning axis and synchronous image capture
- Köhler illumination

CSI Basics


Linear stage control
Computer
Control and
data transmit
Control box
CCD
White-light
LED
mirror
MO
Pupil plane
Compensation plate
Beam splitter
Specimen
Linear stage


1 2 43 9 5 13 10 6 8 111415 716 12
z


raw
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intensity (a.u.)
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6
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-2
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-8
0
100
200
300
400

How to deal with vibration

software

high speed

active compensation

passive compensation

sensitive ⟷ **immune**

single shot

Unambiguity and measuring range

How WE deal with vibrations – passive compensation

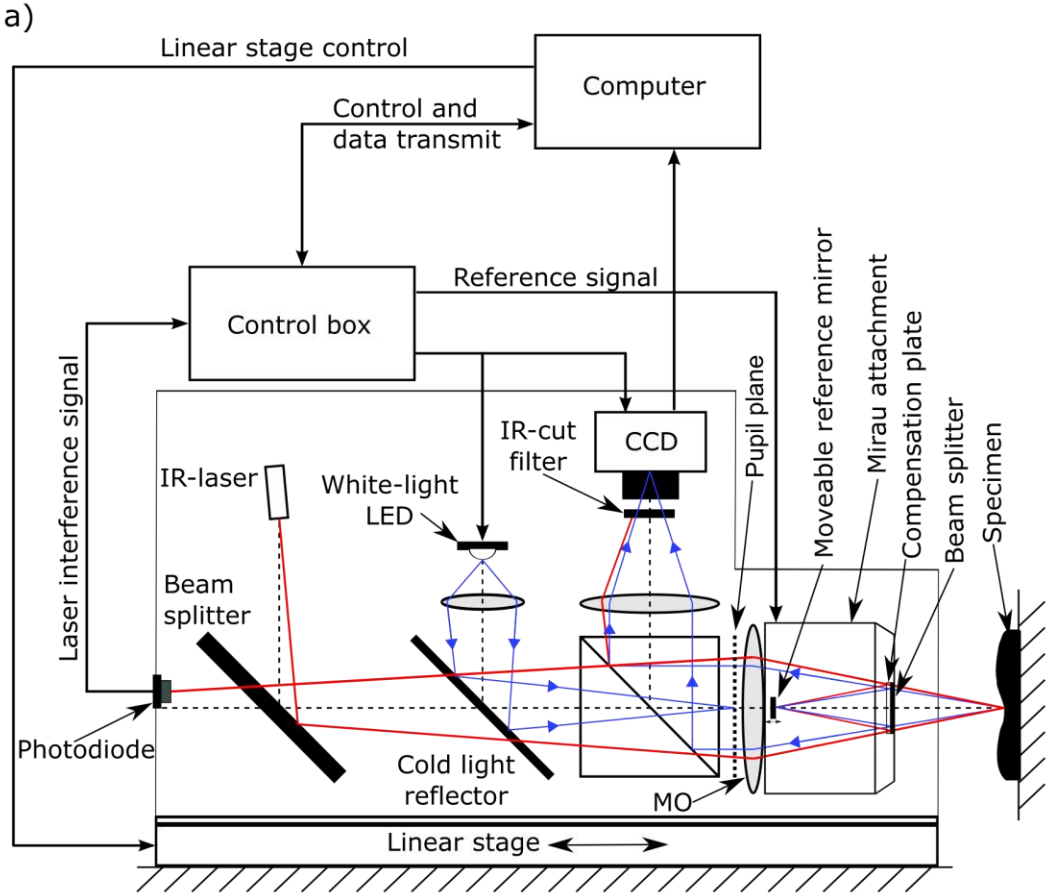
1. Synchronous measurment

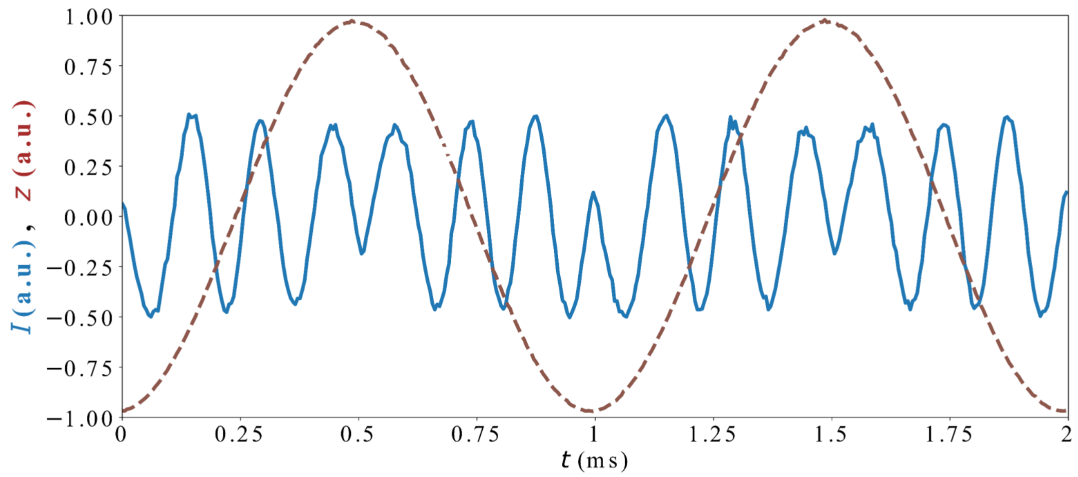
2. Vibration determination

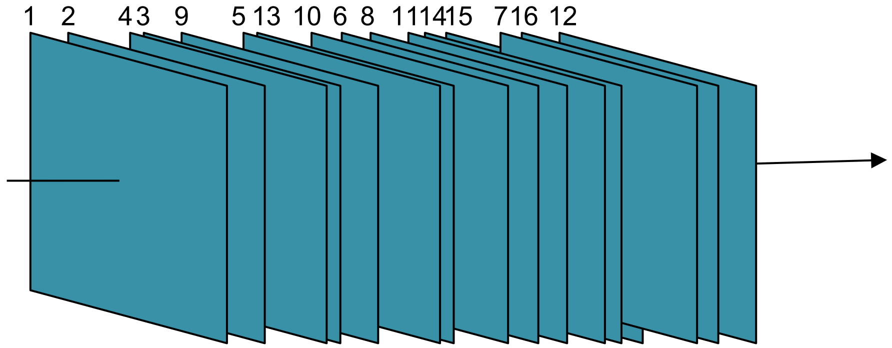
3. Vibration correction

4. Signal processing CSI

Sensor configuration of vibration corrected CSI





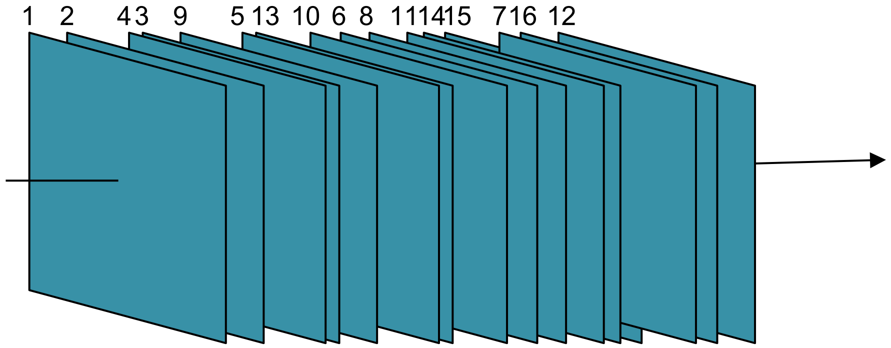


- CSI share the optical path with the IDS
- Köhler illumination
- Optical path length modulation (OPLM) achieved by a sinusoidally deflected reference mirror
- CSI and IDS measure synchronously

How WE deal with vibrations – passive compensation

1. Synchronous measurment

2. Vibration determination



3. Vibration correction

4. Signal processing CSI

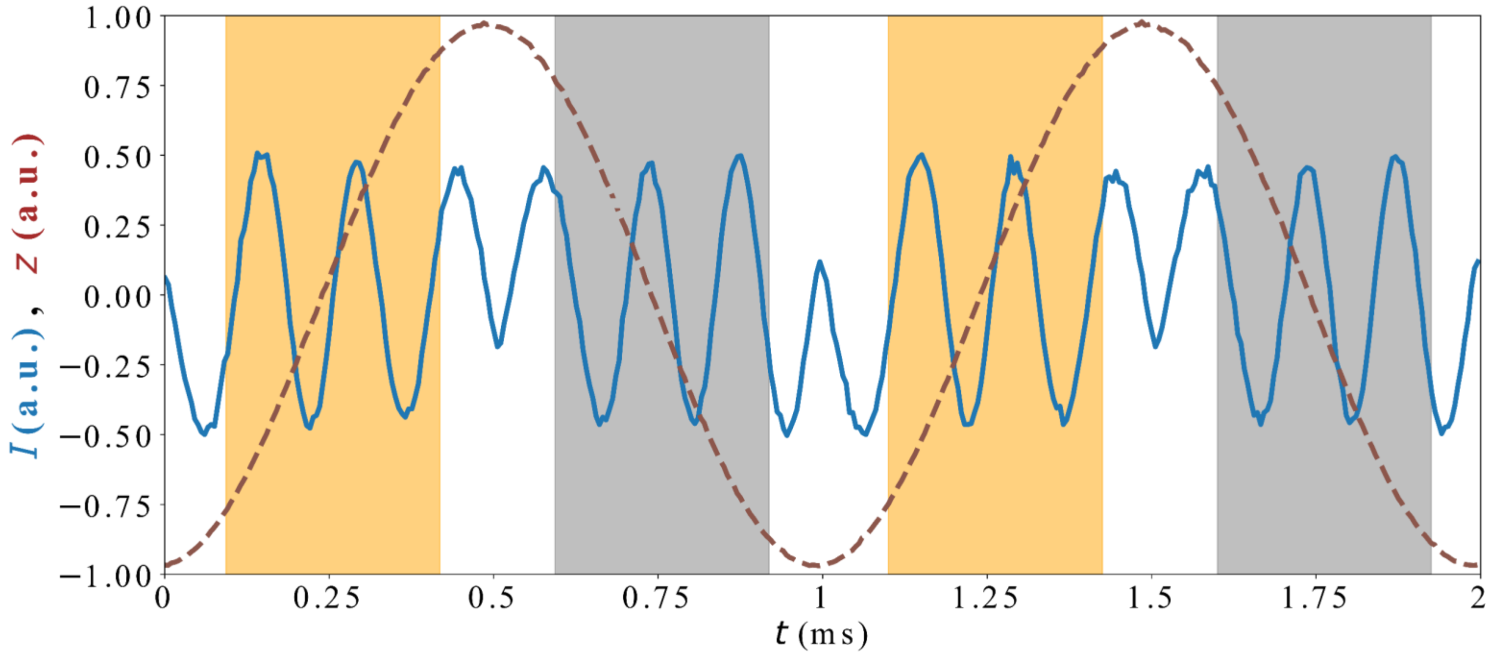
IDS - signal formation and processing

Interference equation: (1) $$I_{\mathrm{int}} = I_{\mathrm{obj}} + I_{\mathrm{ref}} + 2\sqrt{I_{\mathrm{obj}} I_{\mathrm{ref}}} \cos\left(\underbrace{\frac{4\pi}{\lambda_{\mathrm{LD}}}\left[\hat{z}_a \cos(2\pi f_a t) - \Delta z_{\mathrm{m}}\right]}_{\Phi_{\mathrm{IDS}}} \right)$$

Assuming linear movement: (2) $$\Phi_{\mathrm{IDS}} \approx \frac{4\pi}{\lambda_{\mathrm{LD}}}\left[\hat{z}_a 2\pi f_a t - \Delta z_{\mathrm{m}}\right]$$ (3) $$f_{\mathrm{e}} = \frac{4\pi}{\lambda_{\mathrm{LD}}}\hat{z}_a f_a$$

Single-point-DFT (Lock-in method):

(4) $$\Phi_{\mathrm{IDS}} = \arg\left(\sum_{n=0}^{N_{\mathrm{s}}-1} I(n) W(n) \exp\left(-\mathrm{i}2\pi n \frac{f_{\mathrm{e}}}{f_{\mathrm{s}}} \right) \right)$$

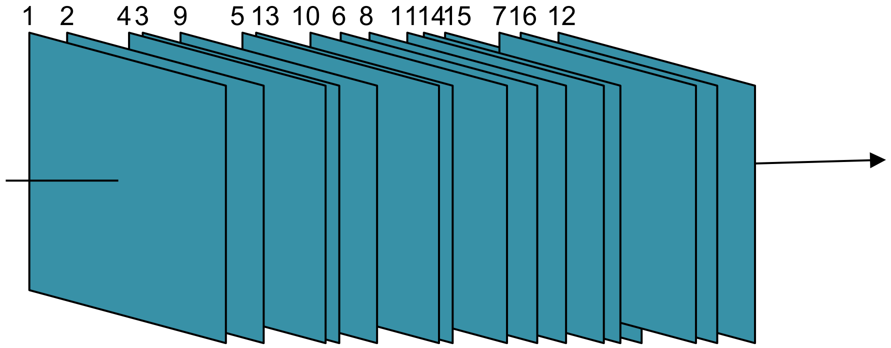


Distance value Δz_m is given by

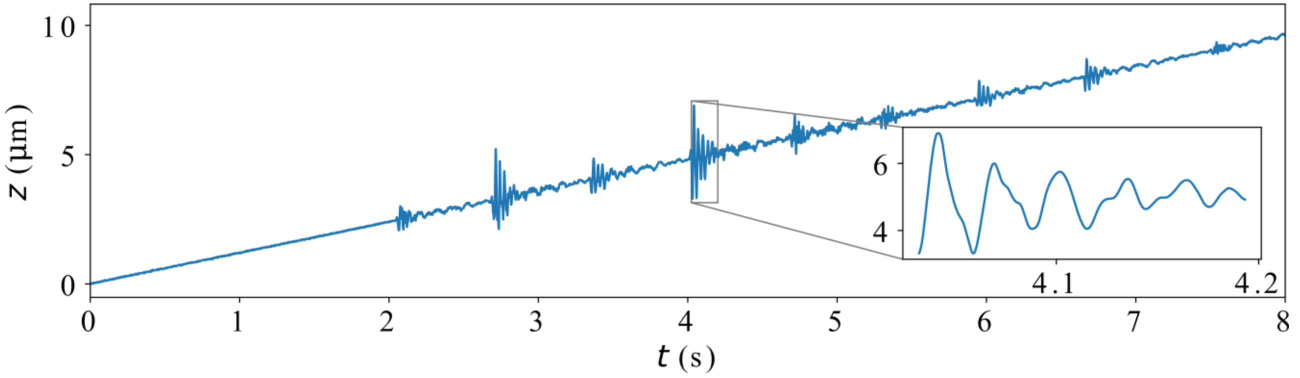
(5) $$\Delta z_{\mathrm{m}} = \frac{\lambda_{\mathrm{LD}}}{4\pi}\Delta\Phi_{\mathrm{IDS}}$$

How WE deal with vibrations – passive compensation

1. Synchronous measurment



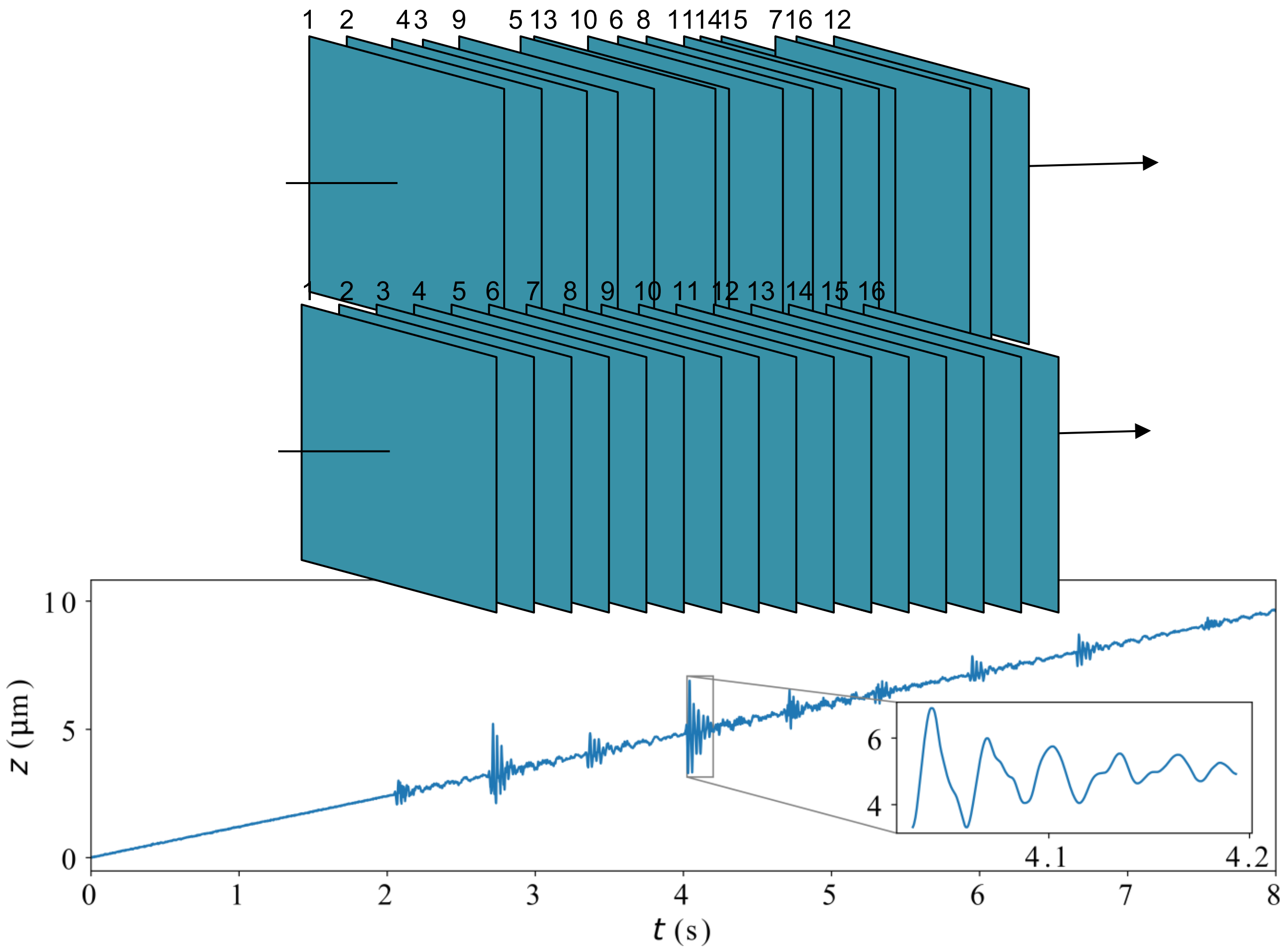
2. Vibration determination



3. Vibration correction

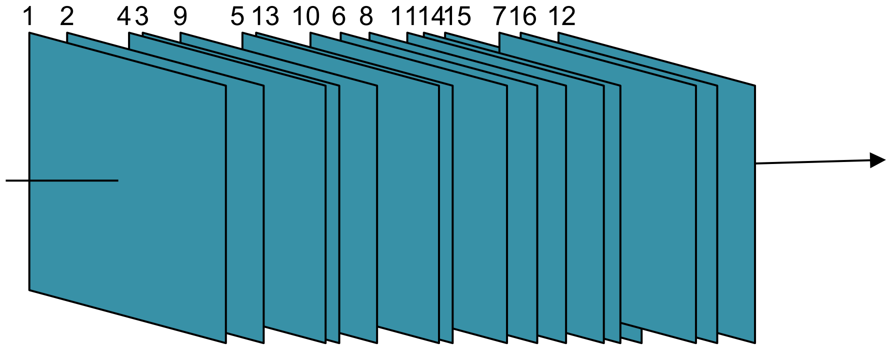
4. Signal processing CSI

vibration correction



How WE deal with vibrations – passive compensation

1. Synchronous measurment



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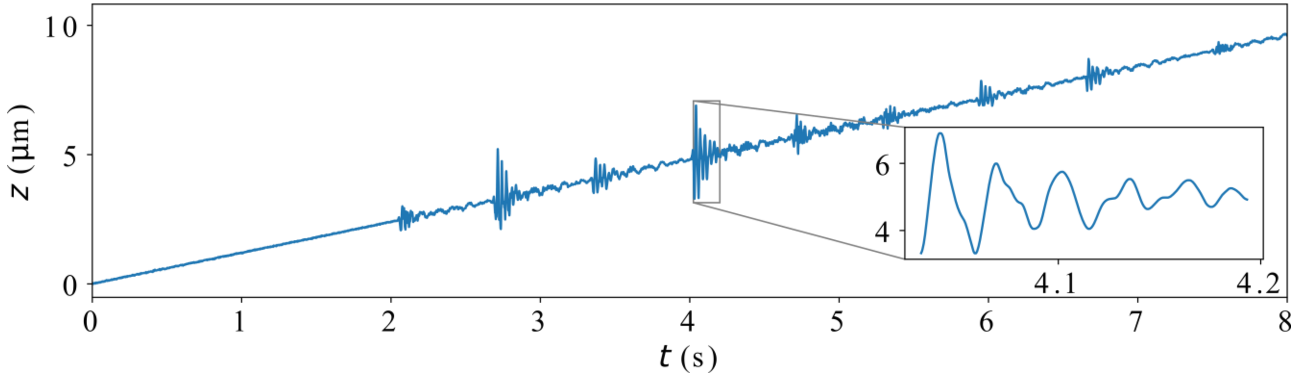
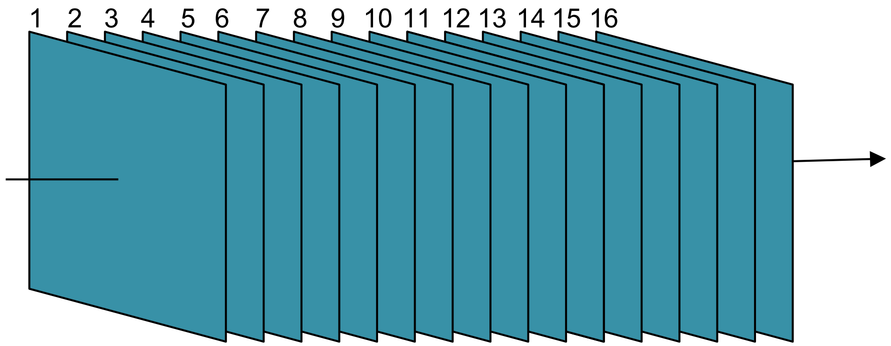
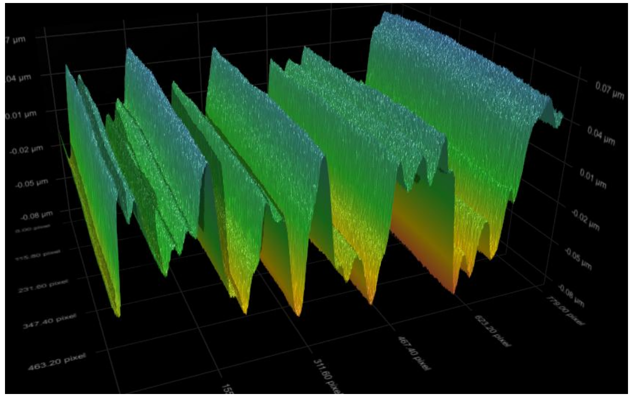


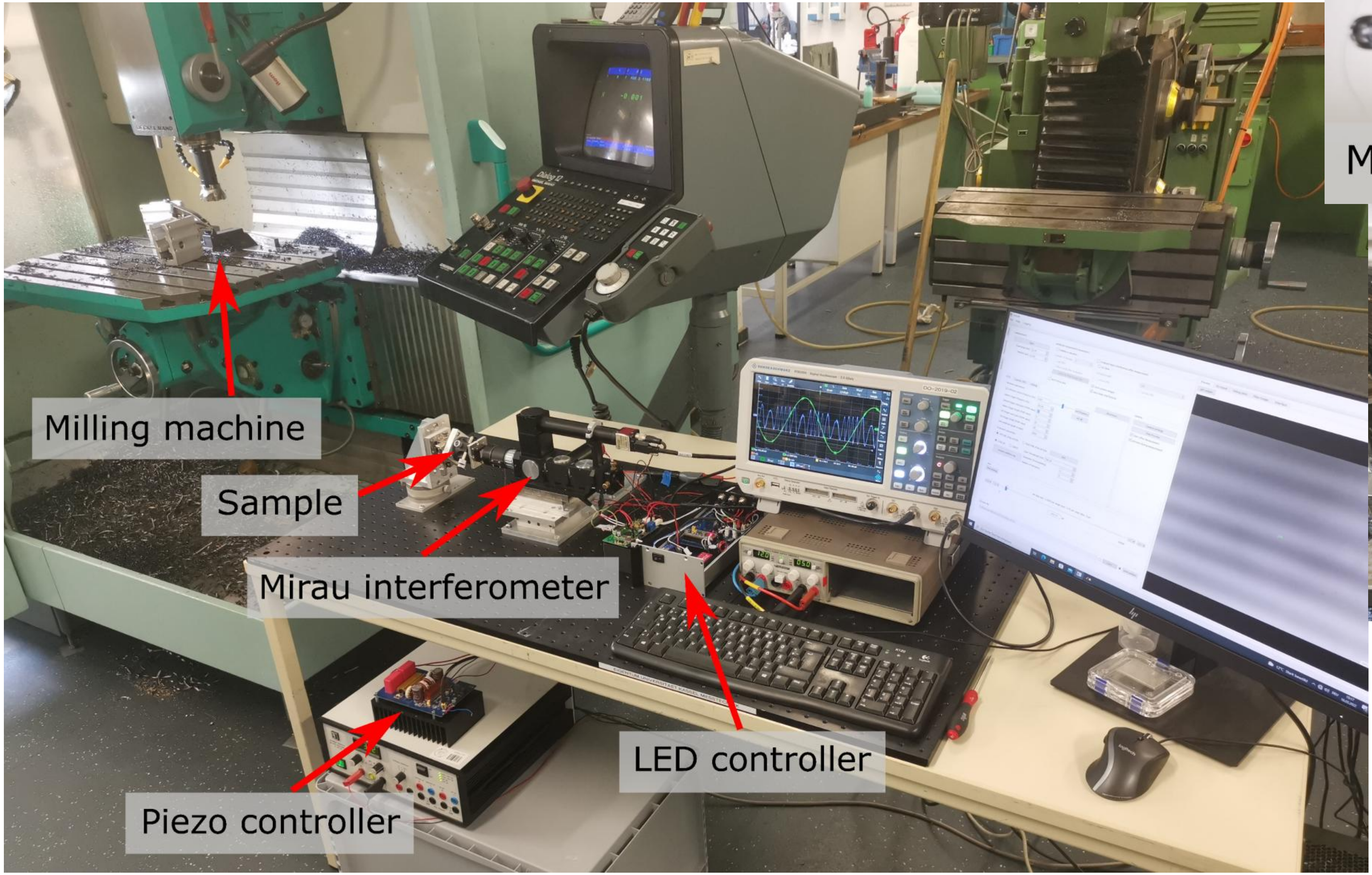
3. Vibration correction



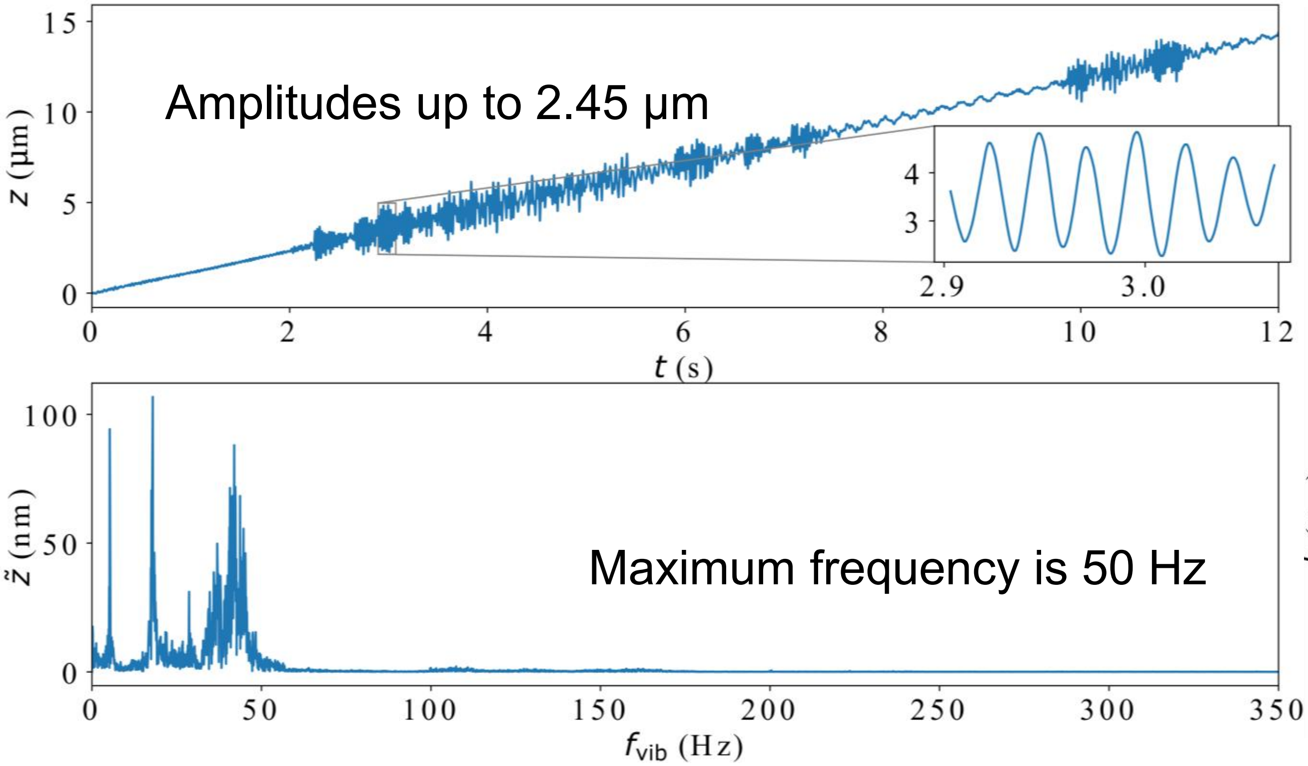
4. Signal processing CSI



Close-to-machine CSI measurement

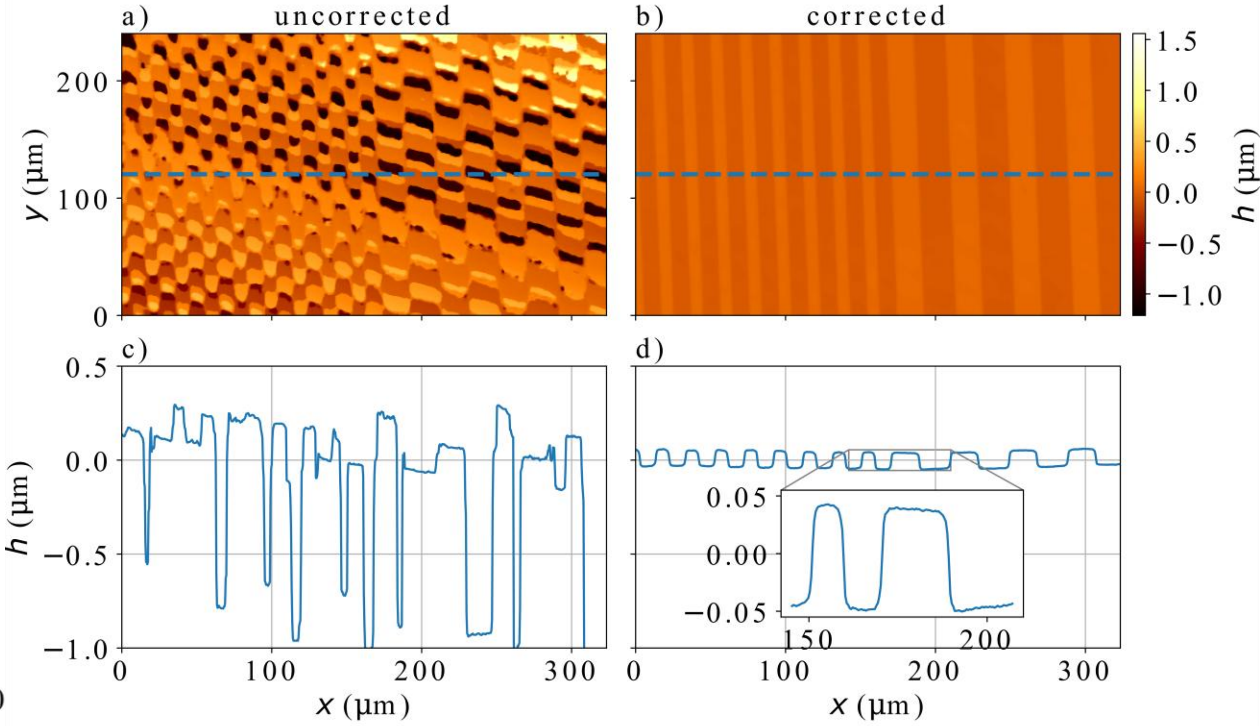


Measurement results – rectangular grating

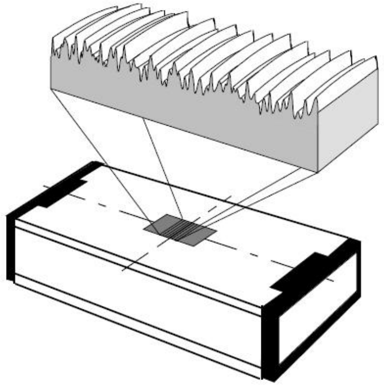


Simetrics RS-M standard

- Nominal height: 90 nm
- Period length: 20 µm and 40 µm



Roughness measurement – repeatibility



roughness standard
Halle KNT4070/03

S_q **(root mean square, rms)**

$$S_q = \sqrt{\frac{1}{MN}\sum_{i=0}^{M-1}\sum_{j=0}^{N-1} h(x_i, y_i)^2}$$

σ_{S_q} **(Standard deviation of** S_q **from** n **successive measurement results)**

$$\sigma_{S_q} = \sqrt{\frac{1}{n-1}\sum_{i=0}^{n-1}\left[S_{q,i} - \overline{S_q}\right]^2}$$

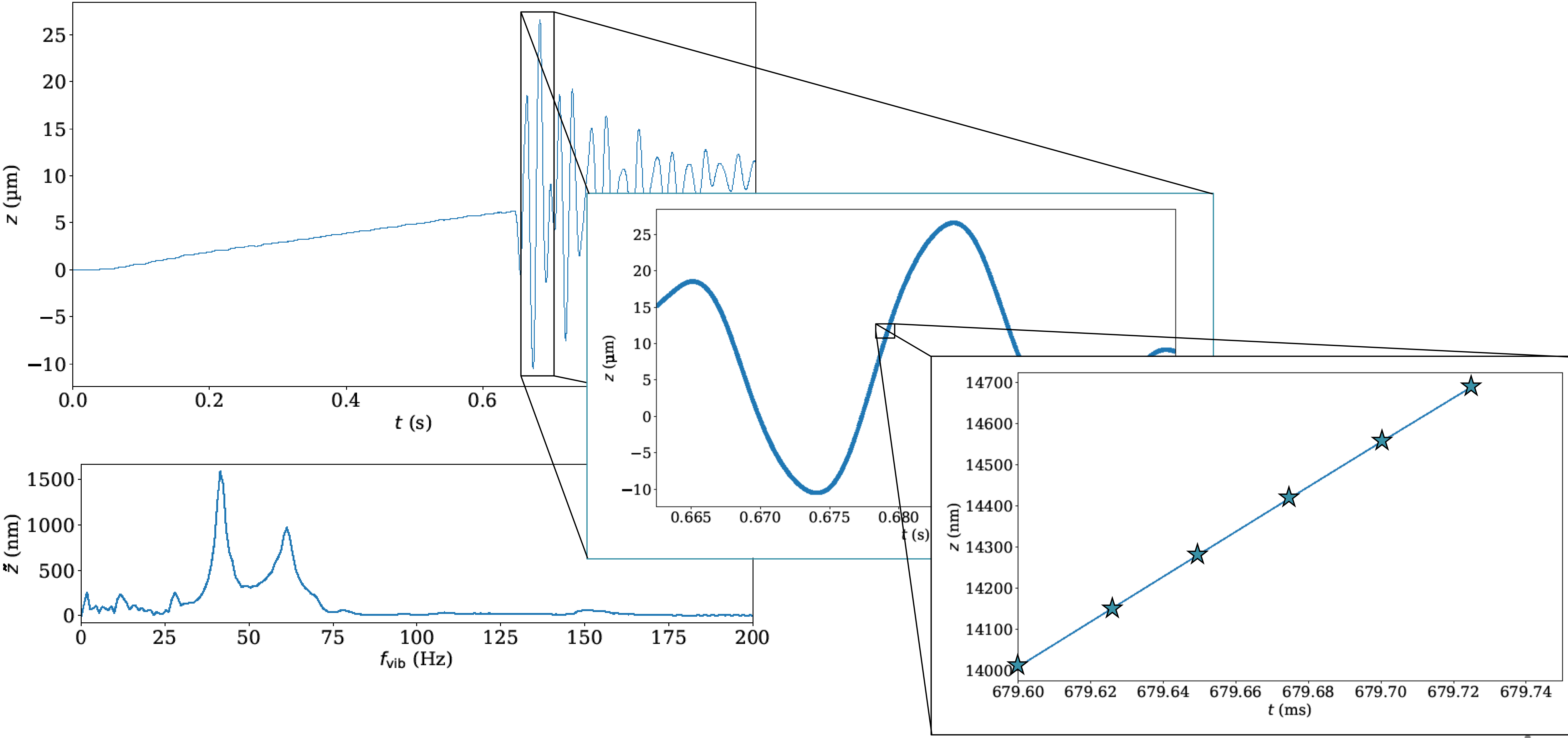
Quelle: HALLE Präzisions-Kalibriernormale GmbH

Measurement results – repeatability

Frequency in Hz	Amplitude in nm	$\overline{S_q}$ in nm	σ_{S_q} in nm
Optimal conditions, w/o correction		34.618	0.084
Optimal conditions, with correction		34.531	0.071
10	500	34.716	0.016
18	500	34.534	0.012
67.5	500	34.592	0.090
135	260	34.699	0.041
Pulse source (shocks)		34.555	0.109

The compensation principle is independent of the vibration frequency

Results – pulse source (multifrequent, transient vibration)



Summary and outlook

- All vibrations are measured correctly by the IDS with high temporal and axial resolution.
- The compensation principle is independent of the vibration parameters.
- The measuring principle is immune to environmental vibrations.
- CSI with vibration compensation can measure in machine-integrated environments.

Das Förderprogramm „Existenzgründungen aus der Wissenschaft (EXIST)“ mit seinen Projekten wird durch das Bundesministerium für Wirtschaft und Klimaschutz und die Europäische Union über den Europäischen Sozialfonds Plus (ESF Plus) gefördert.

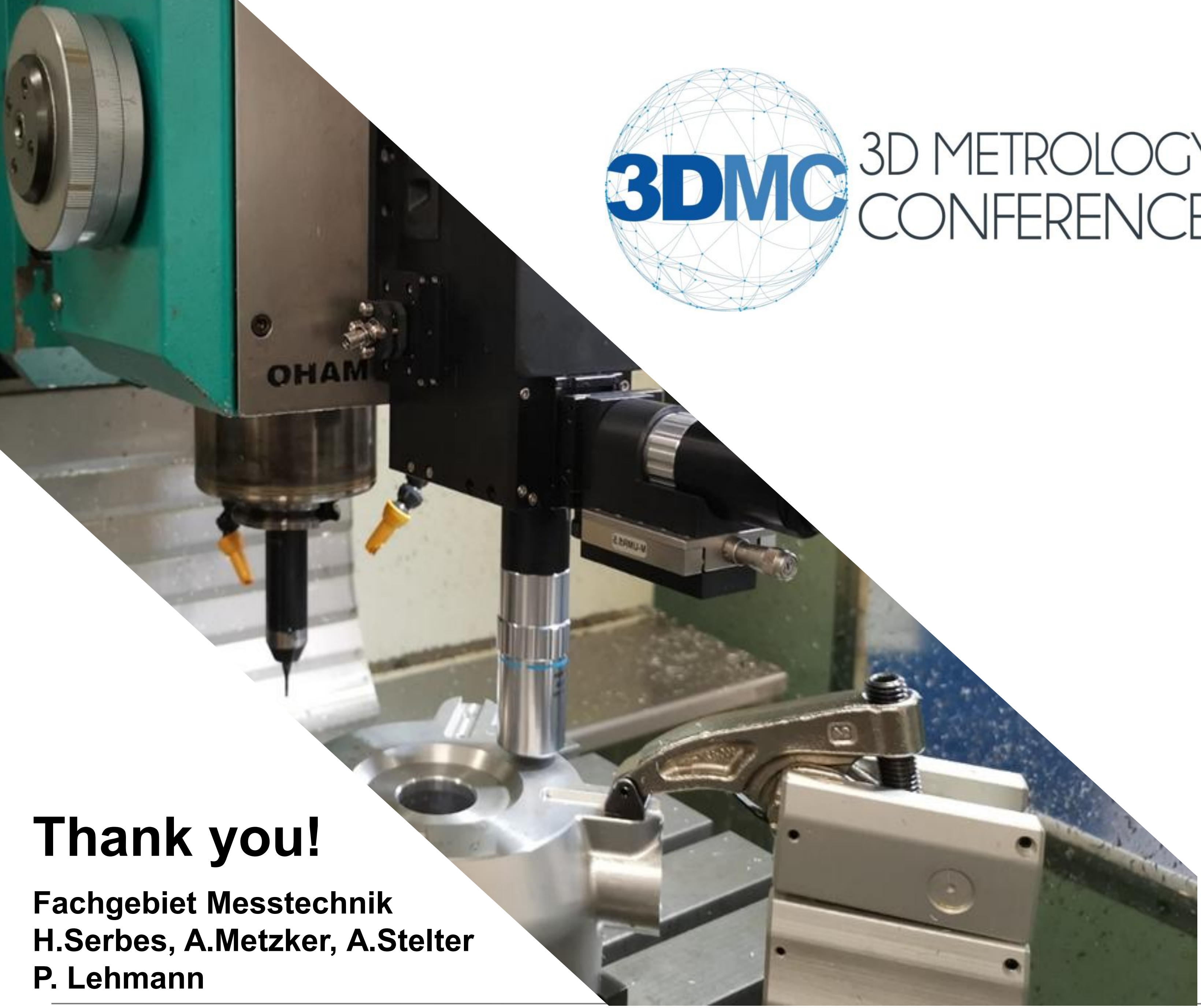
Gefördert durch:

Bundesministerium für Wirtschaft und Klimaschutz

Kofinanziert von der Europäischen Union

eXIST Existenzgründungen aus der Wissenschaft

aufgrund eines Beschlusses des Deutschen Bundestages



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Thank you!

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