



Sensor Integrating Machine Elements Congress

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Functional Reliability and Data Quality of the Load-Sensitive Splined Shaft under Realistic Operating Conditions

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A. Lohrengel

Functional Reliability and Data Quality of the Load-Sensitive Splined Shaft under Realistic Operating Conditions

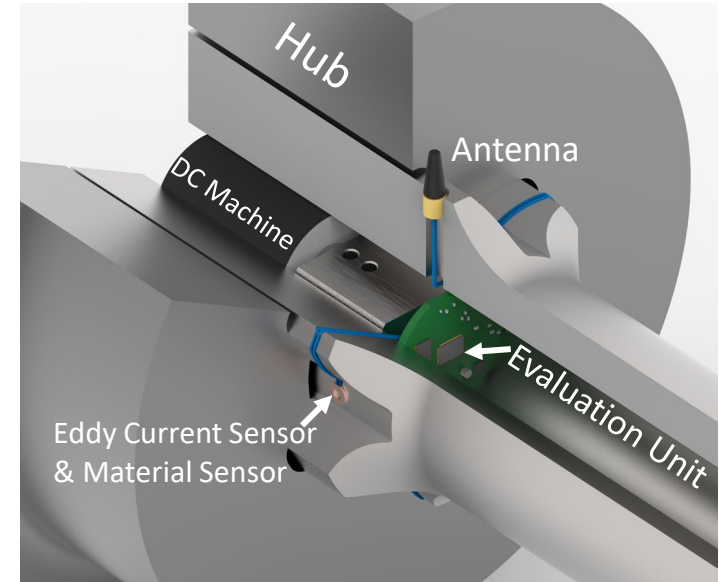


- Project Overview
- Sensor Principle – Material Sensor & Eddy Current Sensor
- Processing Unit
- Energy Harvesting
- Test Bench Setup
- Temperature Compensation
- Test Results under Different Operating Conditions
- Transfer Project – Industry Partners Wanted

- Material sensor in combination with eddy current testing
- Advantages:
 - Overload warning
 - Reduction of maintenance
 - Integrated power supply
 - Wireless data transmission
 - Interchangeability with conventional machine elements

1st FP:

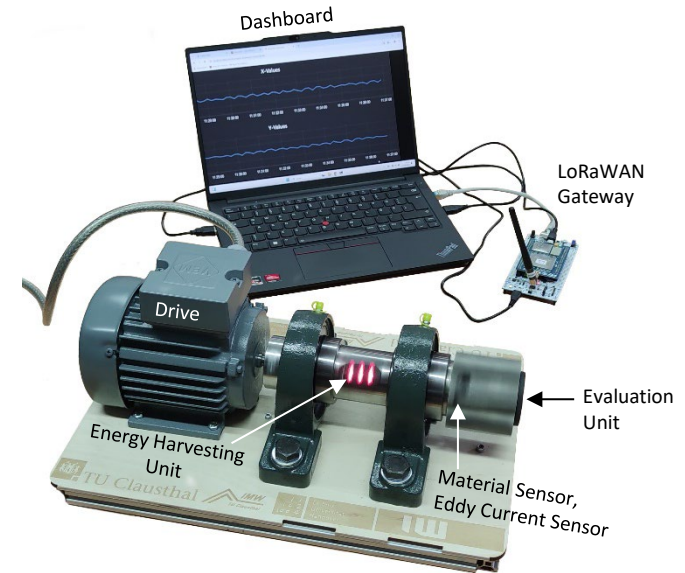
- Transfer of material sensor into splined shaft, development of individual modules



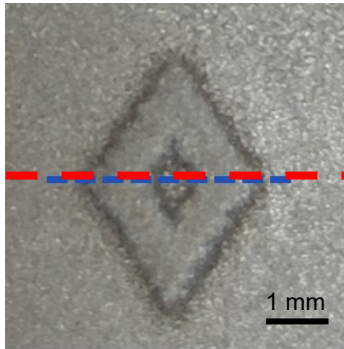
Quanz, M.; Lohrengel, A.; Gansel, R.; Barton, S. (2024): Zahnwelle mit konditionierbarem Lastsensor und integriertem Energy Harvesting. In: 10. VDI-Fachtagung Wellen und Welle-Nabe-Verbindungen 2024. VDI Verlag GmbH, Düsseldorf, pp 193–200

2nd FP:

- Robustness: Common environmental conditions in gearboxes
 - Temperatures up to 90 °C
 - Contact with oil
 - Investigation of total system reliability
- Autonomy: Power supply via energy harvesting & wireless data transmission (LoRaWAN)
- **Objective:** No reduction in the service life of the SiME due to electronic components



- Integrated material sensor in combination with eddy current testing
 - Sensor principle: Transformation of paramagnetic austenite into ferromagnetic martensite
- Advantage: Storage of experienced loads through microstructure change, no continuous readout required compared to strain gauges
- Material: Stainless steel 1.4305 (AISI 303)



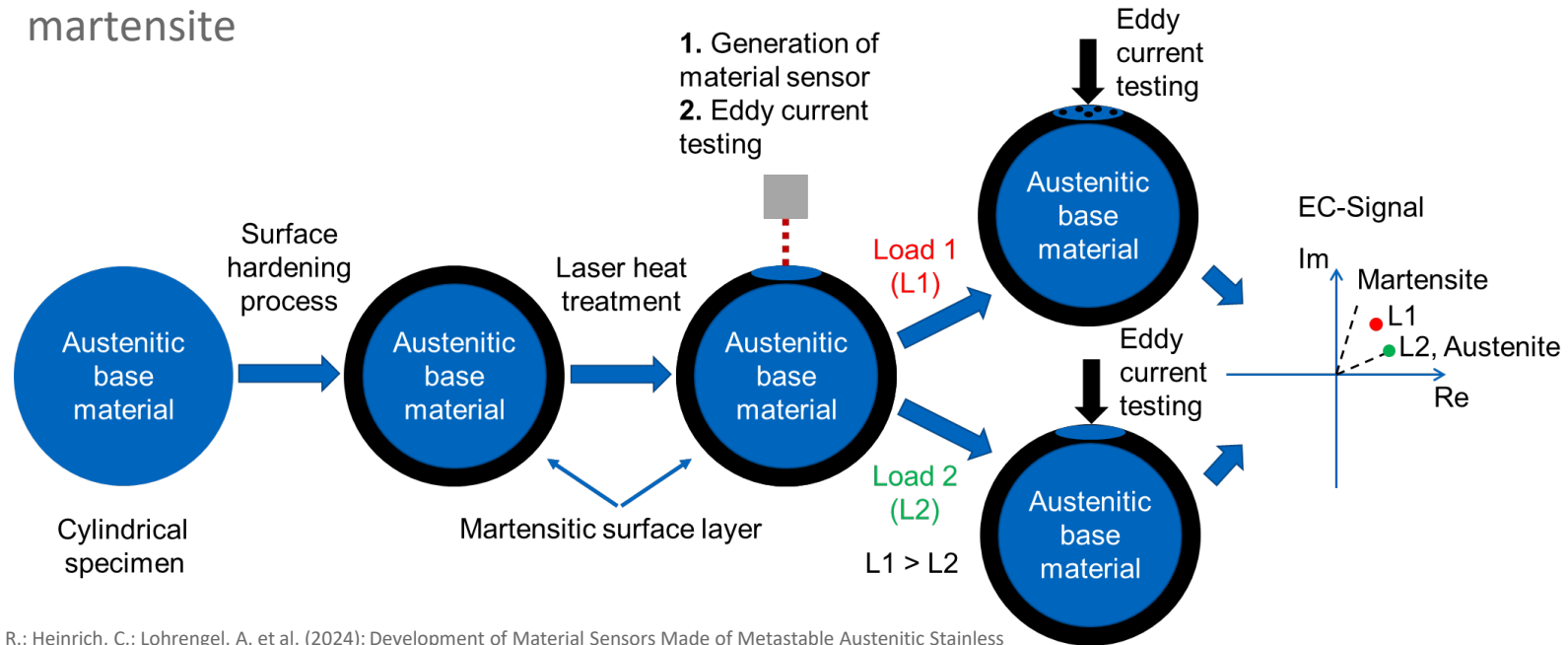
Sensor Shape: Rhombus



Cross-section through an exemplary material sensor with a simplified representation of eddy current testing

According to: Gansel, R.: Lastsensitive Werkstoffsensoren zur prädiktiven Bewertung der Bauteilintegrität, Dissertation, Hannover, Deutschland, 2025.

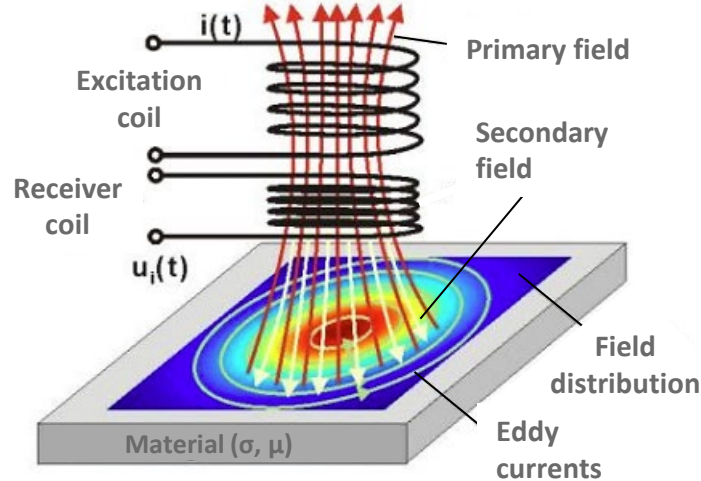
- Integrated material sensor in combination with eddy current testing
 - Sensor principle: Transformation of paramagnetic austenite into ferromagnetic martensite



Gansel, R.; Heinrich, C.; Lohrengel, A. et al. (2024): Development of Material Sensors Made of Metastable Austenitic Stainless Steel for Load Monitoring. J. of Materi Eng and Perform 33, 13570–13582. <https://doi.org/10.1007/s11665-024-09910-9>

Sensor Principle – Eddy Current Sensor

- AC voltage generates a primary field
- Primary field induces eddy currents in the material
- Eddy currents generate a secondary field, dependent on material characteristics (σ , μ)
- Secondary field superimposes on primary field, sensed by receiver coil
- Austenite to martensite transformation causes extreme change in μ , detected via secondary field



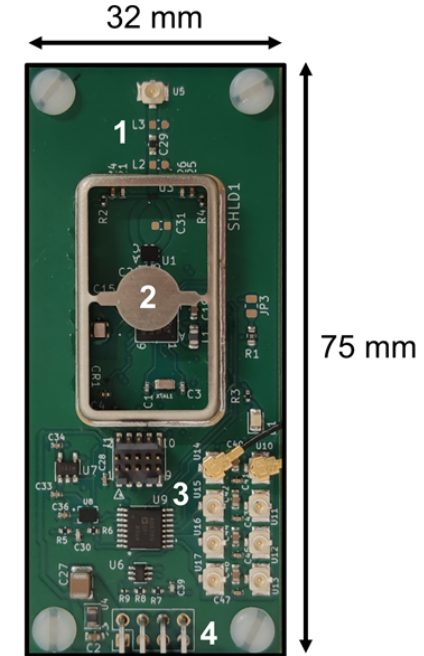
According to: Bernard, M.; Reimche, W.; Bach, F.-W. (2007): Zerstörungsfreie Bestimmung der Randzoneneigenschaften hoch beanspruchter Maschinenbauteile, e-Journal of Non-destructive Testing, 12, pp 1–11.



Processing unit

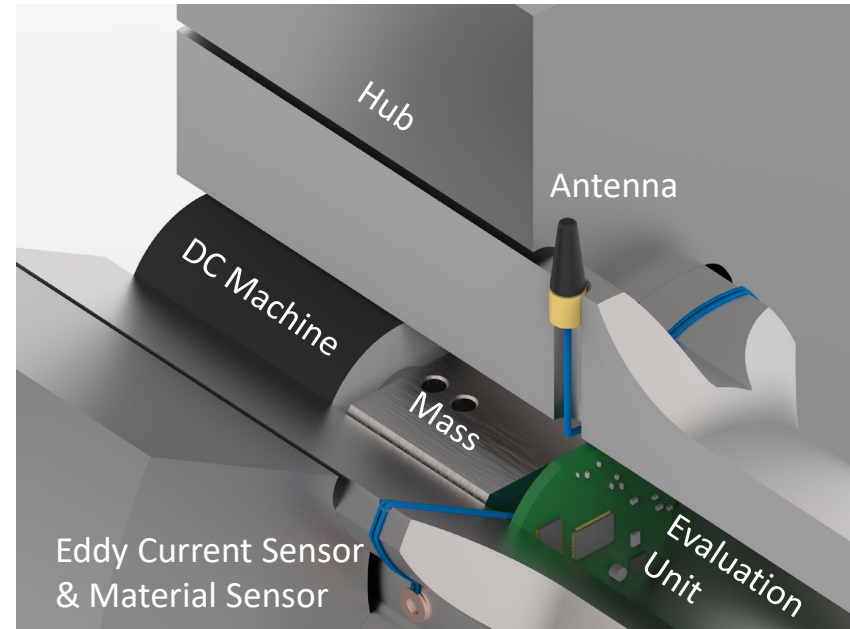
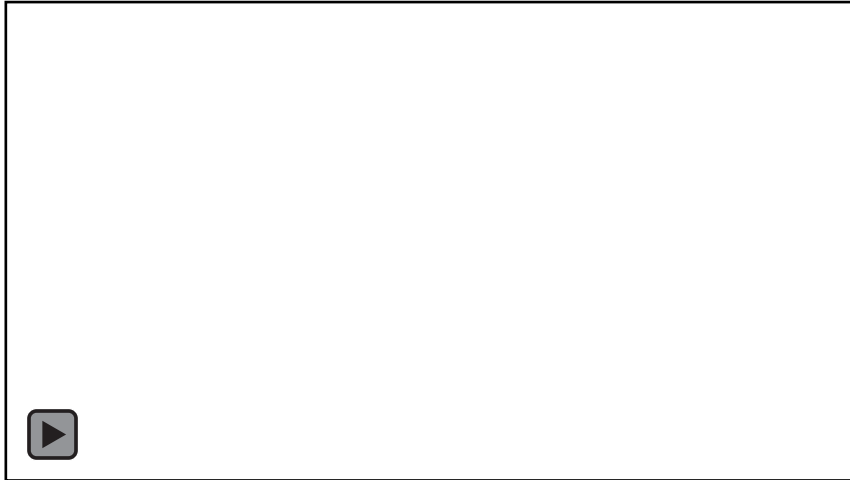
- Signal acquisition and processing of **up to four eddy current sensors** for material characterization
- Communication protocol: **LoRaWAN**
 - Transmission of measurement data
 - Wireless update of the evaluation algorithm
- Energy-efficient operation:
 - **No continuous measurement operation required**
 - Power consumption depending on the number of measurements taken
 - E.g. 1 measurement / 150 s $\approx$ 1.34 mW (1 eddy current sensor)
- Operation of additional sensors possible, e.g. temperature
- **Integrated temperature compensation**

Gansel, R., Zwoch, S., Hartmann, T., Quanz, M., Lohrengel, A., Maier, H., & Barton, S. (2025). Entwicklung eines energieautarken Wirbelstromprüfsystems für die Zustandsüberwachung von Bauteilen und Bauwerken. DGZfP-Jahrestagung 2025, 26.–28. Mai 2025 in Berlin. <https://doi.org/10.58286/31243>



1. Radiofrequency signal path
2. Microcontroller unit
3. Analog circuitry
4. Power supply

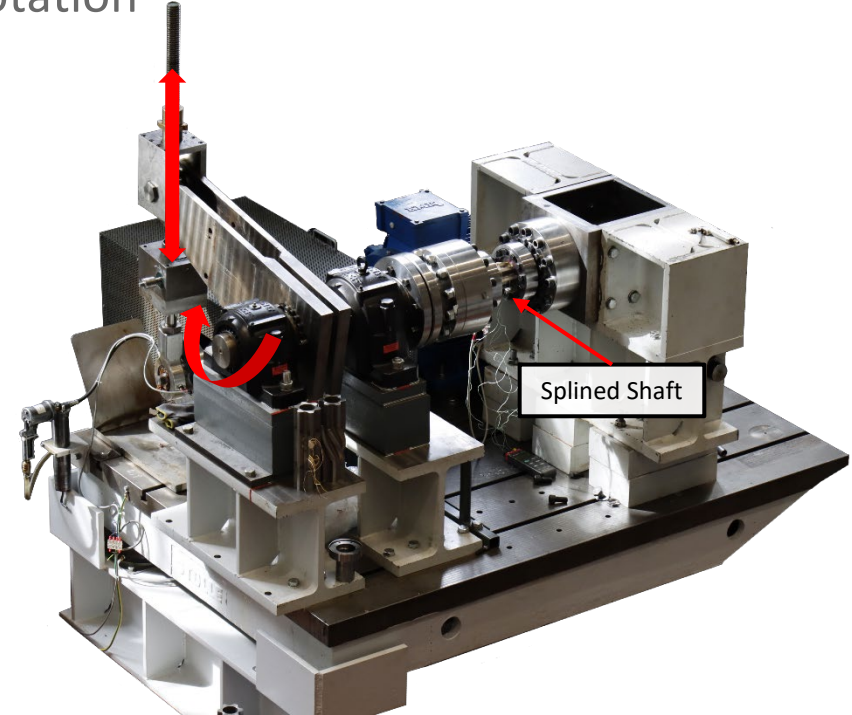
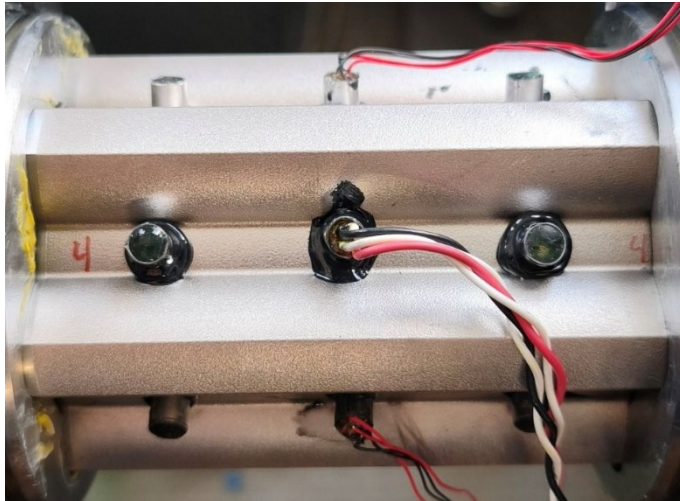
- Necessary power generation in constant operating states



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Test Bench Setup for Cyclic Load Tests

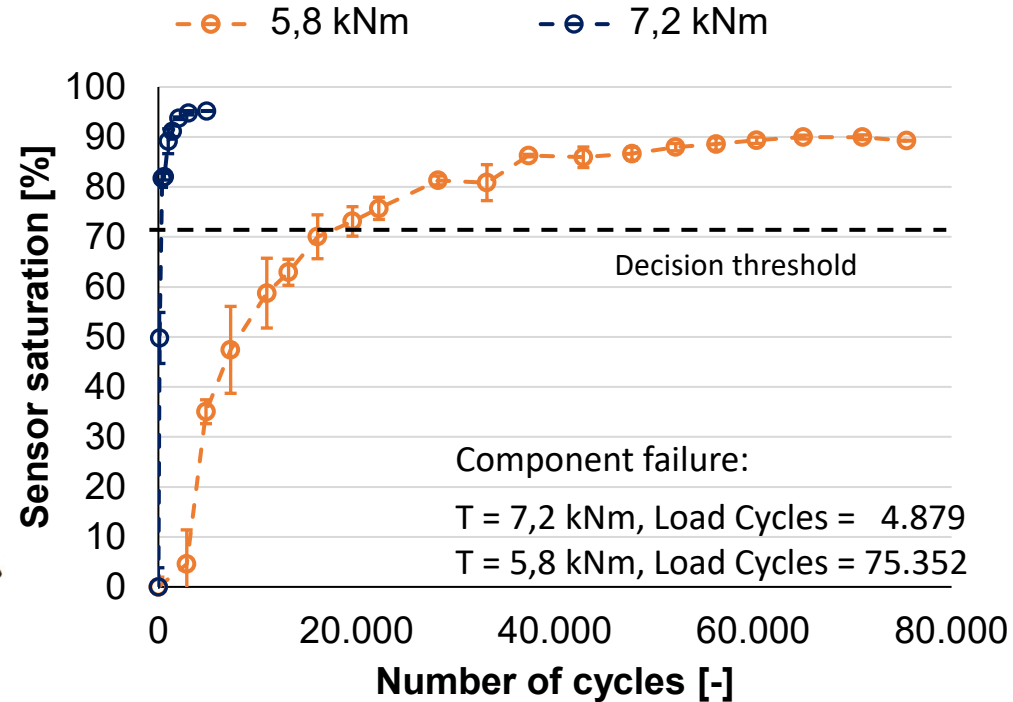
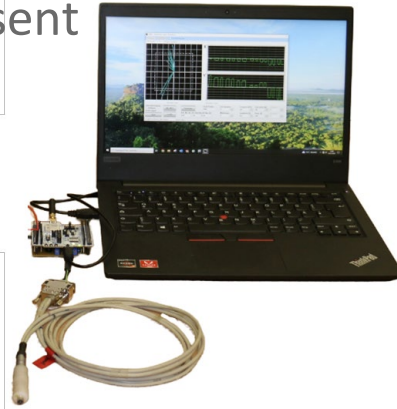
- Cyclic load tests at a constant angle of rotation
- Recording of the torsional moment
- Temperature monitoring



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Test results at varying load levels

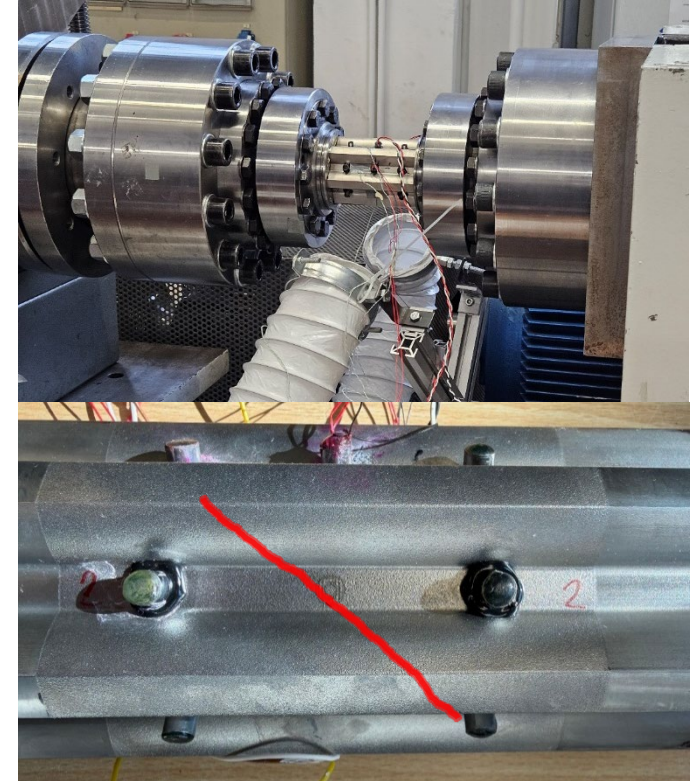
- The higher the overload, the higher the initial transformation & maximum sensor saturation
- Decision threshold above which pronounced cracks are highly likely to be present



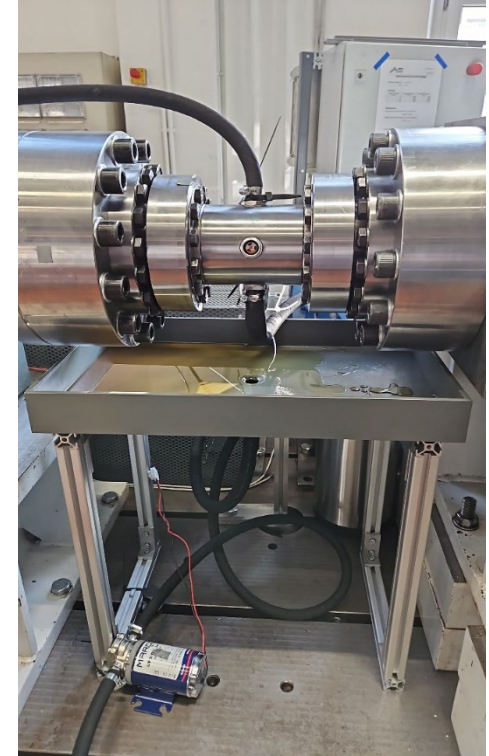
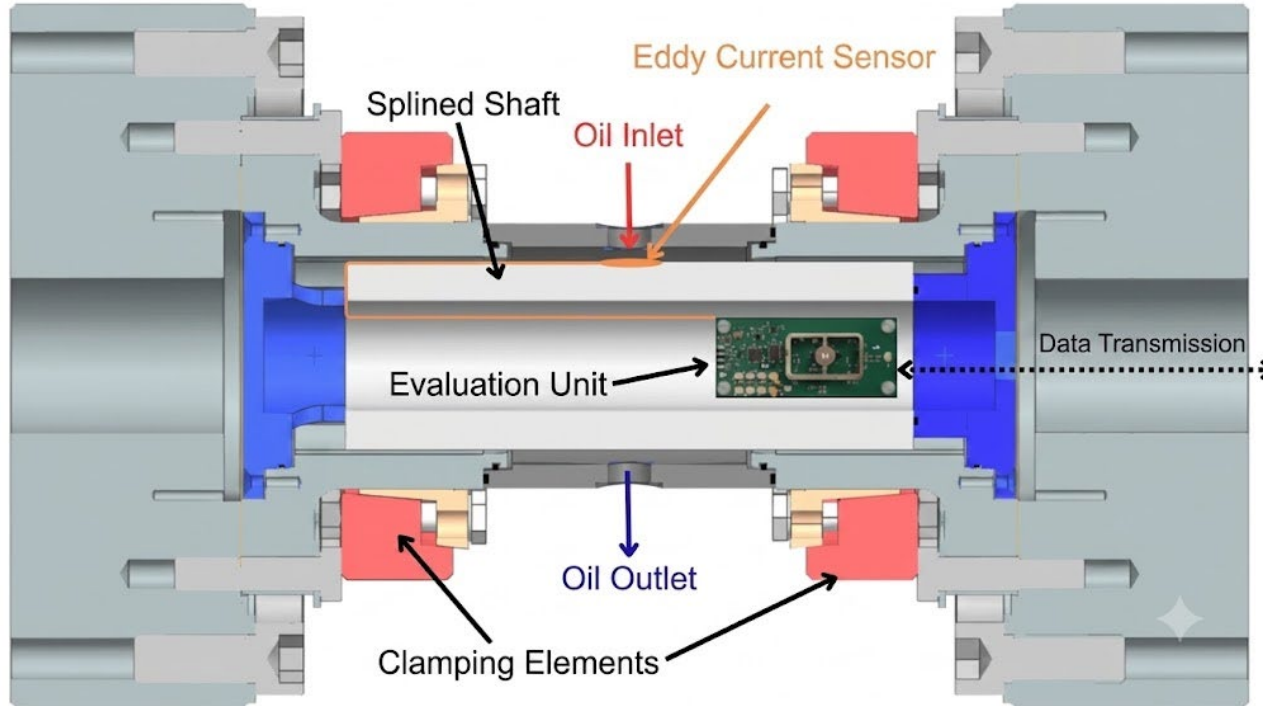
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Tests of Adhesive Connections

- Eddy current sensors and sensor test specimens applied
- Air cooling
 - Splined shaft temperature approx. 40°C
- Torque amplitude approx. 4.7 kNm
- No damage detected to adhesive connections or applied sensors (filler material)



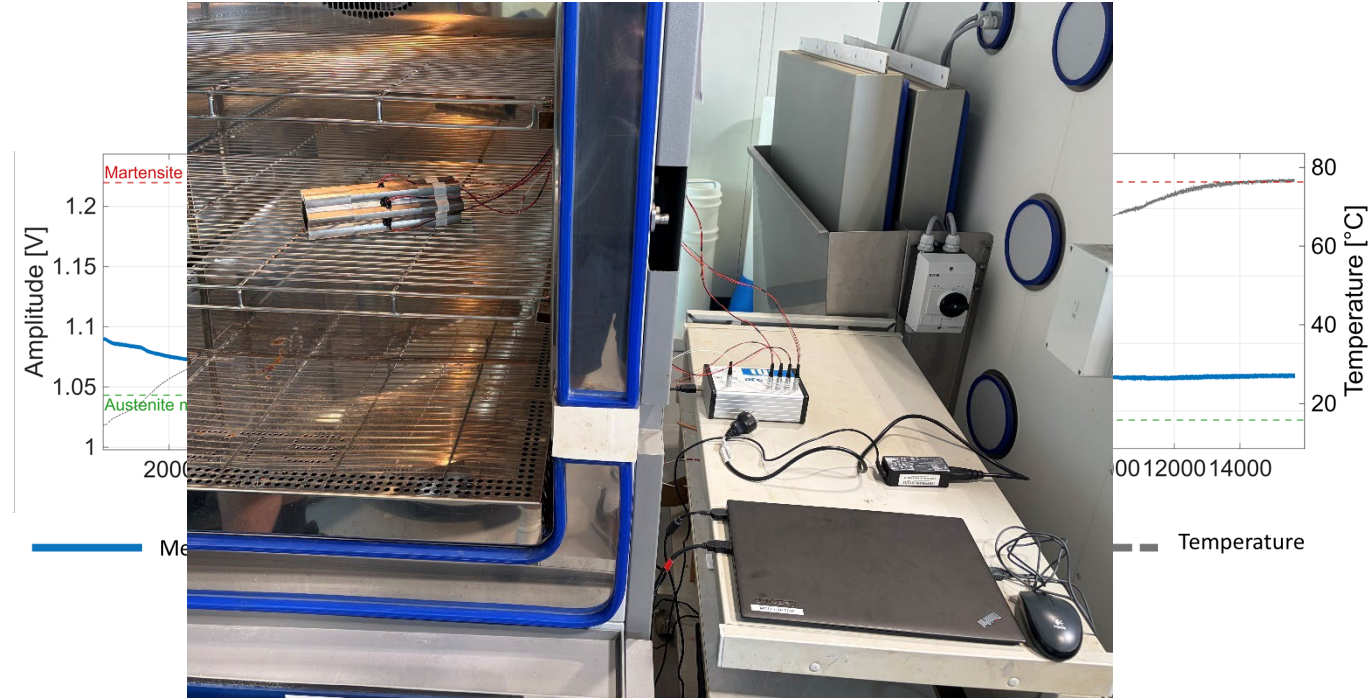
Test Bench Setup with Oil Lubrication



Quanz, M.; Gansel, R.; Barton, S.; Schäfer, G.; Lohrengel, A. (2026): Erweiterung eines Prüfstands für Torsionswechsellastversuche unter Temperatur- und Öleinfluss, Mitteilungen aus dem Institut für Maschinenwesen der Technischen Universität Clausthal, Nr. 50, 10.21268/20260623-9

Temperature compensation

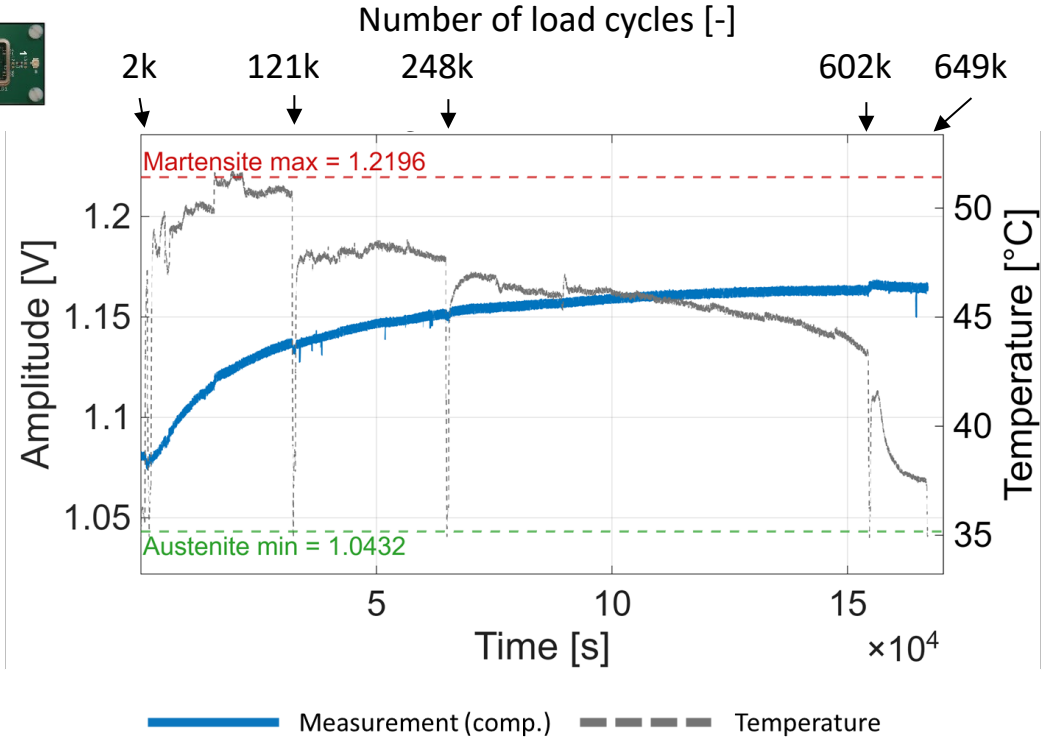
- Temperature influence on eddy current sensors
- Test in a climate chamber, heating the sensors from 15 °C to approx. 80 °C
- Signal decrease in the imaginary part, linear with temperature



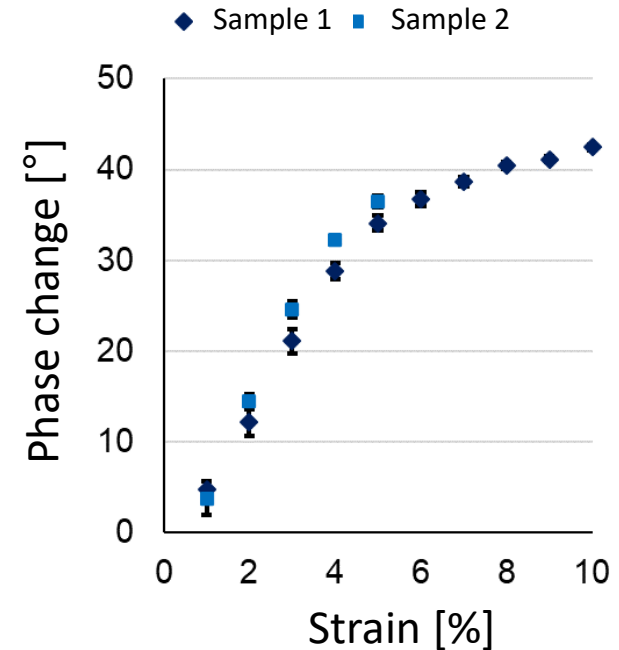
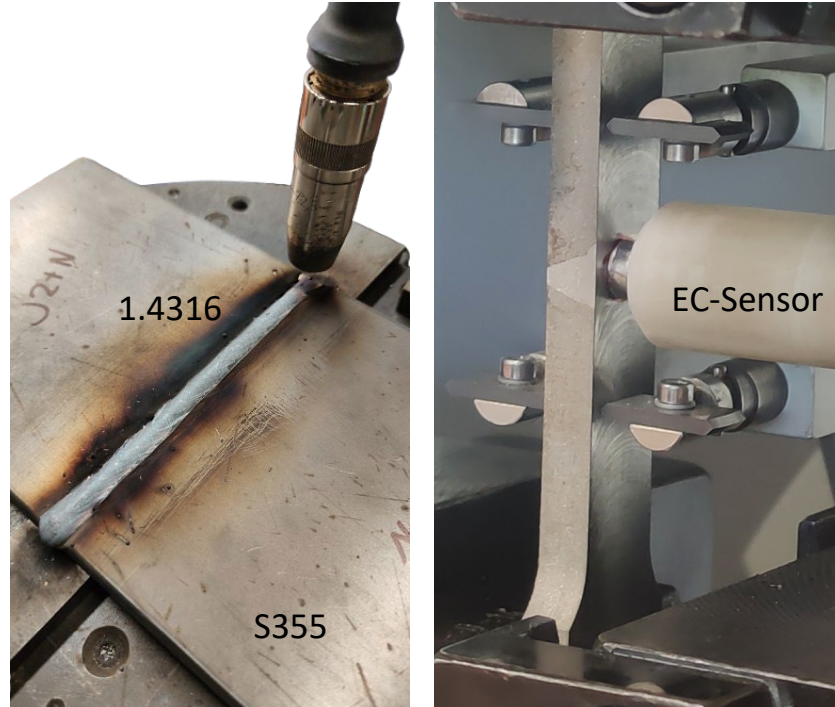
Investigation of the Influence of Oil and Temperature



- Test environment:
Splined shaft and sensors
immersed in oil (40 – 50 °C, Shell
Spirax S3 AX 80W-90)
 - Test duration: approx. 44h /
650.000 load cycles
 - Rising amplitude indicates
triggering of the material sensor
- Sensor functions reliably in oil and
at elevated temperatures



- Goal: Transfer project with industry partner after 2nd funding period
 - Case Study – Integration of Sensor Material in Construction Steel



- Test of adhesive connections successful
- Constant sensor readout with developed processing unit successful
- Sensor functions reliably in oil and at elevated temperatures (40 °C)
 - Further tests at higher temperatures planned
- Two Collaborative Projects
- Industry partners sought for transfer project



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