Measurement of load quantities in rolling bearings using strain gauges integrated into rolling elements, energy-efficient telemetry modules and energy harvesting

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VDI/VDE-GMA Committee 4.51 “Electrical Measuring Methods; Strain Gauges”, Clausthal-Zellerfeld, 05.09.2024



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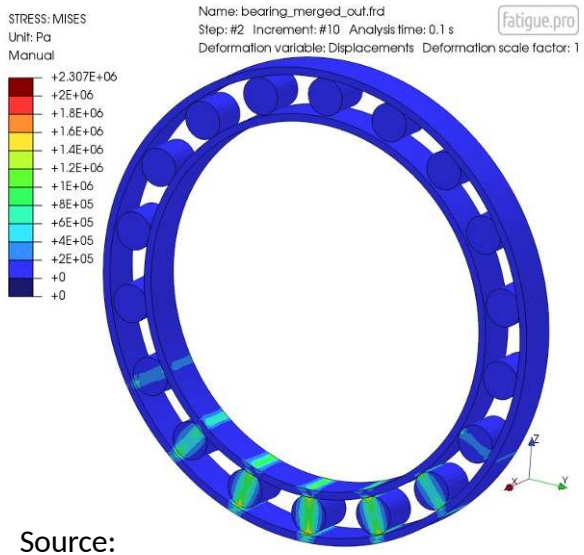
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Problem statement

- What is the load distribution within a rolling bearing?
- High relevance for design and reliability calculations
- Reliability is a dominant issue, especially in wind energy (20-year service life, many full-load hours per year)
- Simulations reflect reality only to a limited extent; **measurements are always necessary for validation**
- Measuring the load distribution in rolling bearings is extremely challenging



Source: Schaeffler



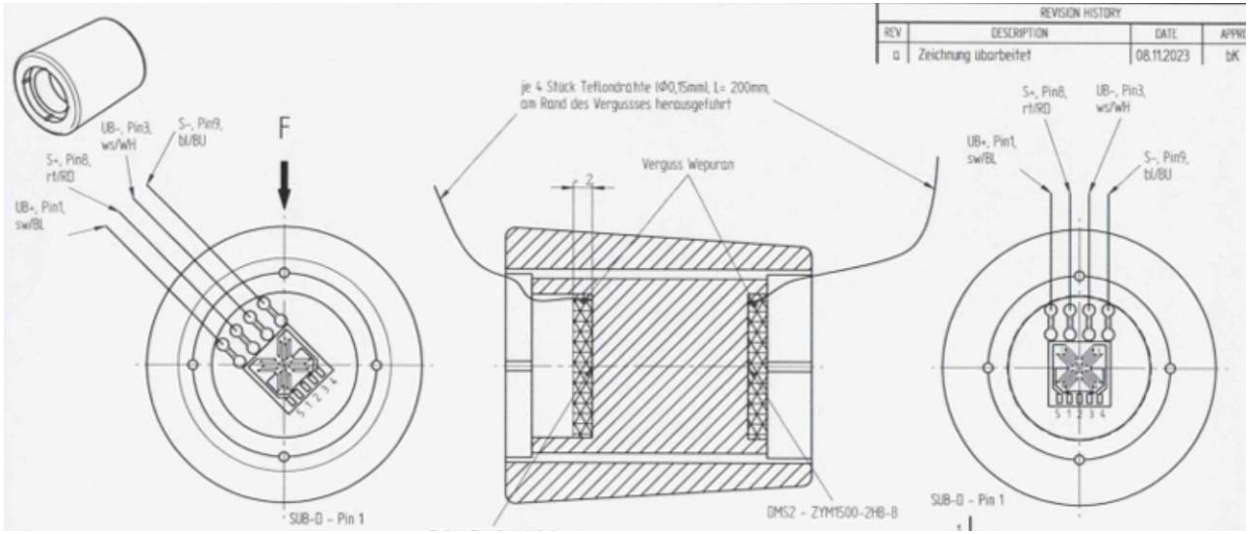
Source: fatigue.pro

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Measurement approach

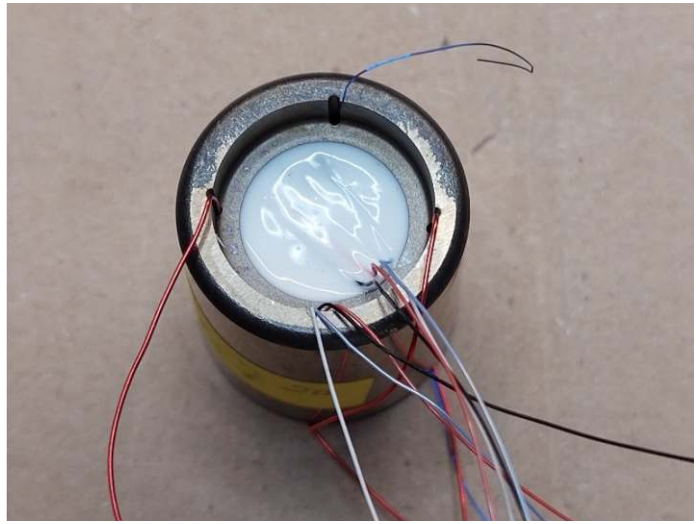
- Idea: integration of strain gauges into rolling elements, incl. telemetry
- Challenges
  - How do you get the sensors into the rolling element?
  - How do you get the data out of the rolling element?
  - How do you get energy into the rolling element?
  - How do you interpret the measurement data?
  - How do you make the sensorized rolling elements resistant to oil and grease?

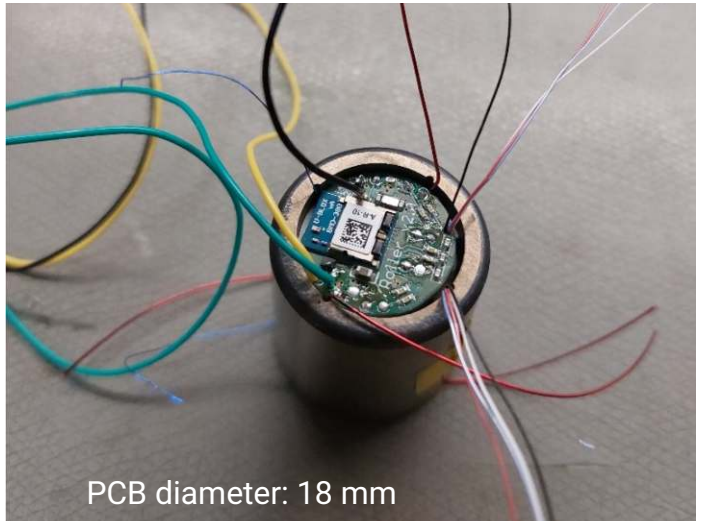


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Measurement approach



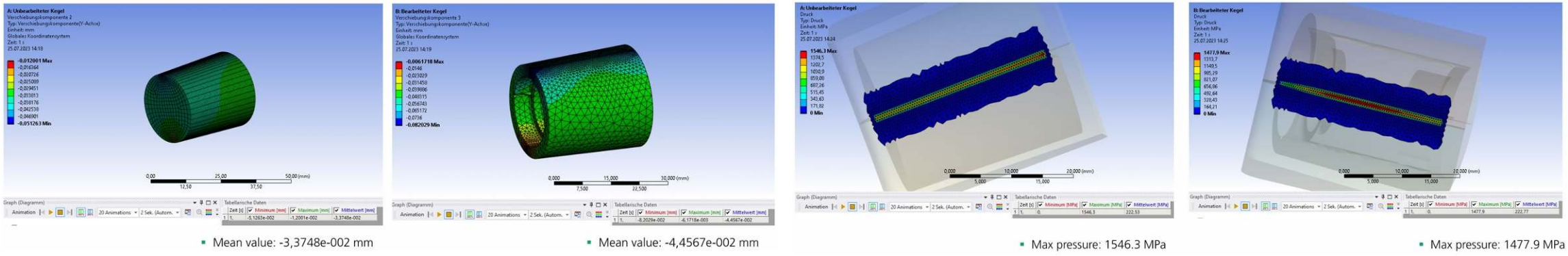




- Two strain gauge channels, 24 bit, sampling rate up to 2 kHz
- Full-bridge strain gauge rosettes applied to the end faces to avoid a central bore
- Strain gauges offset by 45° to each other to obtain more measuring points per orbit
- 6 DoF MEMS IMU, 3-axis accelerometer (max ±32 g), 3-axis gyrometer (max. ±2000 °/s), sampling rate up to 3.3 kHz
- Integrated Li-ion battery (Varta Coin Cell), charged via contact pins while the test is stopped, runtime approx. 3 hours
- Very small cable feedthroughs
- Machined entirely by spark erosion (hardened component) and fully potted

Modeling Part 1 – Finite Element Simulations

- The machining of the rolling elements required to integrate the strain gauges changes the system behavior significantly
- Finite element simulations provide information about how stiffness and pressures change
- The test parameters must take these changes into account (e.g. adjustment of loads)



Change in the stiffness of the rolling element

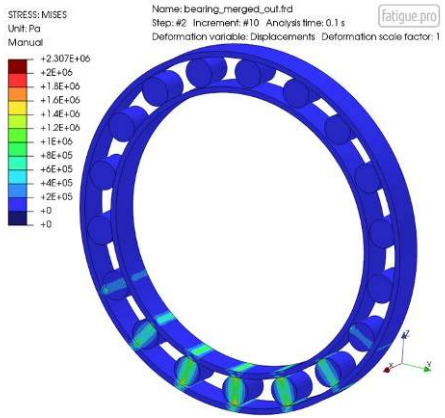
Change in contact pressures

Source: FE simulations provided by Fraunhofer IWES

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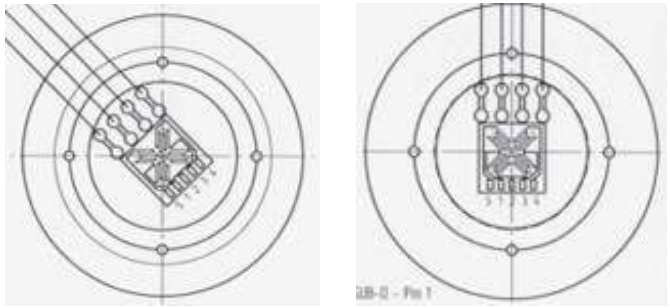
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Modeling Part 2 - Measurement Data



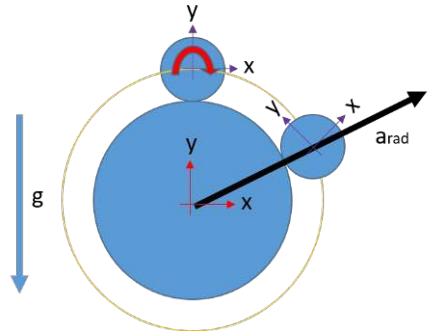
Load zone

- Strain gauge measurement data



- Rated load on roller: 35 kN = 3.5 tonnes
- Analytically calculated strain: approx. 320 µm/m
- One usable measured value every 45°
- One zero crossing every 45°
- Modulation present even under static load
- Envelope curve conceivable
- Better: determine the rotation angle to clearly identify valid, usable measured values

- Inertial sensor (IMU) measurement data



- IMU on the roller's axis of rotation
- Two rotational movements
  - Once per bearing orbit (shaft rotation)
  - Once per roller rotation
- Two acceleration components
  - Gravity
  - Centripetal acceleration (speed-dependent!)
- X/Y acceleration component: results in a modulated oscillation signal
- Z component on a tapered roller: one sine oscillation per roller orbit

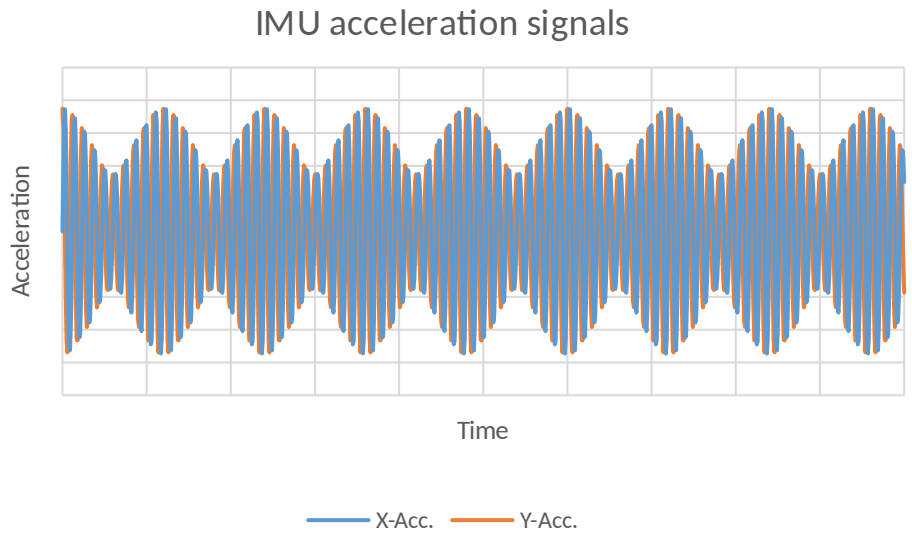
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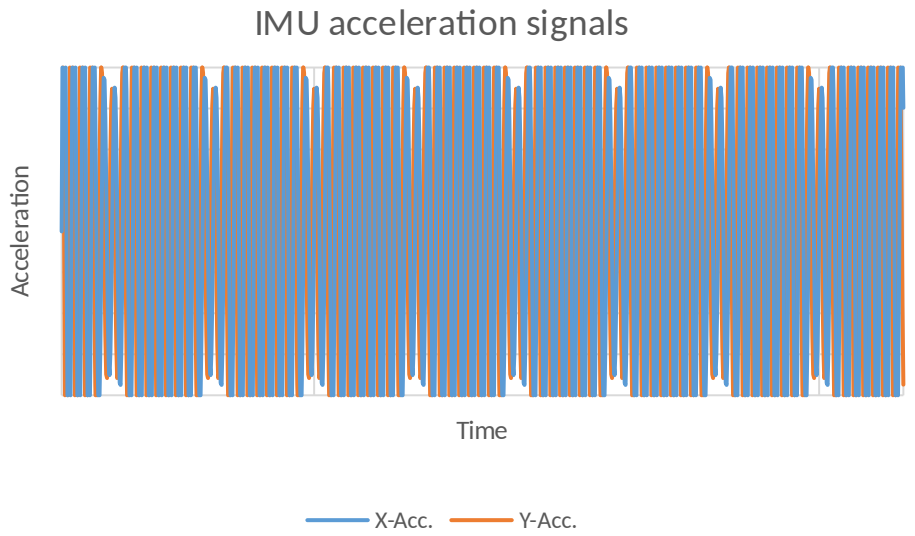
Modeling Part 2 - Measurement Data

- Typical modulation
- Fast oscillation: rotation of the rolling element about its own axis
- Slow oscillation: rotation of the rolling element about the shaft axis (orbit)
- Caution: at higher speeds the accelerometer measuring range may be exceeded, but zero crossings remain unambiguous

- Low speed



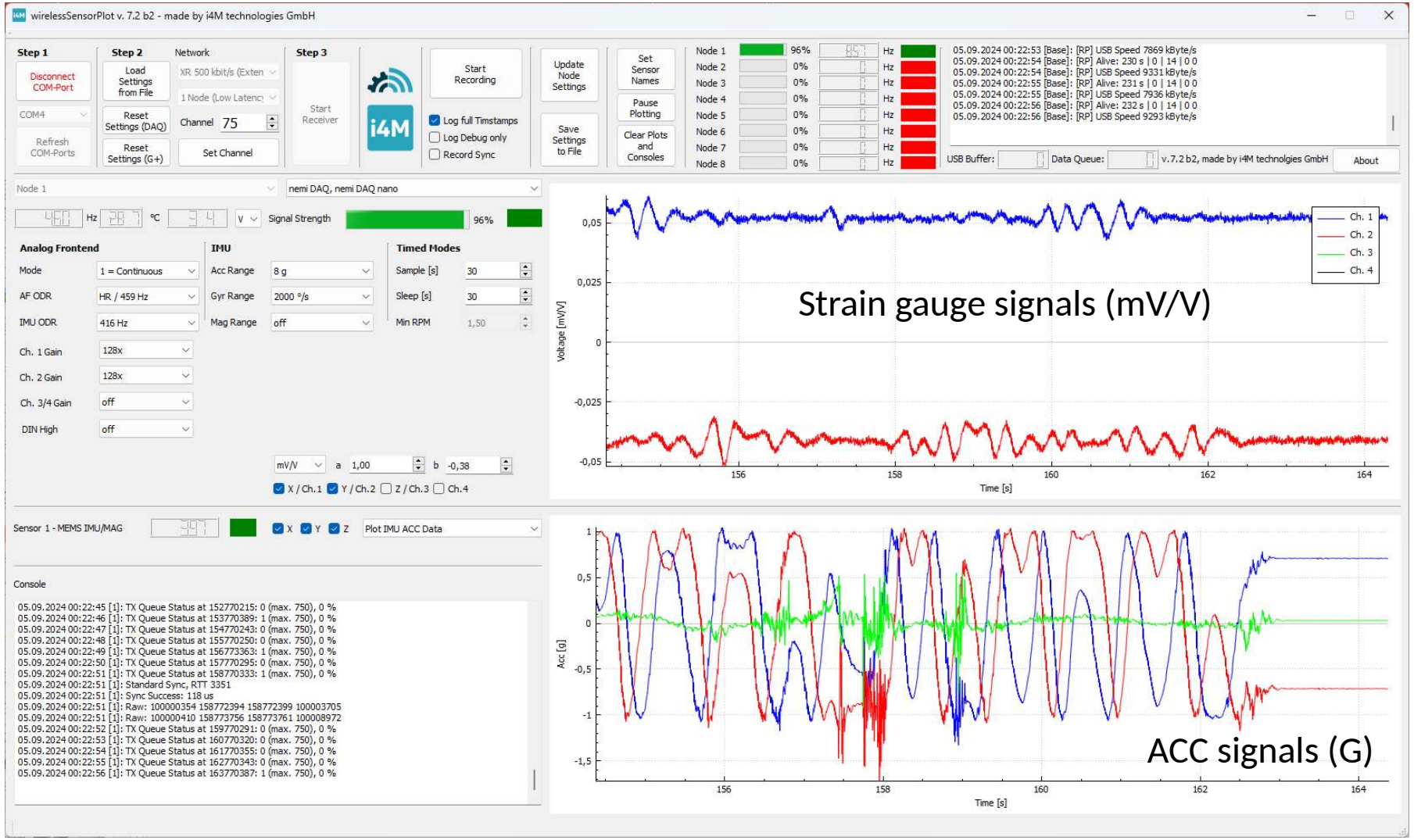
- Higher speed



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System demonstration



Load measurement in rolling bearings using sensorized rolling elements
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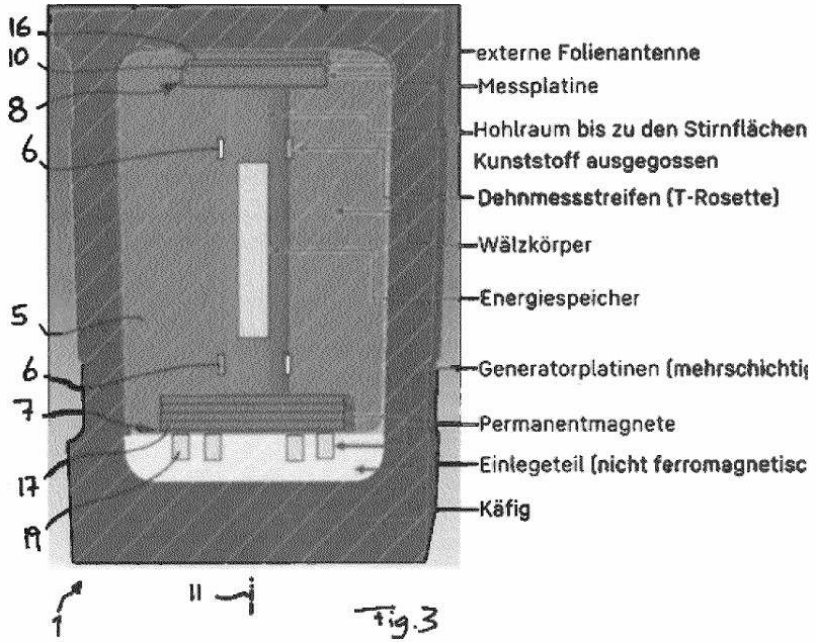
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Power supply options incl. energy harvesting

- The approach presented so far is not suitable for series production, as the energy transfer requires manual effort
- Together with a customer, a suitable energy harvesting approach has been developed, patented and is currently being tested
- Idea: integration of generators into the rolling element





Patent publication DE102022135001

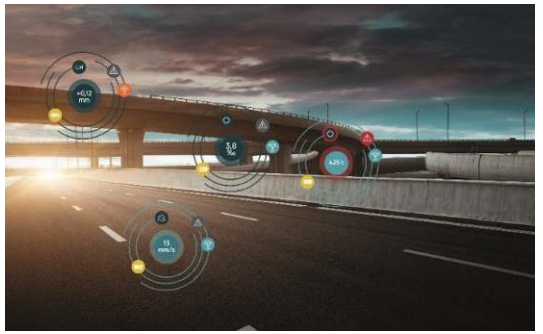
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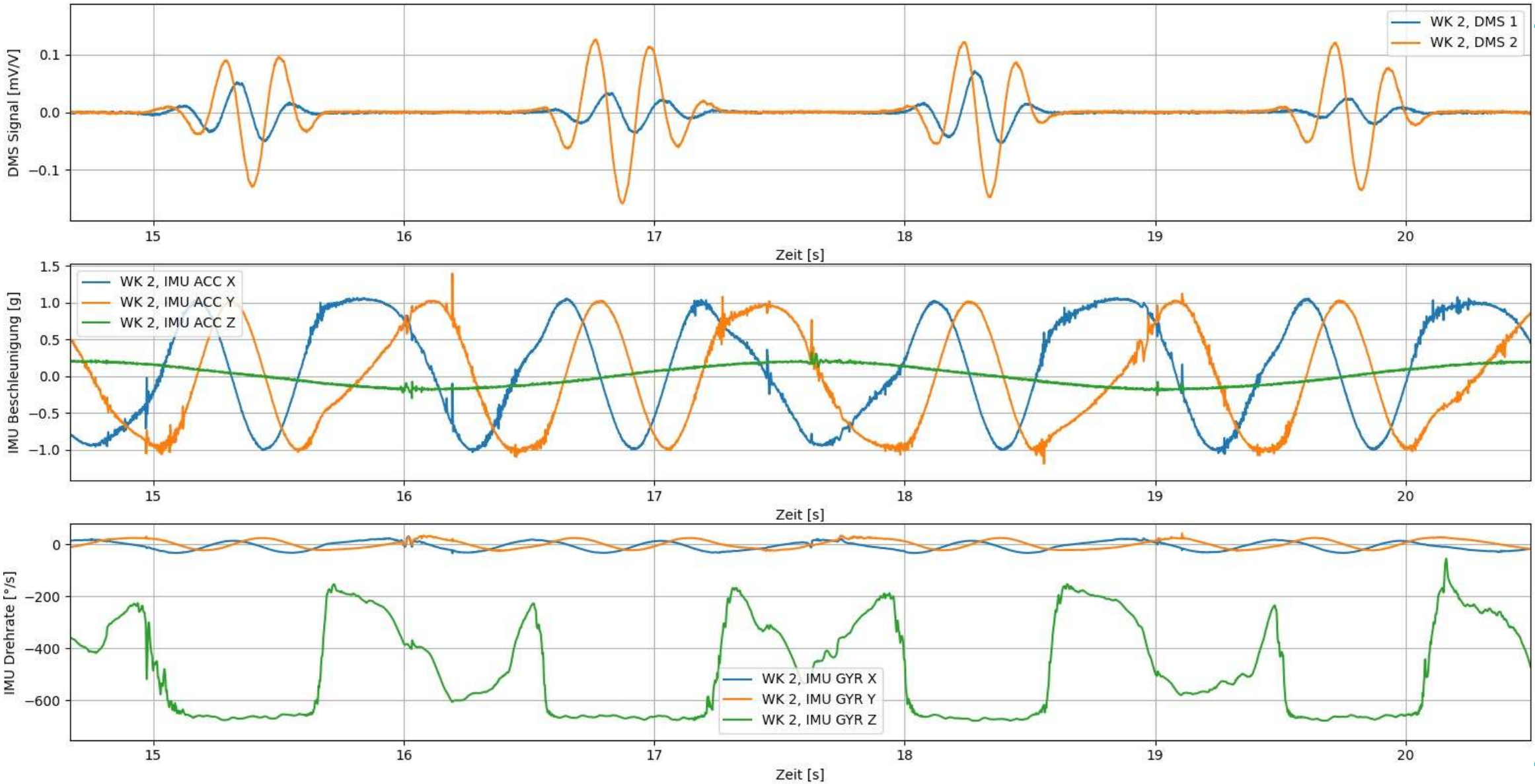
- Specialized in wireless sensor systems for machines, vehicles and infrastructure
- Combining expertise in mechanical systems, data analysis and advanced wireless measurement technology
- Founded in 2016 as a spin-off of two institutes of RWTH Aachen University
- Team of 9 electrical and mechanical engineers
- Serving a wide range of industries, from roller coasters to wind turbines



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