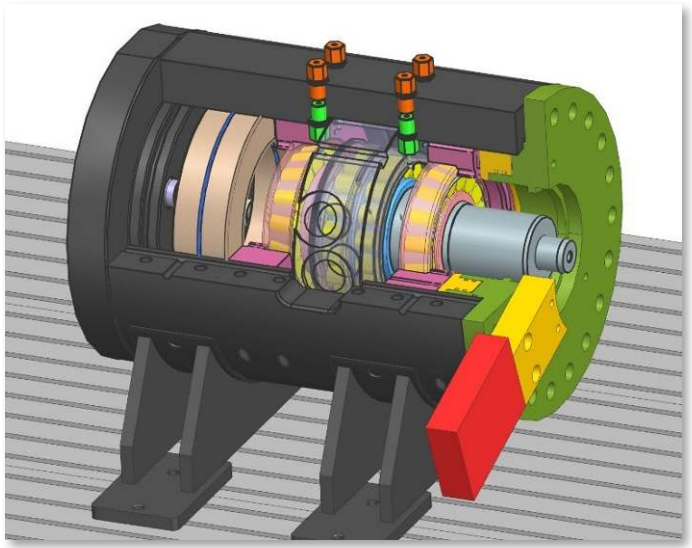
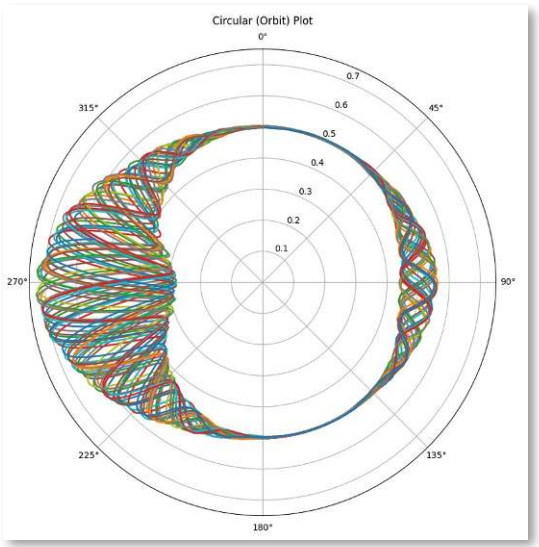
Measurements of kinematic and load-related variables within rollers of a tapered roller bearing for wind energy applications

Martin-Christopher Noll, i4M technologies GmbH
Dr. Matthias Stammler, Fraunhofer IWES







Fraunhofer IWES

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Outline

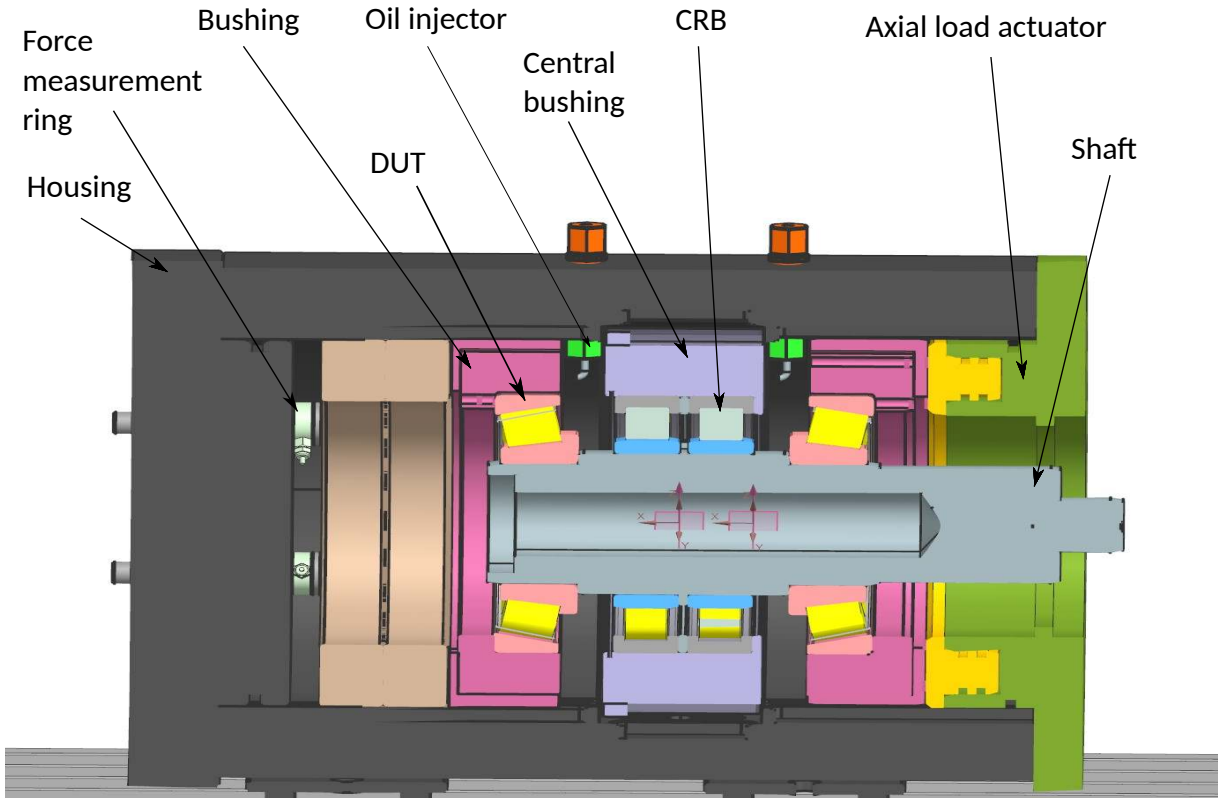
1. Introduction, overview, and motivation
2. Test bench setup and bearings
3. Rolling element-integrated measurement technology
4. Data and analysis methods
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Introduction: Dy-rex Project

- **„Dy**namische **Re**gelung einer a**x**ialen Lastsuperposition“ (Dynamic control of axial load superposition)
- Reduction of harmful rolling element slip while maintaining fatigue life
- Application in critical operating situations such as fault ride through
- Motivation: Reduction of WEC

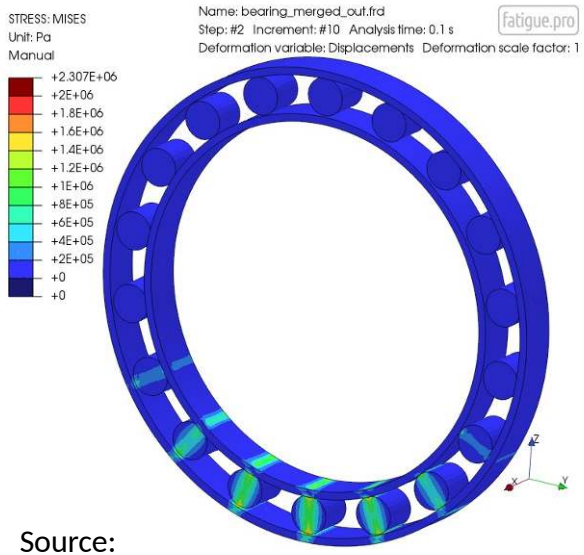


Questions and motivation behind this presentation

- How is the load distributed among the various rolling elements in the orbit of a rolling bearing?
- At which points and in which operating ranges does harmful slip occur?
- High relevance for design and reliability calculations
- Reliability is a dominant issue, especially in the field of wind energy
- Simulations only reflect reality to a limited extent; measurements are always necessary for validation
- Measurements of load distribution and slip in rolling bearings are technically challenging



Source: Schaeffler



Source: fatigue.pro

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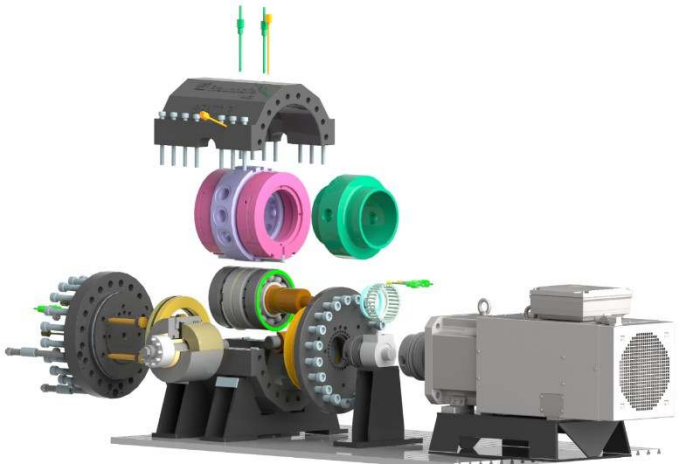
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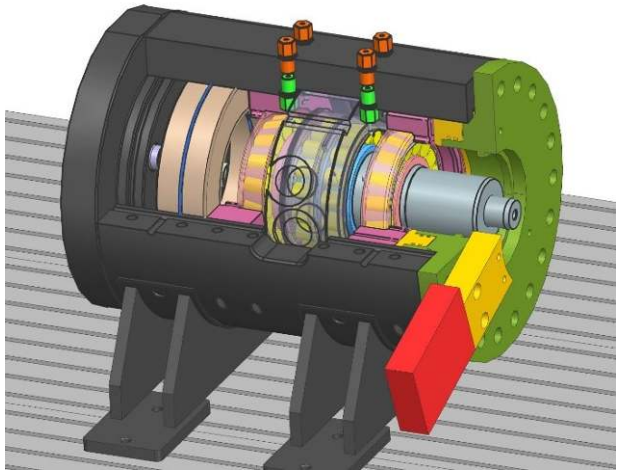
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Test bench setup & storage

- Test bench BEAT0. 3
- Designed for high load and speed dynamics
- Possible roller bearings: 30318, 7318, as well as four-point types
- Ten adjustable oil feeds
- Bearing bushes as hydrostatic plain bearings
- Radial force applied by two tension cylinders controlled by a valve





Parameter	Value	Unit
Max. RPM	3000	rpm
RPM-Dynamic	500	rpm/s
Max. Axial Force	140	kN
Axial Force Dynamic	1120	kN/s
Max. Radial Force	250	kN
Radial Force Dynamic	500	kN/s
Max. outer diameter of test bearing	220	mm
Max. flow rate for oil lubrication	60	l/min

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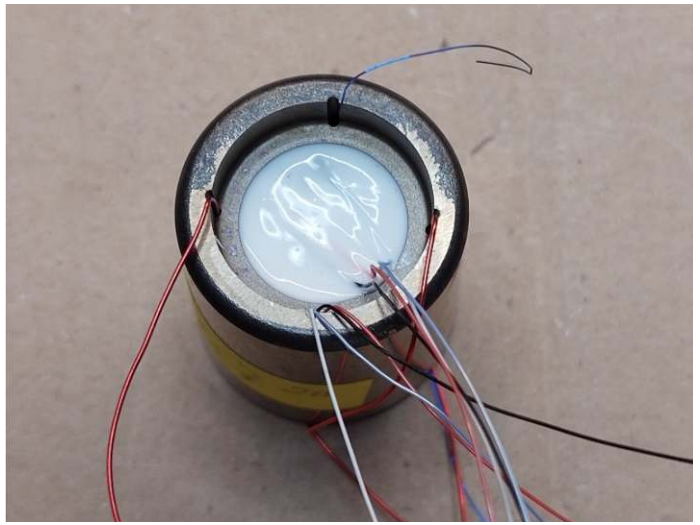
Rolling element integrated measurement technology / i4M Smart Roller

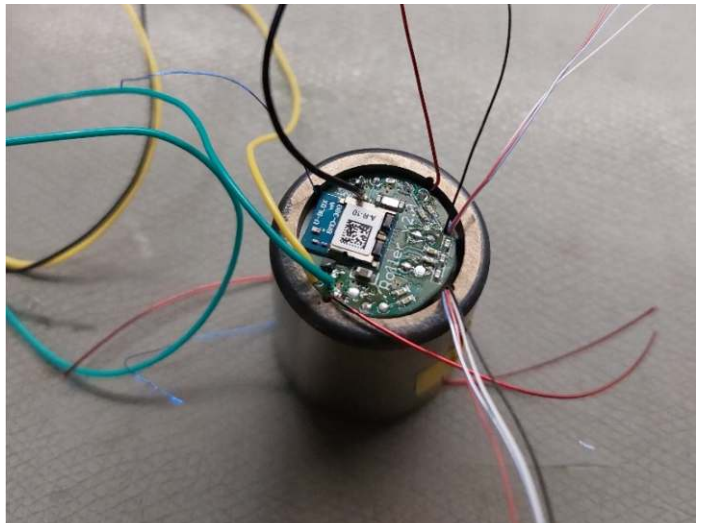
- Rolling element with integrated sensor technology for load (strain gauge) and rotational movement (MEMS IMU)
- **Special feature 1**: Rolling element diameter approx. 23 mm
- **Special feature 2**: Shaft speeds up to 1,500 rpm
- Highly compact, battery-powered radio telemetry (proprietary i4M protocol)
- Integrated load measurement technology
  - Applied to the front faces, no through hole!
  - 24-bit resolution, low noise, **2 kHz sampling rate**
- Integrated motion measurement technology
  - MEMS-based inertial measurement unit (IMU)
  - Triaxial acceleration sensor (accelerometer)
  - Triaxial rotation rate sensor (gyrometer)
  - 16-bit resolution, low noise, **1.6 kHz sampling rate**
- Power supply via integrated rechargeable battery, > 3 h measurement time
- Rechargeable on the test bench via contact pins

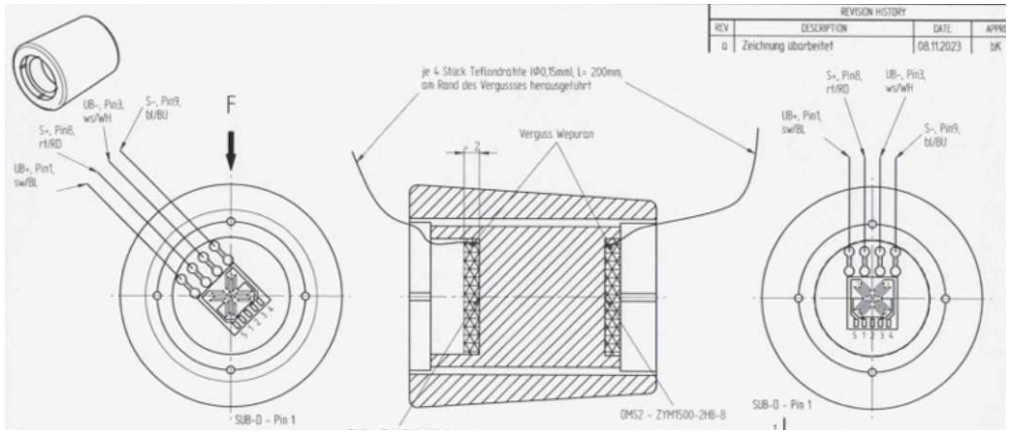


Rolling element integrated measurement technology / i4M Smart Roller

- Strain gages applied to front sides
- No through hole necessary
- Two circuit boards
  - Measuring circuit board with sensors and radio telemetry
  - Power circuit board with battery and charging electronics
- Hardened rolling element manufactured using spark erosion process
- Completely encapsulated with epoxy resin





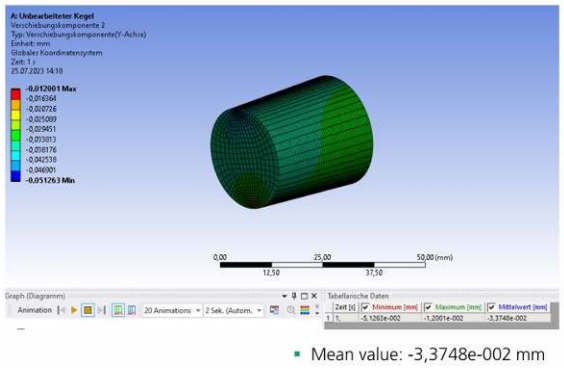


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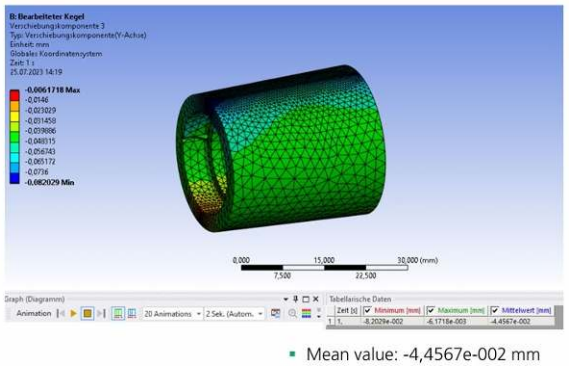
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Rolling element integrated measurement technology / i4M Smart Roller

- The necessary machining of the rolling elements to integrate the measurement technology changes the system behavior
- 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)

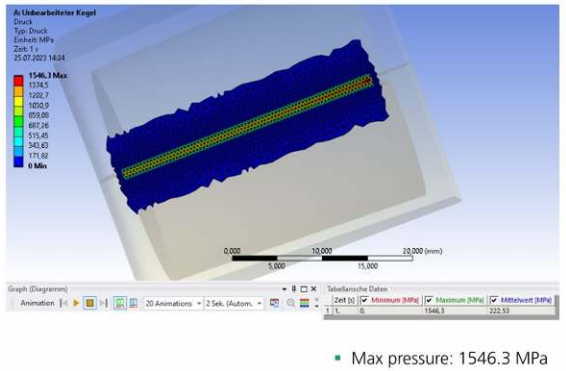


▪ Mean value: -3,3748e-002 mm

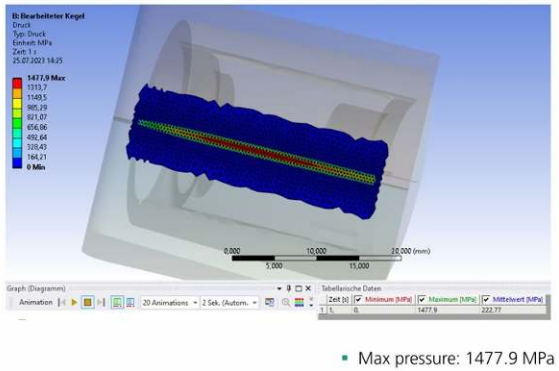


▪ Mean value: -4,4567e-002 mm

Change in the stiffness of the rolling element



▪ Max pressure: 1546.3 MPa



▪ Max pressure: 1477.9 MPa

Change in contact pressures

Source: FE simulations provided by Fraunhofer IWES

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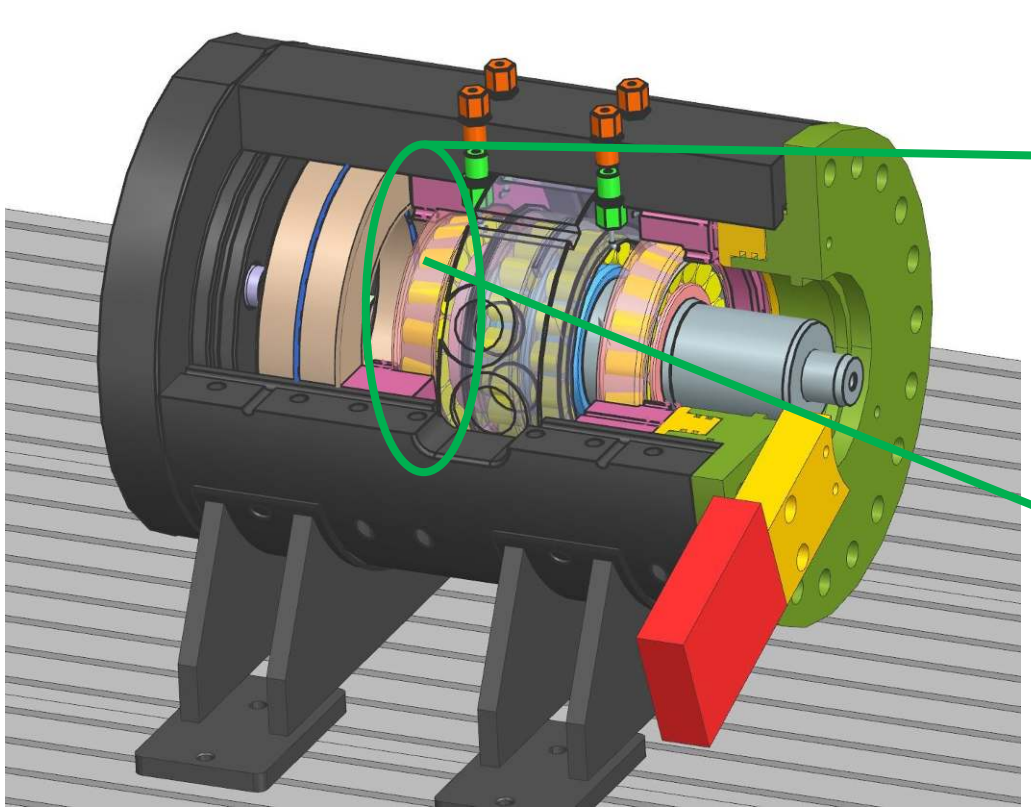
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Outline

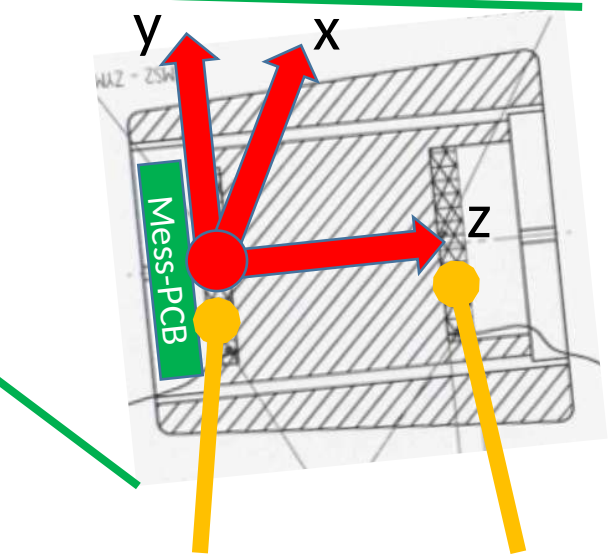
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Data & Analysis Methods

- Definition of the coordinate system of the rolling element-integrated motion sensor technology
- X and Y lie in the plane of the rolling element end faces, Z lies on the rolling element axis of rotation
- Strain gauge channel 1 is located under the measuring PCB (smaller end face), strain gauge channel 2 is located under the power PCB (larger end face)







SG Channel 1 SG Channel 2

Data & Analysis Methods

- Discussion of the data provided using an example
- Load variation on the test bench: Increase in radial force from 0 to 90 kN

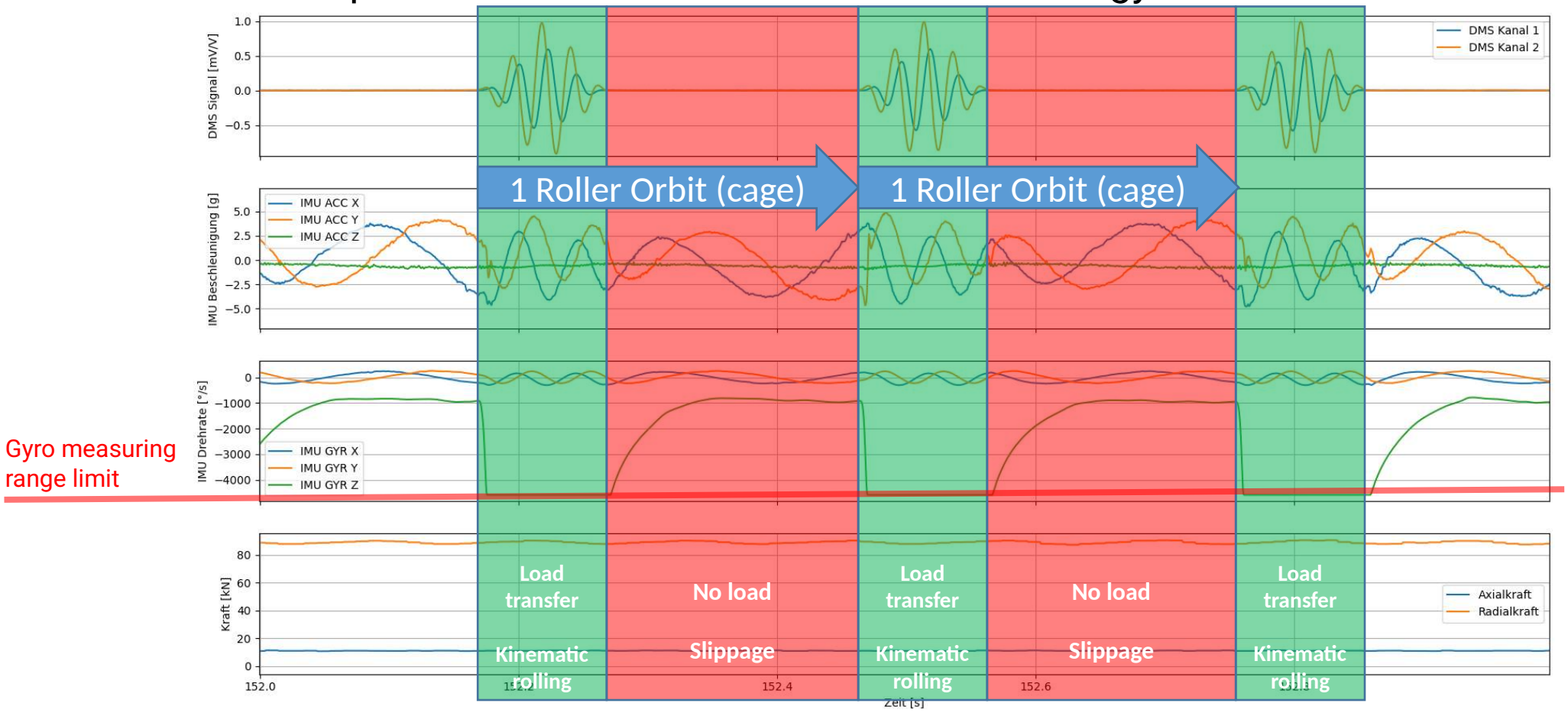


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Data & Analysis Methods

- Discussion of the delivered data using an example
- Identification of slip conditions based on accelerometer and gyrometer data

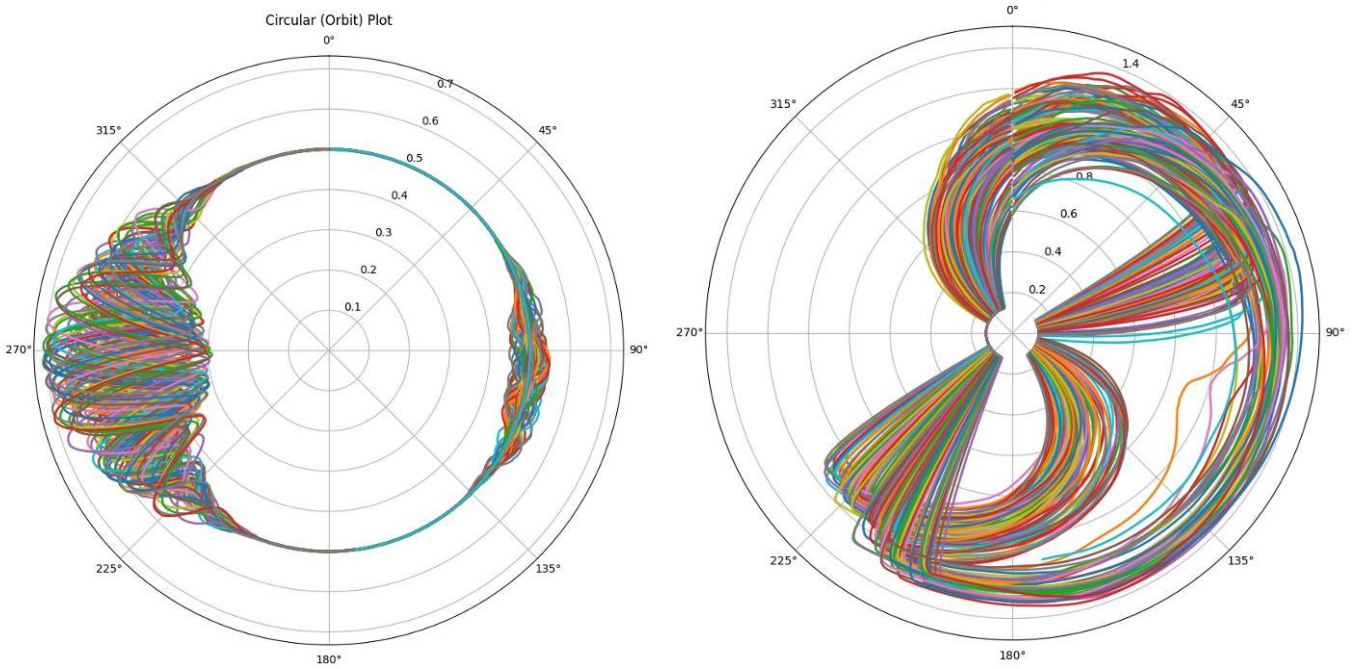


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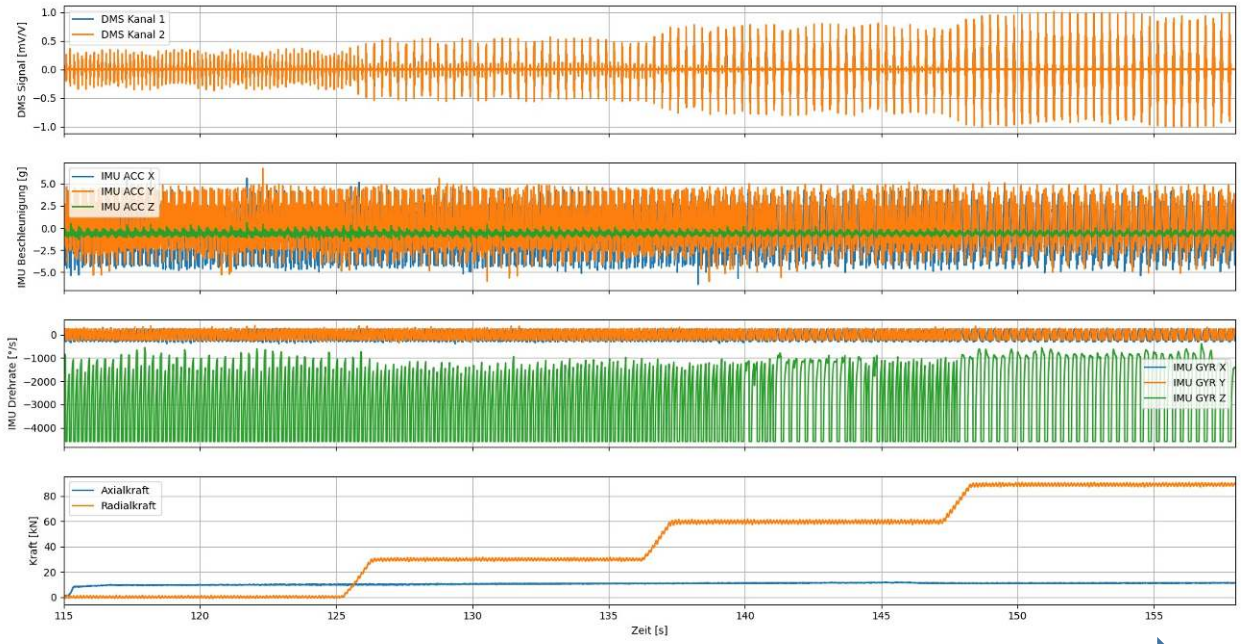
Data & Analysis Methods

- Rotational speed of the rolling element from zero crossings of the rolling element X/Y accelerations, rotational speed of the shaft (for kinematic reference) from test bench data
- Rolling element orbit position (= cage rotation angle and not shaft rotation angle!) from the progression of the rolling element Z acceleration
- Plots of all measured variables over the orbit possible:

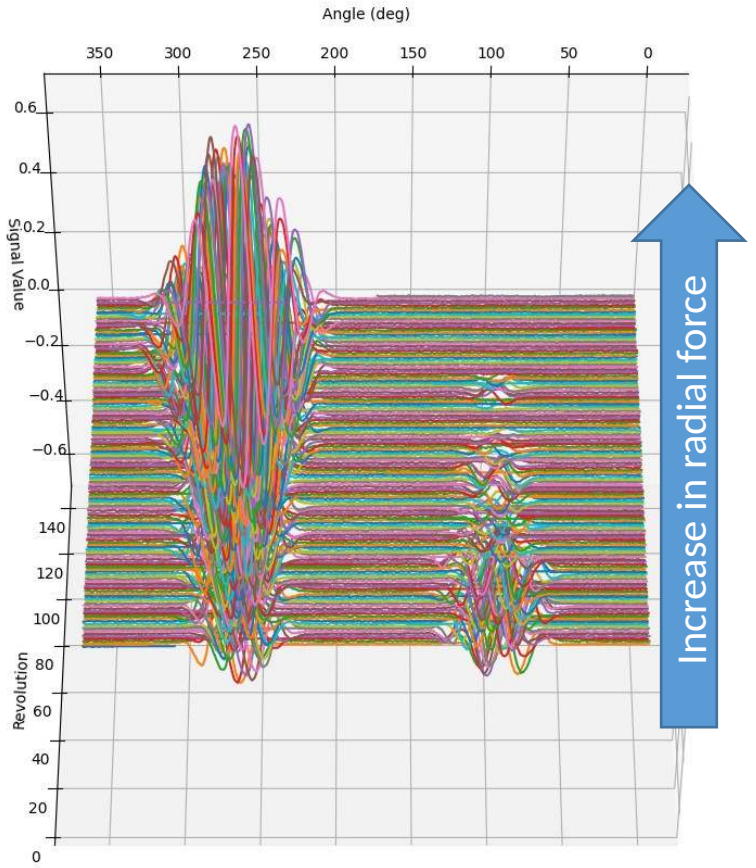


Data & Analysis Methods

- Measurement data can be broken down into individual revolutions and temporal developments can be displayed from revolution to revolution
- Boundary condition: Increase in radial force from 0 to 90 kN with constant axial force of 10 kN



Increase in radial force



Increase in radial force

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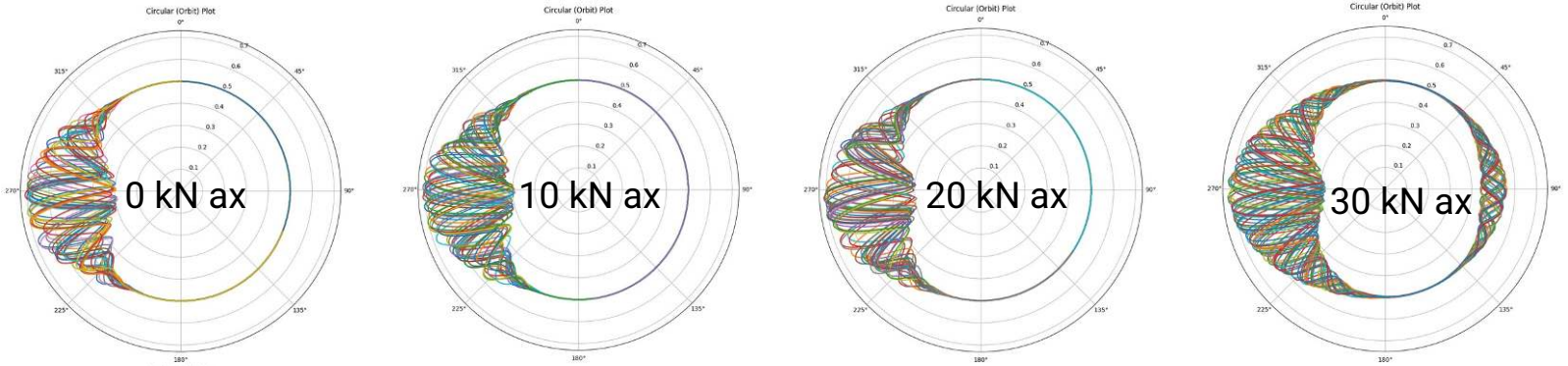
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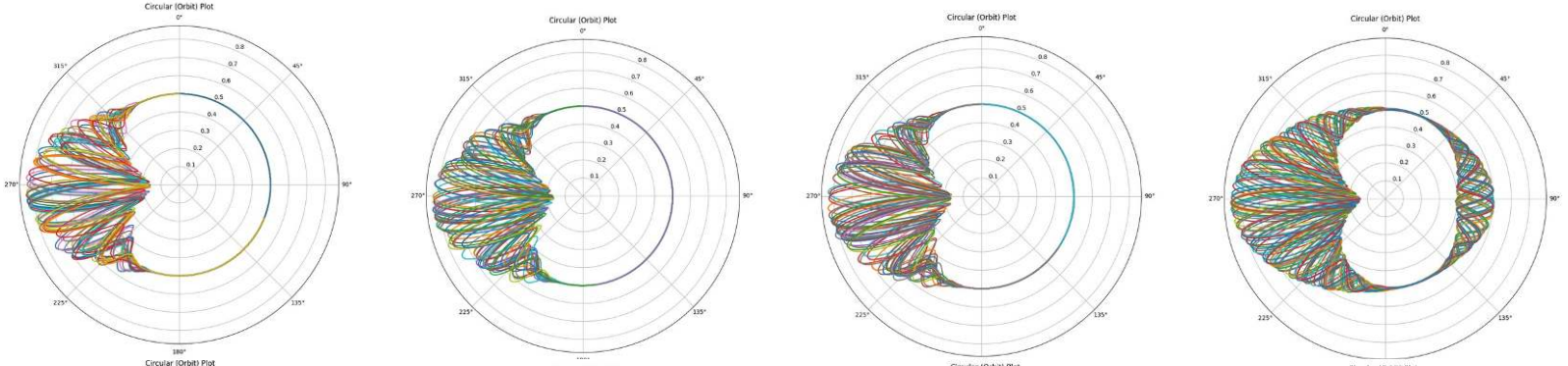
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Results and evaluation

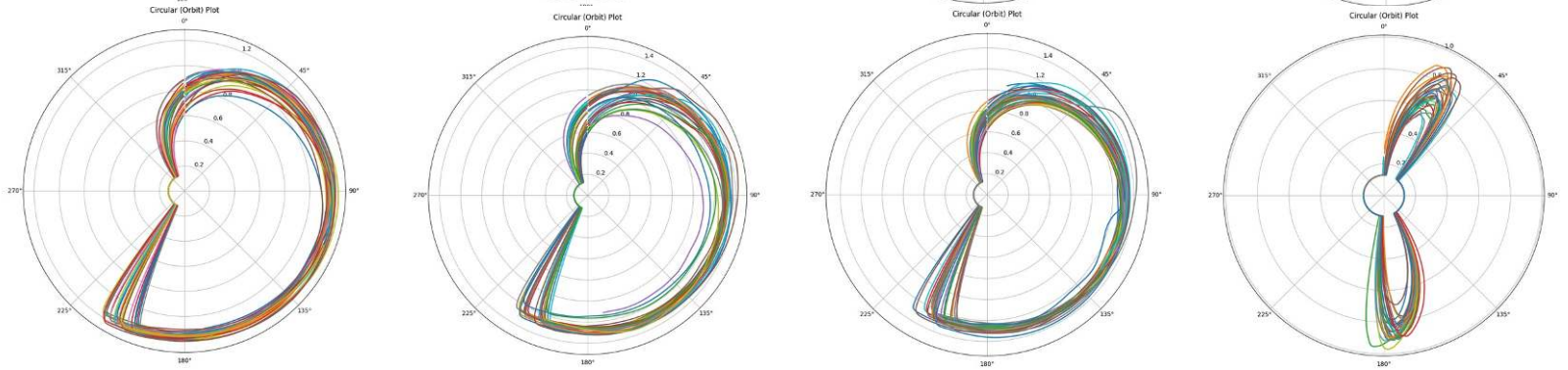
Strain gage
Channel 1



Strain Gage
Channel 2



Roller RPM
Gyro-Z (Slippage =
plot radially outside)



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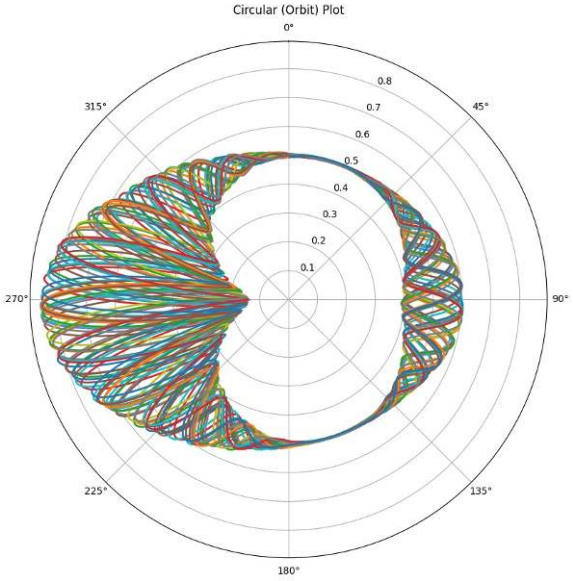
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Summary & Outlook

- Integration of i4M's “Smart Roller” technology also possible in smaller, faster-rotating bearings
- Compact, robust, reliable solution with high data rates and low energy consumption
- High-quality kinematic and load data from the rolling element



- Weakening of small rolling elements must be taken into account
- As expected, the introduction of axial bearing force reduces slippage
- A second load zone is created as the axial bearing force increases
- Second load zone reduces the slip range



- The causes of the second load zone have not been conclusively clarified
- This effect would not be observable without rolling element-integrated measurement technology
- Evaluation of complex operating situations (start/stop, FRT, grid disconnection) is still pending

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Thank you very much for your attention!



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