



Sensor Integrating Machine Elements Congress

Auto-informative Gleitlager (Auto-informative Plain Bearings)

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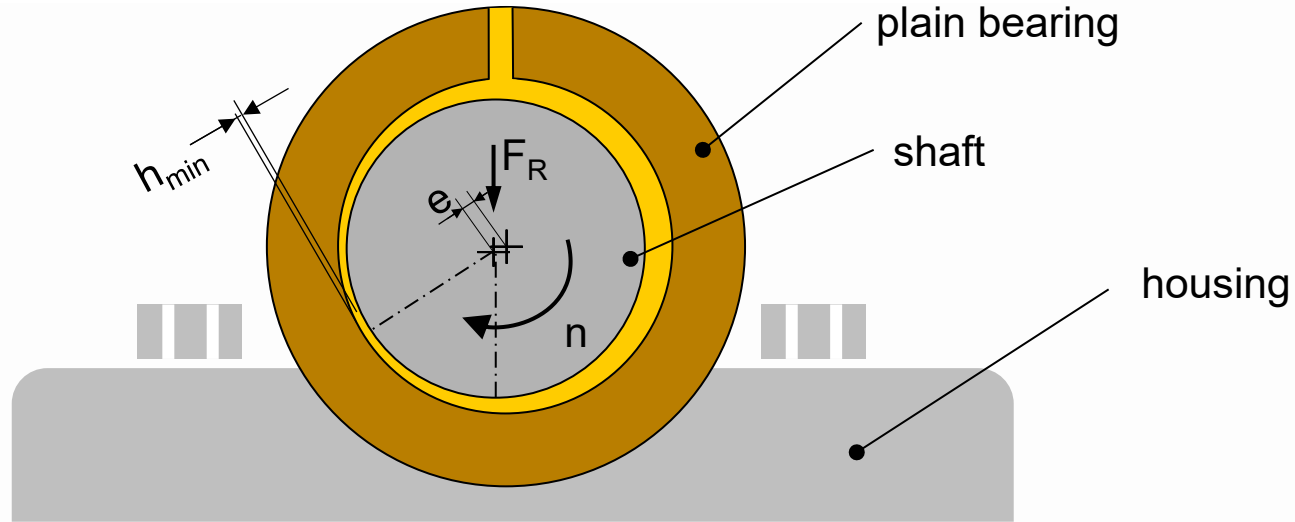
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Darmstadt, 15th of September 2026

Machine element: hydrodynamic plain bearings



Current applications



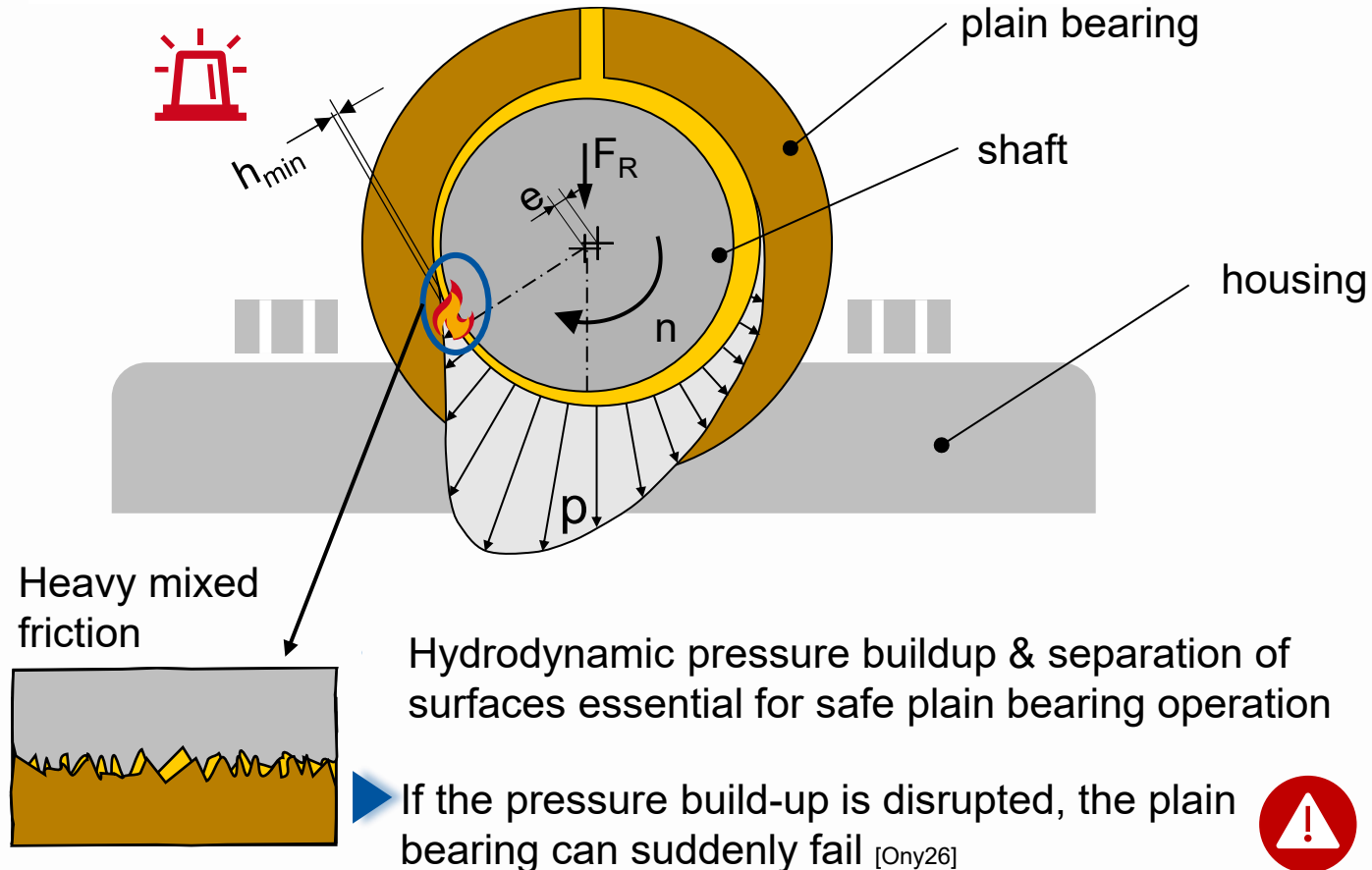
Advantages over roller bearings:

- ▶ Long service life due to resistance to fatigue
- ▶ Good damping properties
- ▶ Low Maintenance
- ▶ Space and weight savings



[Czi20]

Machine element: hydrodynamic plain bearings



Abnormal events as damage cause

- can cause the load-bearing lubricating film to collapse suddenly [van25]



Oil supply failure

Insufficient oil supply causes film breakdown and solid contact



Mechanical overload

High thermal and peak loads lead to the breakdown of the lubricating film



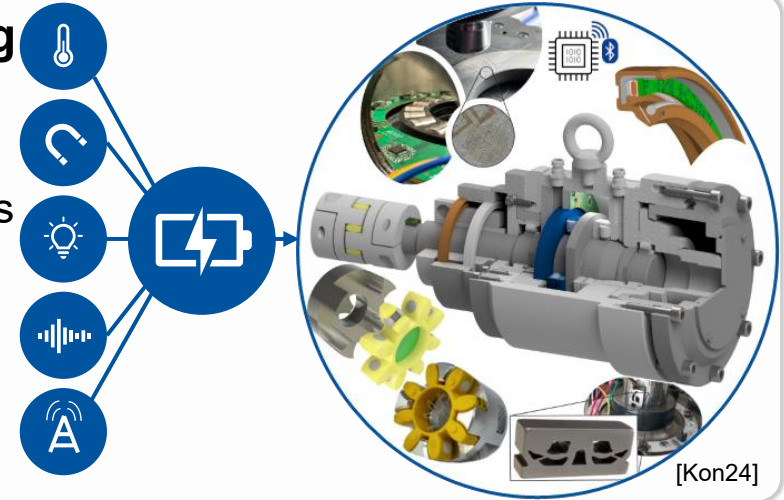
Particle contamination

Solid particles in the oil circuit can cause three-body abrasion

- ▶ Abnormal events can cause rapid failure of the whole drivetrain [Kön24]
- ▶ Condition monitoring systems (CMS) need to detect these abnormal events on time

Energy harvesting (EH) as an enabler for autarkic condition monitoring

- Maximum sensitivity of CMS sensors through integration into the failure-critical machine element
- No practicable installation of wired sensors in multi-axis rotating system assemblies (e.g. gearboxes) possible → EH could eliminate external cabling
- Prevailing environmental conditions of the machine element are used, which are heavily dependent on the operating conditions



DC-DC-converter for a stable power supply to sensor systems

- In machine element applications, the output voltage of energy harvesters fluctuates significantly
- Sensors operate at $V_{DD} = 1.8V; 3.3V$
→ DC-DC converter required to provide stable power supply
- Challenges involved in the DC-DC conversion are:
 1. Overcoming the cold start of the DC-DC converter
 2. Ensuring the SiME's energy demand is met at all times

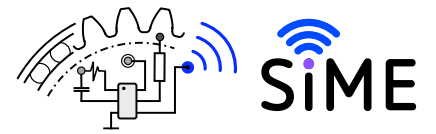


AEM13921:
Minimum cold start
voltage: $V_{INT} = 275 \text{ mV}$

- 1 Motivation
- 2 Method
- 3 Results – Temperaturefield based Condition Monitoring
- 4 Results – Energy harvesting
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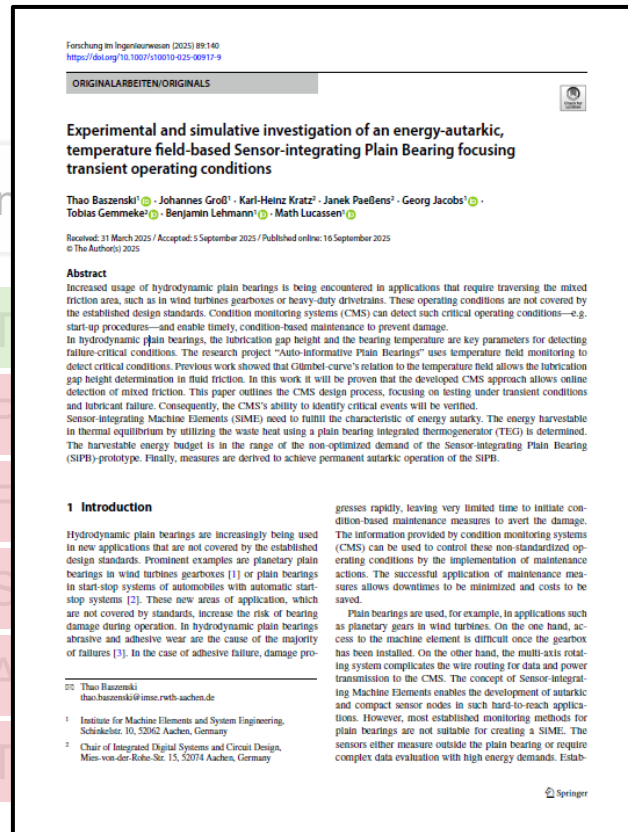
Method

Sub-modules for Sensor-integrating Plain Bearings



Project goal:

CMS for plain bearings that meets the criteria for a sensor-integrating machine element (SiME)



Sensor-integrating Plain Bearing

Energy Harvesting

Piezoelectric
Photoelectric
Triboelectric
Electromagnetic

Data Transmission

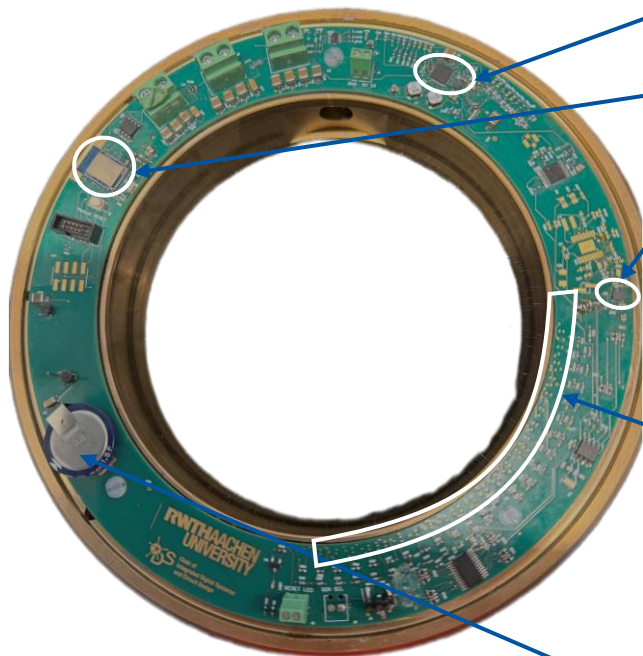
NFC
WLAN
Zig-Bee
Lora
4G/ 5G

Paper included in the “SiME Conference 2024” collection (Springer Engineering Research) [Bas25]
→ Detailed description of the selected submodules



- Wireless data transfer through the bearing housing using BLE
- Experimental proof: abrasion was detectable upon occurrence in [Bas25]
- TFM-based detection of abnormal events has only been investigated simulatively yet

View: back (motor side)



DC-DC-Converter (AEM 13921)

BLE-Module (MDBT42)

Vibration sensor (BMA 530)

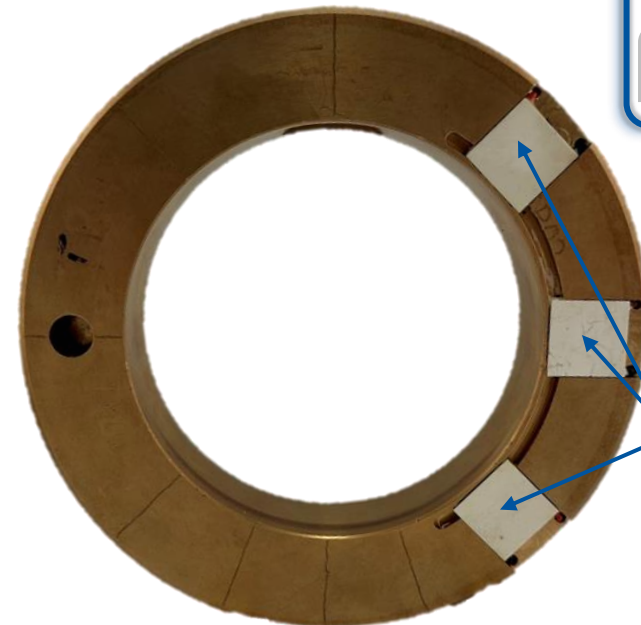
Digital temperature sensors (TI TMP117)

Quantity:	24
Angular resolution:	3.75°
Sample rate:	2.5 Hz
Angular span:	180-266.25°
T _{max} :	150 °C
ΔT:	0.0078 °C

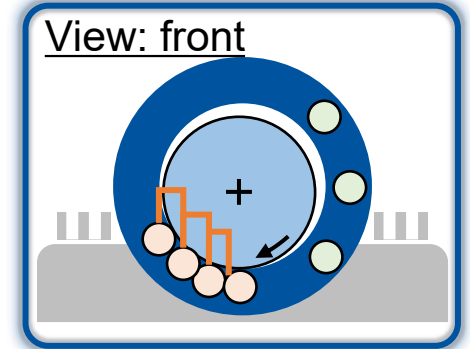
Super-Cap (energy buffer)
Capacitance C: 1.5 F

50 mm

View: front

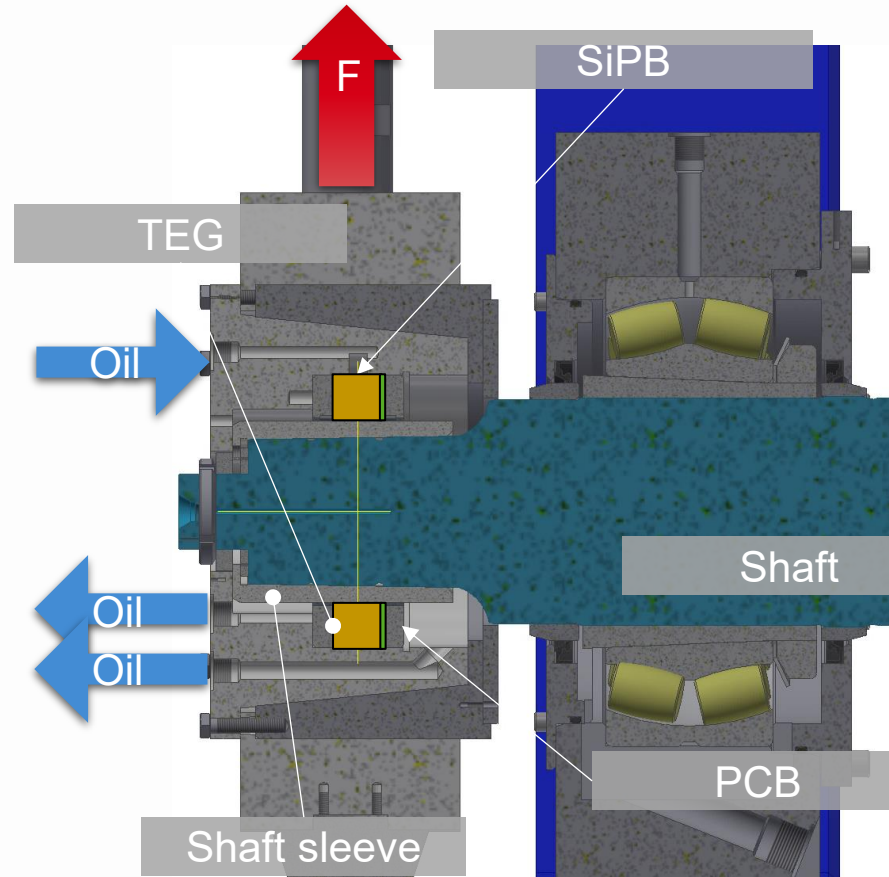
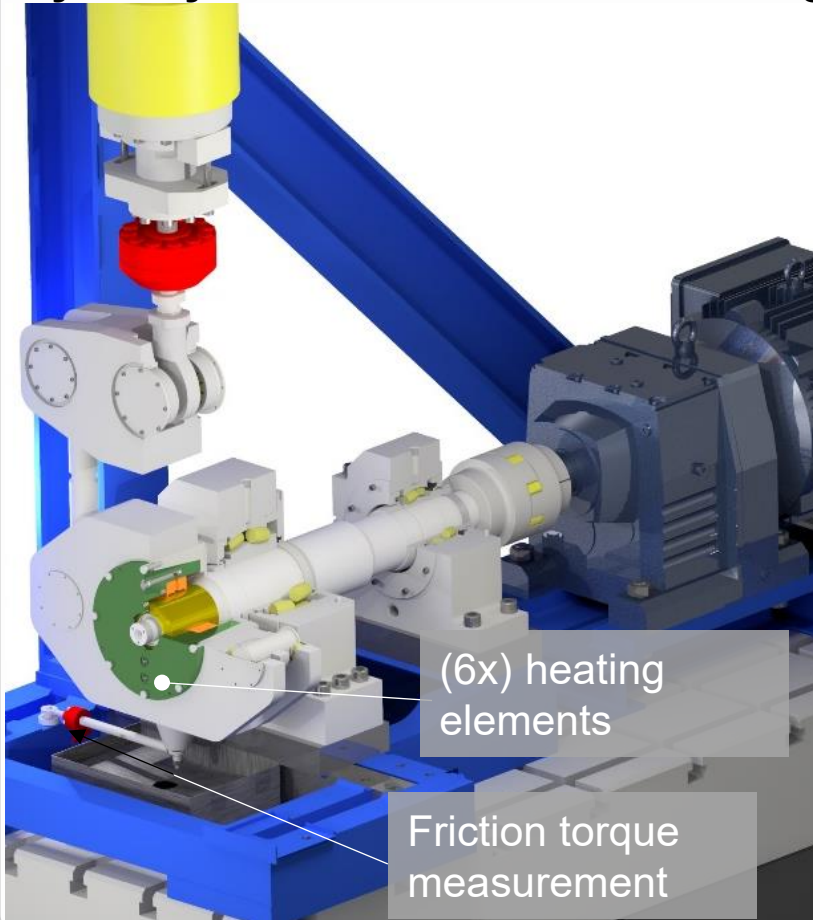


Thermogenerator (MGM250-71-10-16)
Width: 22 mm
Height: 3.2 mm
Quantity: 3
Series connection



Hardware cost prototype (lot size 1): approx. 300 €

Hydrodynamic Radial-Plain Bearing Test Rig (120 mm)



Specific Pressure $\bar{p}$:
max: ~65 MPa
Sliding Speed $\bar{v}$:
0.0006-3.45 m/s

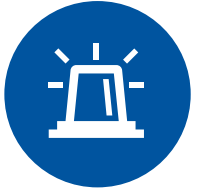
Bearing inner diameter d_i [mm]	120
Bearing width b [mm]	30
Bearing outer diameter d_a [mm]	180
Rel. Bearing clearance ψ [-]	1.1 ‰
Bearing Material	CuSn12Ni2-C [Deu05]
Bearing Roughness R_a [μm]	0.5
Shaft Material	42CrMo4 [Sta26]
Shaft Roughness R_a [μm]	0.5
Shaft Hardness HRC [-]	56
Oil type	Castrol Optigear CT320 (PAO-based gearbox oil) [Cas17]
Oil supply pressure $p_{\text{Oil,in}}$ [MPa]	0.2
Initial Temperature $T_{\text{Initial}} = T_{\text{oil}} = T_{\text{frictionbalance}}$ [$^{\circ}\text{C}$]	20 (Energy Harvesting); 60; 80
Particle contamination level [-]	0.1g (iron dust (4-6 μm)/ 100g (oil)) [Dec25]



Method

Test procedure

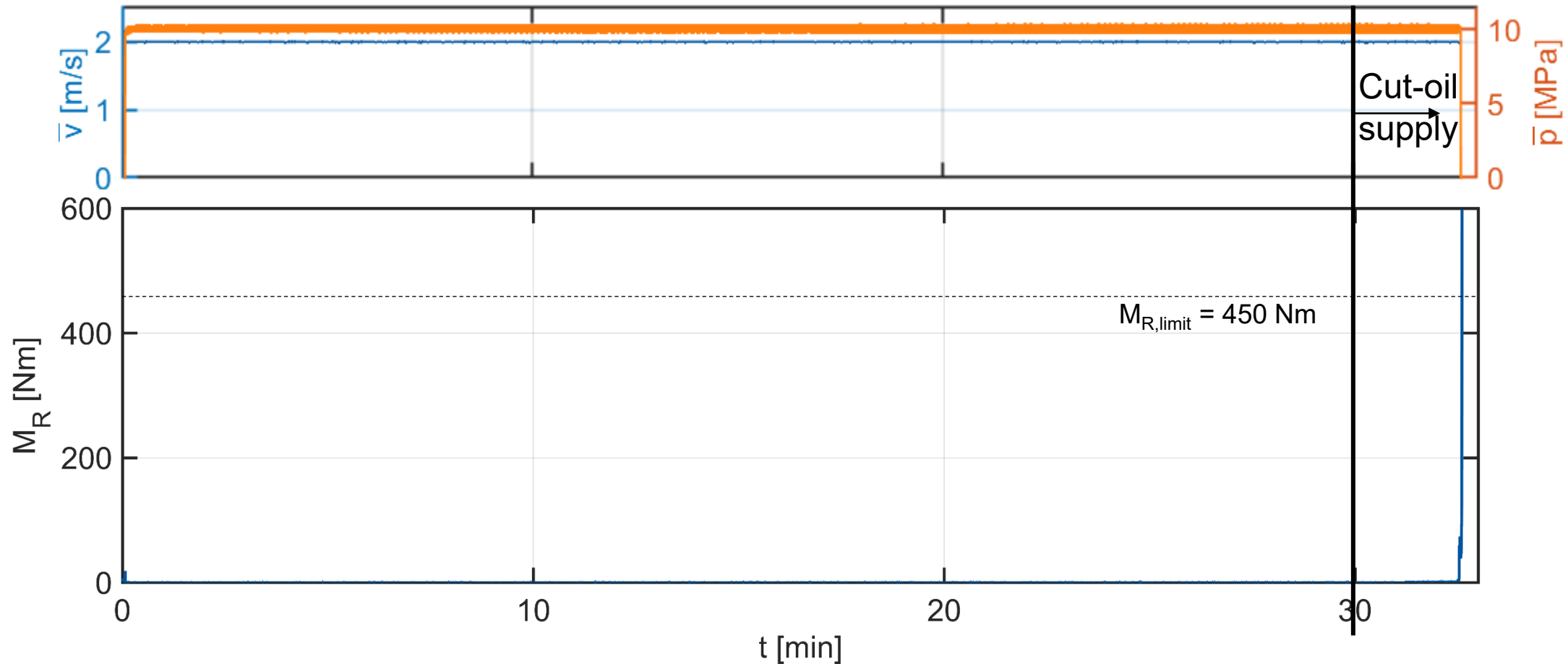
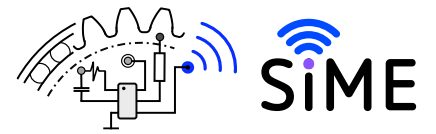
	Test	$\bar{v}$ [m/s]	$\bar{p}$ [MPa]	$T_{Initial}$ [°C]	Experimental Procedure	Termination criterion	Purpose
CMS Focus	OSF	2	10	60	Defined oil cut-off after 30 min regular operation	$M_{R,limit} = 450 \text{ Nm}$	Identify TFM-based characteristics that form before an increase in friction torque M_R
	Mechanical overload	3	60	80	Regular oil supply		
	Conta- mination	0.5	20	60	1. Run-In procedure 2. Contamination		
EH Focus	Energy harvesting	0.25– 3.45	0.5– 20	Ambi ent (20)	Regular operation until thermal steady state (3h) 98x $\bar{v} - \bar{p}$ combinations	-	Determine $\bar{v} - \bar{p}$ –conditions enabling: 1. Cold start DC-DC converter 2. Covering energy demand SiPB



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Temperaturefield based Condition Monitoring

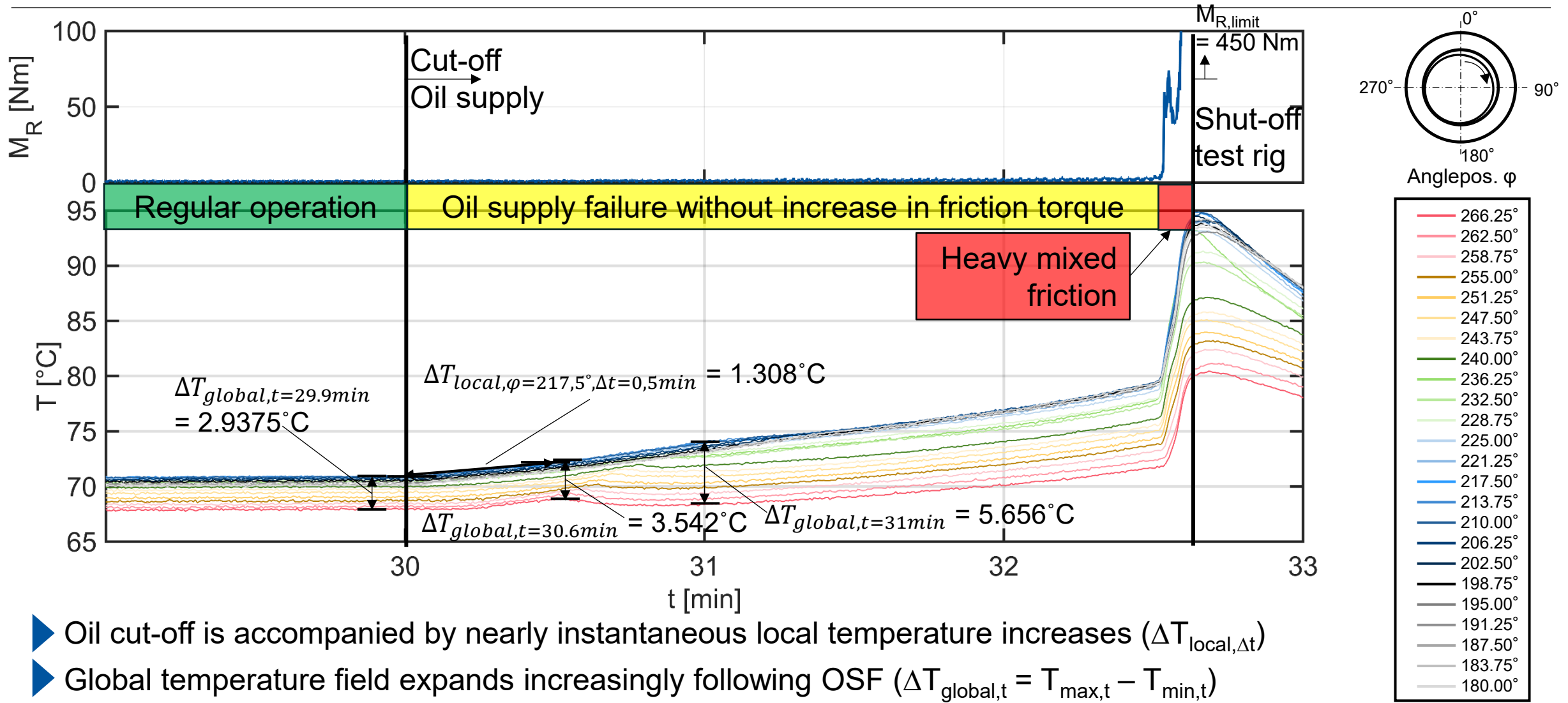
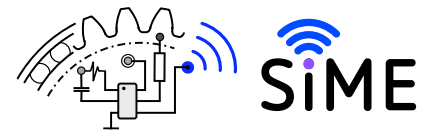
Oil supply failure (OSF) ($T_{\text{Initial}} = 60\text{ }^{\circ}\text{C}$, $\bar{v} = 2\text{ m/s}$, $\bar{p} = 10\text{ MPa}$)



► Termination of the test due to exceeding the friction torque limit ($t = 32.64\text{ min}$)

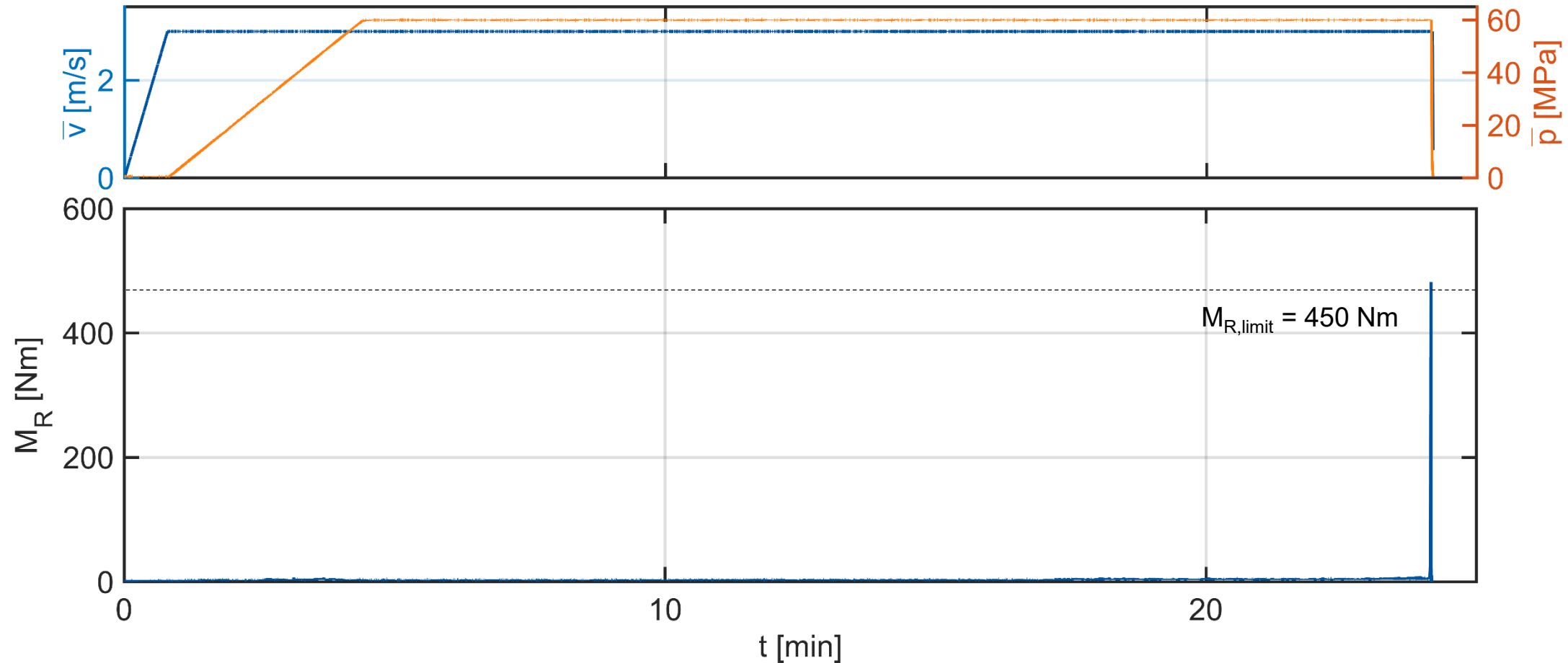
Temperaturefield based Condition Monitoring

Oil supply failure (OSF) ($T_{\text{Initial}} = 60^\circ\text{C}$, $\bar{v} = 2\text{ m/s}$, $\bar{p} = 10\text{ MPa}$)



- ▶ Oil cut-off is accompanied by nearly instantaneous local temperature increases ($\Delta T_{\text{local}, \Delta t}$)
- ▶ Global temperature field expands increasingly following OSF ($\Delta T_{\text{global}, t} = T_{\text{max}, t} - T_{\text{min}, t}$)

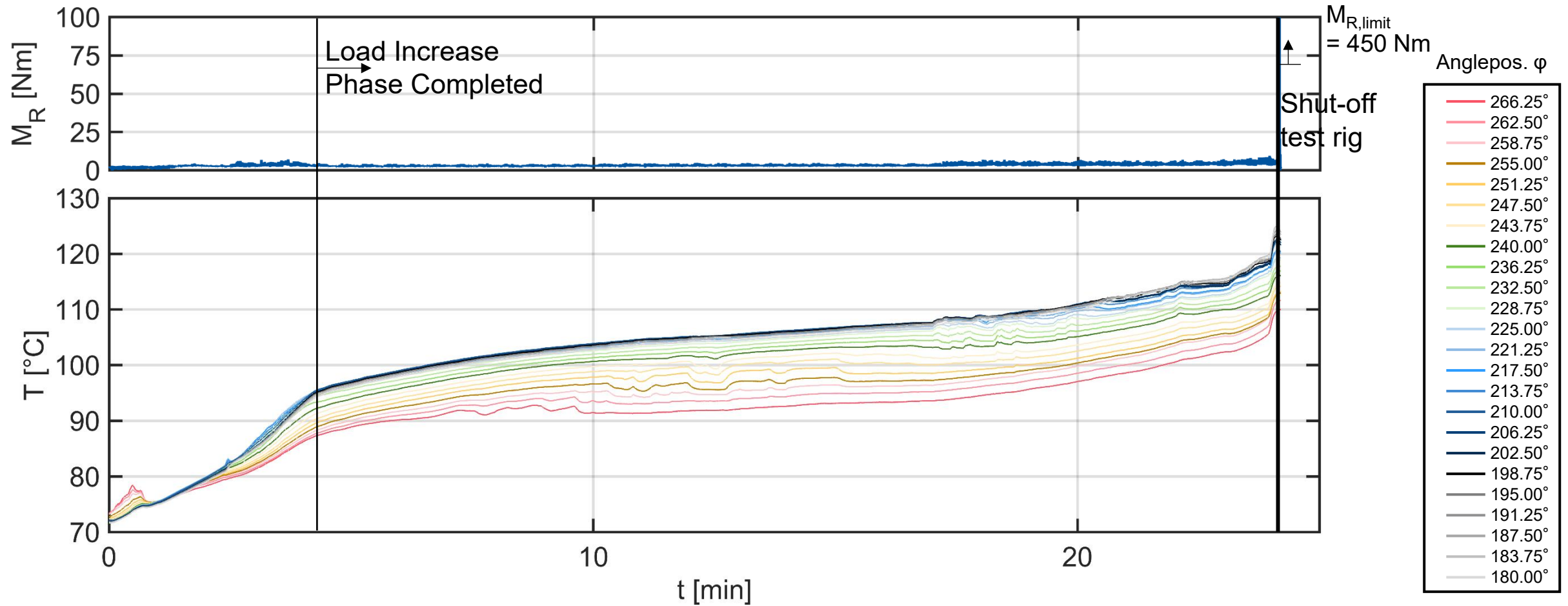
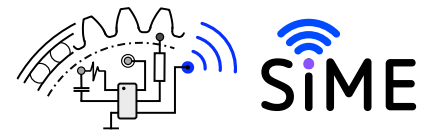
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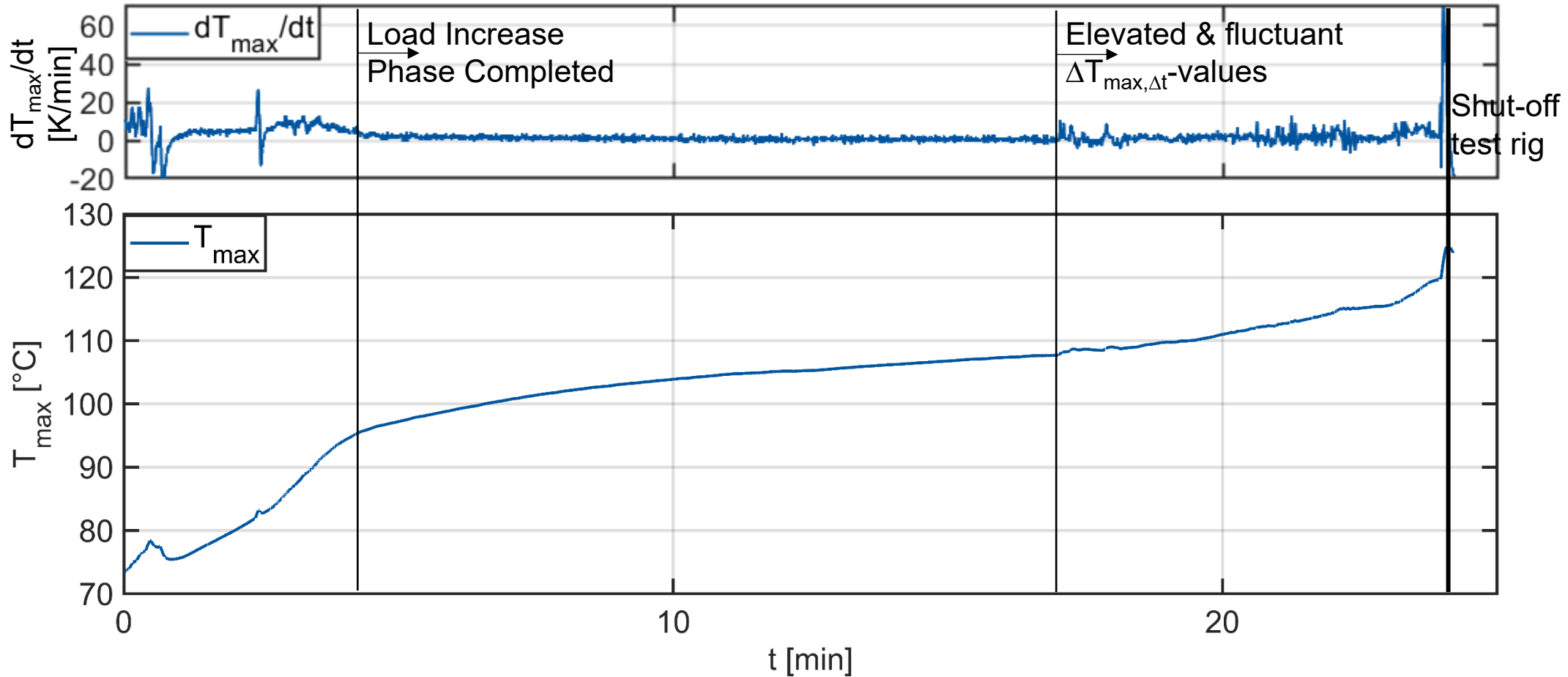
► Termination of the test due to exceeding the friction torque limit ($t = 24.16 \text{ min}$)

Temperaturefield based Condition Monitoring

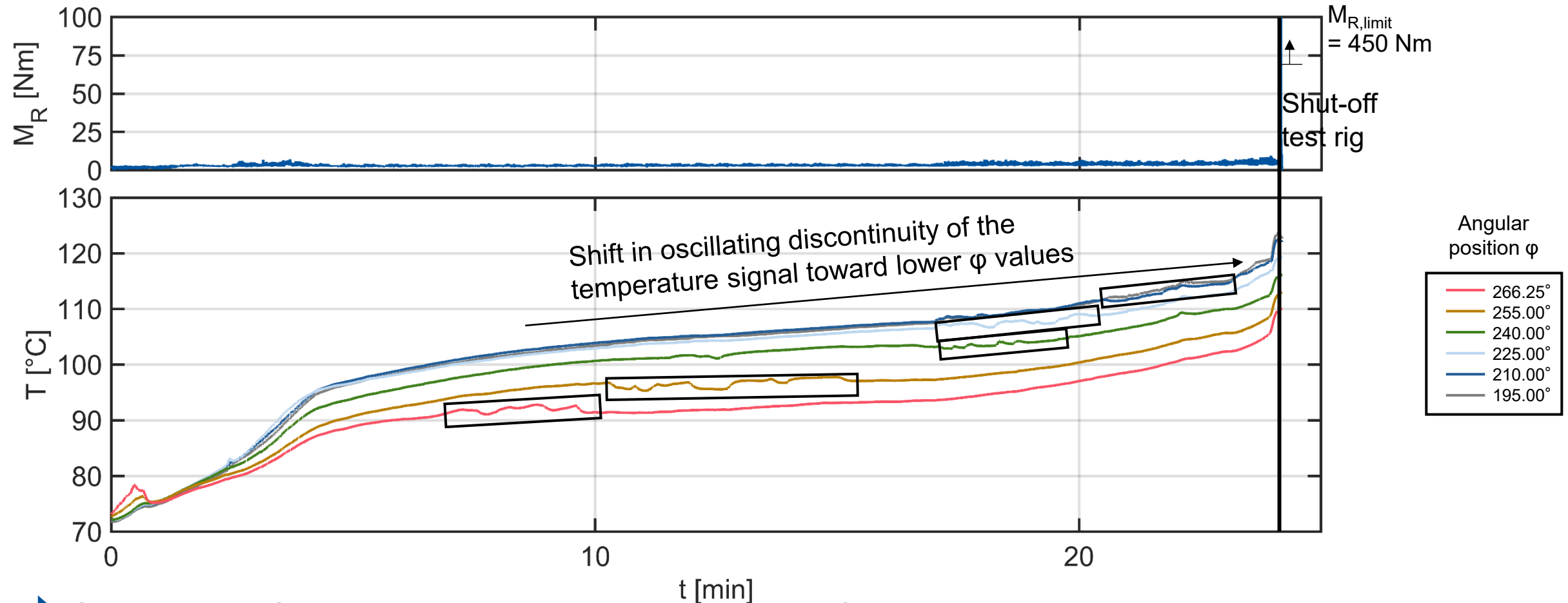
Overheating due to mechanical overload ($T_{\text{Initial}} = 80 \text{ }^{\circ}\text{C}$, $\bar{v} = 3 \text{ m/s}$, $\bar{p} = 60 \text{ MPa}$)



► High temperature level ($>100 \text{ }^{\circ}\text{C}$) & an increasing, unsteady $\Delta T_{\text{max}, \Delta t}$ -gradient as signs of impending damage

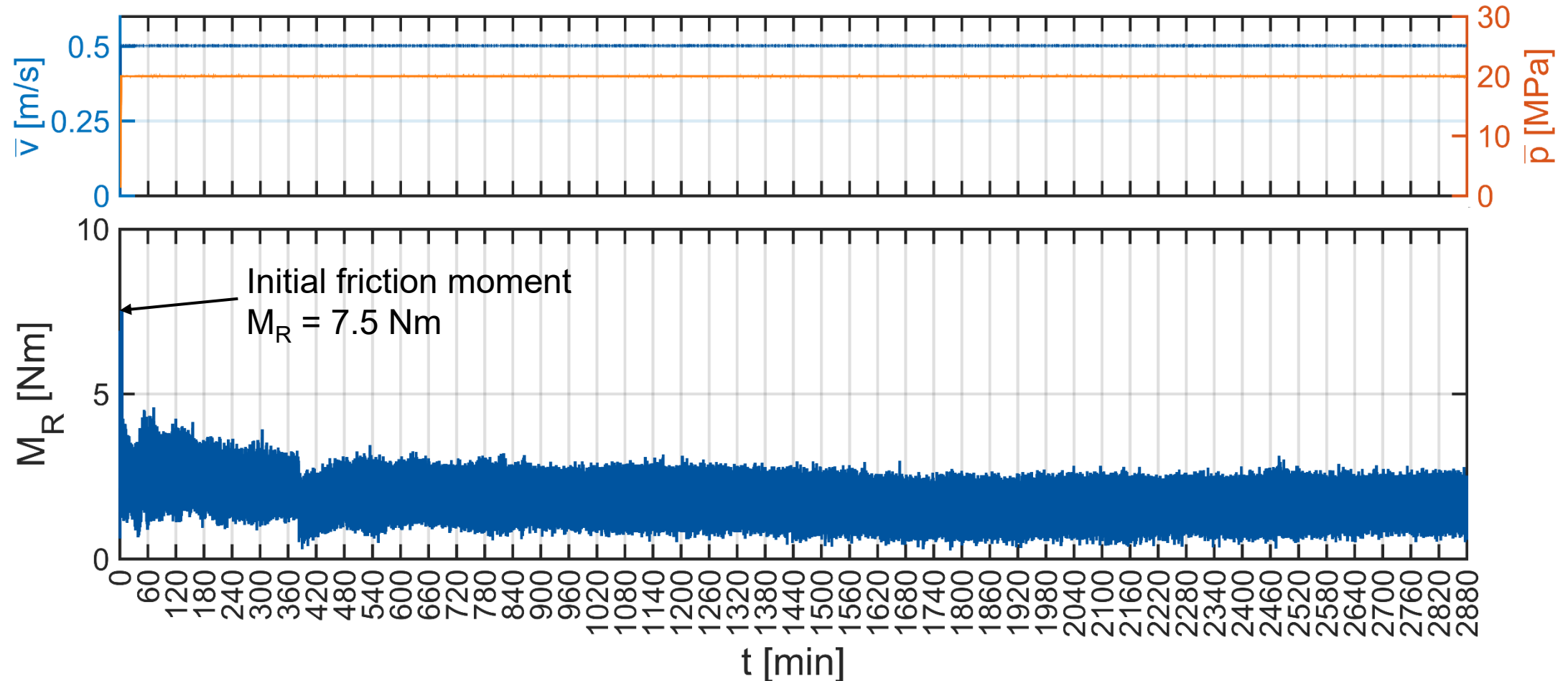


► High temperature level ($>100 \text{ }^{\circ}\text{C}$) & an increasing, unsteady $\Delta T_{\text{max}, \Delta t}$ -gradient as signs of impending damage

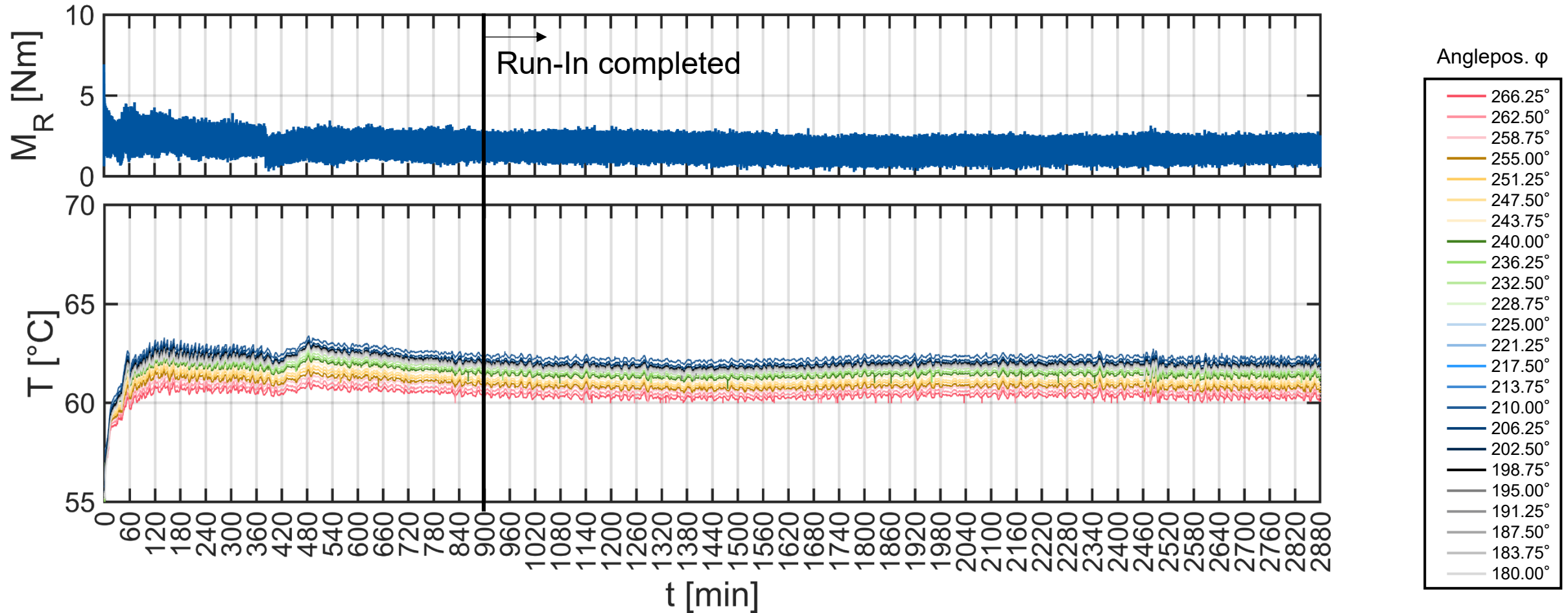


- ▶ Characteristic Oscillations in the temperature signals shifting position during overloading tests
- ▶ Further investigations needed to understand the underlying physical mechanisms

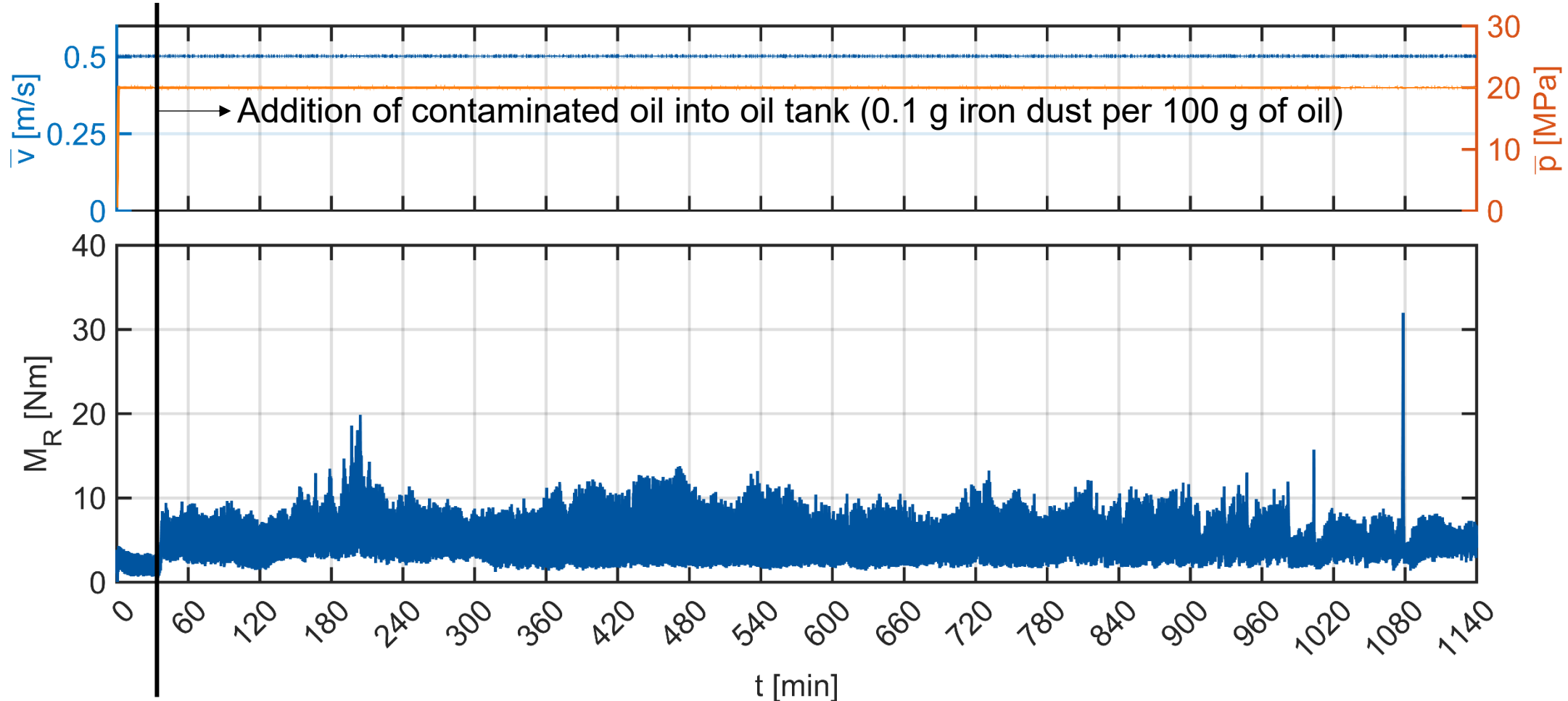
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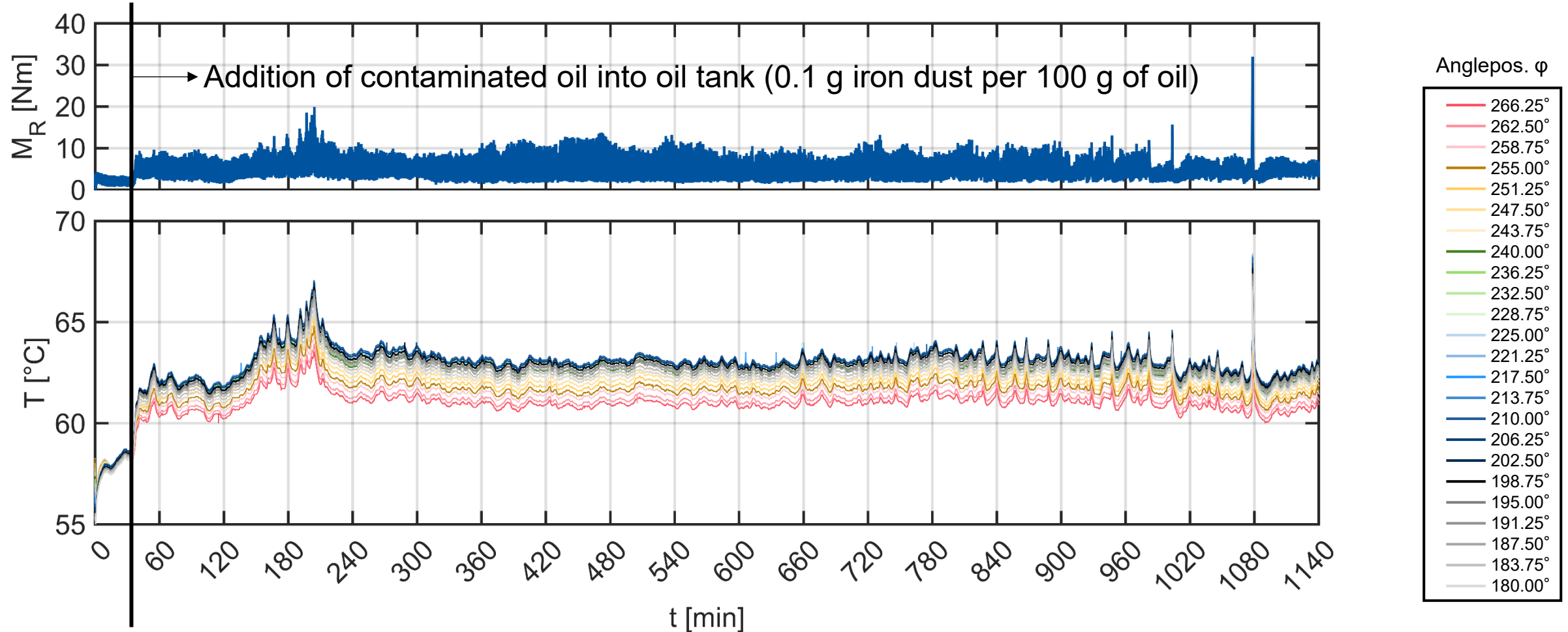
► Purpose: polish roughness peaks, minimal gap height in fluid friction regime during subsequent contamination



► Uniform temperature distribution and friction torque value → Run-in completed after approximately $t = 900$ min



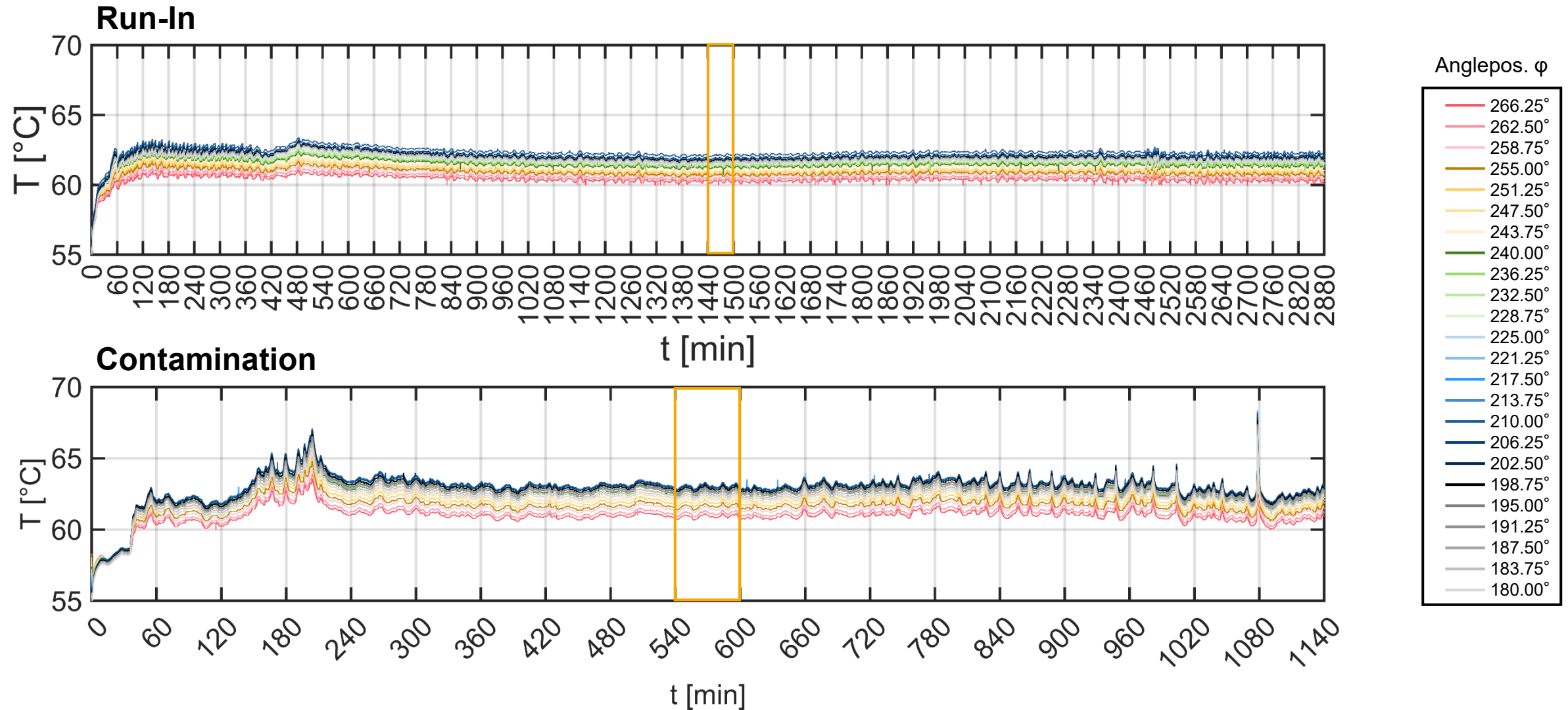
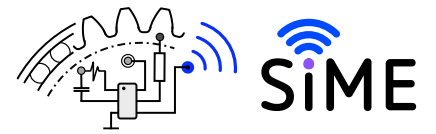
► Three-body abrasion caused, resulting in a more erratic friction torque curve with local peaks during test



► Qualitative temperaturefield curves correlate highly with friction torque curve over time

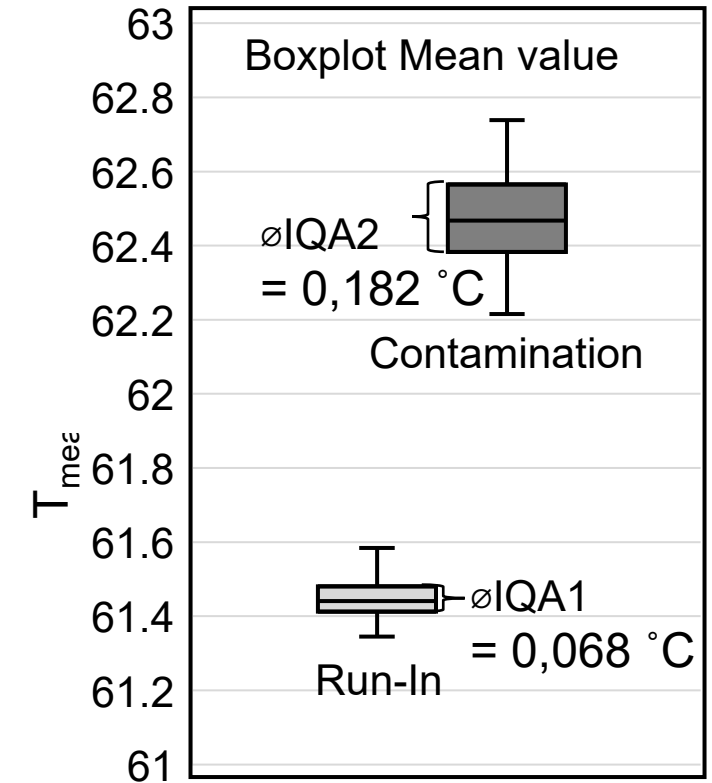
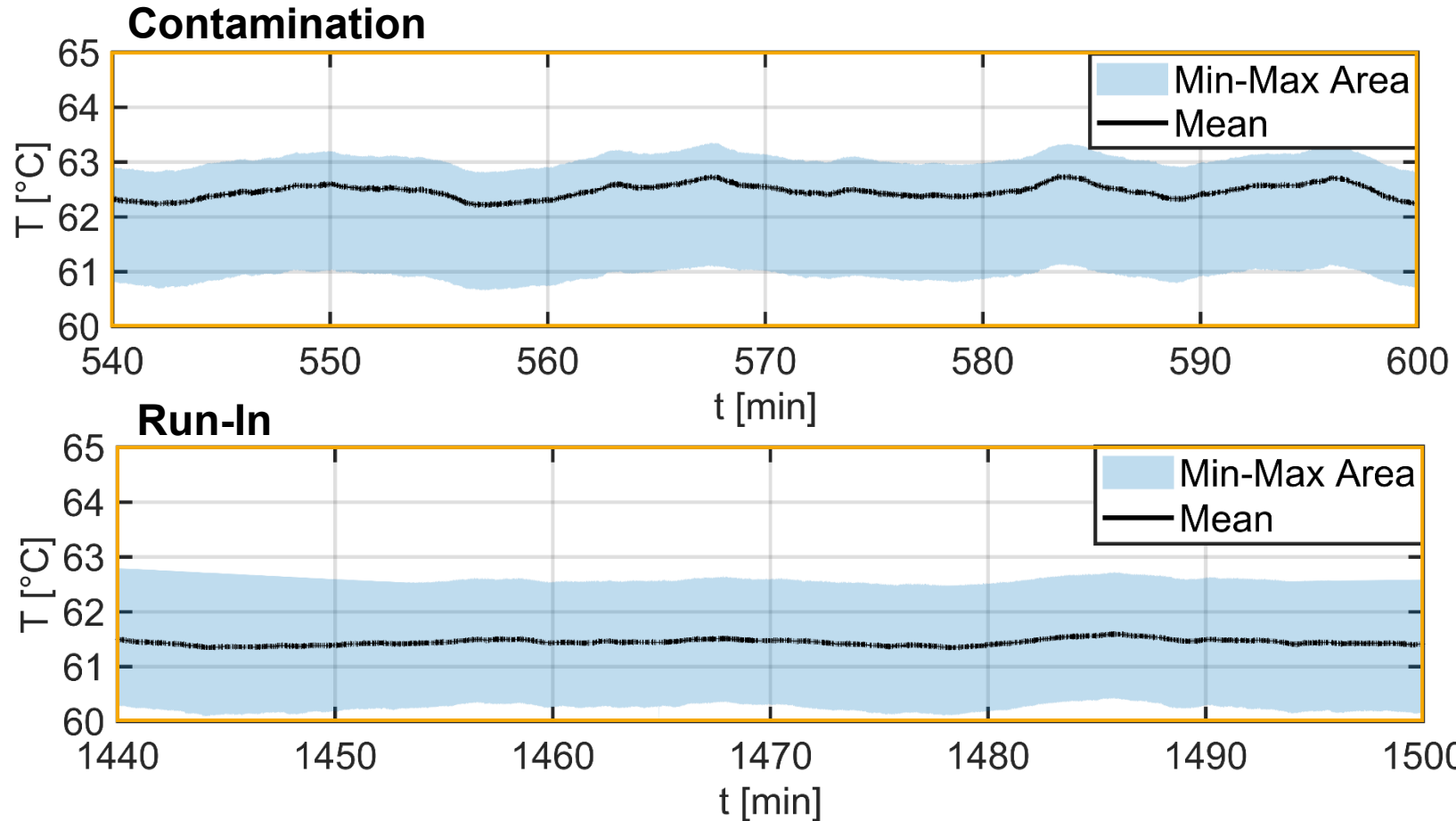
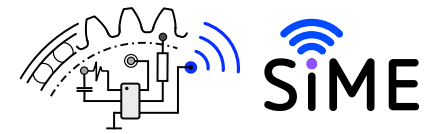
Temperaturefield based Condition Monitoring

Particle contamination – Run-In vs. Contamination



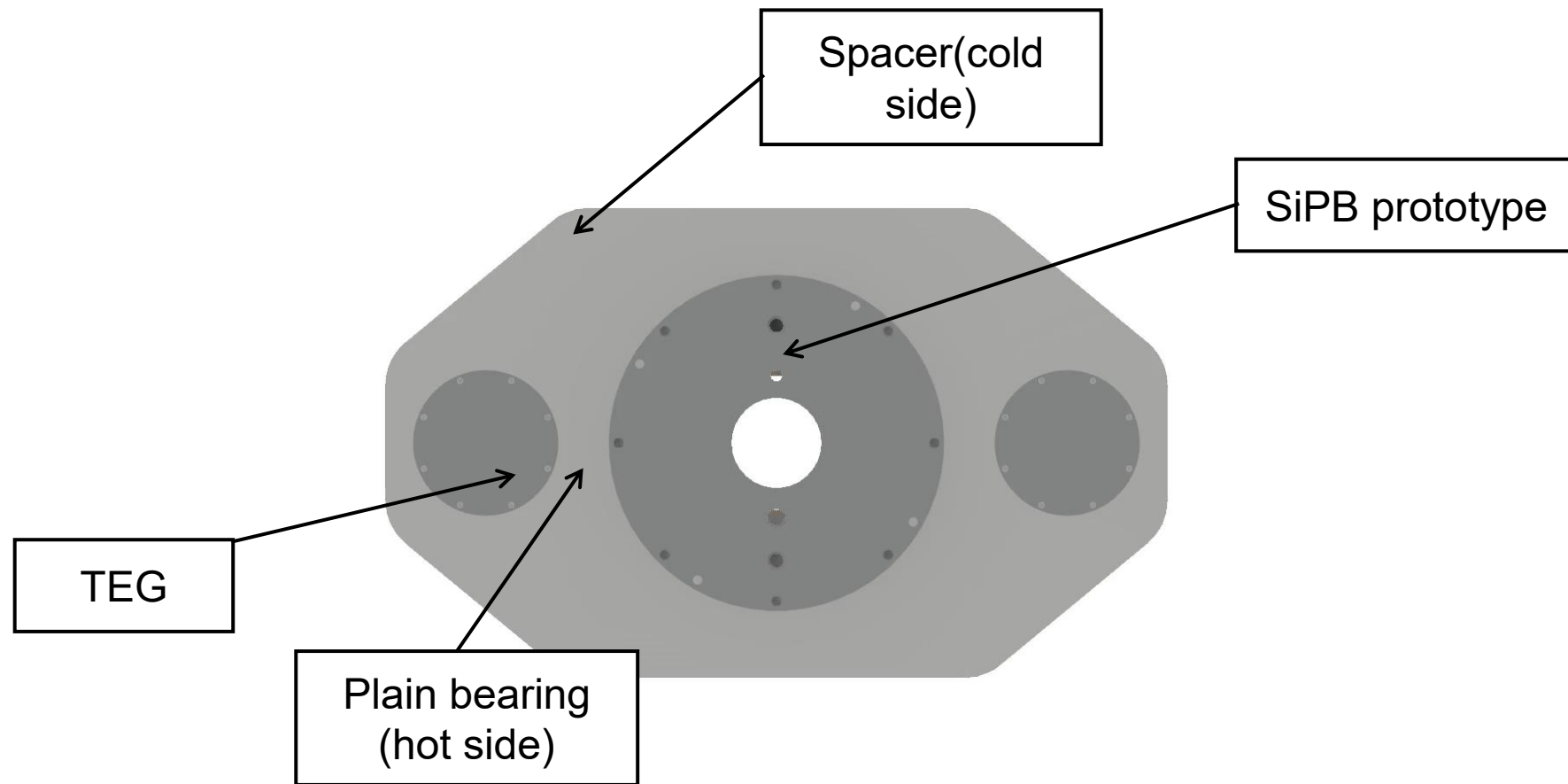
Temperaturefield based Condition Monitoring

Particle contamination – Run-In vs. Contamination



- Interquartile Range (IQA) as a characteristic for the detection of three-body abrasion
- Additionally, friction torque curve can be estimated qualitatively based on the temperature field

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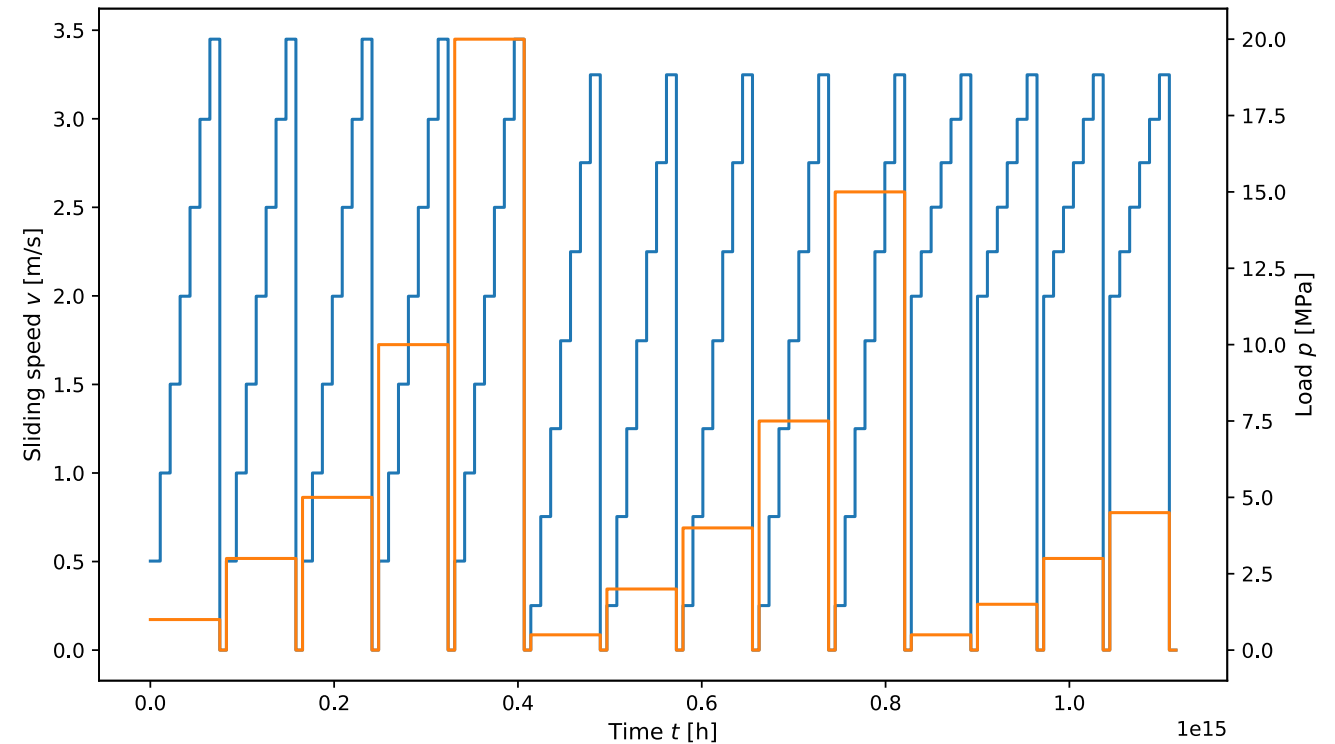


Operating conditions

- Fluid friction regime
- No pre-heating of the lubricating oil or the load actuator
- Thermal steady-state reached
- 3h per load condition

Measurement

- 1st hour: cold start condition and testing
- 2nd & 3rd hour: external power (avoid limitations of energy harvesting)
- Storage capacitor voltage V_{STO}
- Temperature field and TEG power output



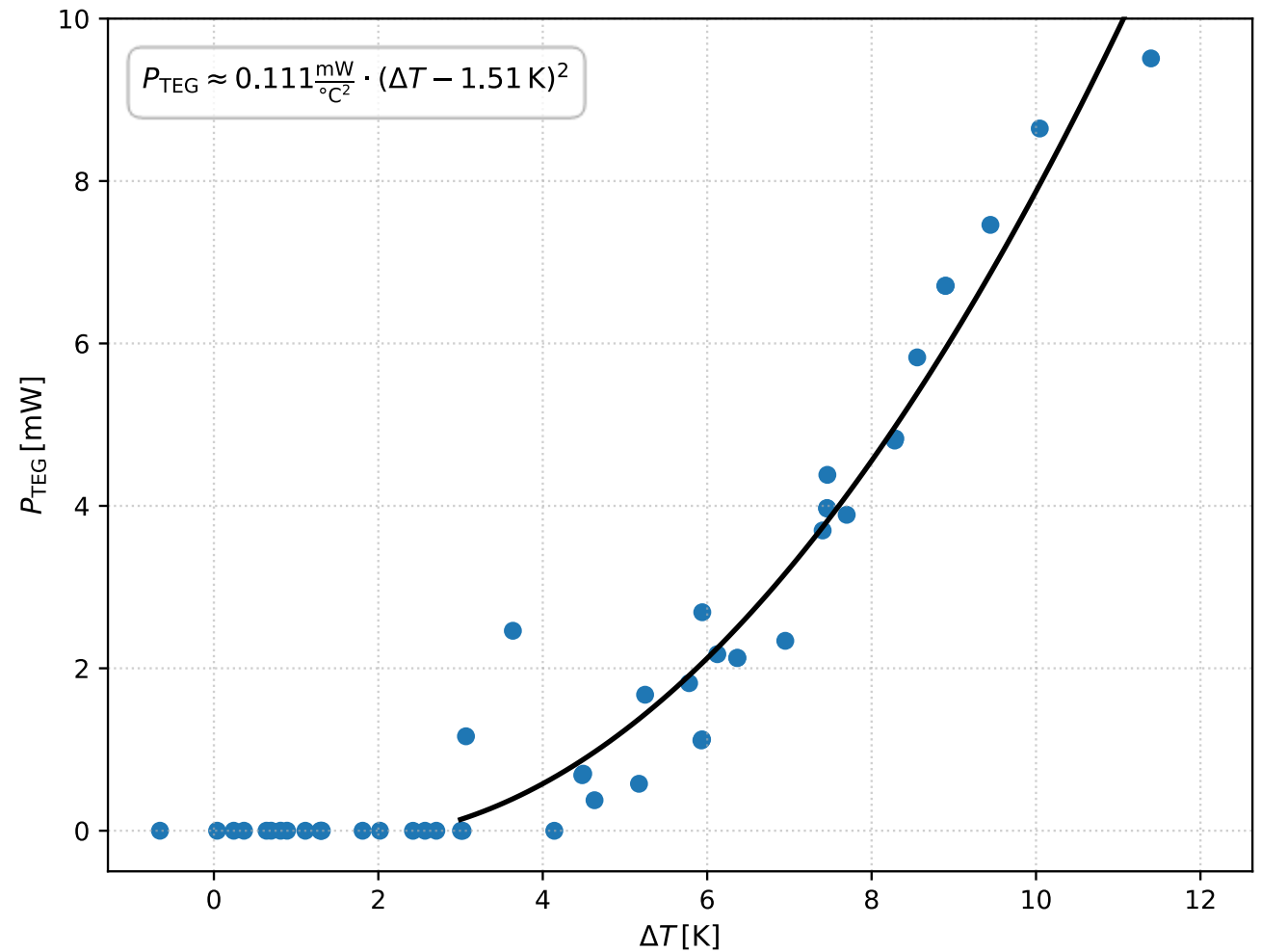
- Temperature difference measured between bearing and spacer by the test rig
- Minimum temperature difference for harvesting: $\Delta T = 2.5^\circ\text{C}$
- RMSE: 0.5485 mW

Relationship between ΔT and P [Row05]

$$P_{\max} = \frac{\alpha^2}{4R_{\text{int}}} \cdot \Delta T^2$$

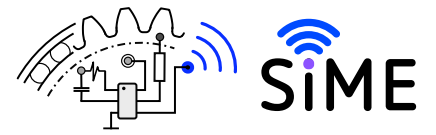
$$\alpha = 0.0125 \frac{\text{V}}{\text{K}}, \text{ calculated from [Ada17]}$$

$$\Rightarrow R_{\text{int}} = 0.35 \Omega$$

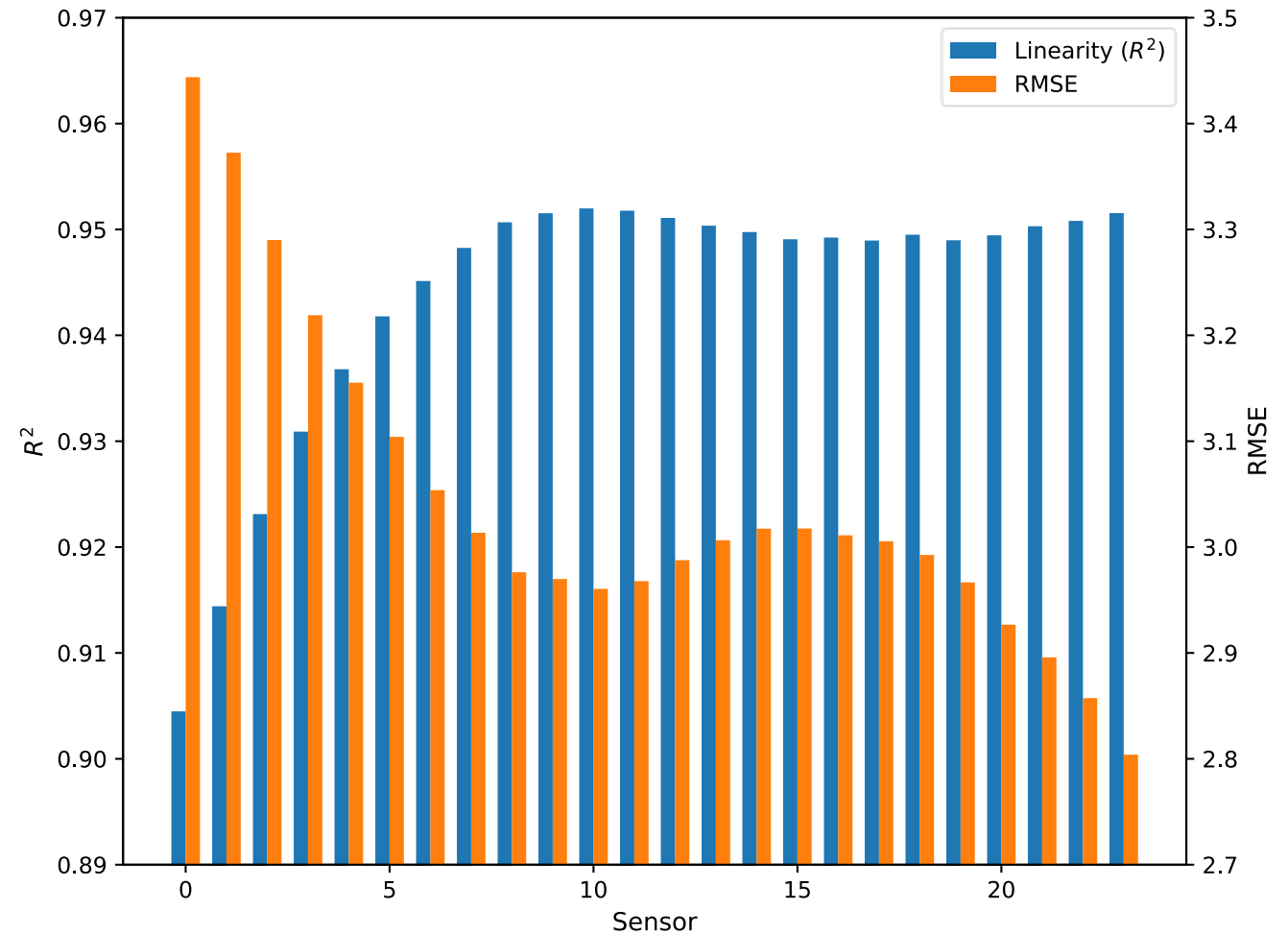


Energy harvesting

Prediction of harvestable power

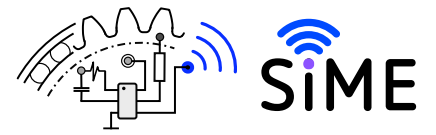


- Prediction of harvestable power by temperature sensors on SiPB prototype
- Goal: linear relationship between ΔT and absolute temperature of n^{th} temperature sensor
- High linearity for sensors T10 and T23
- Lowest RMSE for T23
- Ideal candidate for prediction: T23

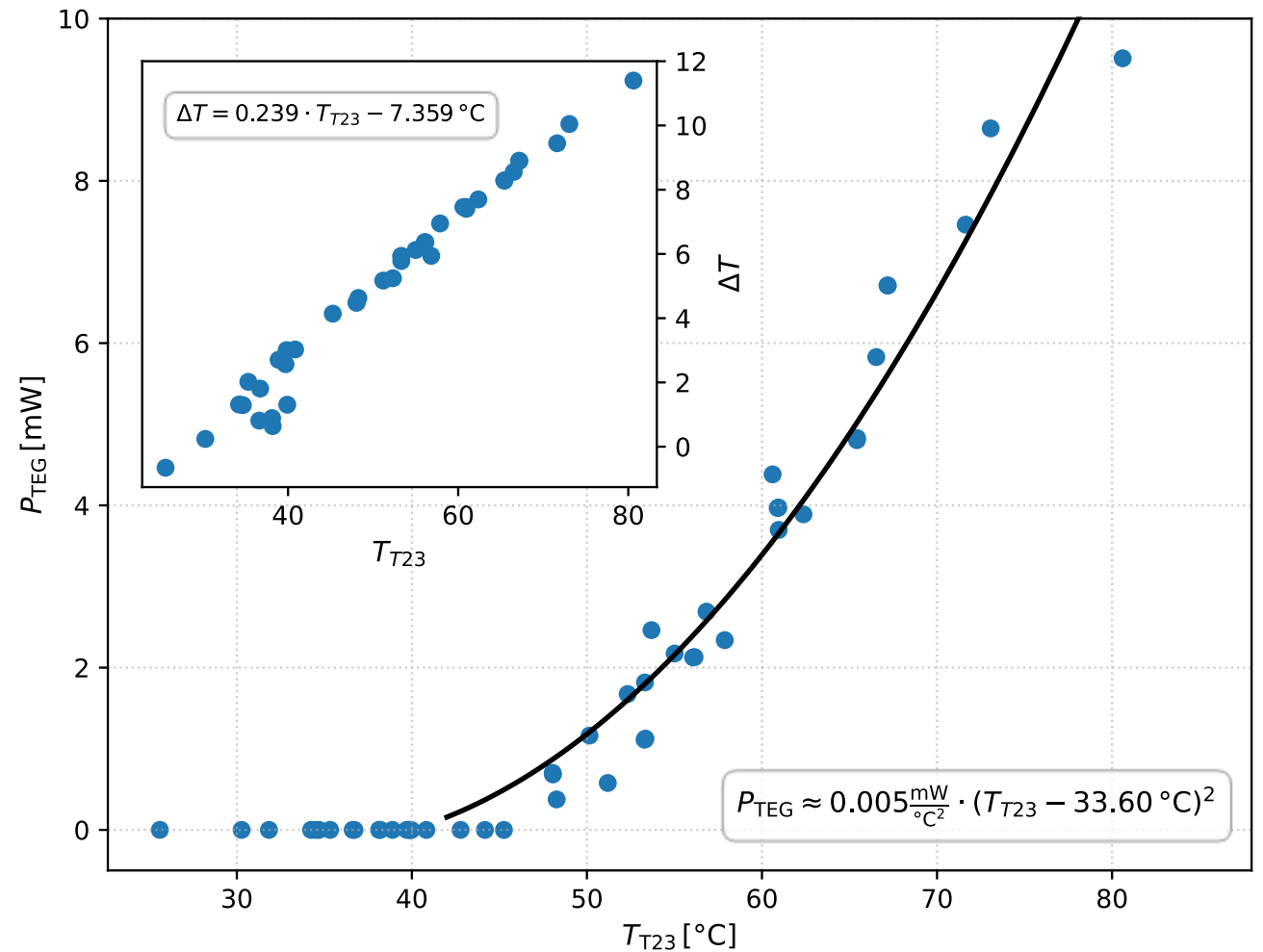


Energy harvesting

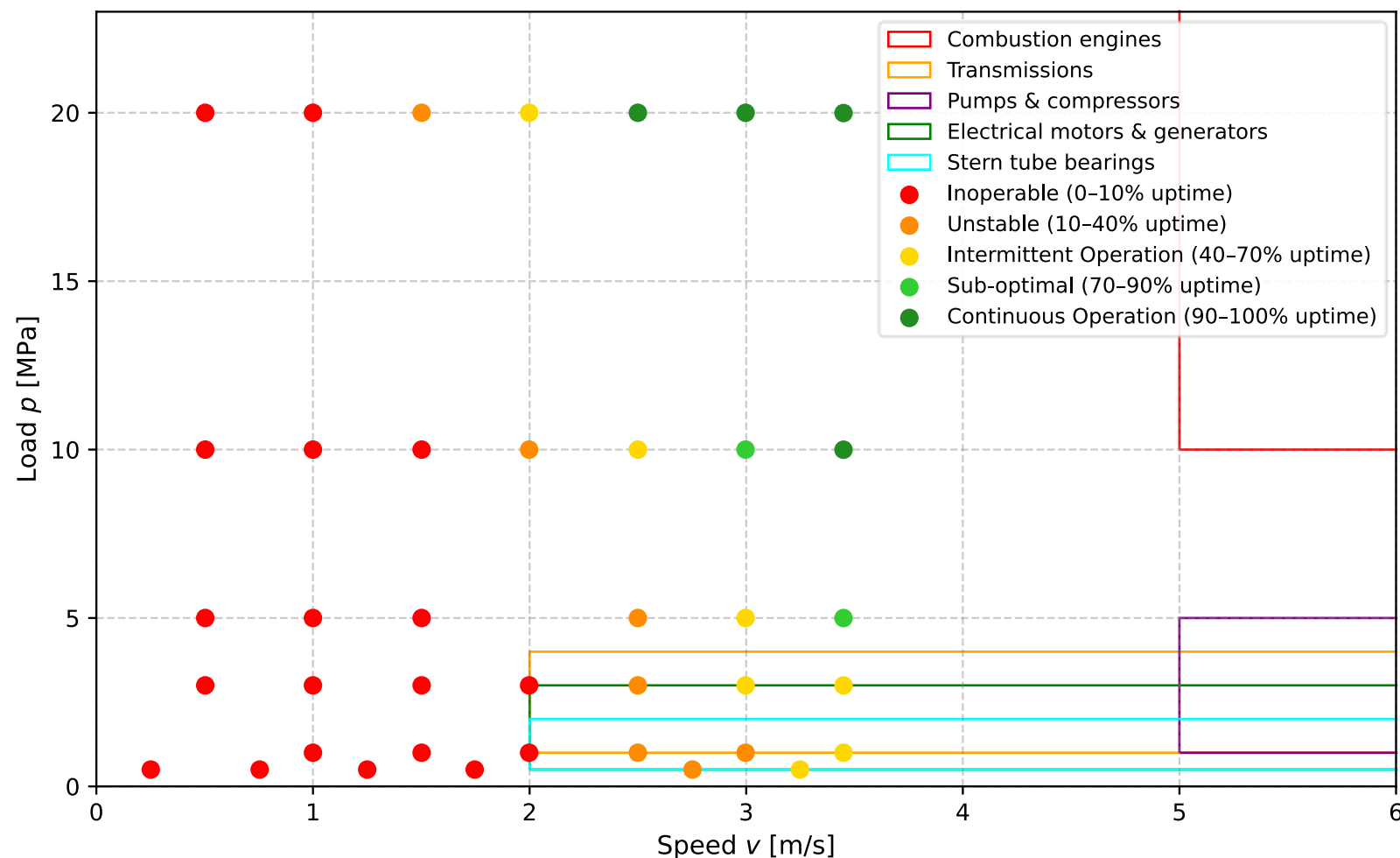
Prediction of harvestable power



- Measurement of absolute temperature at T23 on the SiPB prototype
- Data shows quadratic relationship consistent with the measurement by the test rig
- Prediction of available power by the SiPB prototype
- RMSE: 0.4700 mW

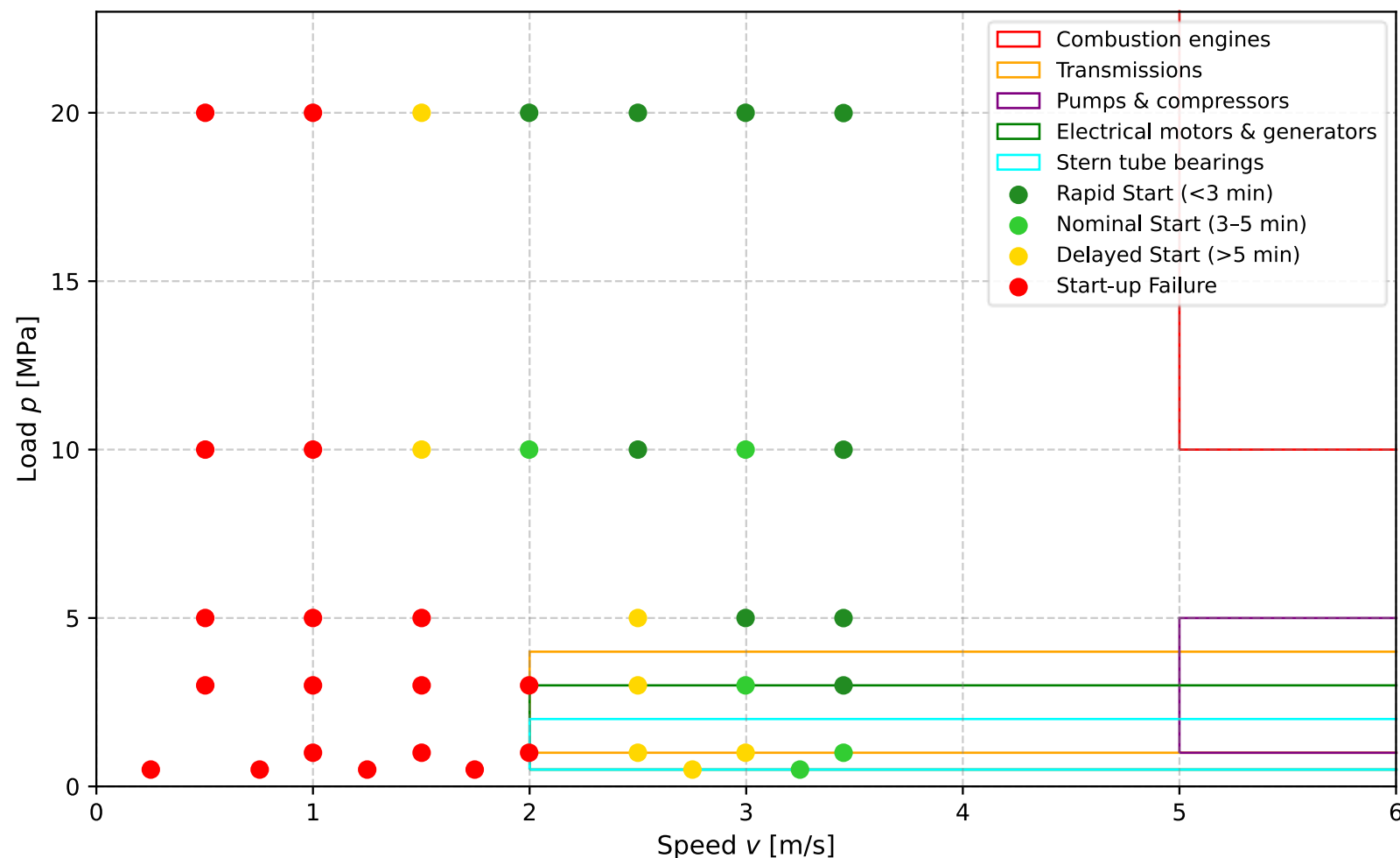


- Operable inside typical operational conditions of various applications
- Unstable or intermittent operation in target system (transmissions)
- Need for further optimizations of energy consumption



Limits of operation:

- Minimum startup time of 2 min
- Nominal startup for speeds
 - ≥ 2 m/s for high loads
 - ≥ 3 m/s for low loads



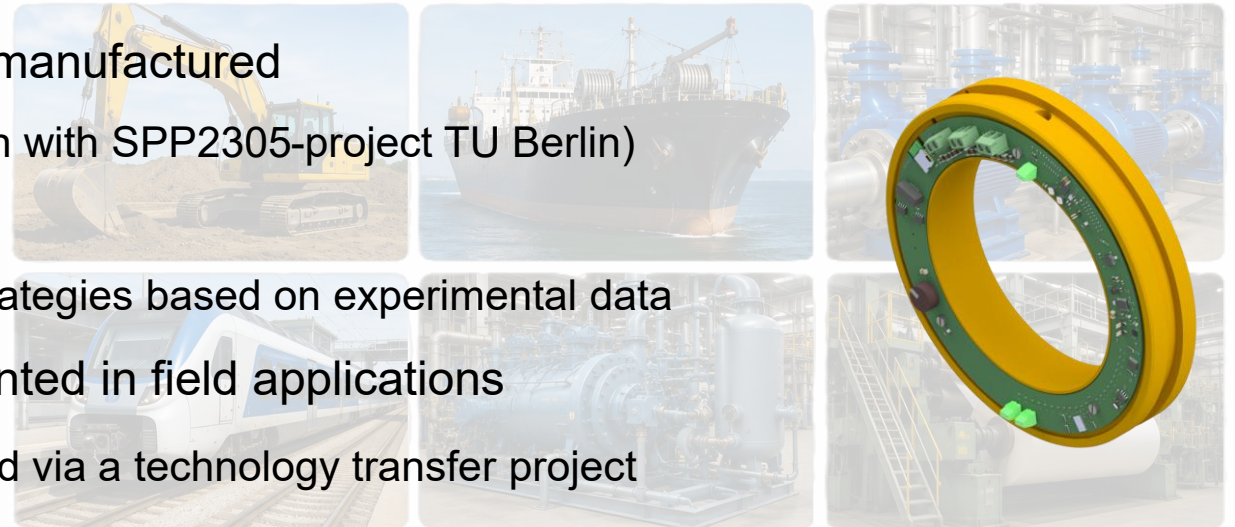
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Conclusion

- Damage critical abnormal events can be detected reliably by the developed TFM-CMS-approach
 - Oil supply failure ($\Delta T_{\text{global},t}$) & Overheating (T_{max} , dT_{max}/dt) detectable at least 2 minutes friction torque increases
 - Three-body abrasion caused by particle contamination can be detected instantly upon occurrence ($\varnothing \text{IQA}$)
- Energy autarky proven at a sliding speed $\bar{v} \geq 2.5 \text{ m/s}$

Outlook

- Final and energy-optimized prototype generation manufactured
 - Vibration sensor for speed estimation (collaboration with SPP2305-project TU Berlin)
 - ➔ Increased robustness of the CMS
 - Developing alarm thresholds and measurement strategies based on experimental data
- The finalized concept is now ready to be implemented in field applications
 - ➔ Seeking industry partners to apply the concept in field via a technology transfer project



Thank you for your interest!

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