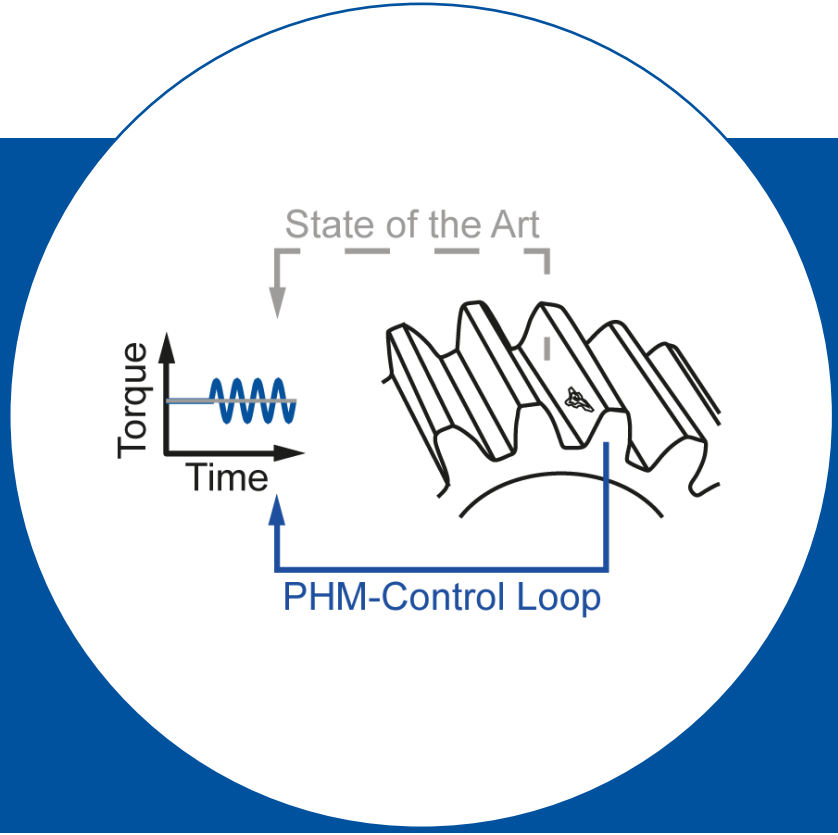
University of Stuttgart
Institute of Machine Components
Drive Technology

Simulation of an Adaptive Operating Strategy to Extend the Lifetime of Wind Turbine Gearboxes



EERA DeepWind conference 2024
Trondheim, Norway – Jan 18th, 2024

EERA DeepWind conference 2024 – 4C) Operation & Maintenance

Simulation of an Adaptive Operating Strategy to Extend the Lifetime of Wind Turbine Gearboxes

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- Motivation
- Adaptive Operating Strategy
- Simulation
- What‘s next?

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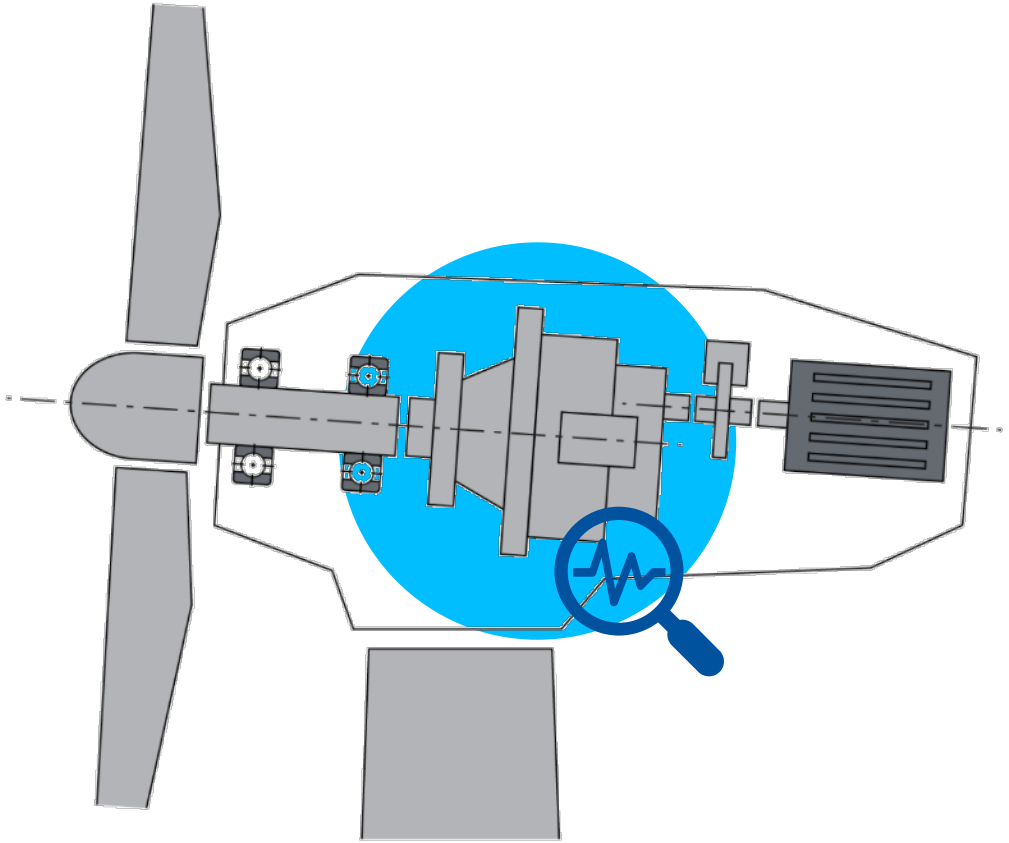
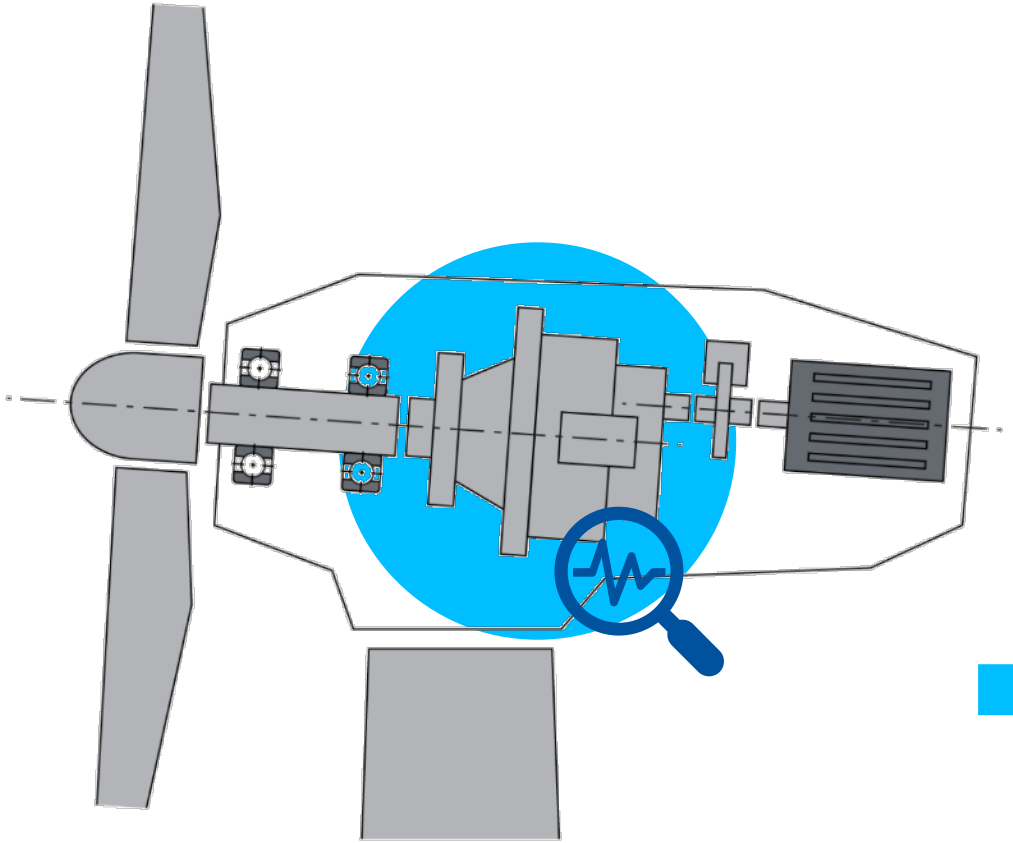
Motivation
Increasing the Remaining Useful Life in Drivetrain Applications



- Drive failures in plants with **high power output** and in **remote locations** cause
  - Downtime of the whole plant
  - High maintenance costs
  - Environmental damages

Motivation
Increasing the Remaining Useful Life in Drivetrain Applications

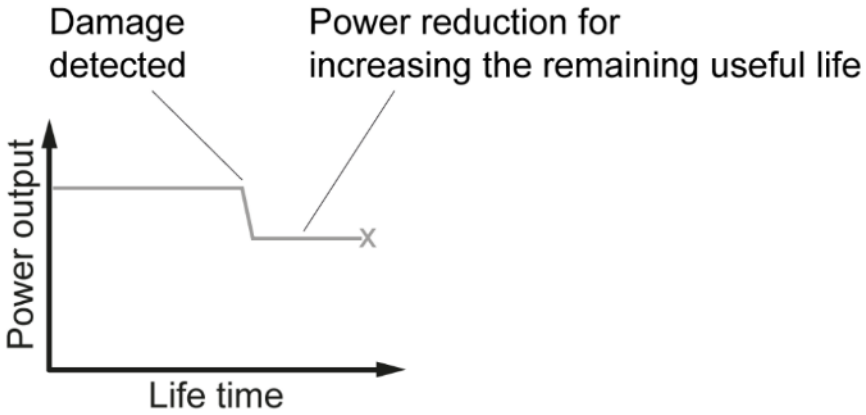


- Drive failures in plants with **high power output** and in **remote locations** cause
  - Downtime of the whole plant
  - High maintenance costs
  - Environmental damages

These systems are often equiped with **condition monitoring systems (CMS)**

Motivation
Increasing the Remaining Useful Life in Drivetrain Applications

State of the art:
CMS and **global power reduction** if a damage is detected



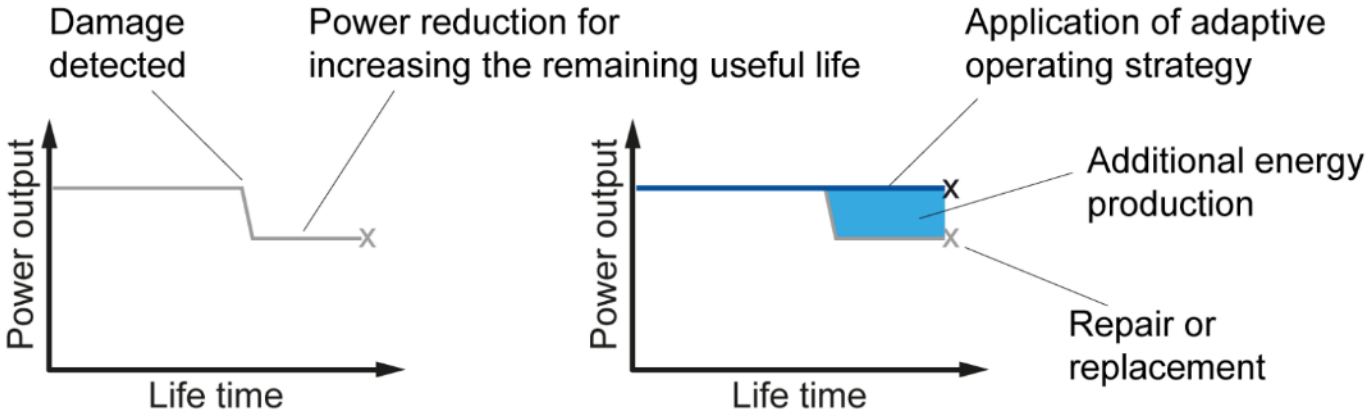
Motivation

Increasing the Remaining Useful Life in Drivetrain Applications

State of the art:
CMS and **global power reduction** if a damage is detected

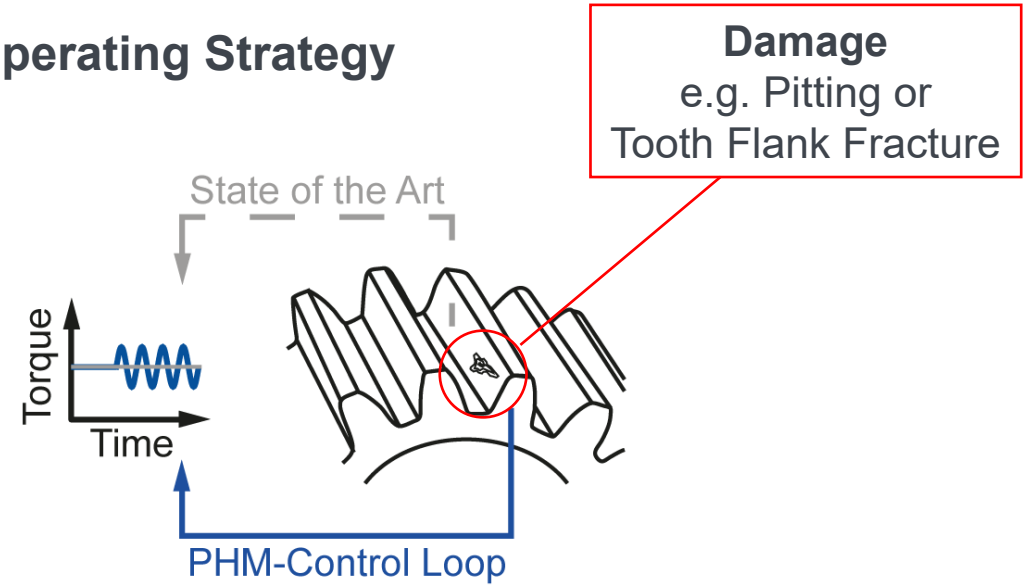
New Approach:
Local load reduction of a damaged part with an adaptive operating strategy

Increasing the remaining useful life with **constant power output**



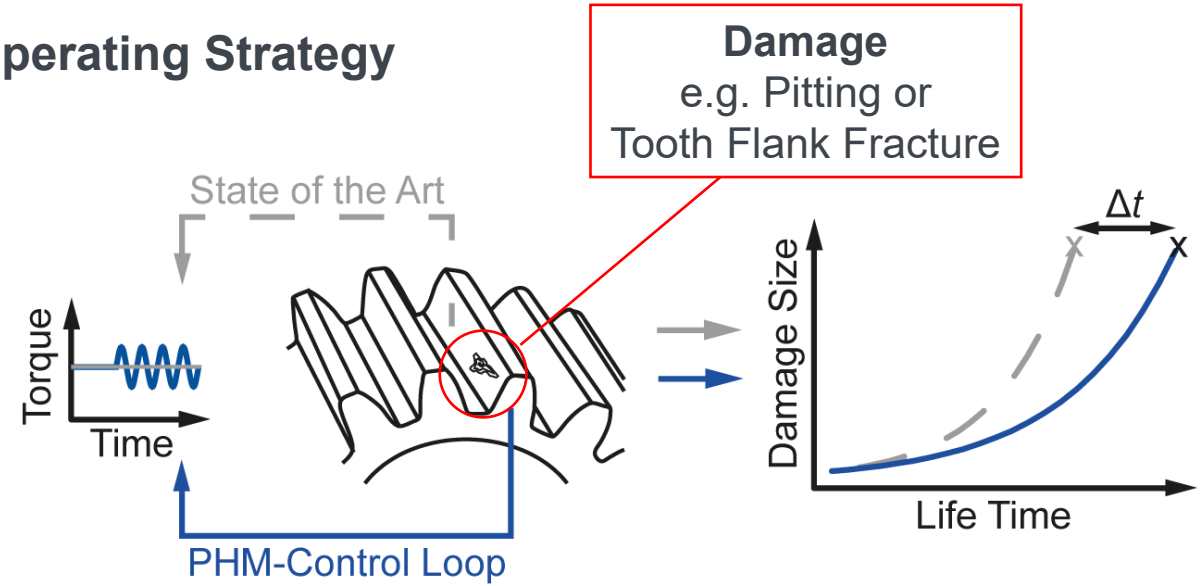
Adaptive Operating Strategy

Adaptive Operating Strategy



1. Detection of a damage during operation
2. Information serves intelligent control of the gearbox via a Prognostic and Health Management (PHM) loop
3. An adapted periodic torque variation is tapped at the gearbox output, while the period is matched exactly to one revolution of the gear.

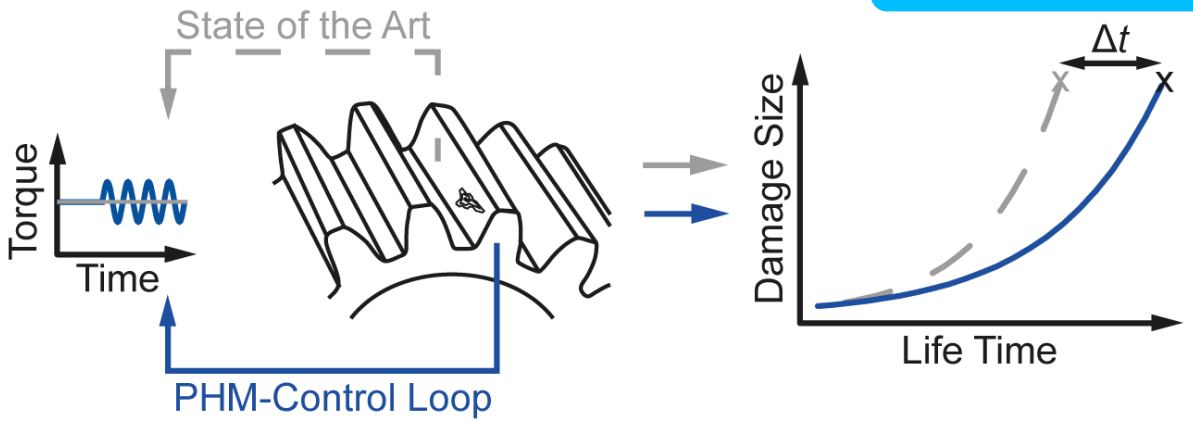
Adaptive Operating Strategy



- Due to the load reduction, the degradation rate (damage progress) is reduced and an increase in RUL is achieved
- The other intact teeth on the circumference compensate for the reduction at the weakest tooth, and the performance over the circumference remains constant.

Adaptive Operating Strategy

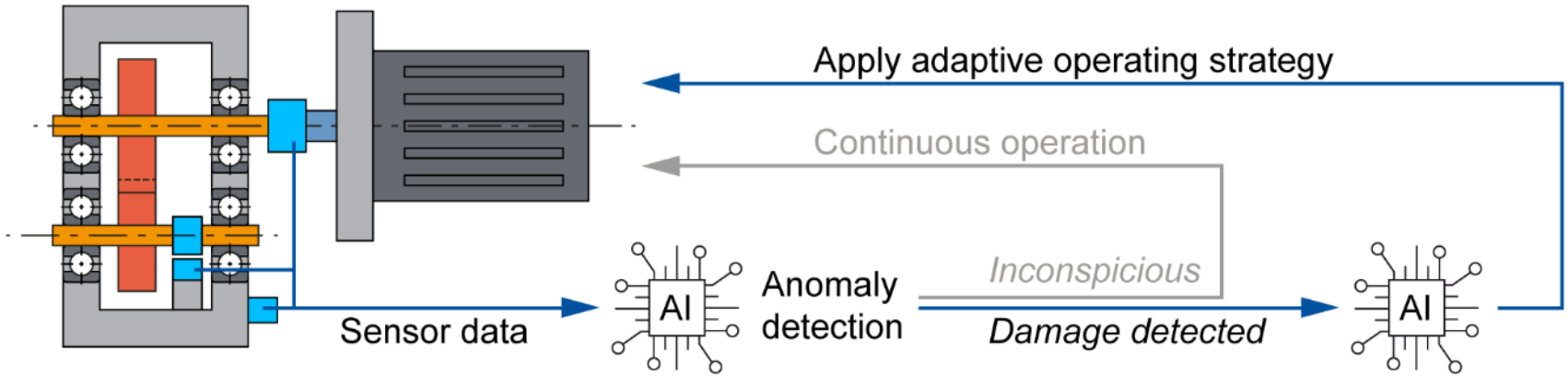
43,56 % increase of RUL



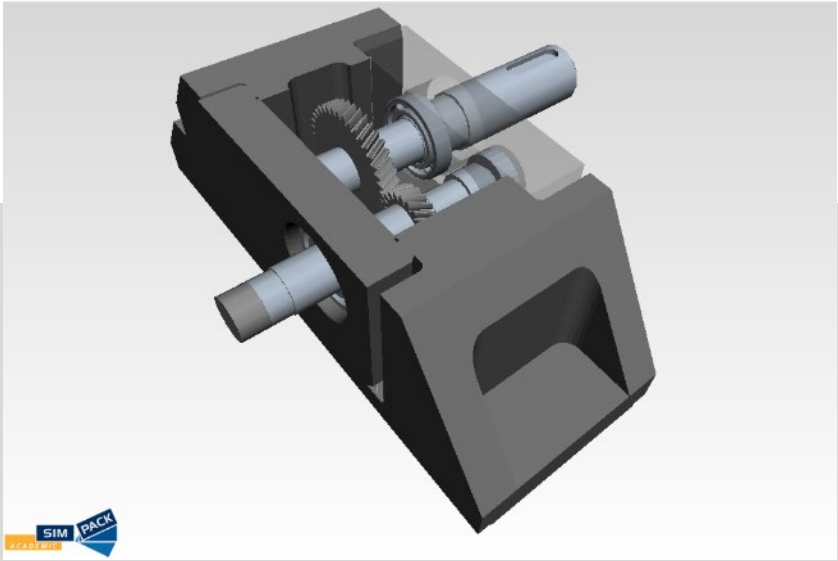
- The theoretical applicability of the adaptive operating strategy is proven for pitting damages
- Maximum potential of an adaptive operating strategy with ideal boundary conditions:
  - **43,56 %** increase of the remaining useful life

Sensor Data Processing
Based on Artificial Intelligence

- Vibration data is evaluated in an AI model using anomaly detection to identify the start of damage as soon as possible
- Second AI model provides the application of the adaptive operating strategy



Objective
MB- and FE- Simulation



Multi Body Simulation in SIMPACK

- Integration of the adaptive operating strategy using Matlab Simulink
- Investigation of effects of torque variation on the overall transmission system

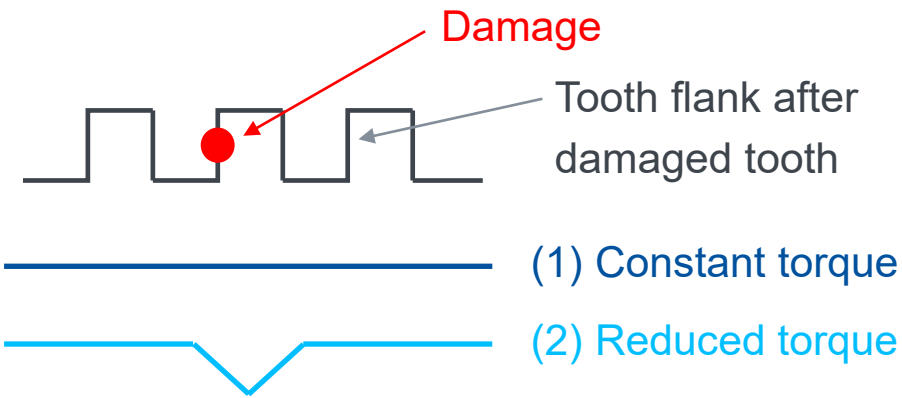
Finite Element Simulation in Ansys

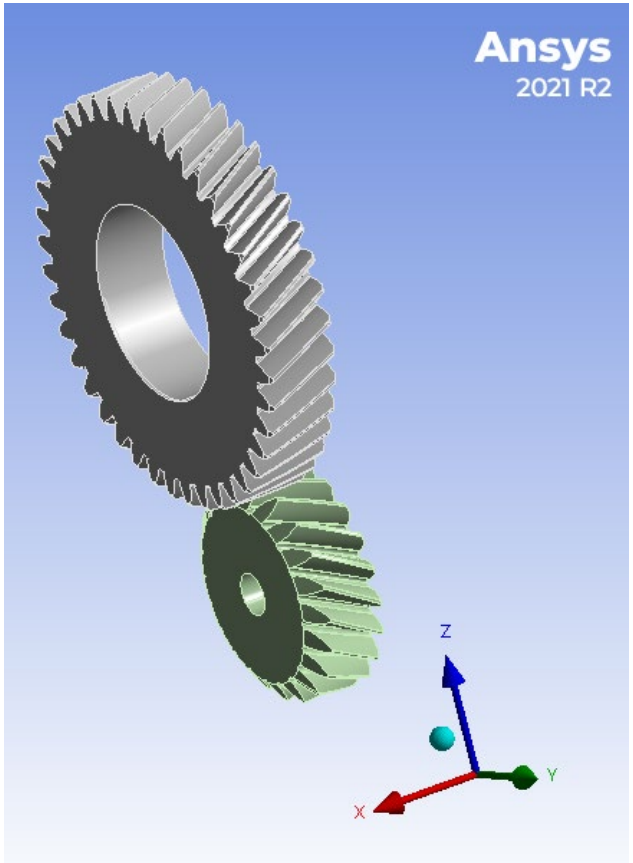
- Investigation of the influence of the adaptive operating strategy
  - Load condition on the pre-damaged tooth
  - Increased load on the other teeth

Simulation

Finite Element Simulation

- Static-mechanical analysis
- Algorithm: Augmented-Lagrange
- Element size: 0.03
- Contact stiffness: 2

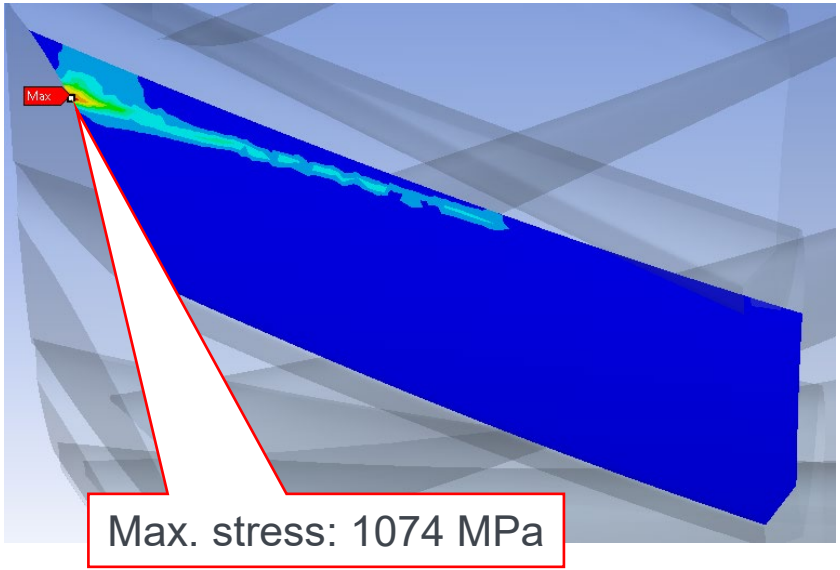




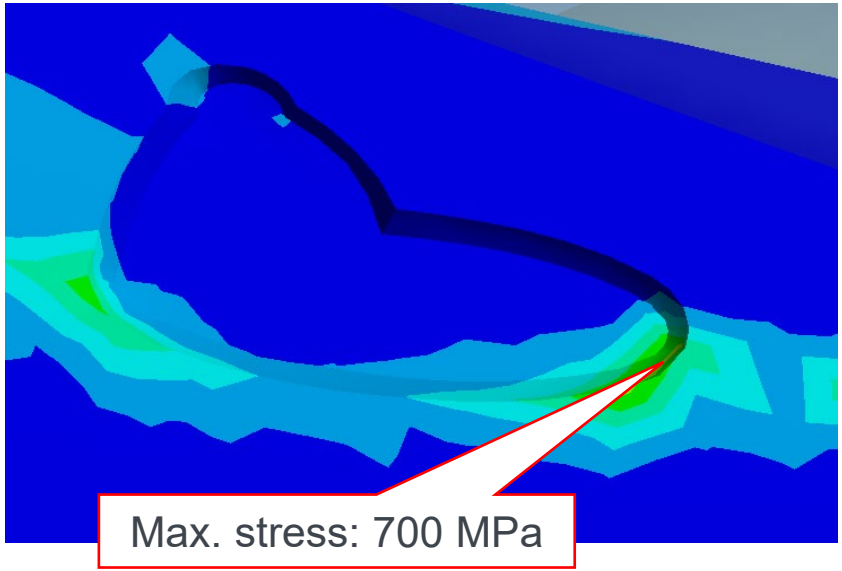
Finite Element Simulation

Simulation with Constant Torque (200 Nm)

WITHOUT DAMAGE



WITH DAMAGE

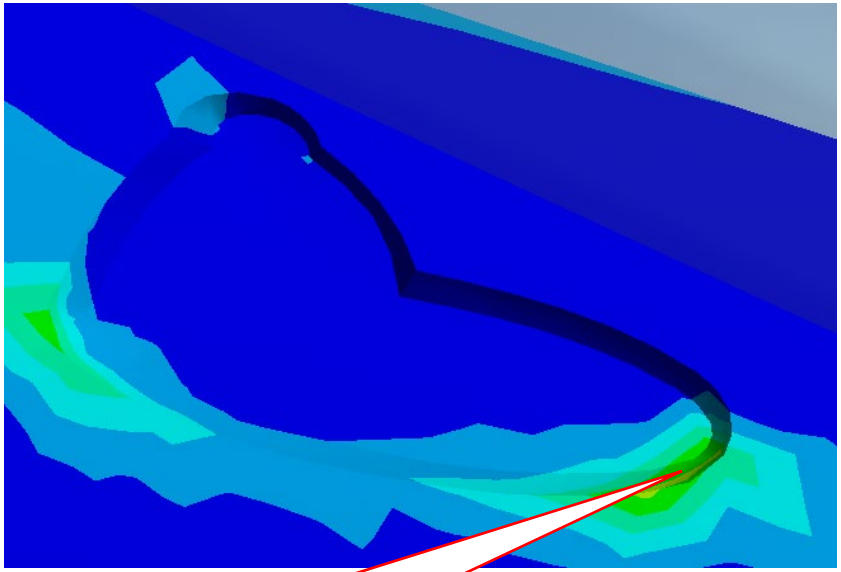


- Validation: Simulation without damage is compared with calculation according to ISO 6336 → 1019 MPa (at 200 Nm)

Finite Element Simulation

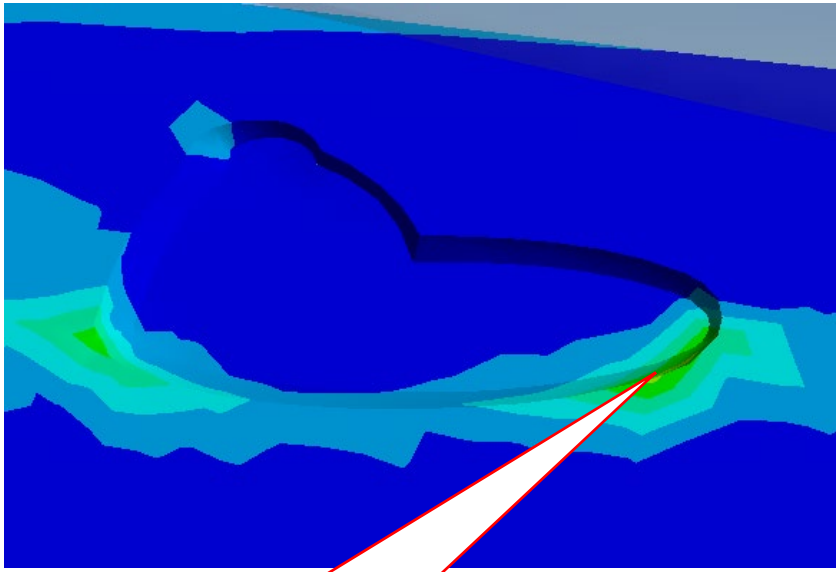
Simulation with Reduced Torque on Damaged Tooth

REDUCTION 5 %



Max. stress: 689 MPa

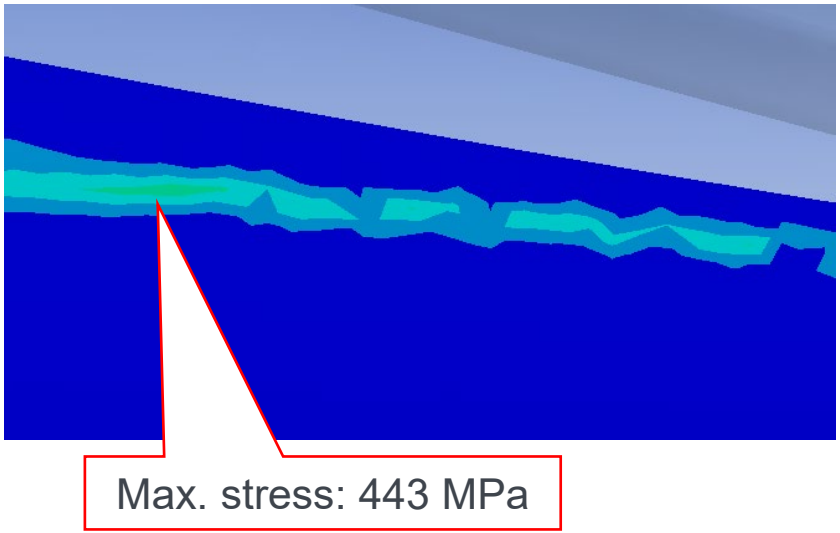
REDUCTION 10 %



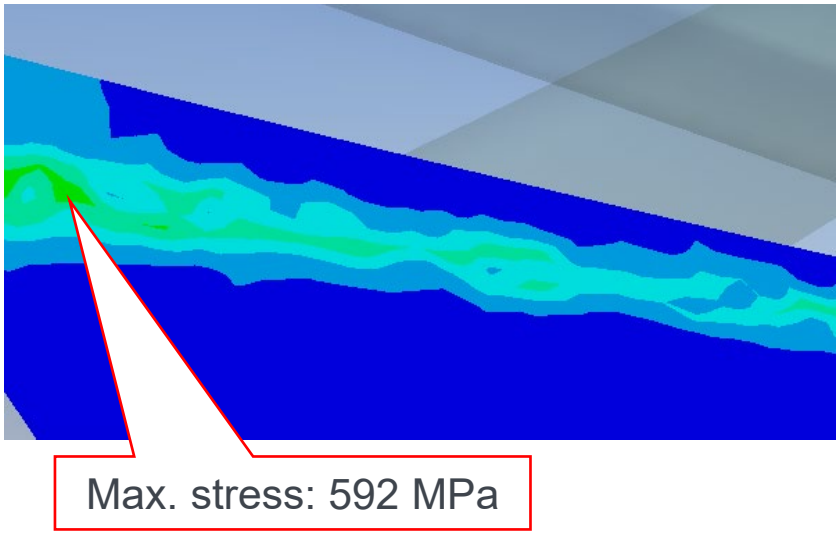
Max. stress: 678 MPa

Finite Element Simulation
Third Tooth

WITHOUT DAMAGE



WITH DAMAGE

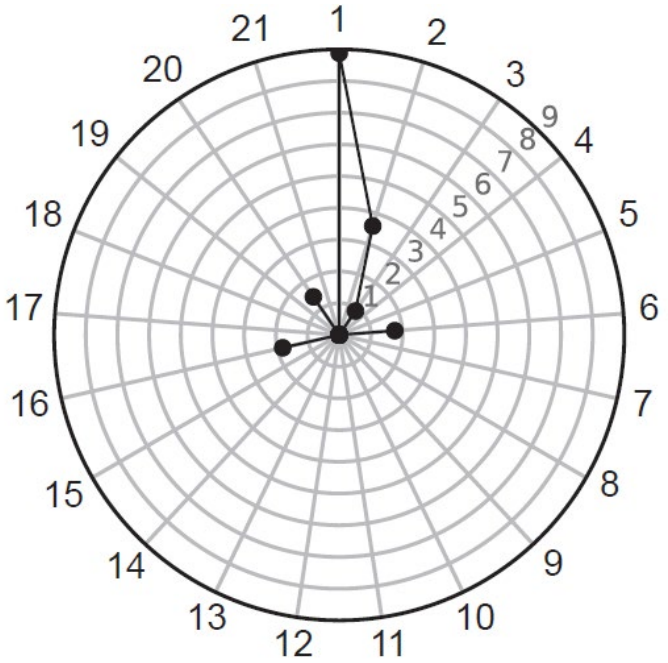


- Increased stress can also be found on tooth after tooth with damage.

Comparison with Experimental Tests

- Probability of a second pitting occurring on the neighboring tooth of the first pitting is increased.

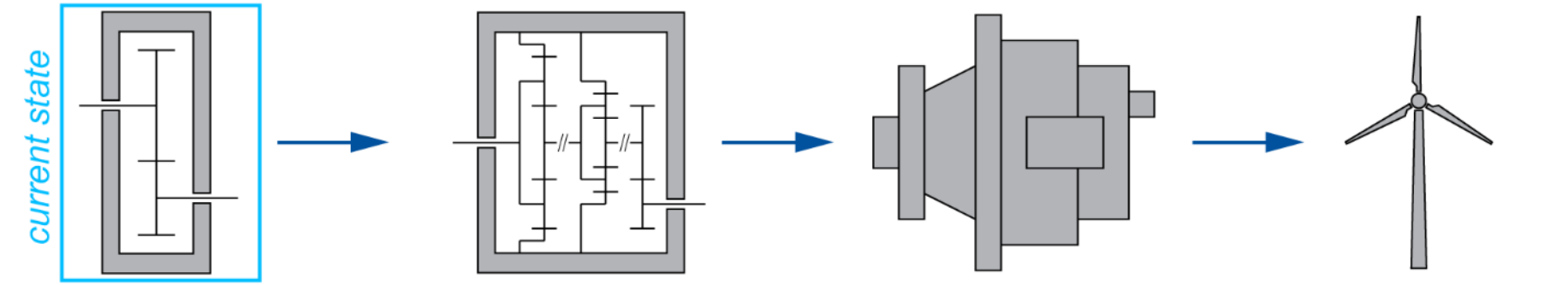
→ This was also demonstrated by the test runs.



What‘s next?

Next Steps

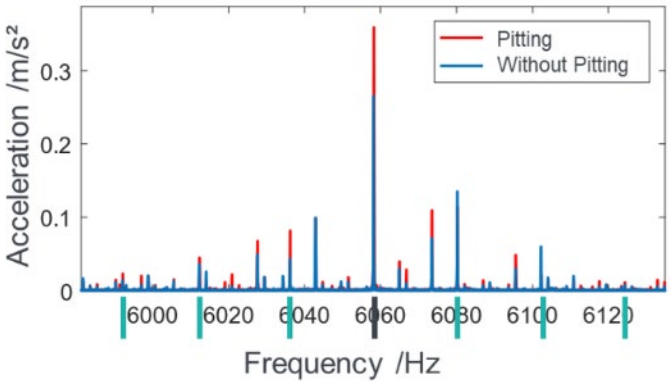
Towards an Implementation of the Adaptive Operating Strategy in Wind Turbines

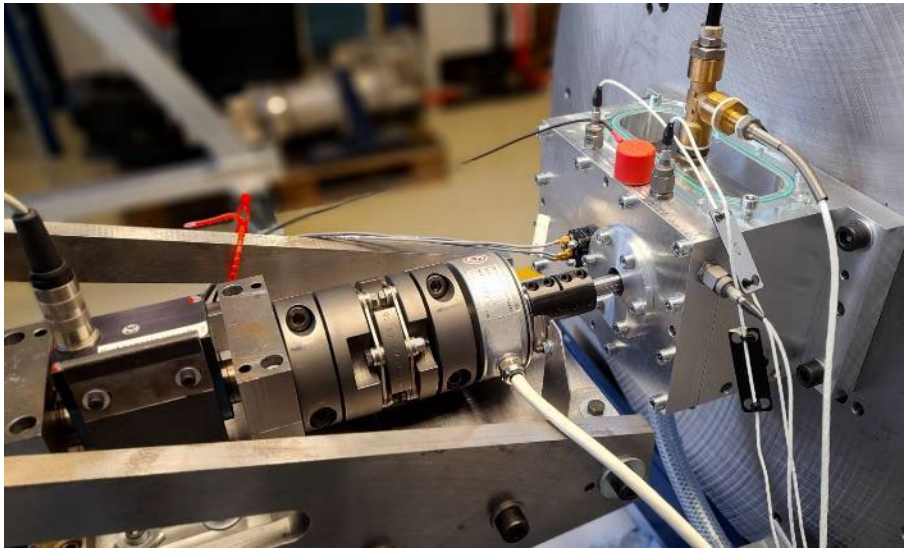


- The findings on the current single stage test gearbox provide fundamental knowledge for the next steps.

Experimental Approach
Evaluation of Vibration Data

- Harmonics of the gear meshing frequency
- Sidebands at the distance of the gear rotation frequency
- Averaged change of these frequency bands





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Thank you!

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