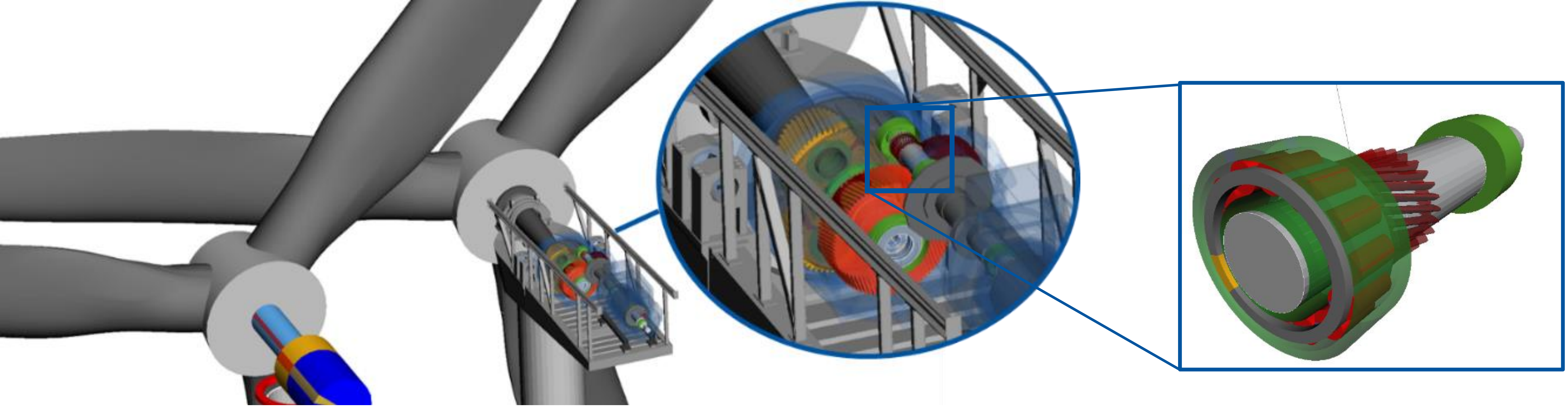

4th Wind and Drivetrain Conference

Multibody Simulation in Wind Energy – From Turbine Design to Detailed Component Load Calculation

Daniel Matzke, M. Sc.

A. Werkmeister, A. Baseer, S. Leupold, T. Duda, B. Rieckhoff,
J. Berroth, R. Schelenz, G. Jacobs

Hamburg, 19.04.2018

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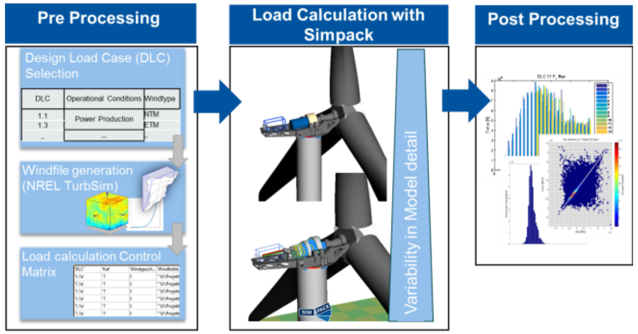
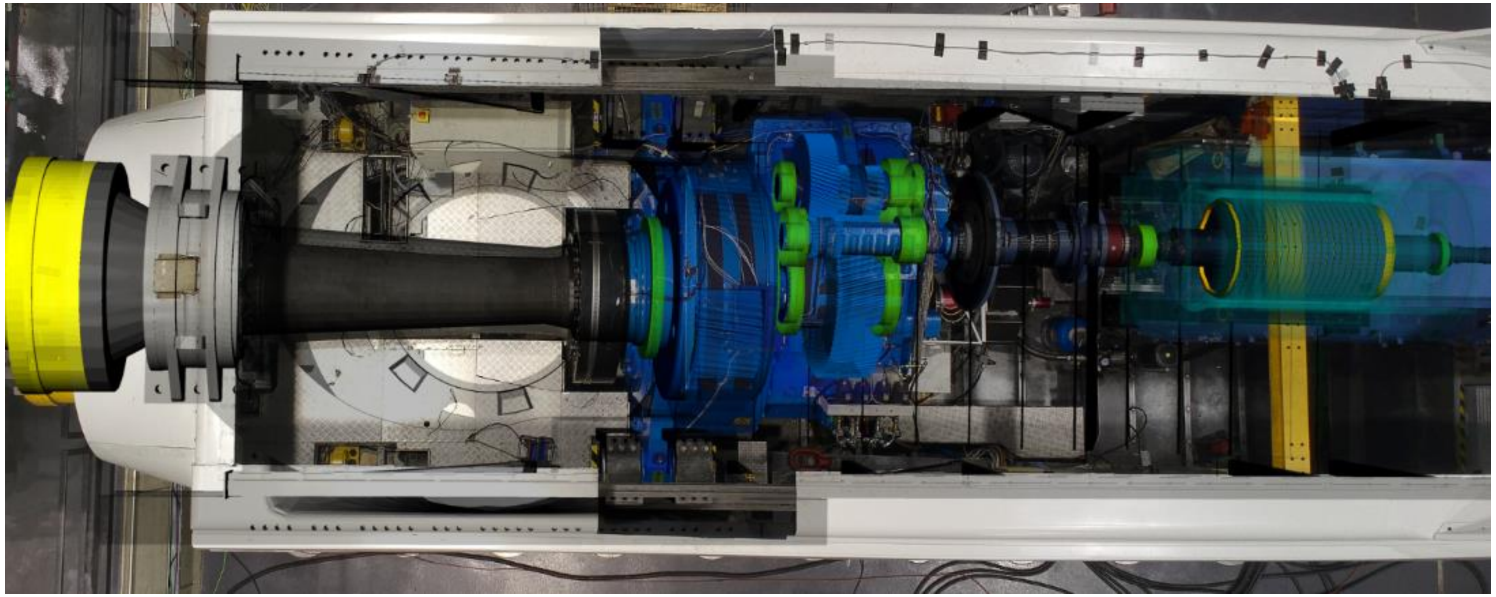
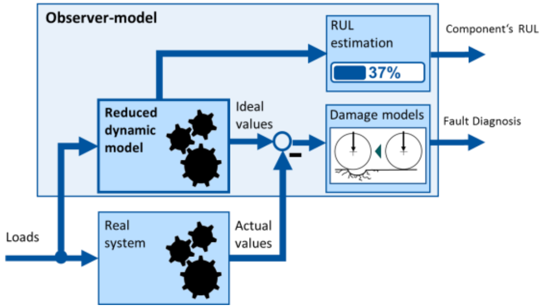
Content



Pre Processing
Design Load Case (DLC) Selection
Windfile generation (NREL TurbSim)
Load calculation Control Matrix
Load Calculation with Simpack
Variability in Model detail
Post Processing

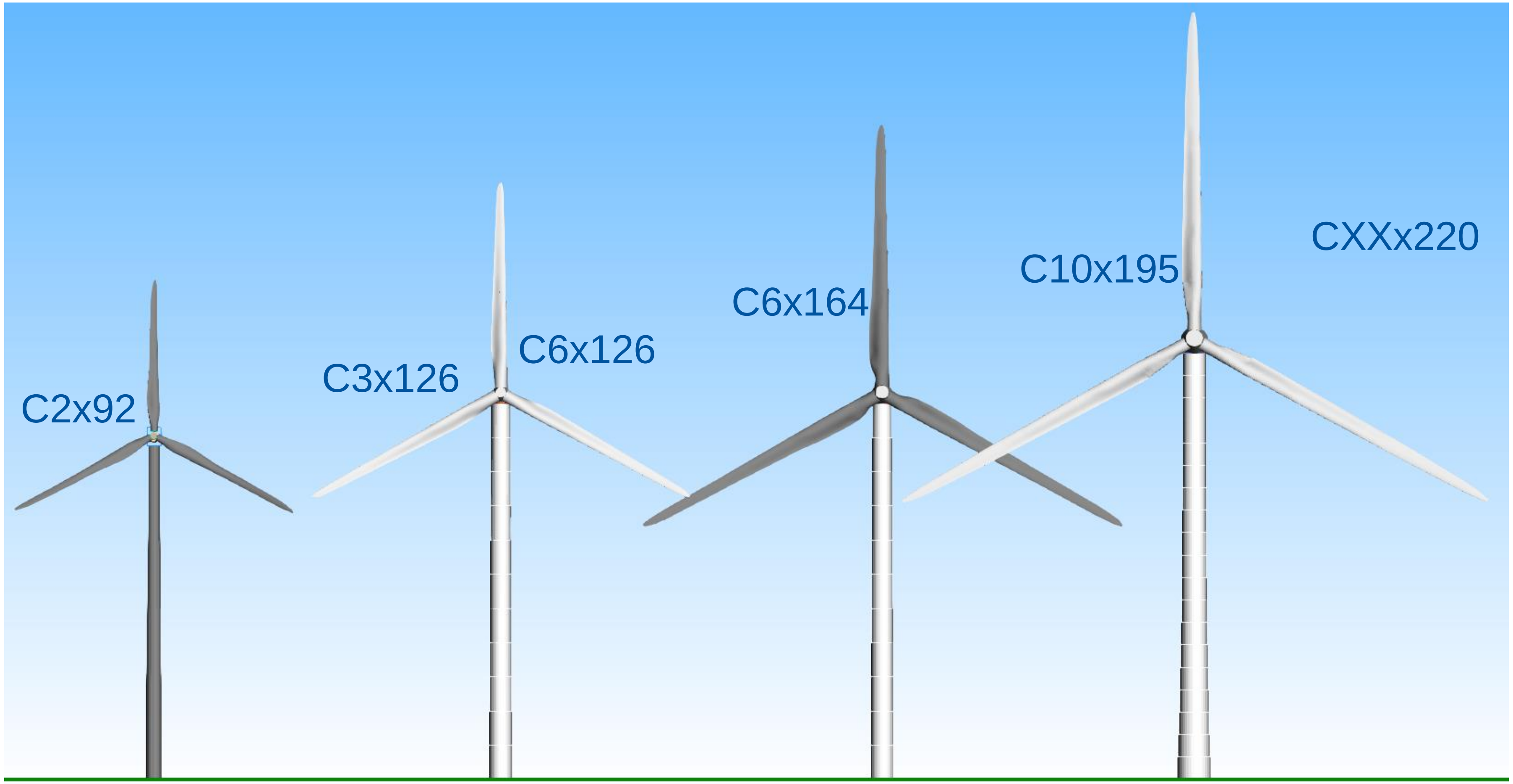




Observer-model
RUL estimation
37%
Component's RUL
Reduced dynamic model
Ideal values
Damage models
Fault Diagnosis
Loads
Real system
Actual values

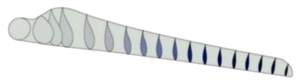
Wind turbine design
Generic wind turbine models – from 2MW up to 10MW+ with 220 m rotor diameter

- The CWD offers generic turbine models for all relevant power clases
- Each can be set up with a wide variety of model fidelity
- All turbines with the same control stragtegies



Wind turbine design
All turbines start with a Rotorblade

Aerodynamic blade definition

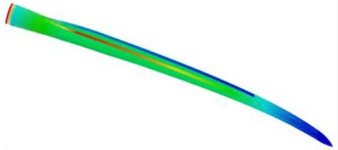


- Aerodynamic profiles
- Defintion of rotor-blade surface

CAD structure

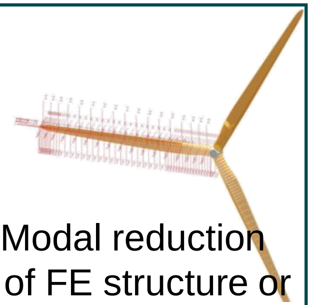
- Rotorblade CAD model

Structural definition FEM

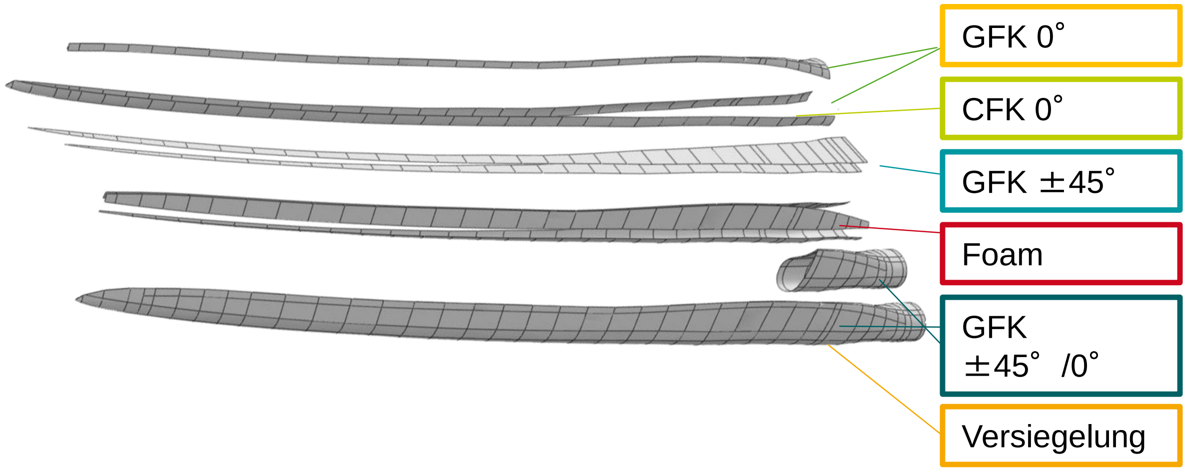


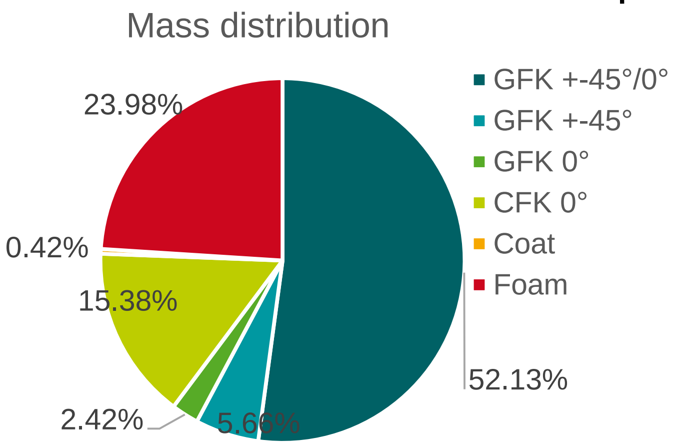
- Definition of composite layup
- and structural analysis

Reduction for MBS simulation



- Modal reduction of FE structure or cor. Beam model for system analysis





Wind turbine design
Design Load Calculation

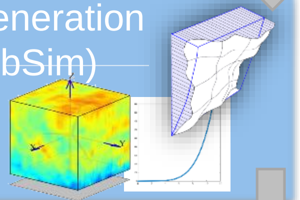
- Beside the rotor a parametric controller with a simple generator model is needed
- Then comprehensive load calculations for the turbine and its components can be conducted
- Calculation is done according to IEC 61400-1 (tested with 2000 DLC)
- ~10min/600s simulation time for standard DLC model
- The design loads can be calculated with arbitrary complex models

Pre Processing

Design Load Case (DLC) Selection

DLC	Operational Conditions	Windtype
1.1	Power Production	NTM
1.3		ETM
..	...	..

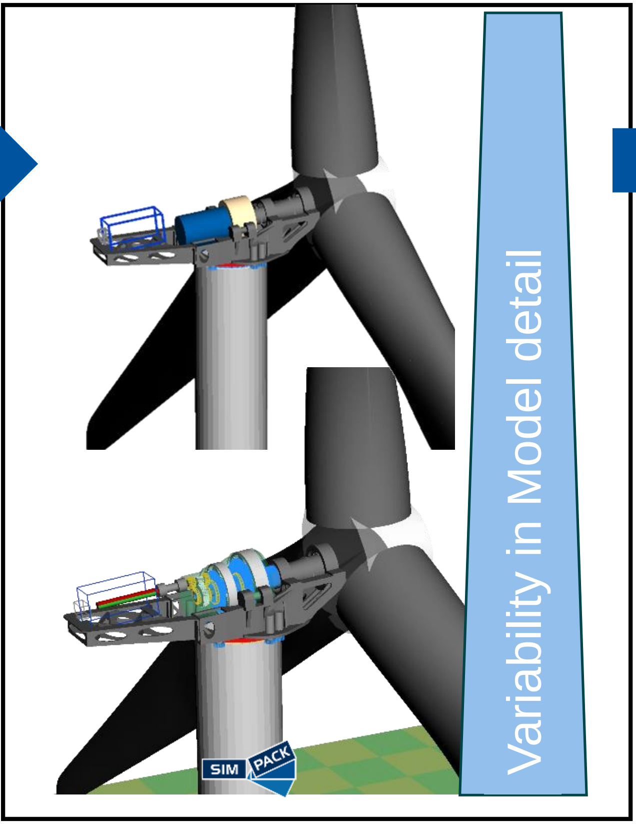
Windfile generation (NREL TurbSim)



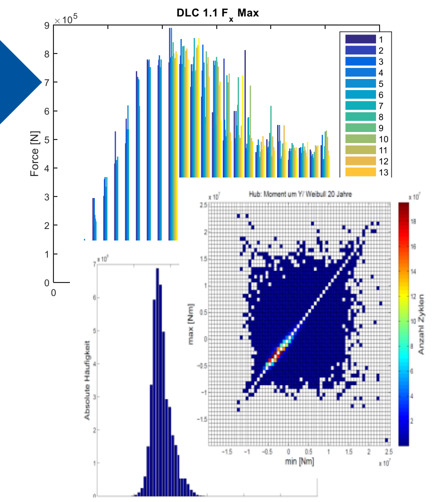
Load calculation Control Matrix

'DLC'	'Kat'	'Windgesch...	'Windfeldd.
'1.1a'	'1'	3	'''U:\Projekt
'1.1a'	'1'	3	'''U:\Projekt
'1.1a'	'1'	3	'''U:\Projekt
'1.1a'	'1'	3	'''U:\Projekt
'1.1a'	'1'	3	'''U:\Projekt
'1.1a'	'1'	3	'''U:\Projekt

Load Calculation with Simpack



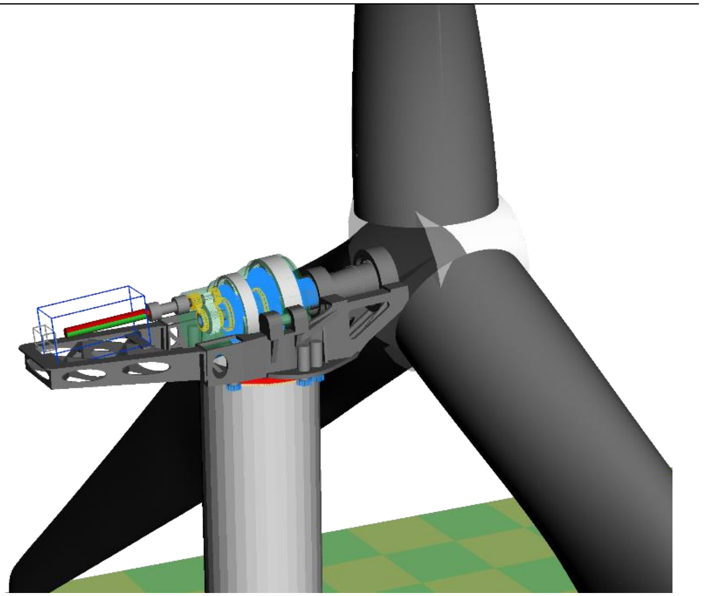
Post Processing



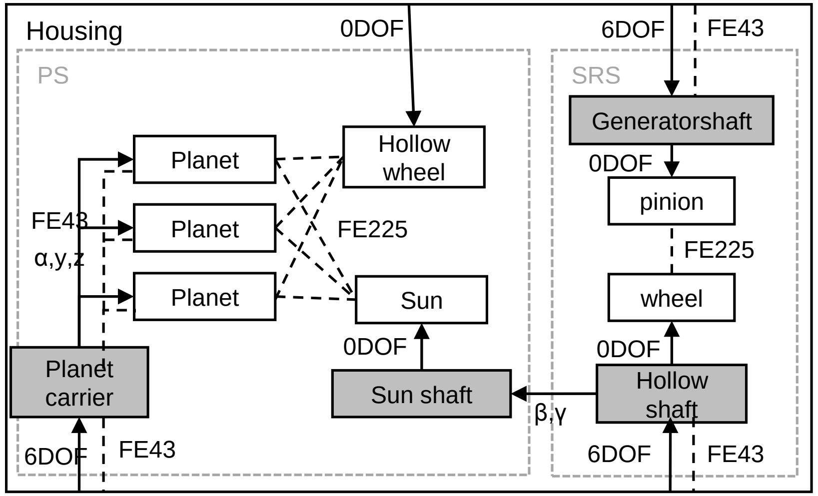
Wind turbine design
Variablity in the detail of the model

- The load calculation can be done with different details of the model
- The level of detail can be modeled with parameter switches
- That way the level of detail can be changed without maintaining different models

- ➢ Reducing the modelling effort
- ➢ Lower error susceptibility



Model component:		#1	#2	#3	#4	#5
tooth	Body	rigid	rigid	rigid	rigid	rigid
	Force element	FE225	FE225	FE225	FE225	FE225
shafts	Body	rigid	flexible	flexible	flexible	flexible
	Joint	α	α	6DOF	6DOF	6DOF
	Joint sun shaft	0DOF	0DOF	β,γ	β,γ	β,γ
Planet carrier	Body	rigid	rigid	flexible	flexible	flexible
	Joint carrier	α	α	6DOF	6DOF	6DOF
	Joint planet	α	α	α, y, z	α, y, z	α, y, z
bearing	Force element	-	-	FE43	FE43	FE43
housing	body	rigid	rigid	rigid	rigid	flexible



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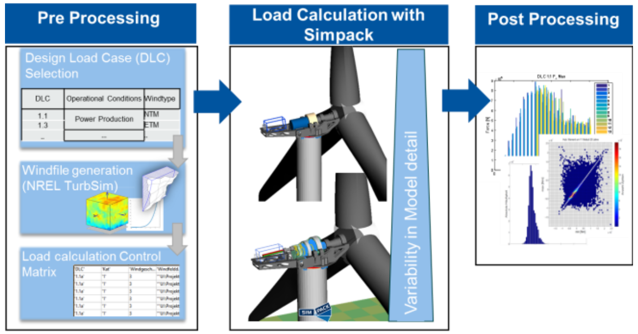

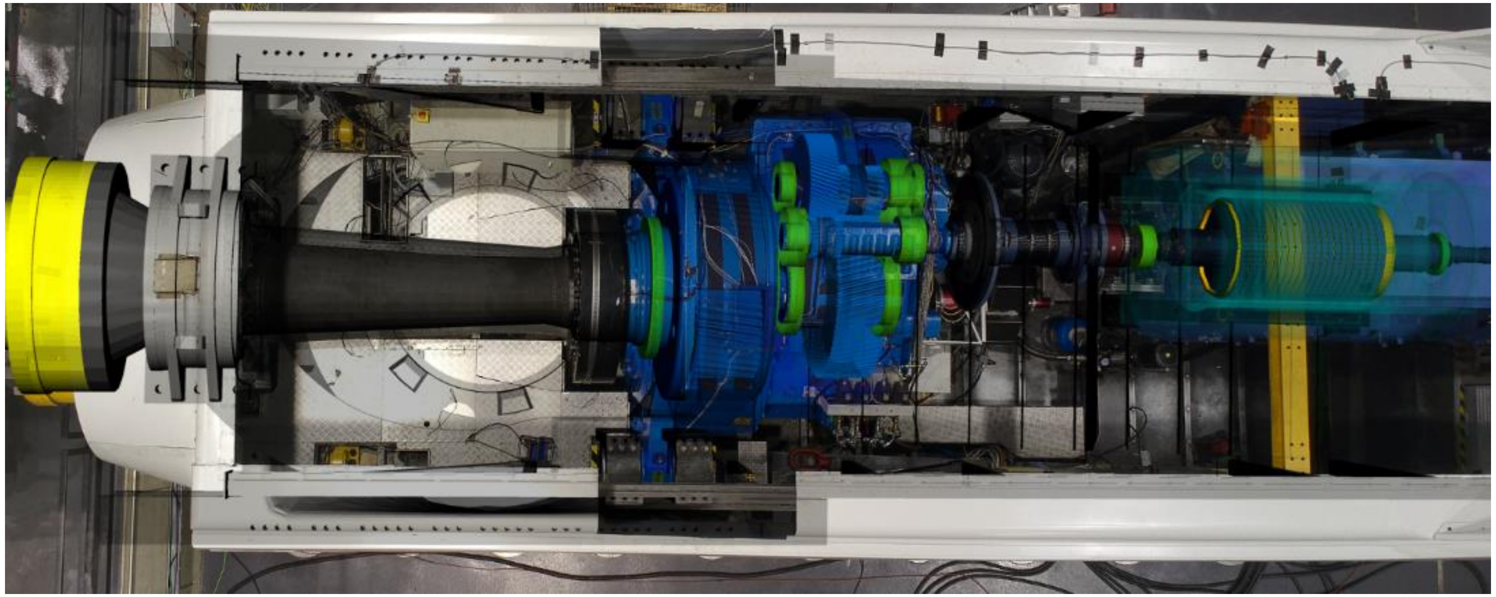

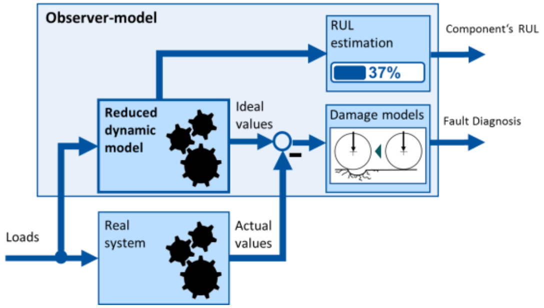

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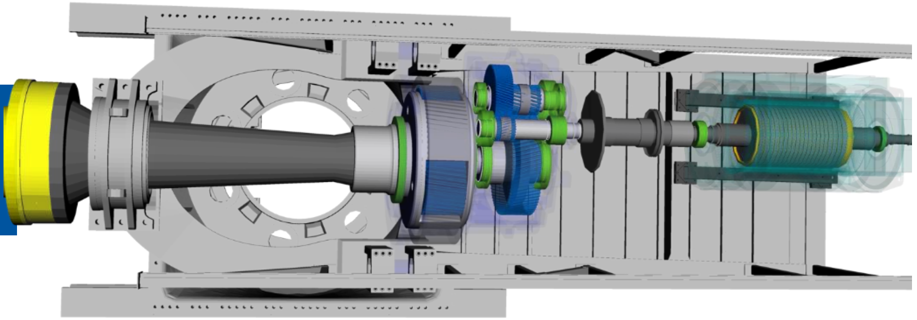
Component design
Validation and explanation of measurements

- The good accessibility of the test bench allows for comprehensive measurements
- In high-complex systems the interpretation of the results is not easy
- Simulation models can be validated with the measurements and help to gain a better understanding of what's happening in the turbine
- The combination of a high complex model with measurements leads to detailed validated component loads
- The level of detail for the load calculation can then be adjusted depending on the design task

Measurements at the system test bench

+

High detailed simulation model



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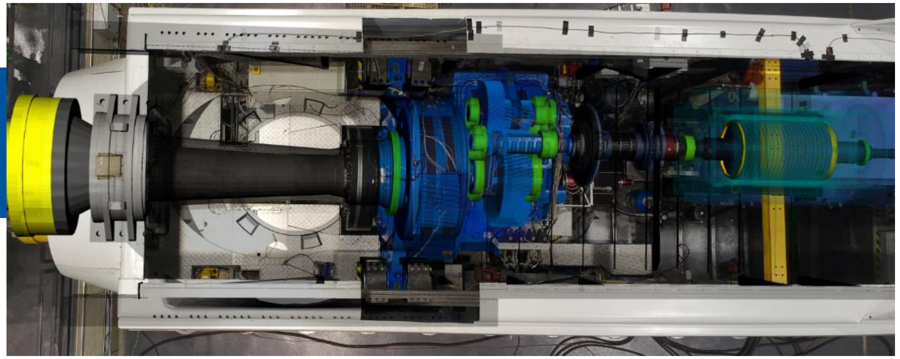
Validated load calculation tool



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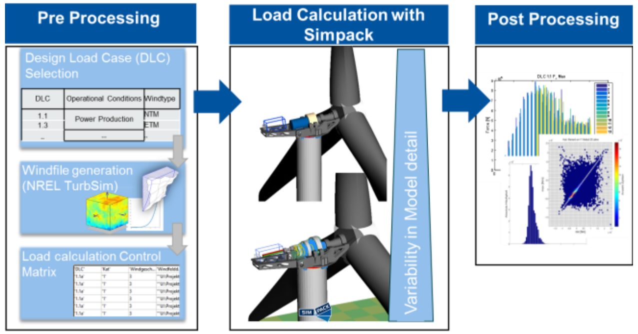

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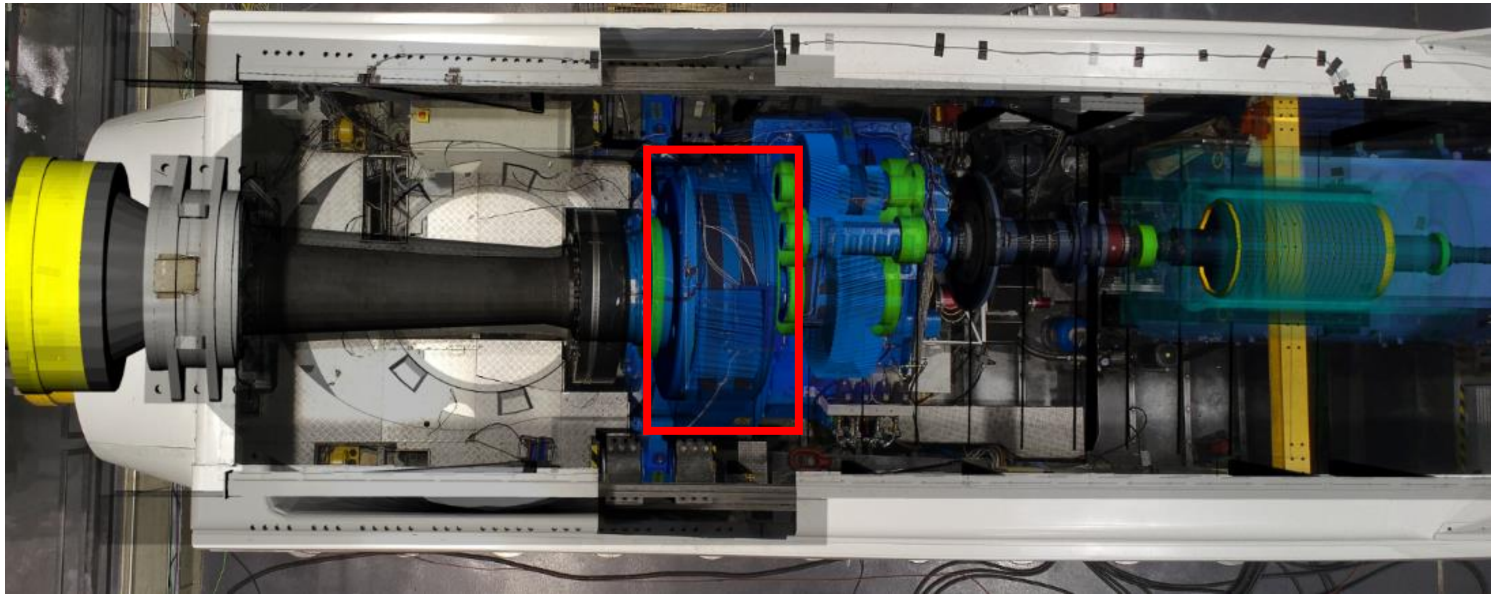

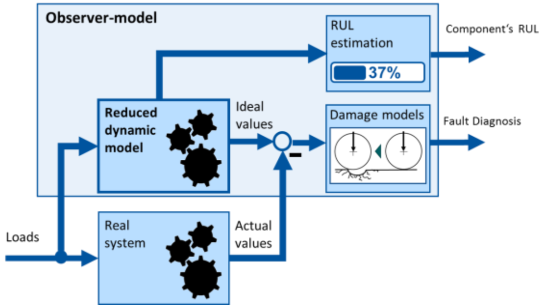

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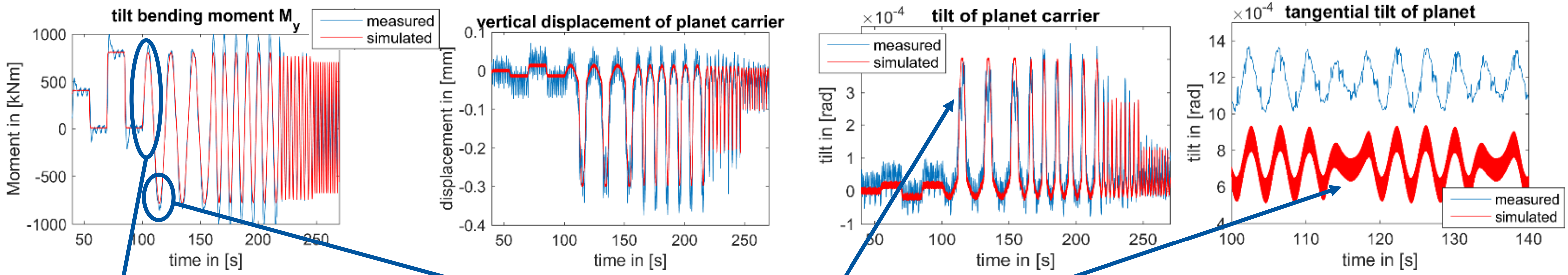
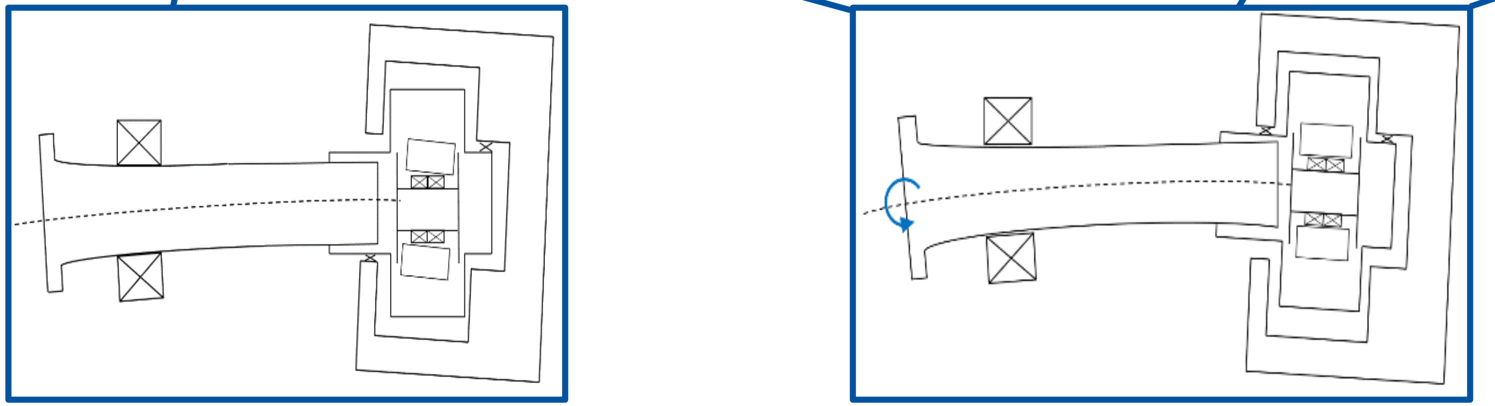
Load calculation in planetary gear stage

Modelling of loads in the planetary gear stage – validation of detailed gear stage model

- Exemplary excerpt of model validation: tilting of carrier and planets due to tilt bending moment
- For constant nominal torque and a constant rotational speed a dynamic tilt bending is applied





Understanding of the complex load states inside the gearbox

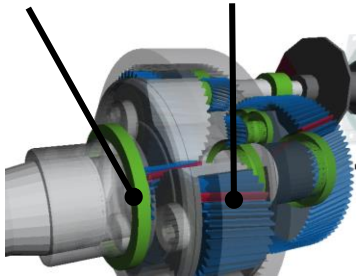
Load time series of displace-ments and components loads are then applied to FE-models

Load calculation in planetary gear stage

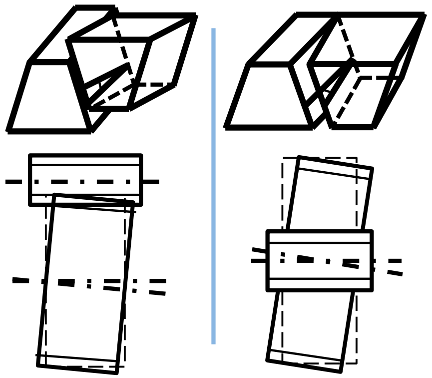
Modelling of loads in the planetary gear stage – gear loads

Load time series

Displacement of carrier and planets



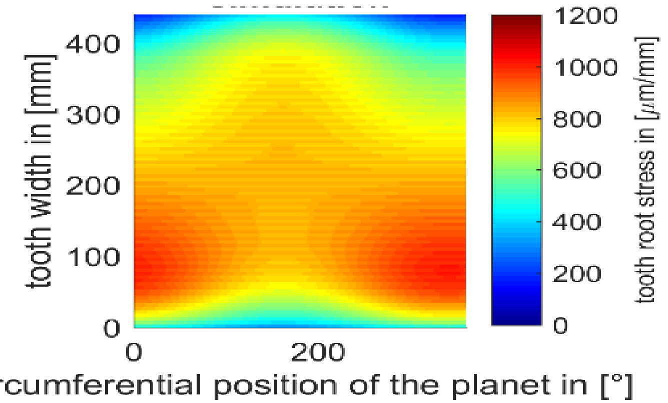
Error of axis



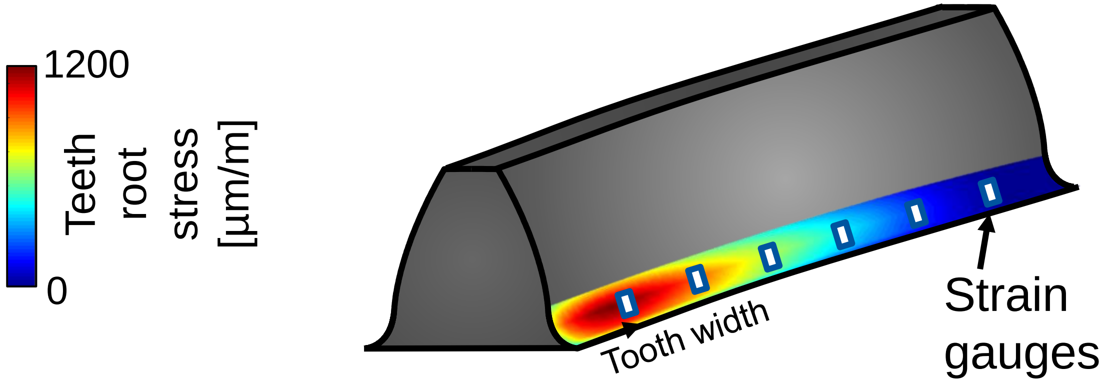
STIRAK

STIRAK

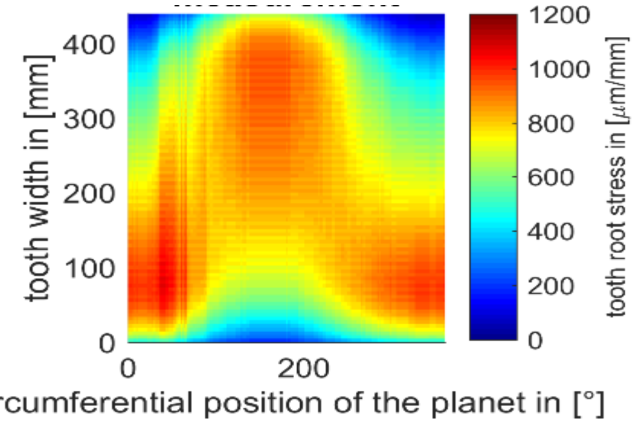
Simulation



Measurement



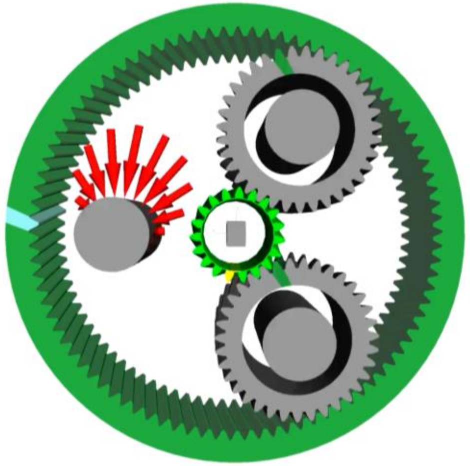
Measurement

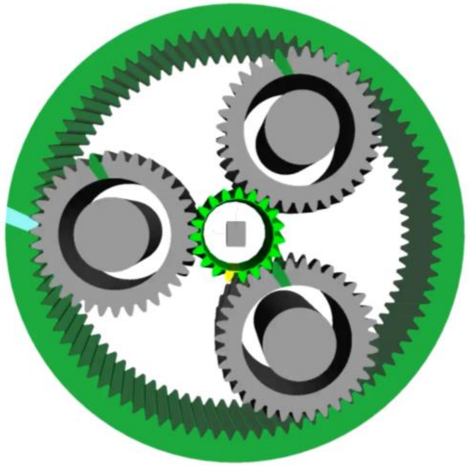


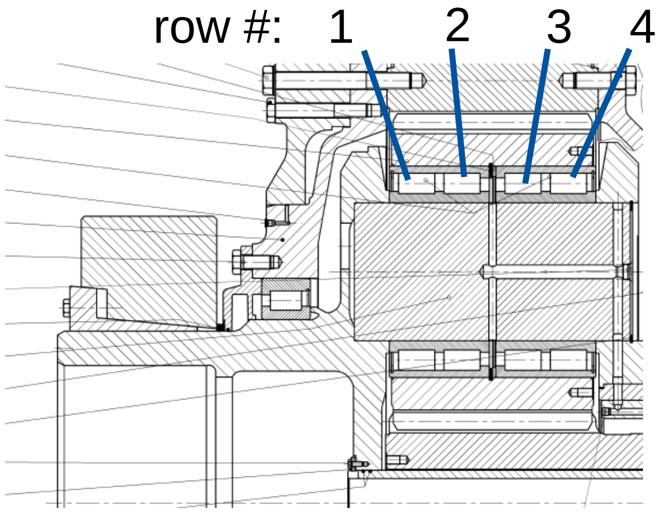
STIRAK calculations and evaluation of measurements kindly provided by our project partner WZL Aachen

Load calculation in planetary gear stage
Modelling of loads in the planetary gear stage – bearing loads

- 6 DOF for planets and carrier – rigid bodies
- Axial load distribution as well as the influence of non-torque-loads matches quite well
- Circumferential load distribution doesn't match

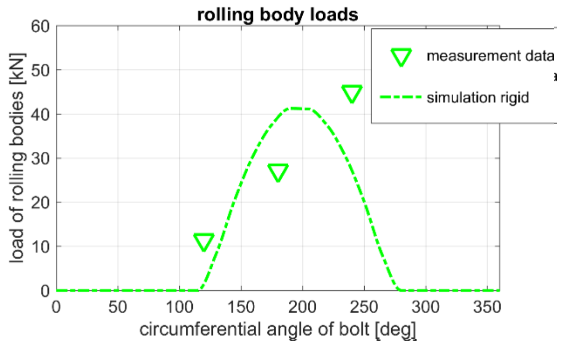






Results for 90° position:

row 1



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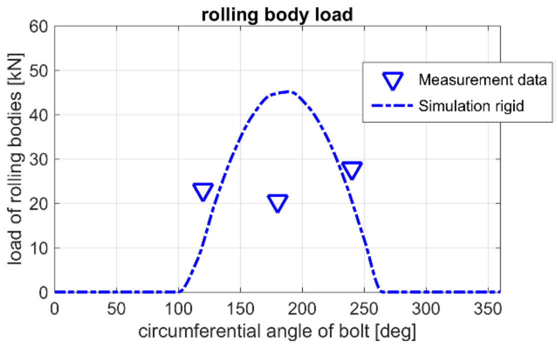

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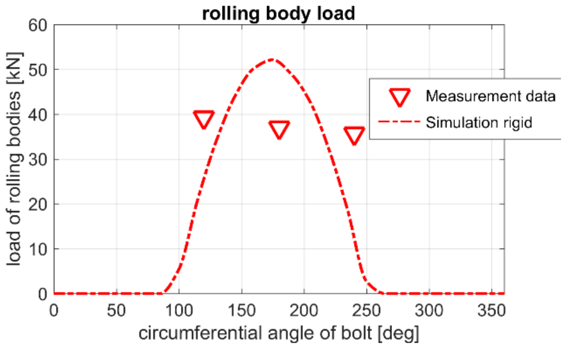

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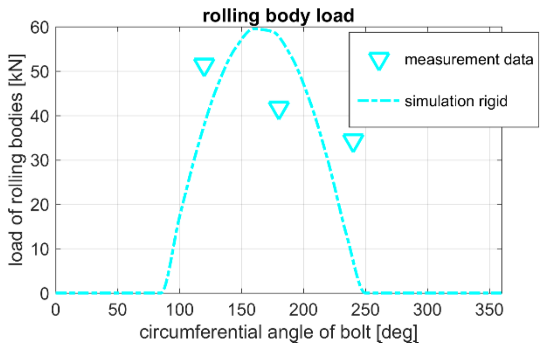
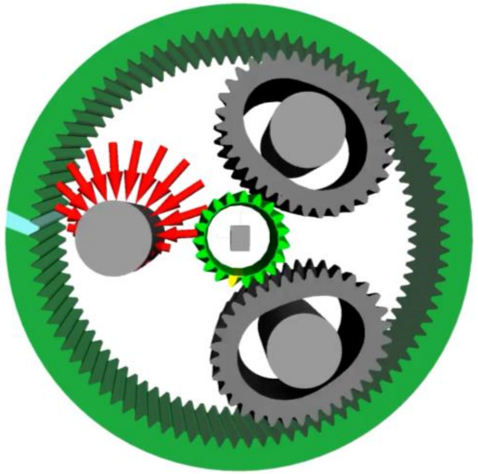
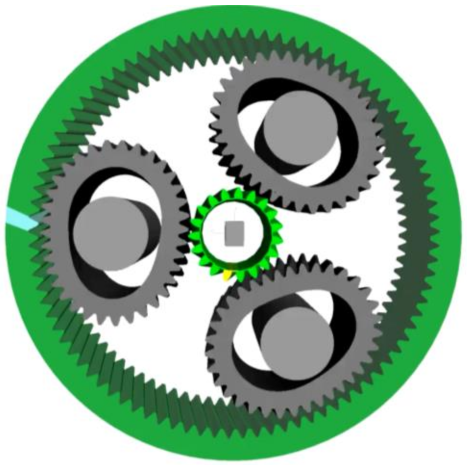


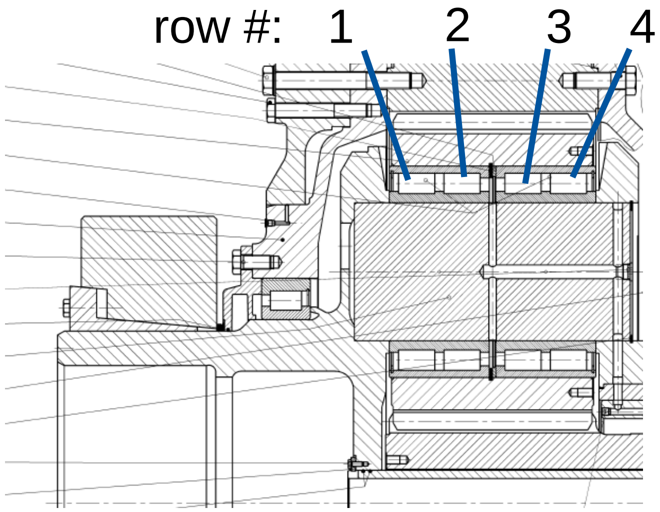
Load calculation in planetary gear stage

Modelling of loads in the planetary gear stage – bearing loads

- 6 DOF for planets and carrier – flexible planets
- Much better match for circumferential load distribution
  → big influence of planet ovalisation







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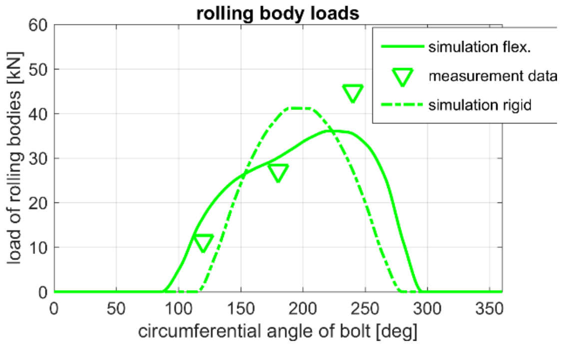

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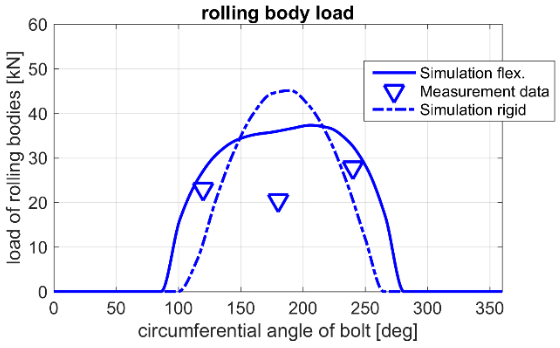

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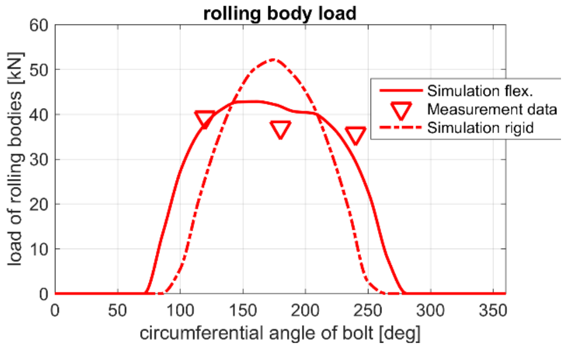

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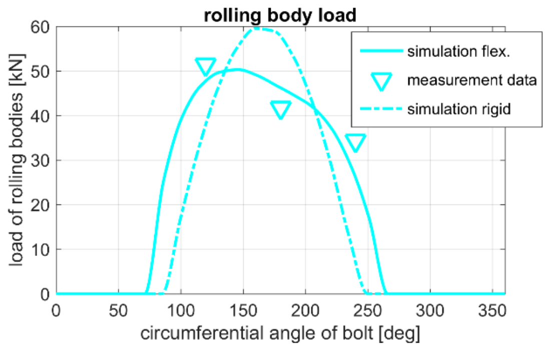

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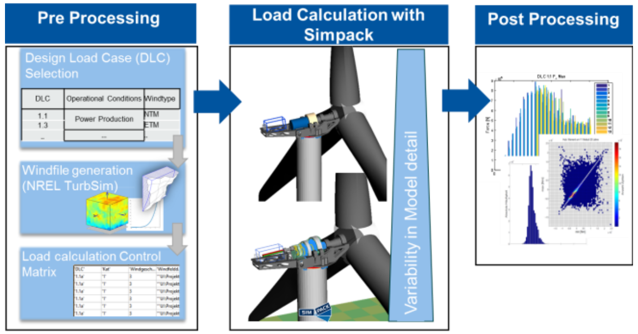

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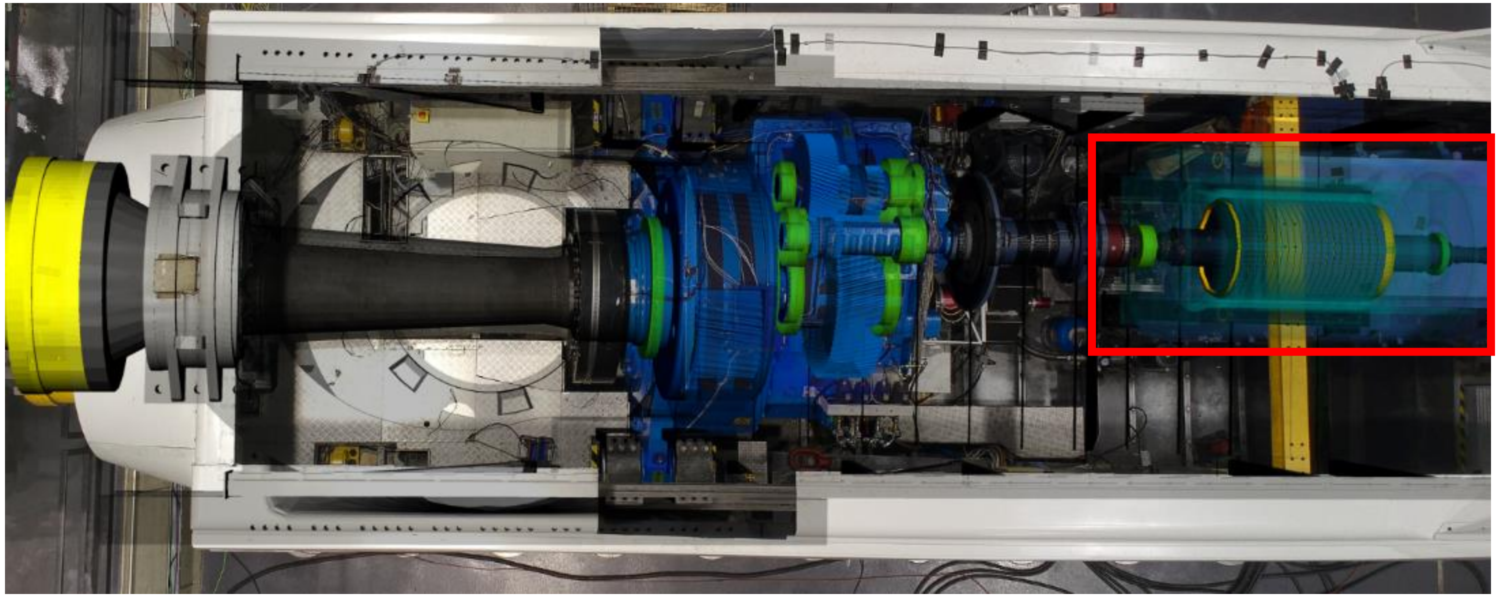

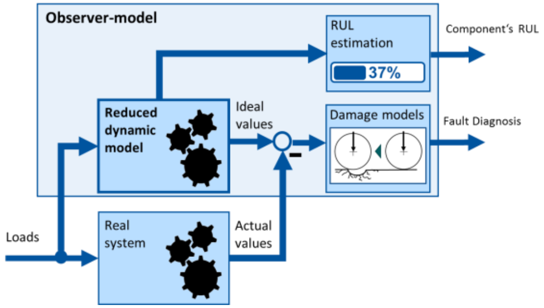

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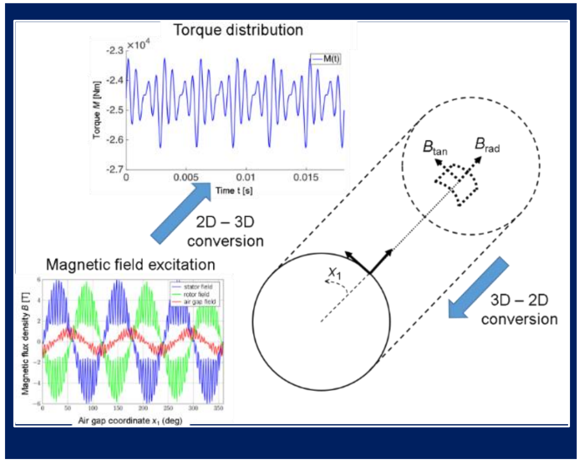
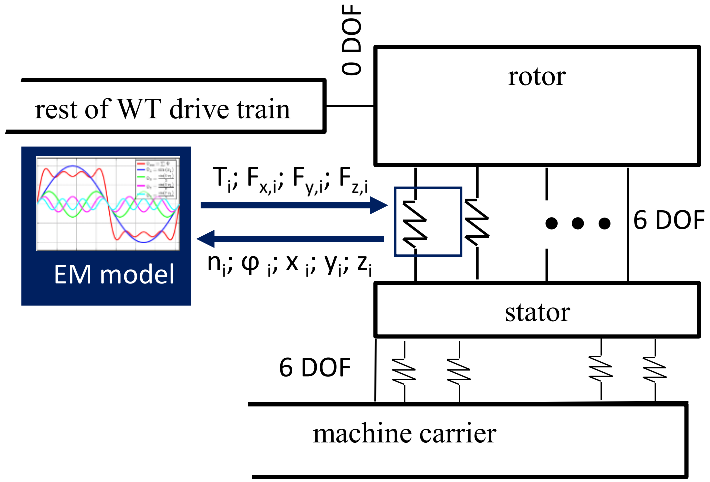
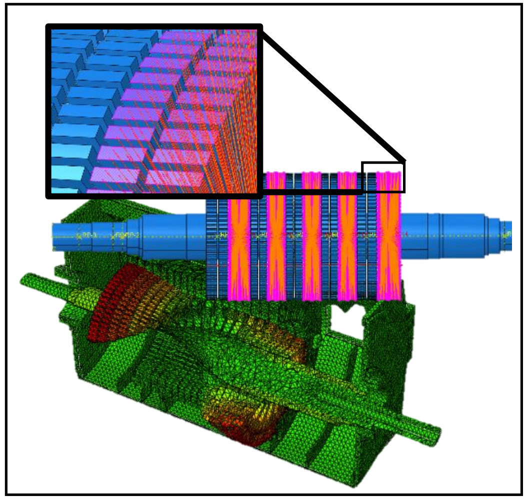
Electromechanical coupling

Feeback of structure deformations for a detailed EM-model of the generator via co-simulation

- 2 D analytical EM-model including harmonics and parasitic effects
- Flexible model of the generator rotor and structure

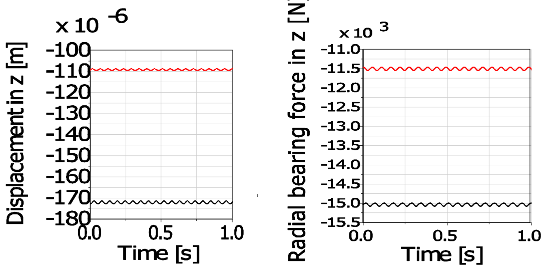






Static effects:

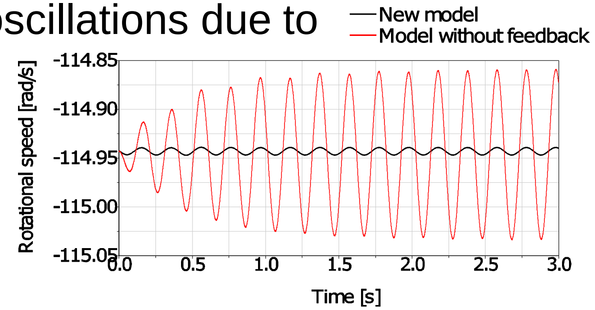
→ unbalanced magnetic pull



Dynamic effects:

→ damping effects of externally excited oscillations due to the generator slip characteristic

→ excitation of the mechanical structure due to electromagnetic effects (harmonics of pole pairs, windings, etc.)



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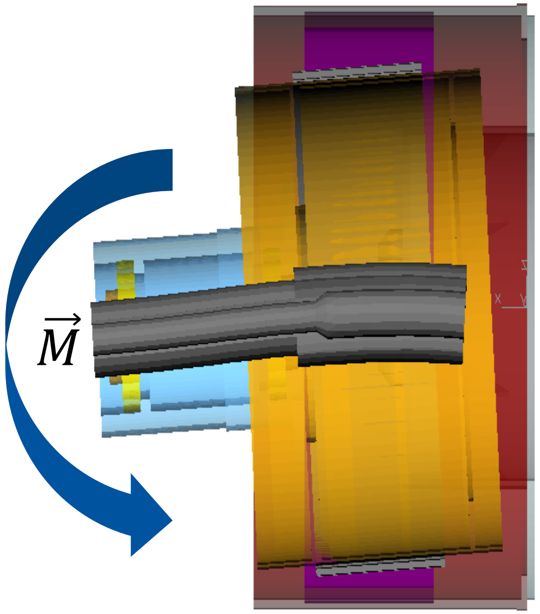
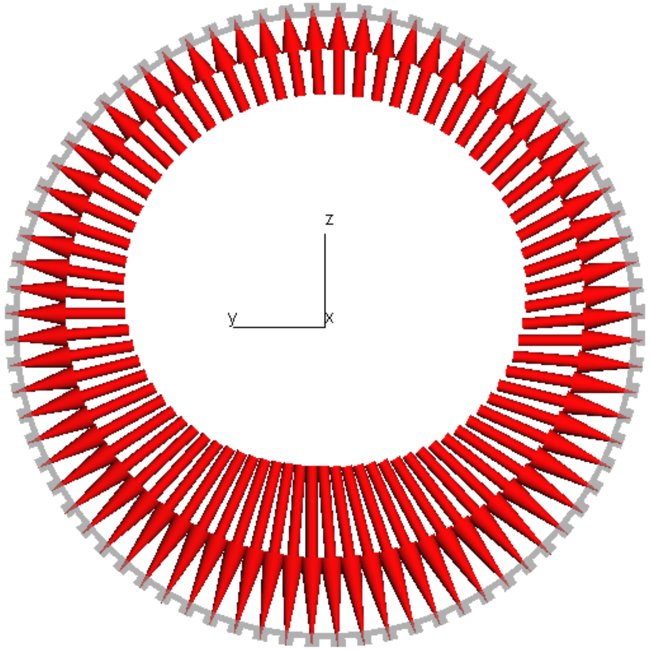
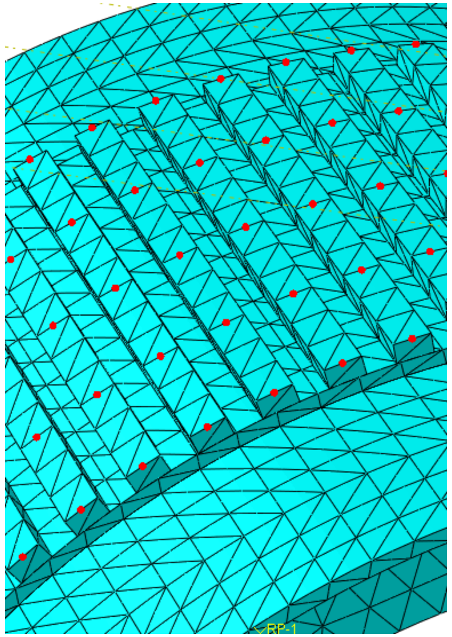
Electromechanical coupling
Electromechanical interaction for Direct-Drive PMSM







- Deformation of drivetrain by non-torque loads, causes
  - Rotor tilting
  - Rotor eccentricities
- Magnetic force application, depending on…
  - local airgap length
  - axial position

→ higher loads dynamic on bearings due to electrical excitations which interact with the flexible structure of rotor and stator

Content

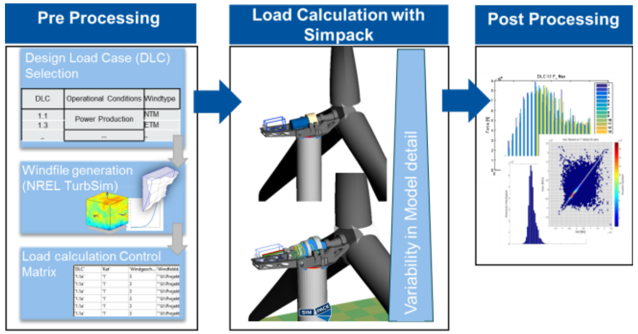
1 Wind turbine design

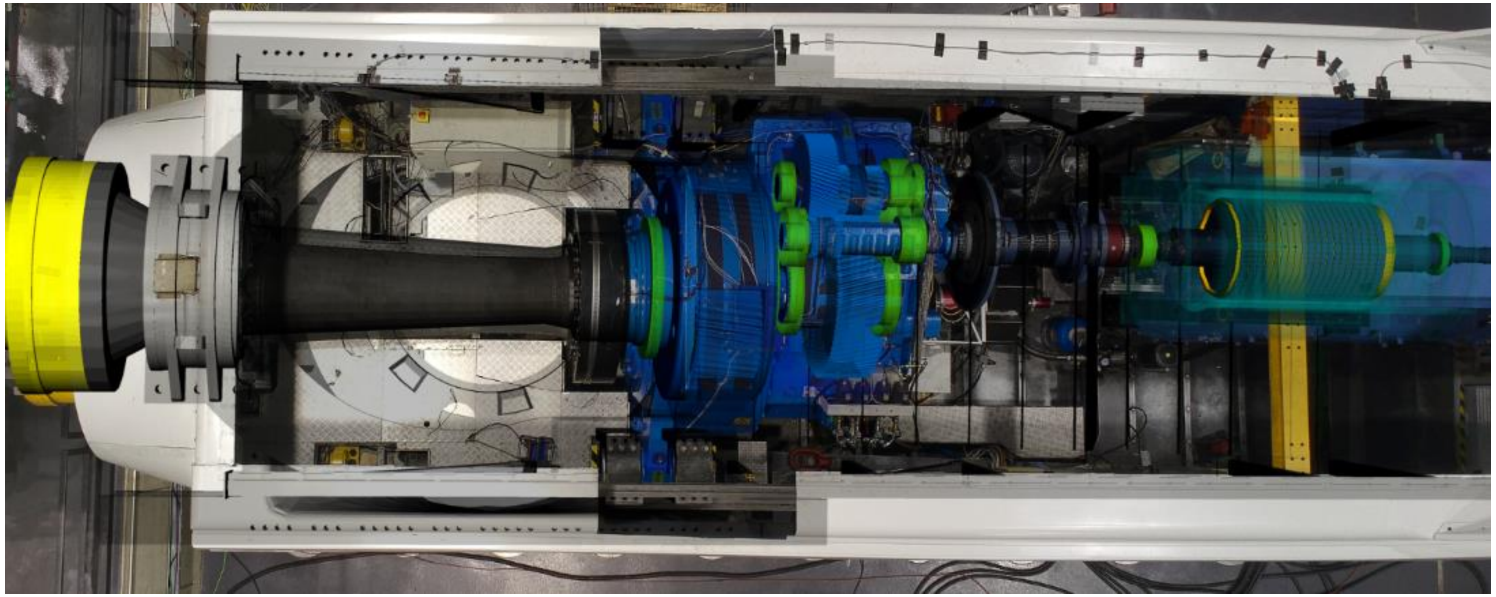
2 Component design

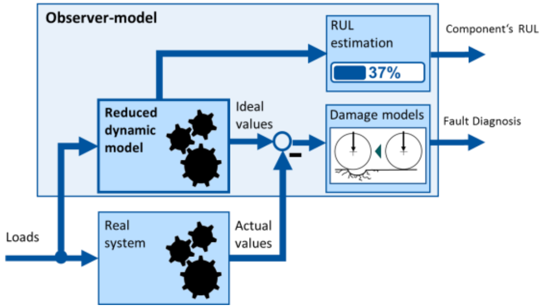
3 load calculation in planetary stage

4 electromechanical coupling

5 Model-based CMS



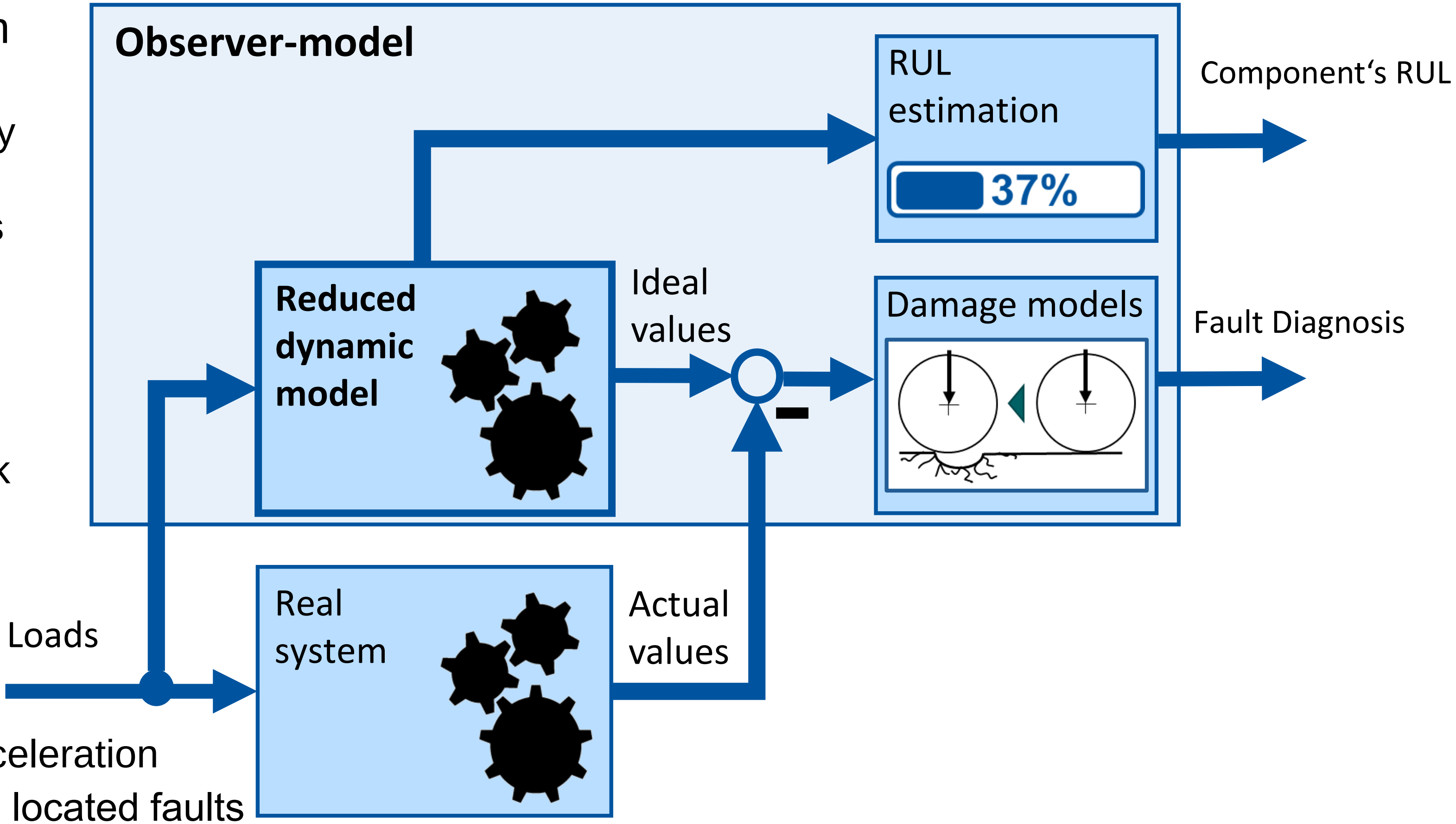




Model-based CMS

Development of a observer-based condition monitoring system (CMS)

- Investigation of model-based CMS with focus on the observer approach
  - Automated CMS with minimum necessary expert knowledge
  - Calculation of unmeasurable state values for detailed operation information
- Observer elements:
  - Reduced dynamic model derived from a highly detailed gearbox model in Simpack
  - Models for RUL estimation of each gearbox component
  - Description of damage influences on system level



- Inputs: torsional loads (strain gauges), acceleration
- Outputs: Component's RUL, detected and located faults

➡ Next step: Use of Simpack for real-time simulation of the observer-model

Thank you for your attention!