TECHNISCHE UNIVERSITÄT DRESDEN

Institut für Maschinenelemente und Maschinenkonstruktion
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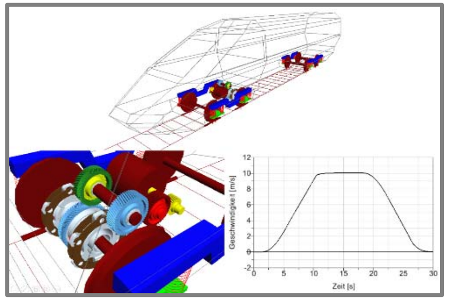
How Multibody-System Simulation Models can Support the Design of Wind Turbines

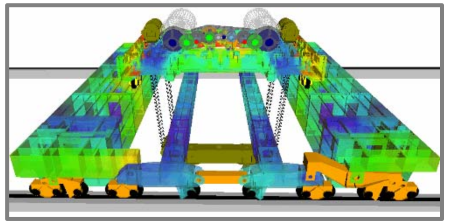
4th Wind and Drivetrain Conference

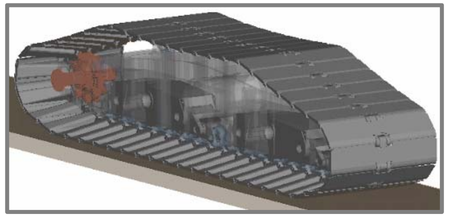
Prof. Dr.-Ing. Berthold Schlecht | Dr.-Ing. Thomas Rosenlöcher

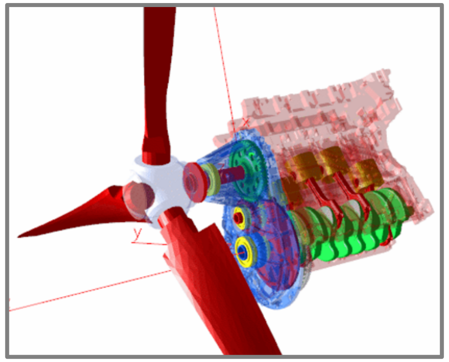
Hamburg, 19. April 2018

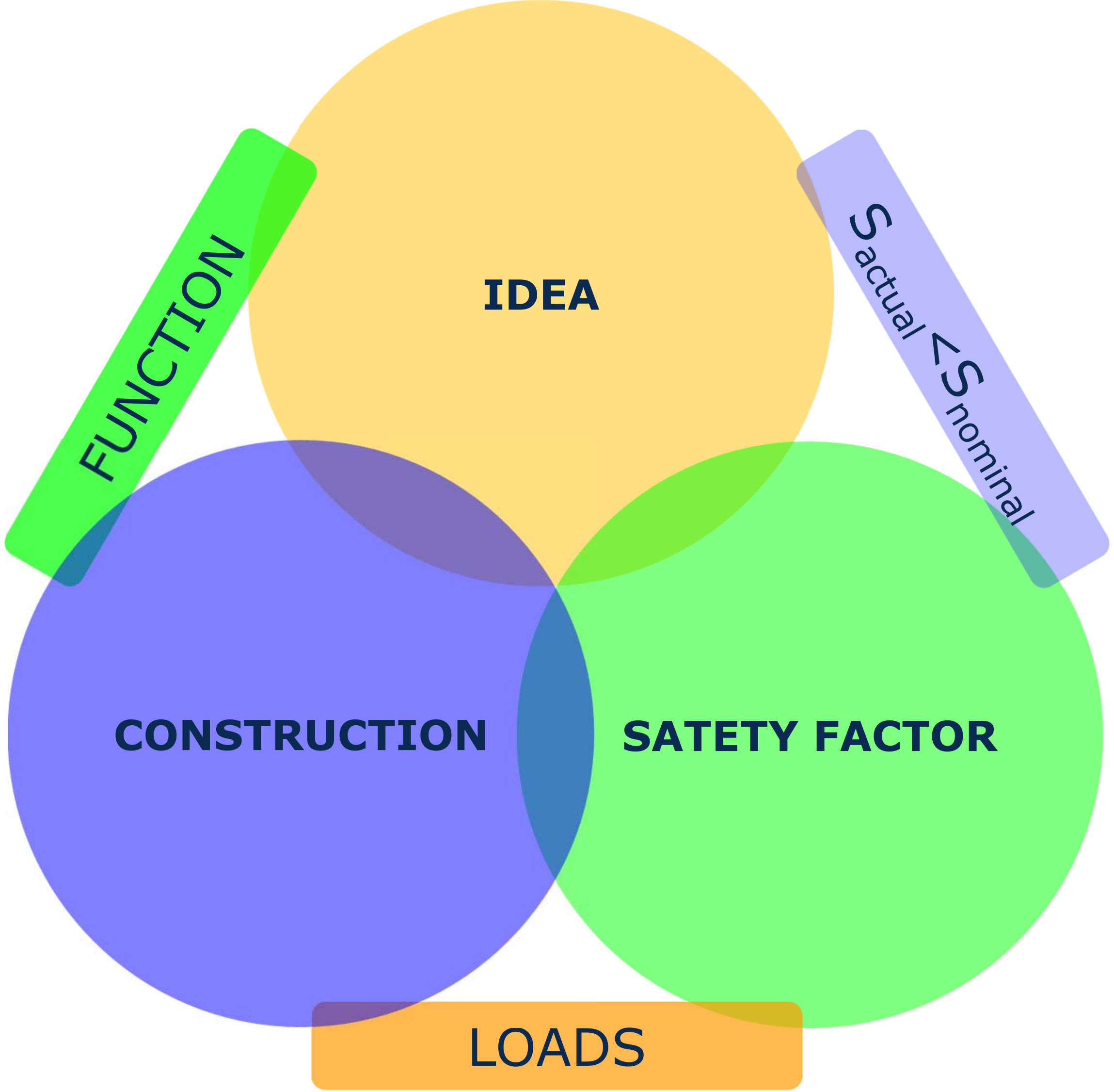
Product development process



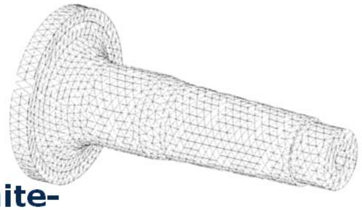




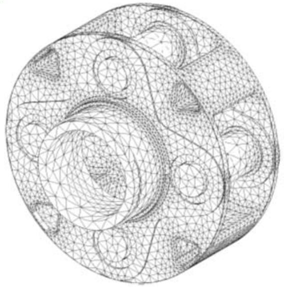




standards
(DIN 743,
ISO 6336)
software
(mdesign,
KissSoft, ..)

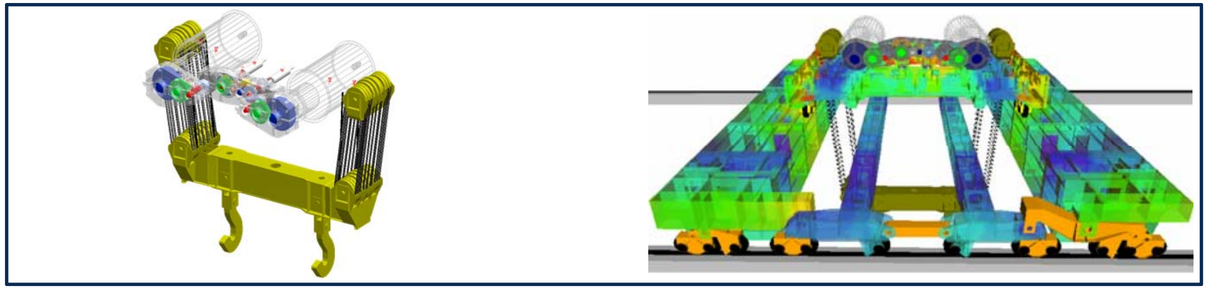


finite-element-method
(Nastran,
Ansys, ...)

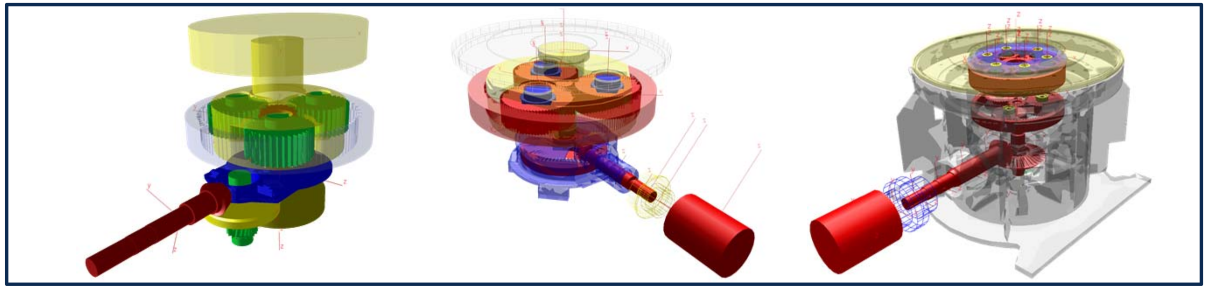


Product development process – load determination

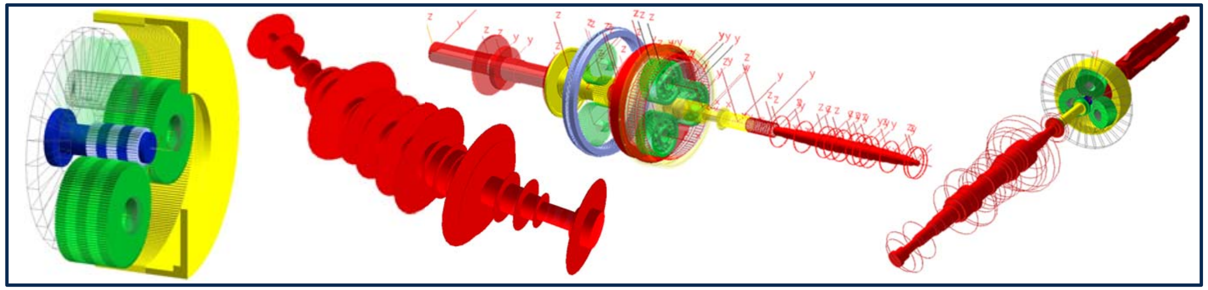
- Ladle cranes
  - Lifted load and emergency stop scenarios
  - ➢ Torque loaded drivetrain



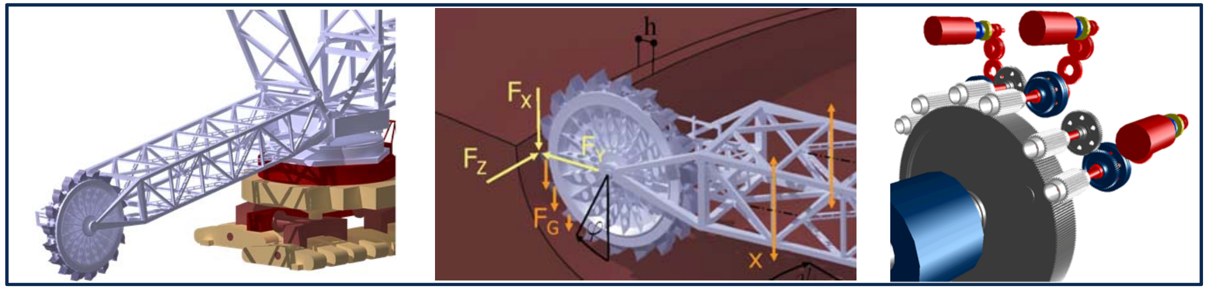
- Roller mills
  - Material size and pressure force
  - ➢ Torque loaded drivetrain



- Compressors and steam turbines
  - Turbine-/compressor power
  - ➢ Torque loaded drivetrain



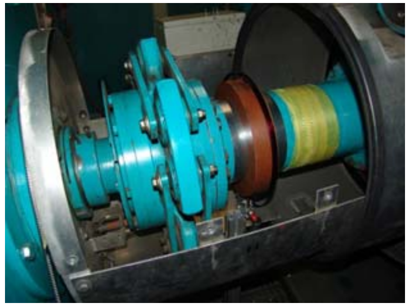
- Bucket wheel excavator
  - Dynamic mining forces
  - ➢ Torque loaded drivetrain

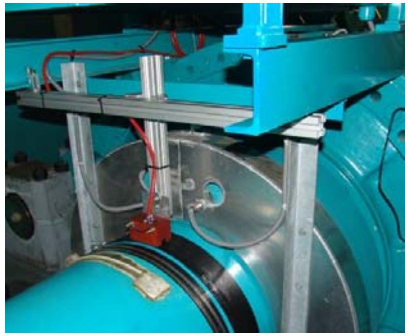


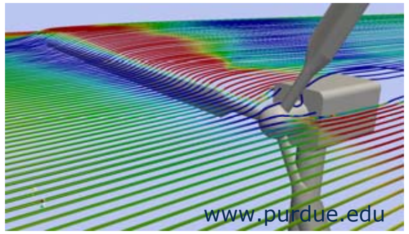
- Measurement
  - Torque, forces, rotational speed, acceleration, displacement, temperature
  - Load determination on the machine element associated with considerable effort
  - Mostly "conversion" of measured values in load for machine element required

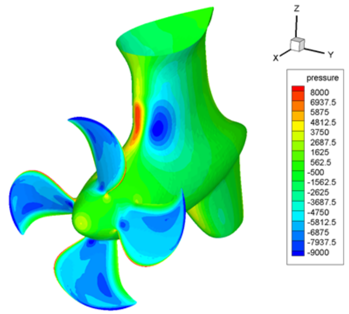
- Simulation
  - Process simulation, fluid dynamics (air, water)
  - Simplified simulation software to determine loads
  - Transferring the calculated loads to the machine element

- Design of drive train components
  - Durable design of shafts and supporting structures in most cases
  - Consideration of load collectives for the service life calculation
  - Durable design of the gearing,
    but load collective influences load distribution in the gear contact









Product development process – load determination

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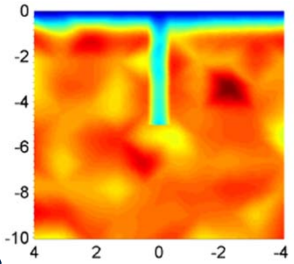
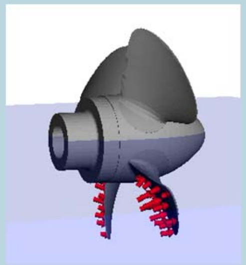
operational load cases

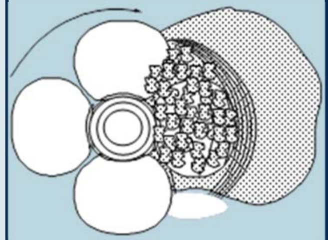
stoch. loads



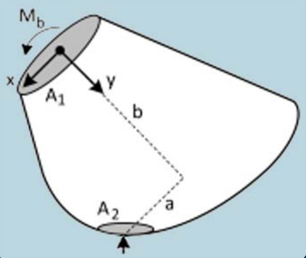
ventilation



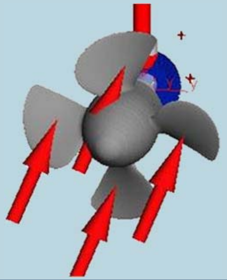
ice loads



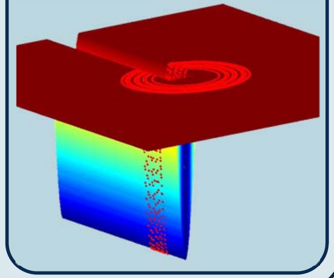
foreign bodies

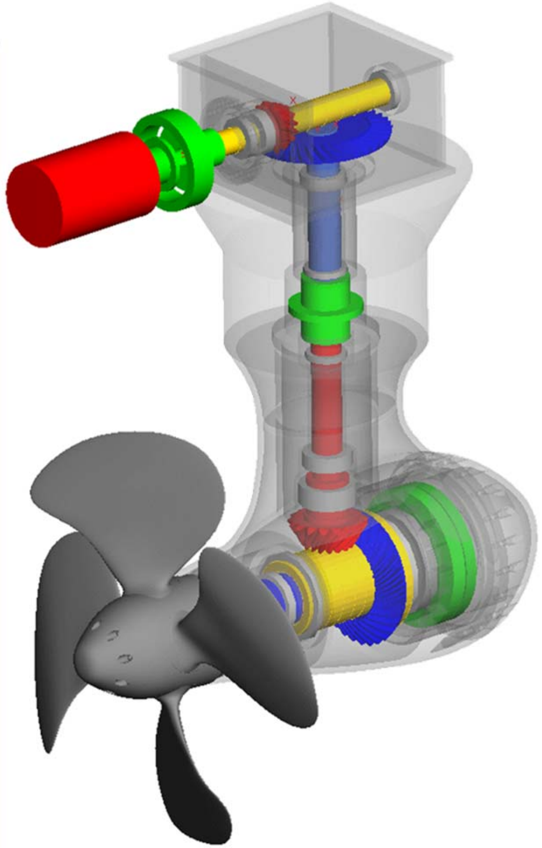


current



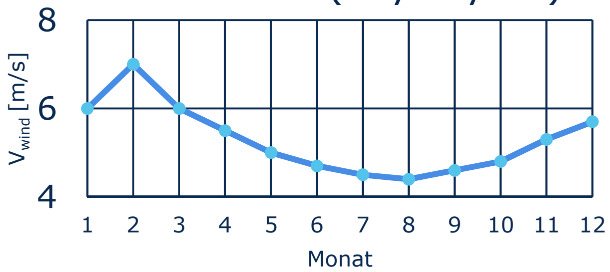
excitation



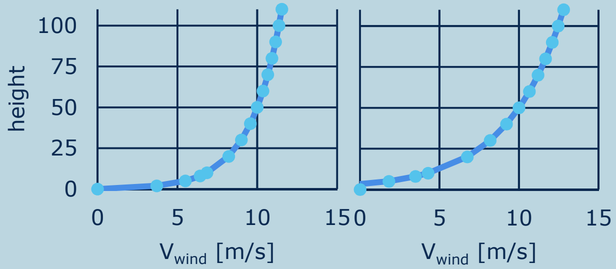


operational load cases

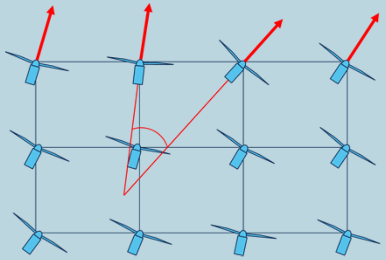
load variation (day & year)



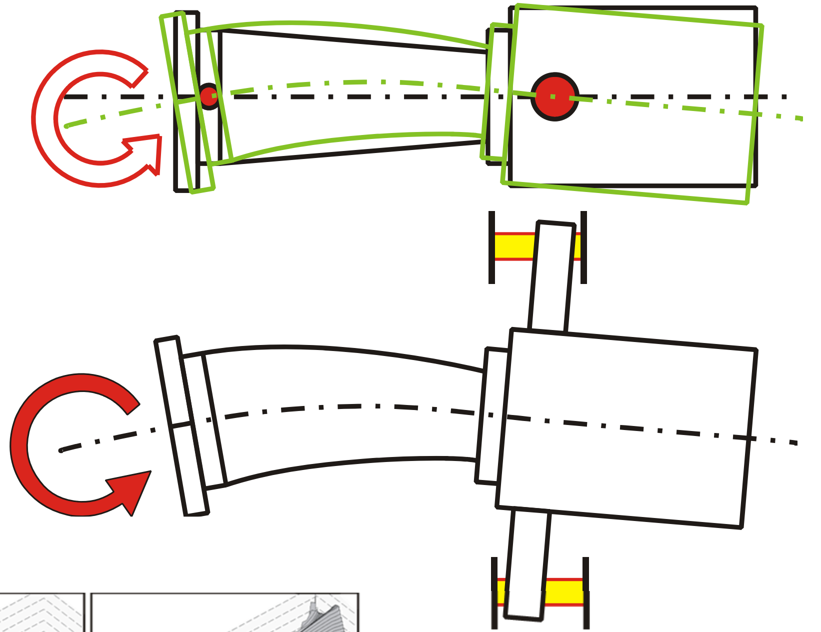
vertical load distribution



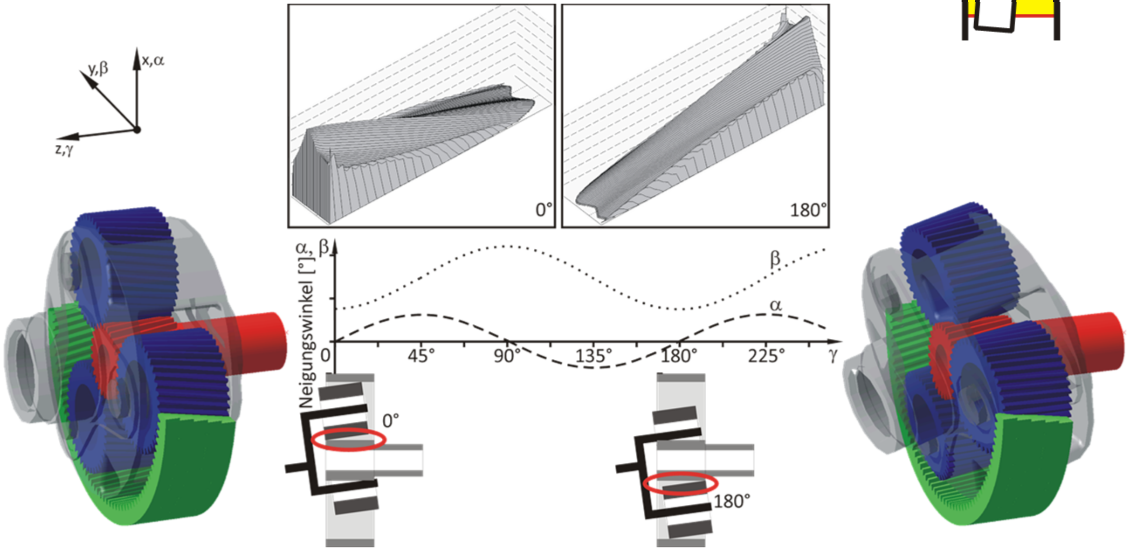
horizontal load distribution



- Transmission of loads by the gearing of the planetary gear stage
- External loads cause misalignment of gears due to inclination of carrier against ring, sun gear



- Inclination increases load, maximum load occurs (planet-ring | planet-sun) at different ends of gearing
- Gearing modification must ensure optimal load distribution
    - Over carrier rotation
    - For different load cases
    - Considering related frequency of occurrence



- Which software can be used? (MBS, LTCA, FE)

Design of the drivetrain for a wind turbine

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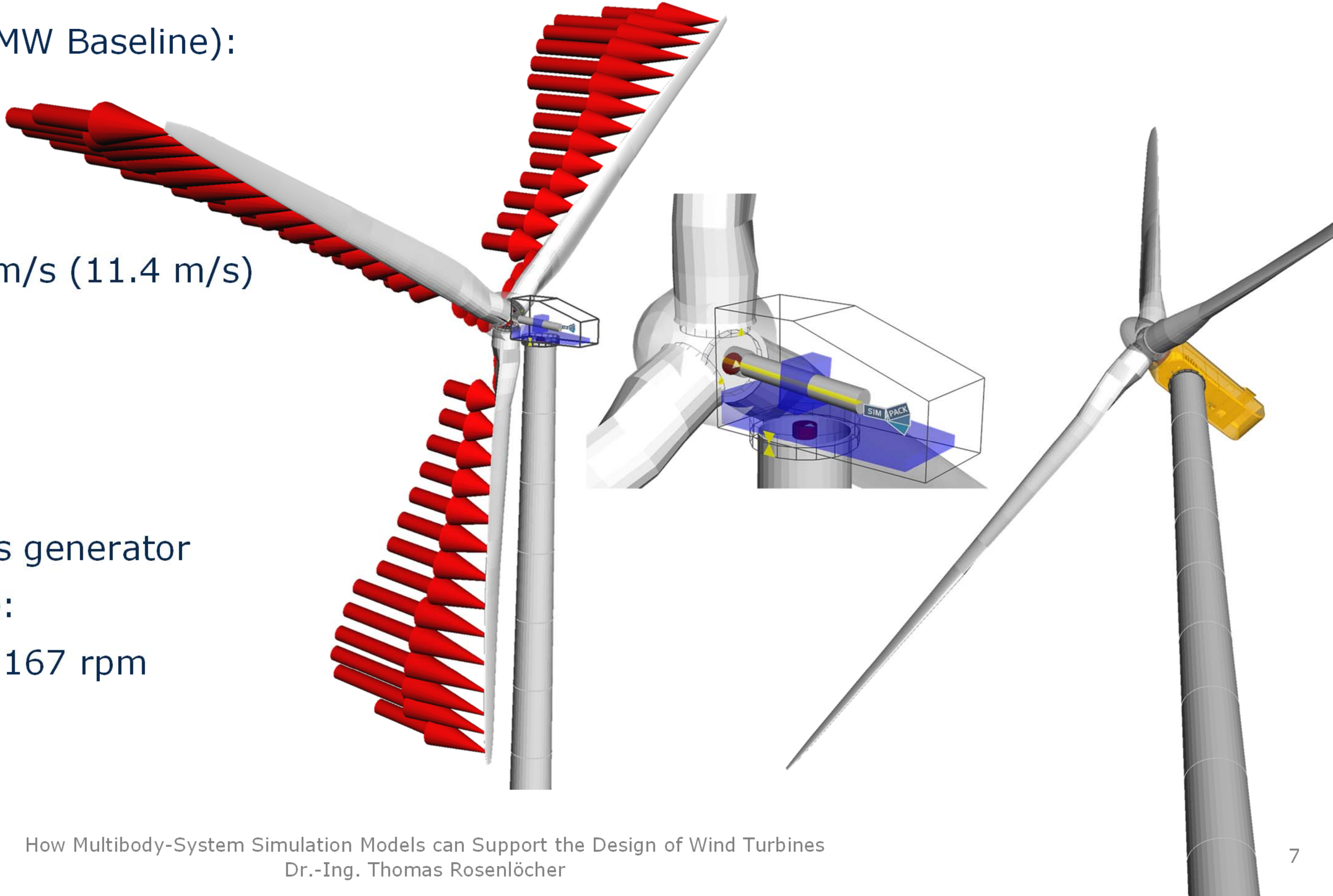
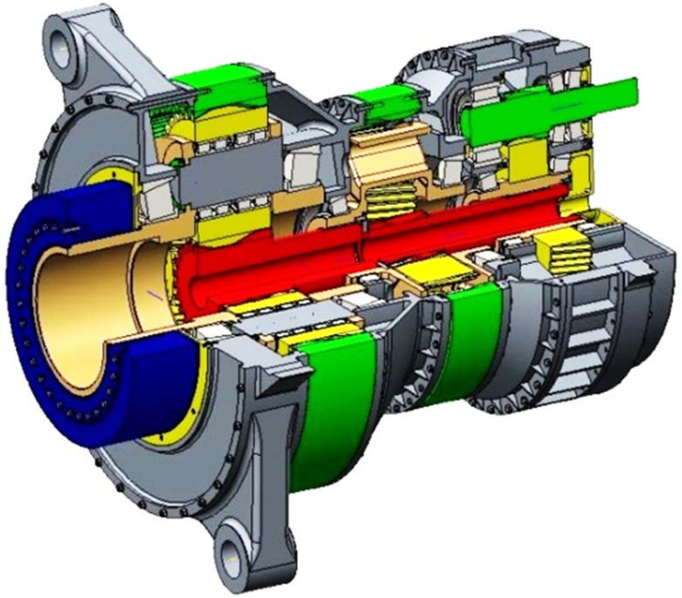
- Specification (NREL 5 MW Baseline):
  - Rotor diameter:
    - 126 m
  - Wind speed:
    - 3 m/s to 25 m/s (11.4 m/s)
  - Rotor speed:
    - 12.1 rpm
  - Concept:
    - double-feed asynchronous generator
  - Operational range:
    - 670 rpm to 1167 rpm

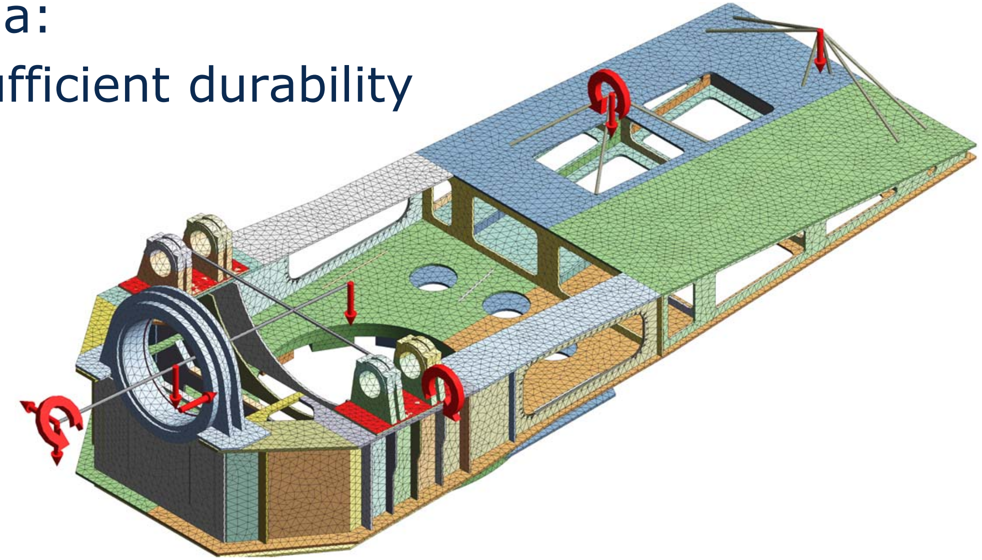


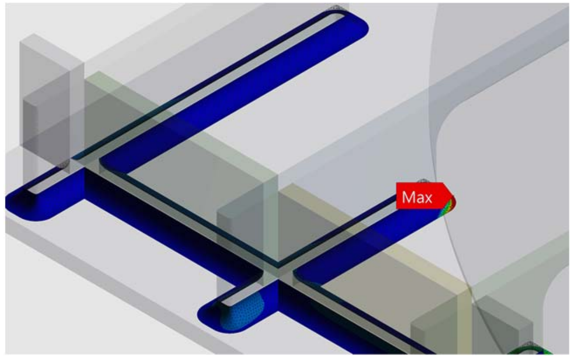
Design of the drivetrain for a wind turbine

- Design of a three-point supported gear box
  - Two planetary gear stages
  - One helical gear stage

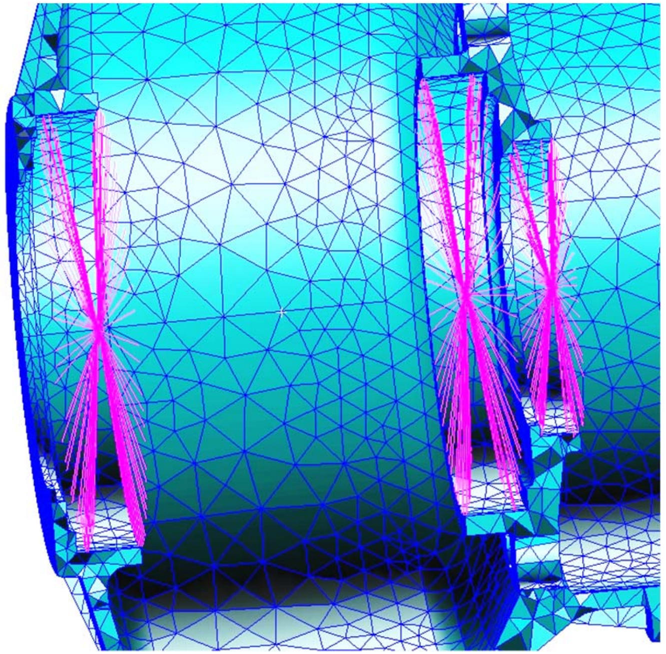


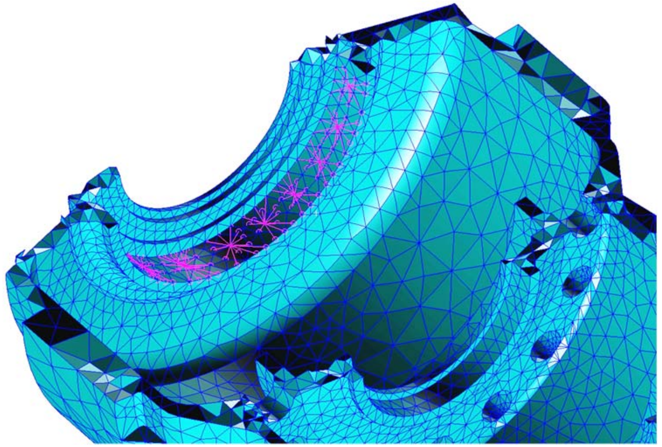
- Mainframe design
  - Welded design, design criteria:
    high stiffness, low weight, sufficient durability





- Modal reduced finite element models
  - Using specific number of mode shapes, load introduction points
  - Load transfer occurs by multi-point-constraints
  - Possible approaches
    - RBE2-elements: cause stiffening of the structure
    - RBE3-elements: no stiffening, pushing and pulling forces
  - Modal reduction requires linearization (element types limited)
  - Solution:
    - Center point is connected to a certain number of MPC's
    - Transfer of pushing loads, no transfer of pulling loads: described by nonlinear bearing characteristic in MBS model



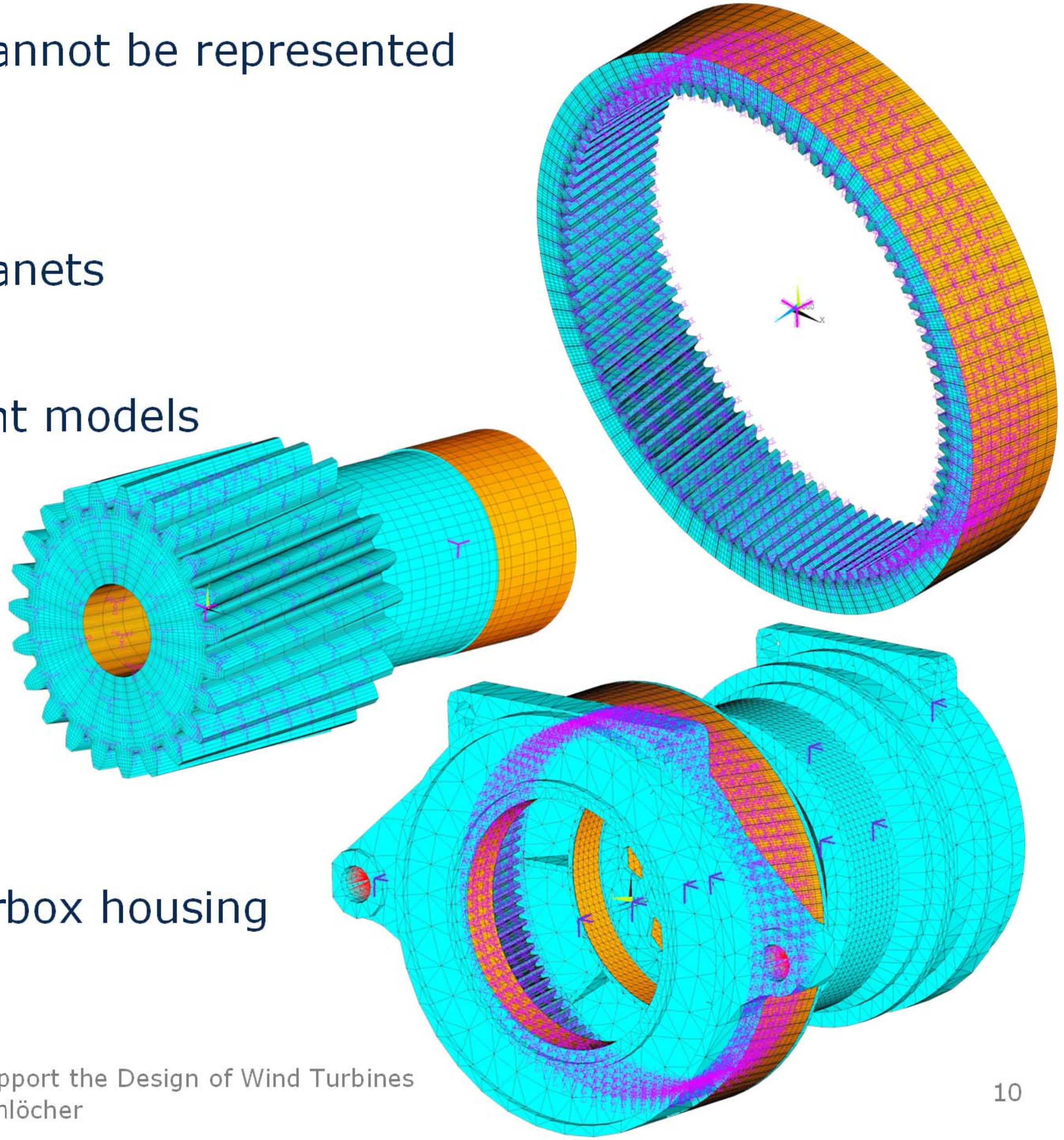


NREL 5 MW Baseline – modelling of elastic gearing

- Effects resulting from sun and ring gear elasticity cannot be represented
  - Sun: twist
  - Planets: deformation of thin rim
  - Ring gear: deformation by gearing forces of planets

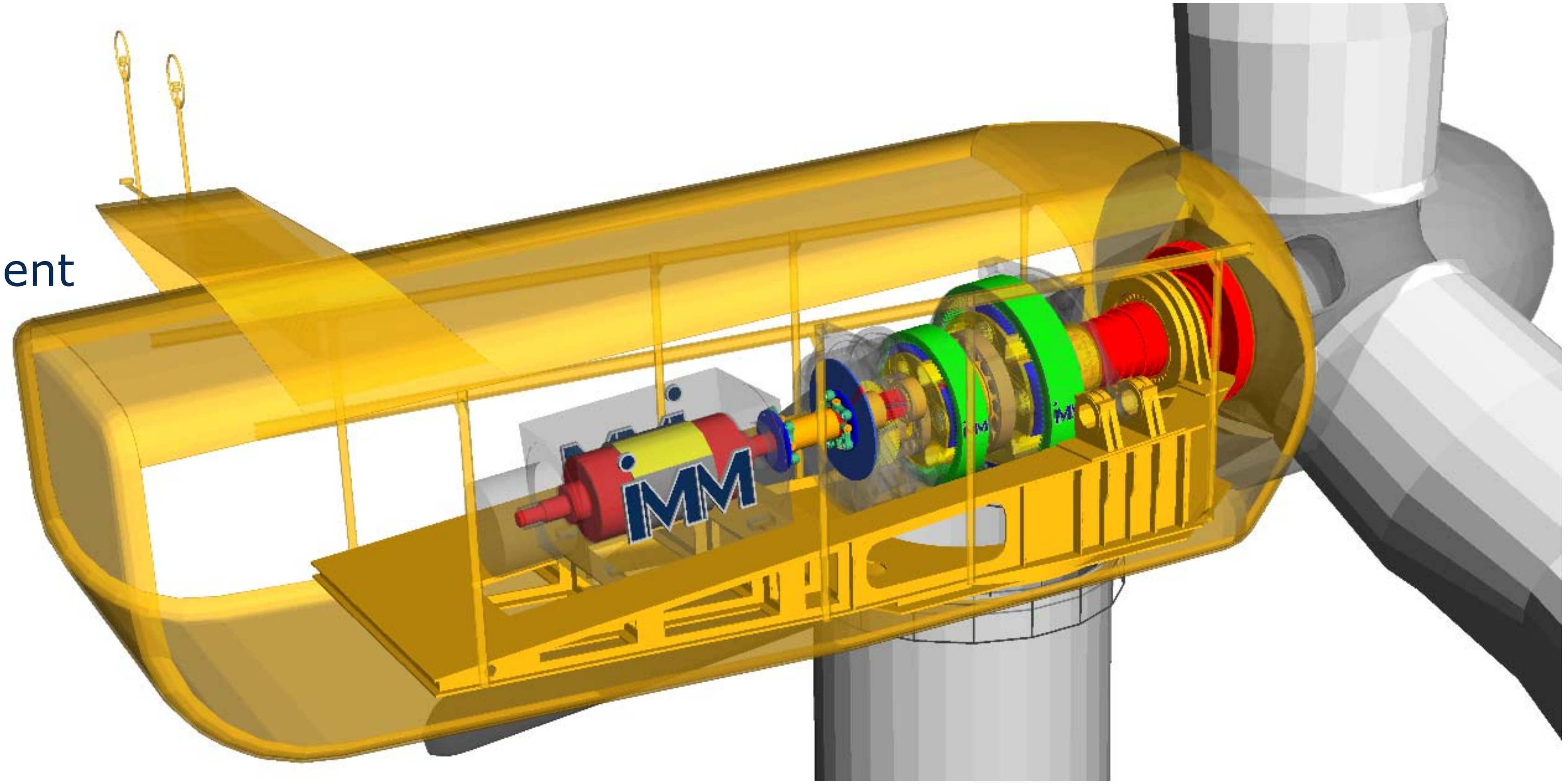
- Integration of gears as modal reduced finite-element models

- Definition of MPCs on each tooth
  - On pitch diameter: tooth stiffness described by FE-model
  - In tooth root: flexibility described by analytical approaches
  - Ring gear implemented in the structure of gearbox housing

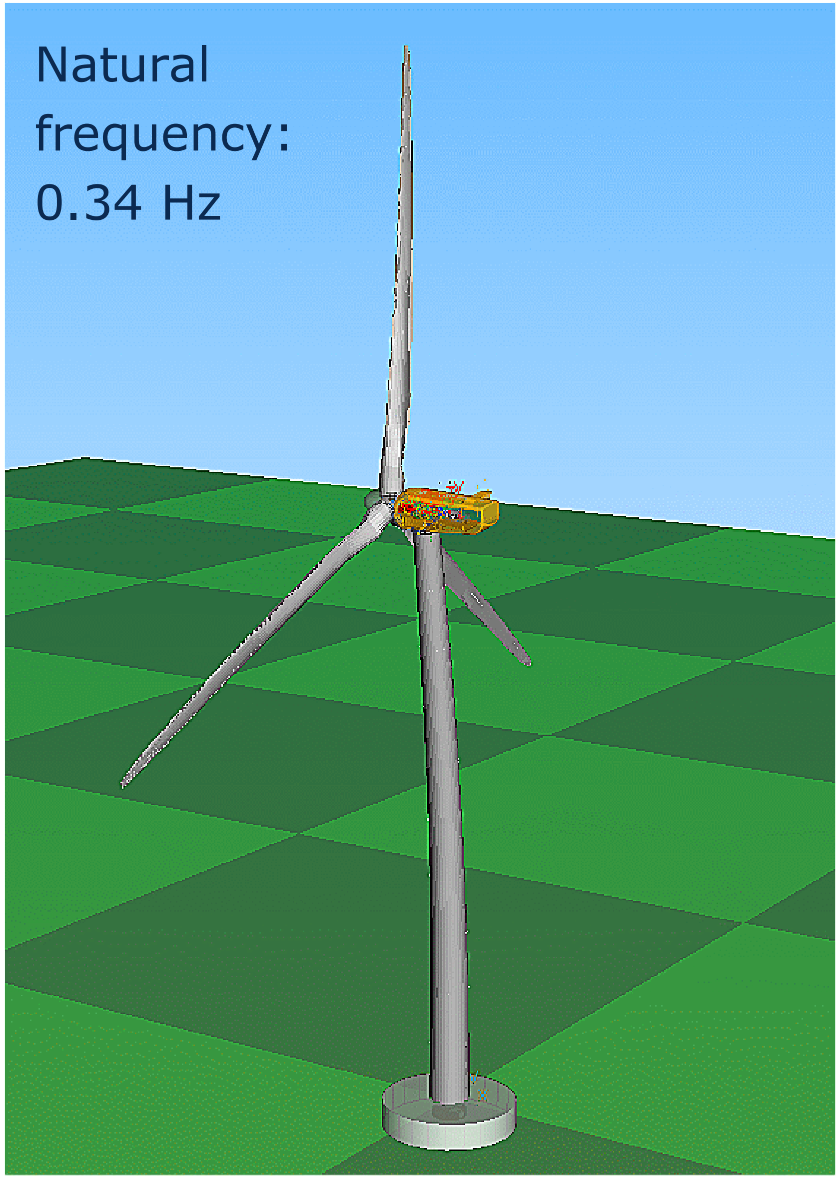


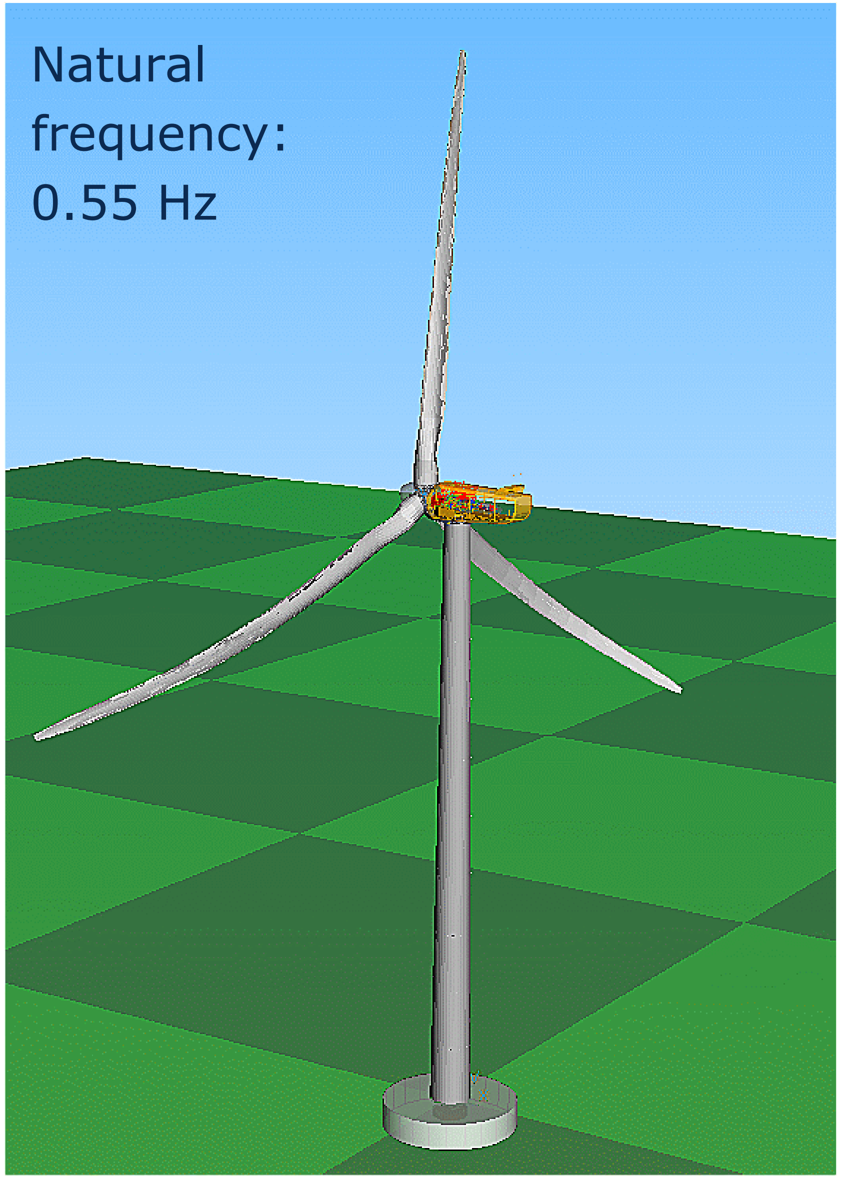
NREL 5 MW Baseline – modelling

- Implementation of the gearbox in the NREL 5 MW Baseline
  - Three-point support
  - 6 DOF
  - Elastic beams:
    - Rotor blades
    - Tower
    - Shafts
  - Modal reduced finite element models:
    - Planet carriers
    - Gearbox housing
    - Mainframe

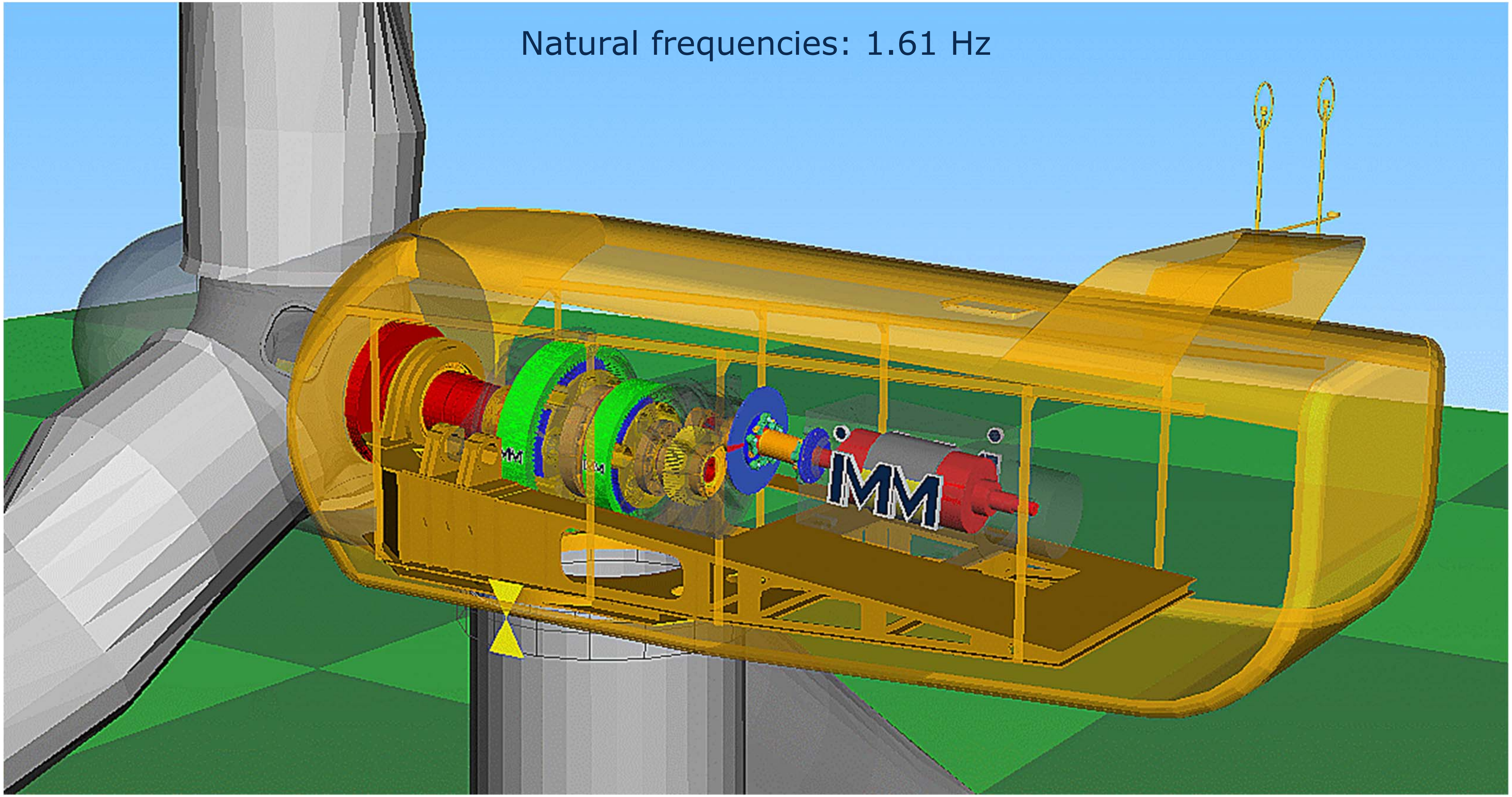


NREL 5 MW Baseline – frequency domain

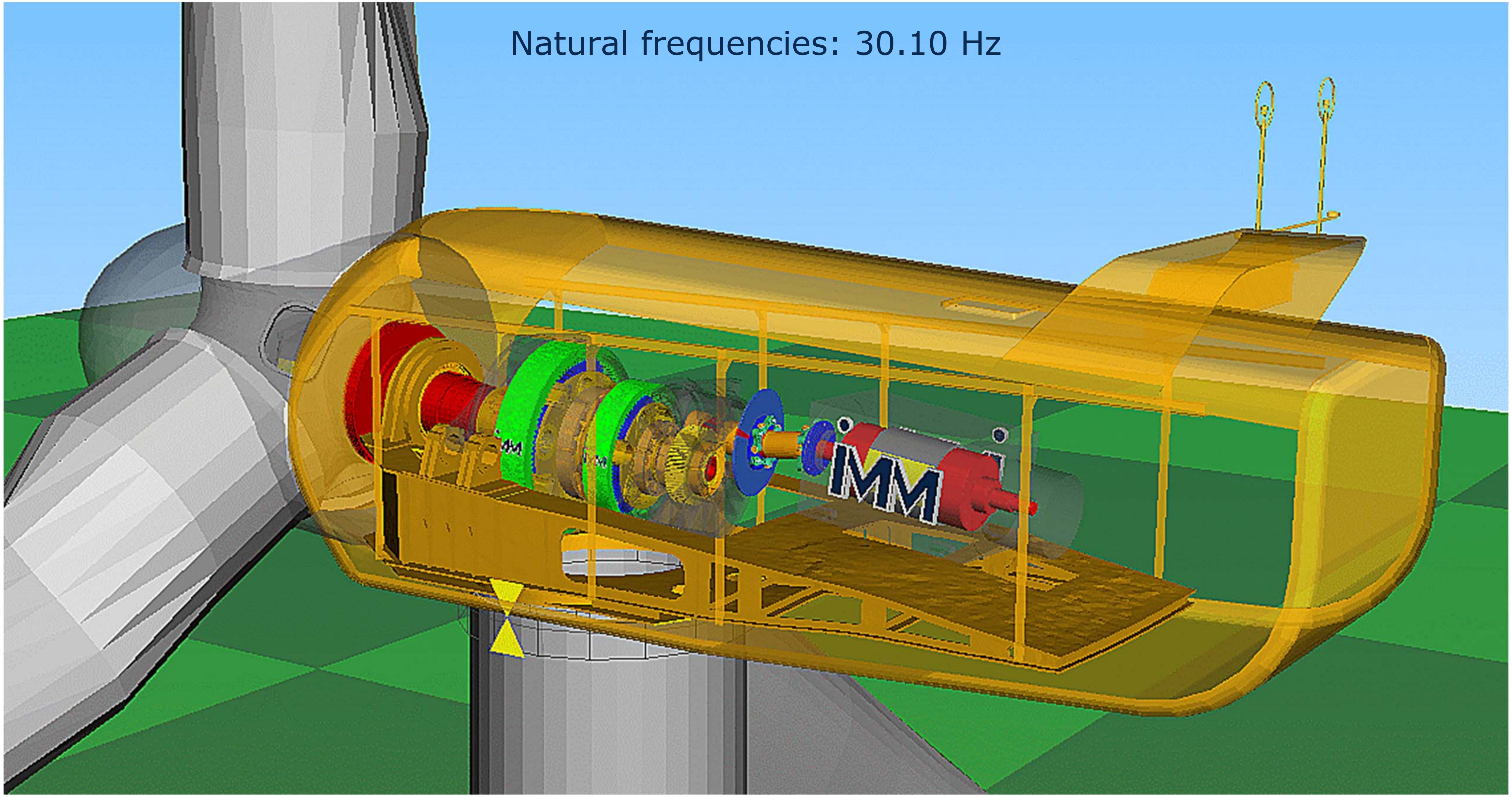




NREL 5 MW Baseline – frequency domain

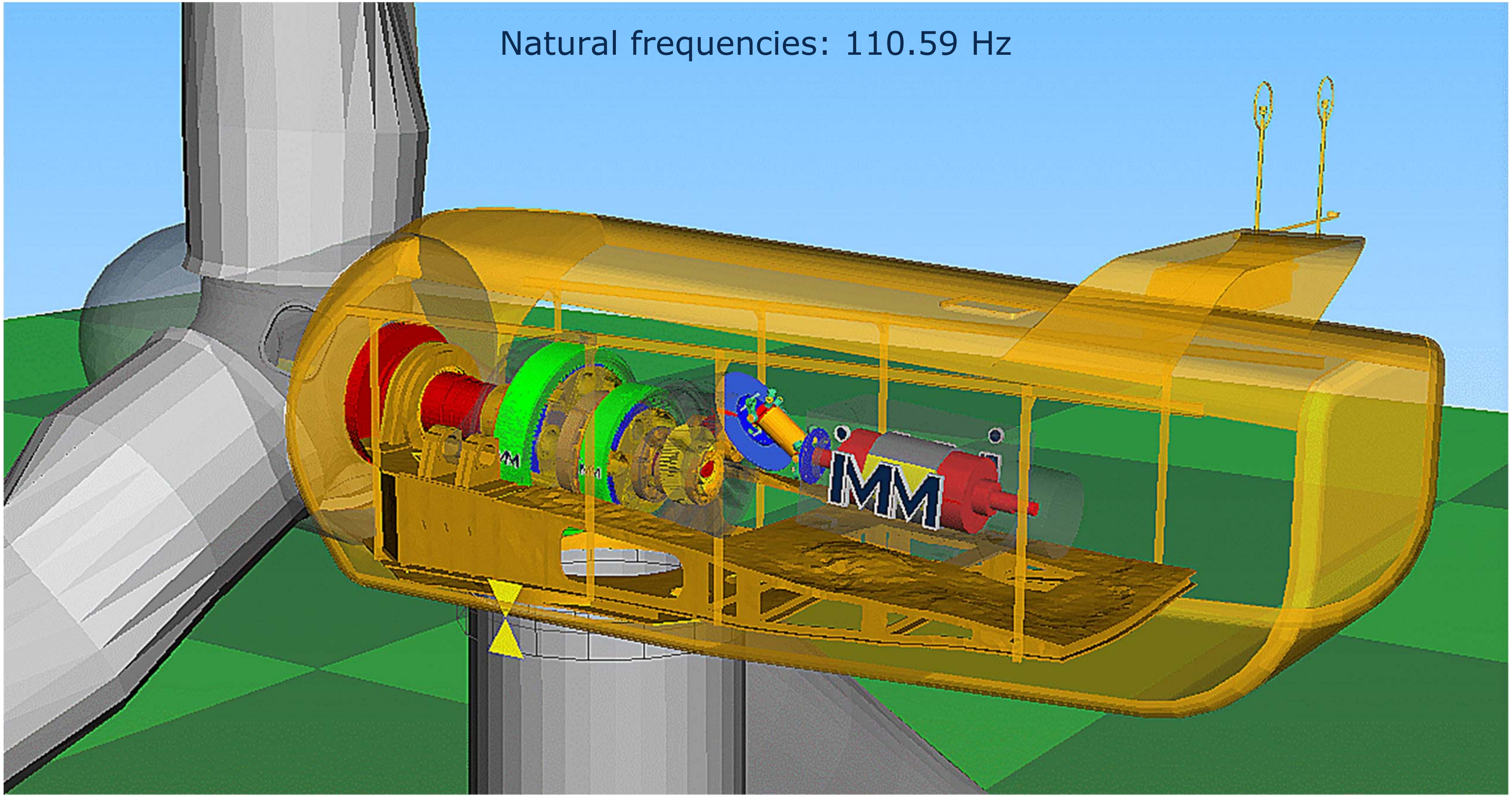


NREL 5 MW Baseline – frequency domain



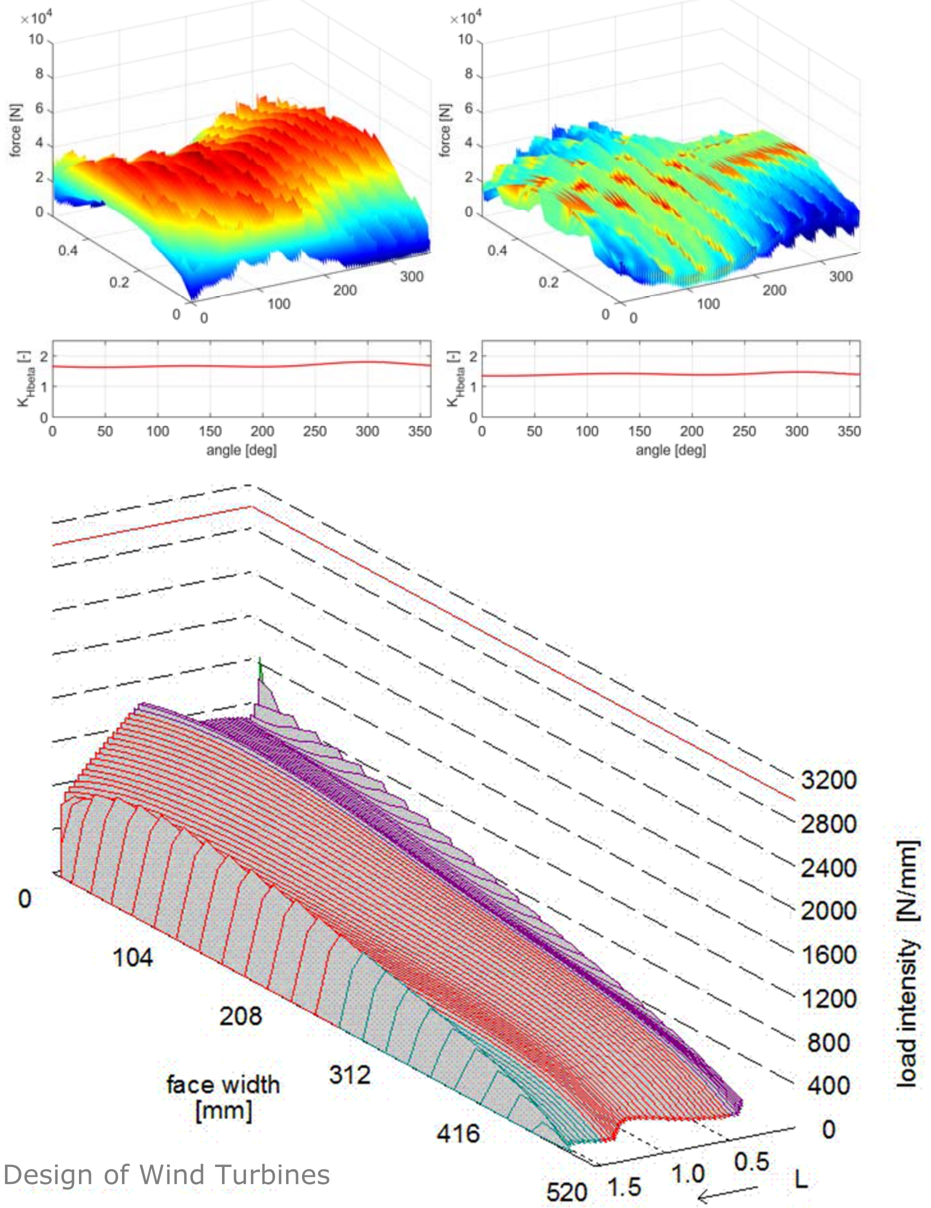
NREL 5 MW Baseline – frequency domain

Natural frequencies: 110.59 Hz



NREL 5 MW Baseline – load distribution analyses

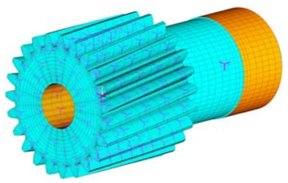
- Simulation of load case in SIMPACK
- Determination of relative displacement
  - sun – planet
  - planet – ring
  - Calculation of helix deviation
  - Calculation of load distribution
  - Optimisation of modification
- New simulation in SIMPACK using optimised modification



NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

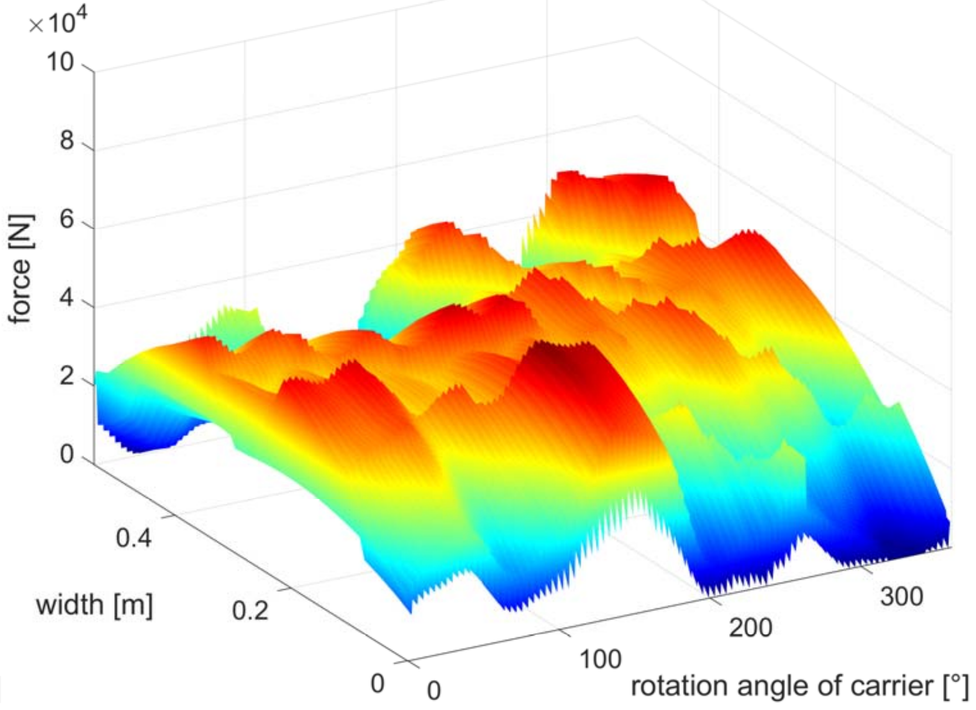
elastically modelled gearing

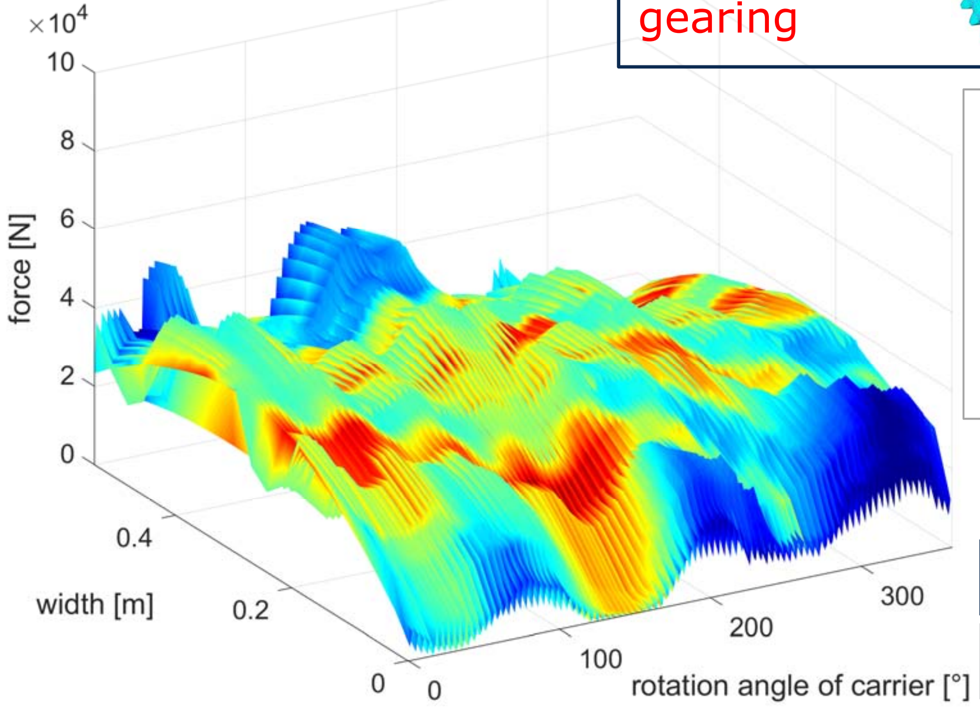


sun – planet

helix angle modification
$f_{H\beta}$ = 90 µm

lead crowing
C_b = 60 µm



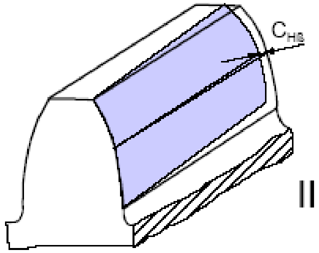


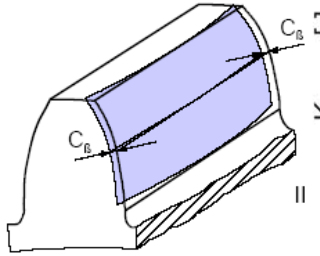
ring – planet

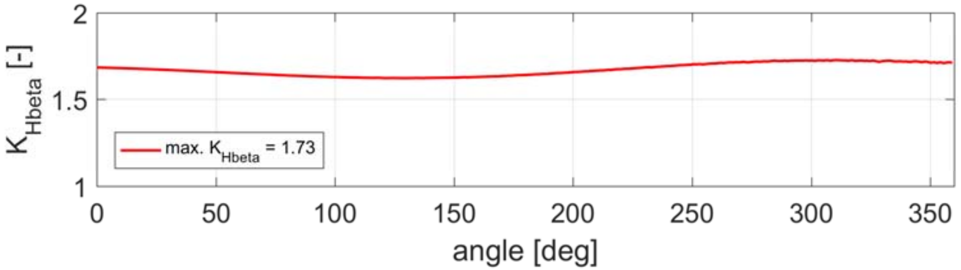
helix angle modification
$f_{H\beta}$ = 250 µm

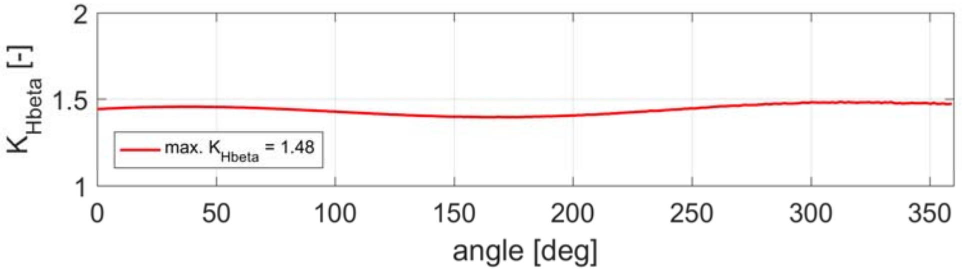
lead crowing
C_b = 30 µm

	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48





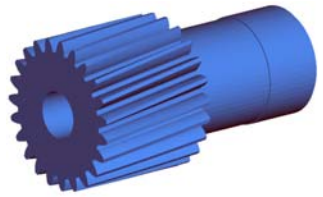




NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

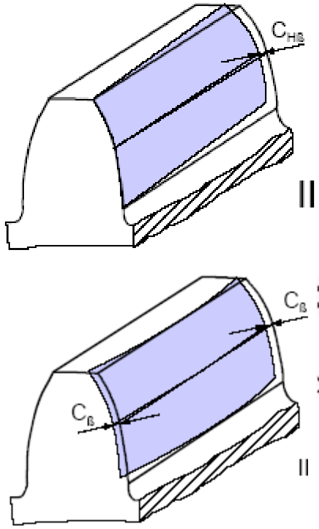
rigidly modelled gearing

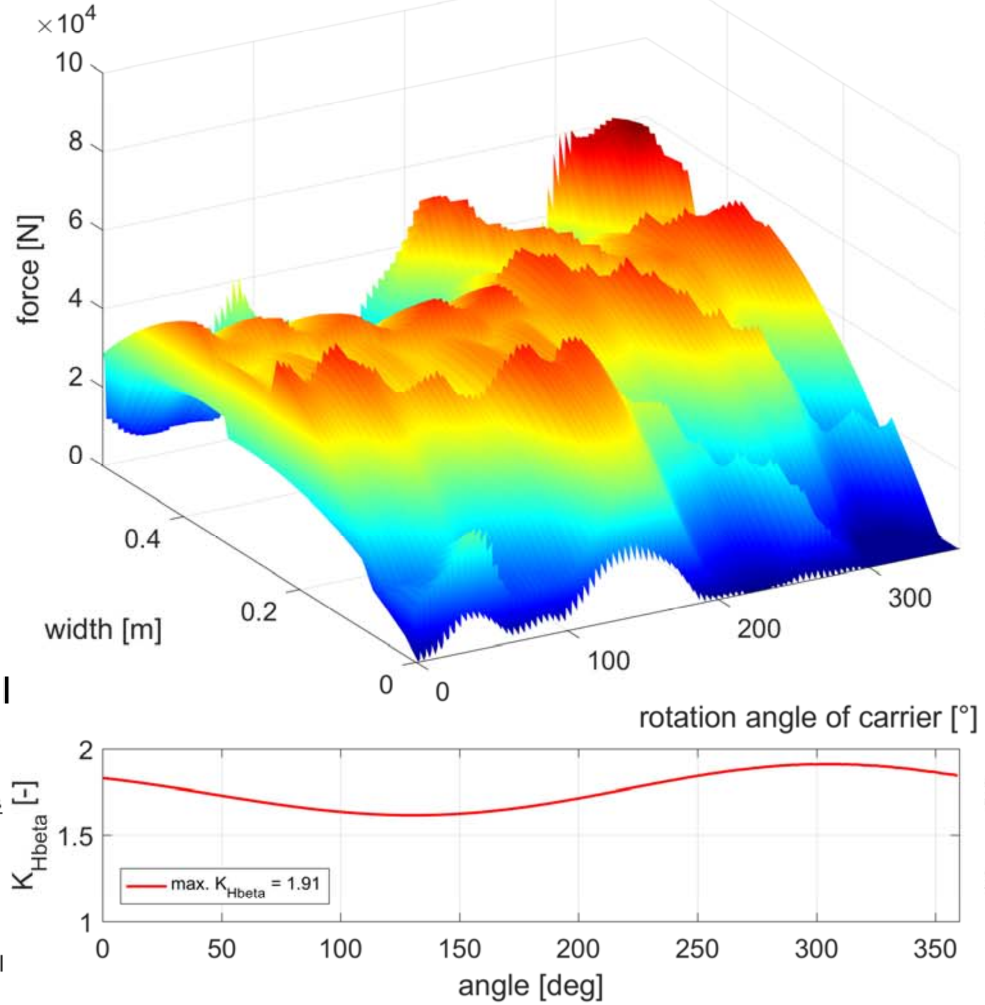


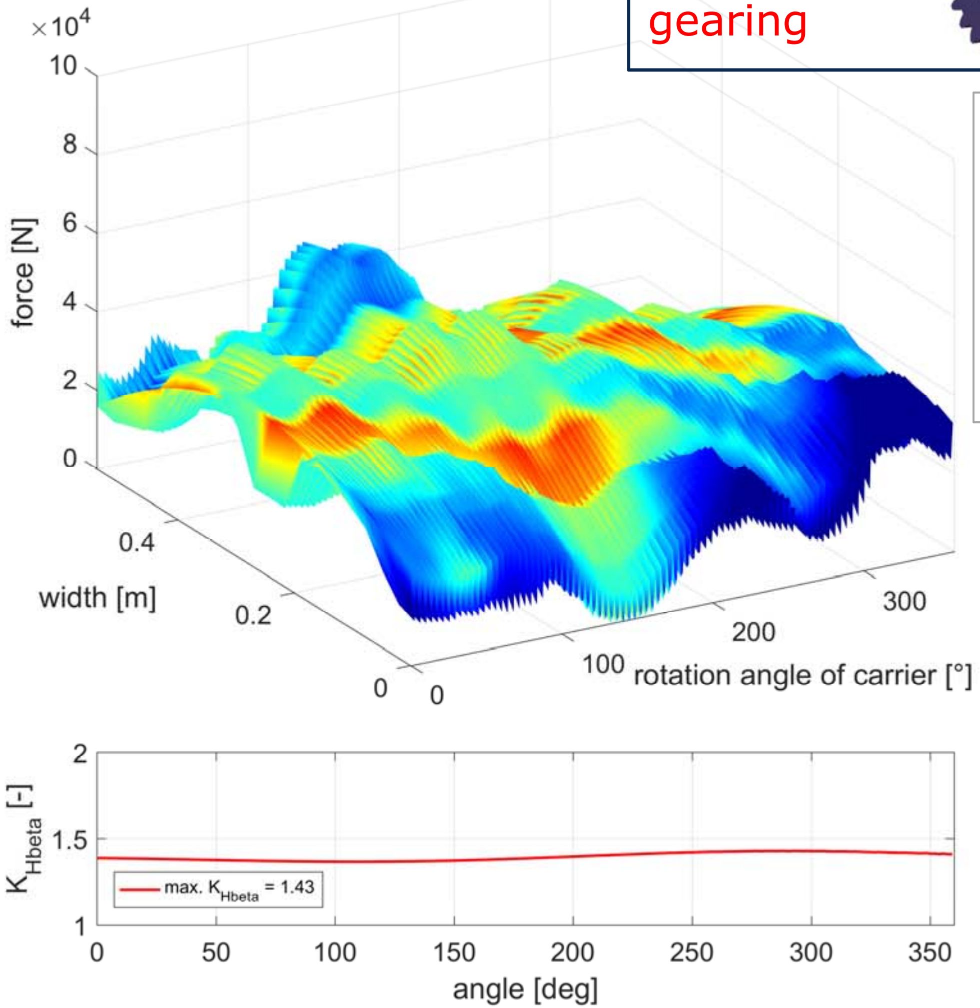
sun – planet

helix angle modification
$f_{H\beta}$ = 90 µm

lead crowing
C_b = 60 µm







ring – planet

helix angle modification
$f_{H\beta}$ = 250 µm

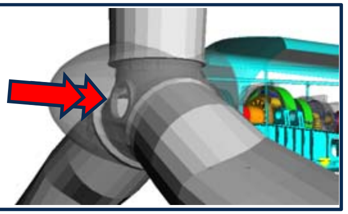
lead crowing
C_b = 30 µm

	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43

NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

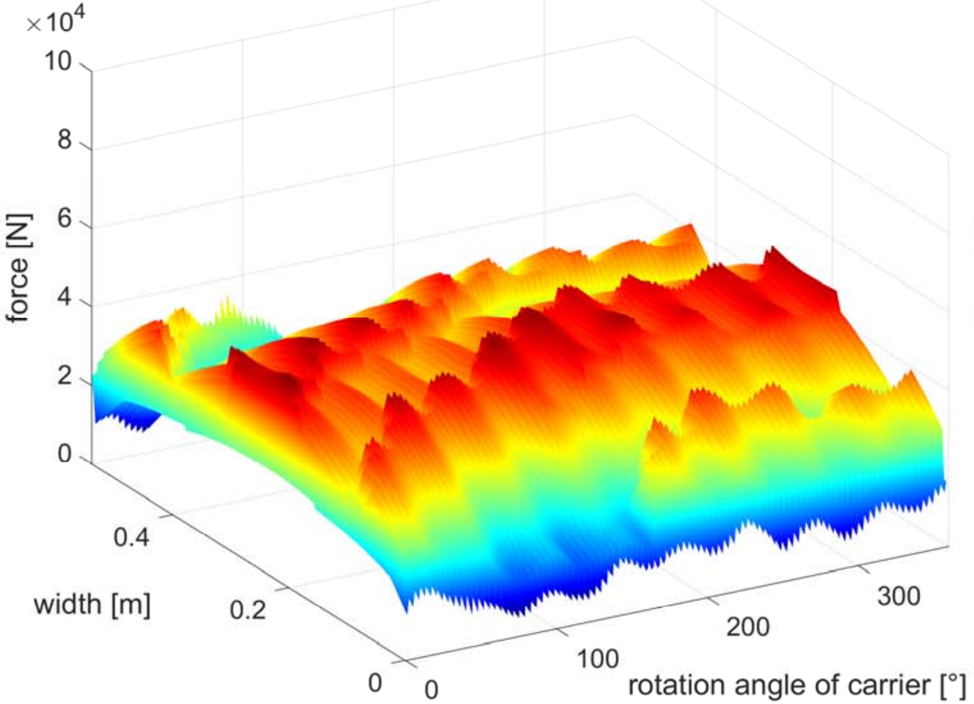
only torque

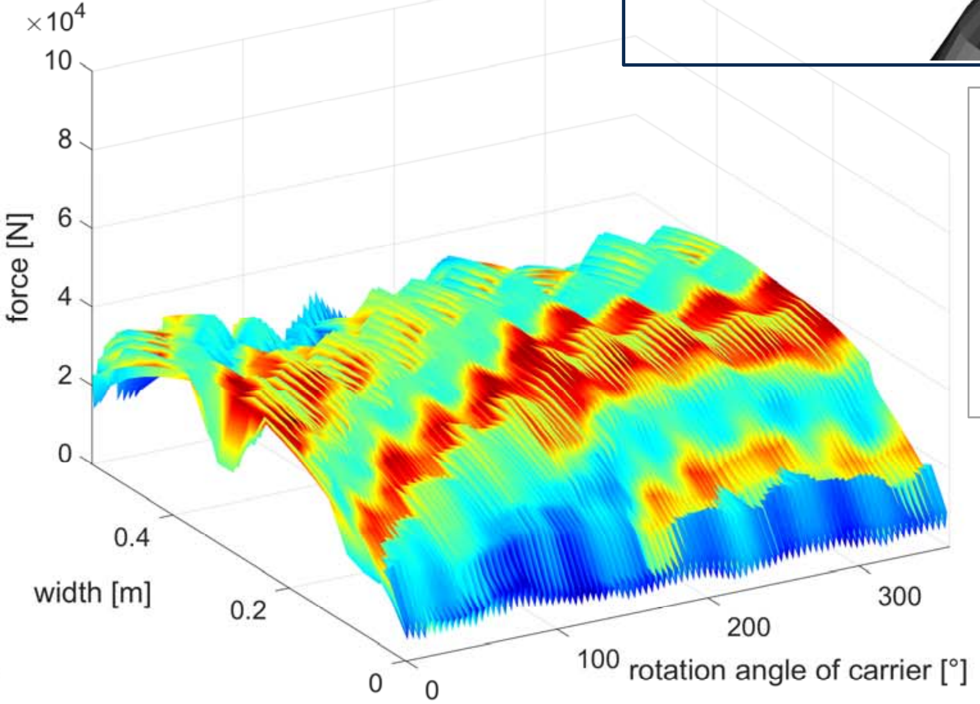


sun – planet

helix angle modification
$f_{H\beta}$ = 90 µm

lead crowing
C_b = 60 µm

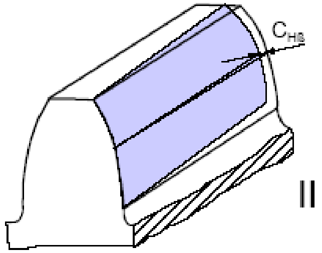


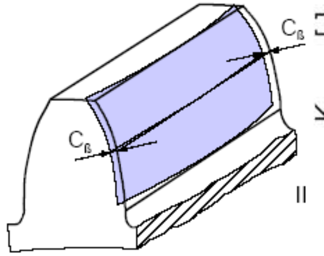


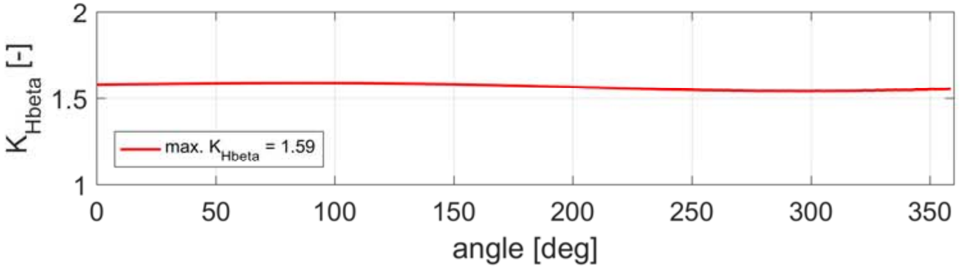
ring – planet

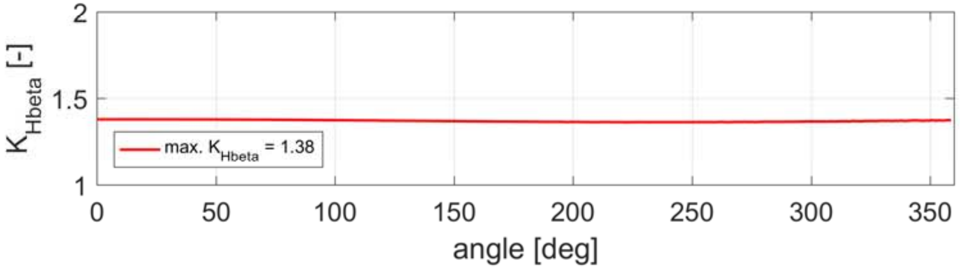
helix angle modification
$f_{H\beta}$ = 250 µm

lead crowing
C_b = 30 µm







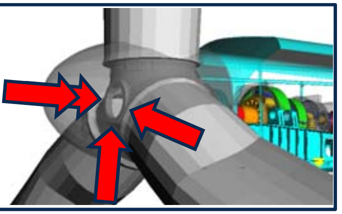


	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38

NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

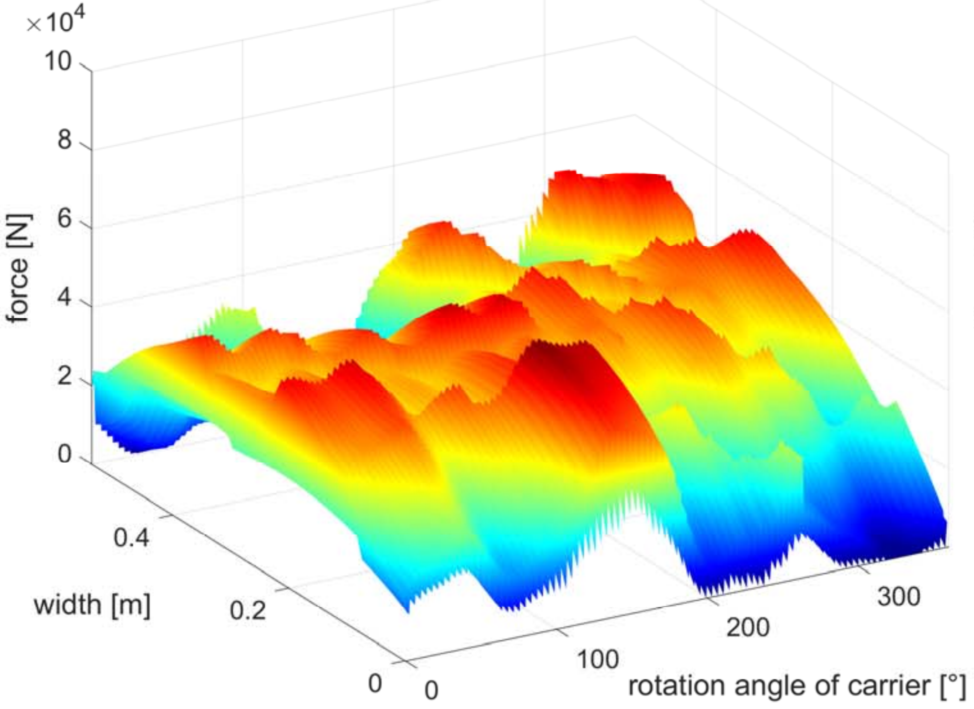
torque
forces
no bending

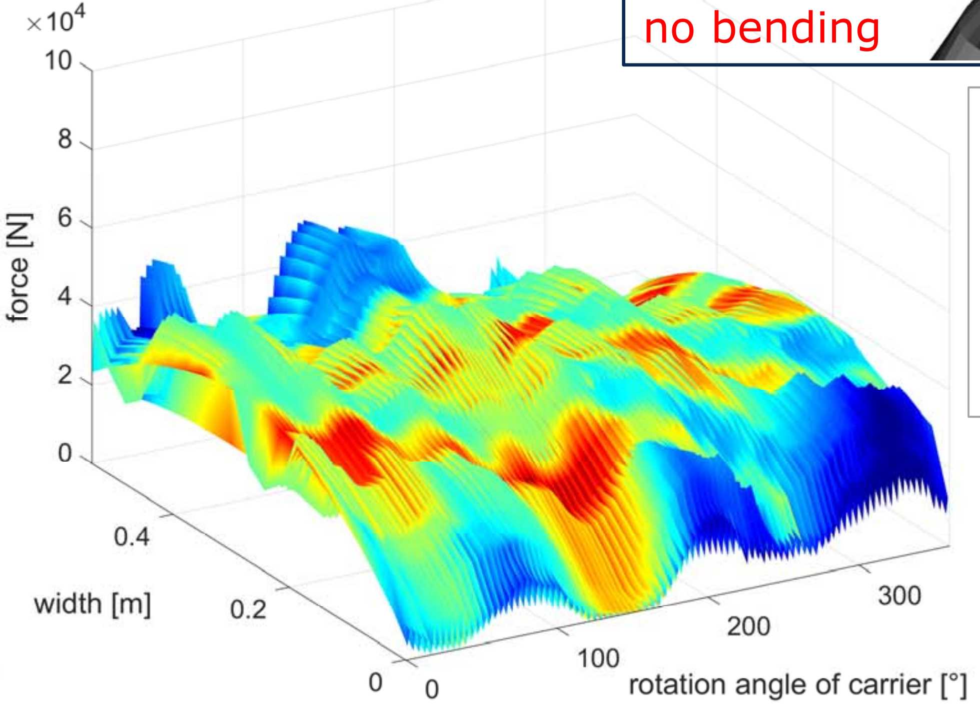


sun – planet

helix angle modification
$f_{H\beta}$ = 90 µm

lead crowing
C_b = 60 µm

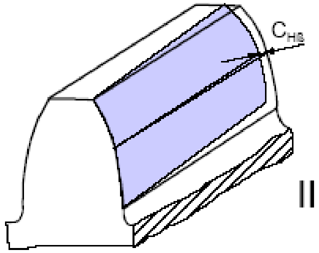


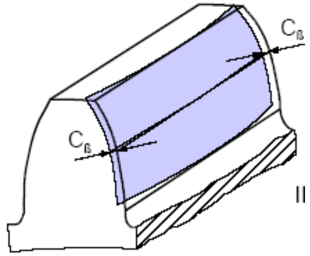


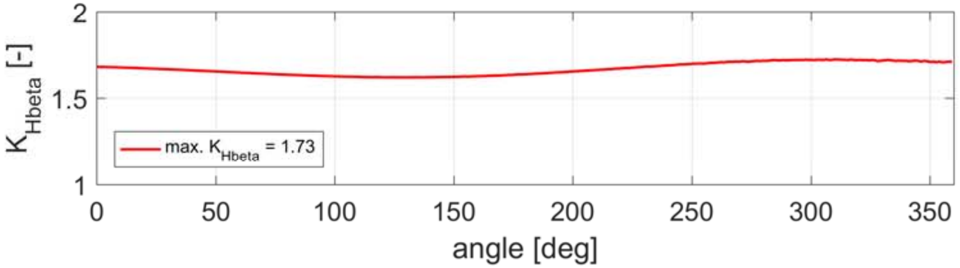
ring – planet

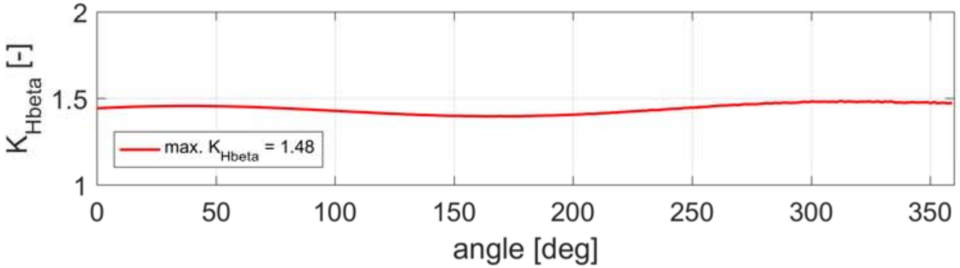
helix angle modification
$f_{H\beta}$ = 250 µm

lead crowing
C_b = 30 µm







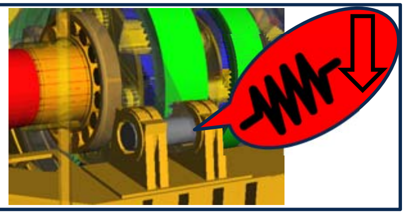


	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38
$M_{bending}$=0	1.73	1.48

NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

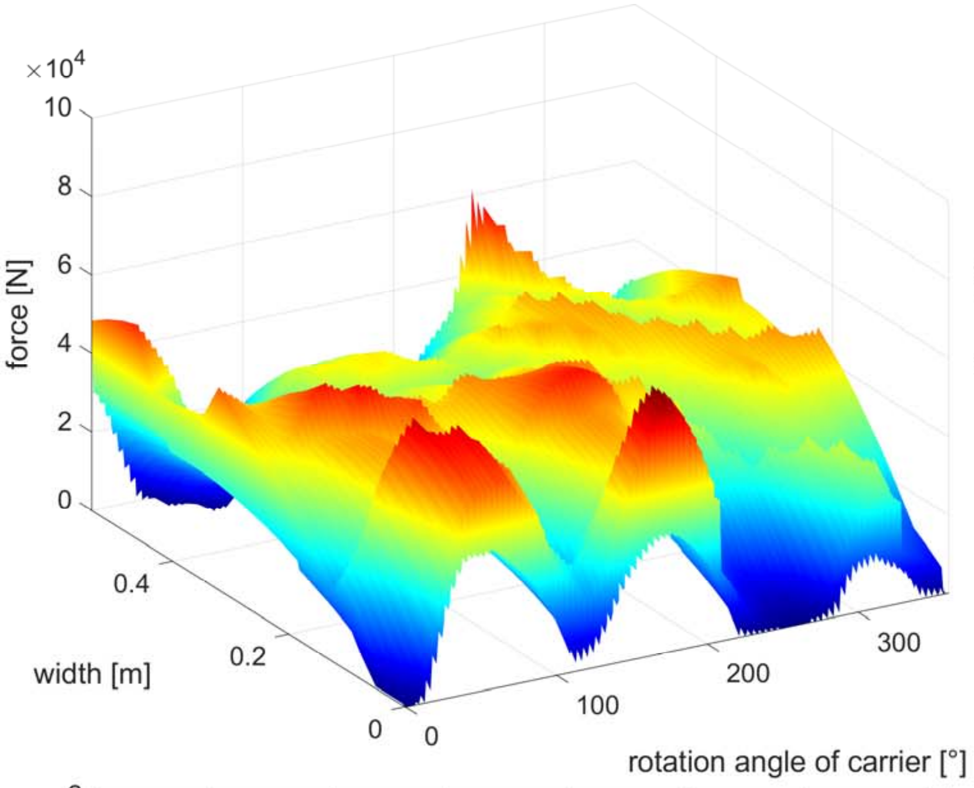
lower stiffness

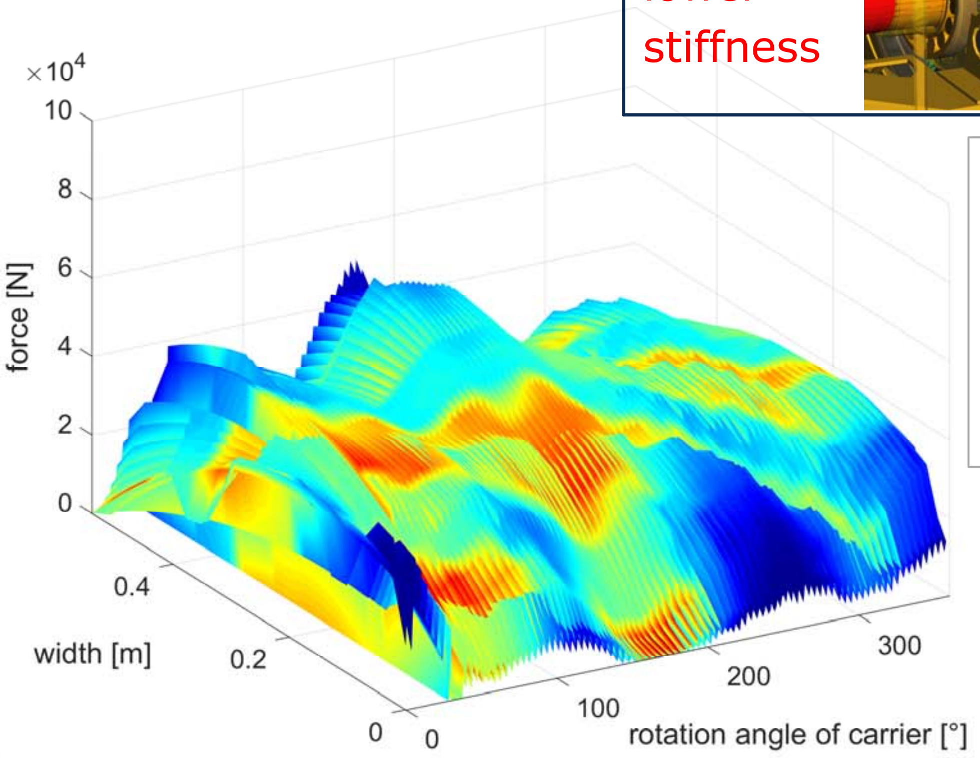


sun – planet

helix angle modification
$f_{H\beta}$ = 90 µm

lead crowing
C_b = 60 µm

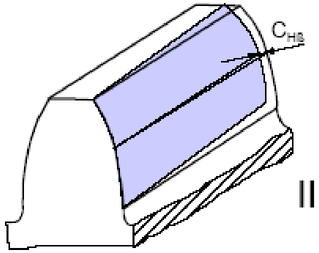


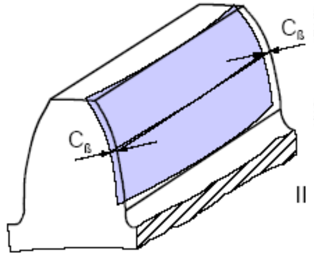


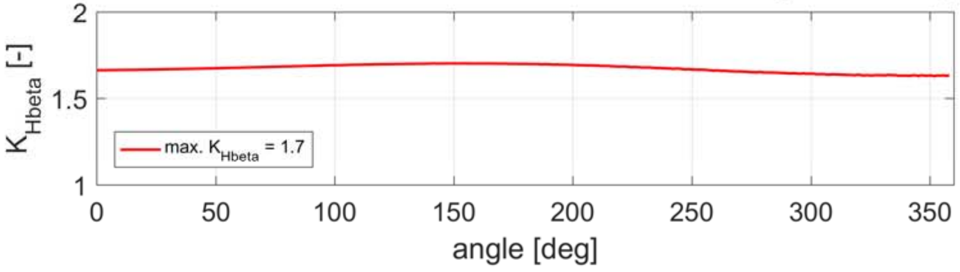
ring – planet

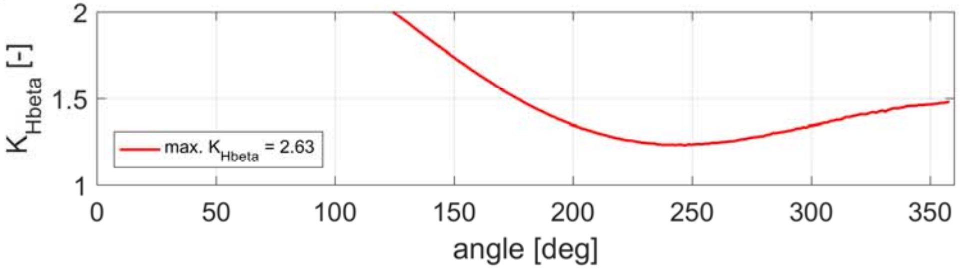
helix angle modification
$f_{H\beta}$ = 250 µm

lead crowing
C_b = 30 µm





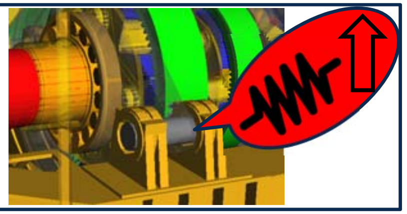




	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38
$M_{bending}$=0	1.73	1.48
reduced $c_{gearbox}$	1.7	2.83

- Load distribution over the width of the gearing and rotation of the planet carrier

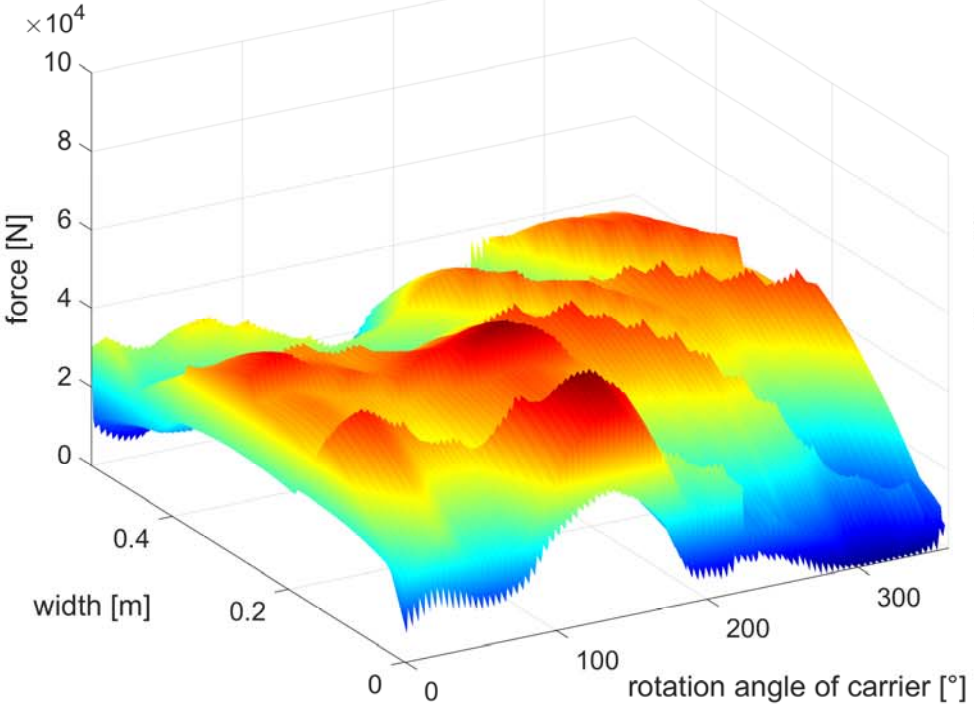
higher stiffness

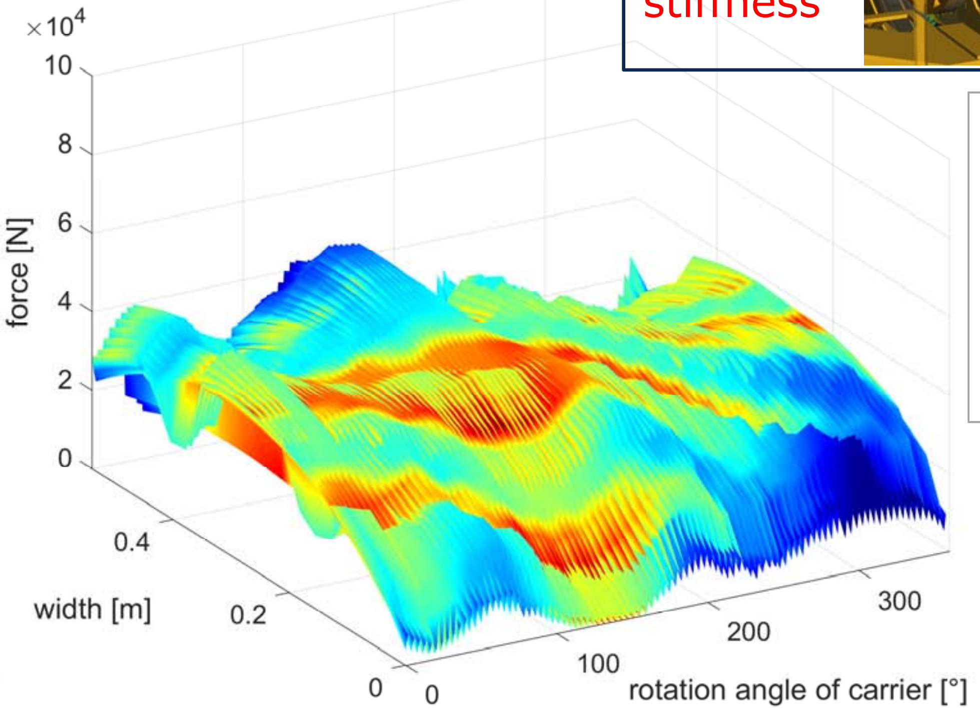


sun – planet

helix angle modification
$f_{H\beta}$ = 90 μm

lead crowing
C_b = 60 μm

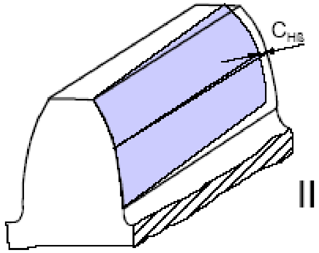


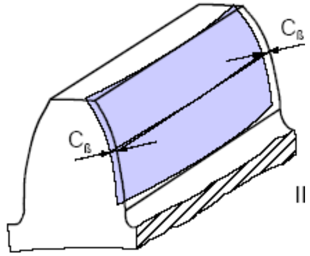


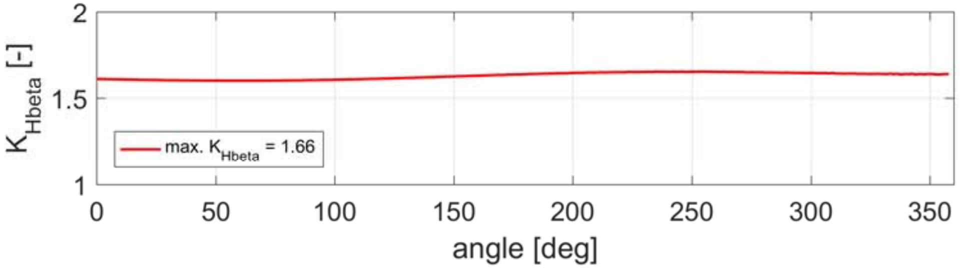
ring – planet

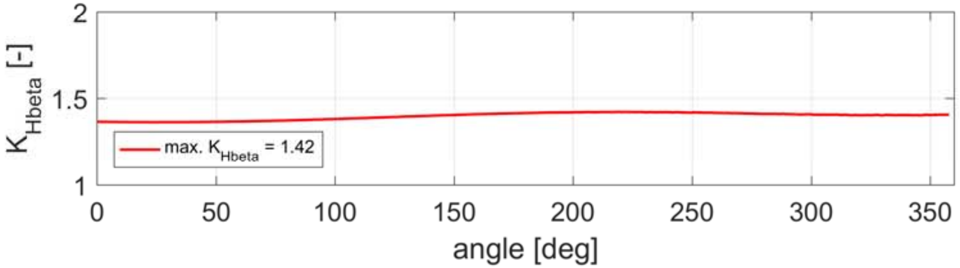
helix angle modification
$f_{H\beta}$ = 250 μm

lead crowing
C_b = 30 μm









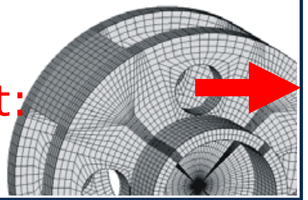
	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38
$M_{bending}$=0	1.73	1.48
reduced $c_{gearbox}$	1.7	2.83
increased $c_{gearbox}$	1.66	1.42

NREL 5 MW Baseline – load distribution analyses

Institut für Maschinenelemente und Maschinenkonstruktion
Prof. Dr.-Ing. Berthold Schlecht
IMM

- Load distribution over the width of the gearing and rotation of the planet carrier

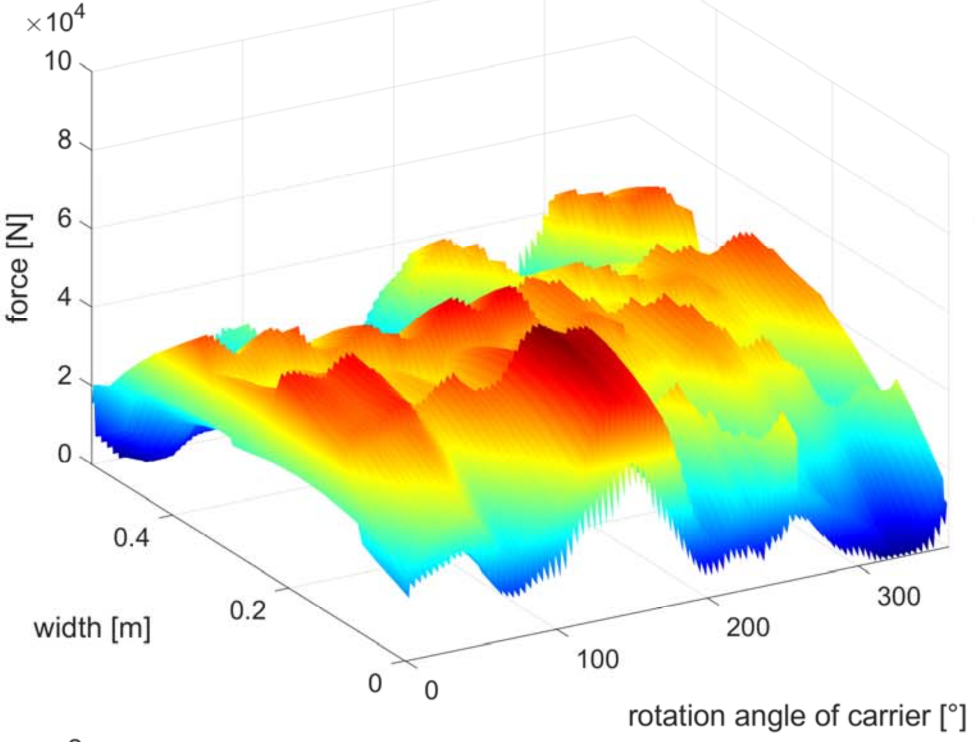
planet pin tangential shift: 50 µm

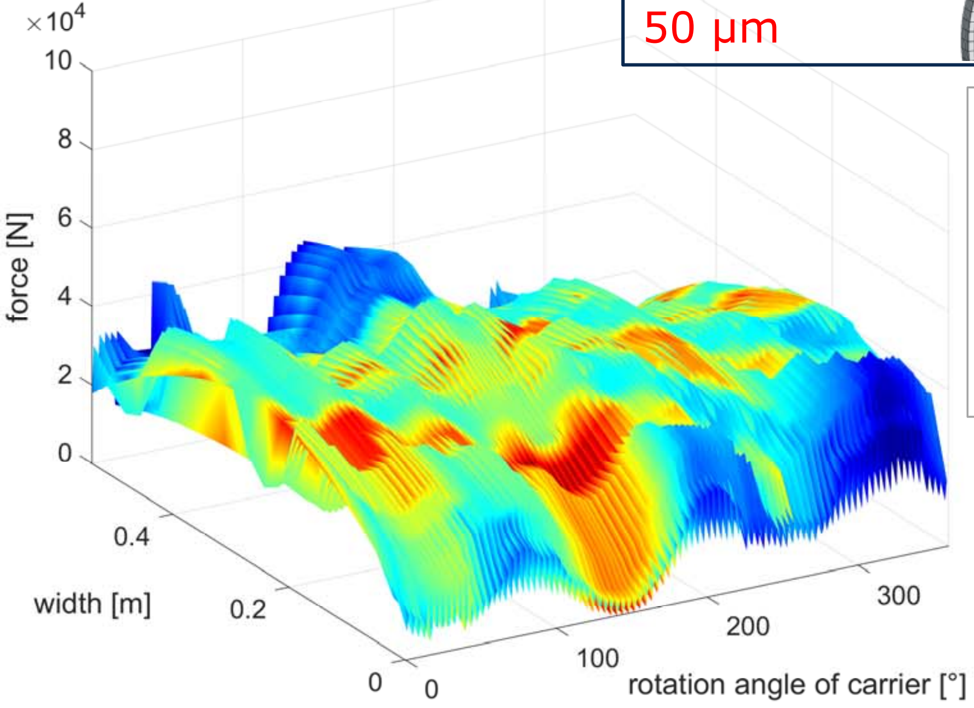


sun – planet

helix angle modification $f_{H\beta}$ = 90 µm

lead crowing C_b = 60 µm

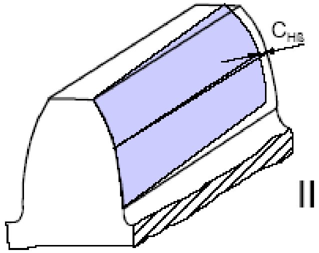


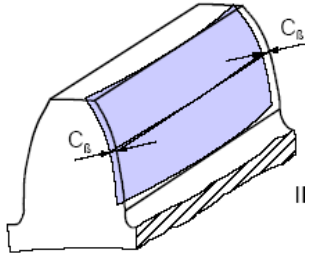


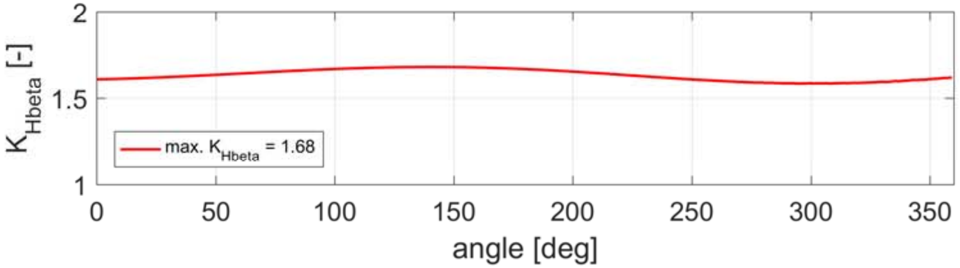
ring – planet

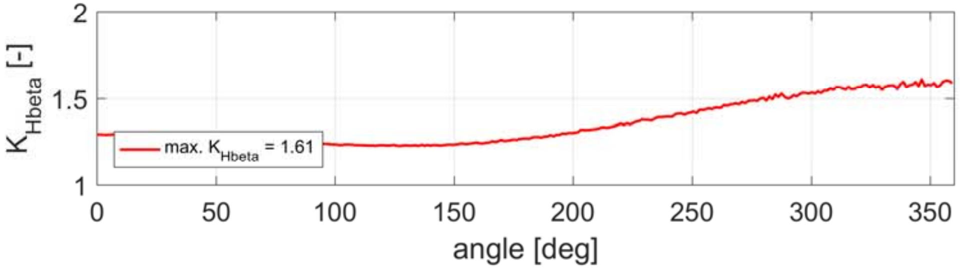
helix angle modification $f_{H\beta}$ = 250 µm

lead crowing C_b = 30 µm







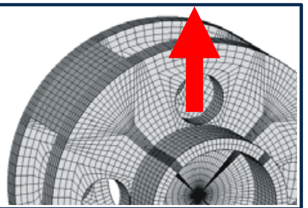


	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38
$M_{bending}$=0	1.73	1.48
50 µm ta.	1.68	1.61

NREL 5 MW Baseline – load distribution analyses

- Load distribution over the width of the gearing and rotation of the planet carrier

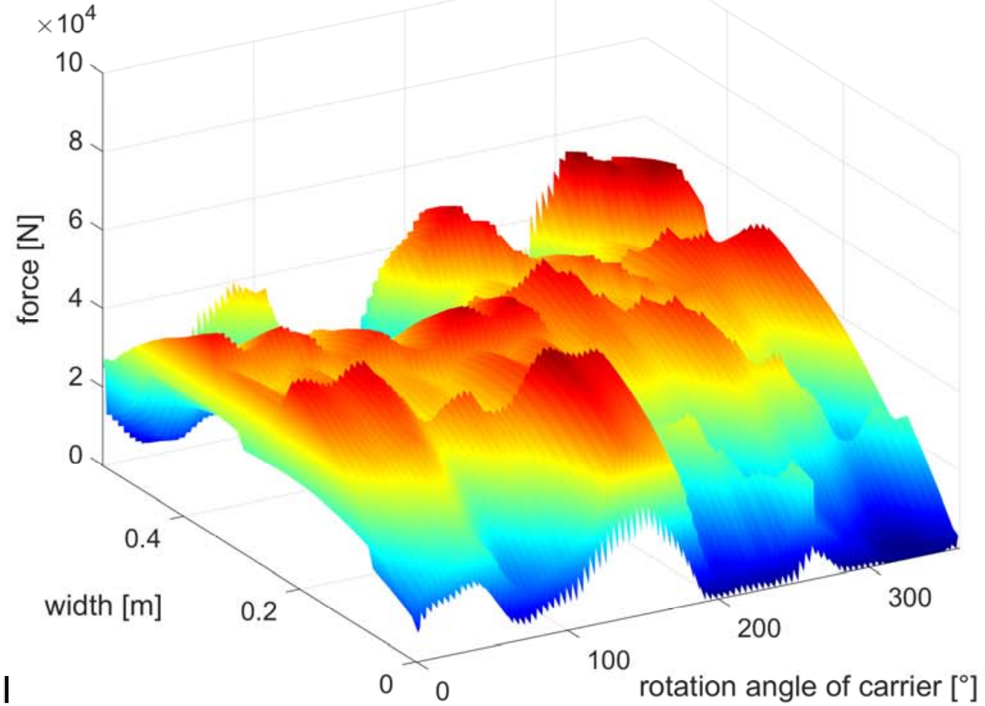
planet pin radial shift: 50 µm

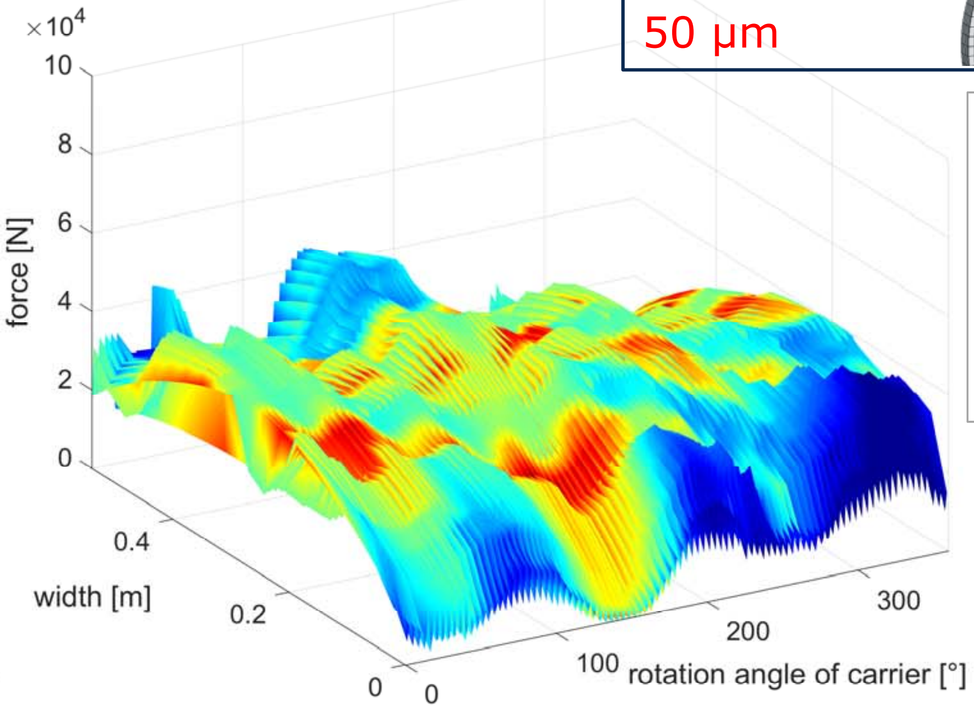


sun – planet

helix angle modification $f_{H\beta}$ = 90 µm

lead crowing C_b = 60 µm

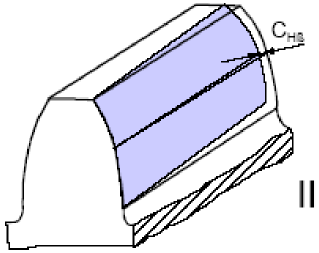


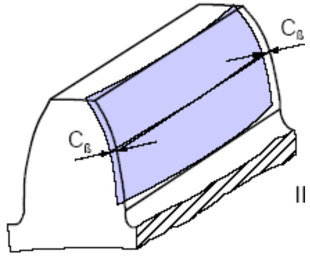


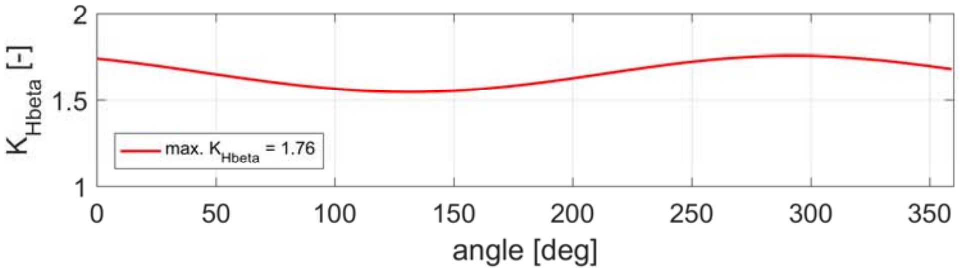
ring – planet

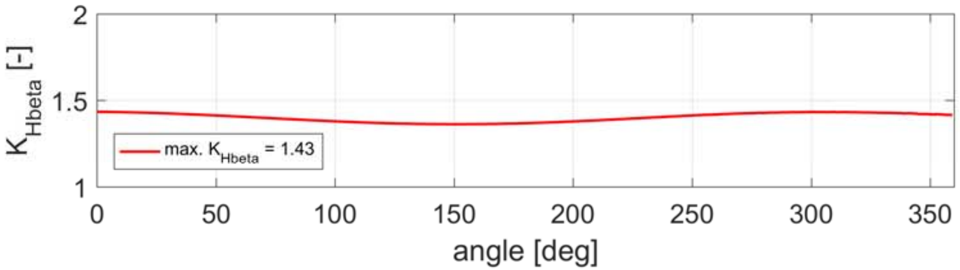
helix angle modification $f_{H\beta}$ = 250 µm

lead crowing C_b = 30 µm



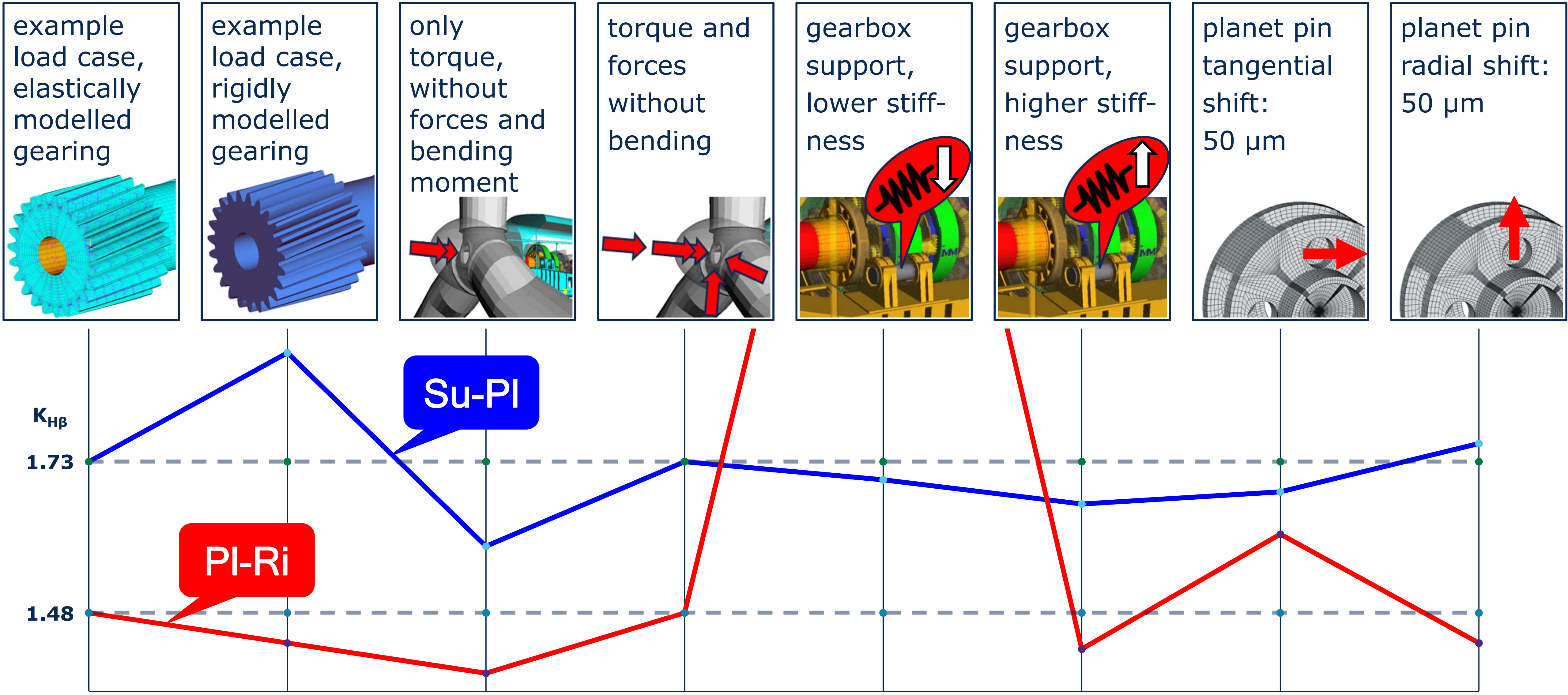






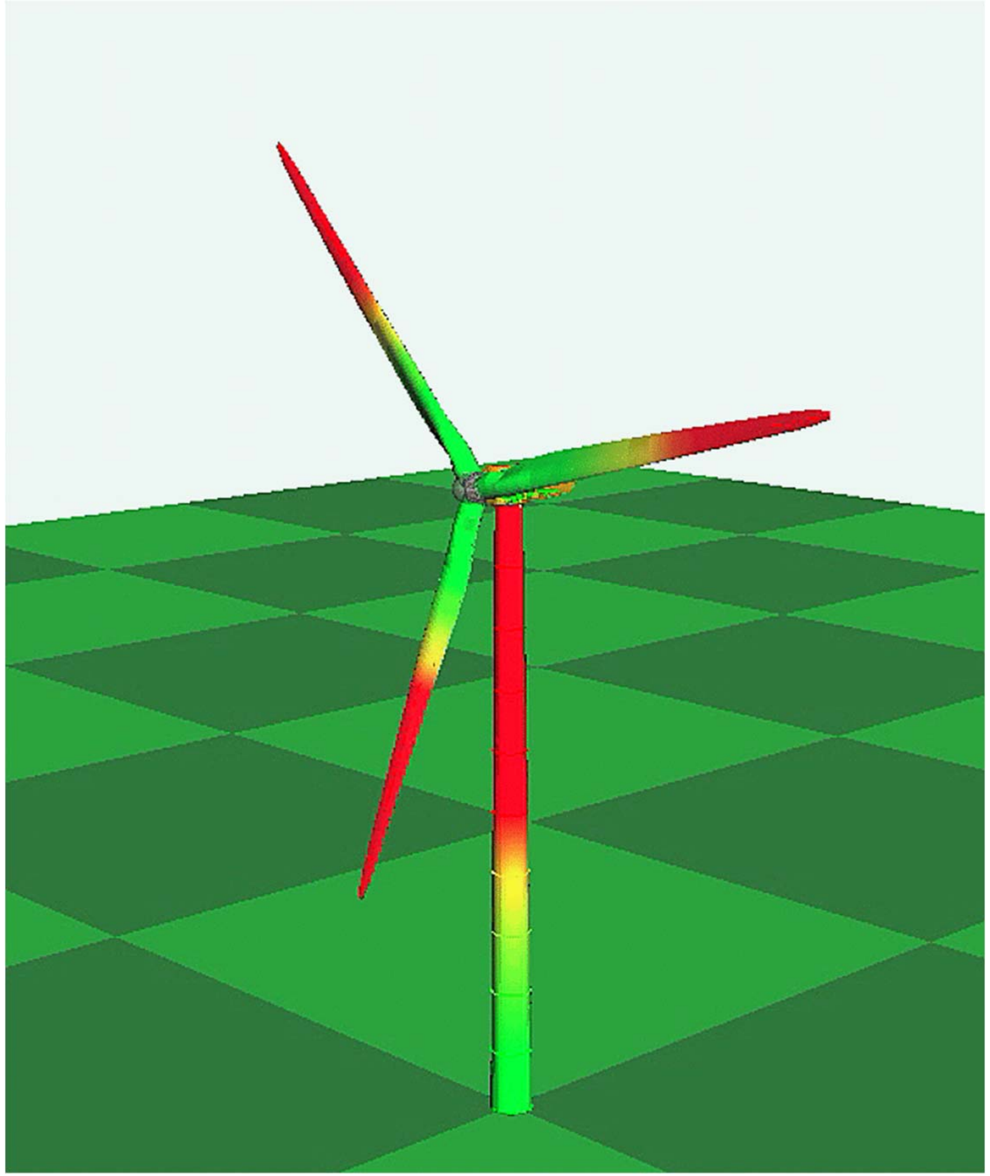
	SoPl $K_{H\beta}$	PlRi $K_{H\beta}$
flex	1.73	1.48
rigid	1.91	1.43
M_{torque}	1.59	1.38
$M_{bending}=0$	1.73	1.48
50 µm ta.	1.68	1.61
50 µm ra.	1.76	1.43

NREL 5 MW Baseline – load distribution analyses



Summary

- Extension of the NREL baseline model by a detailed drive train
- Analysis in the frequency and time domain
- Optimisation of the modification using the multibody-system model and load distribution analysis
- Optimisation for only one load case, finally an optimisation for the occurring operational conditions required
- Load distribution “distribution” and determination of the damage sum could be a criterion for an optimisation process



Thank you for your attention

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»Wissen schafft Brücken.«