Welcome

Design of e-Drive Gears

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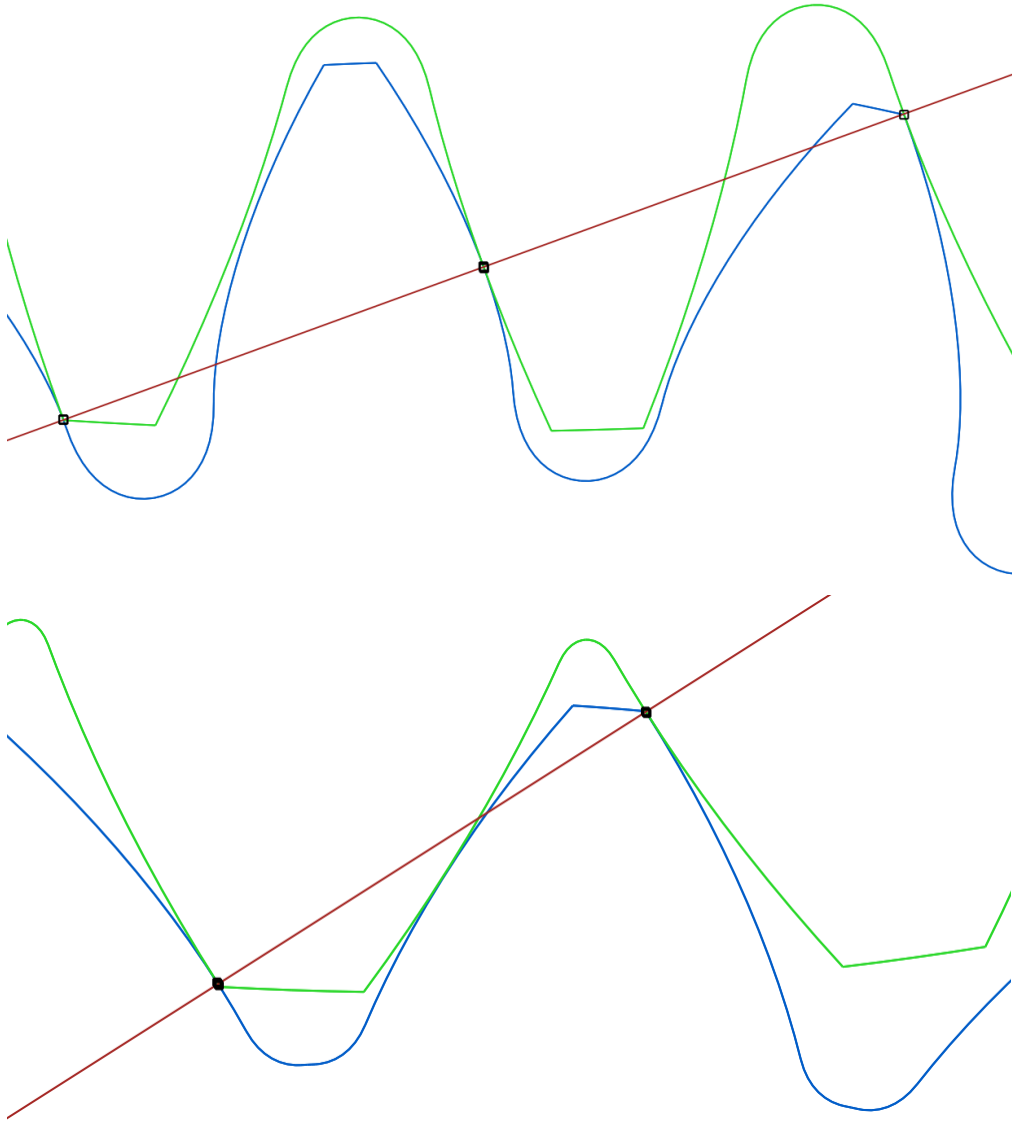
KISSsoft AG

Challenges in e-Drive Gear Design

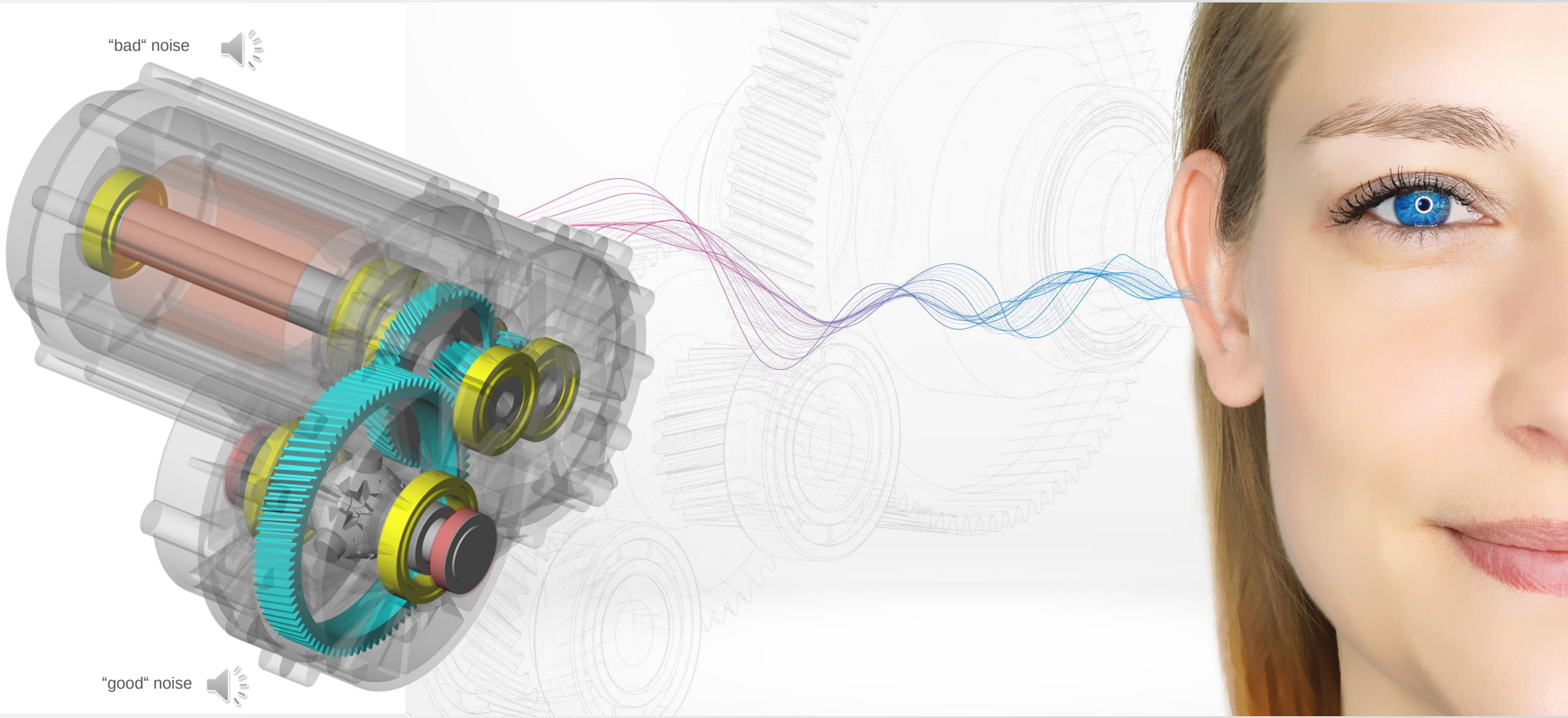
High, low, negative torque

Low vibration → High contact ratio

High efficiency → Low contact ratio



From Gear Mesh to Audible Noise



Source: FZG, München

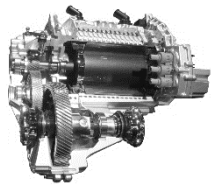
Design Tasks

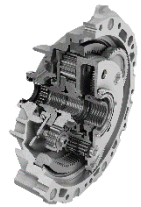
E-drives → no combustion engine → no noise masking

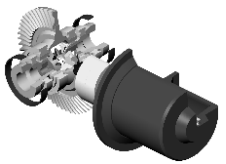
Optimize tooth stiffness → low vibration

Optimize tooth strength → high torque capacity

Optimize tooth shape → low losses

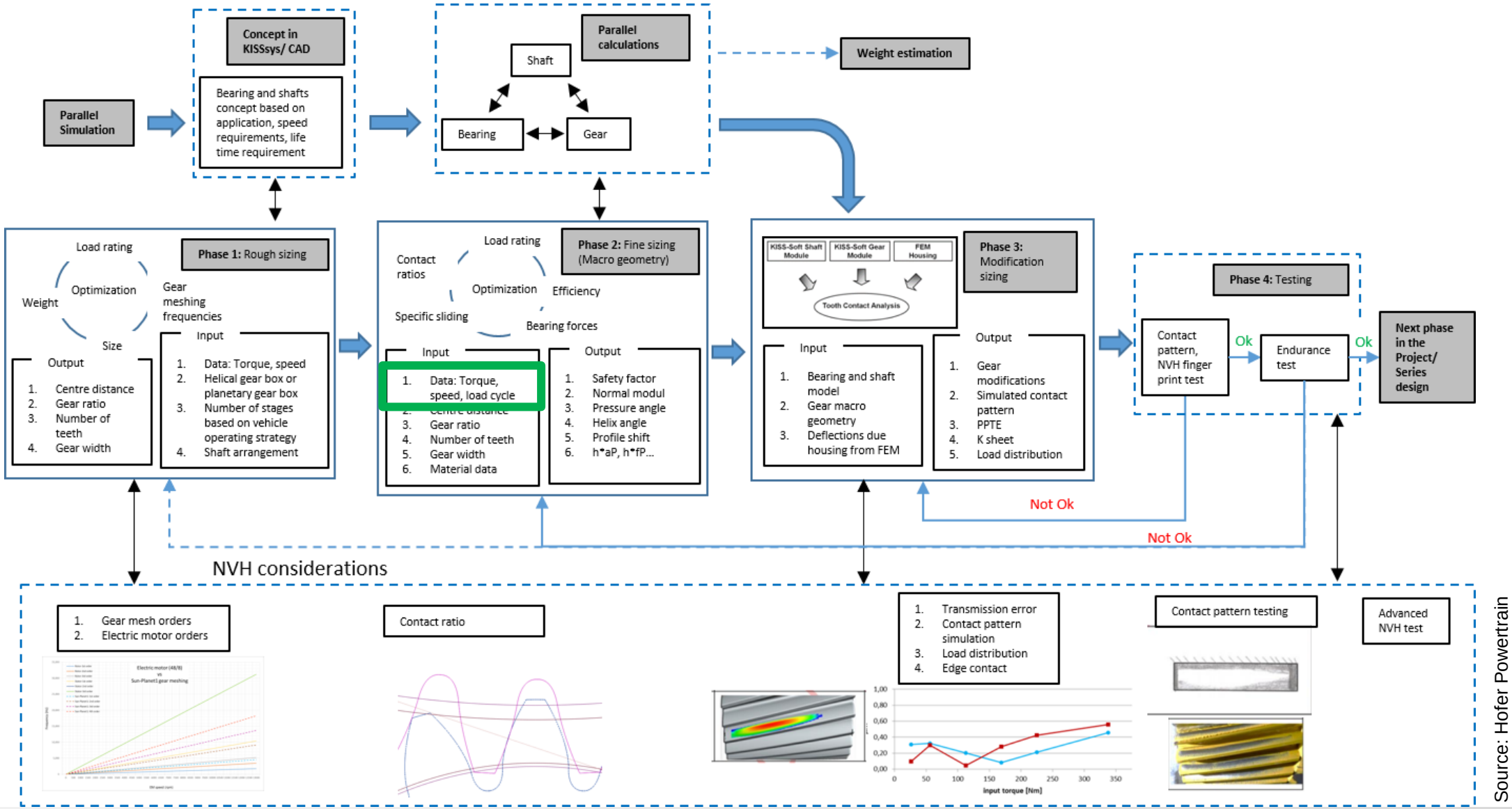






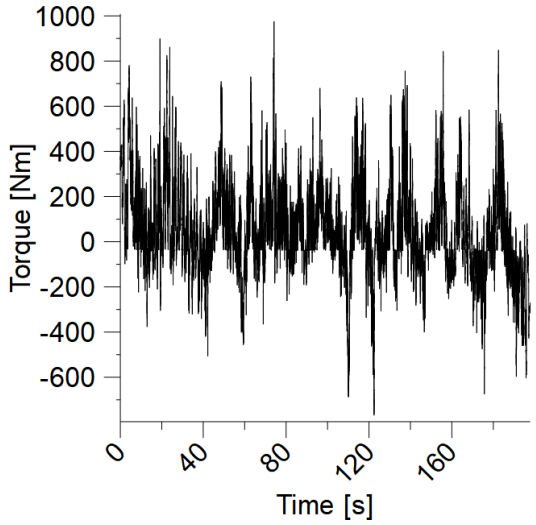
Gear Design

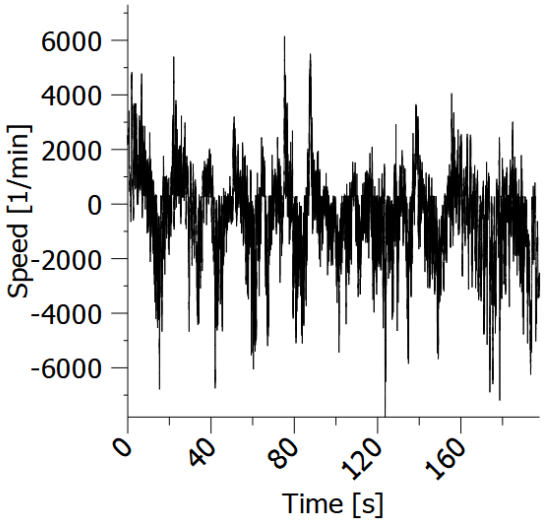
Process Flow

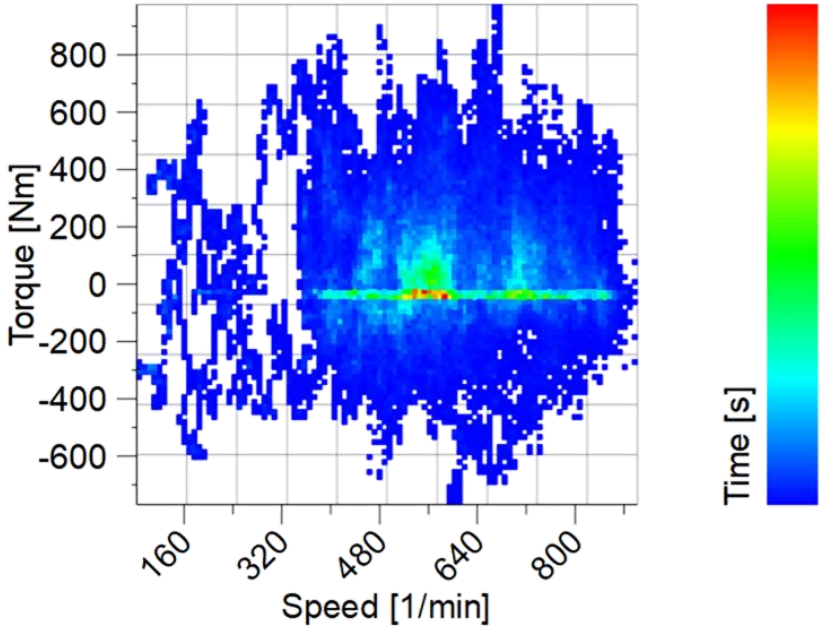


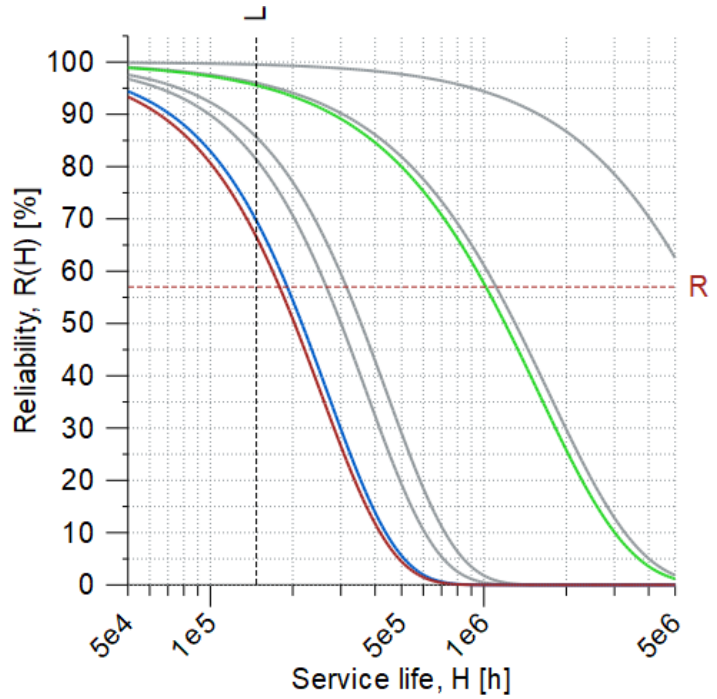
Source: Hofer Powertrain

Load Spectrum from Measured Data









Drive cycle simulation or measurement → Torque/speed series → Load spectrum → Gear life, reliability

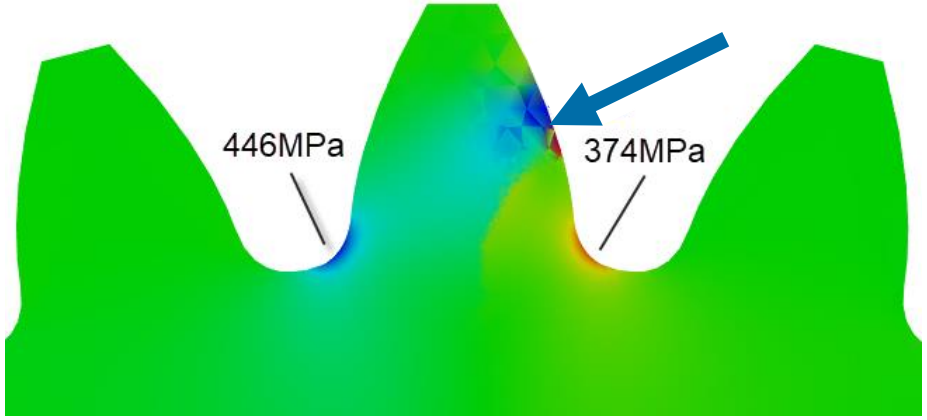
Load Spectrum from Measured Data

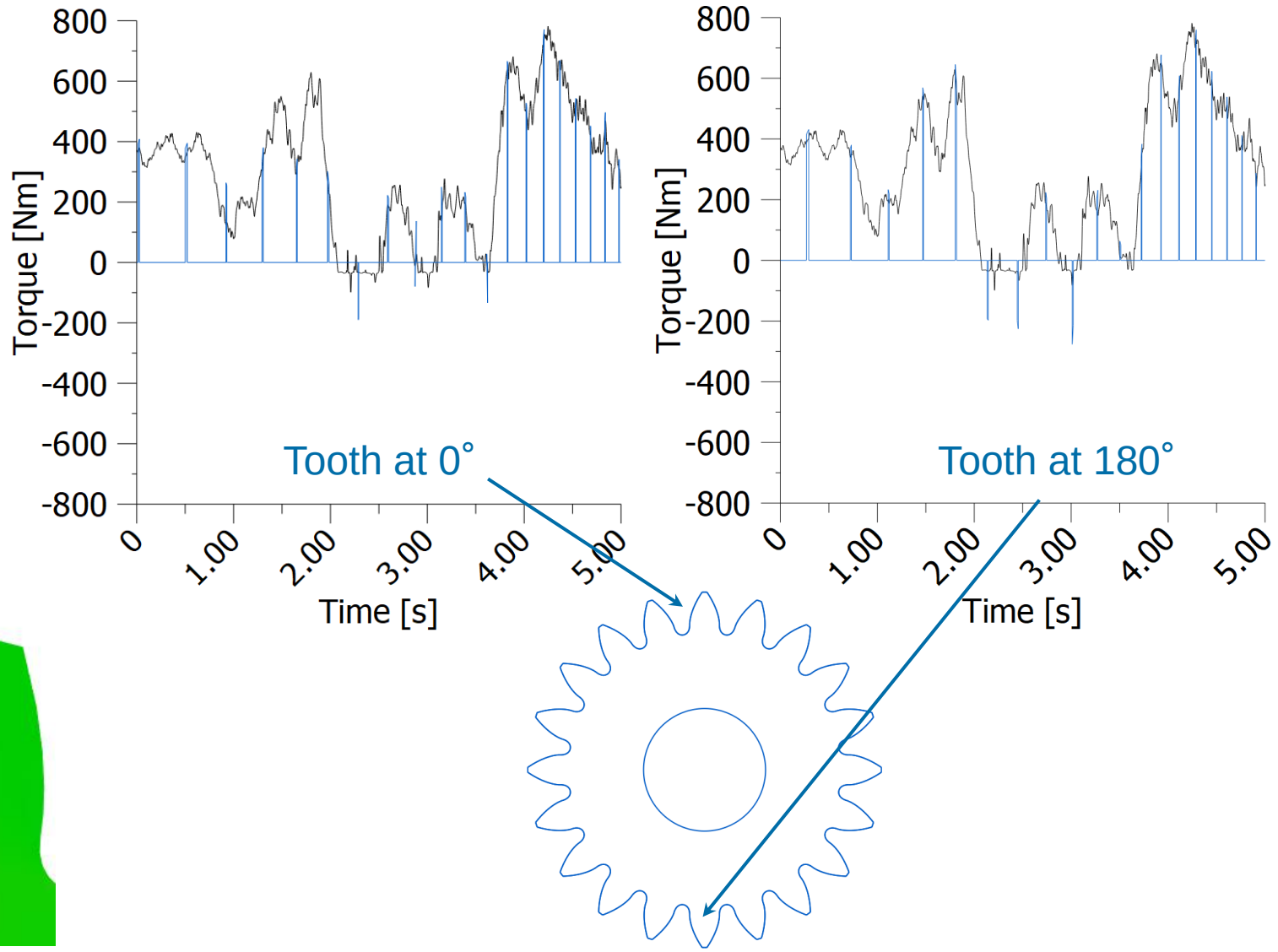
Every tooth has different loads

Both flanks loaded

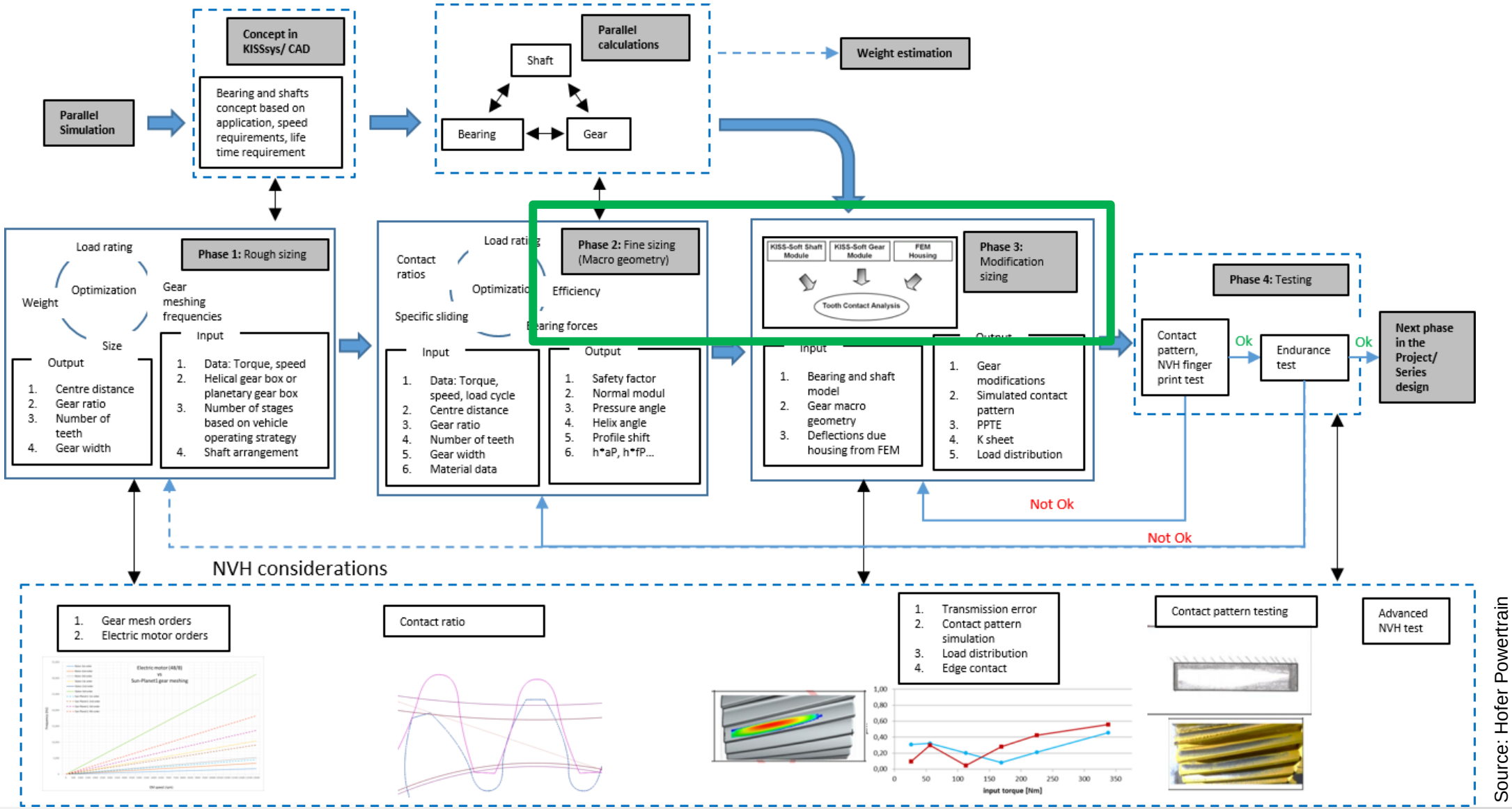
Root reverse bending

Root compressive strength





Process Flow



Source: Hofer Powertrain

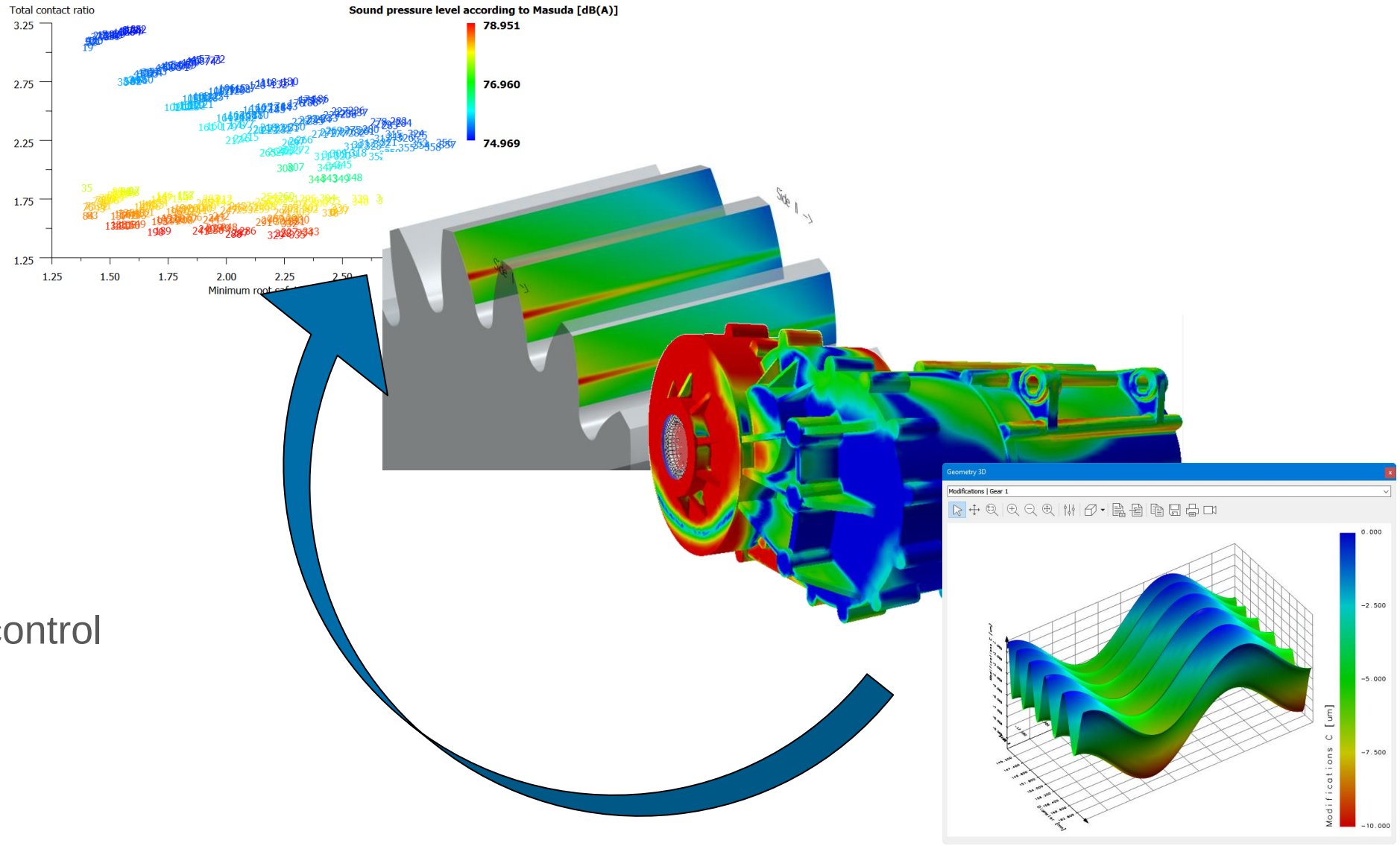
Gear Optimization

Macro geometry

Micro geometry

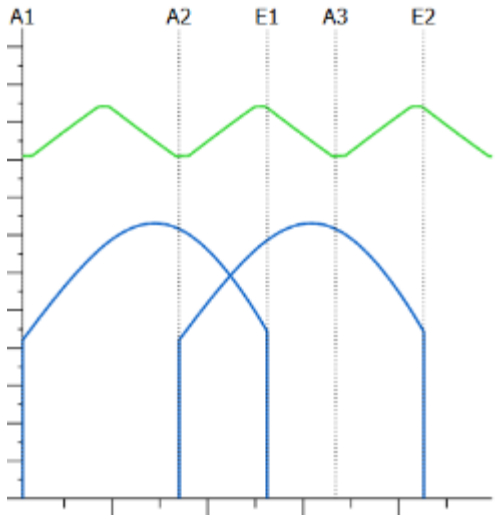
NVH simulation

Manufacturing, quality control

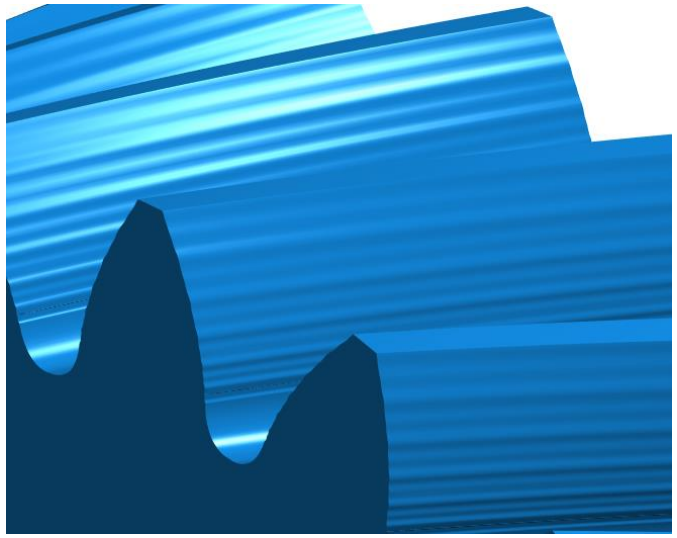


Total Gear Solutions Gleason

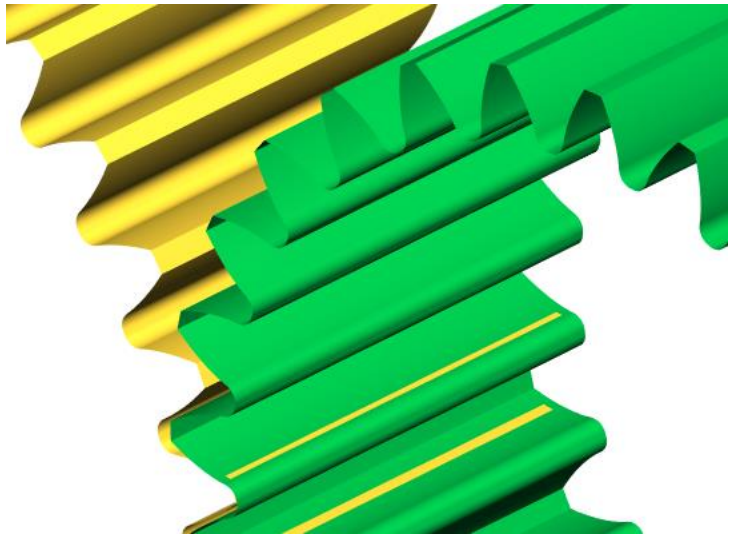
Vibration Excitation from Tooth Mesh



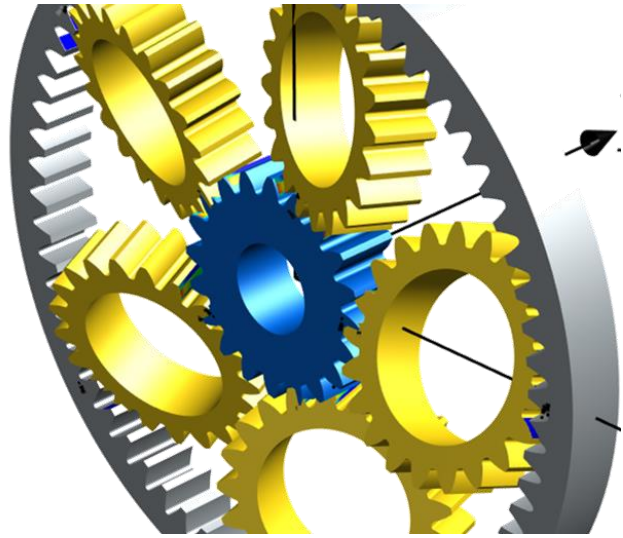
Stiffness variation



Flank imperfections



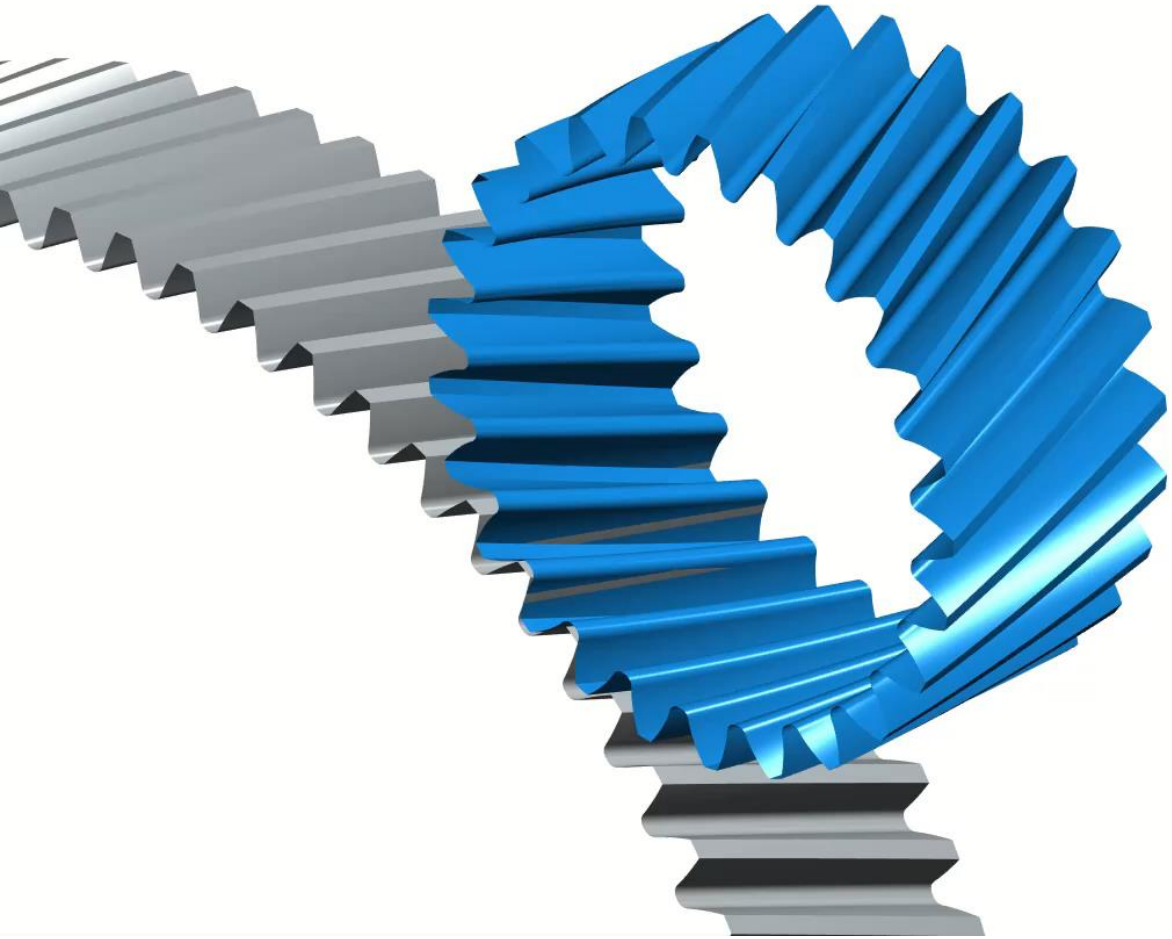
Meshing impact



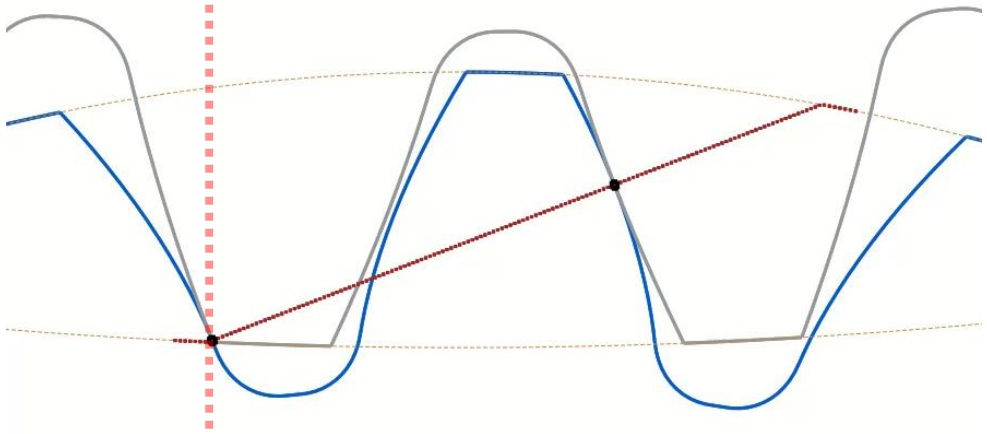
Misaligned system

Vibration Excitation from Tooth Mesh

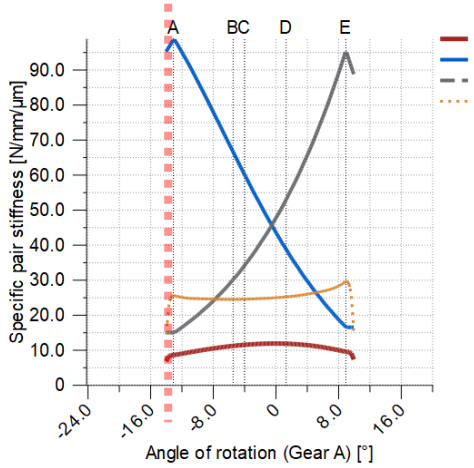
Why is the **mesh stiffness** not constant?

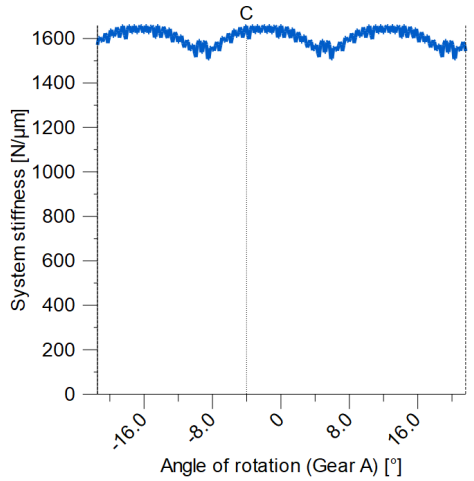


The number of teeth engaging changes



Single tooth / mesh stiffness changes

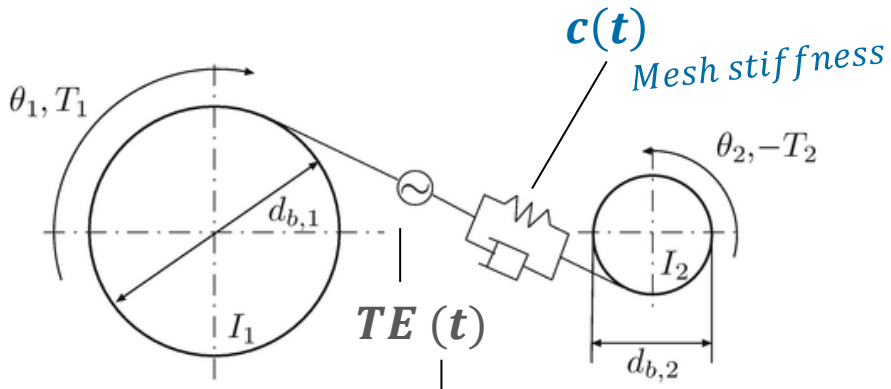


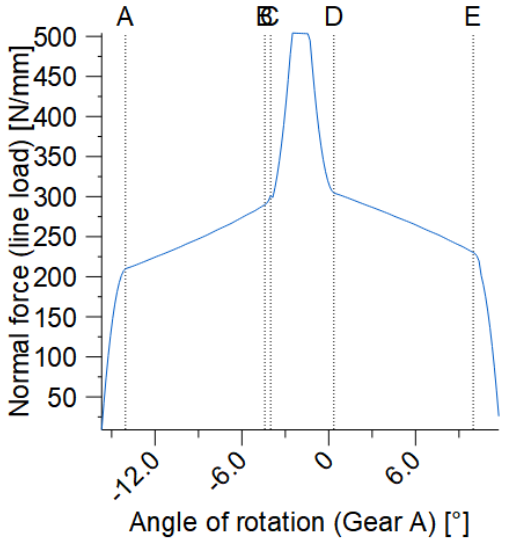


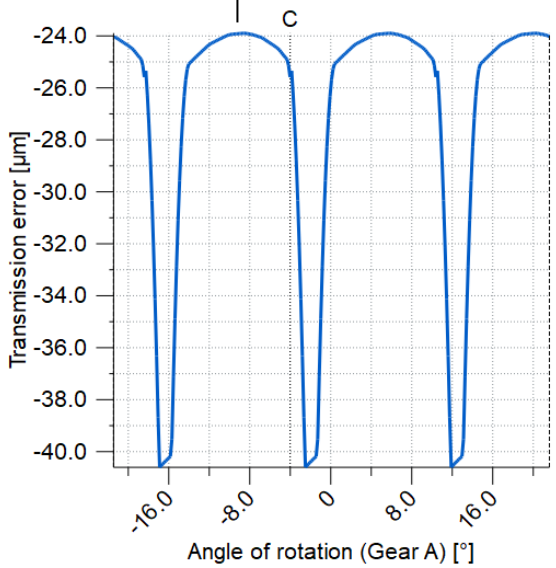
Vibration Excitation from Tooth Mesh

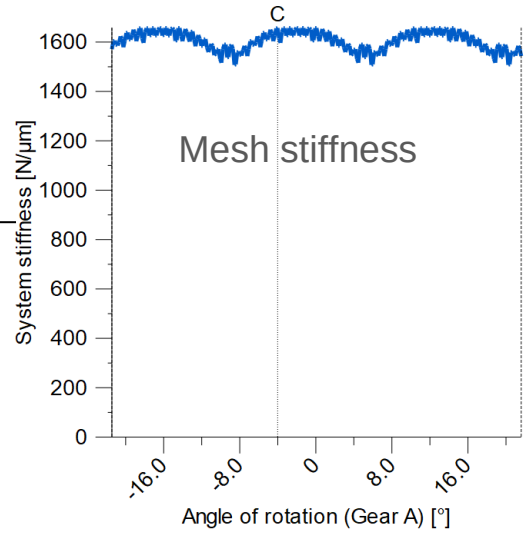
How is **mesh stiffness** related to **transmission error**?

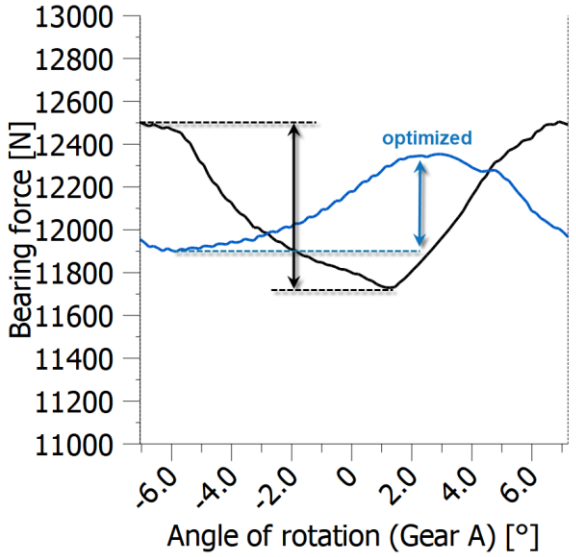
$$F(t) = c(t) \cdot TE(t)$$





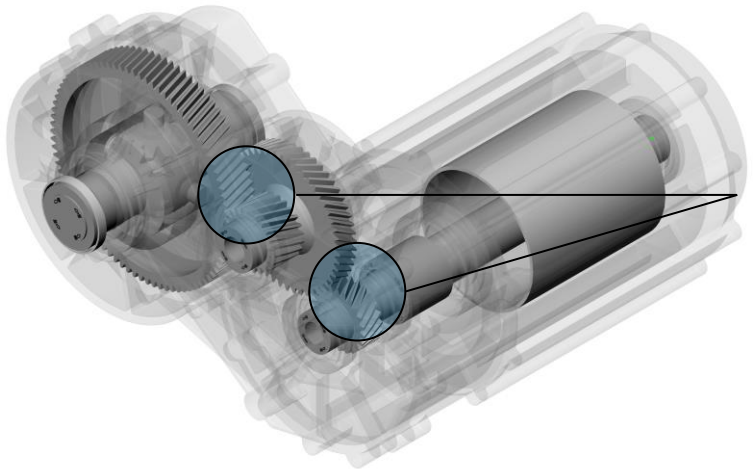


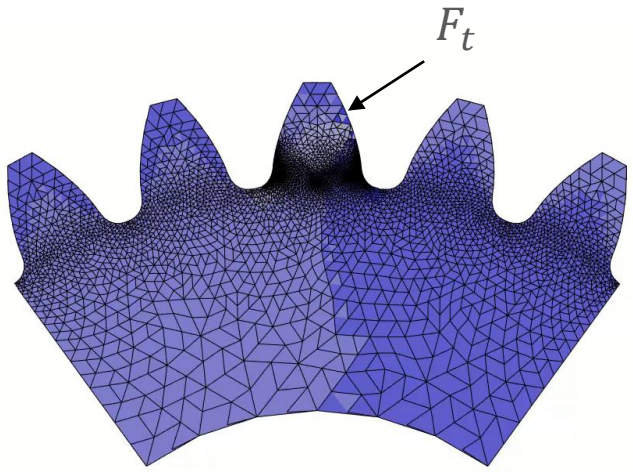




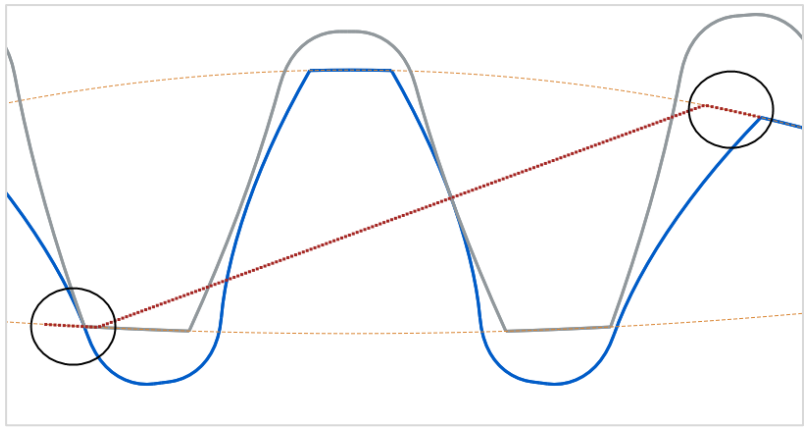
Vibration Excitation from Tooth Mesh

Transmission error → noise

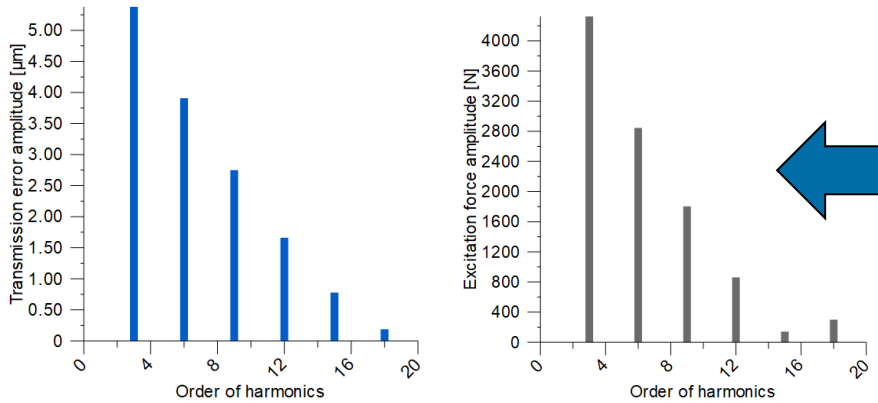


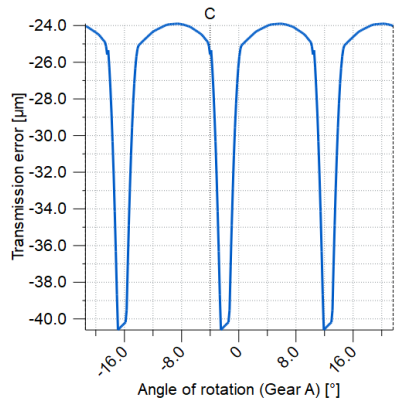


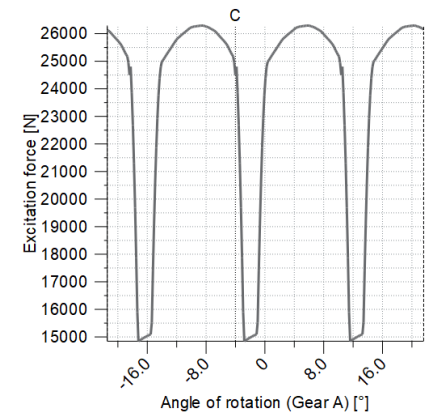
Contact shocks / change of pressure angle



Transmission Error (TE) / Force Excitation







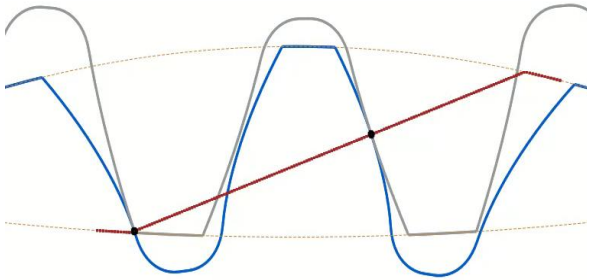
Total Gear Solutions Gleason

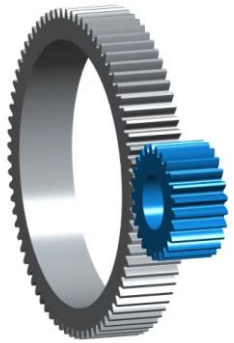
Fine sizing (improve gear macro-geometry)

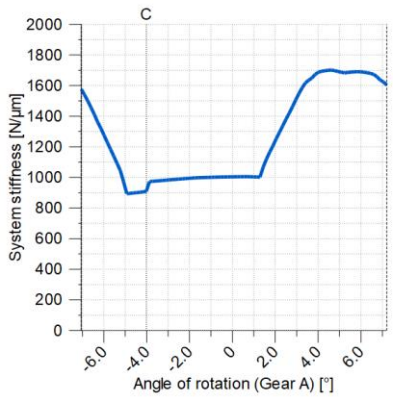
$m_n = 3\,mm \quad \beta = 0° \quad \boldsymbol{\varepsilon_\alpha = 1.66}$

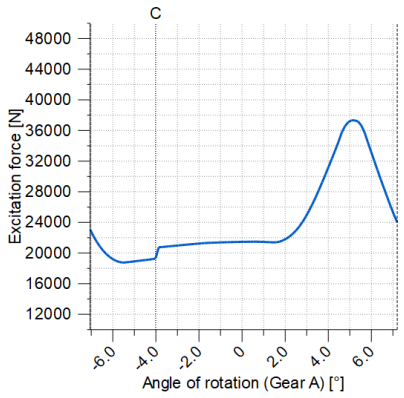
$h^*_{fP0} = 1.2 \;\; h^*_{aP0} = 1.25 \;\; h^*_{aP0} = 0.38$

redesign →



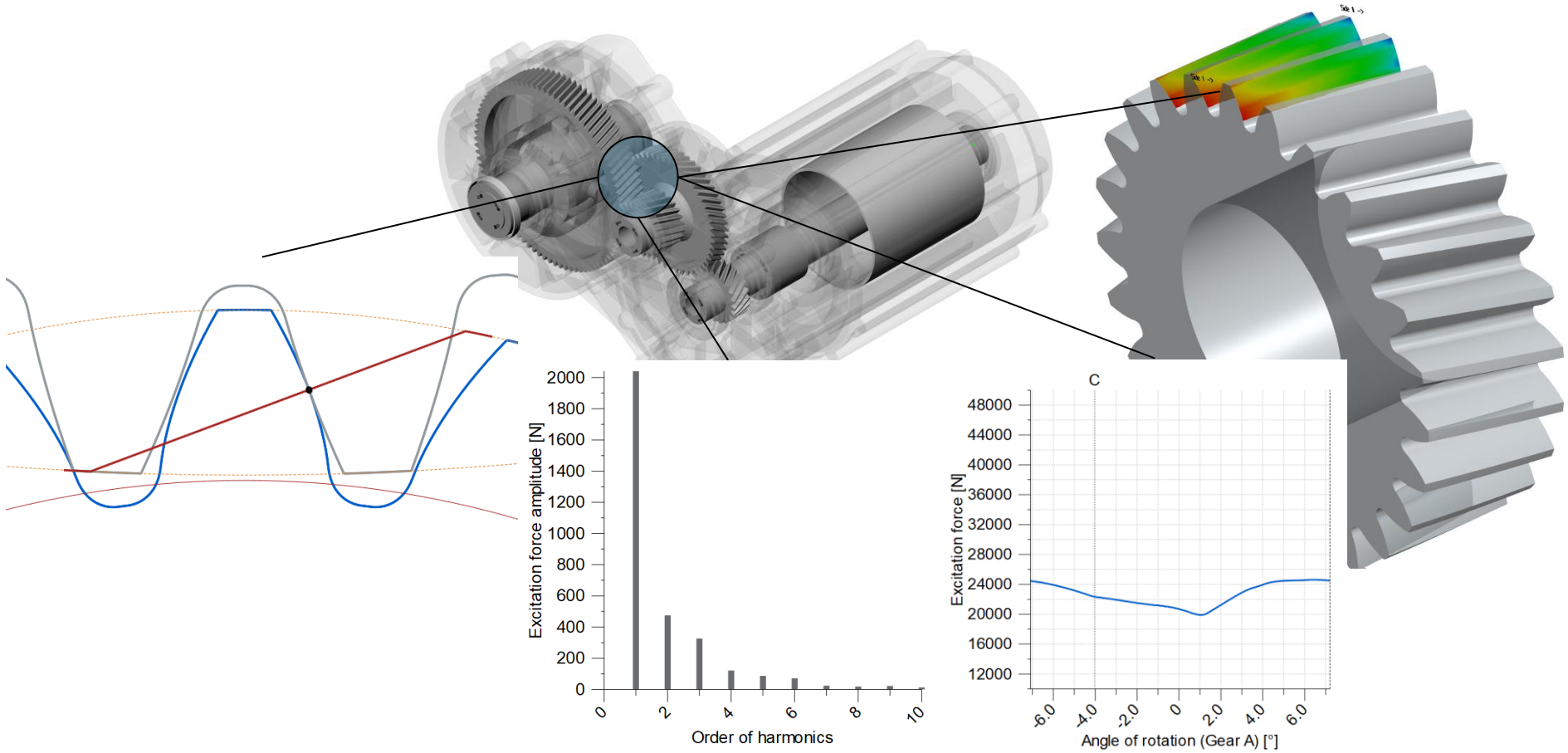


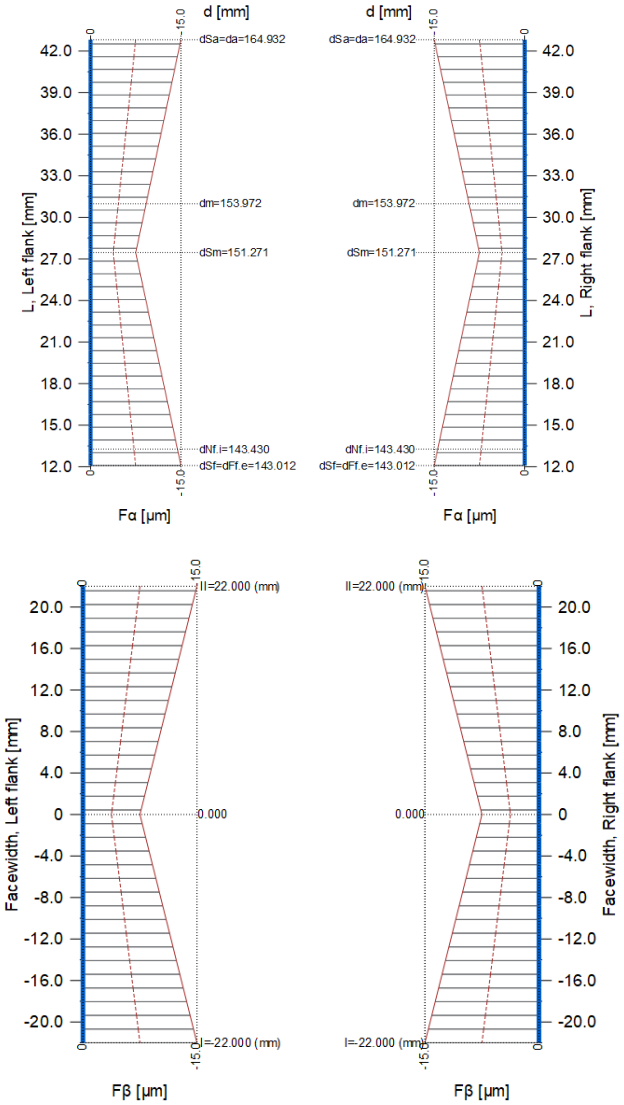




Loaded Tooth Contact Analysis (LTCA)

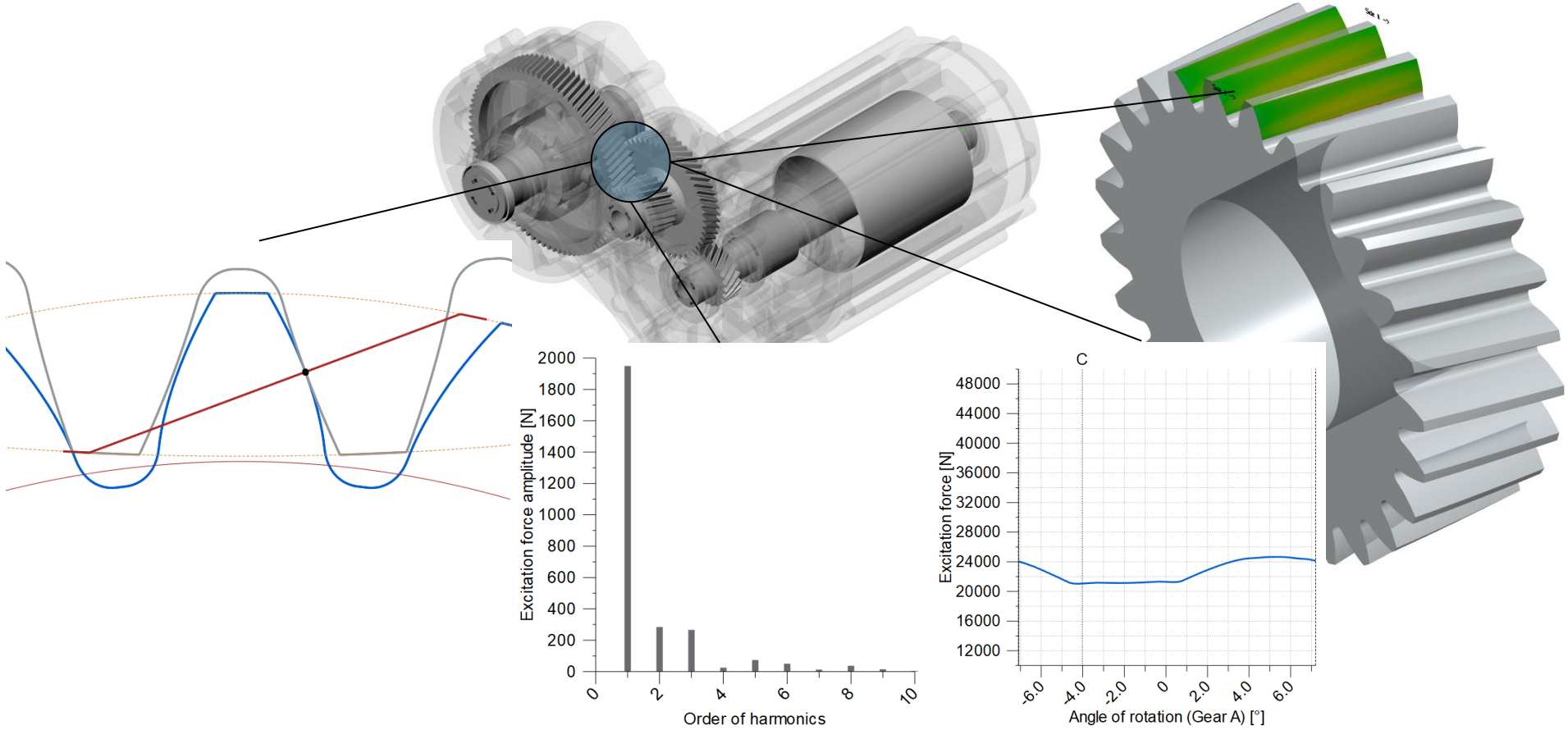
- No modifications applied

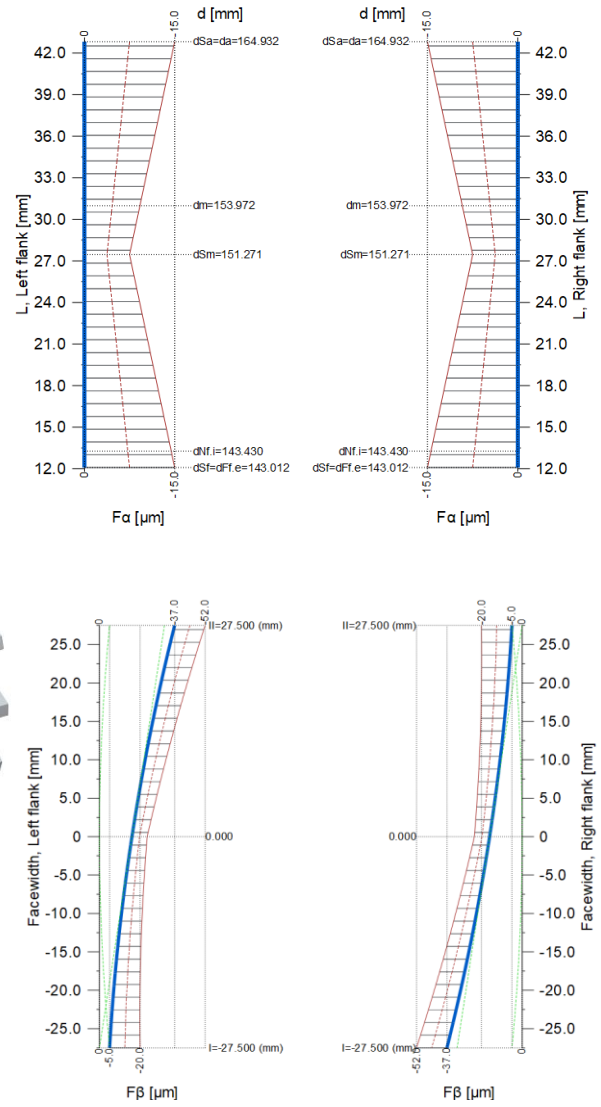




Loaded Tooth Contact Analysis (LTCA)

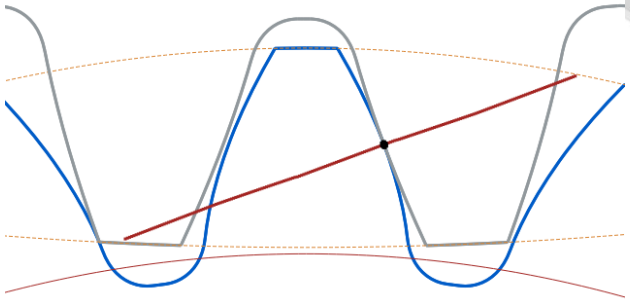
- Sizing of **flankline** (lead) modifications to optimize the contact pattern

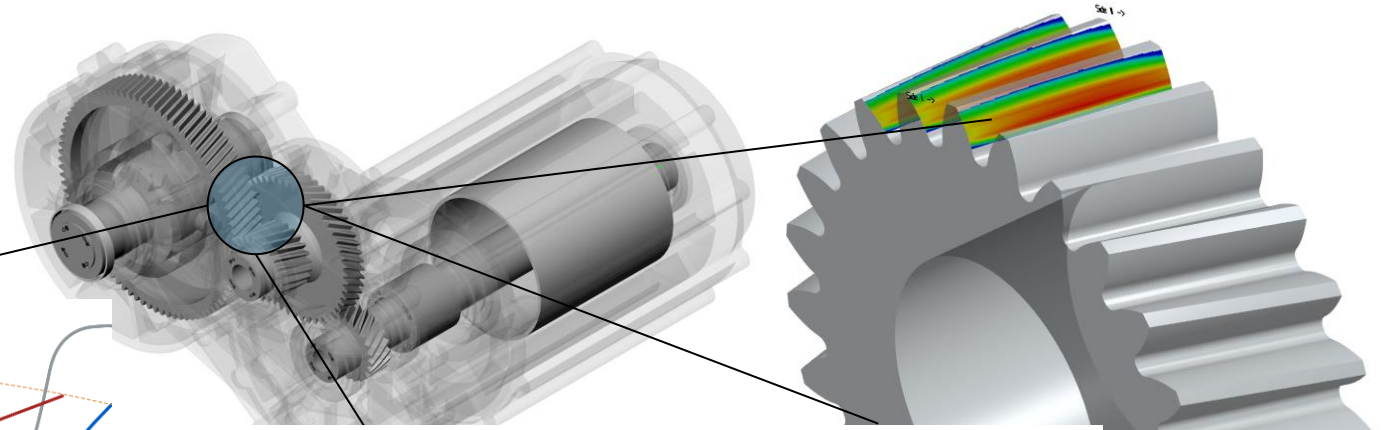


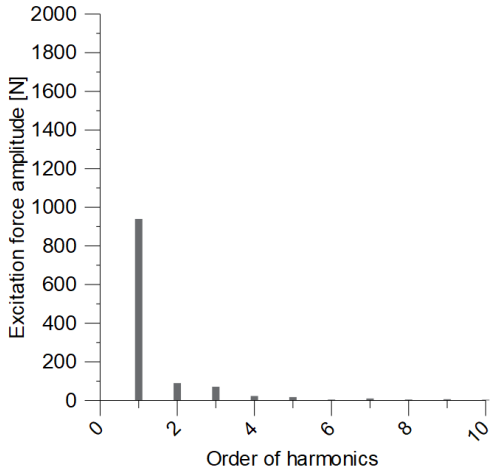


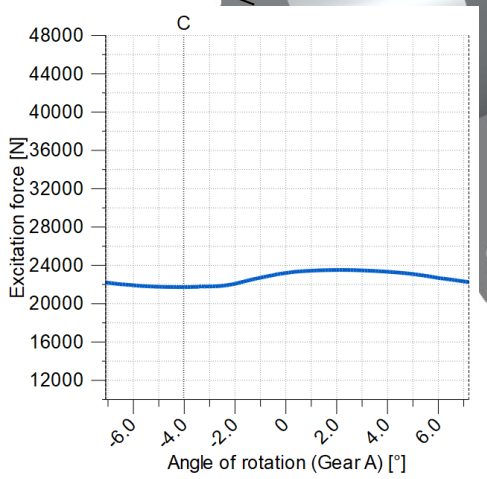
Loaded Tooth Contact Analysis (LTCA)

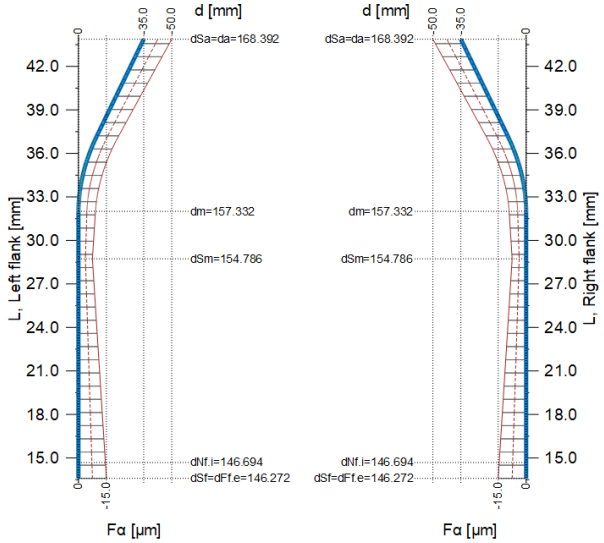
- Sizing of **profile** modifications to reduce amplitudes of TE, FE, higher orders of harmonics

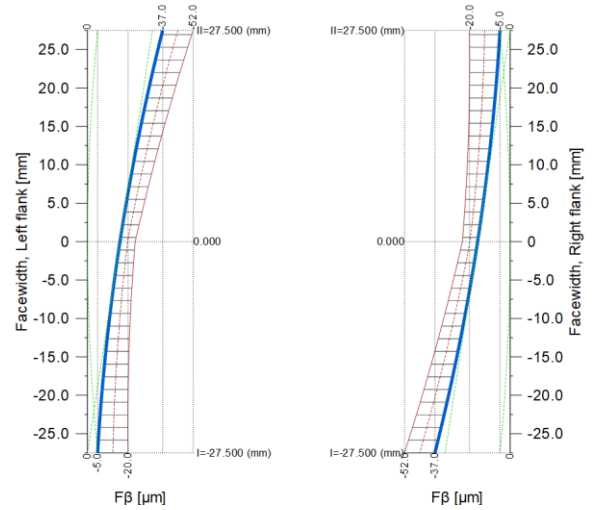






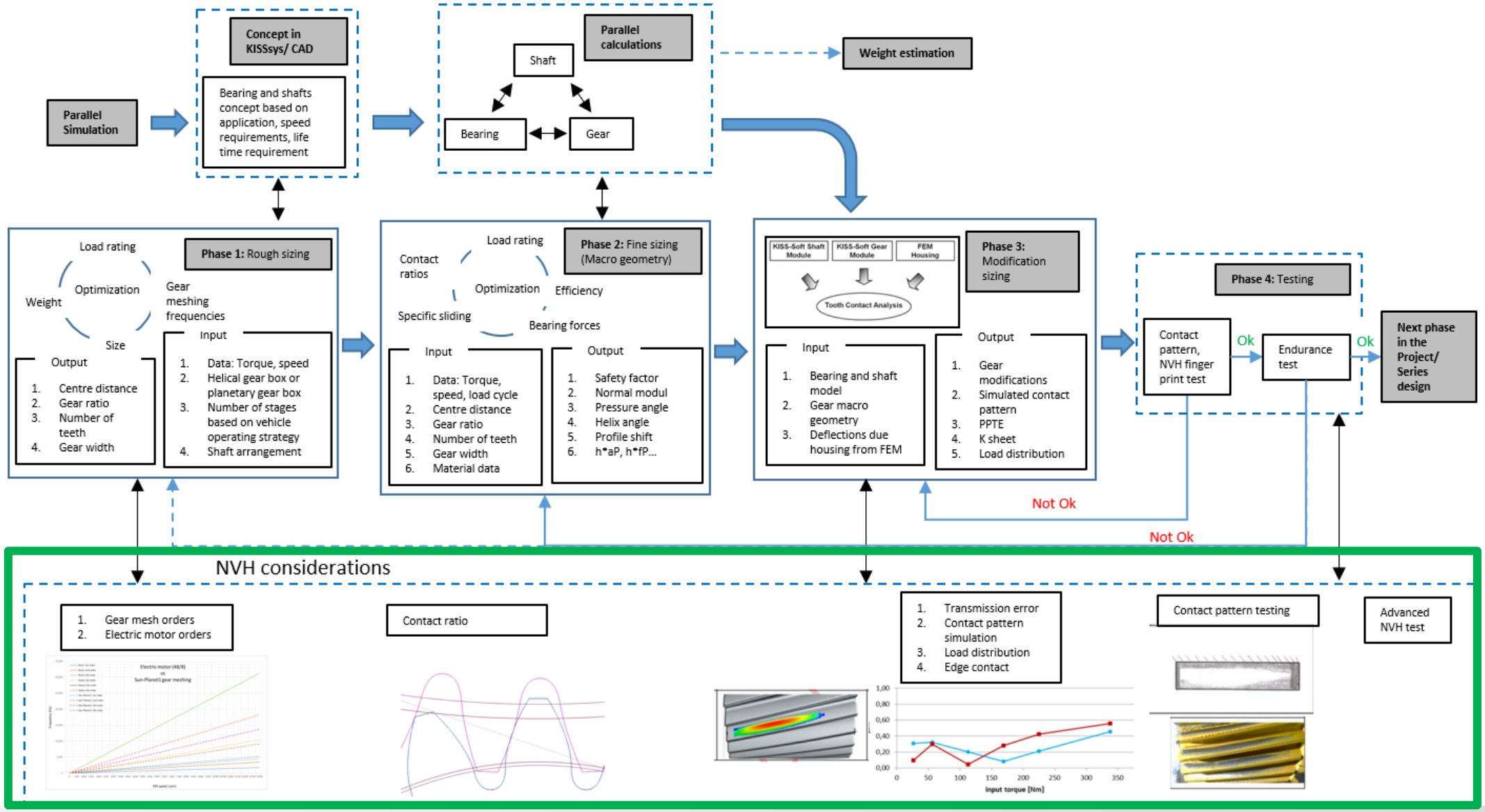






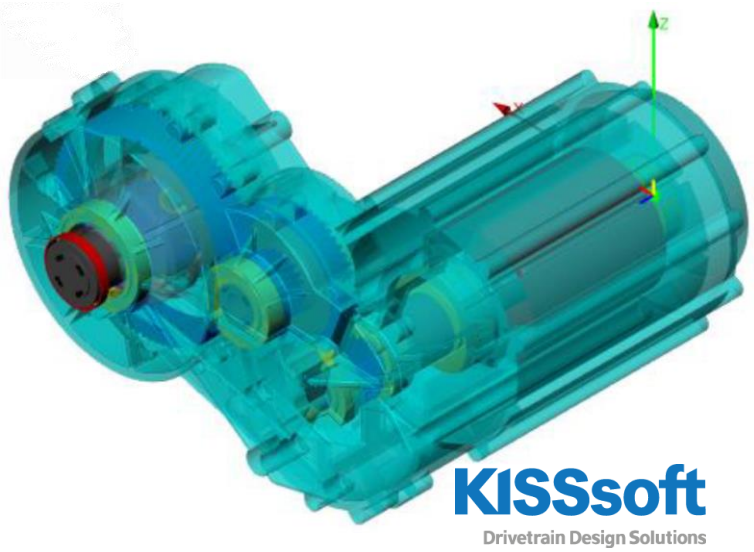
NVH Evaluation

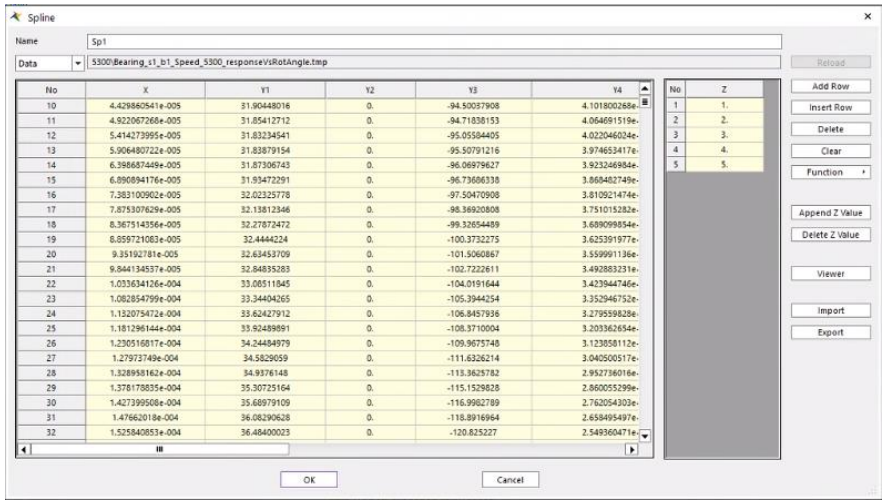
Process Flow

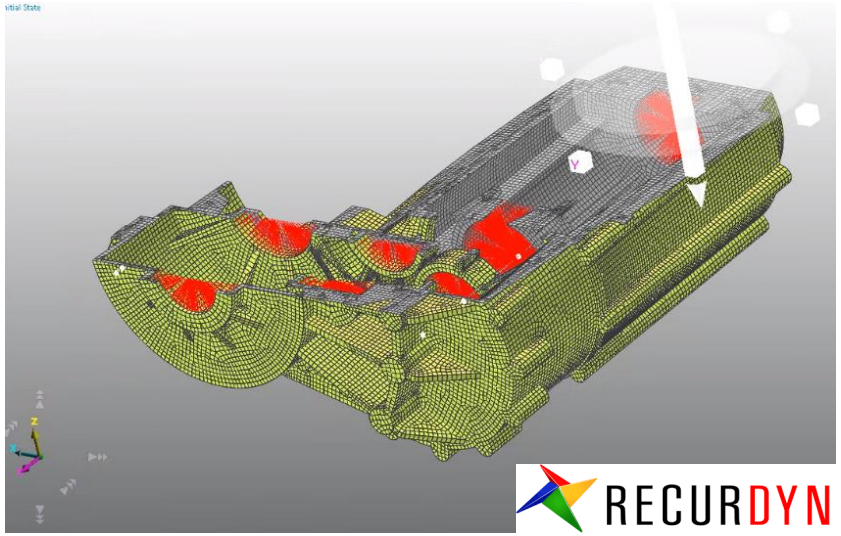


Source: Hofer Powertrain

Housing Response



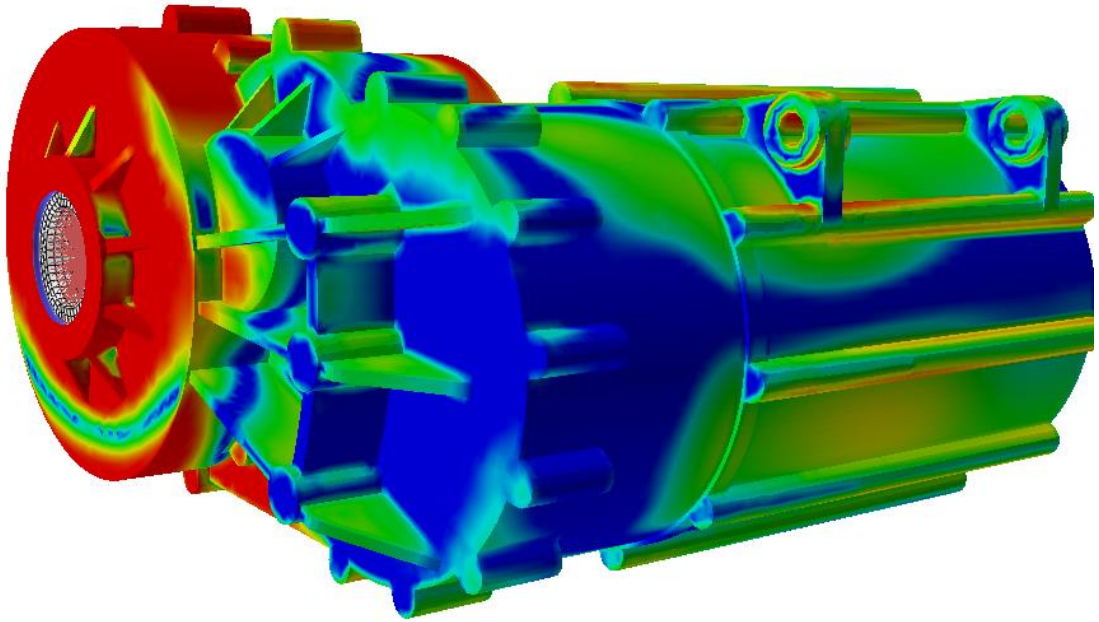




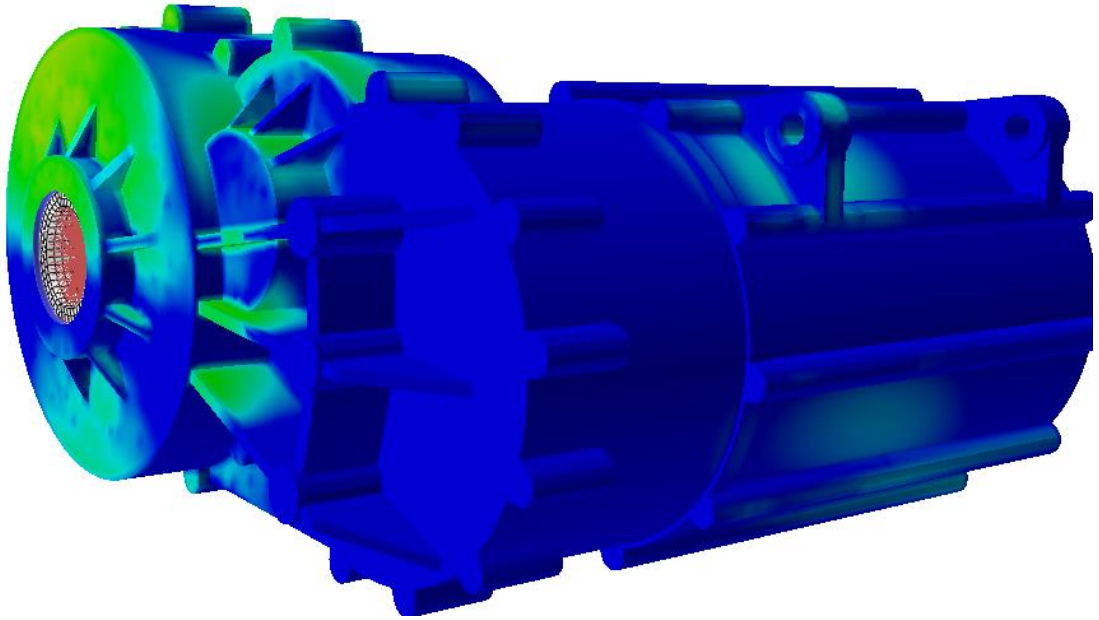
KISSsoft → Time dependent gear mesh and bearing forces

RecurDyn → Housing response

Equivalent radiated power (ERP)



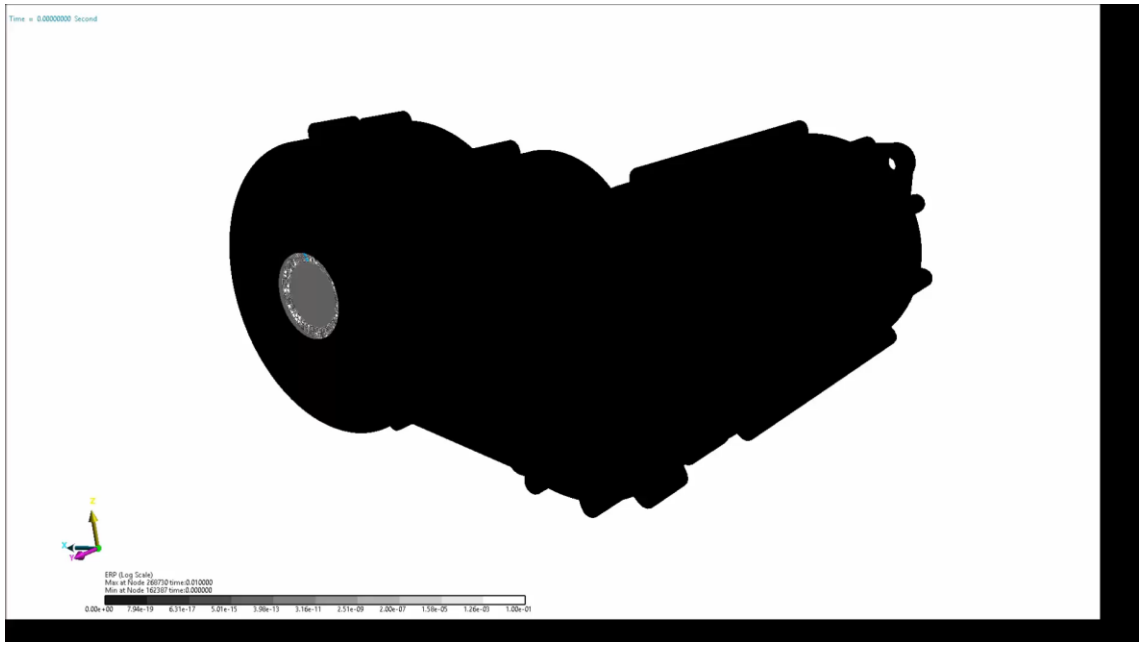
Before gear optimization



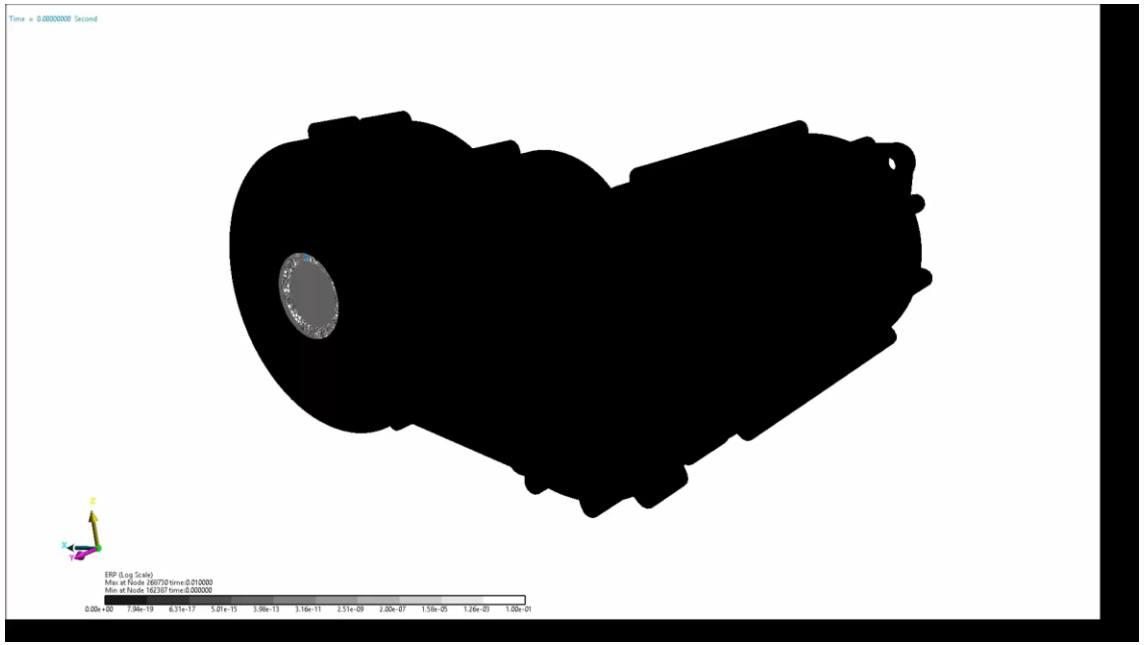
After gear optimization

Housing Response

Evaluation of structure bourne noise (SBN)



LCR design

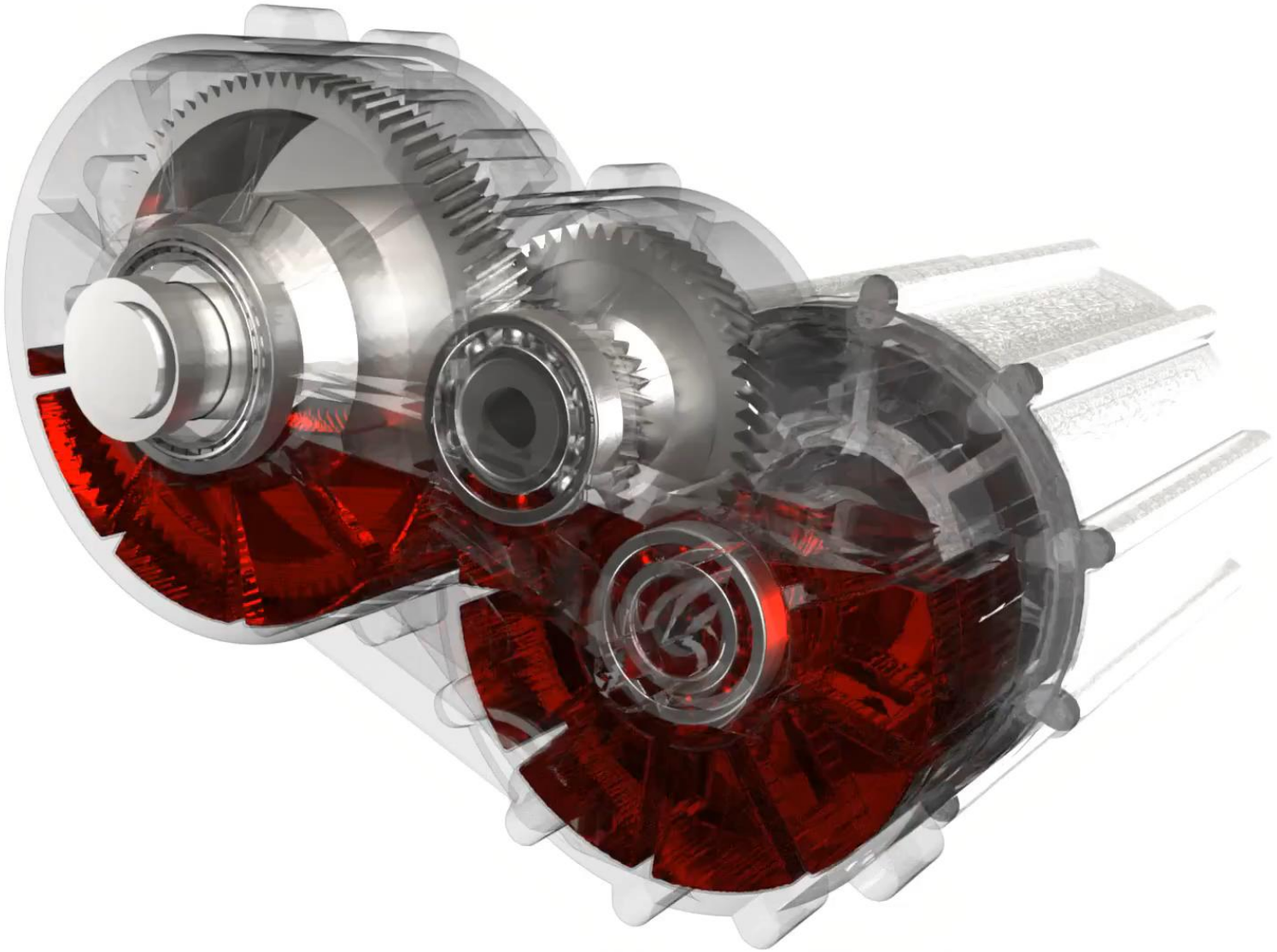


HCR design

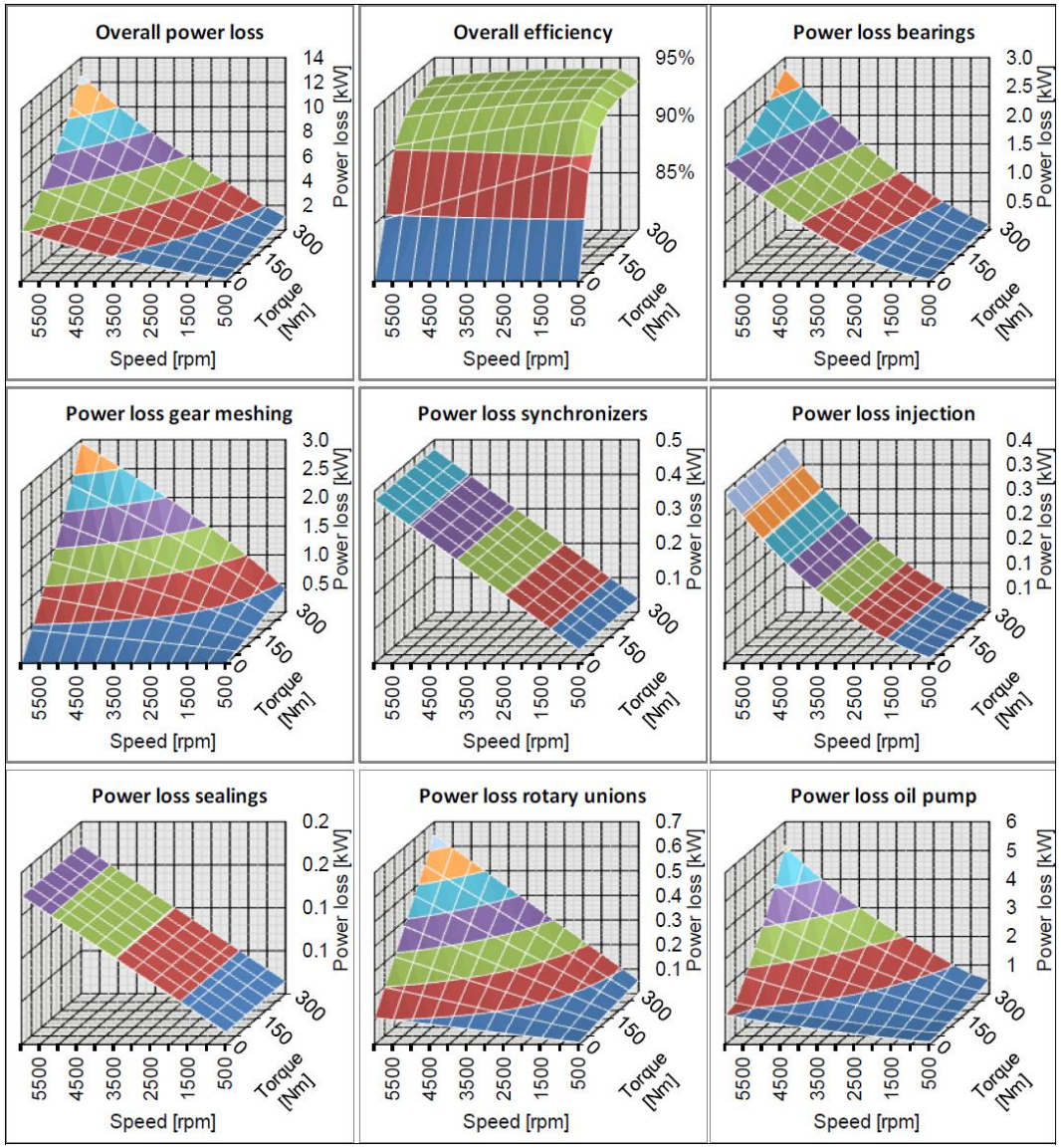
Power Losses

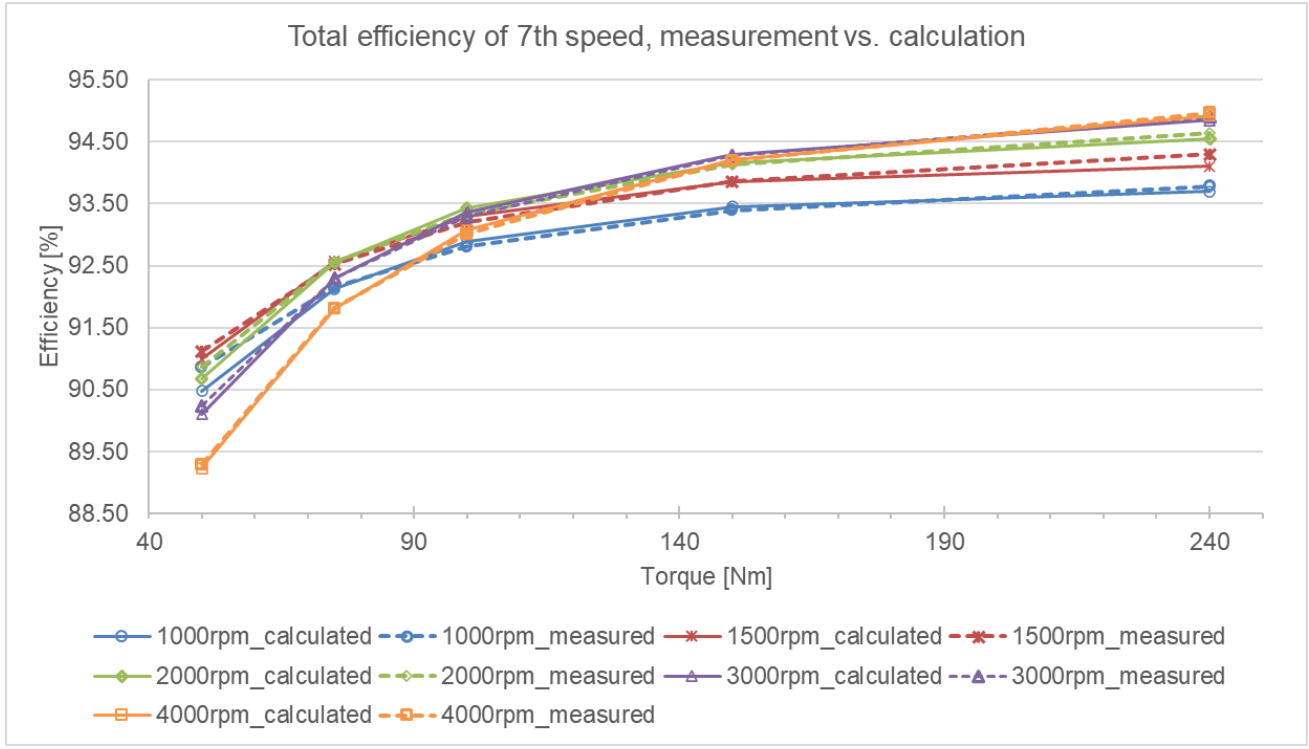
Power Losses

- **Gear mesh losses**
- **Churning losses**
- **Winding losses**
- **Bearing losses**
- **Seal losses**
- **Other components**



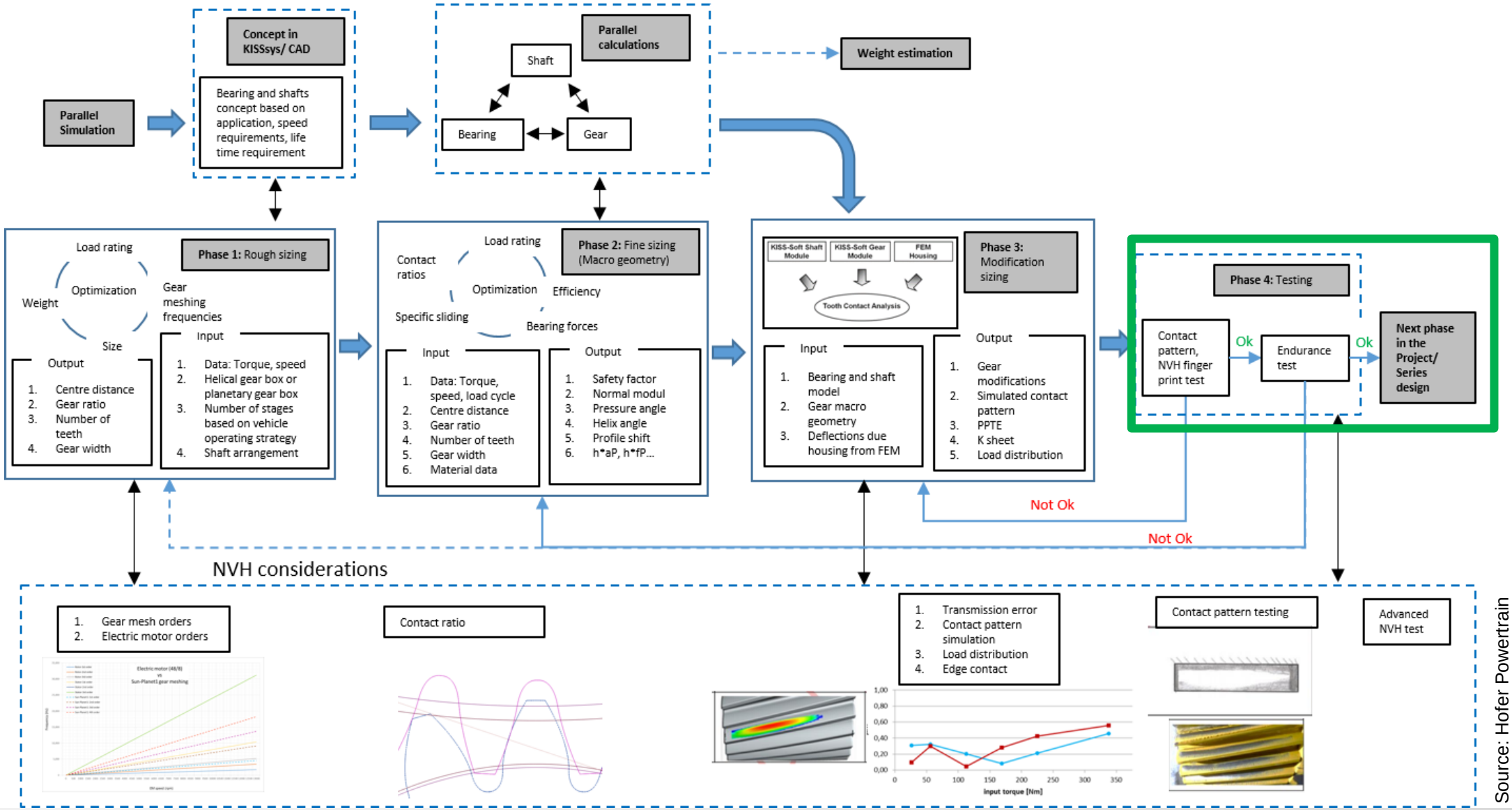
Power Losses





Manufacturing Deviations

Process Flow



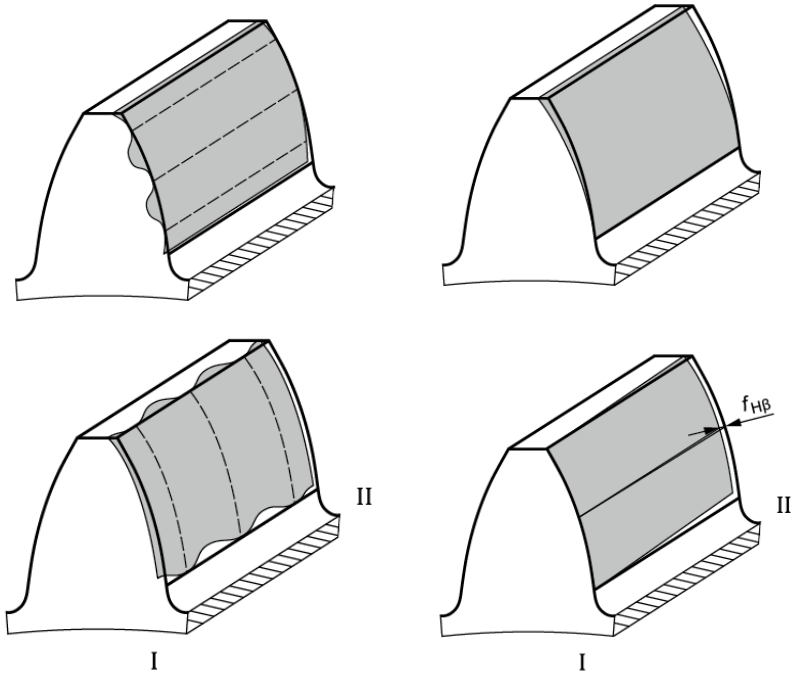
Source: Hofer Powertrain

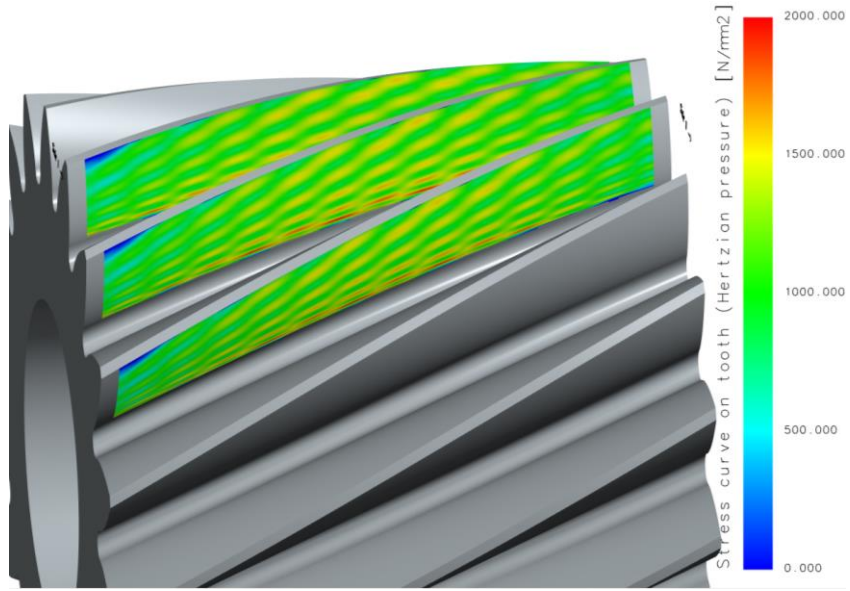
Manufacturing deviations -> influence on NVH

Considered in the design phase

Possible to simulate manufacturing deviations in KISSsoft

- Profile form deviation - $f_{f\alpha}$
- Profile slope deviation - $f_{H\alpha}$
- Helix form deviation - $f_{f\beta}$
- Helix slope deviation - $f_{H\beta}$

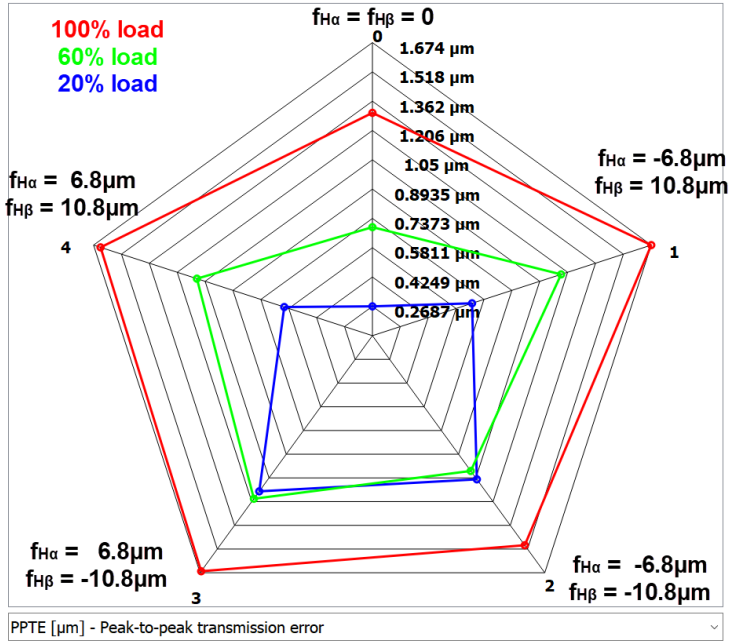


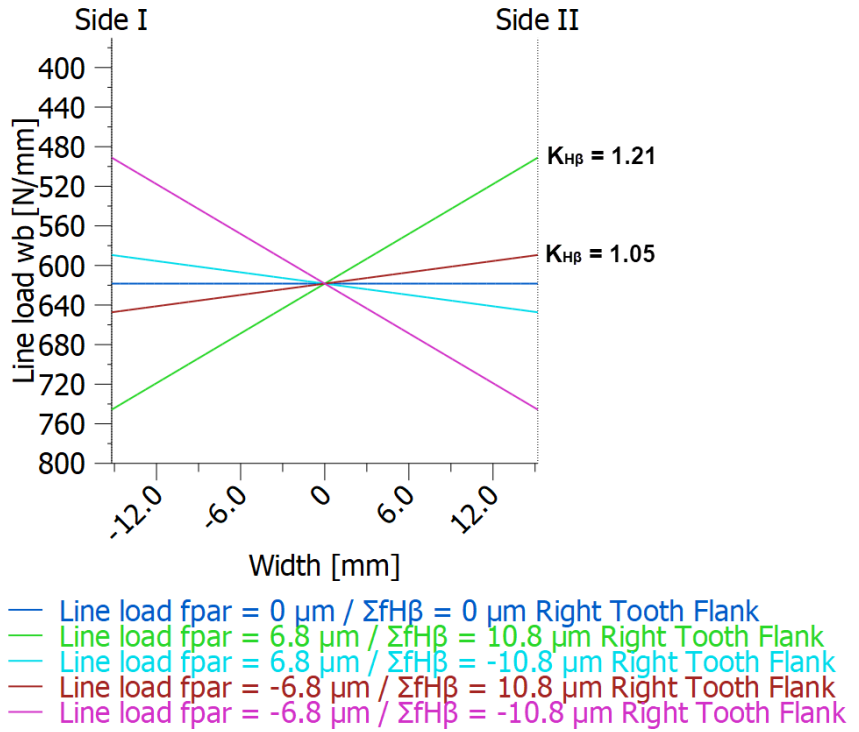


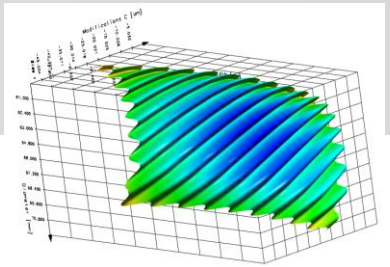
Tolerances $f_{H\alpha}$ and $f_{H\beta}$ from the gear quality and housing manufacturing tolerances.

$f_{H\alpha}$ and $f_{H\beta}$ -> indication for the robustness against the tolerances cumulation

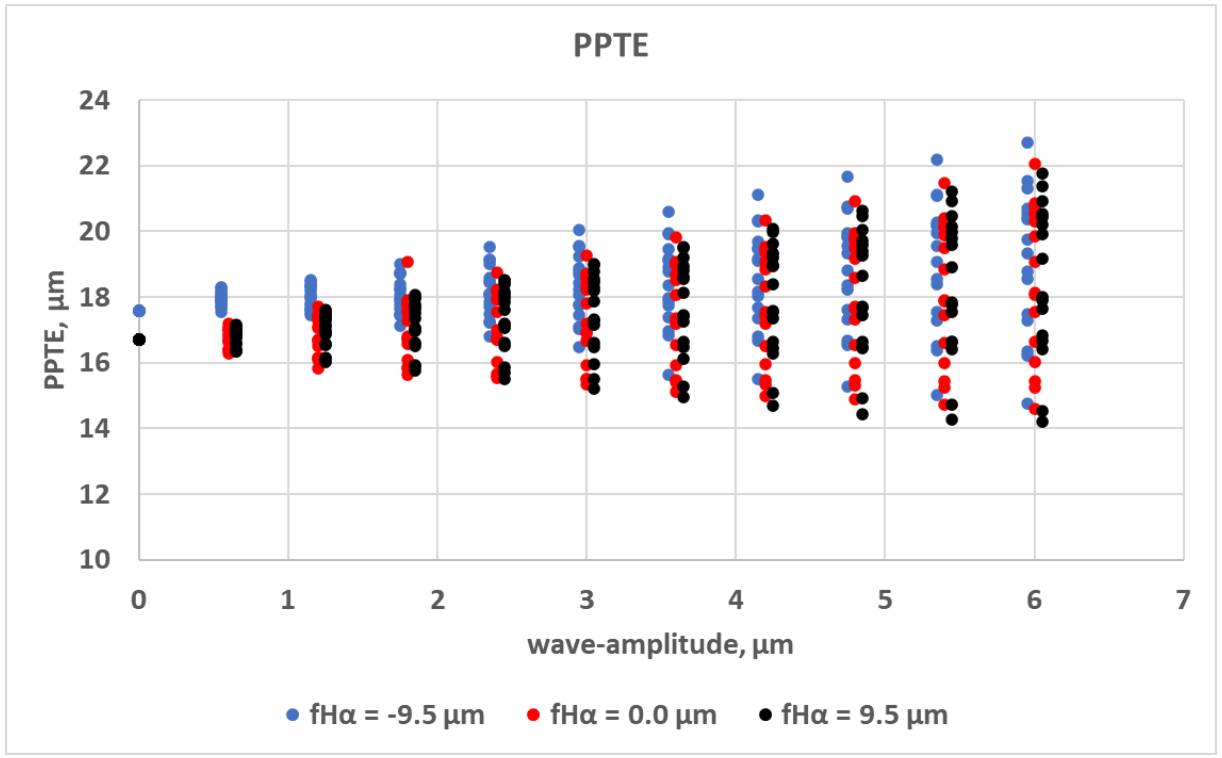
Modification sizing in KISSsoft

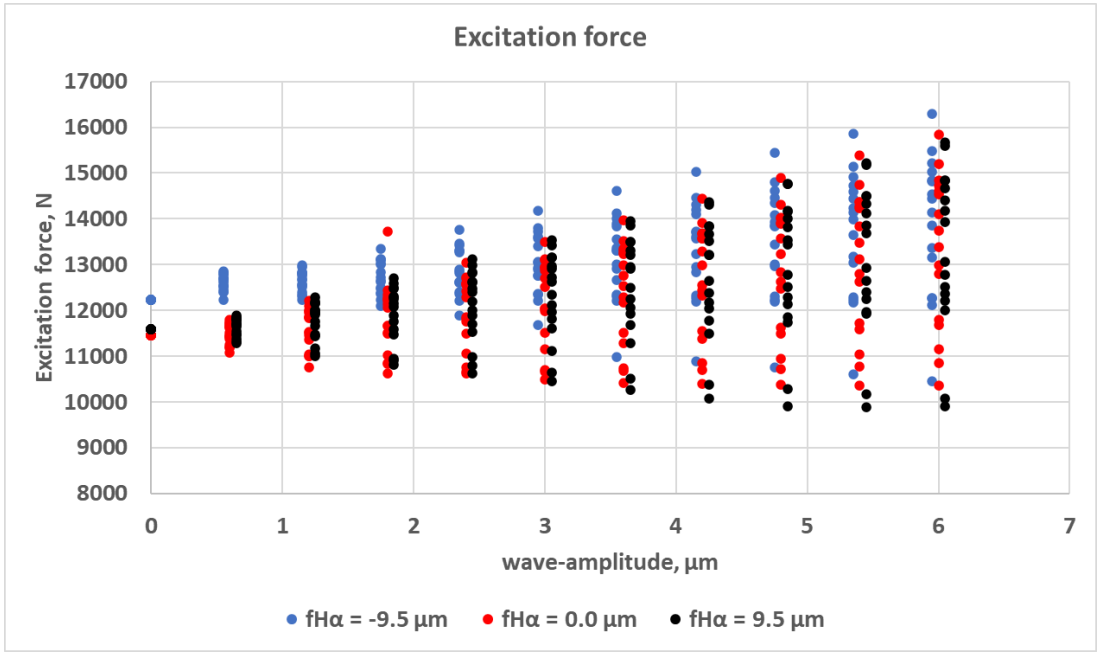


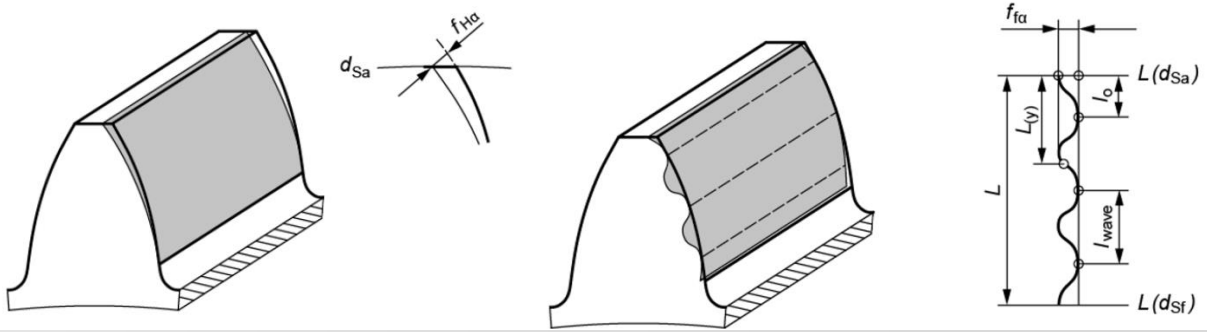




Effect of manufacturing deviations (waviness + profile slope deviation)







Conclusions

Conclusions

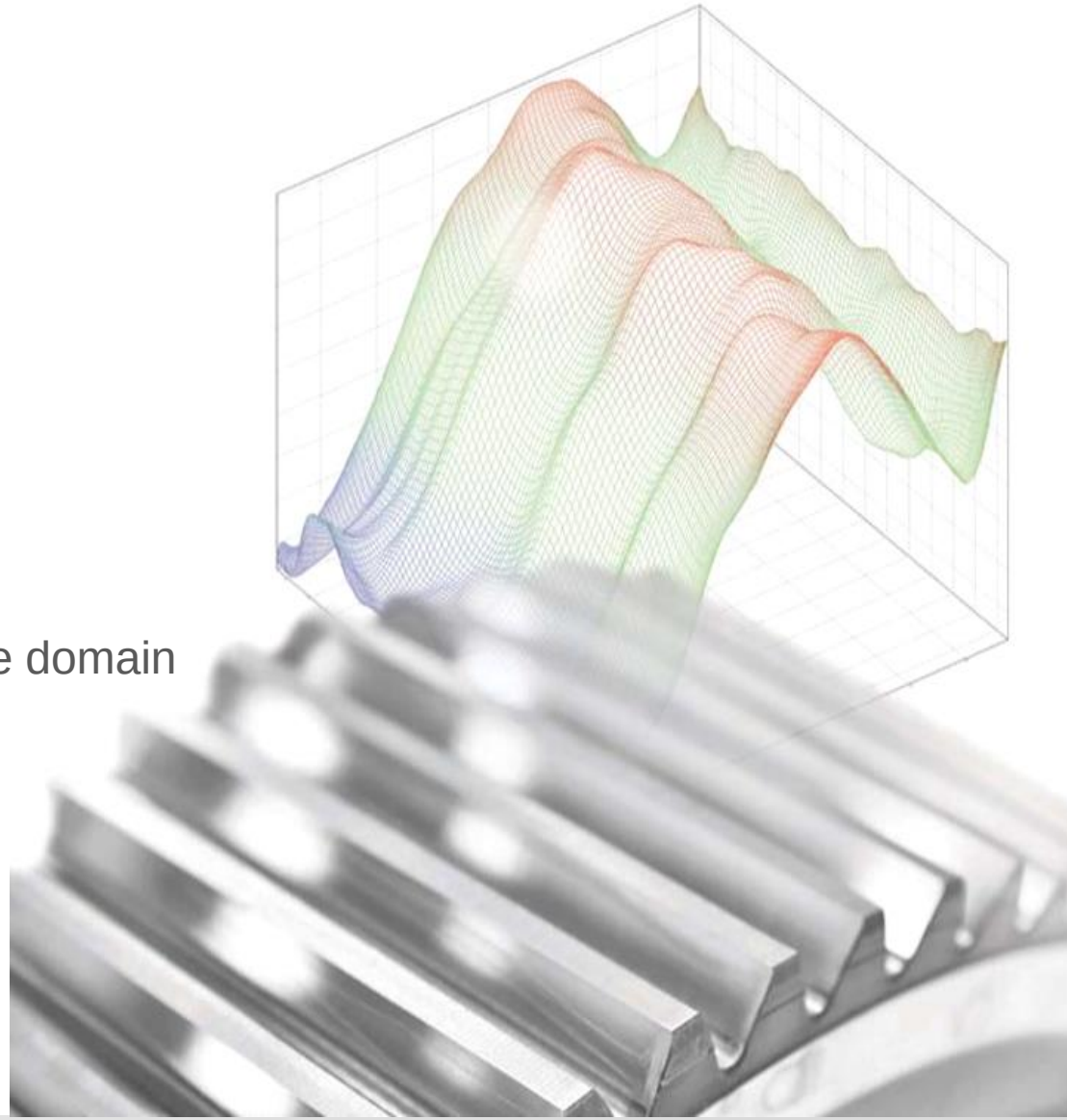
Different challenges in EV drive gearboxes

KISSsoft provides tools for complete evaluation of EV drives

Optimizing macrogeometry in **KISSsoft**

Optimizing microgeometry in **KISSsoft**

For NVH transmission analysis it is recommended to use time domain approaches - **RecurDyn**



Requirements for gears in e-drive differentials are significantly increasing in many respects:

- Higher bending and surface stress capabilities.
- Higher load density requirements in general.
- NVH considerations and noise reduction.
- Dynamic load cases instead of mainly static loads.

Watch out for the upcoming special “Differentials in e-Drives”

Welcome to the e-Drive Days

Design of the e-Drive Gears

Dr. Aljaž Pogačnik
KISSsoft AG