

Welcome

Design of e-Drive Gears

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KISSsoft AG

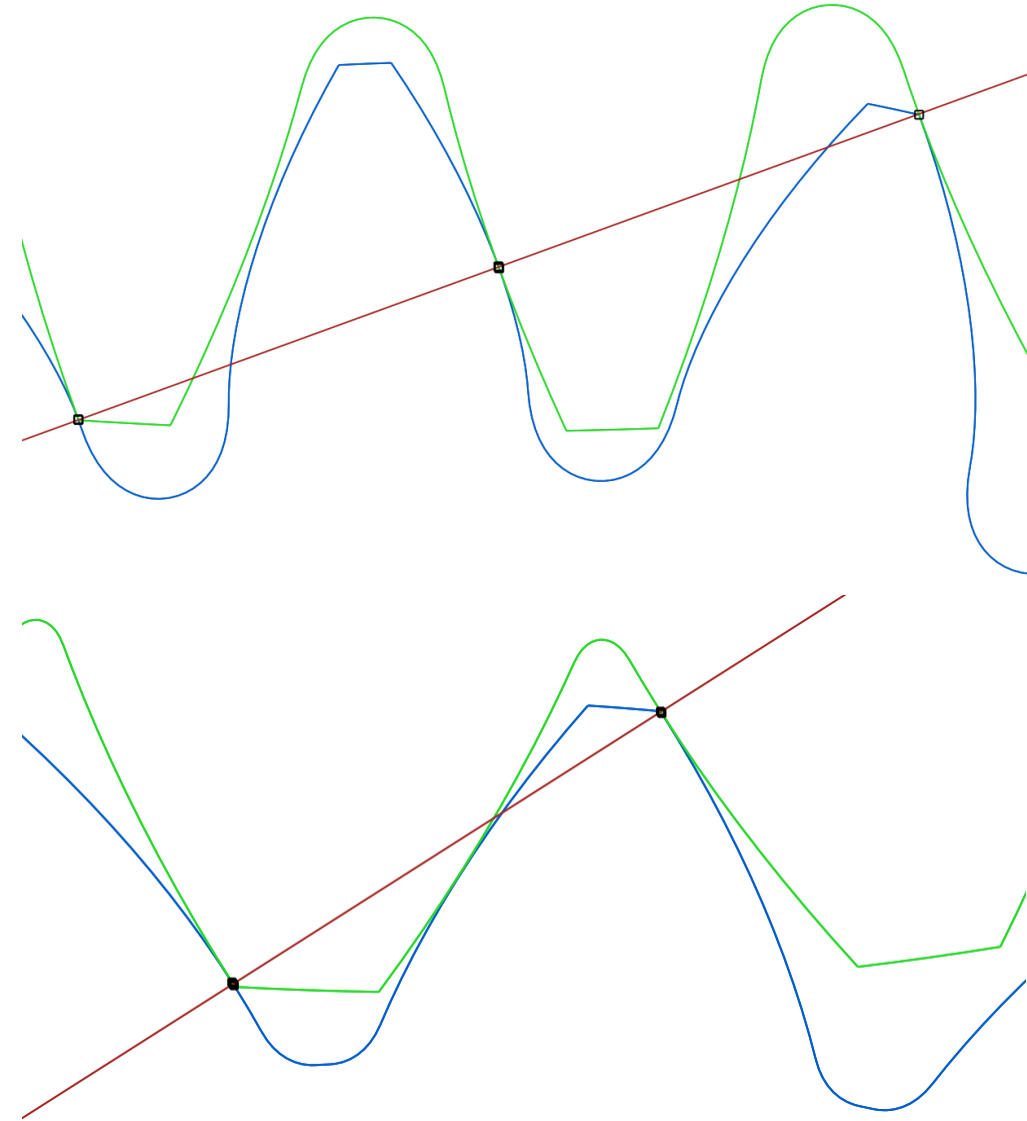


Challenges in e-Drive Gear Design

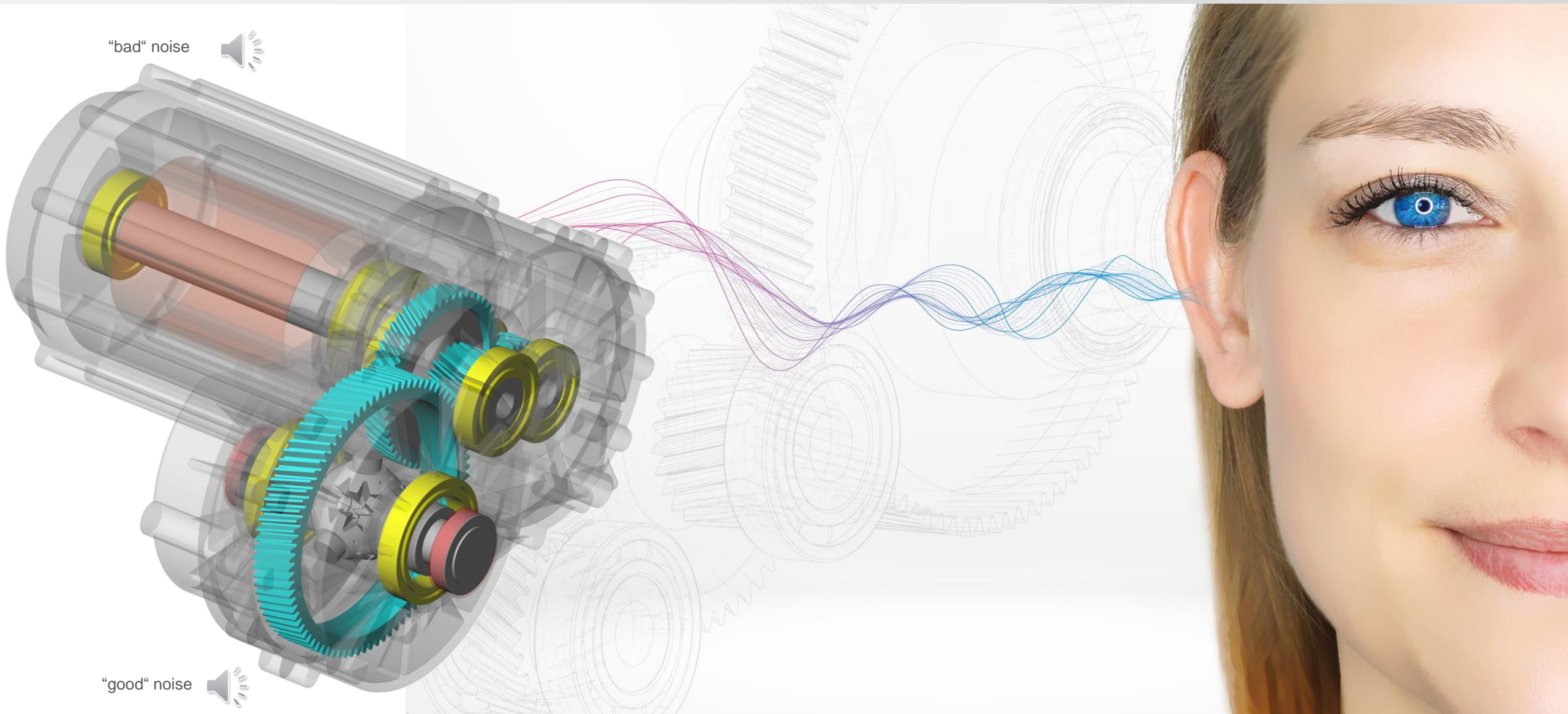
High, low, negative torque

Low vibration → High contact ratio

High efficiency → Low contact ratio



From Gear Mesh to Audible Noise



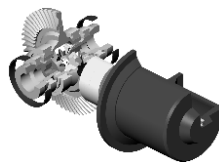
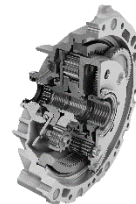
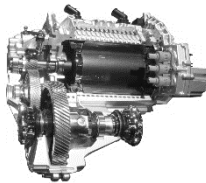
Source: FZG, München

E-drives → no combustion engine → no noise masking

Optimize tooth stiffness → low vibration

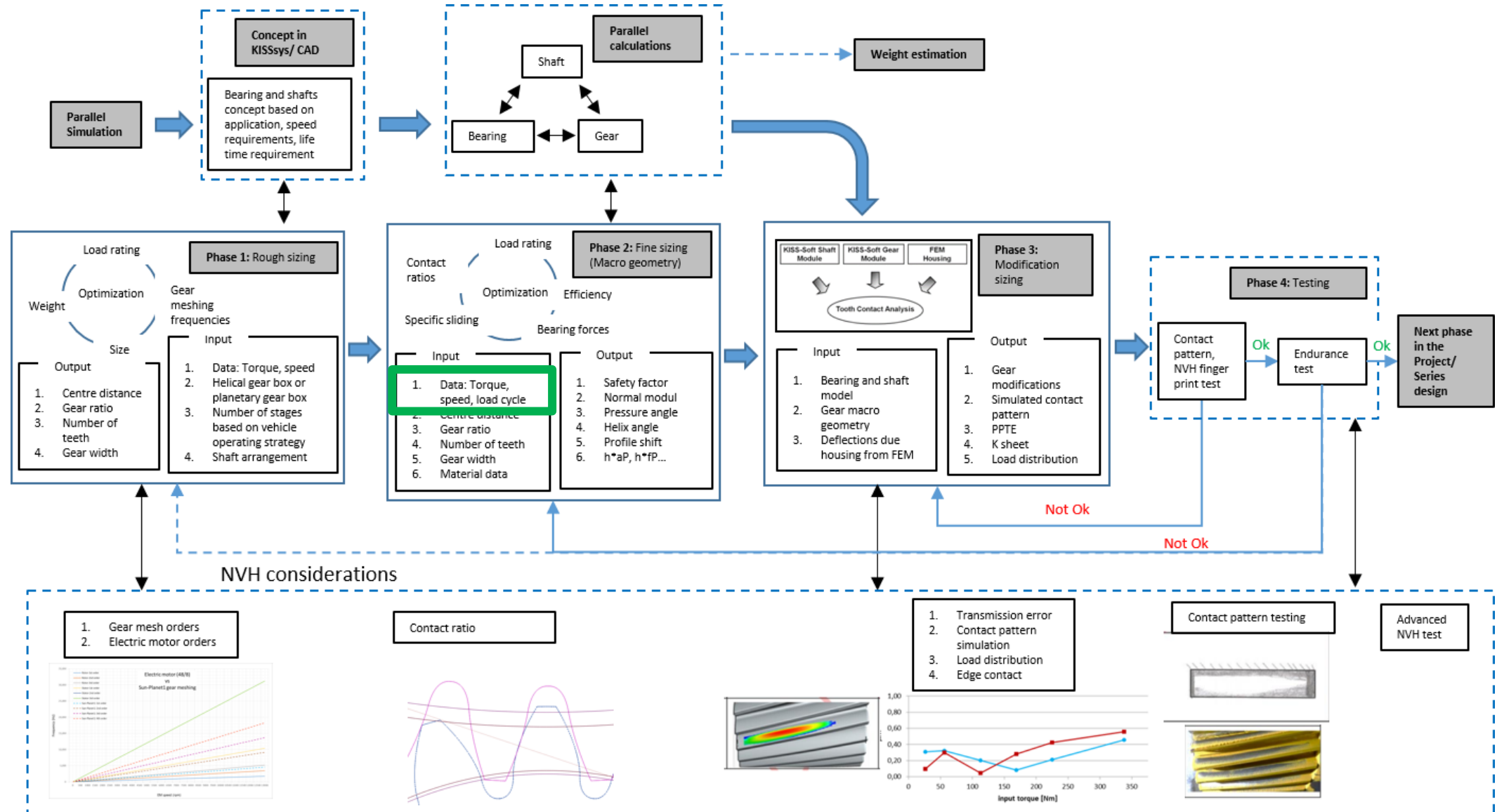
Optimize tooth strength → high torque capacity

Optimize tooth shape → low losses



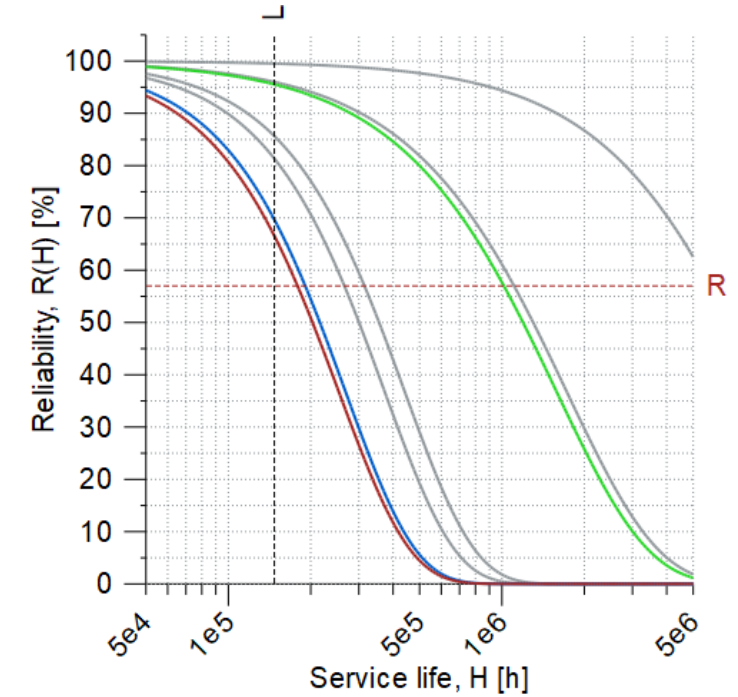
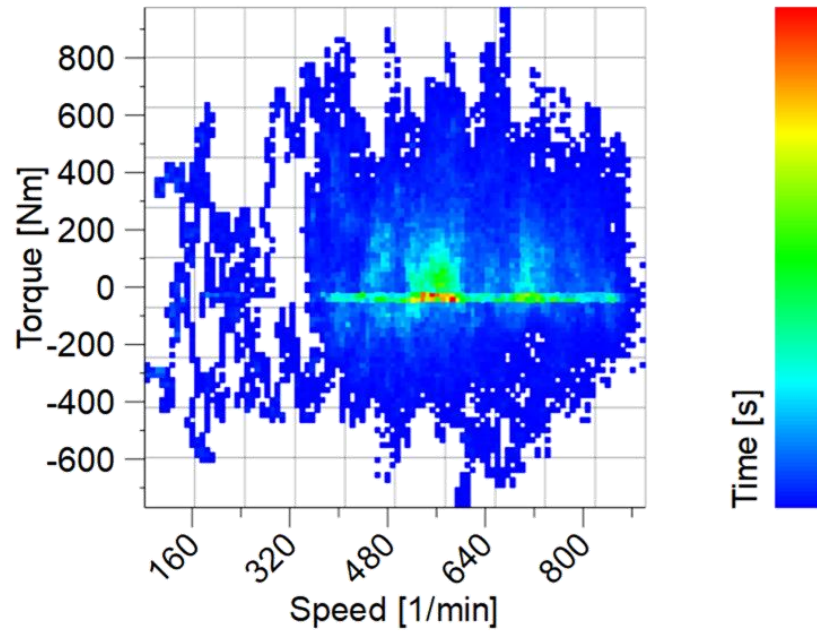
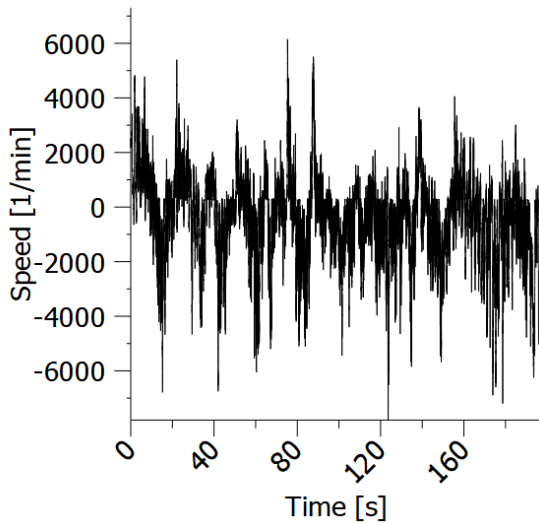
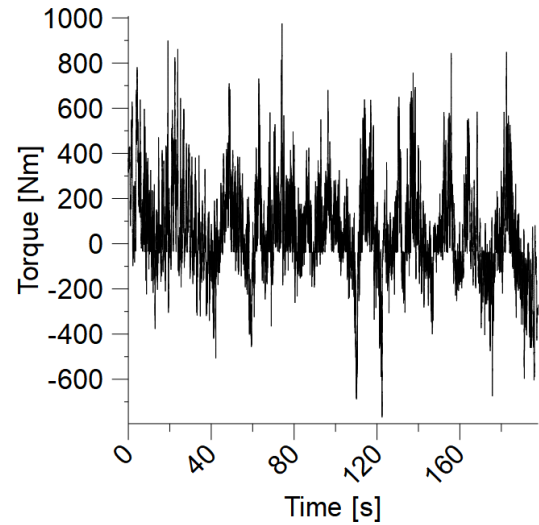
Gear Design

Process Flow



Source: Hofer Powertrain

Load Spectrum from Measured Data



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

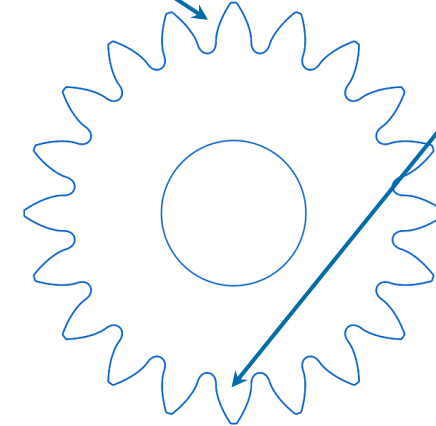
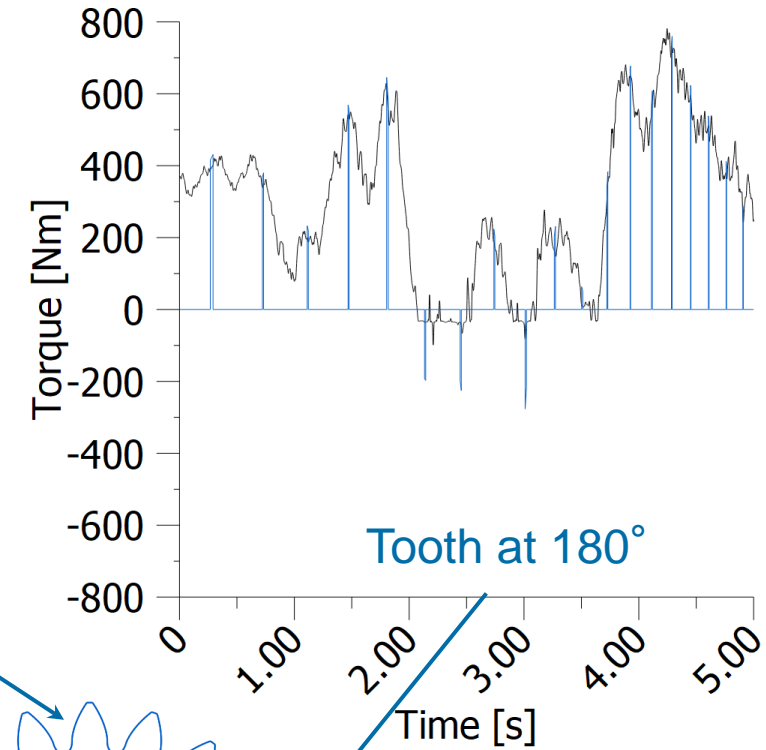
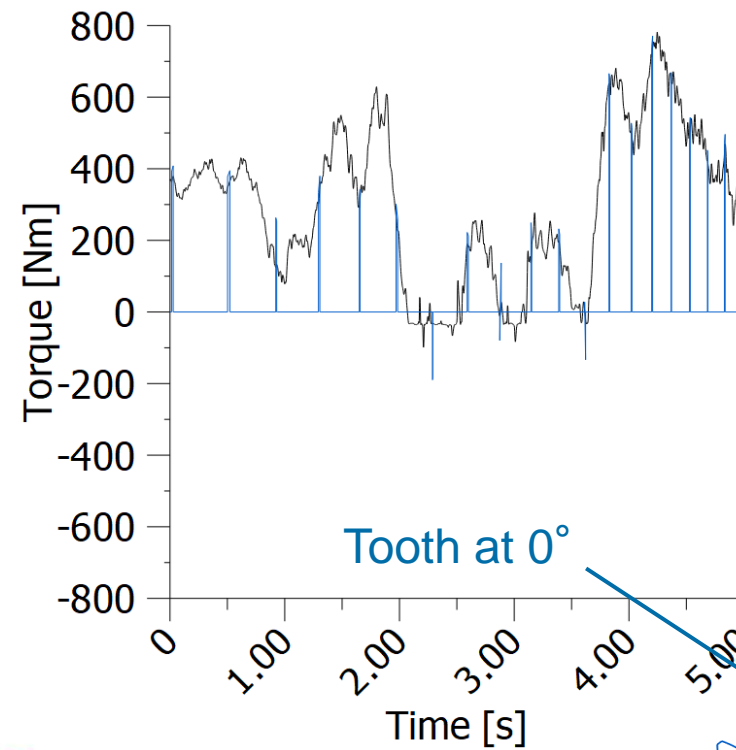
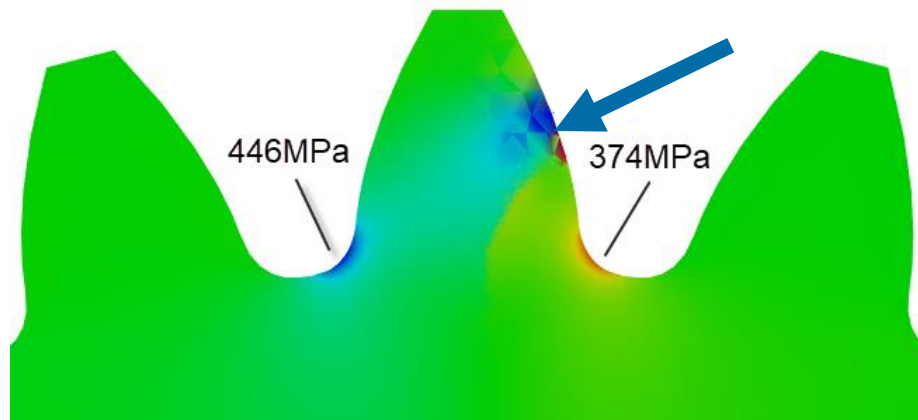
Load Spectrum from Measured Data

Every tooth has different loads

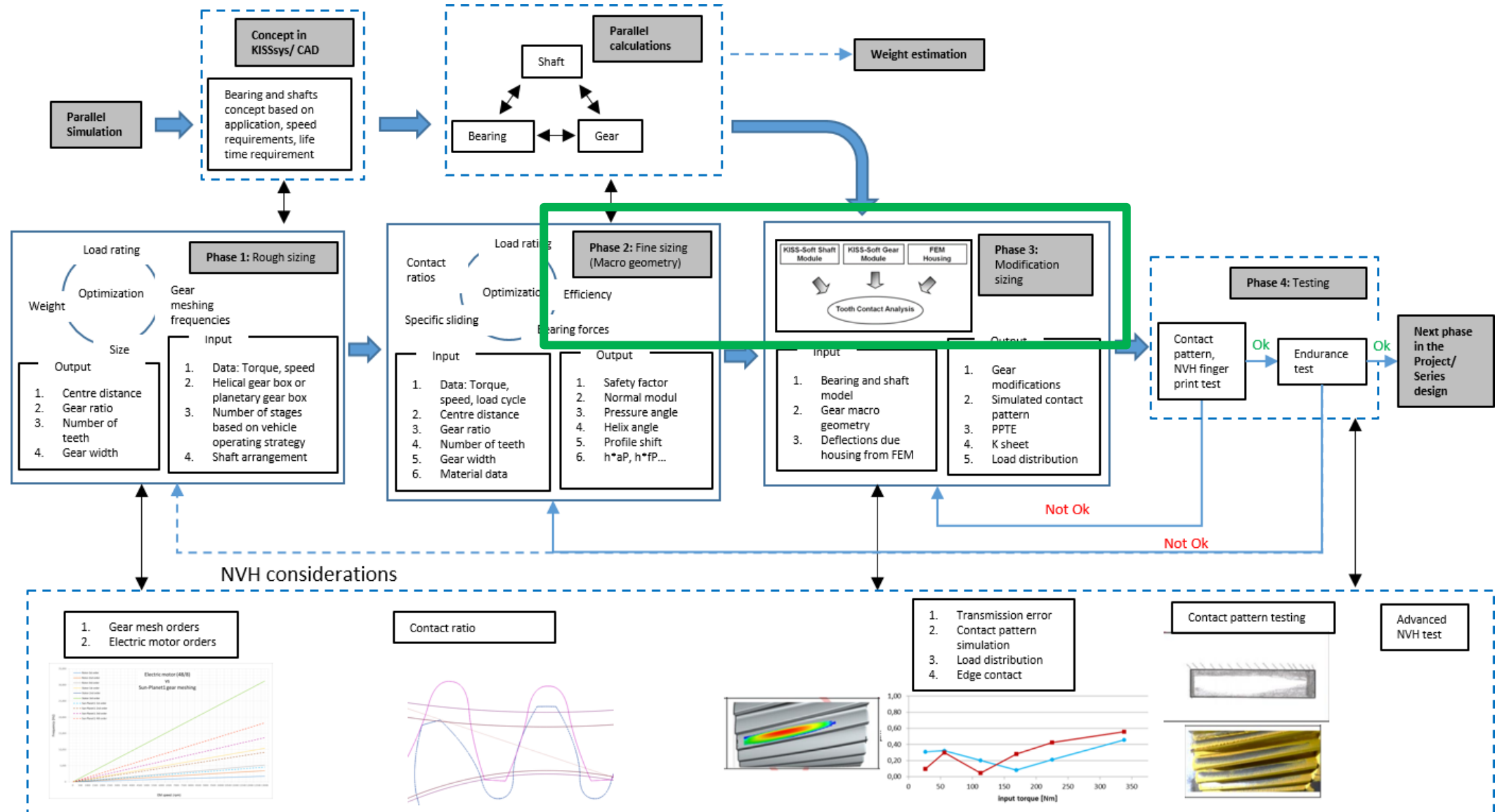
Both flanks loaded

Root reverse bending

Root compressive strength



Process Flow



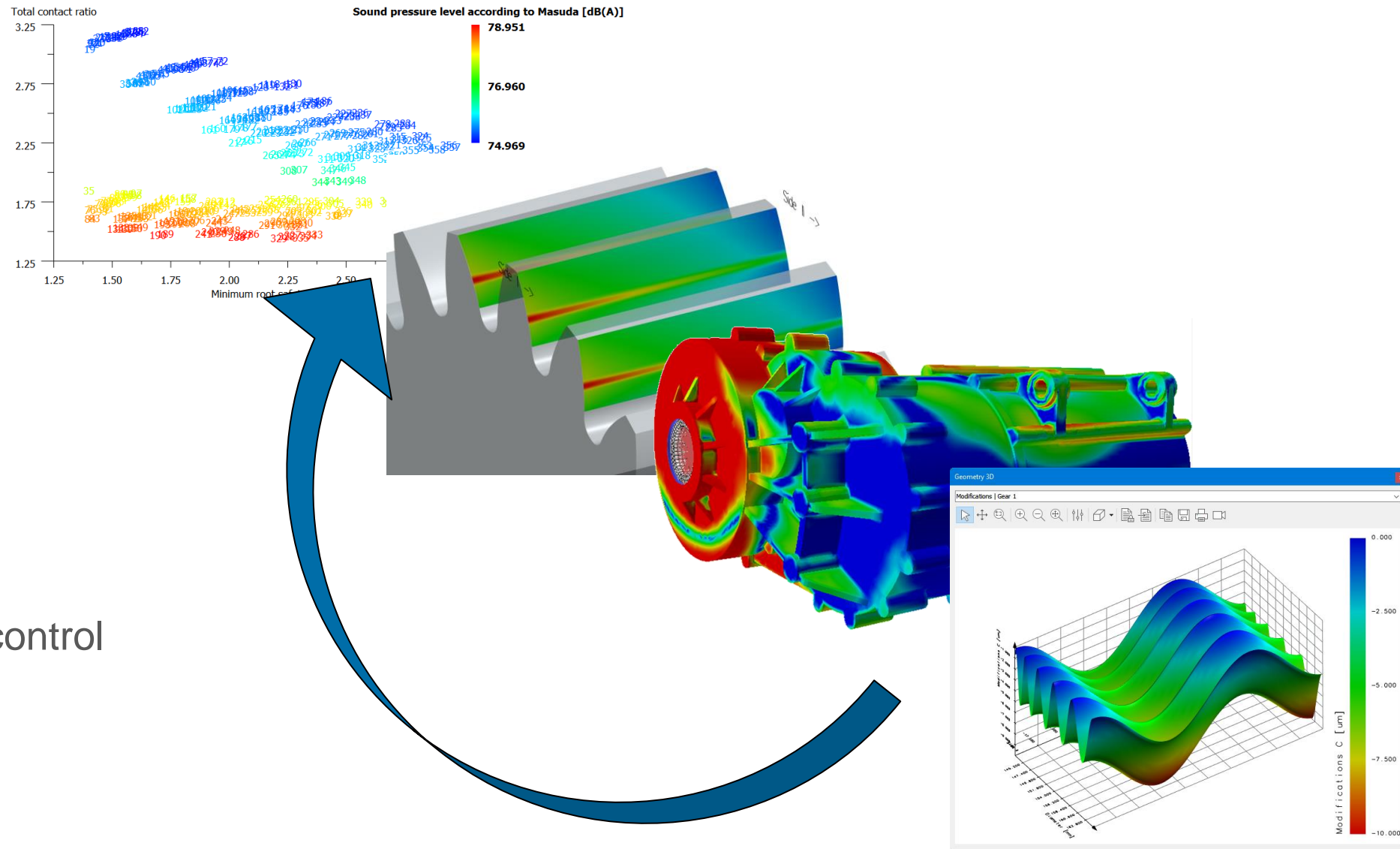
Source: Hofer Powertrain

Macro geometry

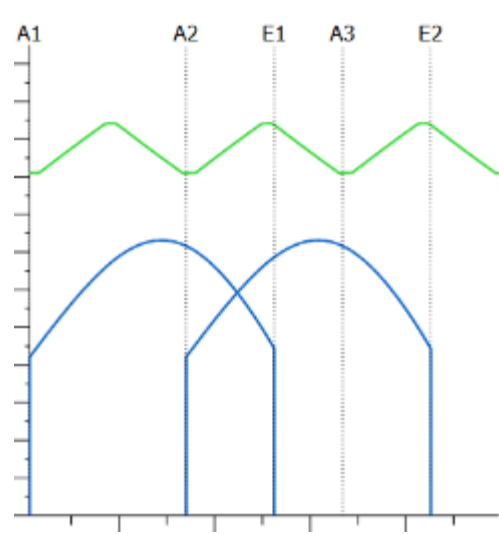
Micro geometry

NVH simulation

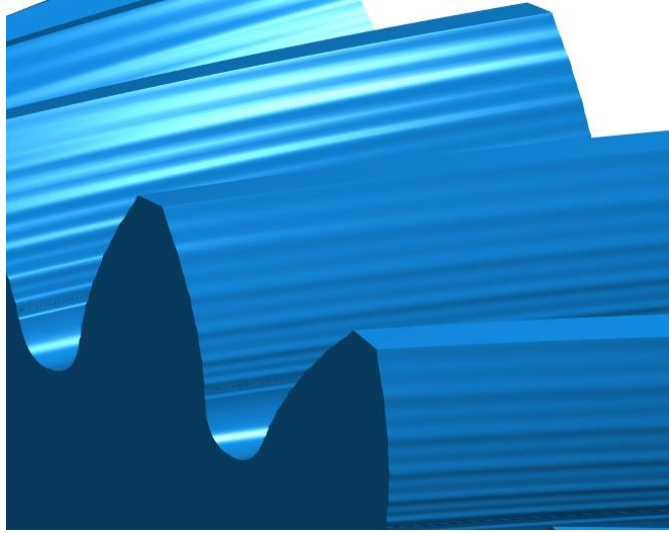
Manufacturing, quality control



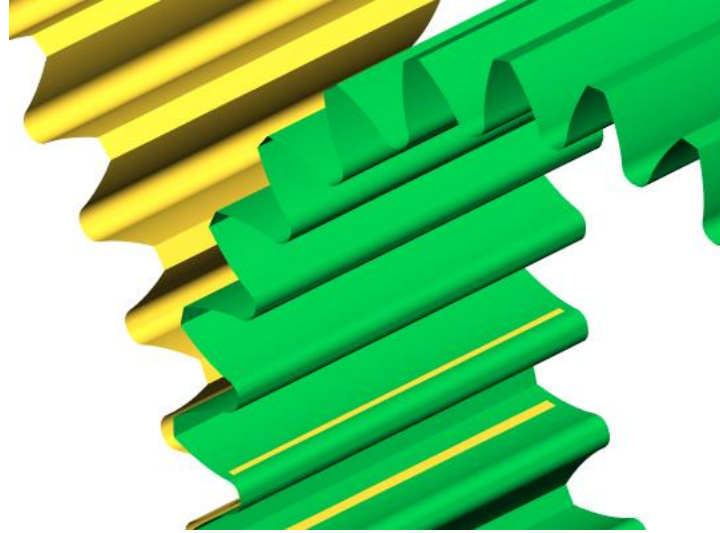
Vibration Excitation from Tooth Mesh



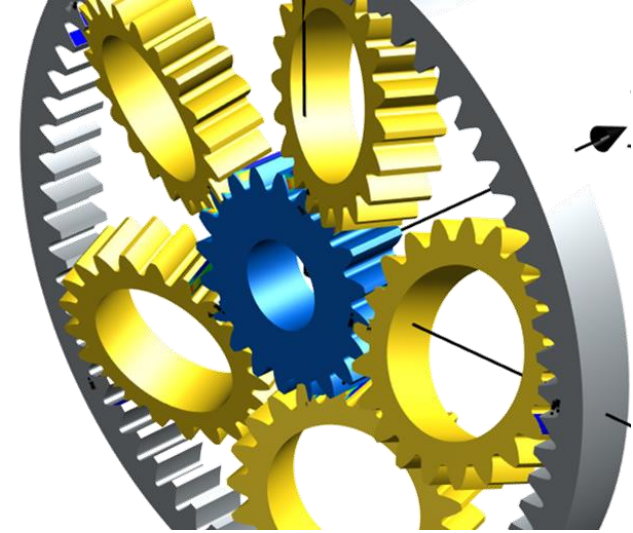
Stiffness variation



Flank imperfections

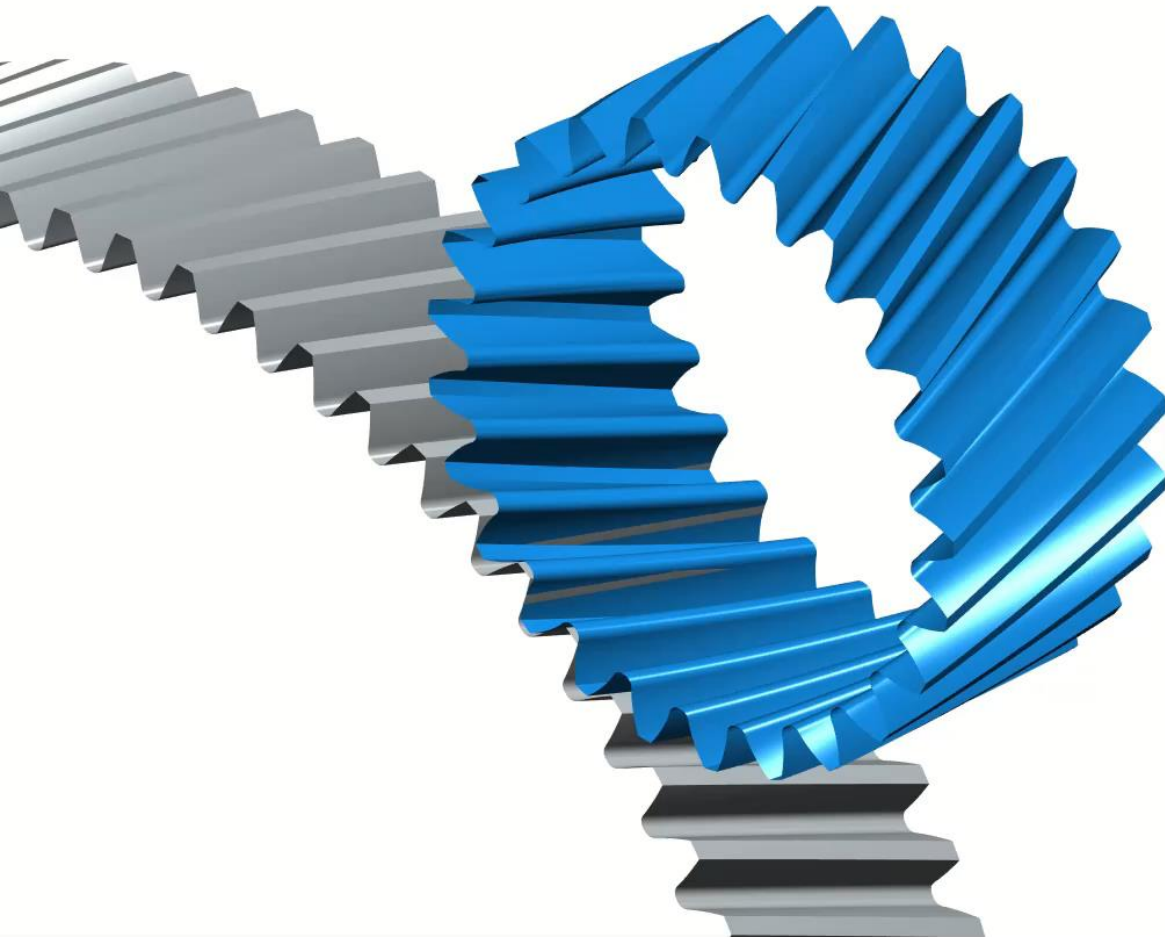


Meshing impact

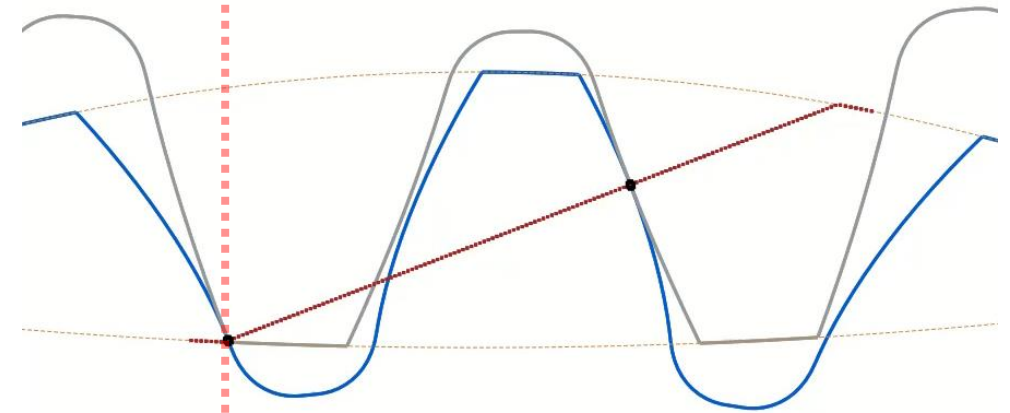


Misaligned system

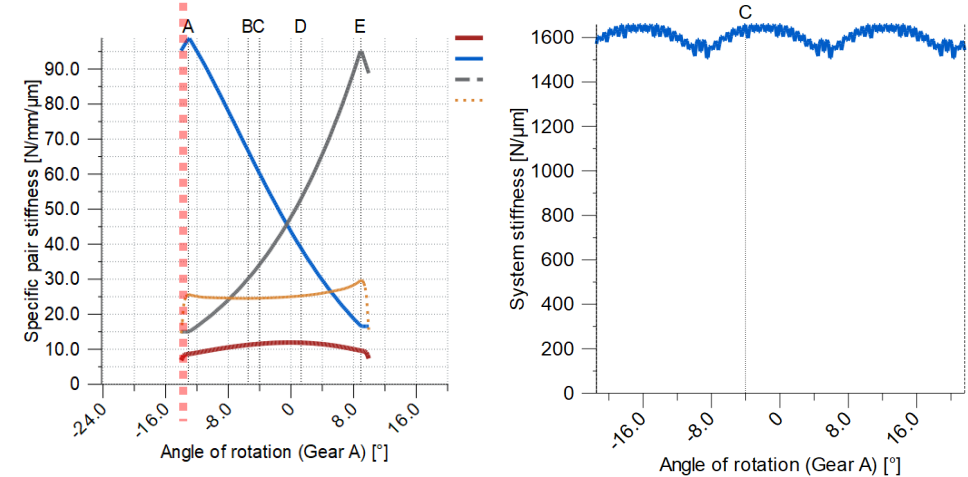
Why is the **mesh stiffness** not constant?



The number of teeth engaging changes

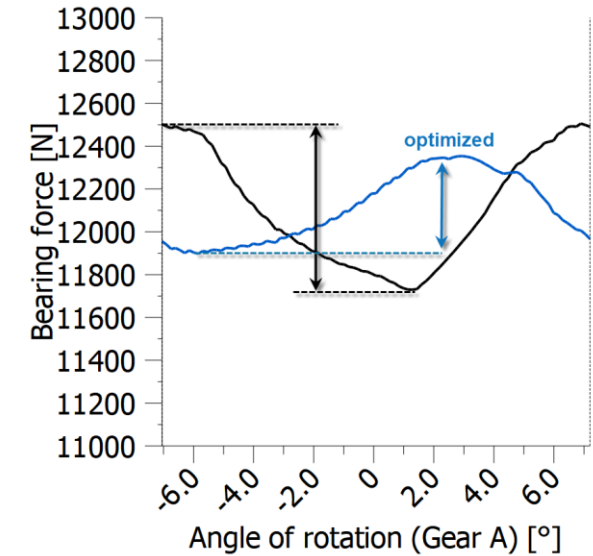
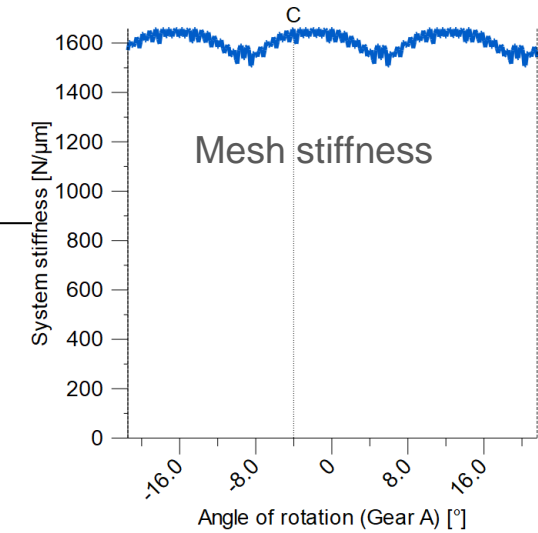
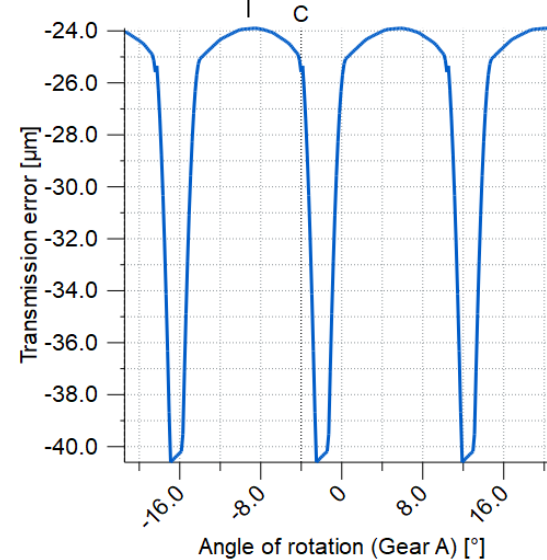
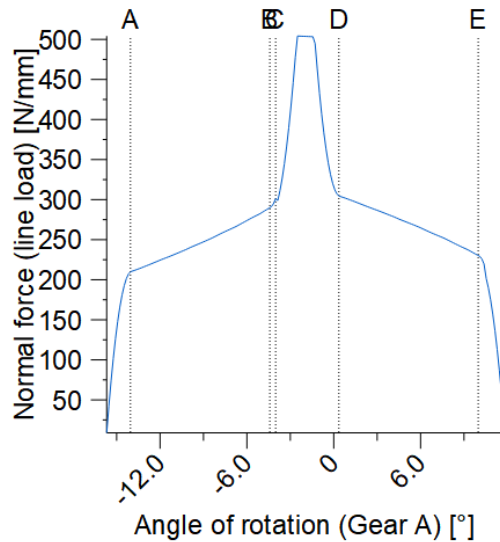
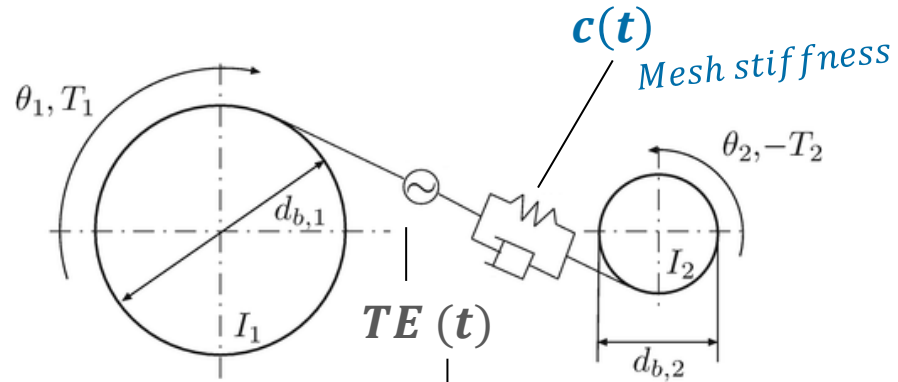


Single tooth / mesh stiffness changes

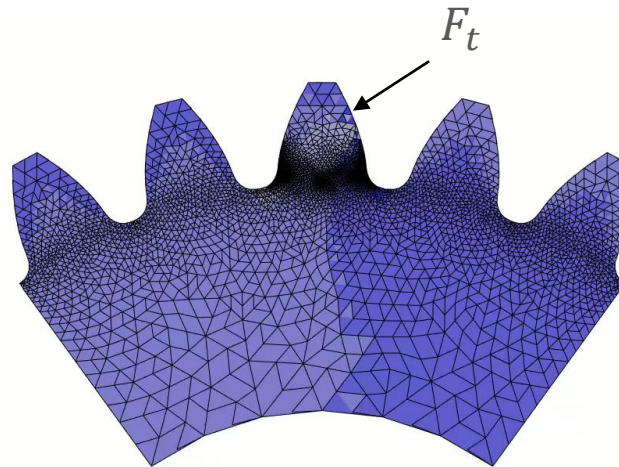
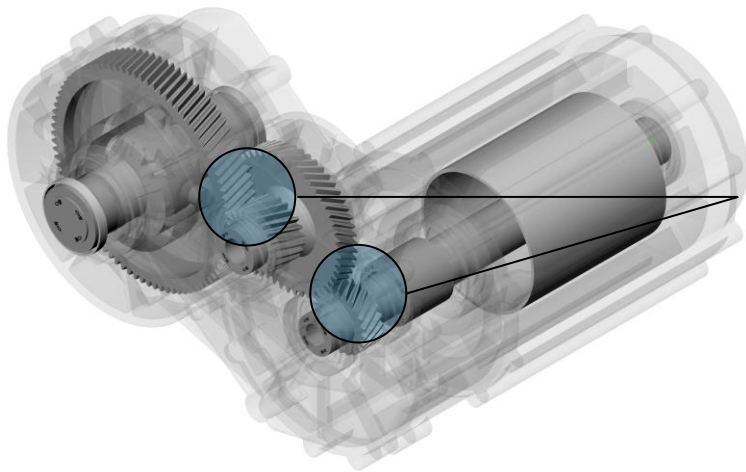


How is **mesh stiffness** related to **transmission error**?

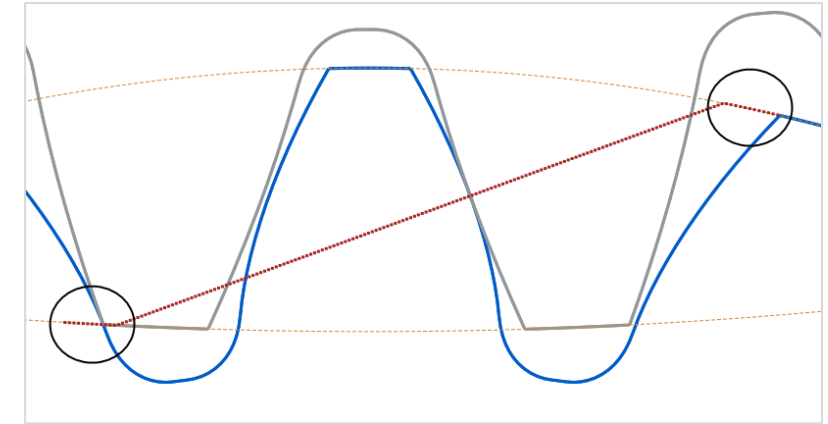
$$F(t) = c(t) \cdot TE(t)$$



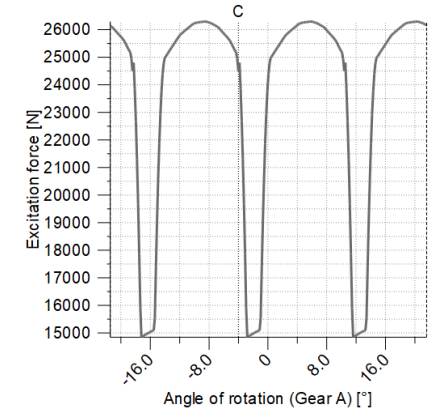
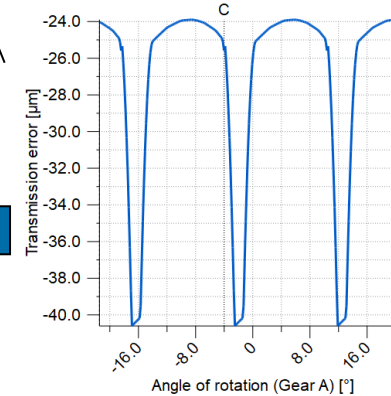
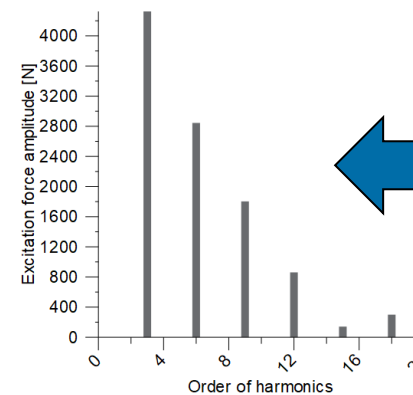
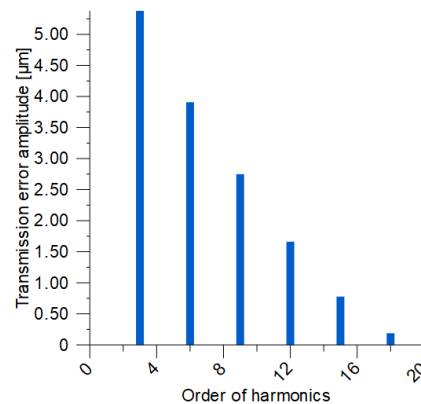
Transmission error → noise



Contact shocks / change of pressure angle



Transmission Error (TE) / Force Excitation

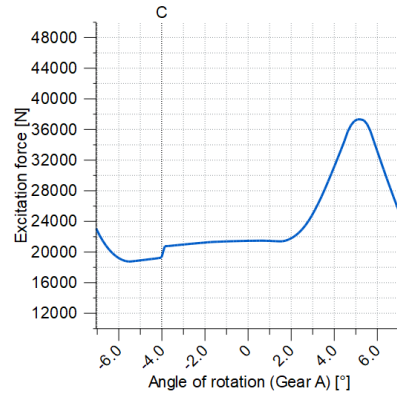
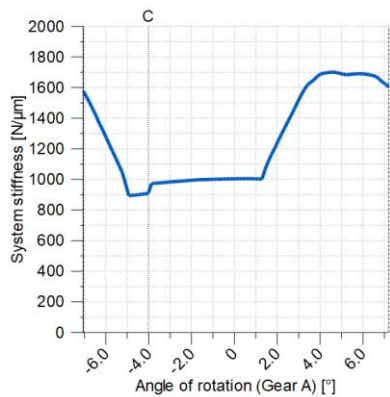
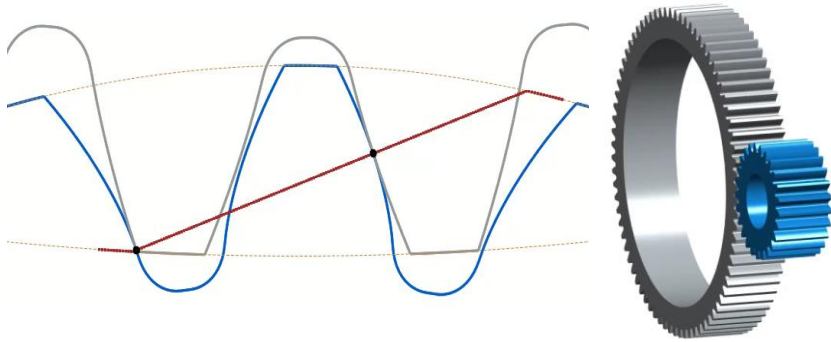


Fine sizing (improve gear macro-geometry)

$$m_n = 3 \text{ mm} \quad \beta = 0^\circ \quad \varepsilon_\alpha = 1.66$$

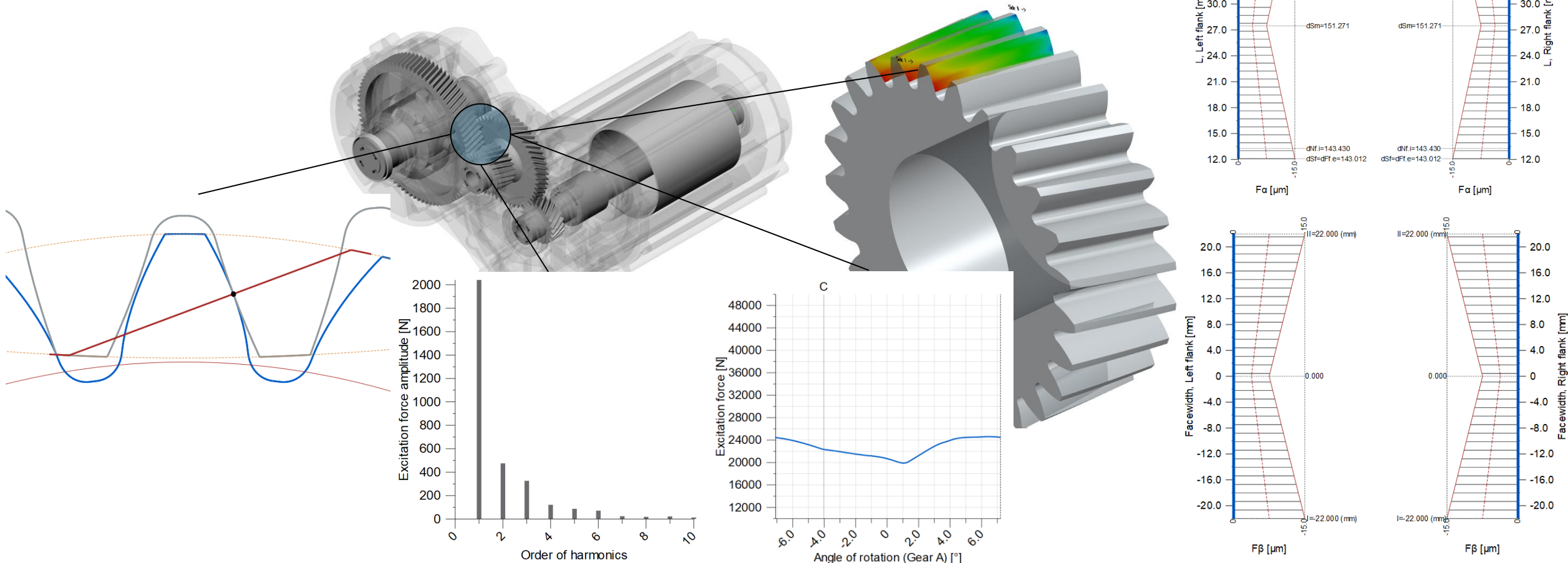
$$h_{fP0}^* = 1.2 \quad h_{aP0}^* = 1.25 \quad h_{aP0}^* = 0.38$$

redesign



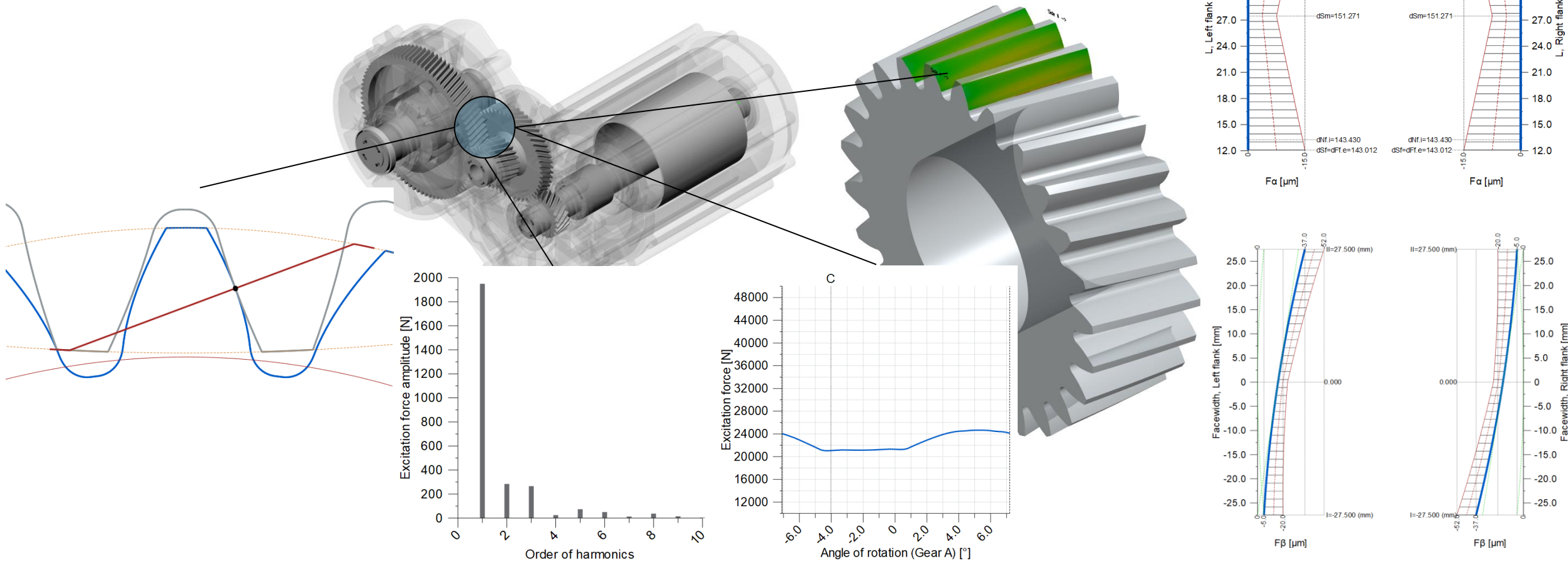
Loaded Tooth Contact Analysis (LTCA)

- No modifications applied



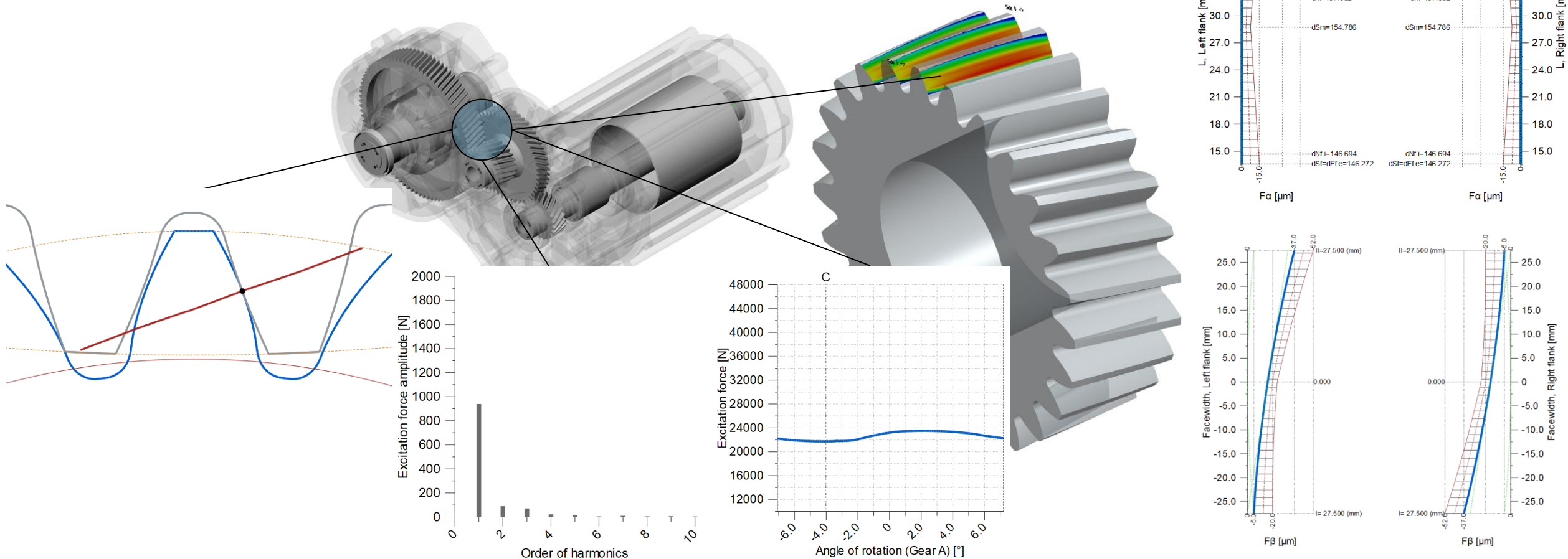
Loaded Tooth Contact Analysis (LTCA)

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



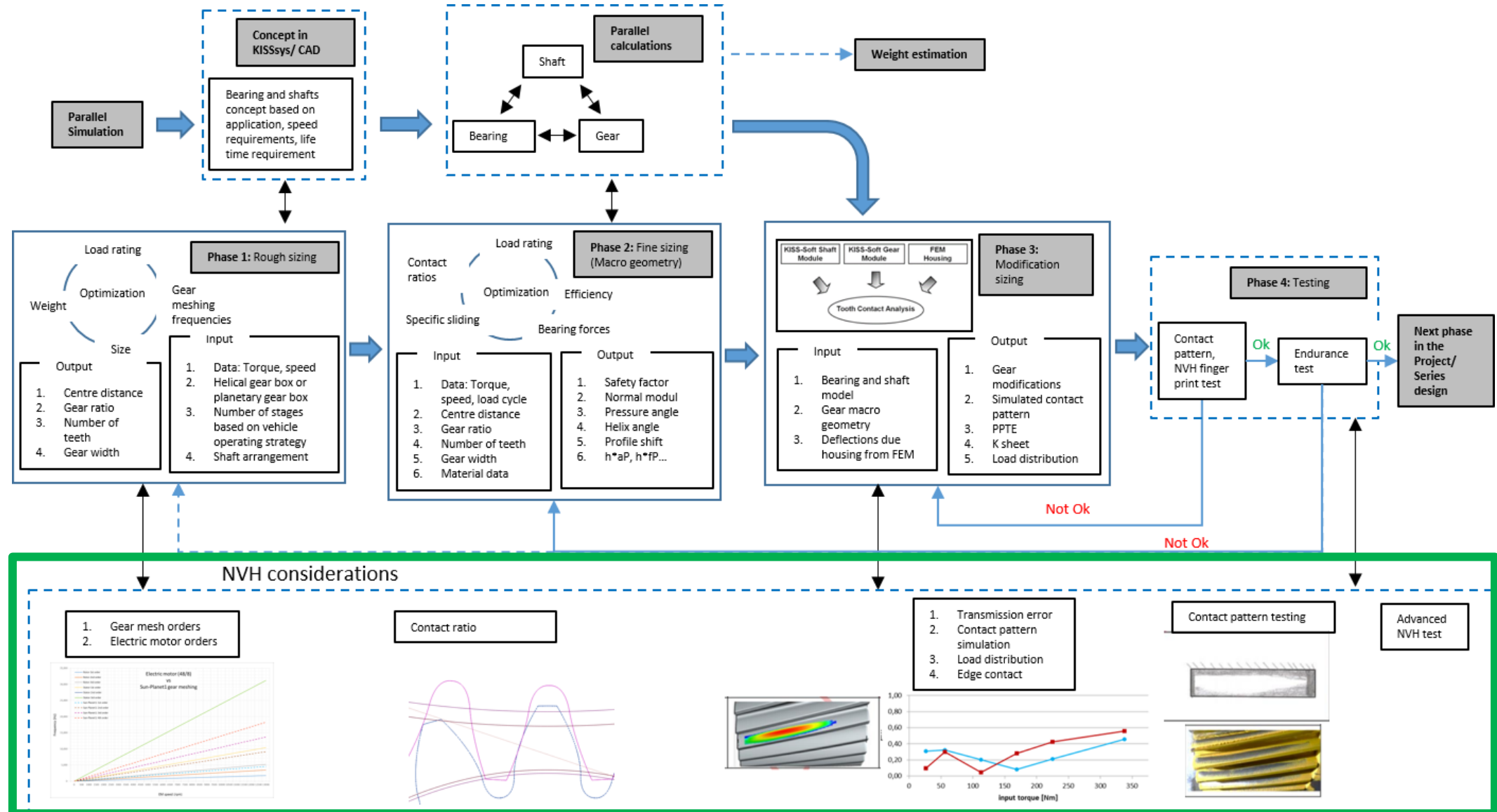
Loaded Tooth Contact Analysis (LTCA)

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



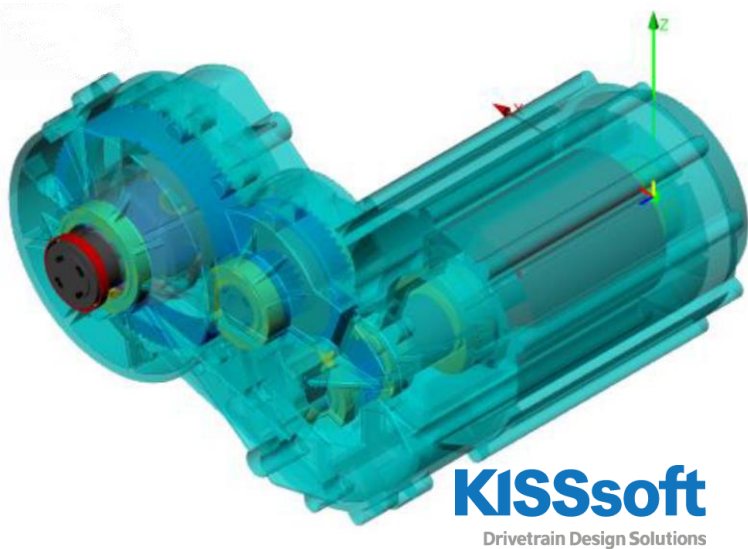
NVH Evaluation

Process Flow



Source: Hofer Powertrain

Housing Response



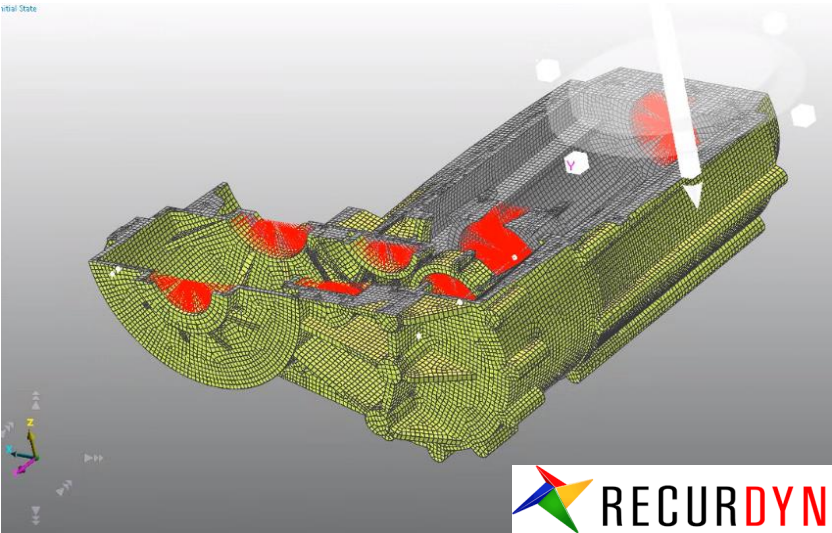
Spline

Name: Sp1

Data: 53000bearing_v1_b1_Speed_5300_responseVsRotAngle.tmp

No	X	Y1	Y2	Y3	Y4	No	Z
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11	4.922067266e-005	31.85412712	0.	-94.71830153	4.064091519e-005	2	2.
12	5.414273995e-005	31.83234541	0.	-95.05504405	4.022046024e-005	3	3.
13	5.906480722e-005	31.83879154	0.	-95.50791216	3.974653417e-005	4	4.
14	6.398687449e-005	31.87306743	0.	-96.06979627	3.923246984e-005	5	5.
15	6.890894176e-005	31.93472291	0.	-96.73666335	3.868402749e-005		
16	7.383100902e-005	32.02325778	0.	-97.50470908	3.810921474e-005		
17	7.875307629e-005	32.13812346	0.	-98.36920808	3.751015282e-005		
18	8.367514056e-005	32.27872472	0.	-99.33954409	3.690909854e-005		
19	8.859721083e-005	32.4444224	0.	-100.3732275	3.625391977e-005		
20	9.351927811e-005	32.63453709	0.	-101.5060867	3.559991136e-005		
21	9.844134537e-005	32.84893383	0.	-102.7232611	3.492883231e-005		
22	1.033634126e-004	33.08511845	0.	-104.0191644	3.423944746e-005		
23	1.082854799e-004	33.34404265	0.	-105.3944254	3.352946752e-005		
24	1.132075472e-004	33.62427912	0.	-106.8457936	3.279599828e-005		
25	1.181296144e-004	33.92489891	0.	-108.3710004	3.203362654e-005		
26	1.230516817e-004	34.24484979	0.	-109.9675748	3.123558112e-005		
27	1.27973749e-004	34.5829059	0.	-111.6326214	3.040500517e-005		
28	1.328958162e-004	34.9376148	0.	-113.3625782	2.952736016e-005		
29	1.378178835e-004	35.30725164	0.	-115.1529828	2.860055299e-005		
30	1.427399508e-004	35.68979109	0.	-116.9982789	2.762054302e-005		
31	1.47662018e-004	36.08290628	0.	-118.8916964	2.658495497e-005		
32	1.525840853e-004	36.48400023	0.	-120.825227	2.549360471e-005		

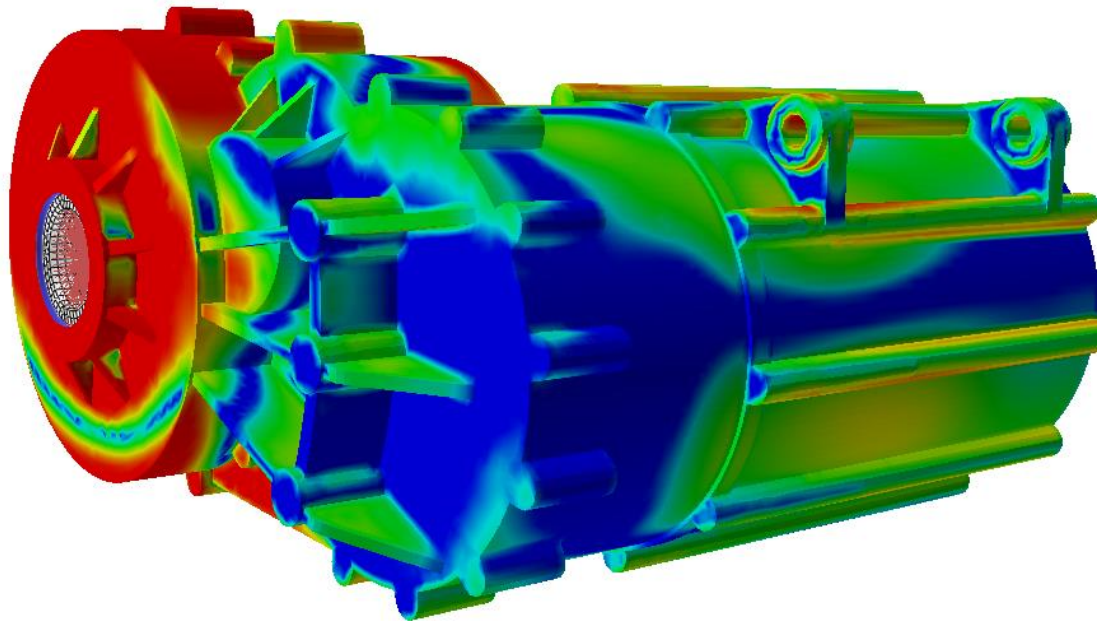
OK Cancel



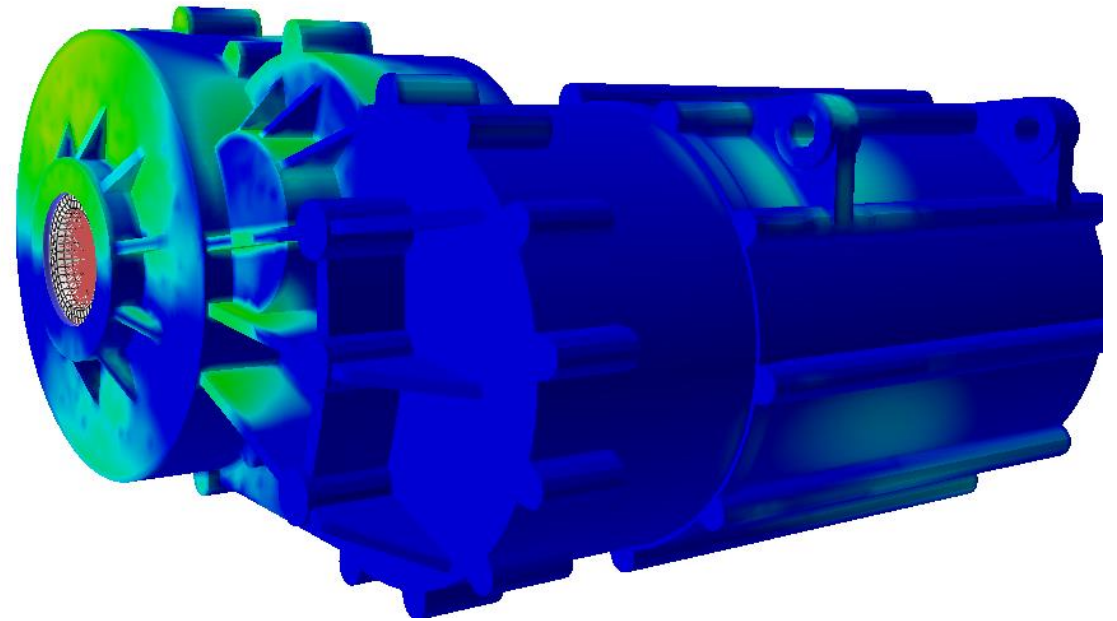
KISSsoft → Time dependent gear mesh and bearing forces

RecurDyn → Housing response

Equivalent radiated power (ERP)

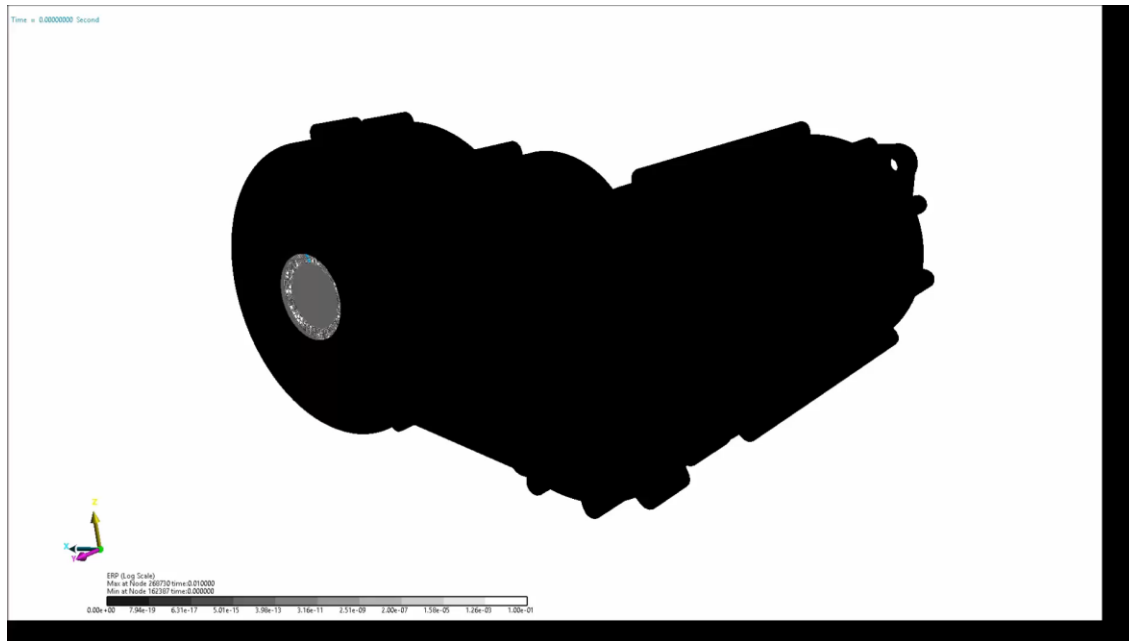


Before gear optimization

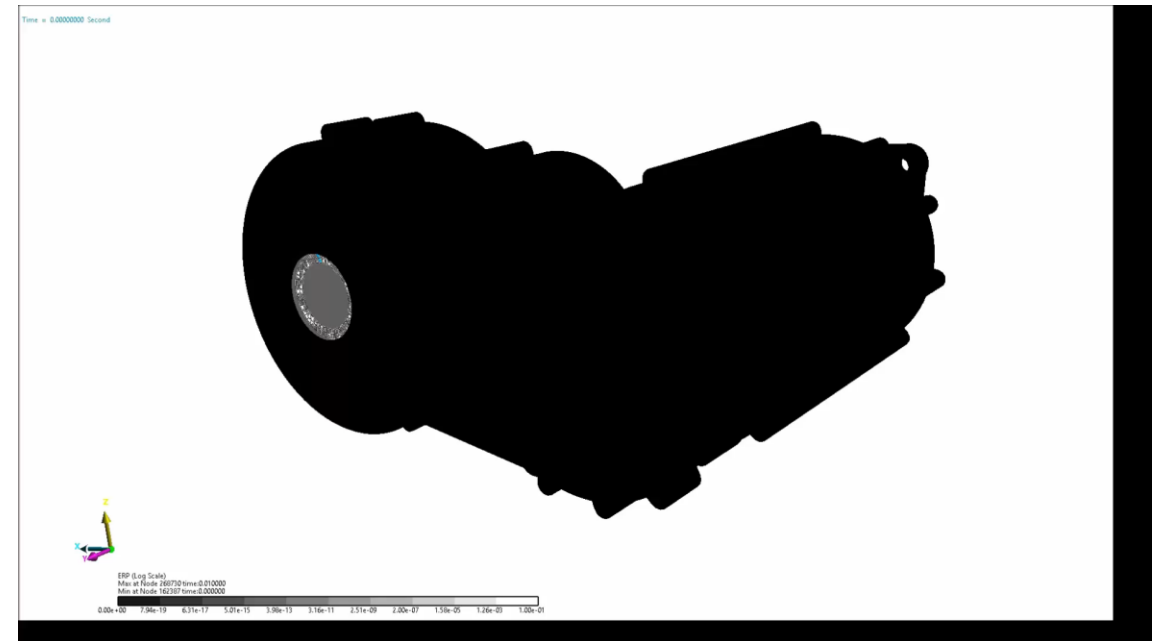


After gear optimization

Evaluation of structure borne noise (SBN)



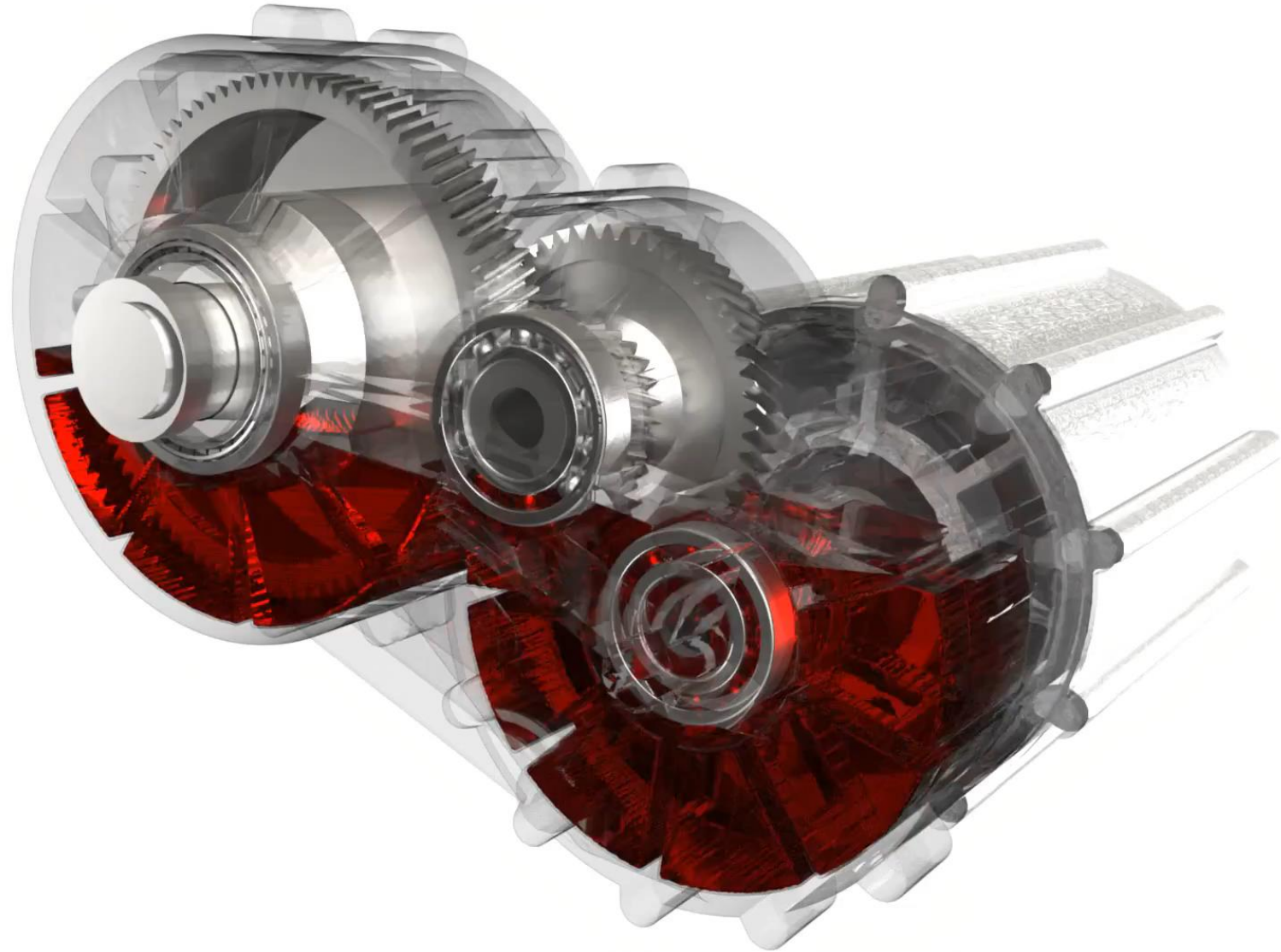
LCR design



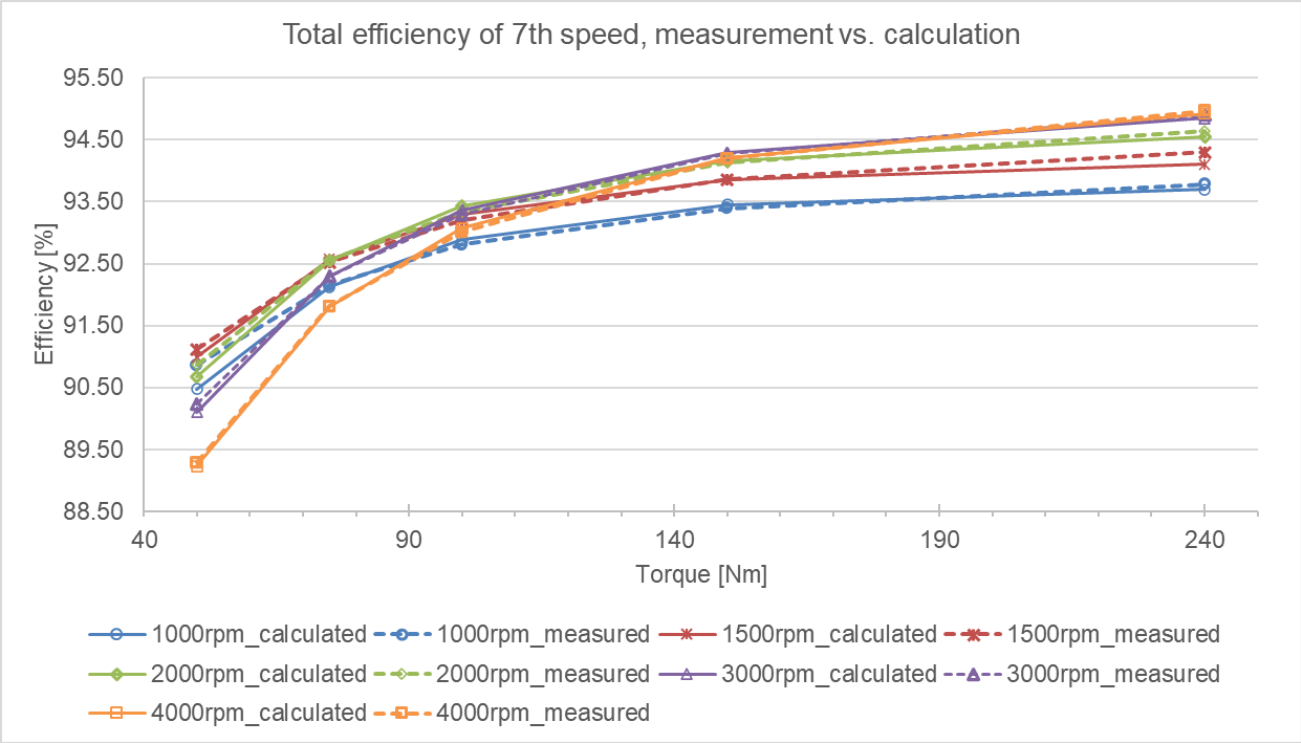
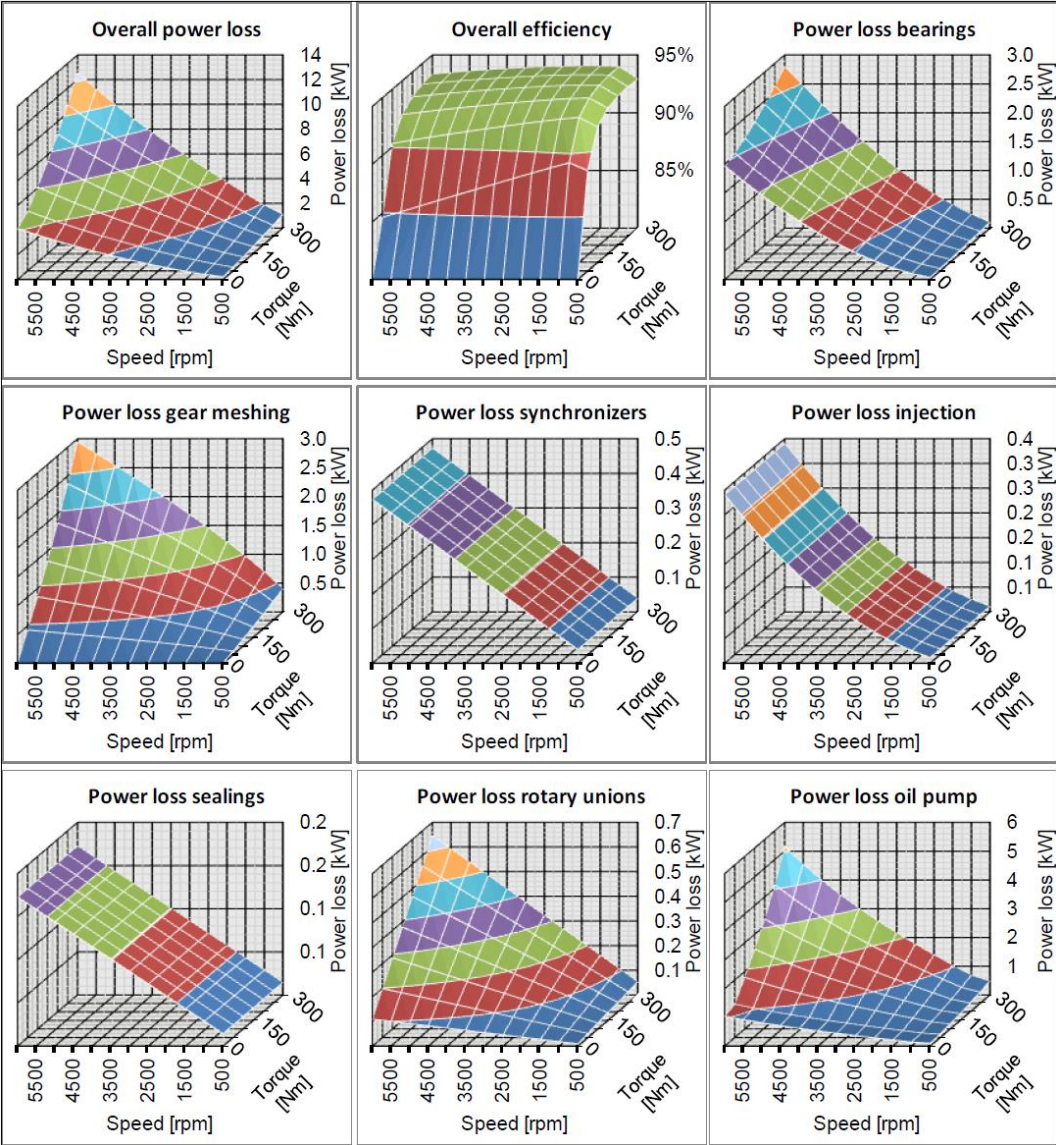
HCR design

Power Losses

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

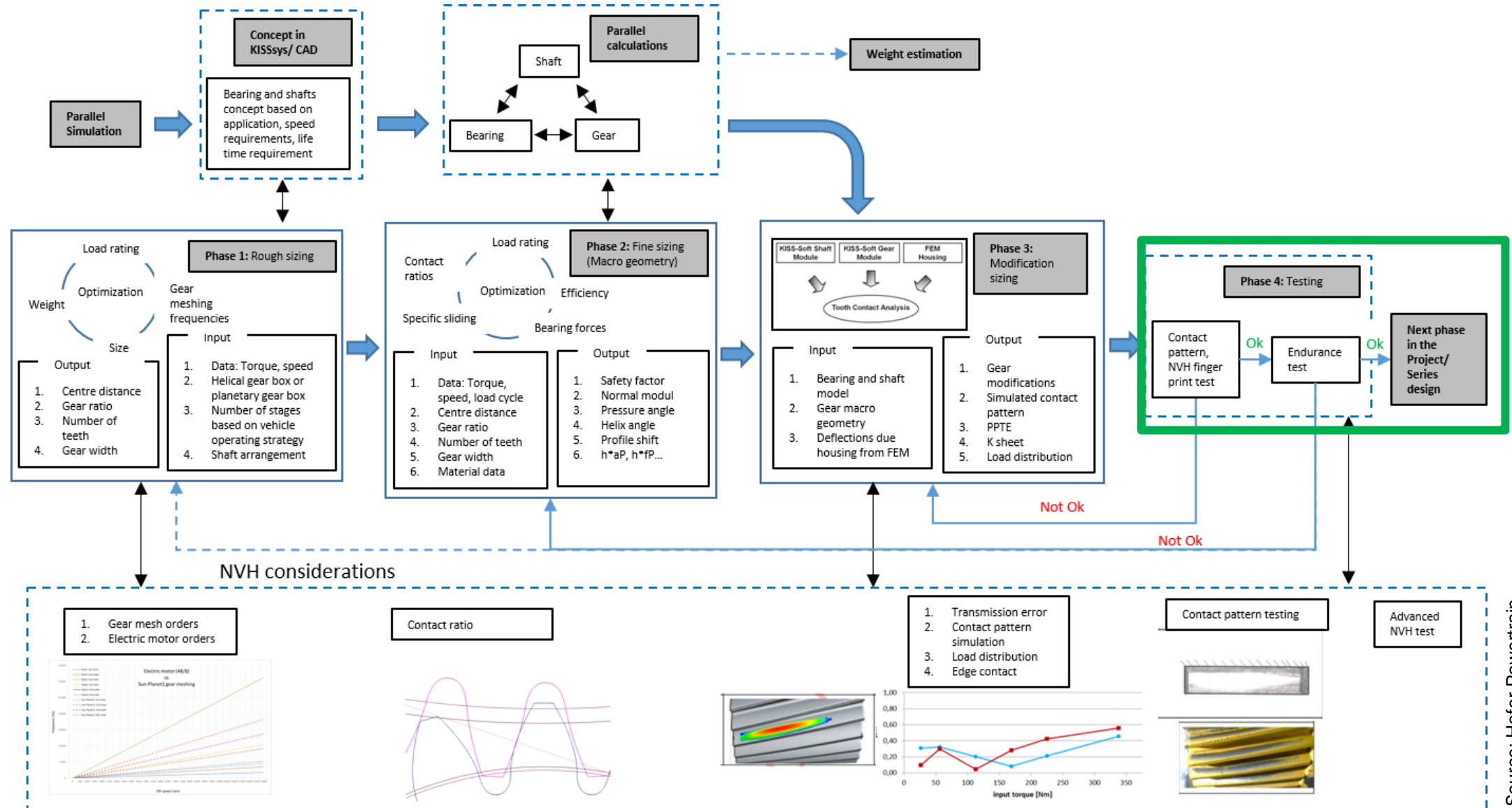


Power Losses



Manufacturing Deviations

Process Flow



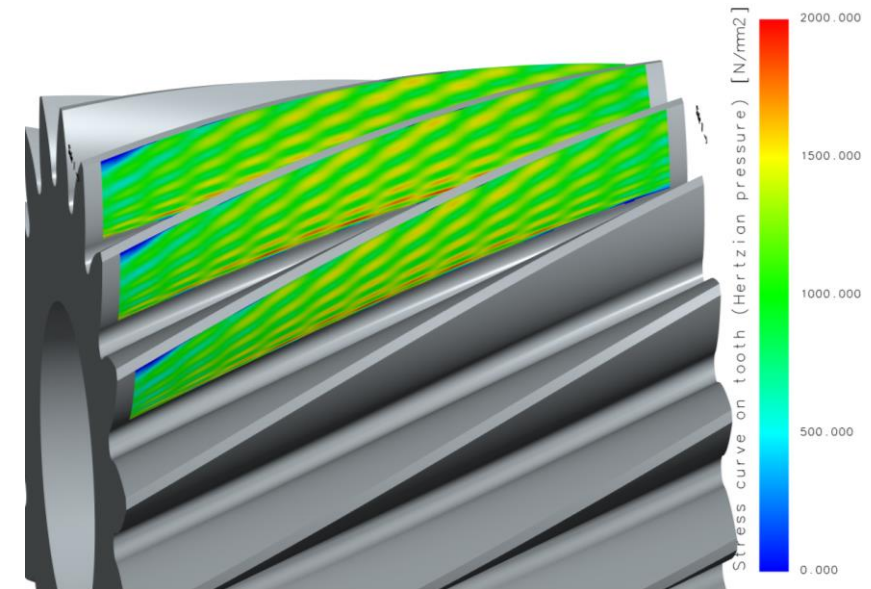
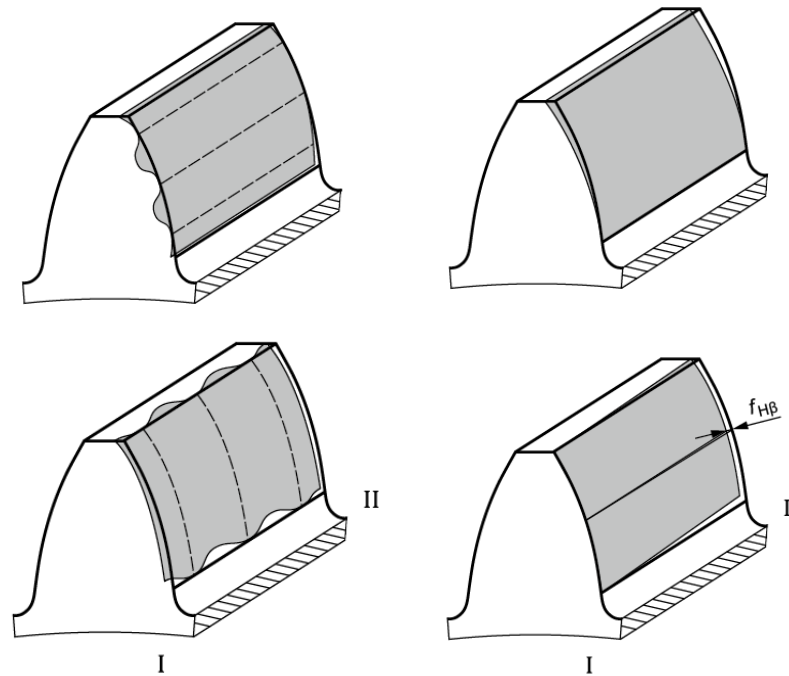
Source: Hofer Powertrain

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 - $f_{H\beta}$

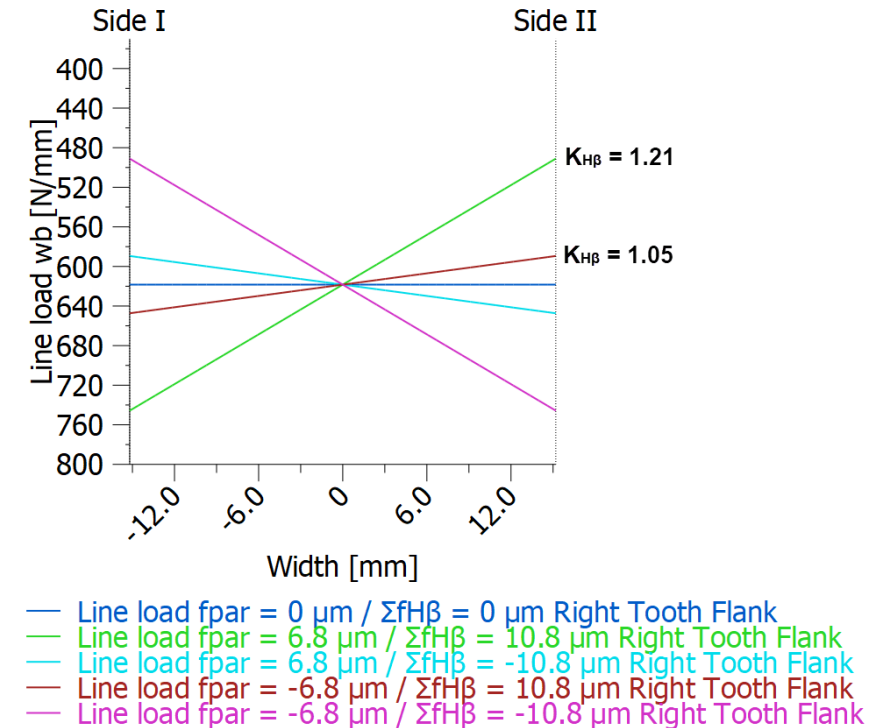
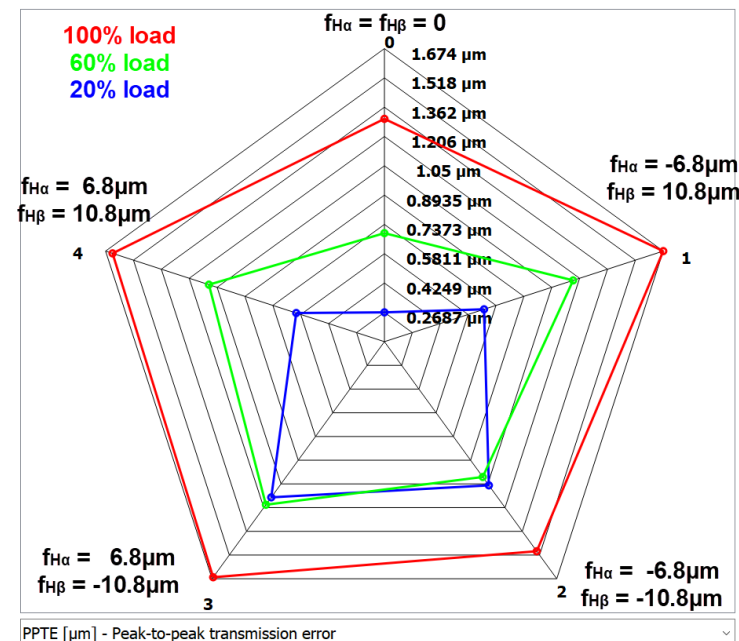


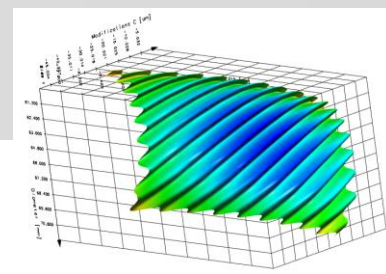
Manufacturing Deviations

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

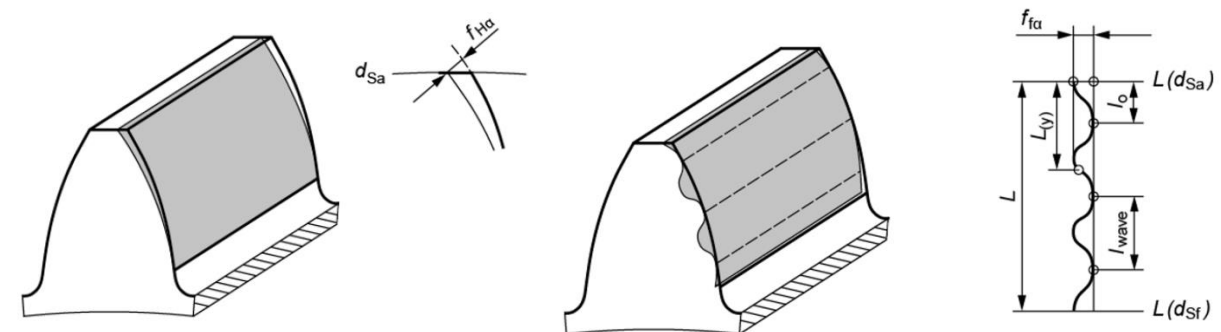
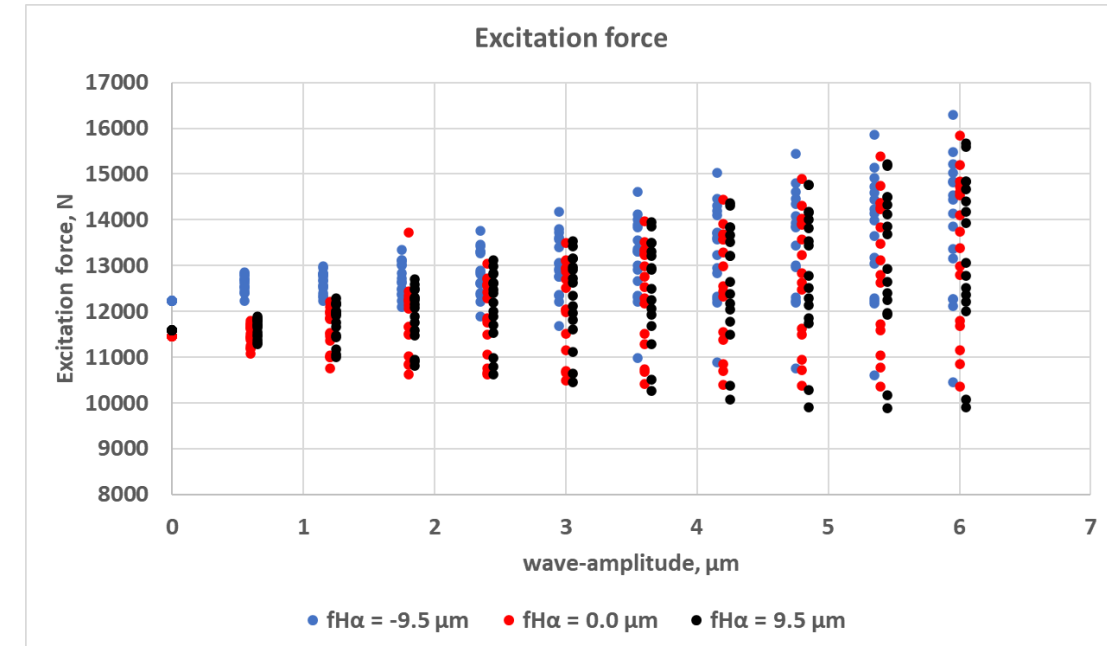
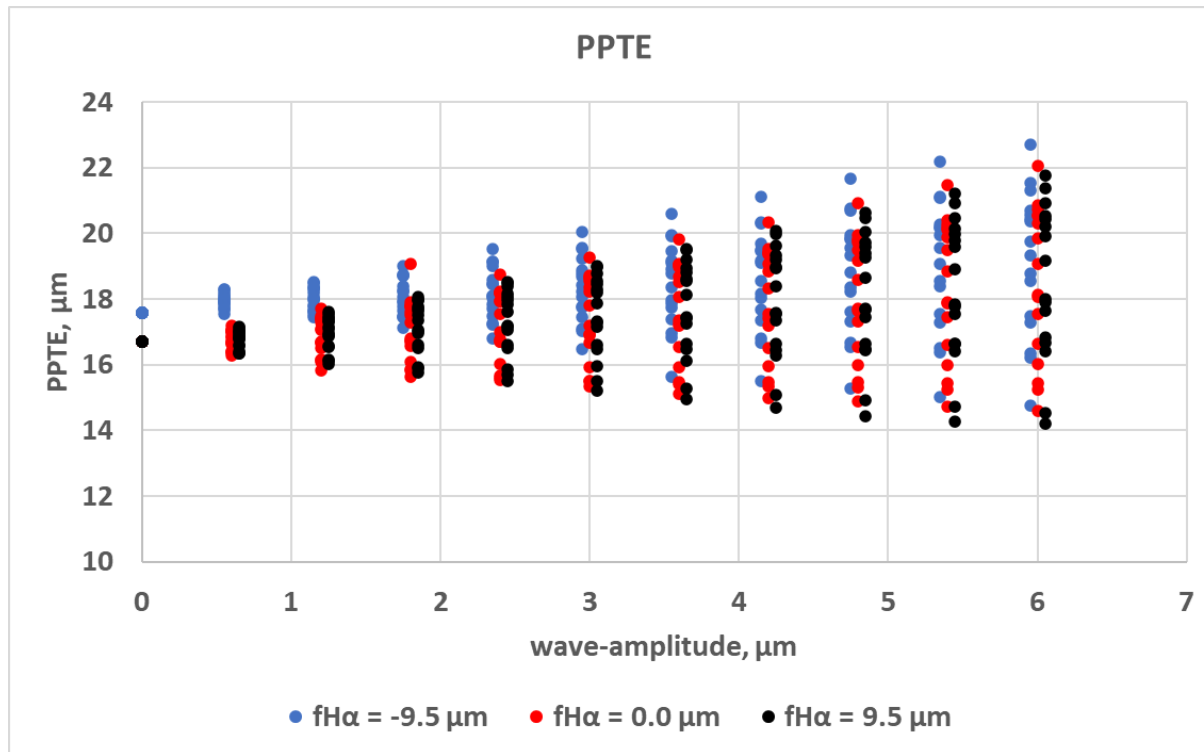
$f_{H\alpha}$ and $f_{H\beta}$ -> indication for the robustness against the tolerances cumulation

Modification sizing in KISSsoft





Effect of manufacturing deviations (waviness + profile slope deviation)



Conclusions

Conclusions

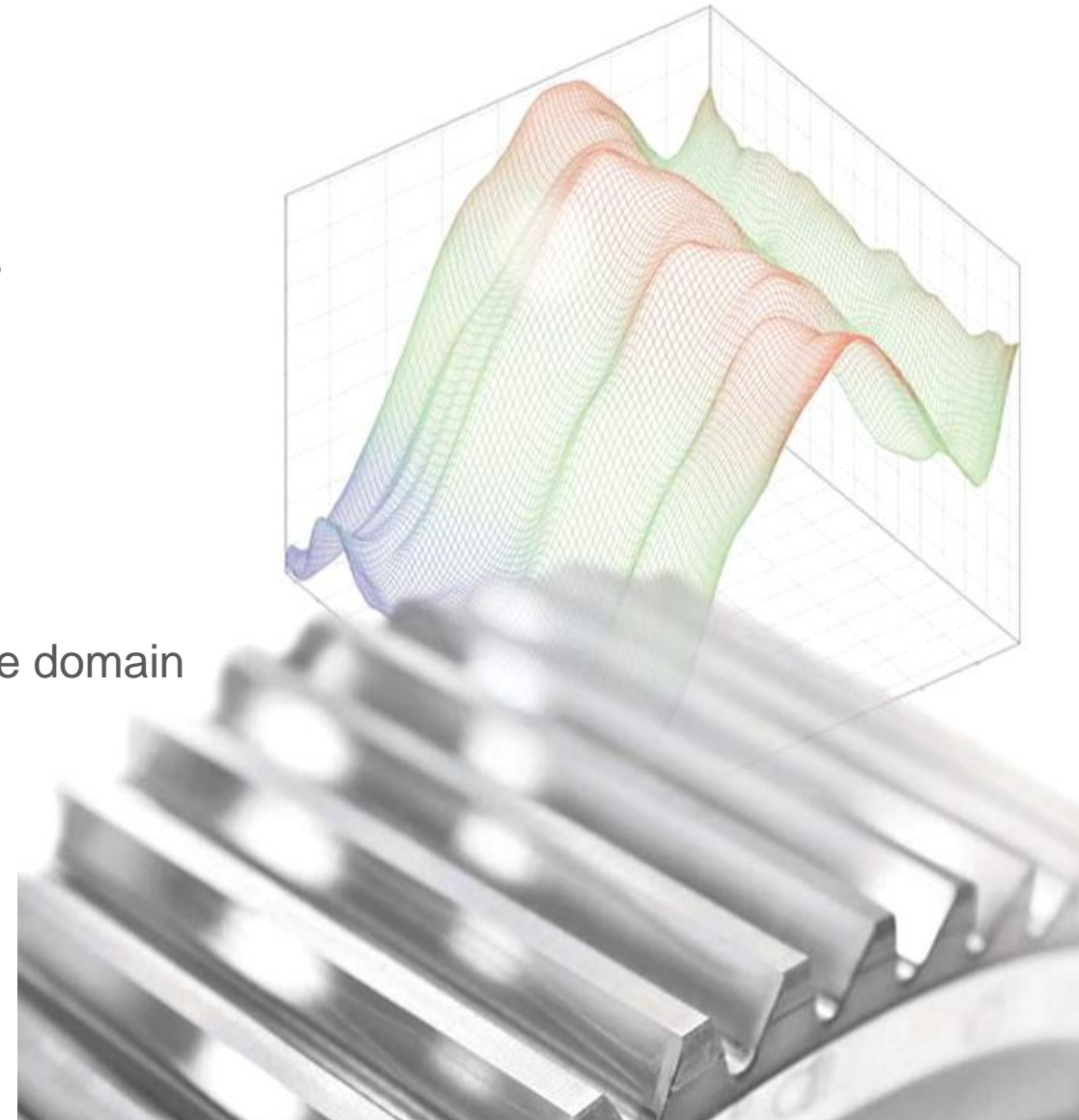
Different challenges in EV drive gearboxes

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

