

Weight Optimization of Transmission Housings under Static and Dynamic Loads

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Privately held and independent Finite Element Technology company since 1984 located in Stuttgart, Paris, and Tokyo.

Developing and marketing of the FE analysis software PERMAS with graphical user interface VisPER.

Unified software for thermo-mechanics, vibro-acoustics, and optimization.

High-level specialists with many years of experience form a powerful team. High performance solvers and functional innovations account for the team's success.



Passenger cars



Powertrain



Aerospace



Machine Tools



Commercial vehicles



Power tools

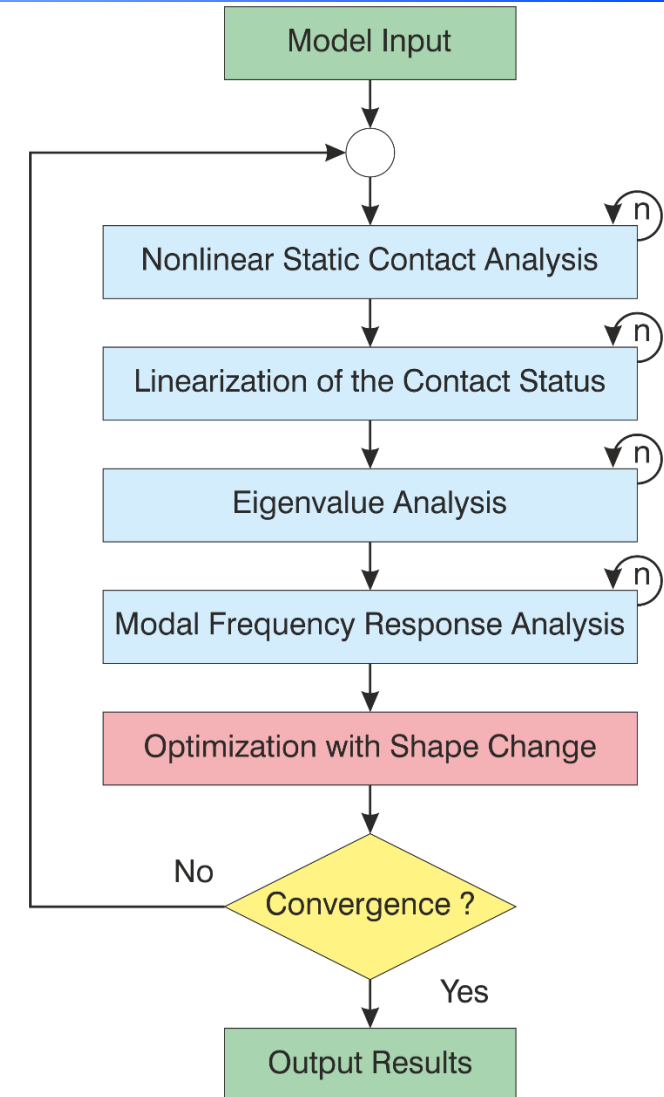


Ships

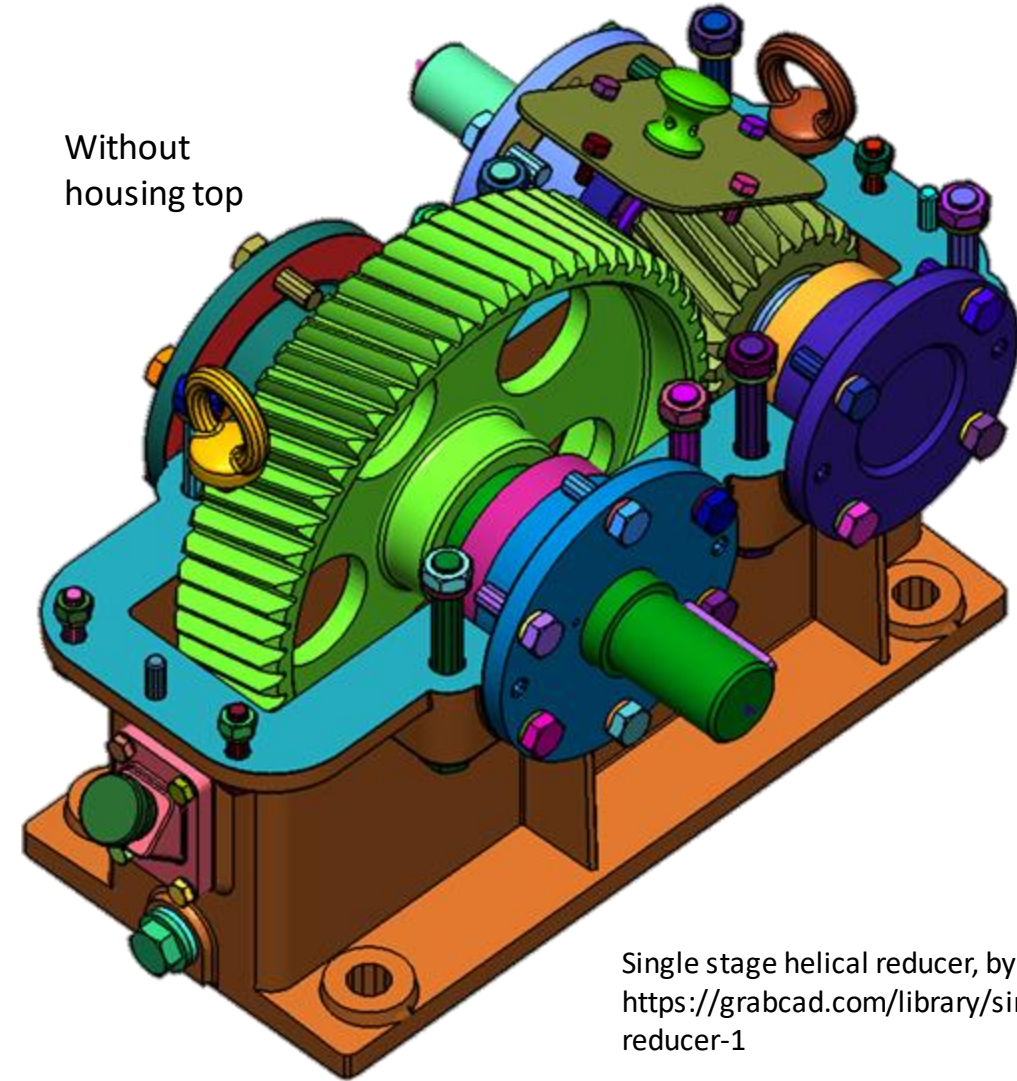
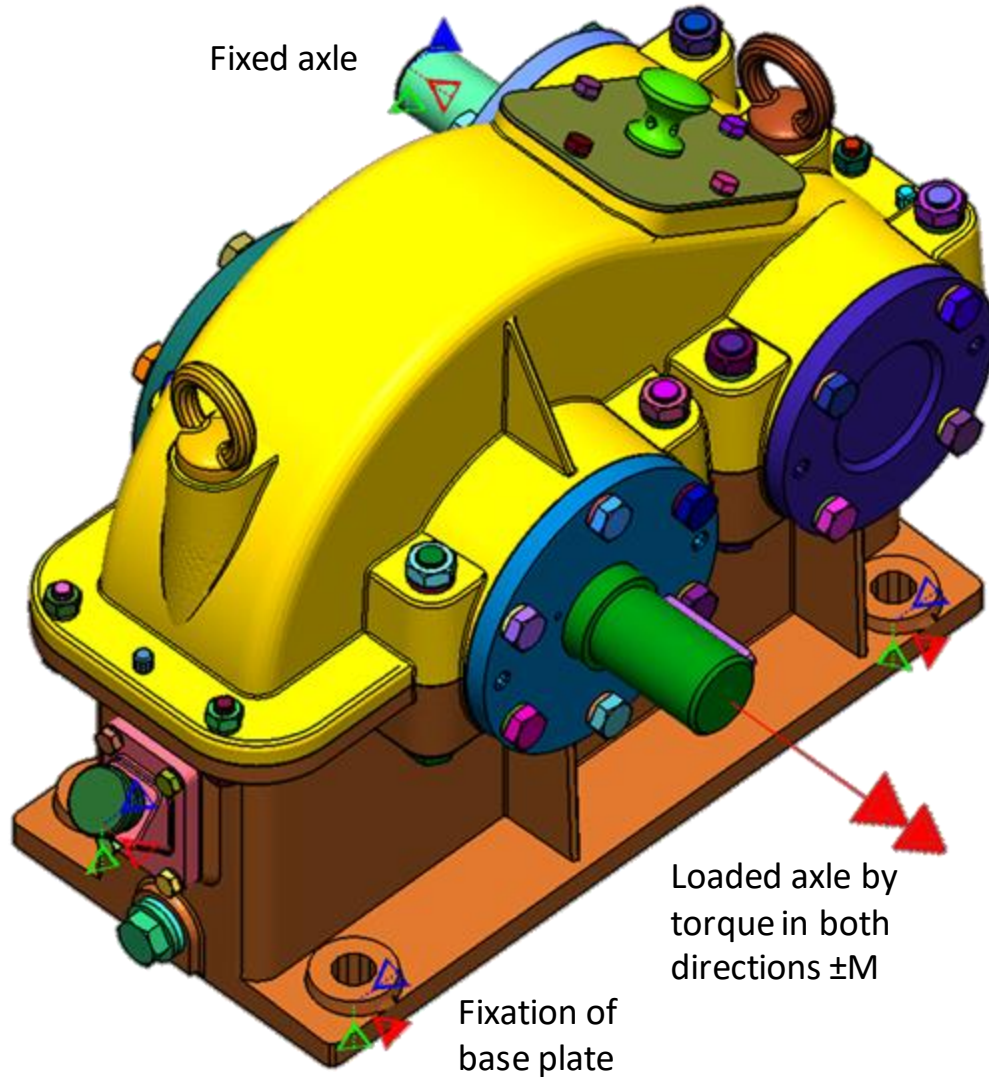
Introduction



- For freeform optimization with static load cases and contact, PERMAS is frequently used to reduce weight, e.g. of transmission housings.
 - Here, the optimization method used is OC (Optimality Criterion), which is best suited for freeform optimization of stress constraints and stress objectives.
 - PERMAS uses an enhanced method to allow weight objectives and additional sensitivity-based constraints.
- Assemblies like transmission housings are also facing dynamic load cases.
- To combine both static and dynamic load cases for freeform optimization, one optimization loop has to do several analysis steps (see attached graph)
- The following presentation will explain how this is performed in PERMAS.



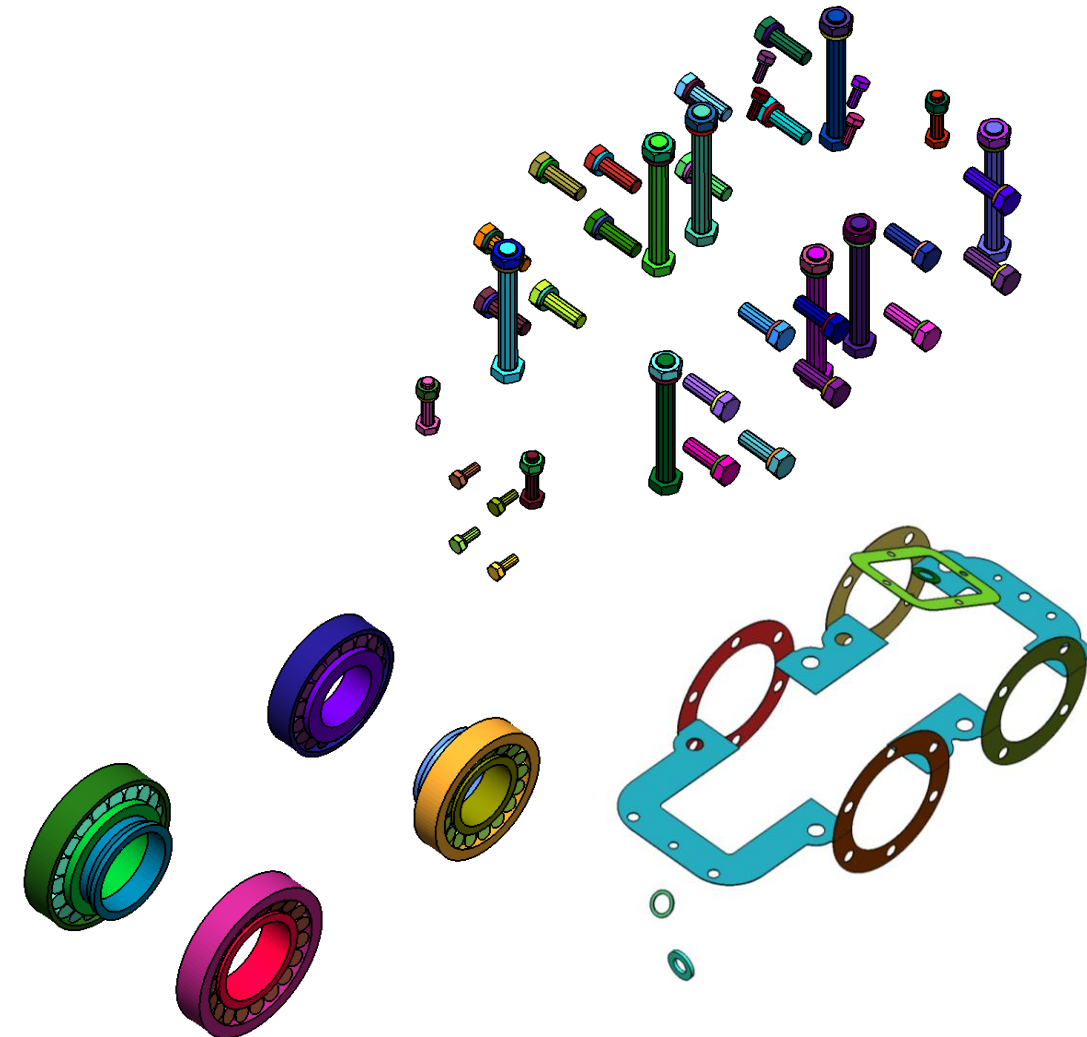
Full Solid Model of all Transmission Parts



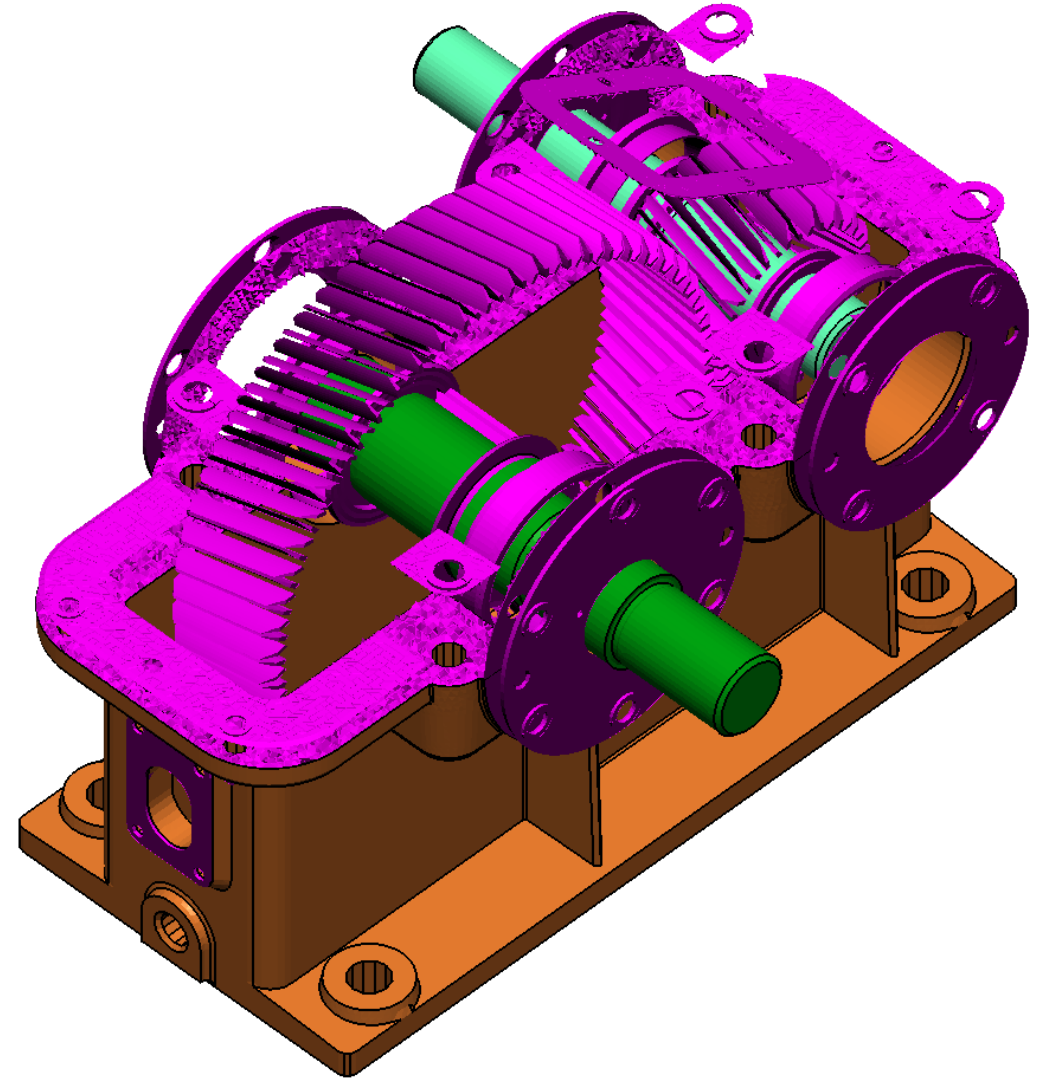
Single stage helical reducer, by Paweł Patej, source <https://grabcad.com/library/single-stage-helical-reducer-1>

Bolts, Bearings, Seals

- There are **39 bolts** M6, M8, M10, M12.
 - M8 and M12 bolts with nuts.
 - All bolts with washers and pretension.
 - Pretension force depends on bolt size.
- All **4 bearings** are fully modeled by solid elements
 - Inner and outer rings as well as all rollers.
 - Contact is taken into account between rollers outer races.
- All **seals** are defined with linear material behavior.
 - Including material damping.



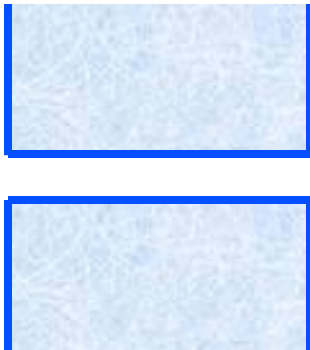
- Contacts are between
 - all bolt heads and the related bodies
 - all nuts and the related bodies
 - all contacting bodies,
 - rollers and outer races of bearings,
 - all bodies sitting on the axles,
 - gear wheels,
 - axle caps and housing parts,
 - bottom and top housing parts.
- All contacts are shown by purple color in the attached picture.



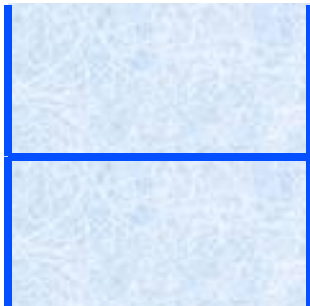
Linearization of Contact States

Contact states after
contact analysis

Open gap



Closed gap,
no slipping

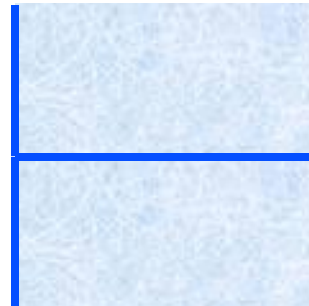


Contact states
during vibration

Open gap,
no closing

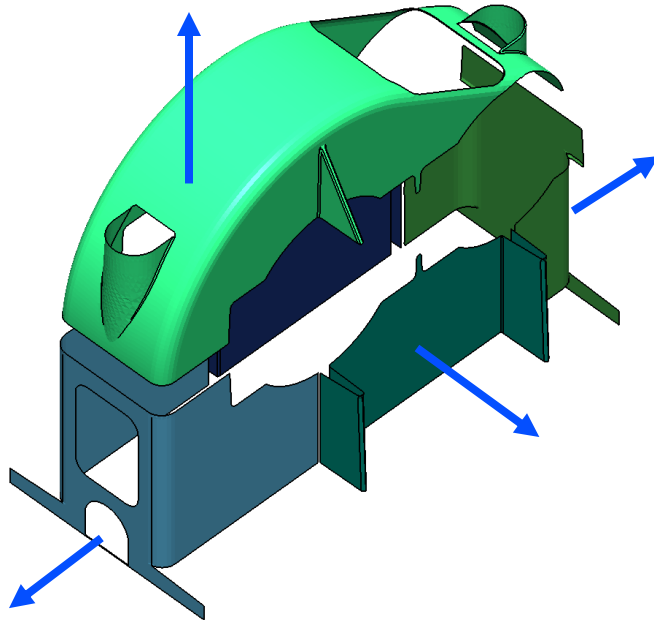


Closed gap,
no opening,
no slipping

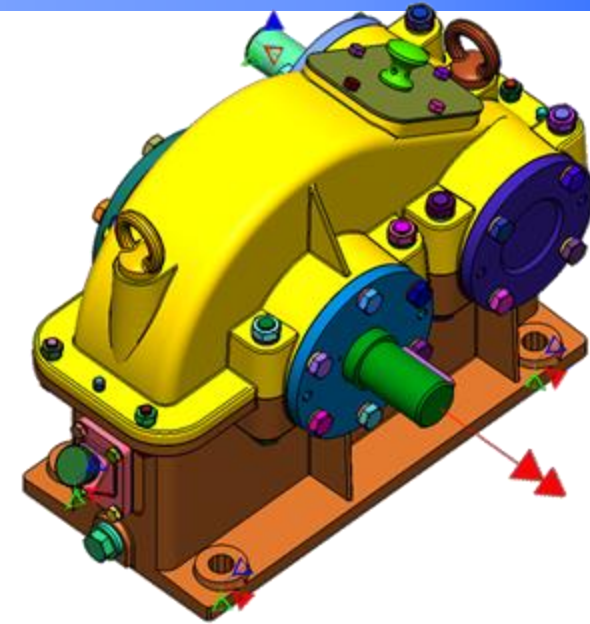


- All active contacts are coupled after contact analysis (except between the wheels).
- The coupling will be different for the two load cases.
- Other linearization strategies are also available (as with pressure dependency).

Optimized Surface and Loading

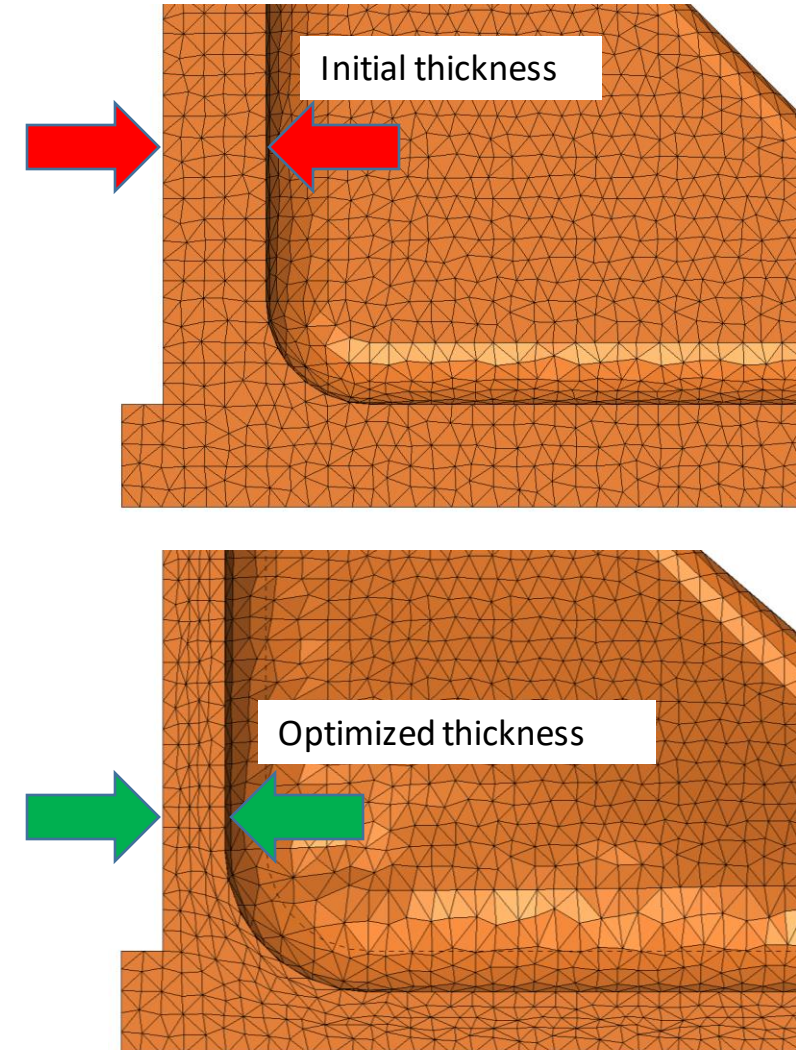


- The attached picture shows the optimized surfaces.
- The different colors indicate different conditions for the release direction of these surface parts.
- Initial wall thicknesses:
Upper part 7mm, Lower part 8mm
- Range for thickness change:
-4mm to +4mm (-1mm to +1mm for ribs)



- There are two torque loading cases of 870 Nm but in opposite direction.
- The stress due to bolt pretension only is seen as not critical. So, only the stress differences between torque and pretension are used for optimization.
- In dynamics, the contact forces between the wheels are used as excitation.

- Freeform optimization is a non-parametric optimization method based on optimality criteria best suited for stress optimization of freeform surfaces.
- The coordinates of the mesh are changed but the topology of the mesh remains unchanged.
- The weight is taken as objective.
- Additional constraints are:
 - Stress constraints for the principal stresses,
 - Sound radiation constraints,
 - Release directions (for castability).



Sound Radiation - Theory



Sound Radiation Power P is defined as:

$$P = \rho c \sigma \int_A v_n^2 dA [W]$$

with

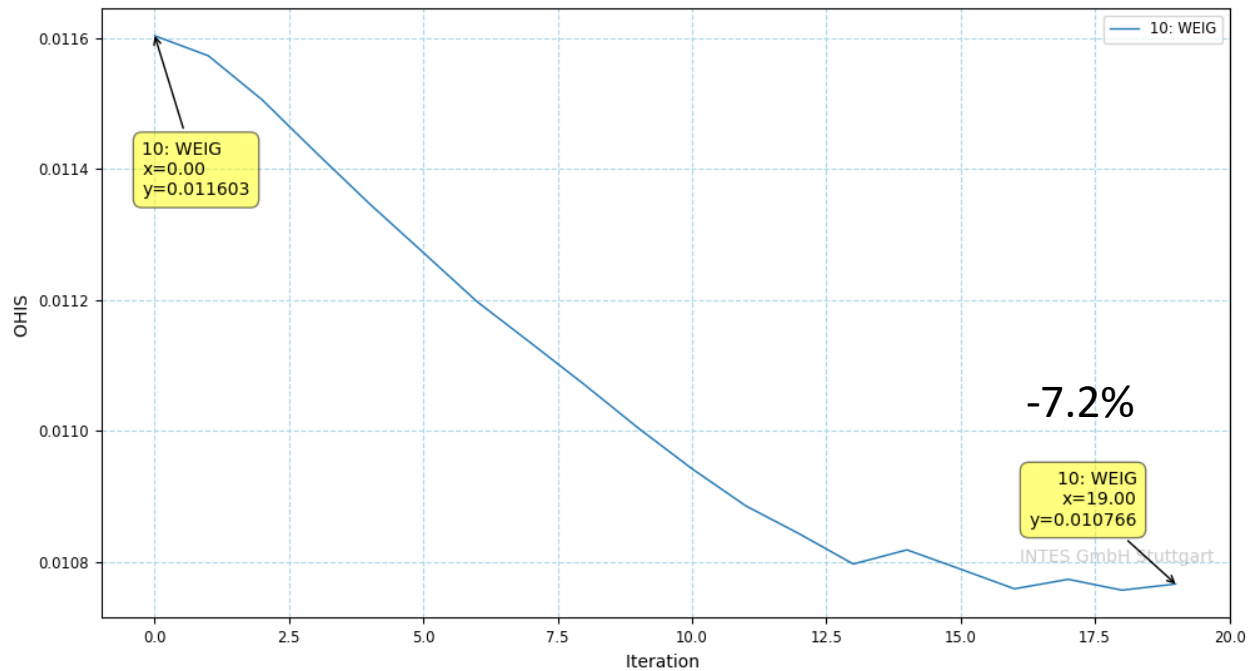
- ρ Density of the media (like air with 1.2041 kg/m³)
- c Speed of sound of media (like air with 343.2 m/s)
- σ Radiation efficiency which indicates how much less power an object radiates than a rigid piston with the same area
- v_n Component of the velocity normal to the vibrating surface
- A Area of radiating surface

Setting the proportionality factor $\rho c \sigma = 1 [kg s/m^2]$

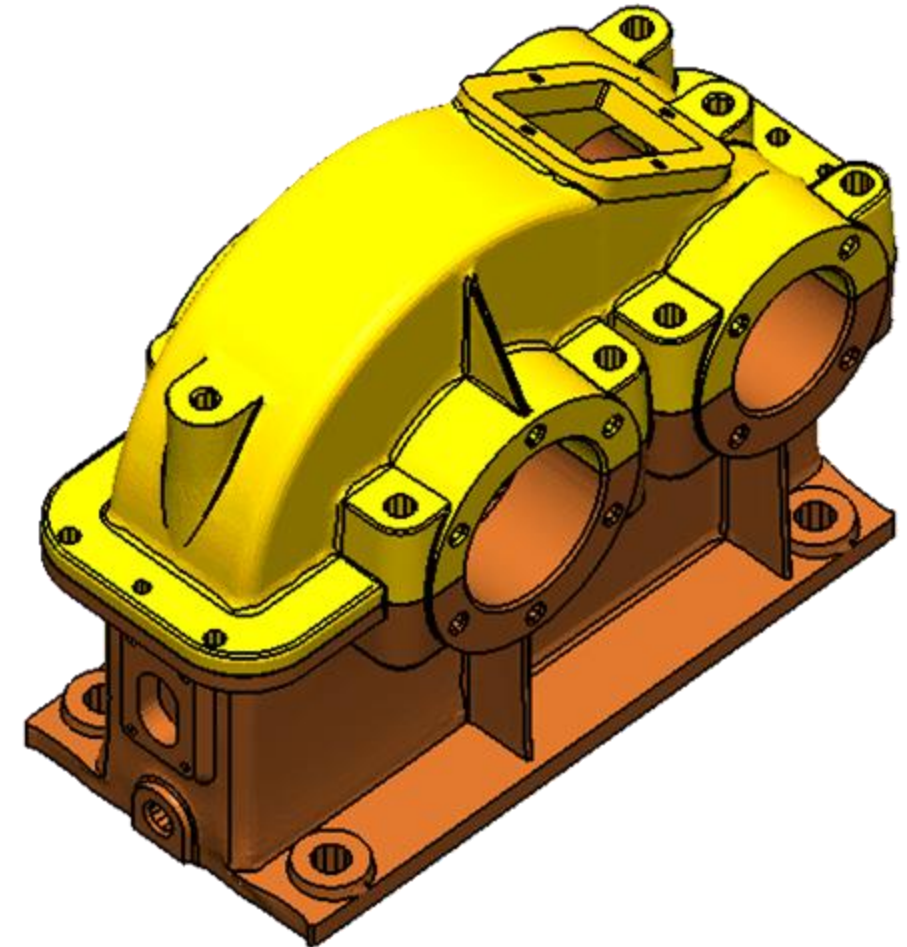
Sound Radiation Power P' is calculated as:

$$P' = \int_A v_n^2 dA [W]$$

Objective: Minimum Weight



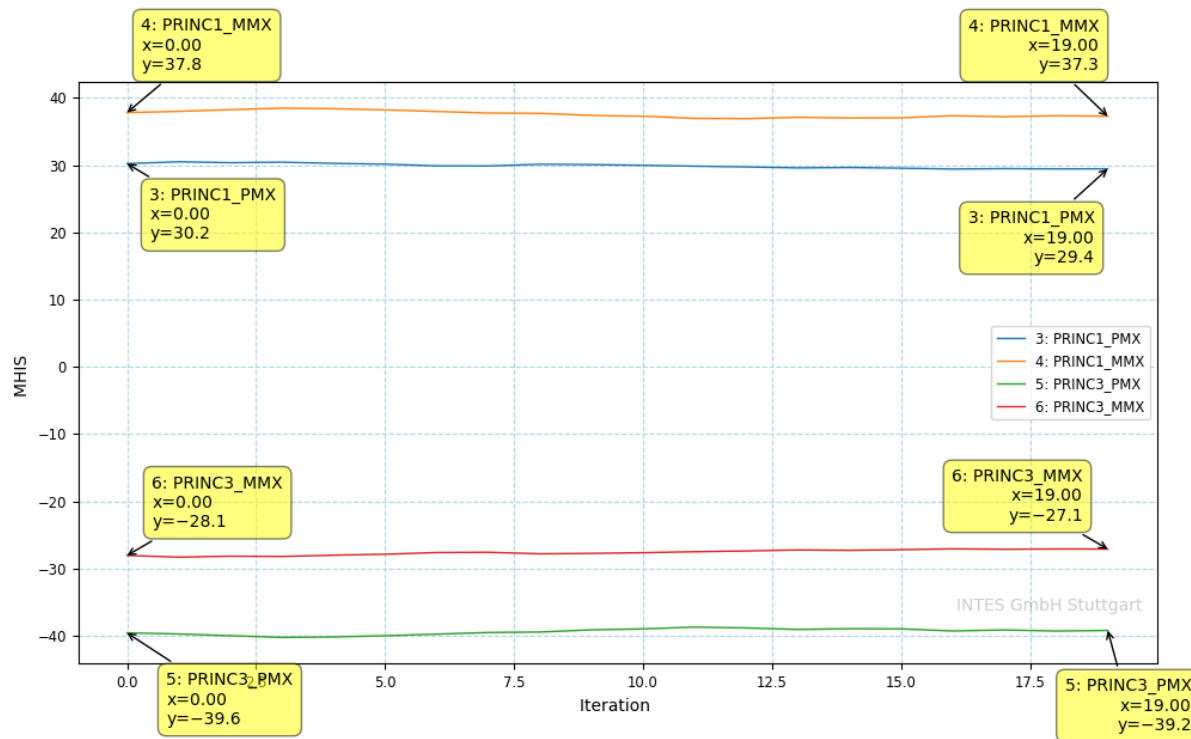
Geometry change (magnification factor 1.)



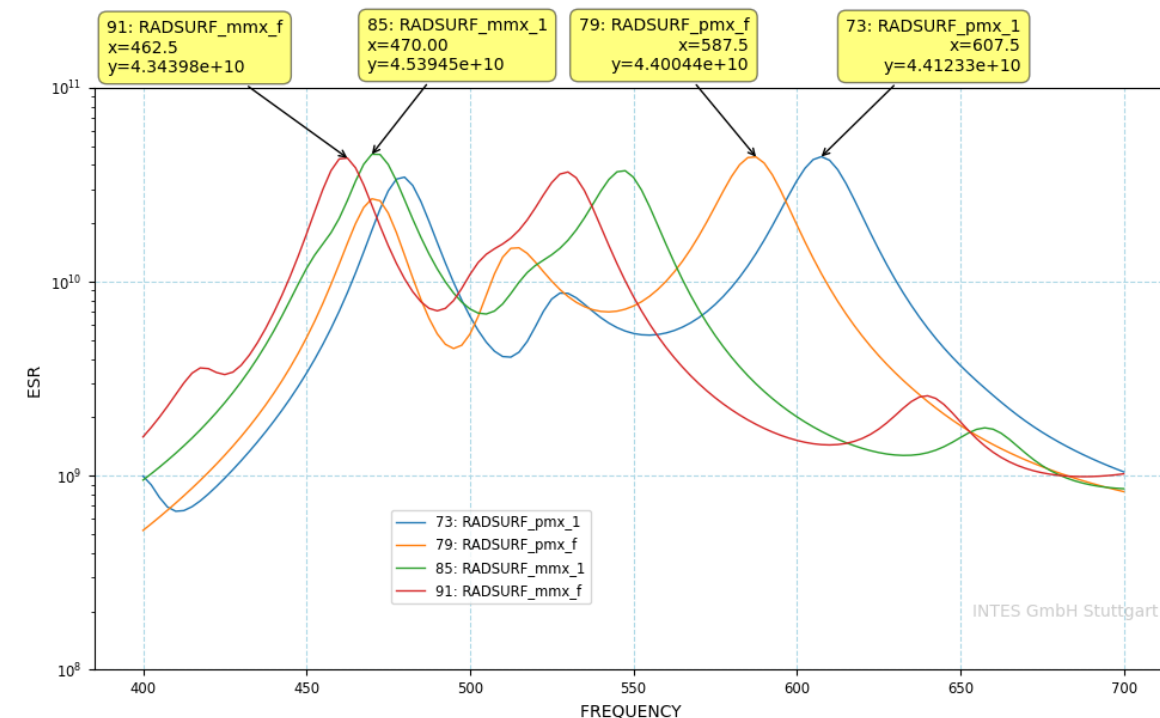
Constraint Conditions for Principal Stresses and Sound Radiation



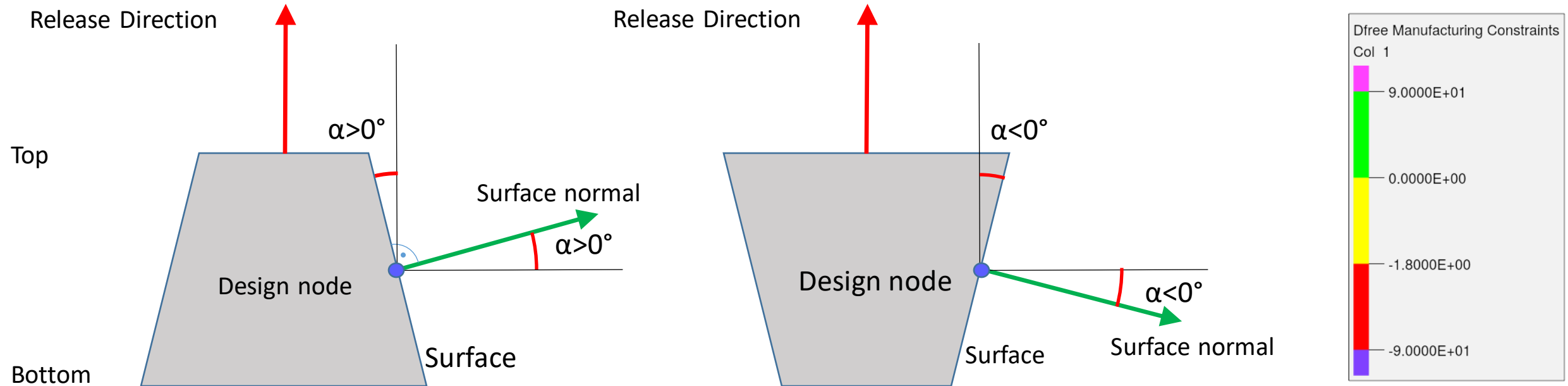
- Principal stresses are initially within limits and remain there during the optimization
- Sound radiation for negative torque is initially violated. After optimization, both sound radiation limits are fulfilled.



Stress limits	+M	-M
Tension: SIG1	45.0 MPa	45.0 MPa
Compression: SIG3	-55.0 MPa	-55.0 MPa
Sound radiation	4.4E10 W	4.4E10 W



What is about Release Direction ?

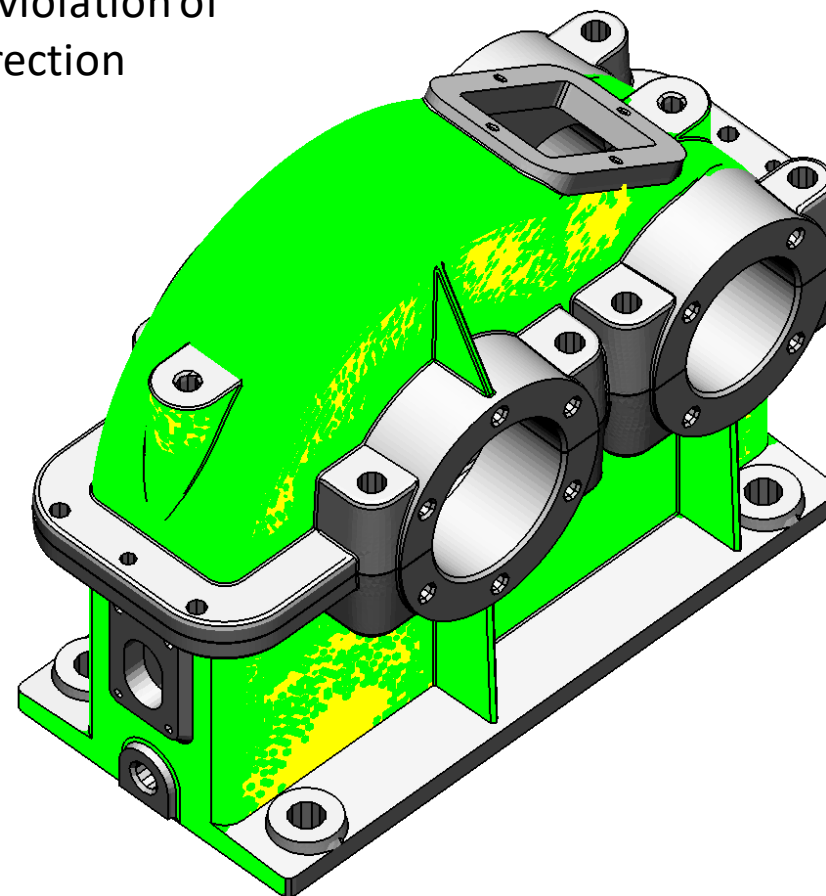
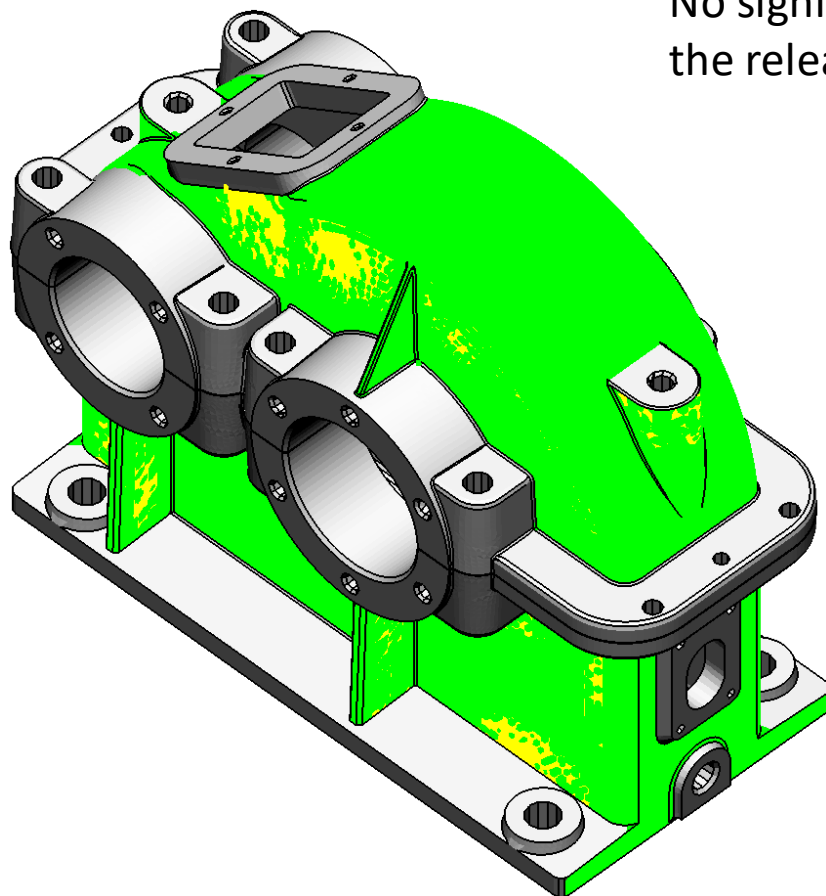
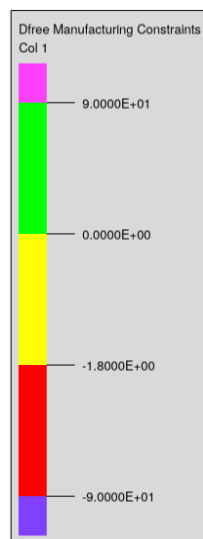


The following result is available:

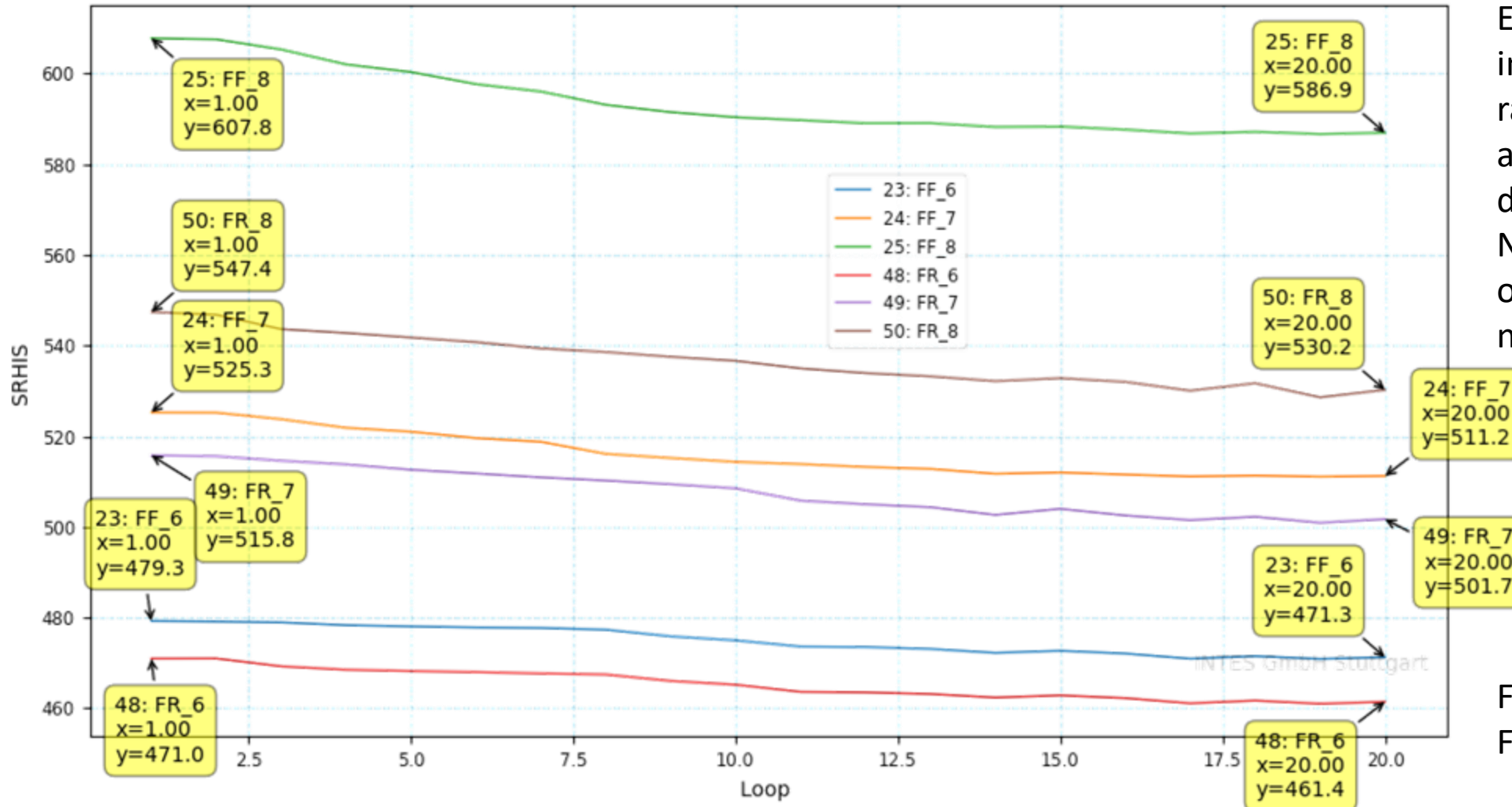
- The angle α between 90° and -90° , where positive values are good and negative values are bad.
- Small negative values may occur due the setting of an acceptable violation of design constraints (default is 2%).
- Therefore, a special legend may be used to allow for a fast overview on release direction results (see above on the right).

Release Direction

No significant violation of
the release direction



Recorded Eigenfrequencies

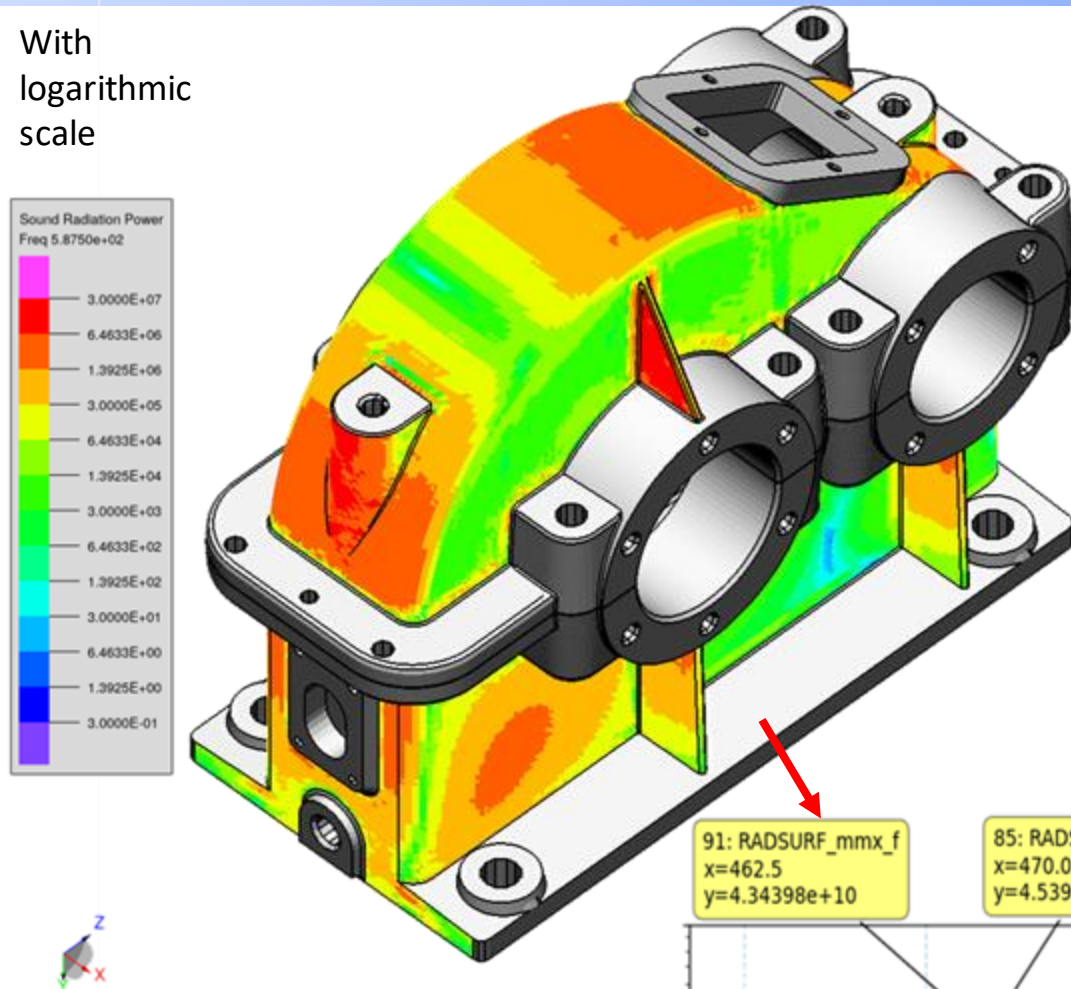


Eigenfrequency changes in the relevant frequency range 400 to 700 Hz automatically recorded during the optimization. No additional optimization constraint necessary.

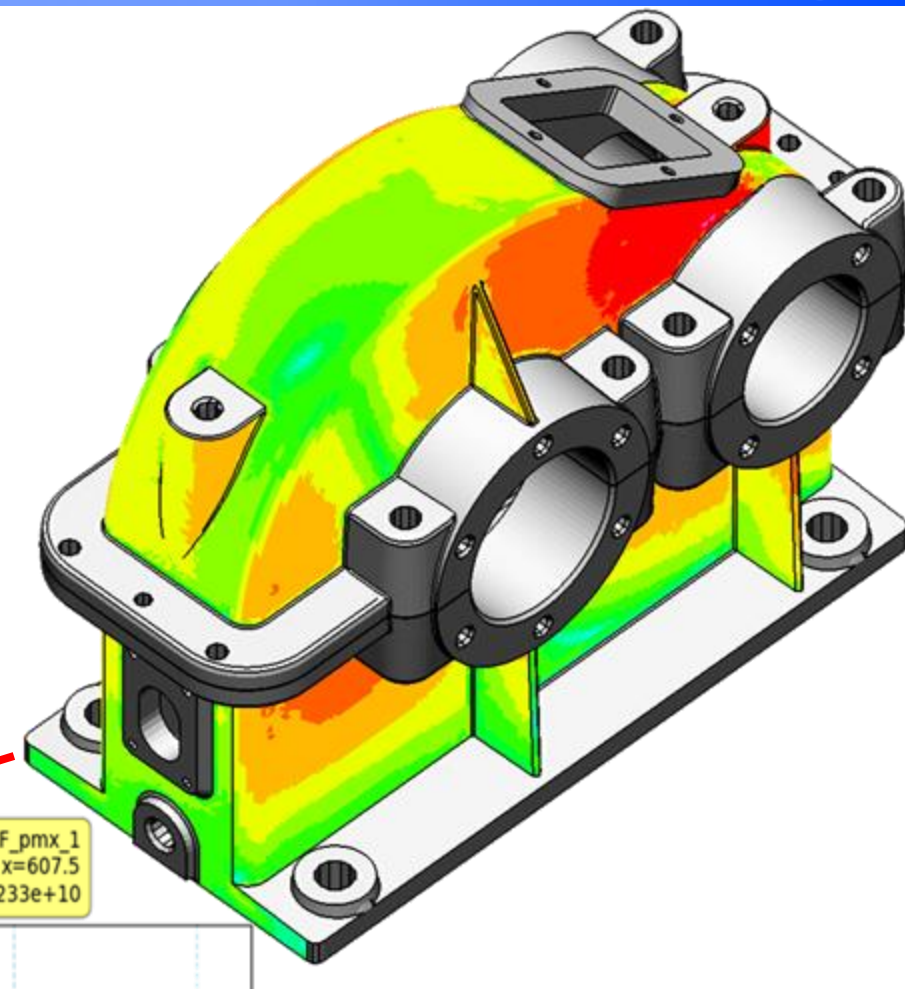
FF: positive torque
FR: negative torque

Sound radiation

With
logarithmic
scale

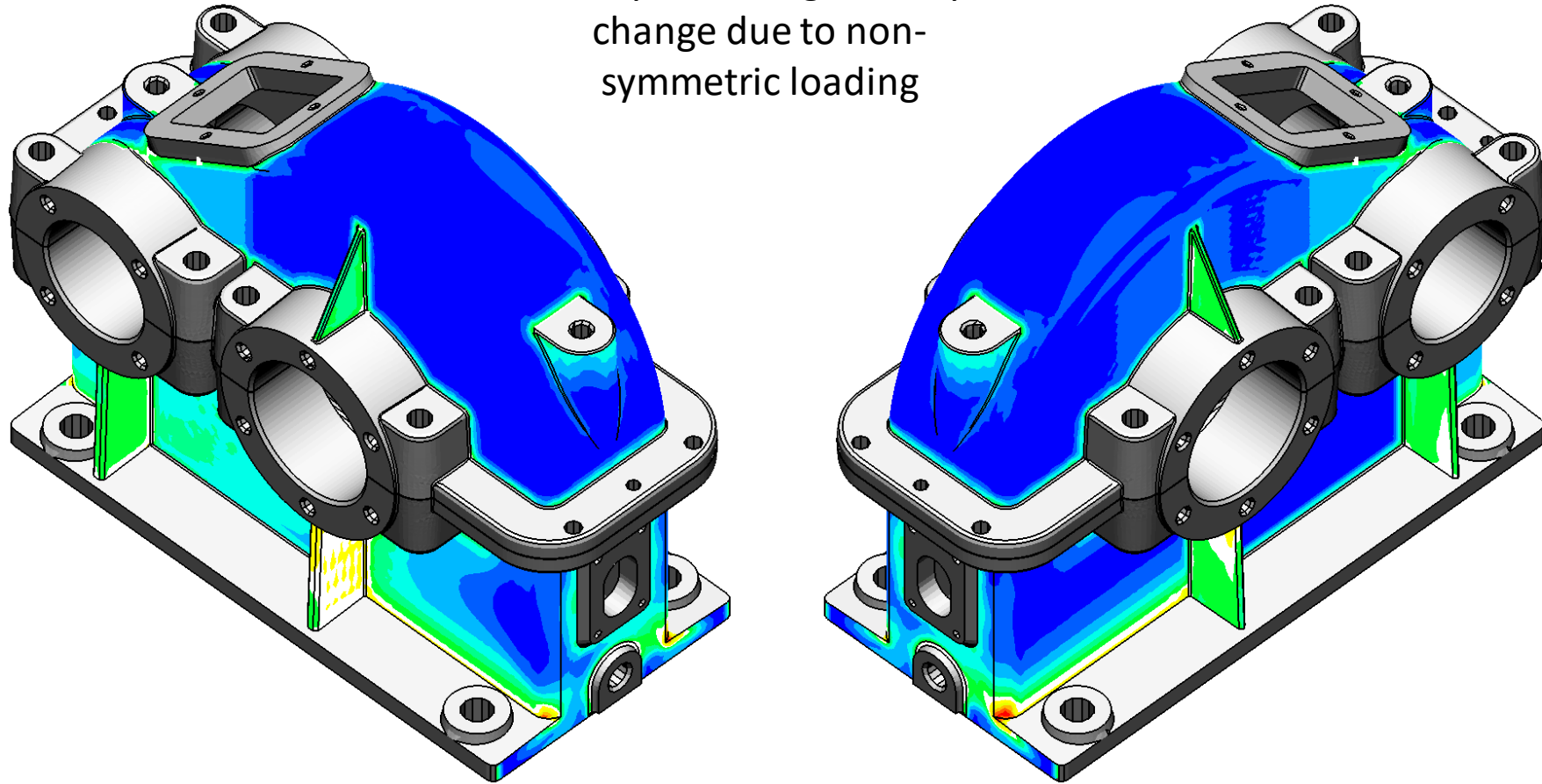
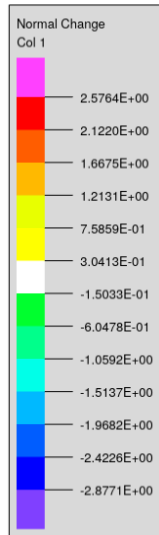


Both pictures at the
frequency
with the highest
radiation
after optimization



Thickness Change

No symmetric geometry
change due to non-
symmetric loading



Green and blue indicate a thickness reduction –
Yellow and red indicate a thickness increase

- The model size is:
 - 1.9 Million elements (mainly TET10, HEXE8)
 - 2.5 Million nodes
- The run time on a 28 cores computer is 16.9 h from start to end of job.
- With 20 optimization loops, there are on average 50.7 m for each loop.
- Each loop covers 2 contact analyses, 2 eigenvalue analyses, 2 frequency response analyses, and 1 optimization step.

Summary



- The model shown in this paper has been assembled with housing, gearwheels and **all parts using solid elements**.
- Its freeform optimization comprises **contact** analysis, **eigenvalue** analysis, and **frequency** response analysis each two times for a positive and a negative torque.
- The transition from a nonlinear contact analysis to a linear dynamic analysis has been achieved by a suitable **linearization of the contact status**.
- The optimization of the weight is controlled by **principal stress constraints** and **sound radiation constraints** as well as **release directions**.
- The history of the eigenfrequencies is recorded without setting additional frequency constraints for the optimization.
- The optimization and all related analyses are executed in **one single computation** run. PERMAS has been used as analysis and optimization tool (see www.intes.de).

