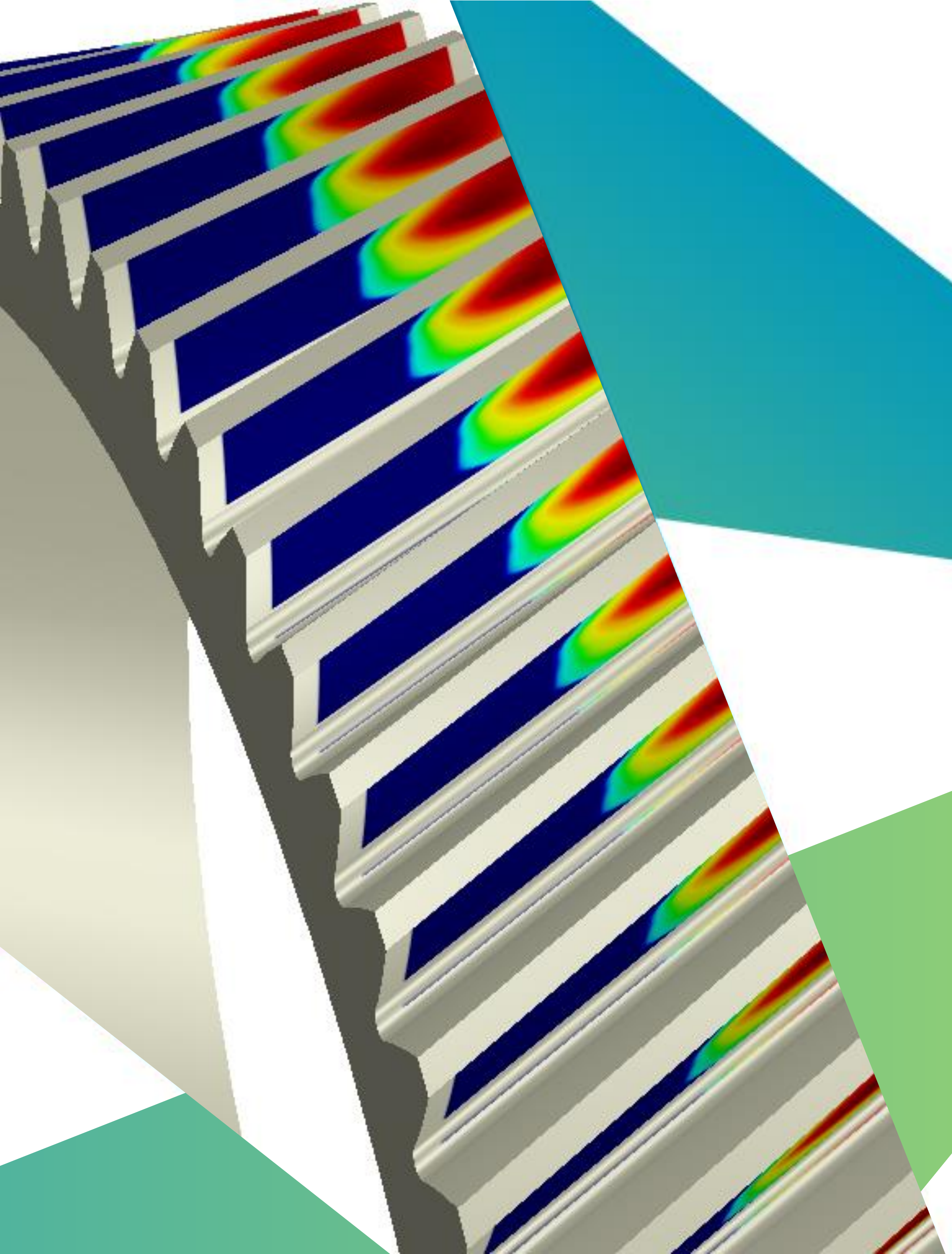

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Structural optimisation of gearbox housings for minimum gear mesh misalignment

Annabel Shahaj, Riza Jamaluddin, Stewart Hughes, Hexagon, Manufacturing Intelligence Division

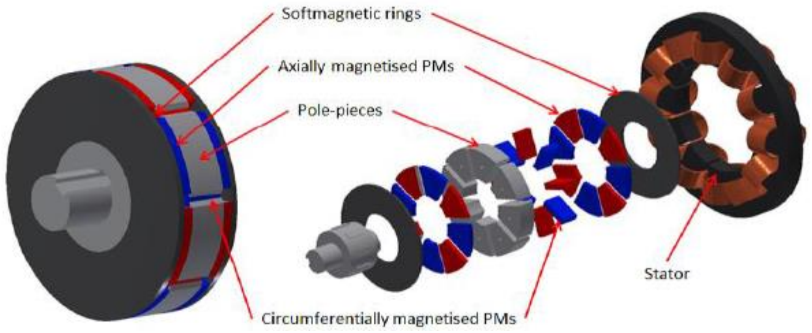
Kyle Grubb, GRM Consulting

Agenda

- Introduction to the EDISON project
- Industry challenges
- Transmission design approach
- Gearbox housing structural optimisation
- Example case study
- Summary and conclusion

The EDISON Project

Co-funded by Innovate UK, the UK's innovation agency



Project partners

- Romax Technology (lead),
- Jaguar Land Rover,
- Dassault Systemes UK,
- GRM Consulting,
- National Physical Laboratory,
- University of Sheffield

Duration

- 3.25 years (April 2018 - June 2021)

Overview

The project will develop:

Novel ferrite magnet motor technology for a passenger vehicle application

Electromechanical analysis toolset enabling effective system optimisation and integration

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Industry challenges

Sustainable products

- The automotive industry is currently seeing more and more pressure to produce products that are sustainable which means being cost effective, lightweight and robust.
- Lightweight structures are inherently more flexible and this introduces additional challenge to design engineers.
- The deflection of the complete drive system leads to misalignment of the gear mesh that could compromise the performance of the gears.
- Such misalignment can be corrected by gear microgeometry corrections which generally result in satisfactory gear design.
- However, corrections by gear microgeometry alone is inadequate when the misalignment is very high.
- An approach that uses structural optimisation in conjunction with a CAE lead gearbox design process should be considered, as it serves many advantages to the gear designer.

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Transmission Design Approach

Traditional approach

Gearbox internals

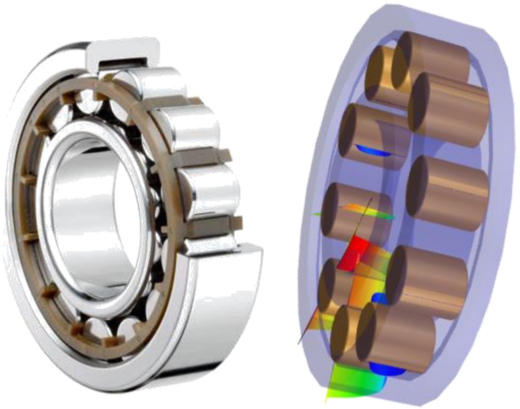
Gearbox housing design

System static deflection

Gear microgeometry corrections

Procurement

- Design specifications with requirements and targets
- Sizing and design of gearbox internal components
  - Gears
  - Bearings
  - Shafts
  - Spline
  - ….etc



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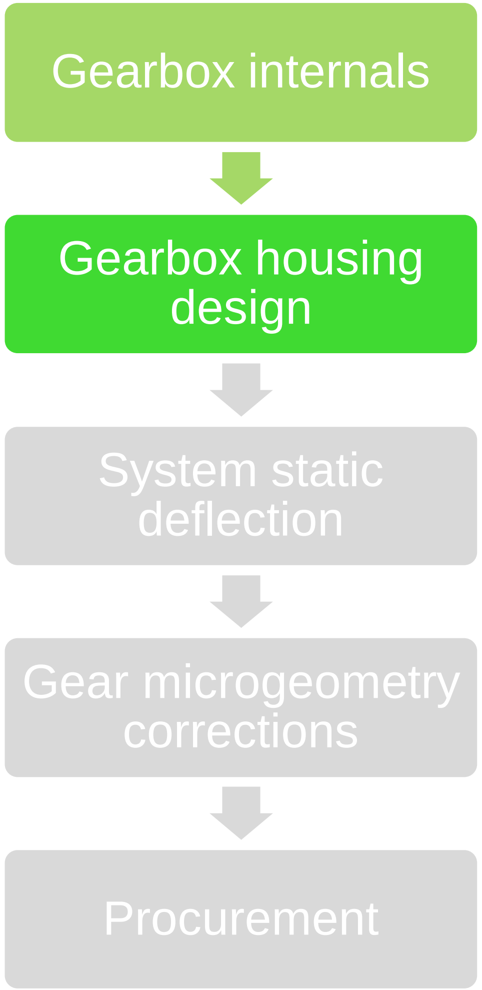
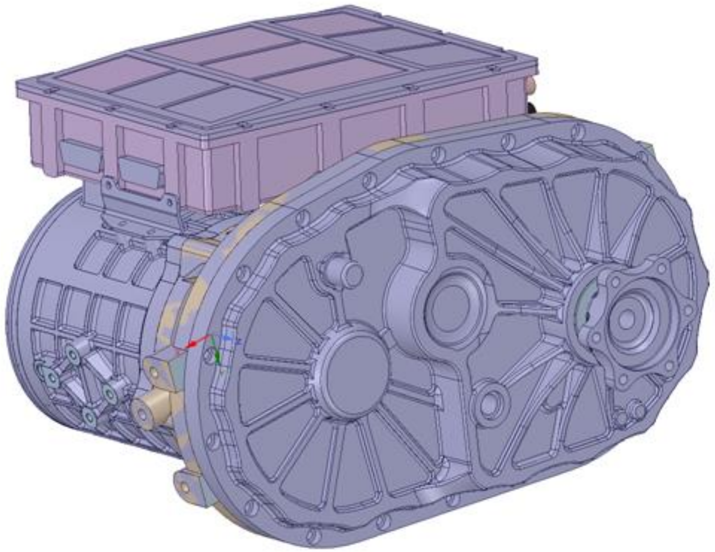
Transmission Design Approach

Traditional approach



- In a gearbox, the housing performs a few main functions:
  - Provide sufficient structural strength
  - Provide interface with the rest of the vehicle
  - Prevent dirt getting into the gears and bearings
  - Contain the lubricant
  - Minimise radiated noise from the gears
  - Maintain adequate alignment of internal components

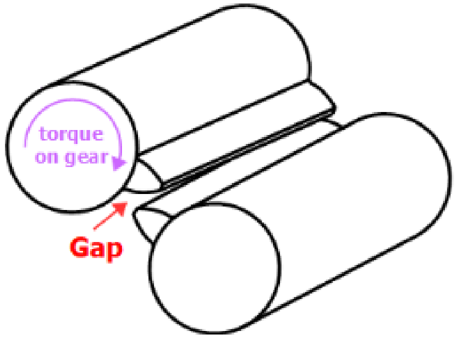


Transmission Design Approach

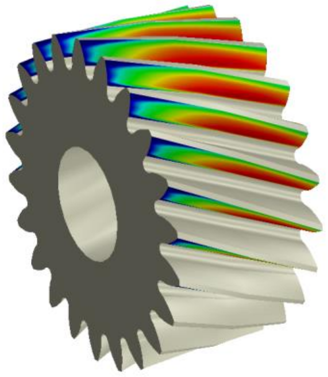
Traditional approach

- Gearbox internals
- Gearbox housing design
- System static deflection
- Gear microgeometry corrections
- Procurement

- Build the system and analyse under required loading conditions
- System deflects under load which leads to gear mesh misalignment
  - Shaft deflection
  - Bearing deflection
  - Housing deflection



Misaligned gear mesh



Gear edge loading

Gear micro-pitting failure

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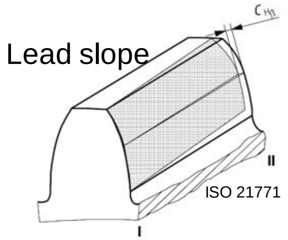
Transmission Design Approach

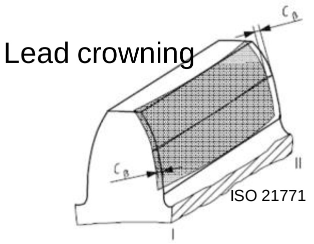
Traditional approach

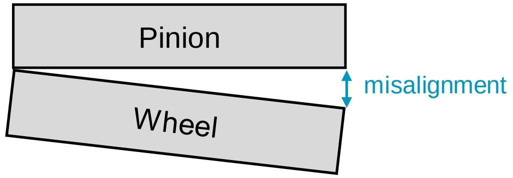
Gearbox internals
↓
Gearbox housing design
↓
System static deflection
↓
Gear microgeometry corrections
↓
Procurement

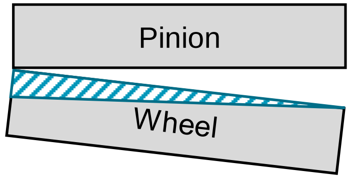
- Apply gear micro-geometry corrections to refine the gear contact condition.
  - Reduce contact stress
  - Reduce transmission error (TE) – source of gear noise

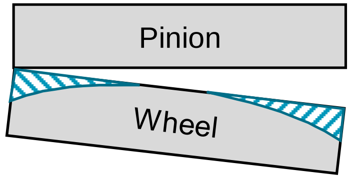
OK for low misalignment



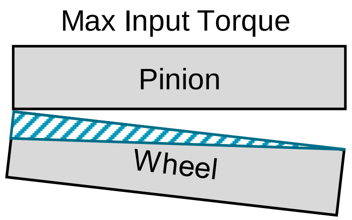


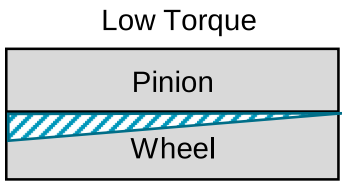






- Difficulty in correcting for large misalignment variation across operating points





Sub-optimal design for large misalignment condition

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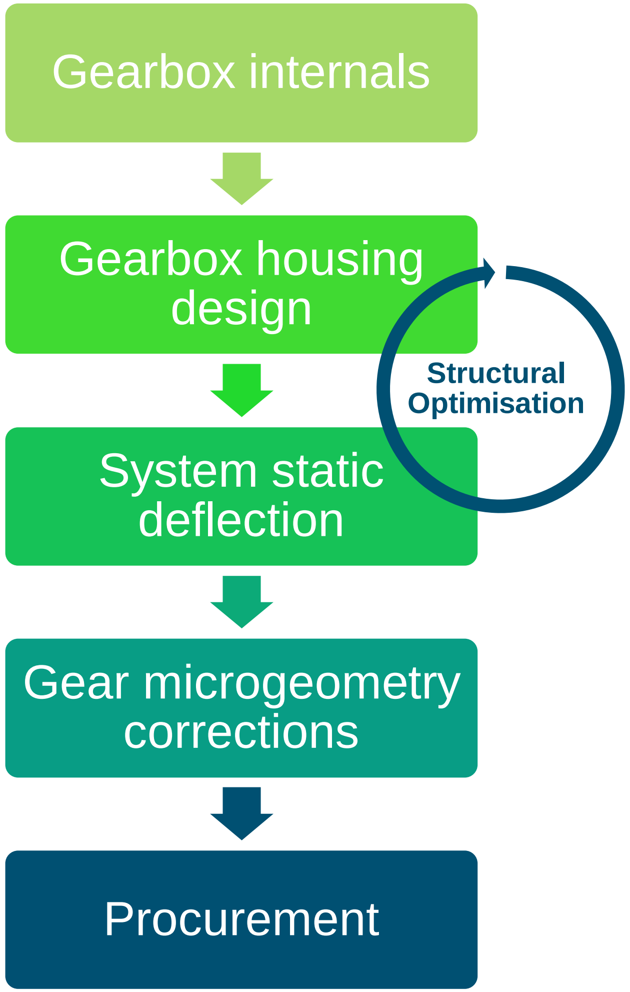
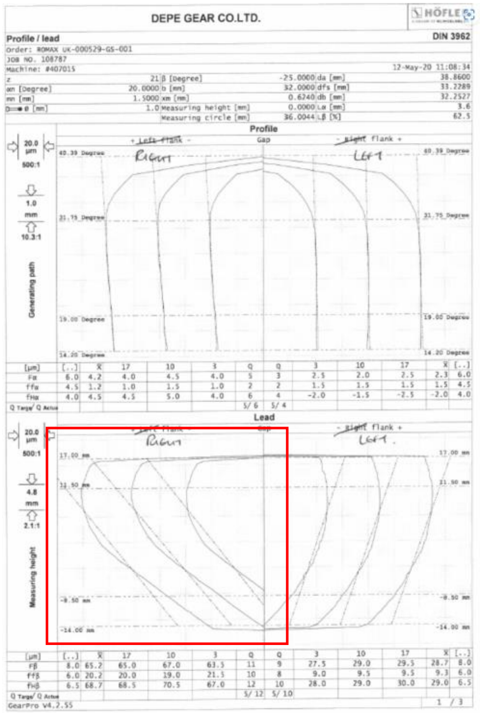
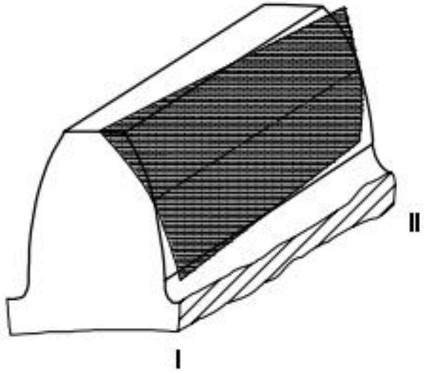
Transmission Design Approach

Traditional approach



- Excessive gear micro-geometry corrections leads to complexity in manufacturing
  - Gear profile deviates from design intent
  - Introduce unwanted corrections such as flank bias/twist
- Increased in cost and relatively poor gear performance





Gearbox Housing Structural Optimisation

Romax Enduro and GRM co-simulation workflow

- The solution is the coupling of Hexagon Romax Enduro to GRM's optimisation tools.

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System integration and electro-mechanical analysis

GRM OPTIMISED ENGINEERING DESIGN

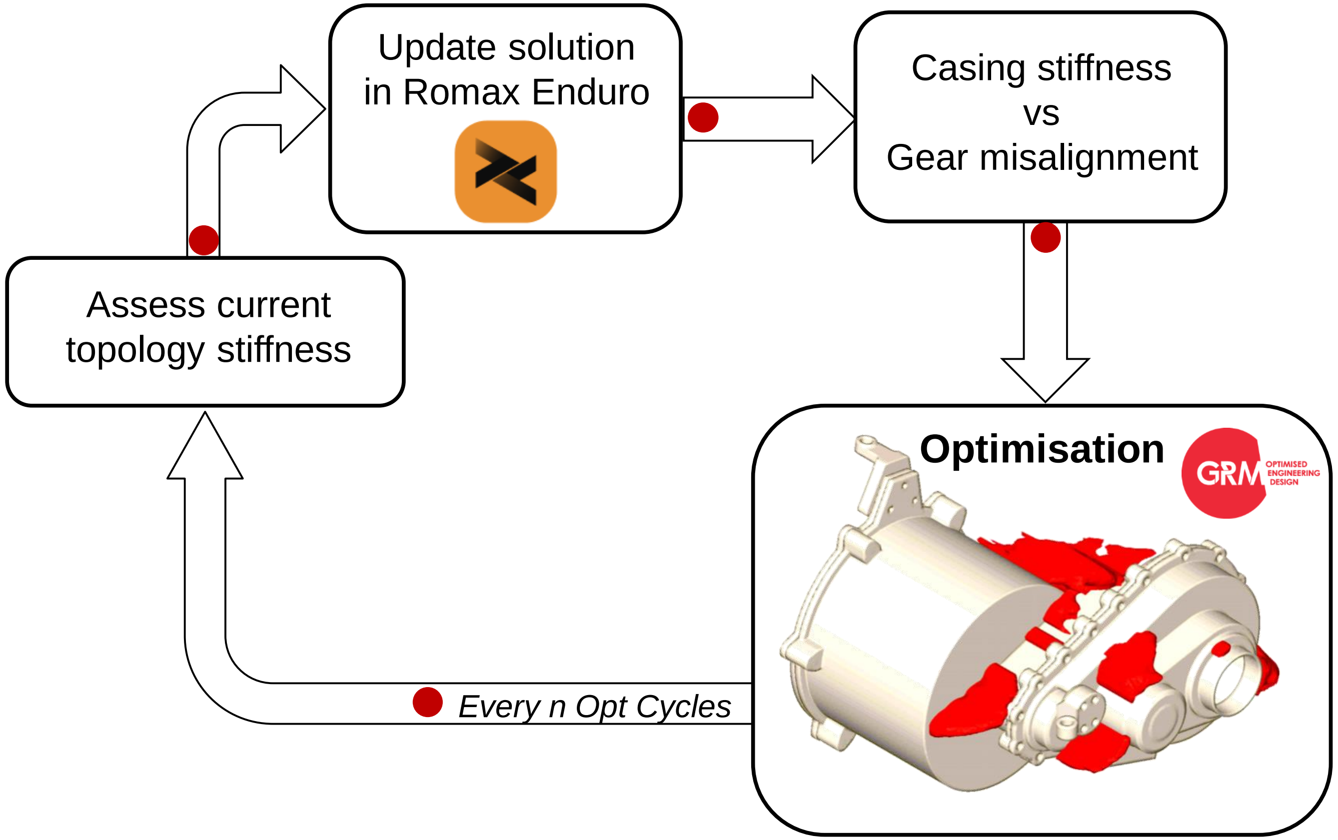
Structural optimisation

Romax Enduro

Romax transmission system simulation

GRM OPTIMISED ENGINEERING DESIGN

Housing optimisation



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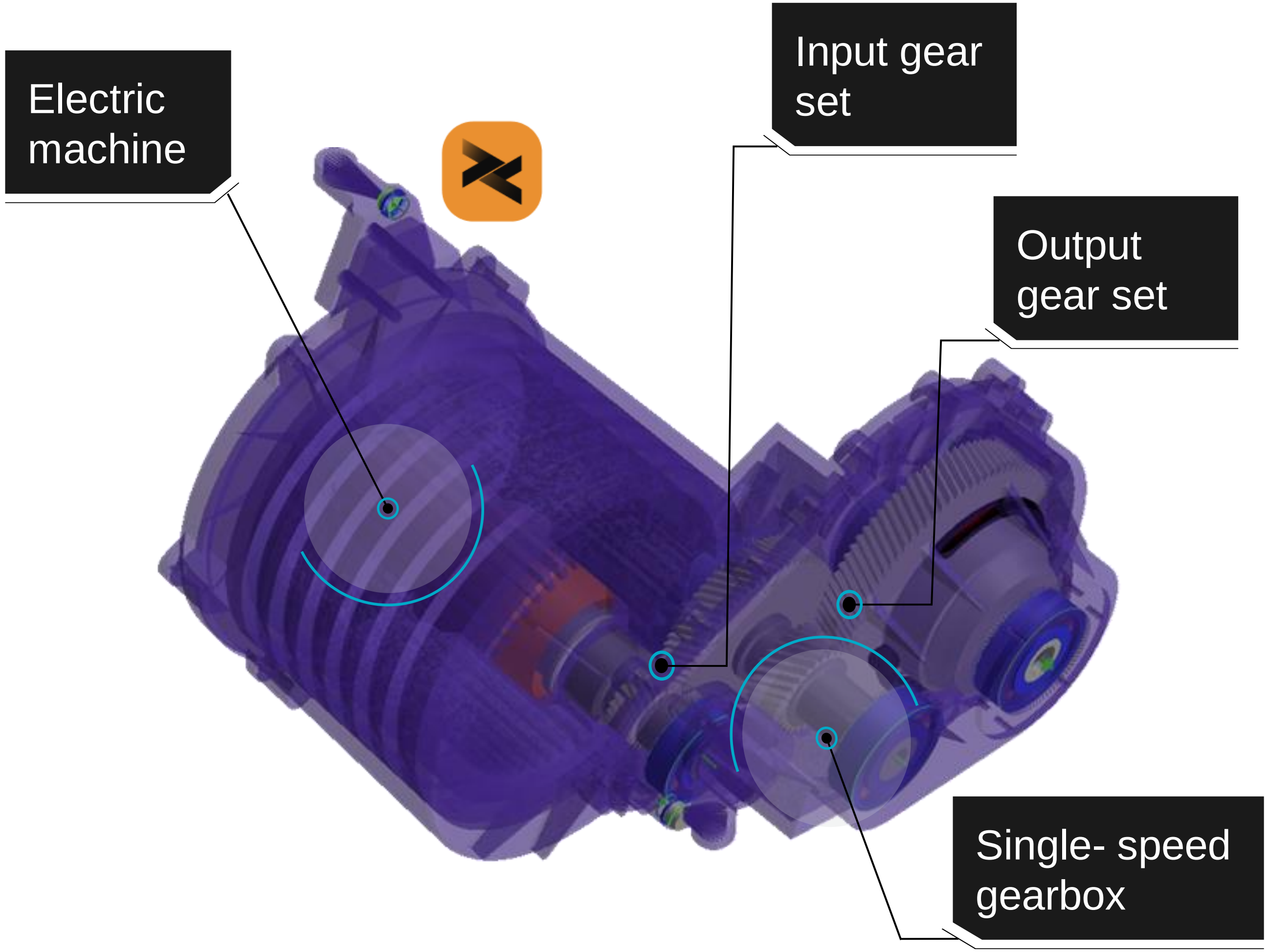
Co-simulation Workflow Case Study

Electric drive unit (EDU) housing optimisation

- **Basic e-Powertrain design specification**
  - Gearbox: 2-stage, single speed, Ratio = 9.1
  - 160Nm maximum input torque
  - Two load cases (max torque in drive and coast) considered
- **Objective**
  - Reduce the gear mesh misalignment variation across operating points in order to design for low stress, low noise and high efficiency.
- **Approach**
  - Optimise the EDU housing to reduce gear mesh misalignment, and reduce mass whilst keeping the stresses within material yield and



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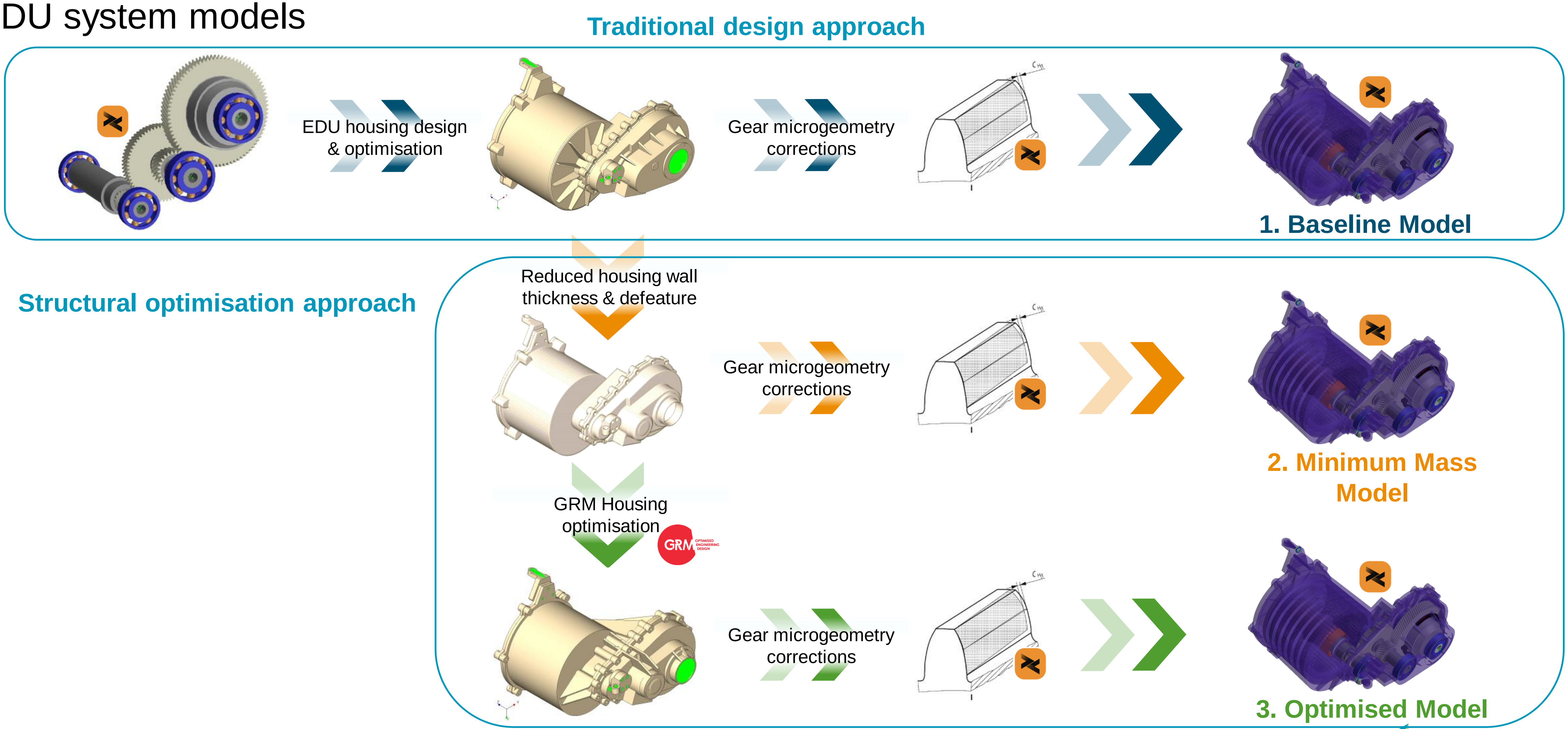
Design Approaches

EDU system models

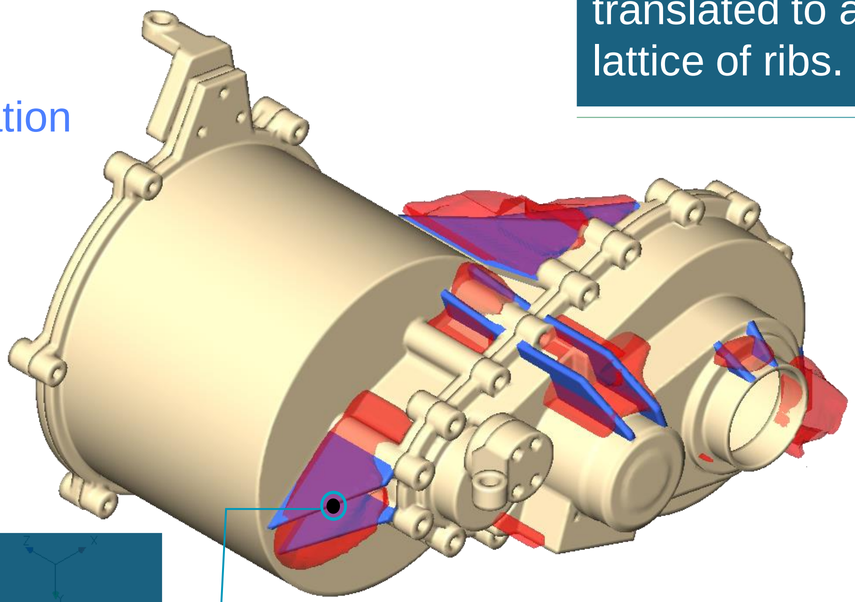


Co-Simulation Results

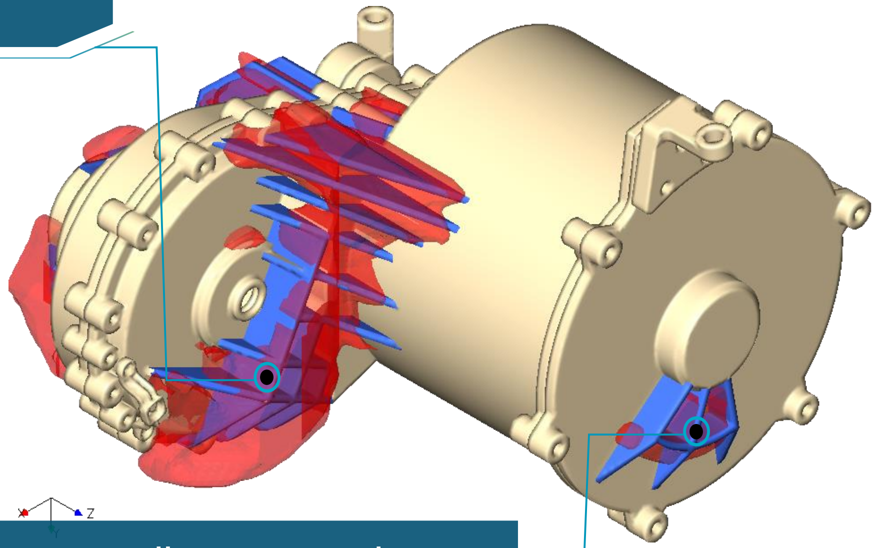
Gearbox housing optimisation

- GRM interpreted their topology result (overlaid in transparent red) into a gear box casing design using predominantly 5mm thick ribs:

Key:
Topology result
Topology interpretation



Bulk reinforcement material translated to a cross-hatched lattice of ribs.



Mounting features extended and reinforced with ribs.

Ribs extending outwards to circumference in radial fashion.

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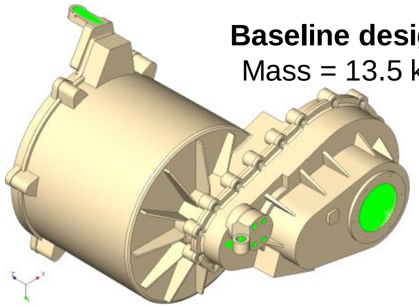
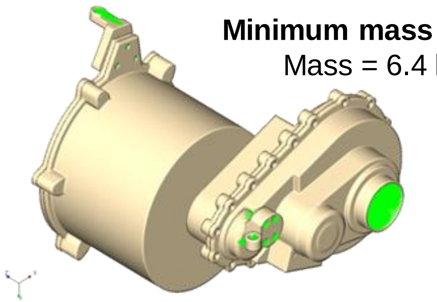
Co-Simulation Results

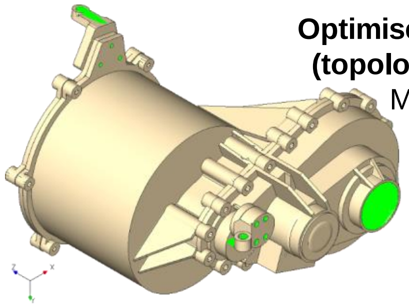
Gear mesh misalignment comparison



Baseline design
Mass = 13.5 kg

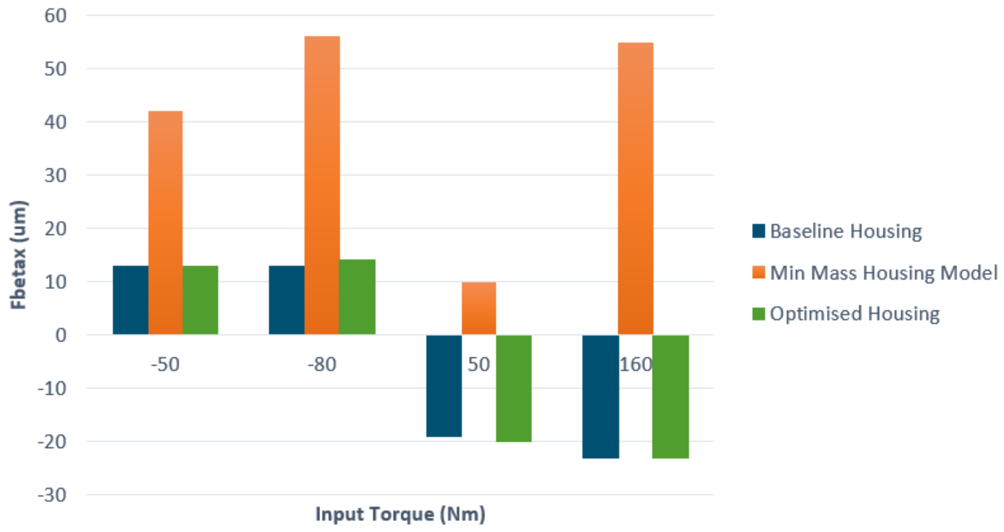


Minimum mass model
Mass = 6.4 kg

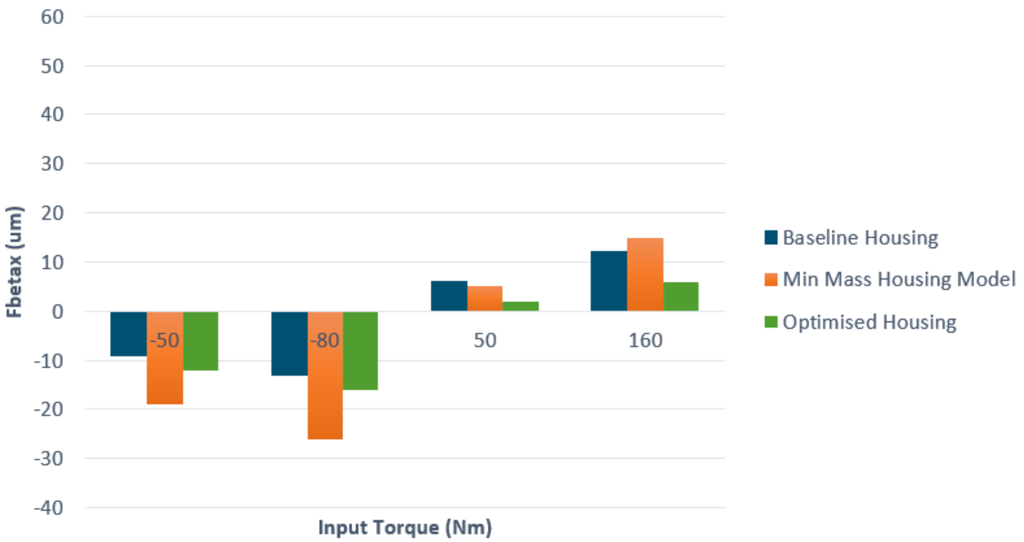


Optimised housing design (topology interpretation)
Mass = 7.6 kg

Input Gear Set Gear Mesh Misalignment Comparison between Baseline, Min Mass Model and Optimised



Output Gear Set Gear Mesh Misalignment Comparison between Baseline, Min Mass Model and Optimised



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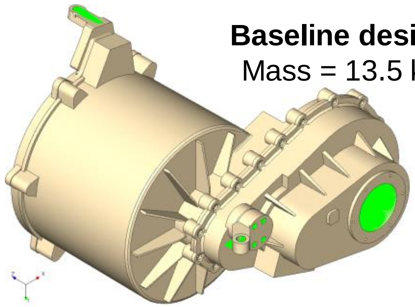
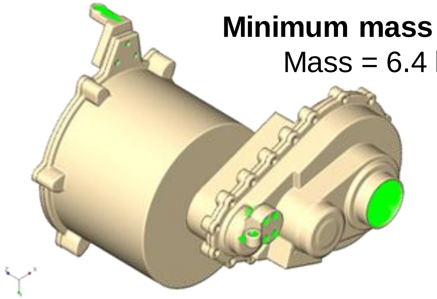
Co-Simulation Results

Gear mesh transmission error (TE) comparison

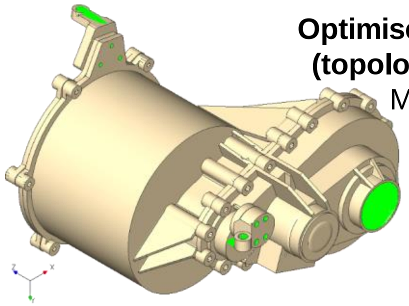
Baseline design
Mass = 13.5 kg



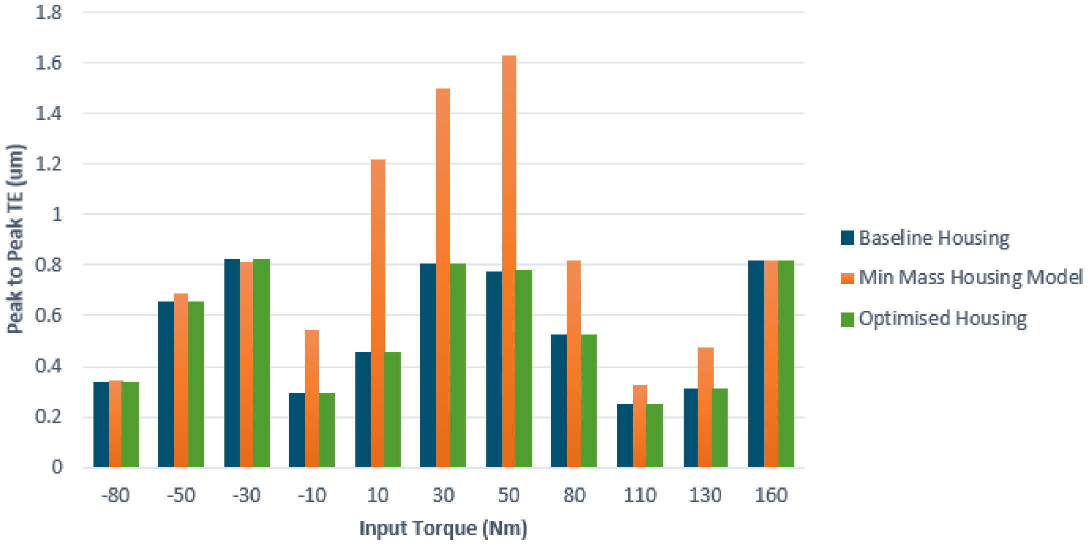
Minimum mass model
Mass = 6.4 kg



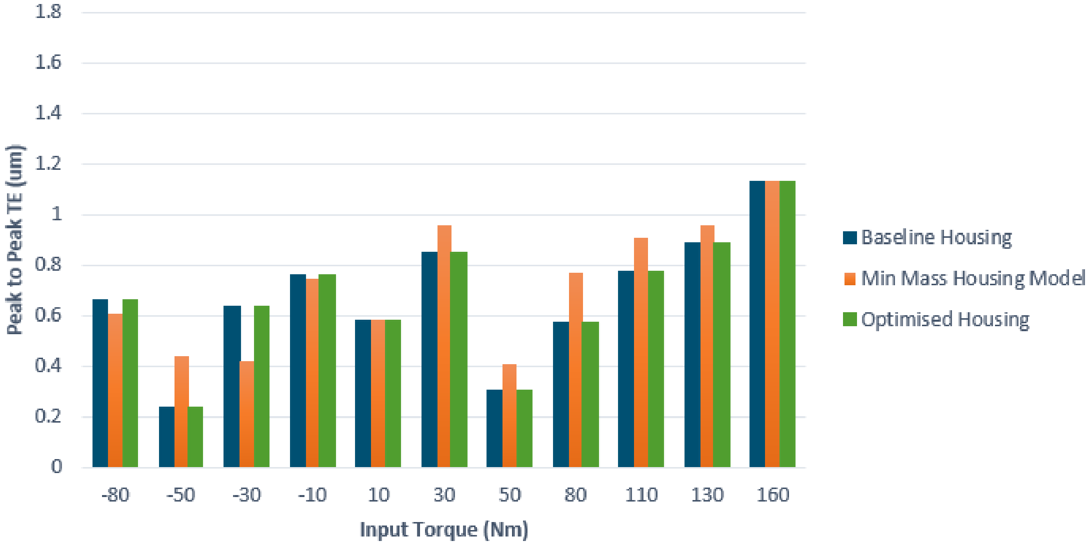
Optimised housing design (topology interpretation)
Mass = 7.6 kg



Input Gear Set Peak to Peak TE Comparison between Min Mass Model, Baseline and Optimised Design



Output Gear Set Peak to Peak TE Comparison between Min Mass Model, Baseline and Optimised Design



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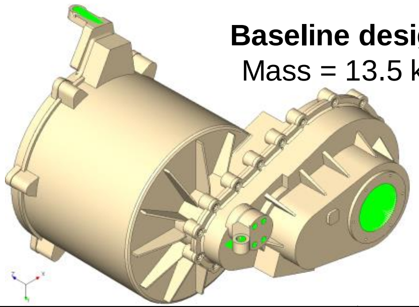
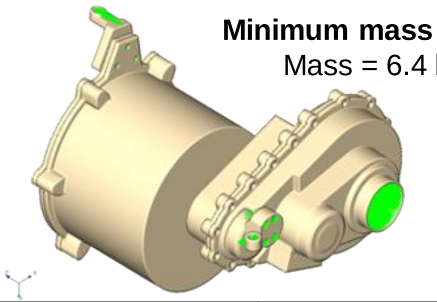
Co-Simulation Results

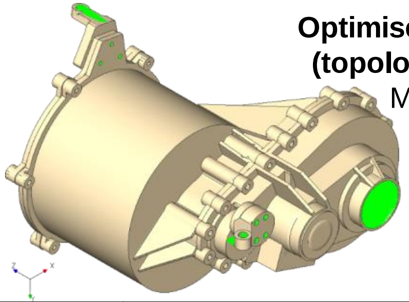
Input Gear Mesh contact stress distribution comparison (Drive flank)



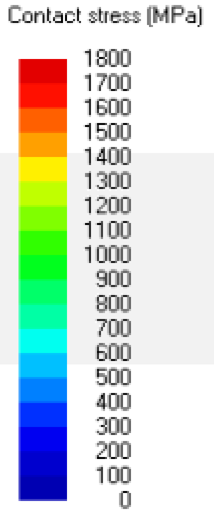
Baseline design
Mass = 13.5 kg

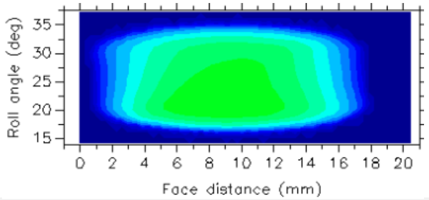
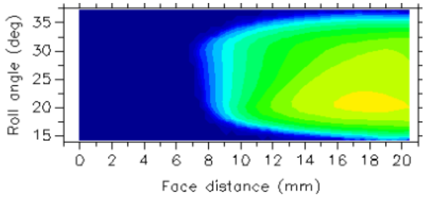
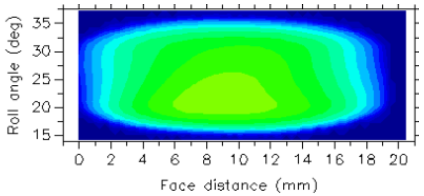
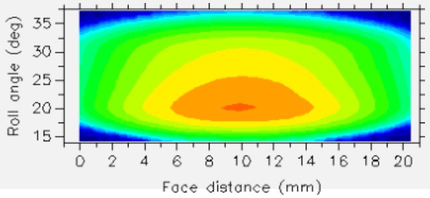
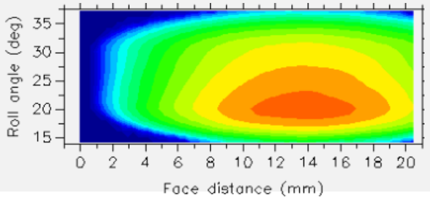
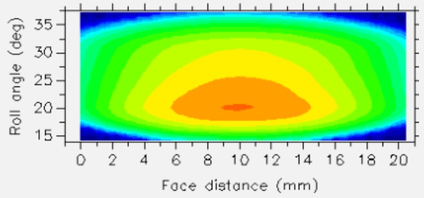
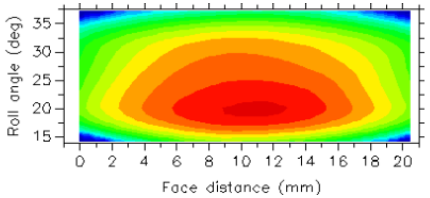
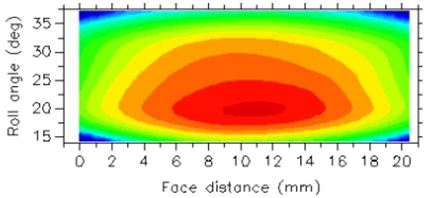
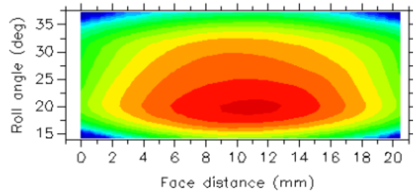


Minimum mass model
Mass = 6.4 kg



Optimised housing design (topology interpretation)
Mass = 7.6 kg



	Baseline	Min Mass	Optimised
Lead crowning (um)	8.0	8.0	8.0
Lead slope (um)	-20.0	45.0	-20.0
50Nm Input Torque			
110Nm Input Torque			
160Nm Input Torque			

Summary & Conclusion

- Multi-attribute structural optimisation approach demonstrated here **allows lightweighting of the EDU without compromising on the gear performance**.
- Process makes it easier to achieve a more **favourable gear contact distribution** and TE without the need to apply large amount of microgeometry corrections on the gears.
- The gear microgeometry is used to **refine the design and not for correcting a poor detailed design**.
- The approach enables designers to consider characteristics which would otherwise be too complex to do ‘blind’ e.g. the **interaction between strength and stiffness**.
- Can also be used in the **early design stages**, allowing the blending of manual iteration with the understanding of complex system interactions i.e. the effect of housing compliance on the behaviour of the gearbox internals.

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Thank you

riza.jamaluddin@hexagon.com

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