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# Gear modelling and optimization; experimental validation

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# WP1 - Gear design, simulation and testing

MetAGEAR
UNIVERSITAS STUDIORUM MUTINENSIS ET REGIENSIS 1175
UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA
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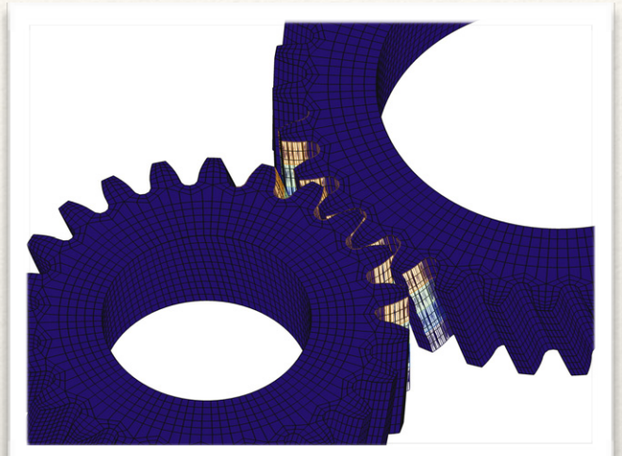
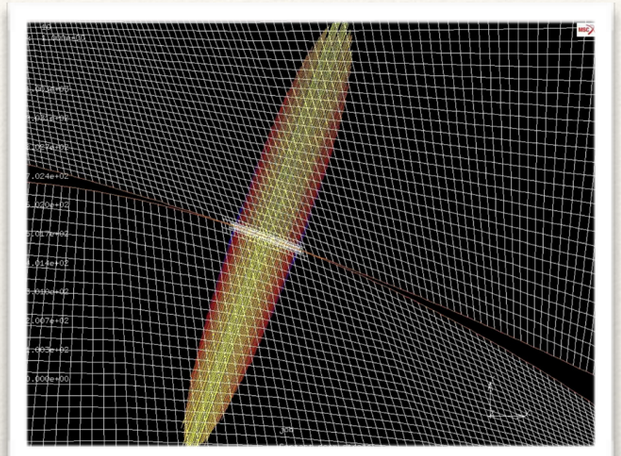
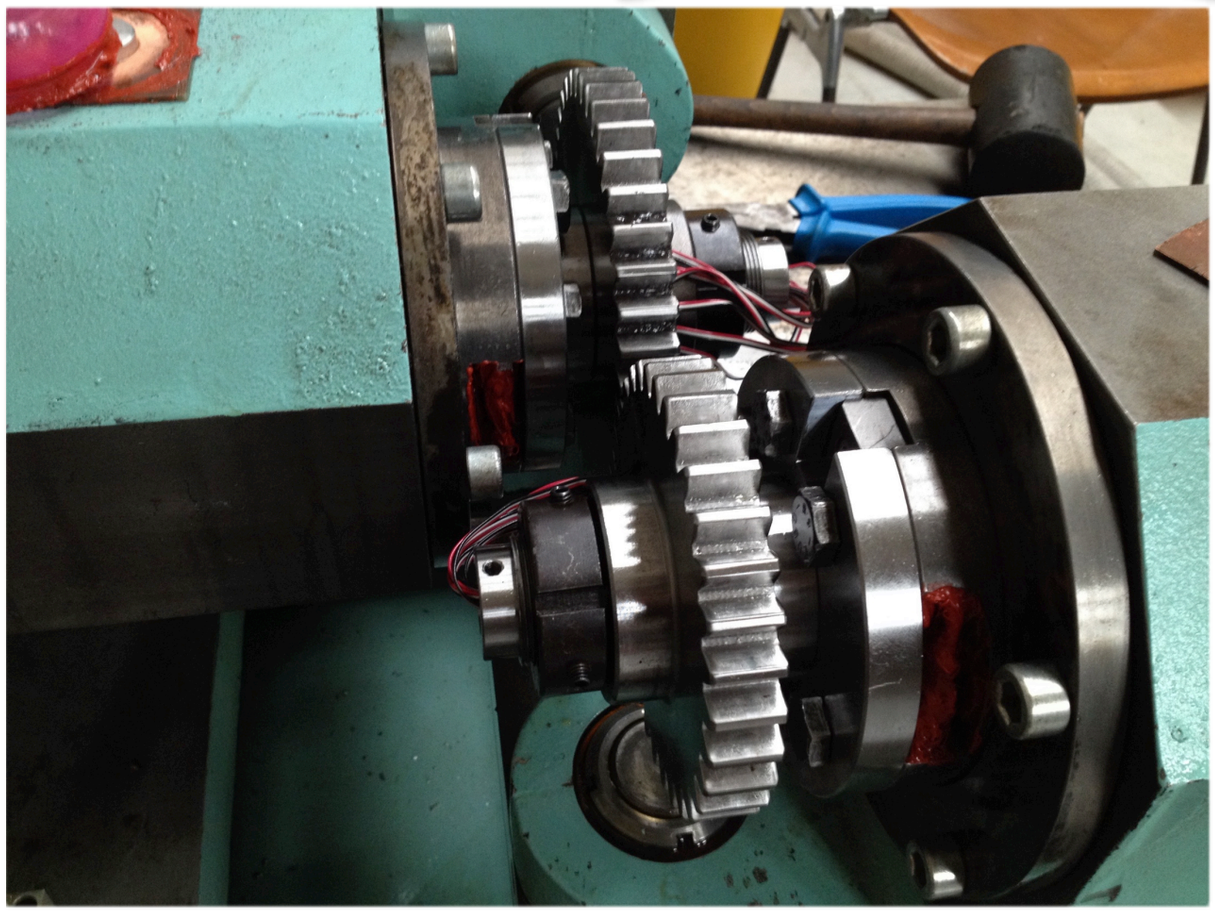
# OR1 - Gear design, simulation and testing

## MAIN TASKS:

1. Developing a **software for analysis and optimization** of gearboxes starting from design parameters and material properties
2. Developing a **test rig** for experimental validation of models, and for assessment of optimal gear design solutions

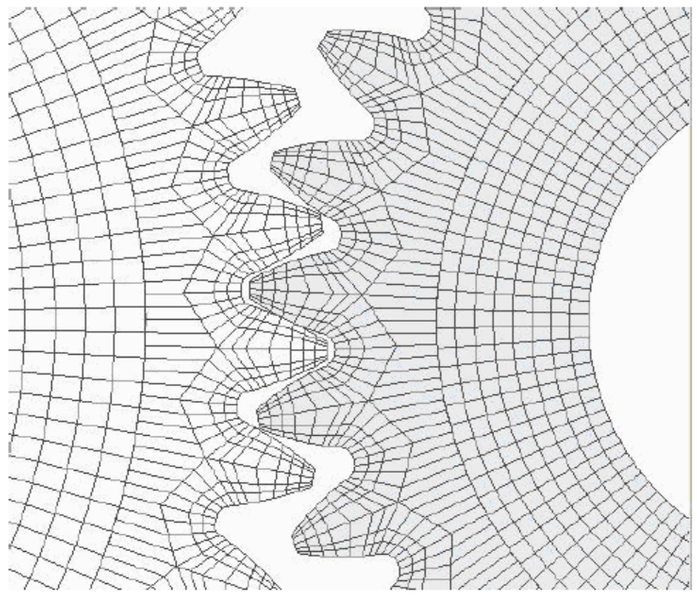


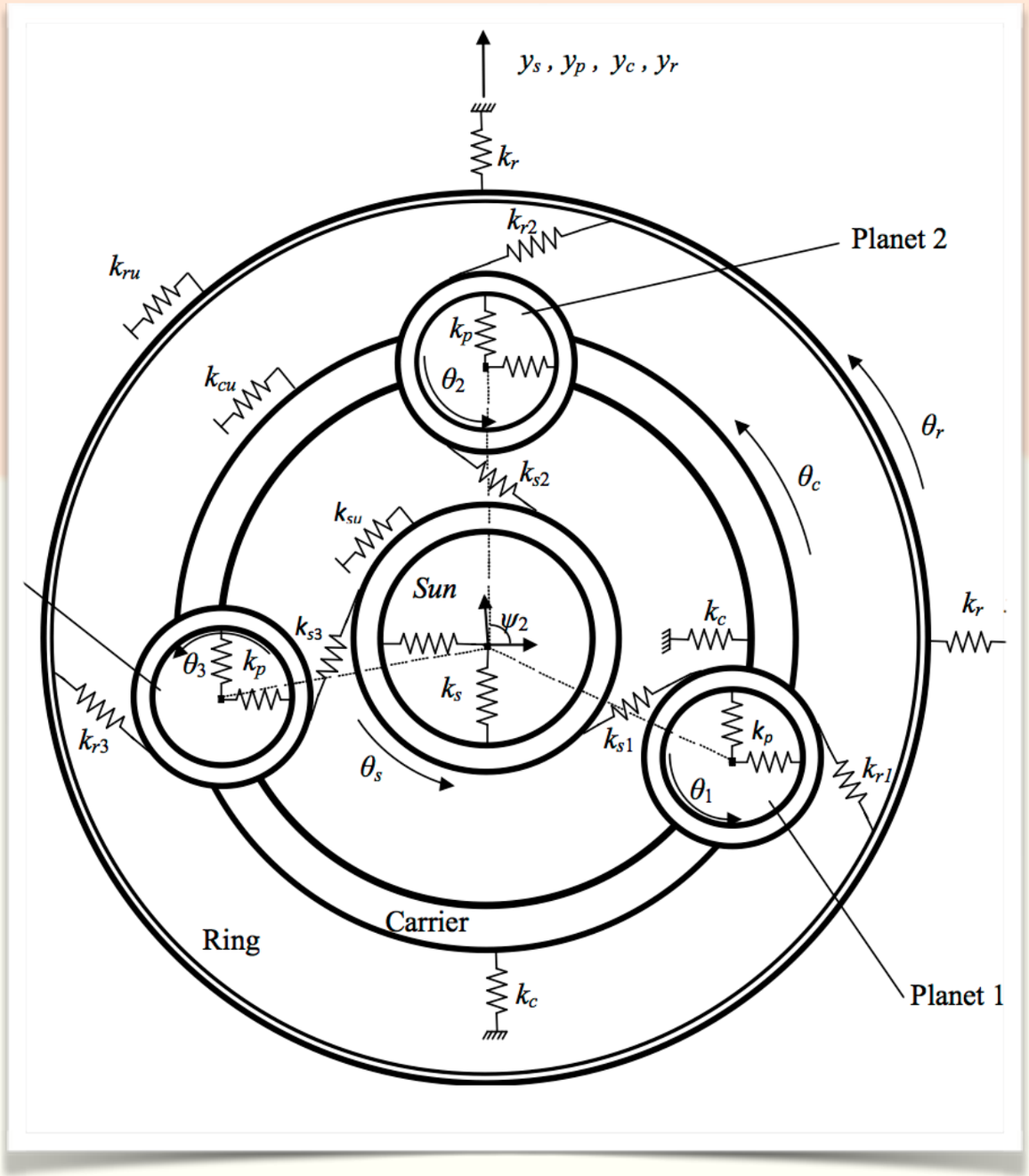




# Task 1: Modelling/optimizing planetary gears

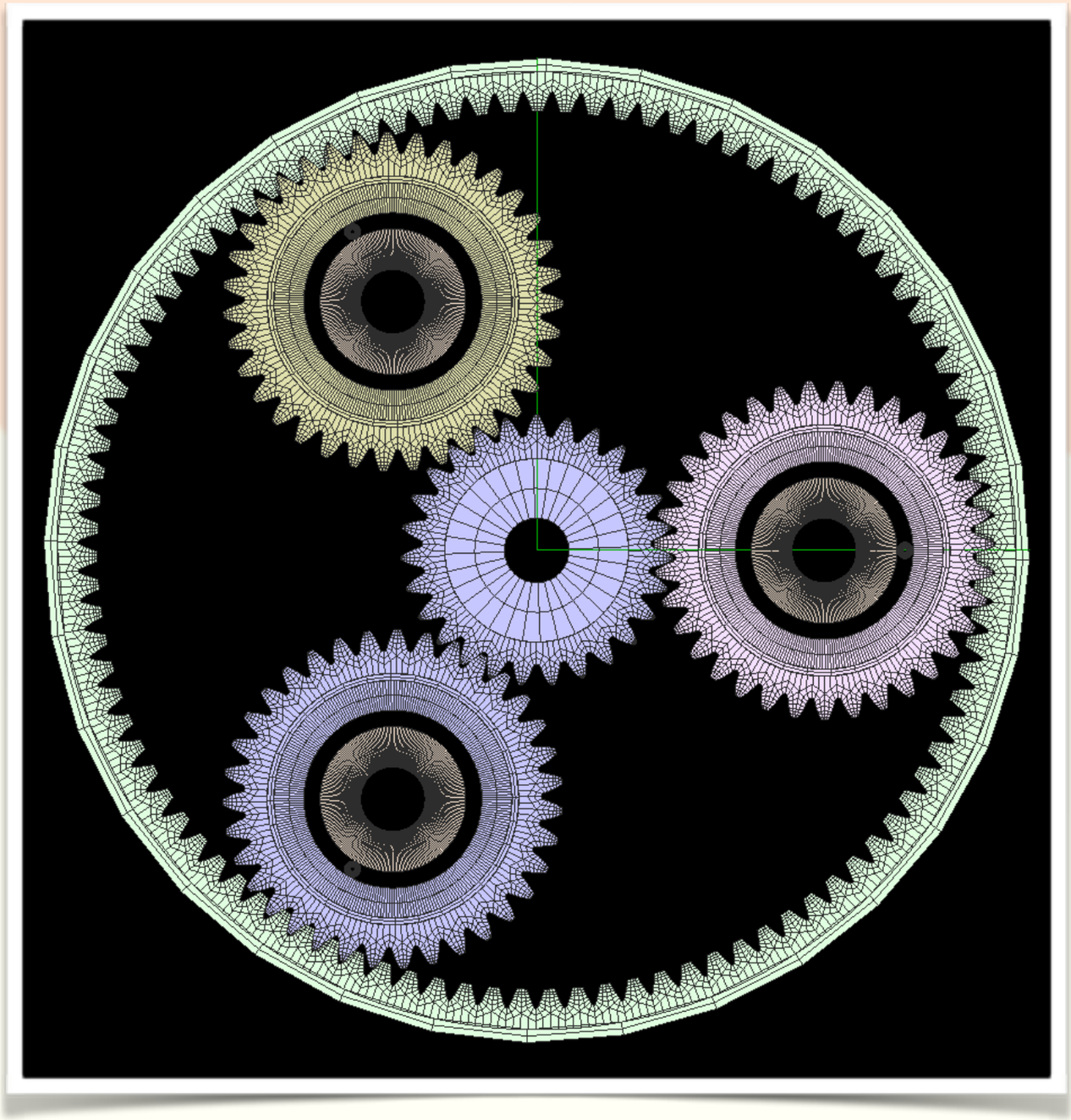
- Static analyses can be carried out using Finite Element models
- Dynamic behavior of planetary gear can be modeled using lumped parameter model





# Optimizing planetary gears

- The goal is to optimize profile reliefs in order to reduce overall planetary gear vibrations
- Static FE and lumped parameter models are combined in order to get a fast and reliable optimum
- A static model of the whole system is used to validate the proposed approach



# Dynamic model of a planetary gear with modifications

FE model of sun-planet and planet-ring meshes

Profile modifications

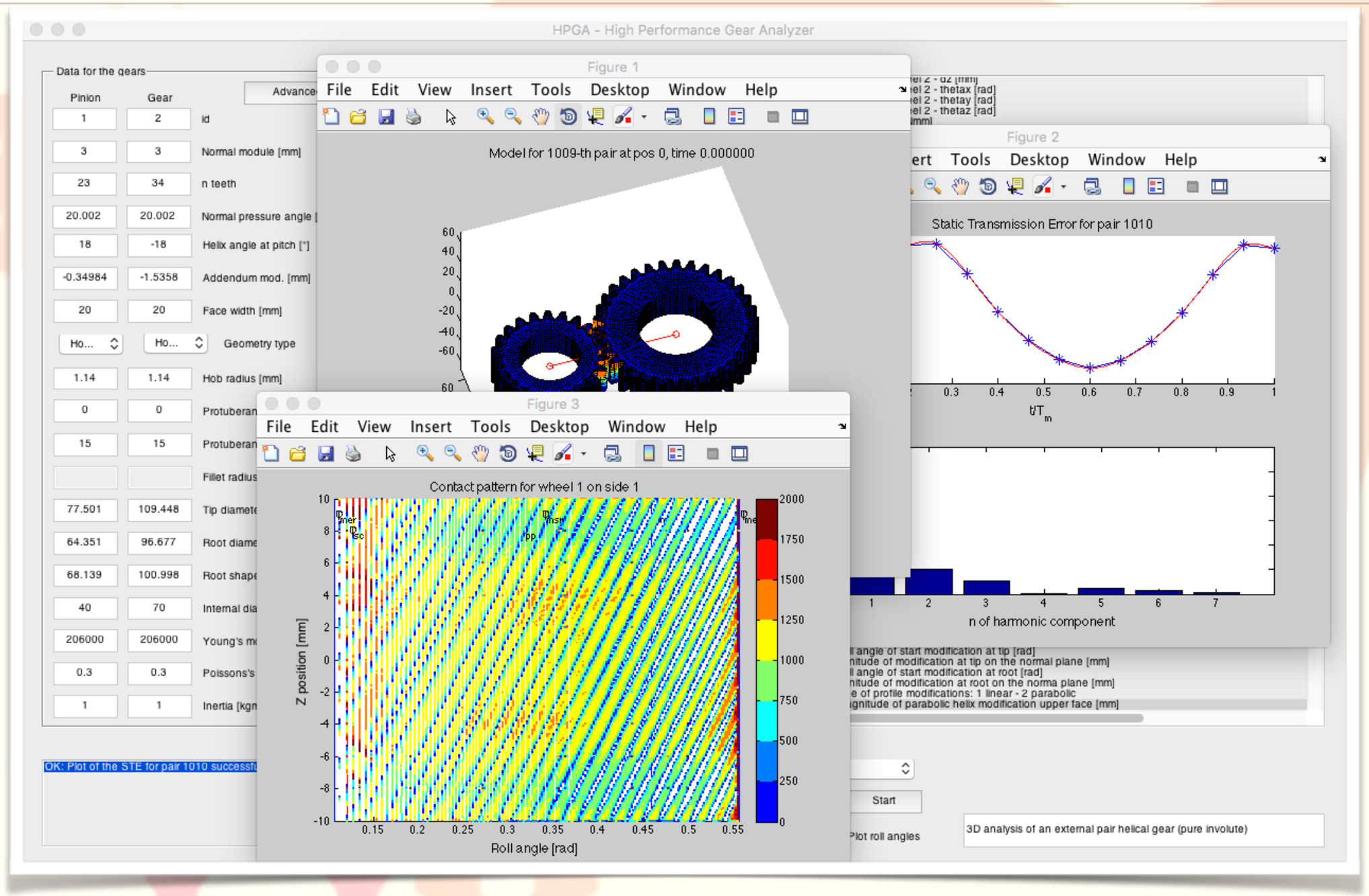
Time-varying stiffness

Errors

Lumped parameters model

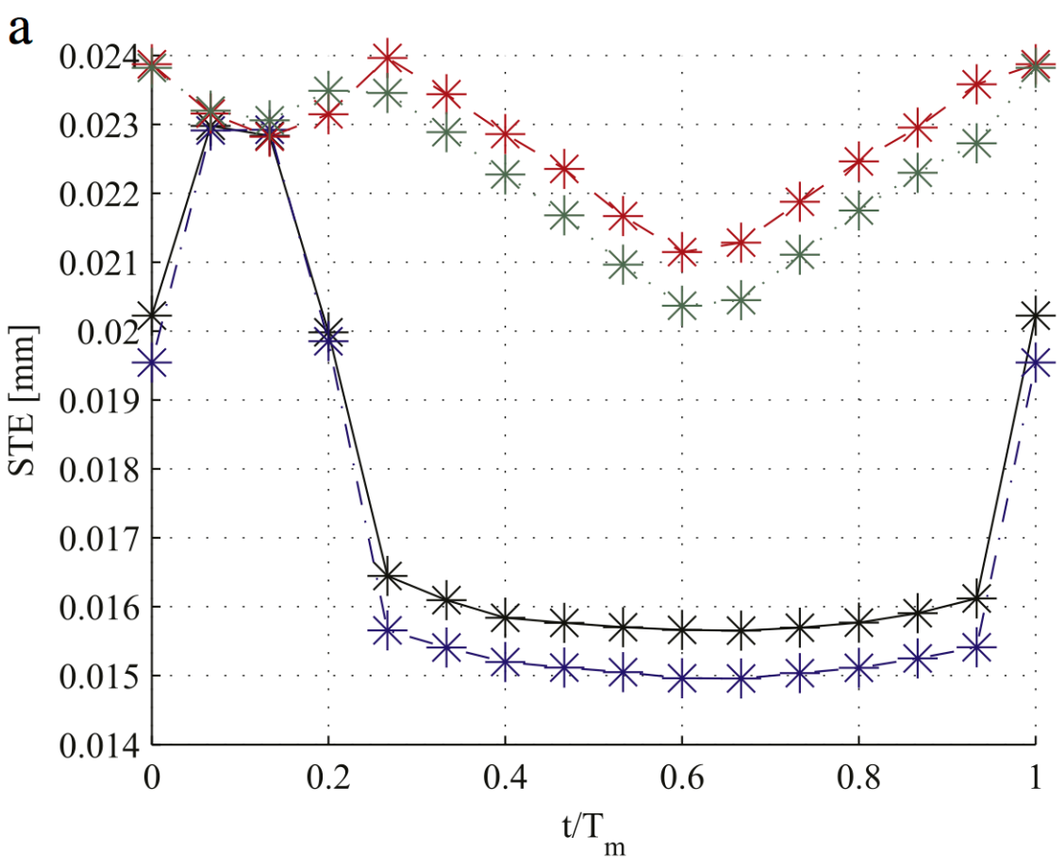
- The first step is modeling both meshes by FEM, using our software HPGA
- Later on, rigid rotations due to profile modifications are taken into account

# Computing mesh stiffness with HPGA

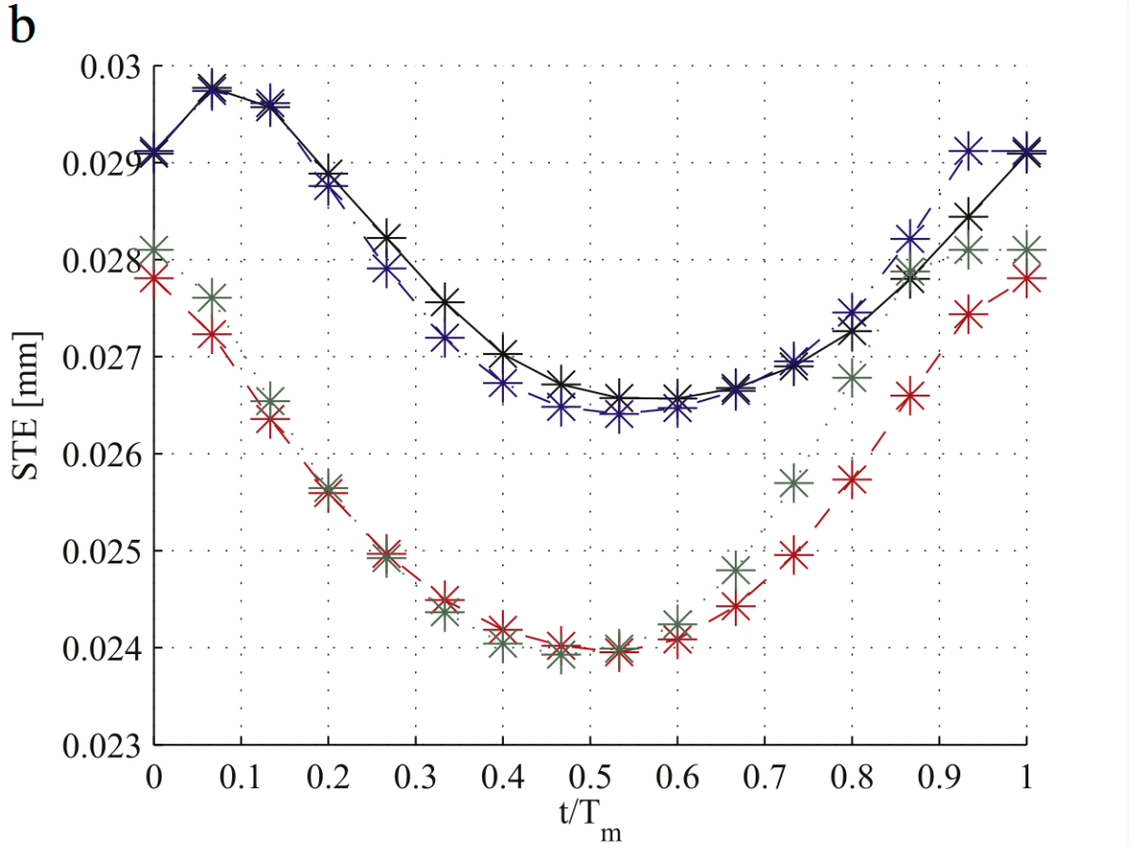



- HPGA - High Performance Gear Analyzer is a software for static modeling of helical pairs
- HPGA has been ported on a HPC server (Cineca Galileo)

# Validation by STE computation



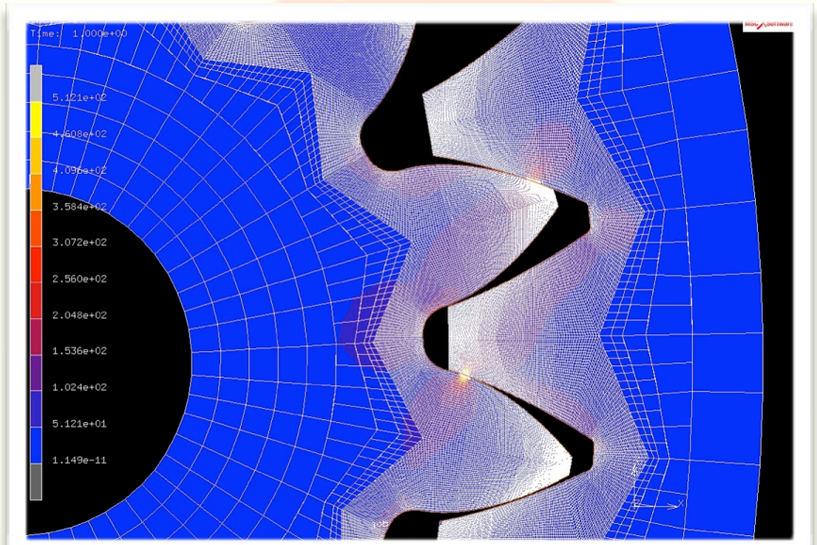

STE comparison – 2D with/without profile modifications

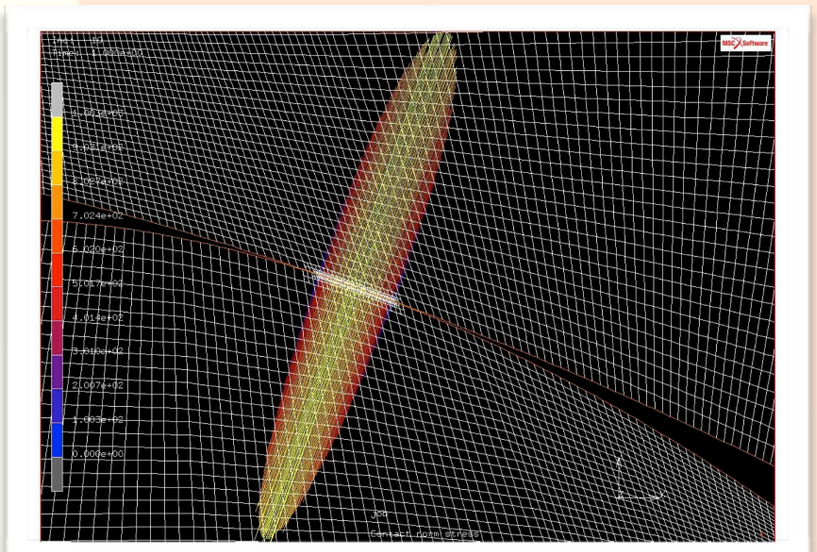


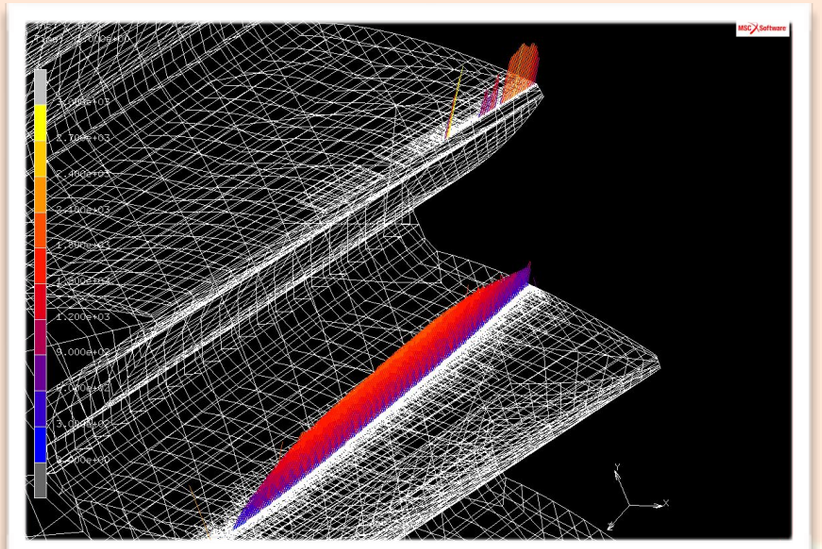

STE comparison – 3D pair with crowning, with/without misalignments

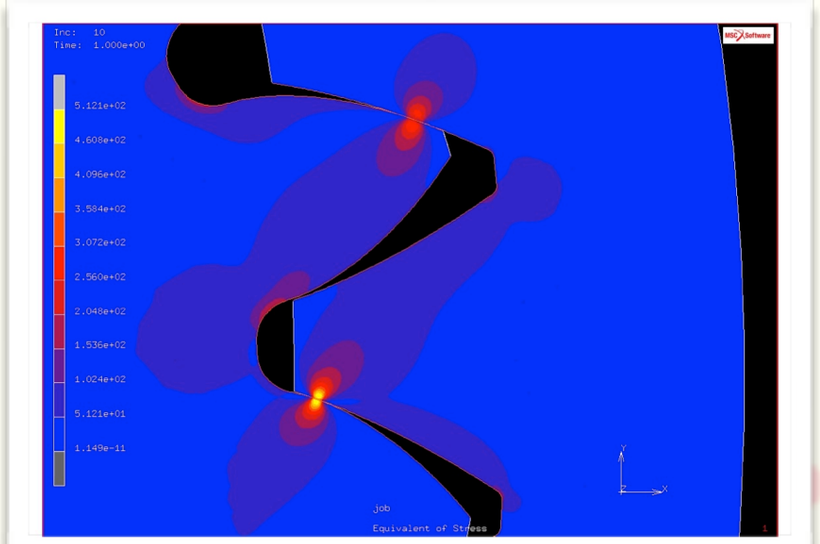
- The static transmission error is correctly evaluated by the proposed approach (with respect to Calyx)
- The model is capable to represent the effect of profile reliefs and misalignments

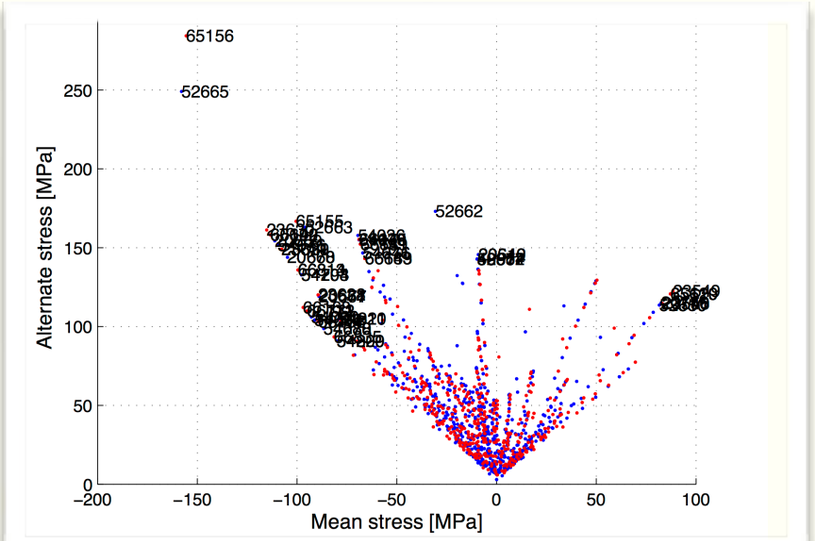
# Contact pressure and fillet stress

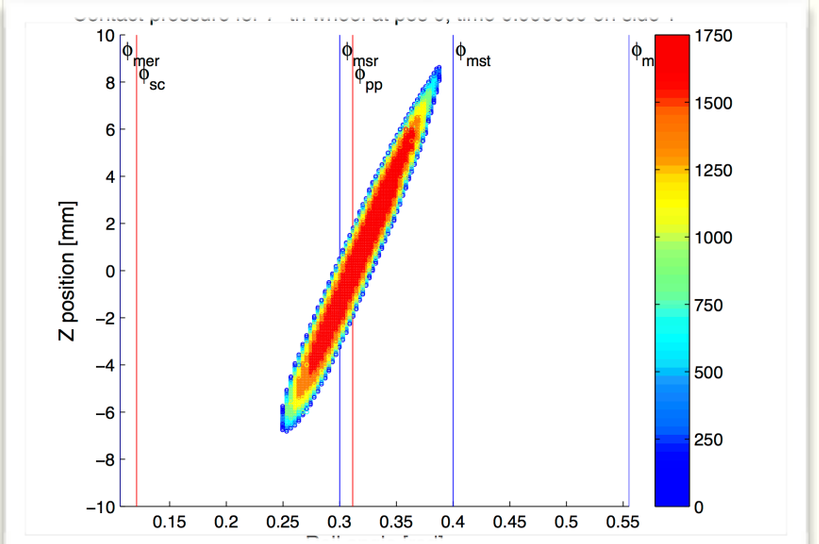


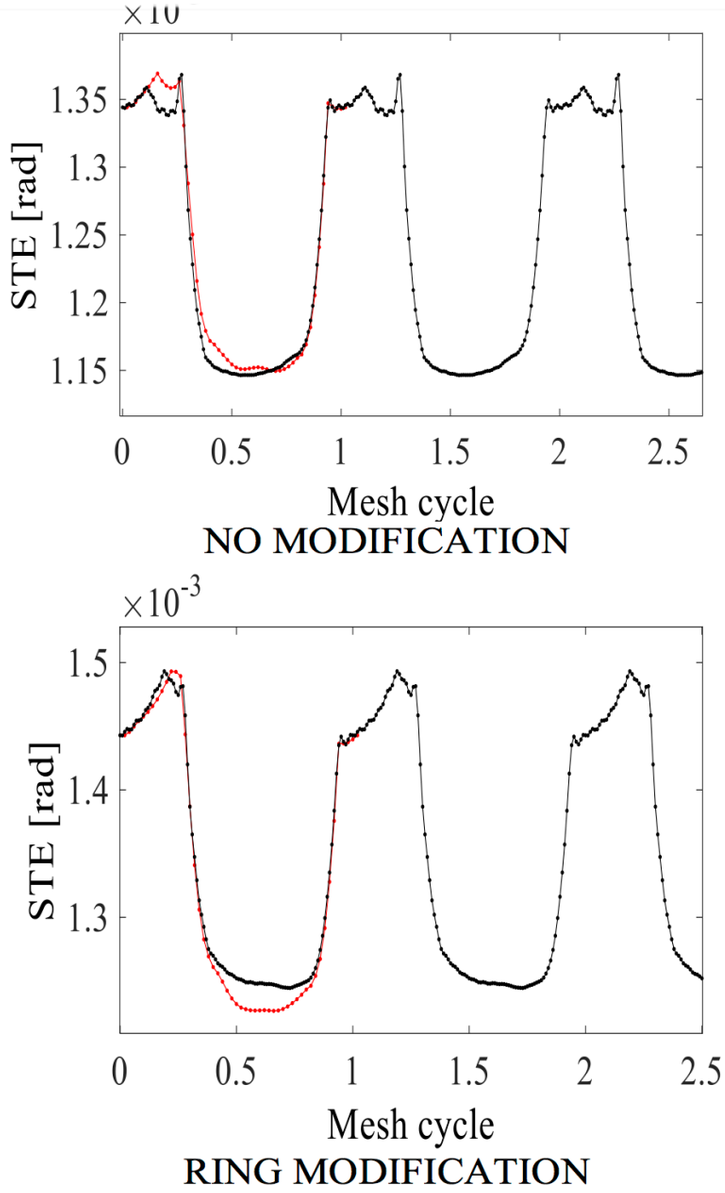



# Modelling profile modifications in planetary

$$f_{rx}=\begin{cases} x_r - x_n - \dfrac{\varepsilon_{rp}}{\sin(\psi_n+\alpha_r)} & \Delta_r \geq 0 \\ 0 & -2b_r < \Delta_r < 0 \\ x_r - x_n - \dfrac{(2b_r+\varepsilon_{rp})}{\sin(\psi_n+\alpha_r)} & \Delta_r \leq -2b_r \end{cases}$$

$$f_{ry}=\begin{cases} y_r - y_n - \dfrac{\varepsilon_{rp}}{\cos(\psi_n-\alpha_s)} & \Delta_r \geq 0 \\ 0 & -2b_r < \Delta_r < 0 \\ y_r - y_n + \dfrac{2b_r-\varepsilon_{rp}}{\cos(\psi_n-\alpha_s)} & \Delta_r \leq -2b_r \end{cases}$$

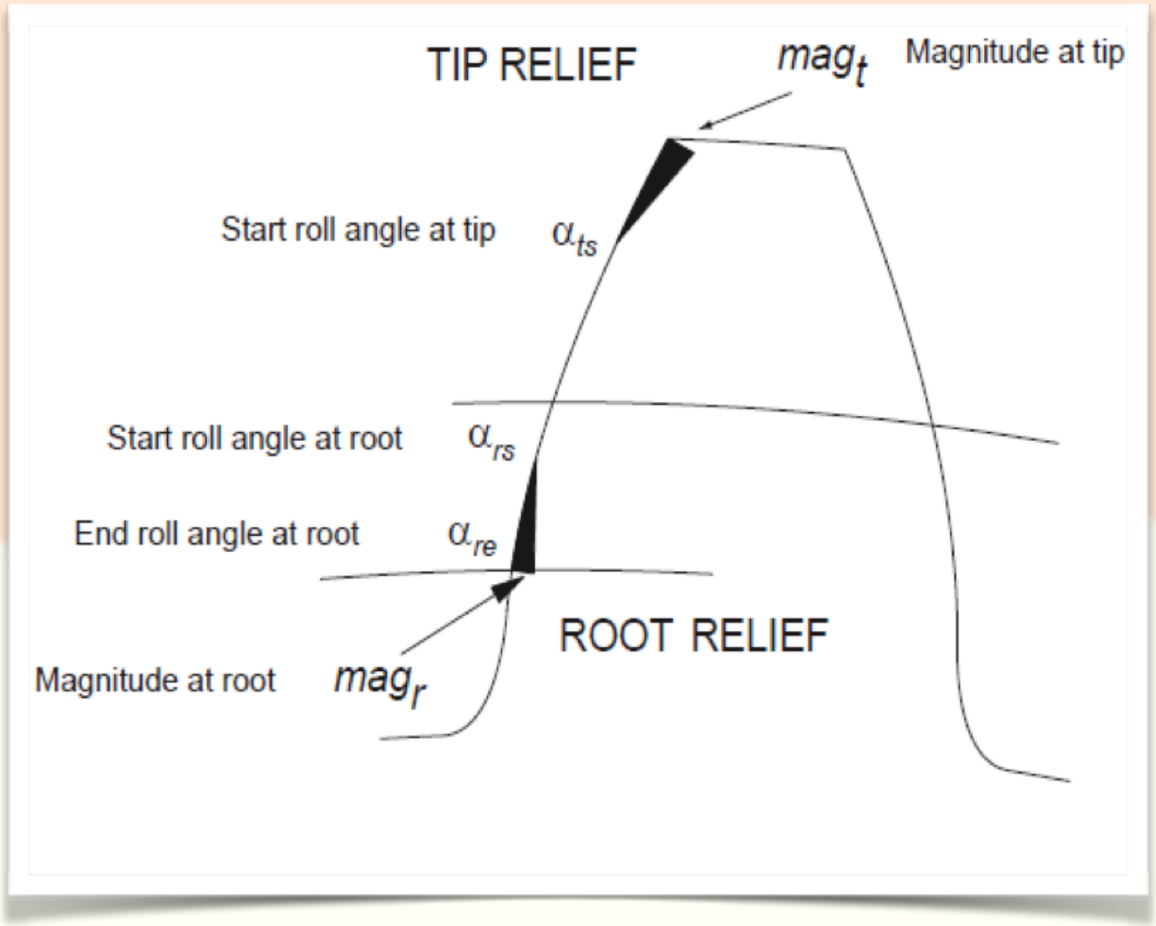
$$f_{rt}=\begin{cases} \theta_r.r_{br} - \theta_n.r_{bn} - \varepsilon_{rp} & \Delta_r \geq 0 \\ 0 & -2b_r < \Delta_r < 0 \\ \theta_r.r_{br} - \theta_n.r_{bn} - \varepsilon_{rp} + 2b_r & \Delta_r \leq -2b_r \end{cases}$$

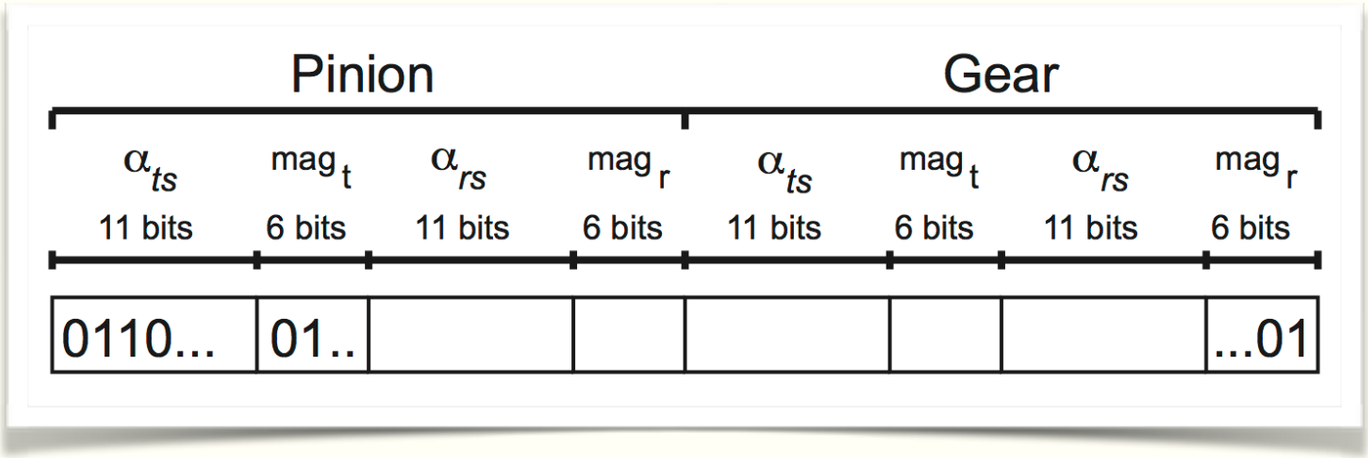



- Profile modification are introduced in the model
- The model is validated by comparison with a full model (Calyx Planetary2D)

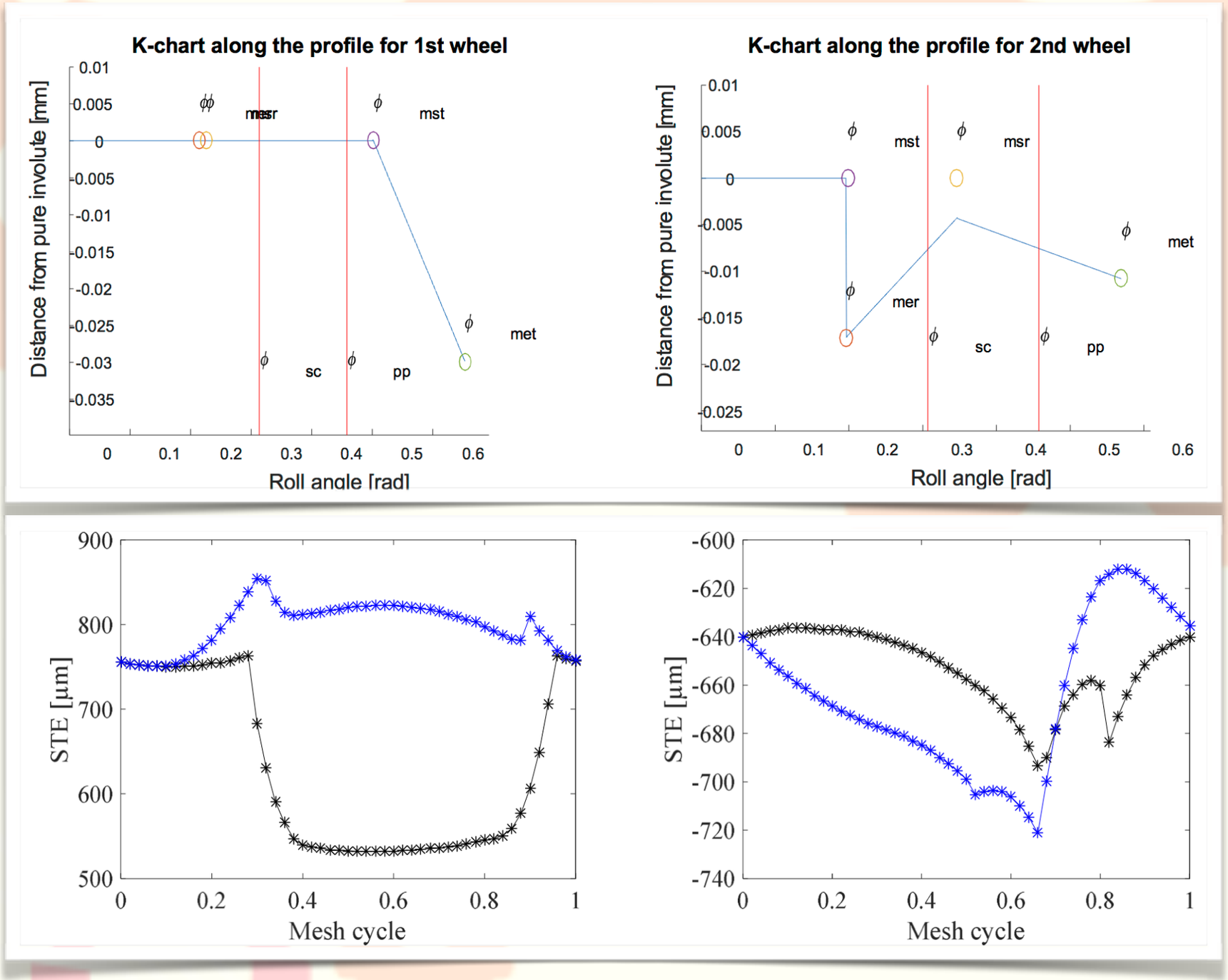
# Optimization of profile reliefs

- Optimization parameters:
  - Sun profile reliefs (tip and root)
  - Planet profile reliefs (tip and root)
- Objective function:
  - Peak to peak of the STE of the planetary gear
- No modifications on ring



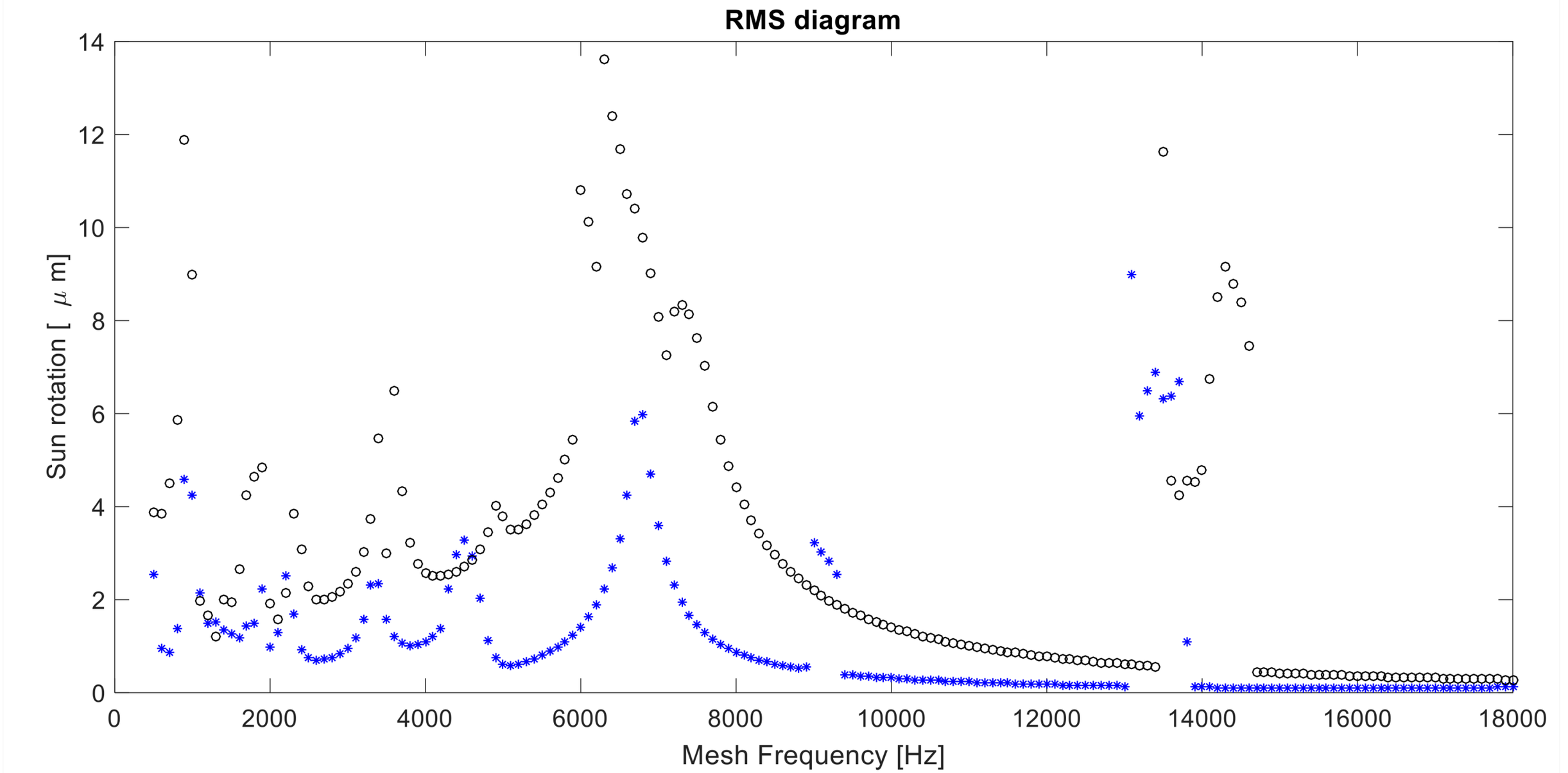



# Optimal modifications



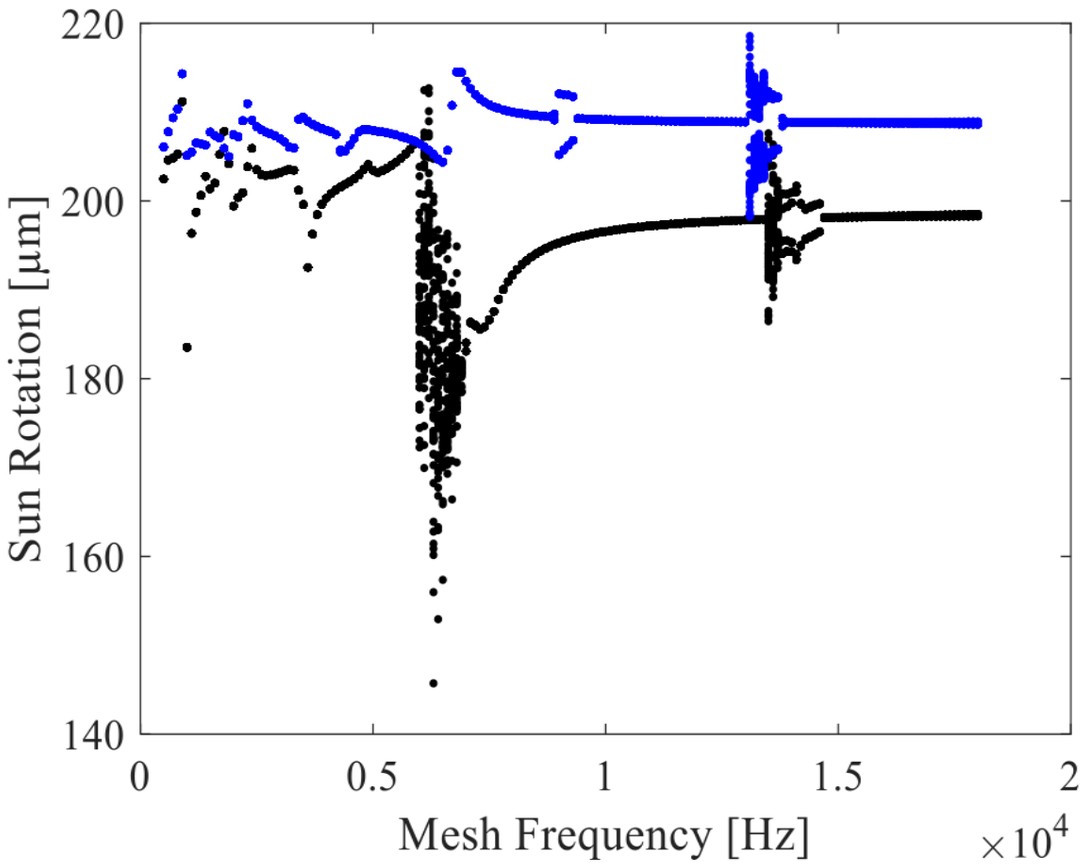

- Peak to peak of global STE is reduced from 154 µrad to 21 µrad (-86%)

# Dynamic effect of optimization

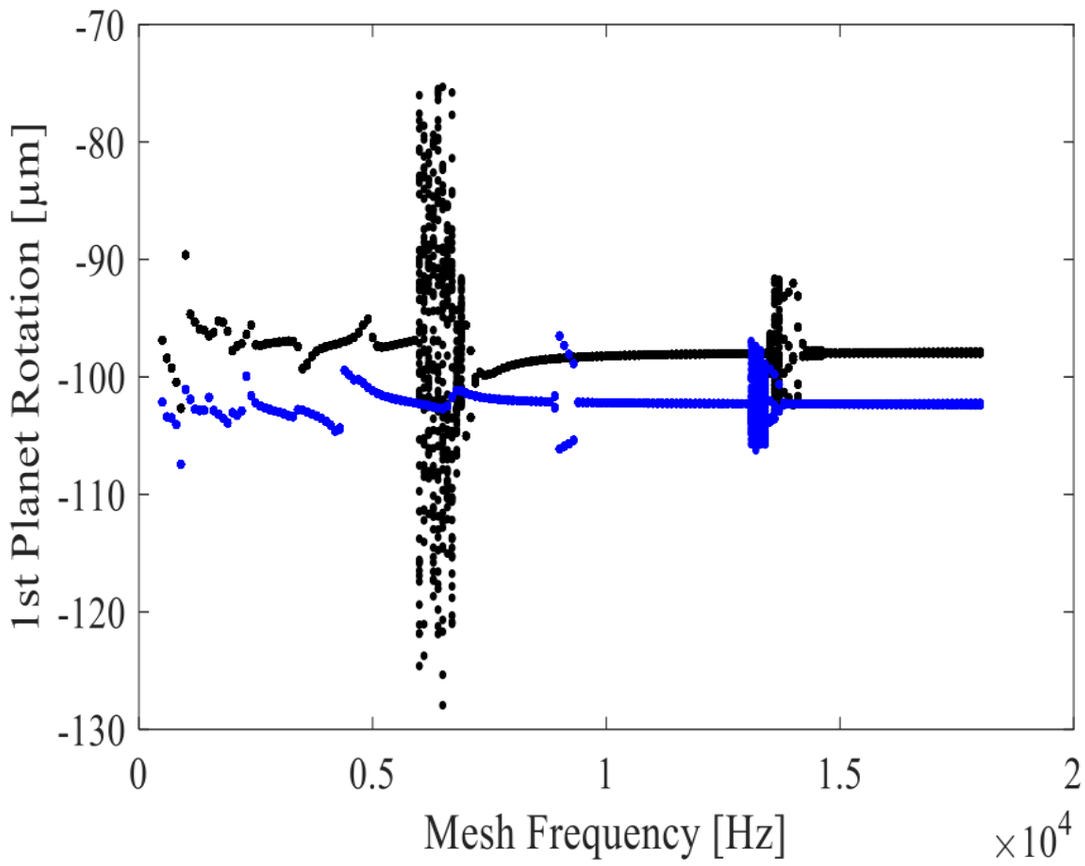



- Profile modifications are optimized by means of a genetic algorithm
- The dynamic scenario shows a significant vibration reduction with optimal reliefs

# Dynamic effect of optimization



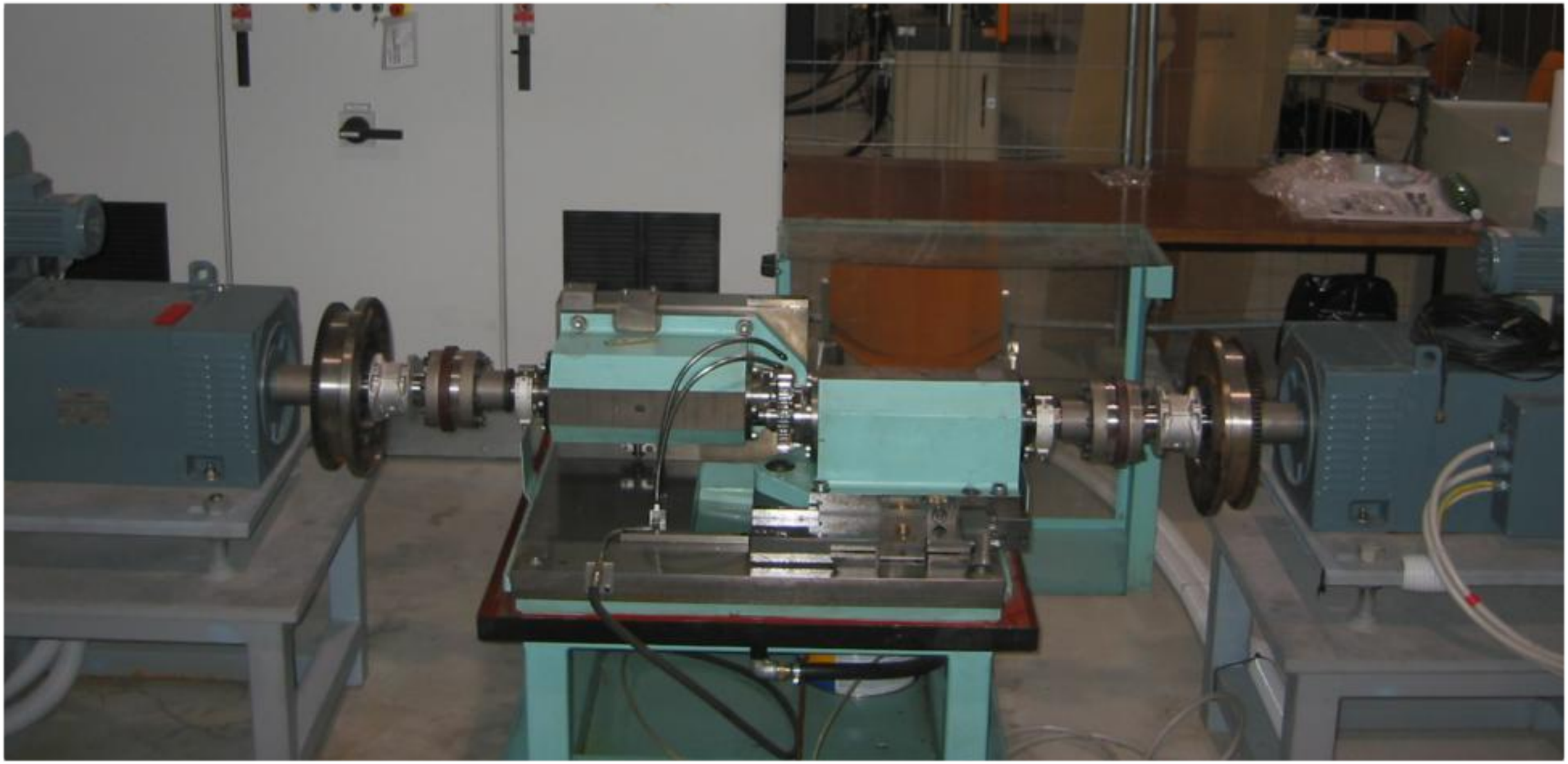

(a)




(b)

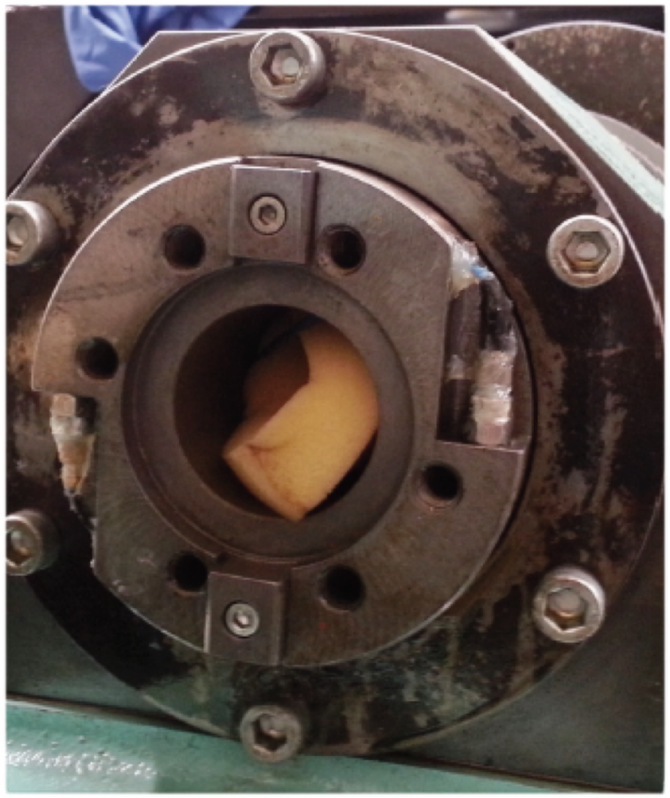
- The bifurcation diagrams show that instability regions are smaller for optimized gears
- Instability disappears for the resonance at 6900 Hz

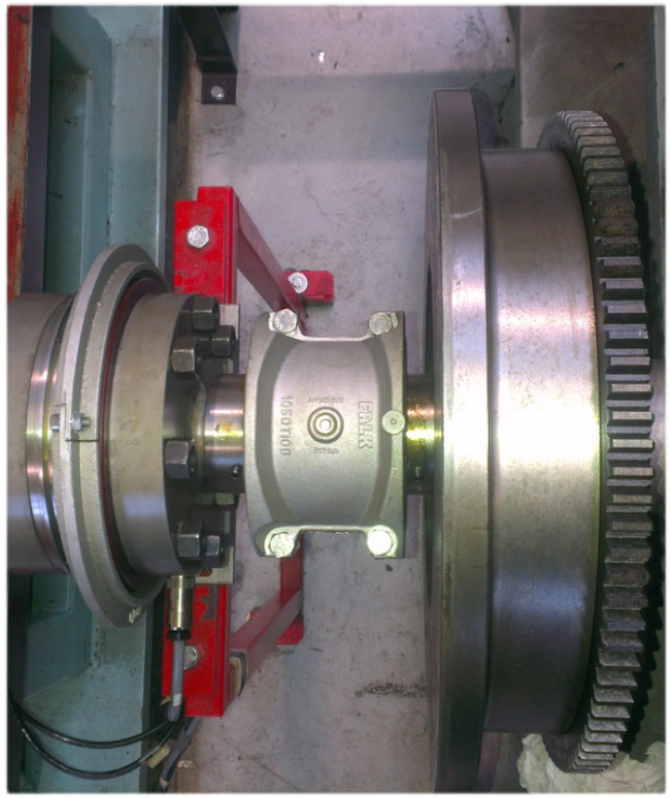
# Task 2: A test rig for coatings/treatments on gears

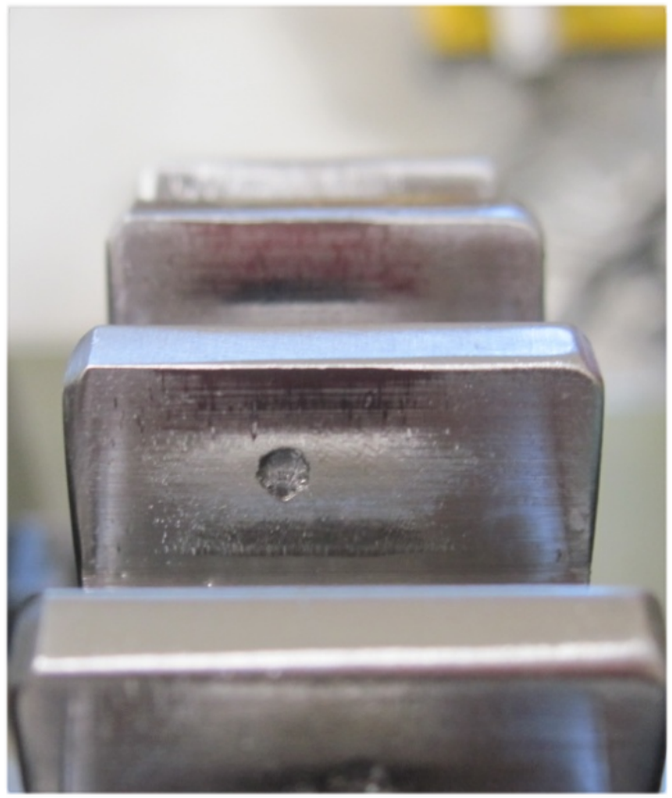


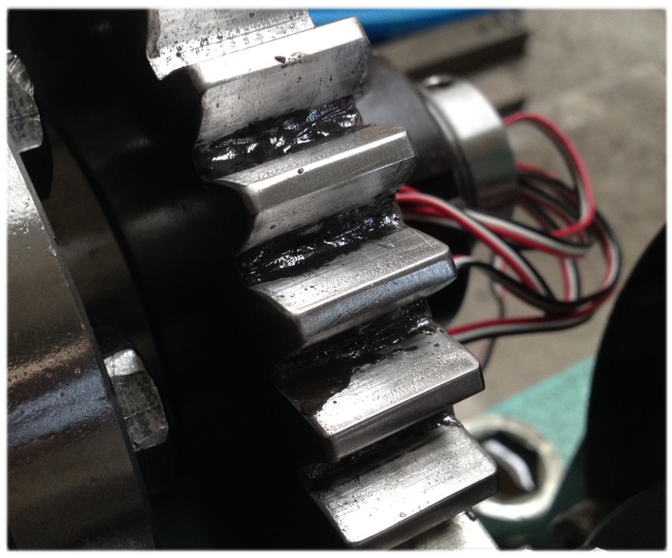
- A test rig for gear pairs (developed thanks to CNH) is presents in Modena
- The test rig has been adapted for testing coatings and treatments

# Measured physical quantities



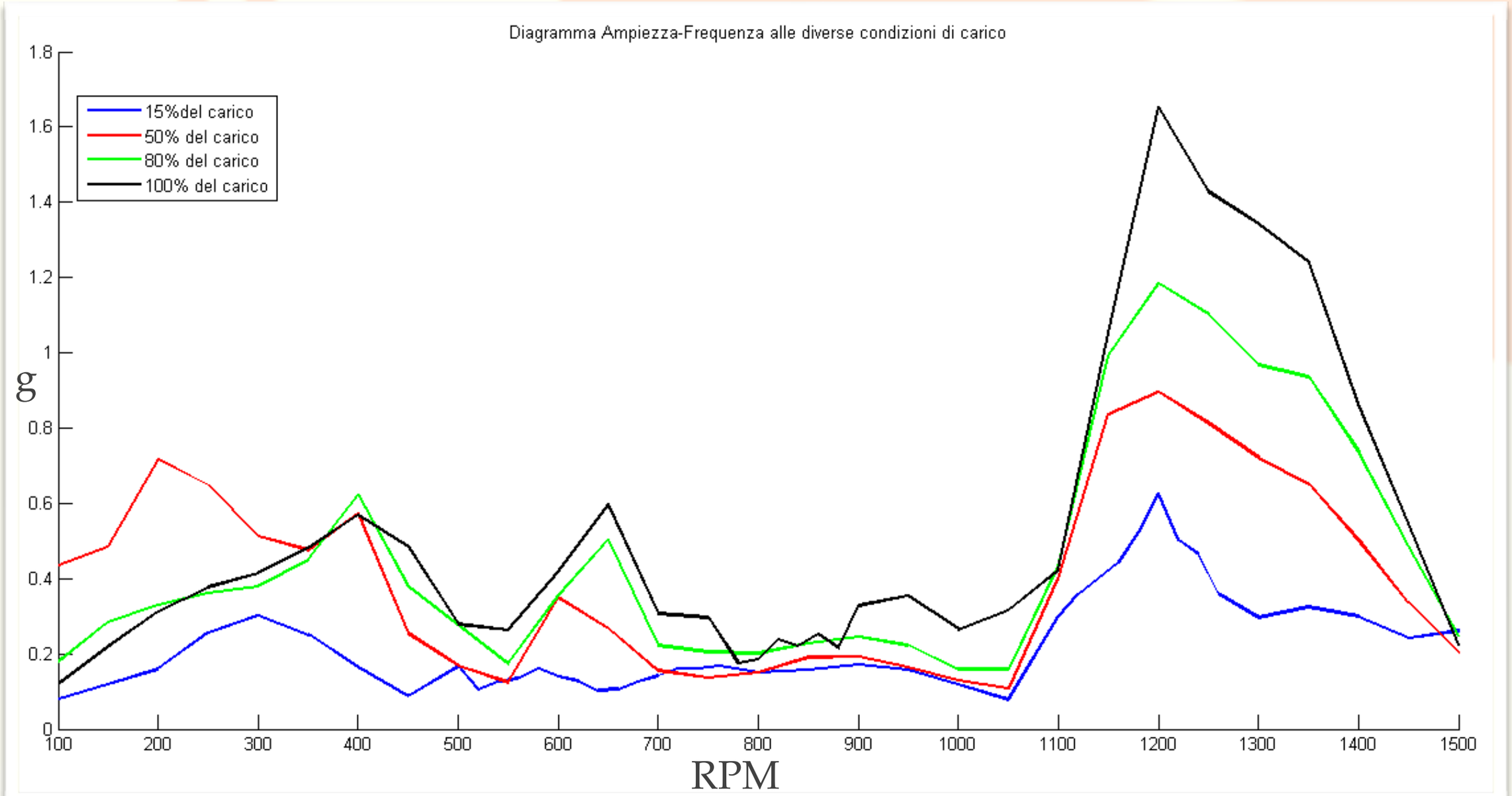






- Tangential vibration (by means of four accelerometers + slip rings) or strain
- Torque at pinion/gear, and therefore efficiency
- Fatigue testing (with limited load)

# DTE measurement




- The dynamic response of the system can be measured at varying speed
- This approach will be used to test less noisy gears (profile modifications or coatings)

# Test sequence

Coatings and treatments are tested on a tribometer

↓

Coatings and treatments are tested on 1:1 spur gears at our lab.

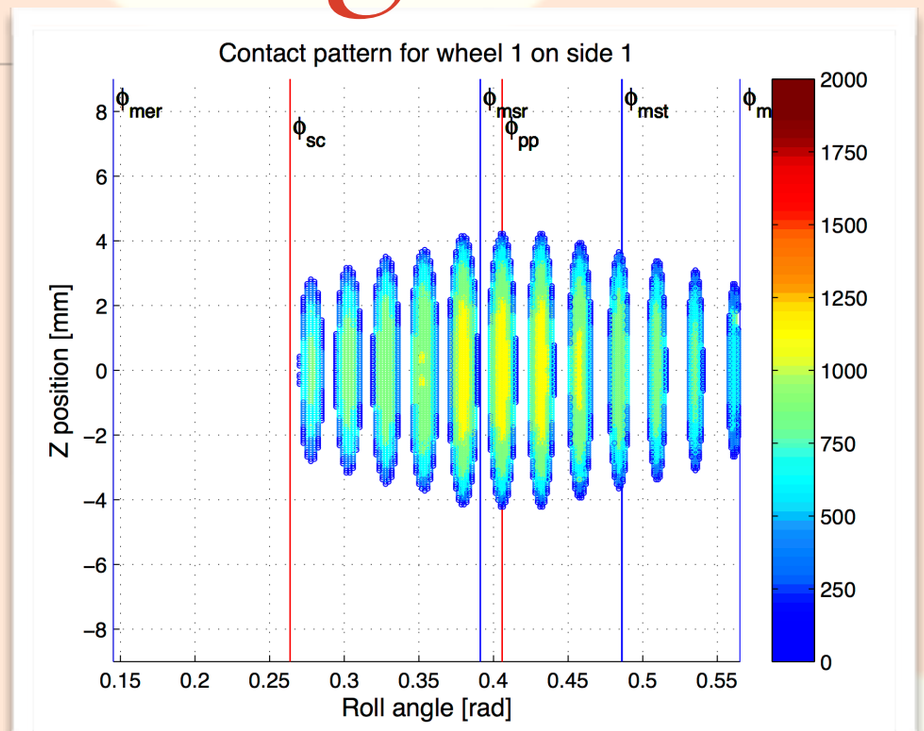
↓

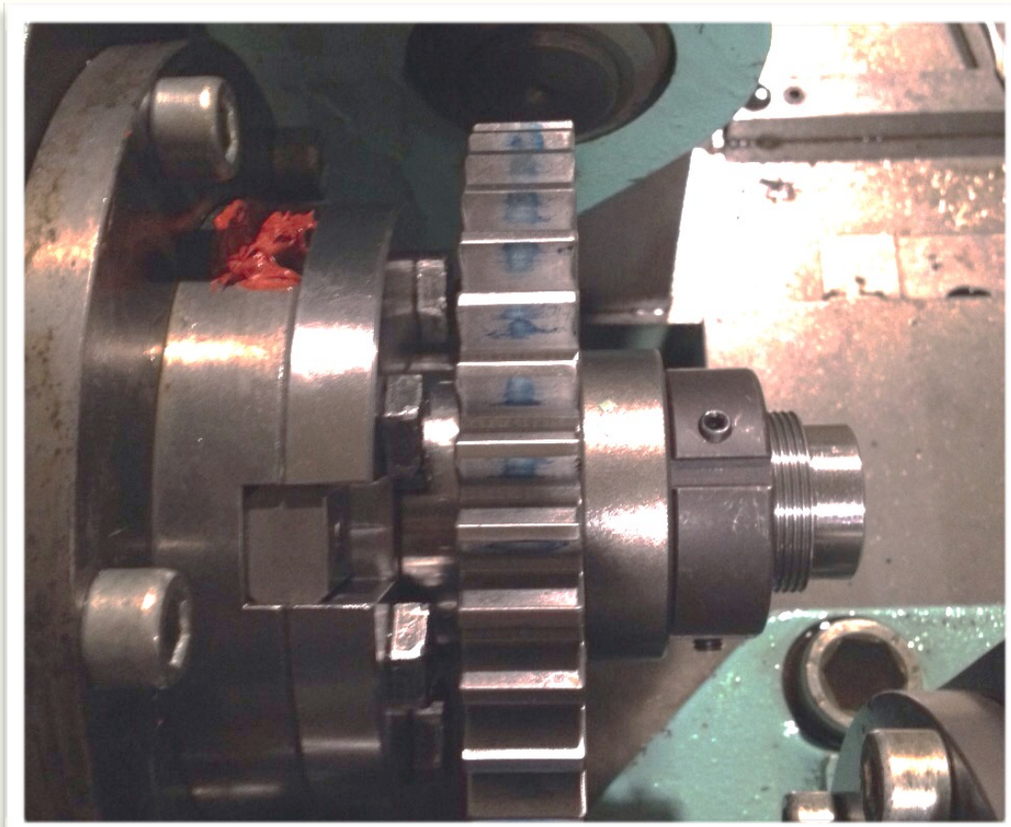
Best treatments will be tested by Bonfiglioli on a complete planetary gear

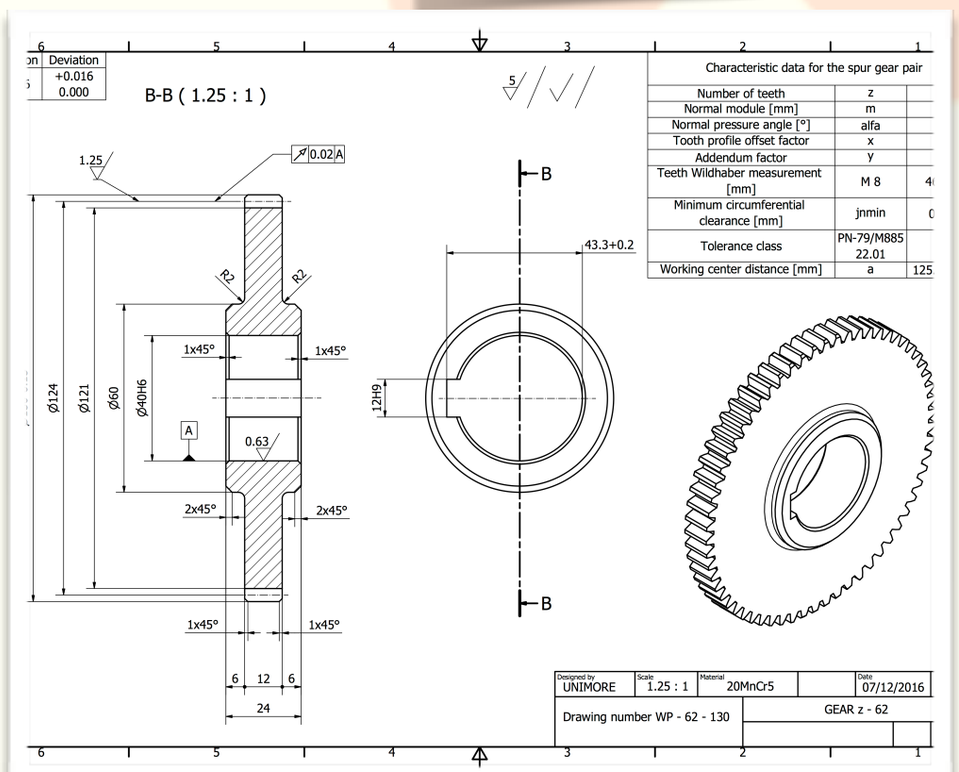
- In our test rig efficiency and durability will be investigated
- In the real application, optimal treatments will be applied to the sun or both to sun and planets

# Gear design for testing

- The test rig has limited torque
- In order to perform pitting tests, 1:1 gears have been designed using HPGA for simulations
- A large crowning is applied





# Conclusions

- Within MetAGEAR project, gear design methods previously developed by our lab. have been extensively used for simulation, optimization, as well as for designing experiments
- A new method for including profile modifications in planetary gear models is proposed and validated
- A new gear pair have been designed for performing tests on new treatments (OR 3)

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