Investigation of Radial Gap Size Change under Load and the Impact on Performance for a Twin Screw Compressor using Numerical Simulation

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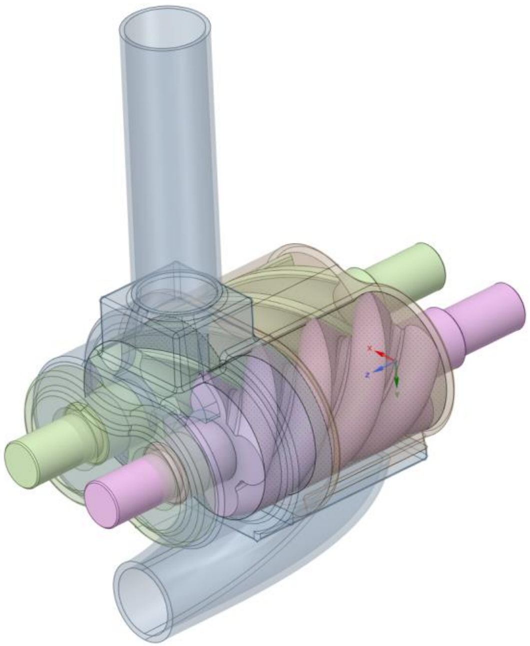
Introduction

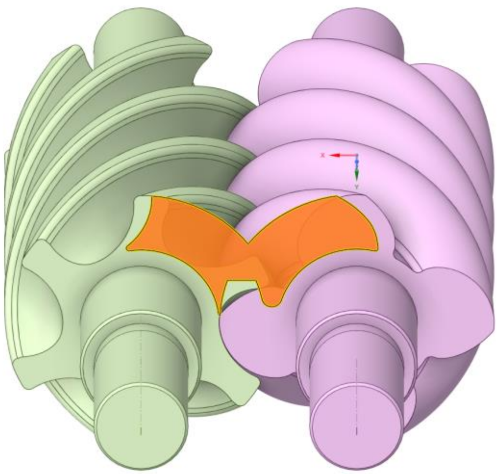
- Simulation of a twin screw compressor
  - With reference clearances
  - With changed clearances according to deformations based on thermal and pressure loads

➔ **Impact on calculated performance?**

- Compressor data
  - Twin screw compressor with SRM profiles

		Male rotor	Female rotor
Number of lobes	-	4	6
Length	mm	168.1	
Tip diameter	mm	101.9	101.1
Root diameter	mm	58.7	57.9
Rotor Wrap angle	deg	300	200
Center distance	mm	80	
Inner volume ratio	-	2.2	





Introduction

- Worflow of performed study

Ansys CFX

Transient CFD analysis

Calculate flow field with reference clearances

Ansys Mechanical

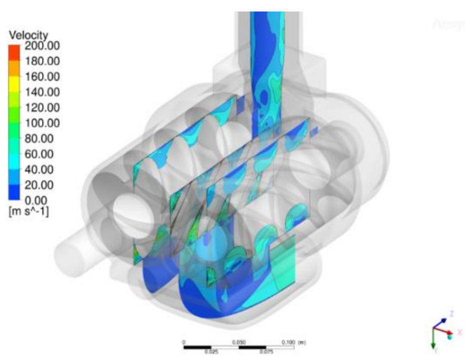
Static structural analysis

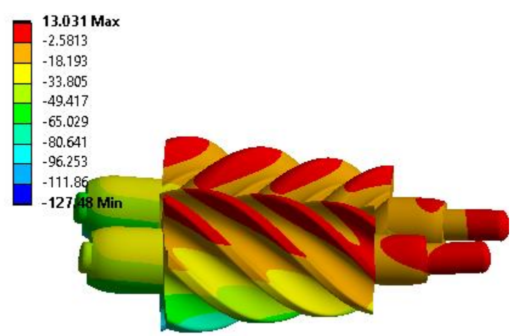
Calculate deformations based on CFD result

Ansys CFX

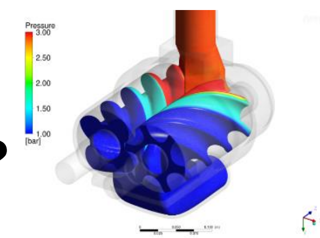
Transient CFD analysis

Rerun with deformed rotor geometry



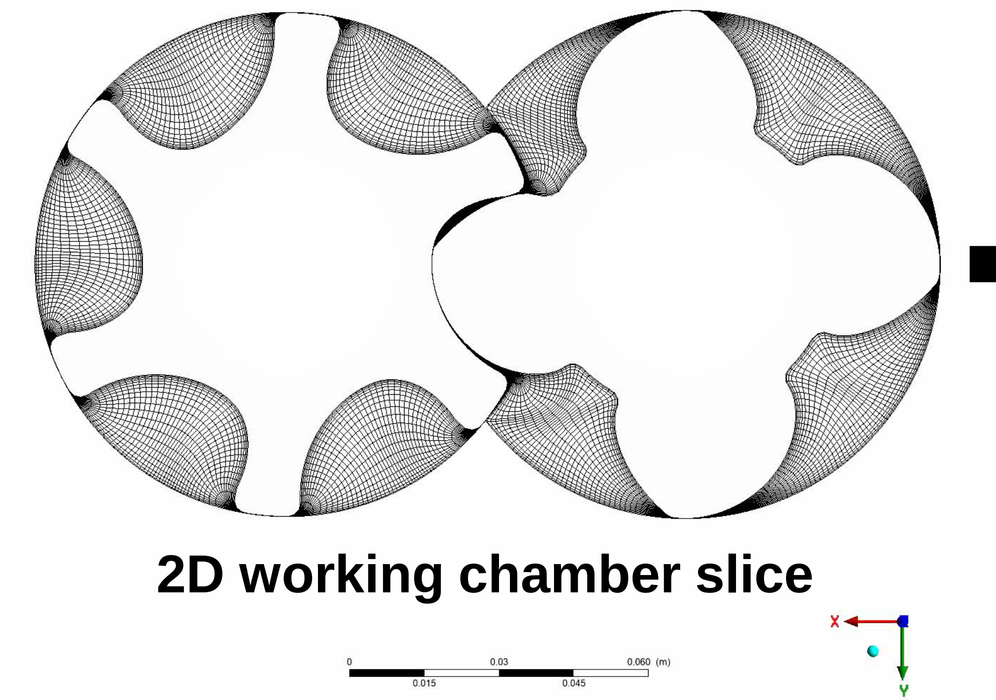


Flow rate?
Power?
Volumetric efficiency?

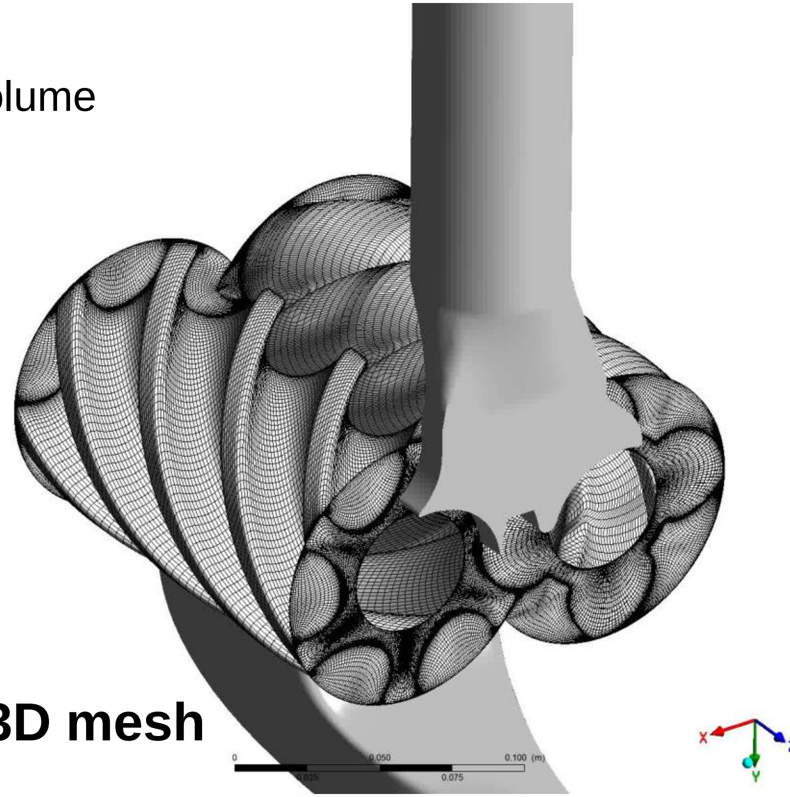


Rotor chamber modeling

- Deforming rotor chamber volume is meshed prior to simulation
  - Meshing software: TwinMesh
  - Grid generation for each angle increment (=1° for male rotor)
    - Meshing of a 2D working chamber slice
    - Translation into 3D grid with specified wrap angle
  - Radial and axial gaps are part of the resulting volume



2D working chamber slice



3D mesh

Rotor chamber modeling

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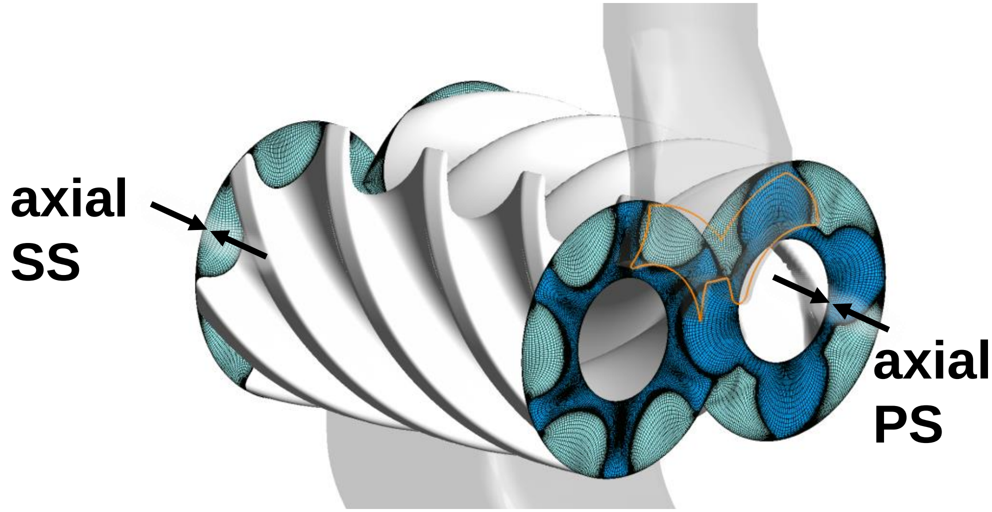
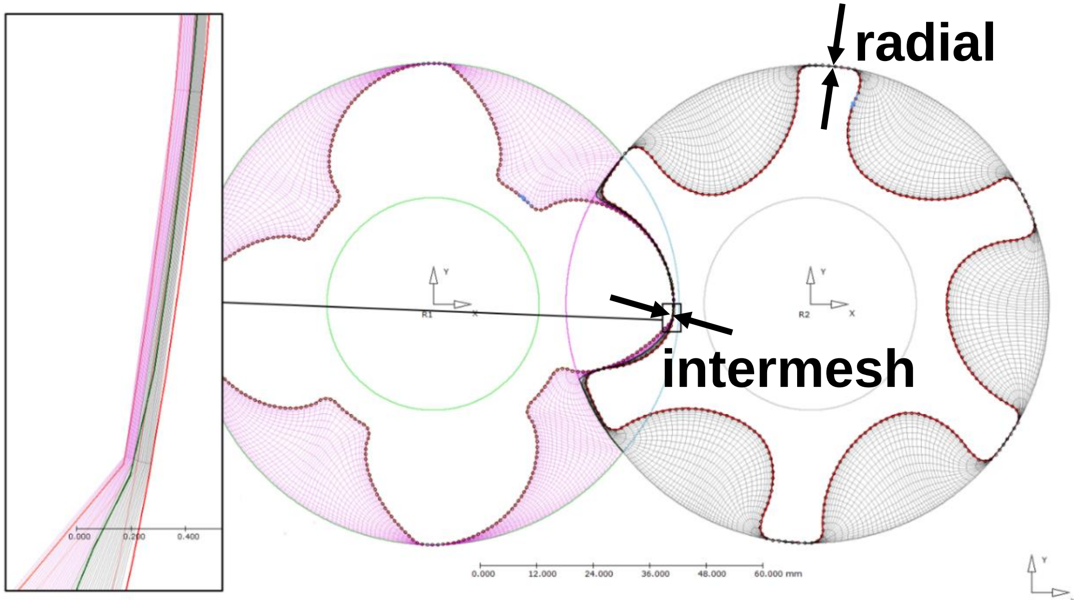
- Reference clearances (undeformed geometry)
  - Reference clearance sizes are present in the Working chamber grids
  - Element number over gaps:
    - Radial: 20
    - Intermesh: 40
    - Axial: 8

Clearances in µm	
Radial male (uniform)	50
Radial female (uniform)	50
Axial male (equal for pressure and suction side)	100
Axial female (equal for pressure and suction side)	100
Intermesh	100





Simulation setup (CFD)

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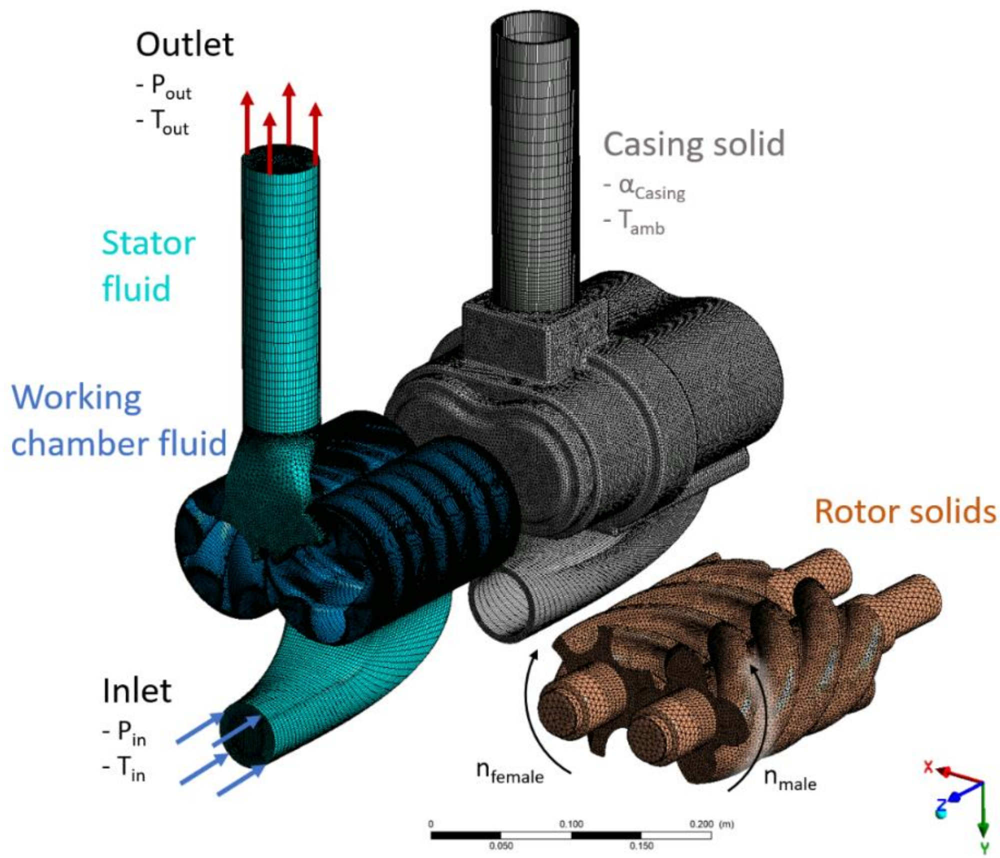
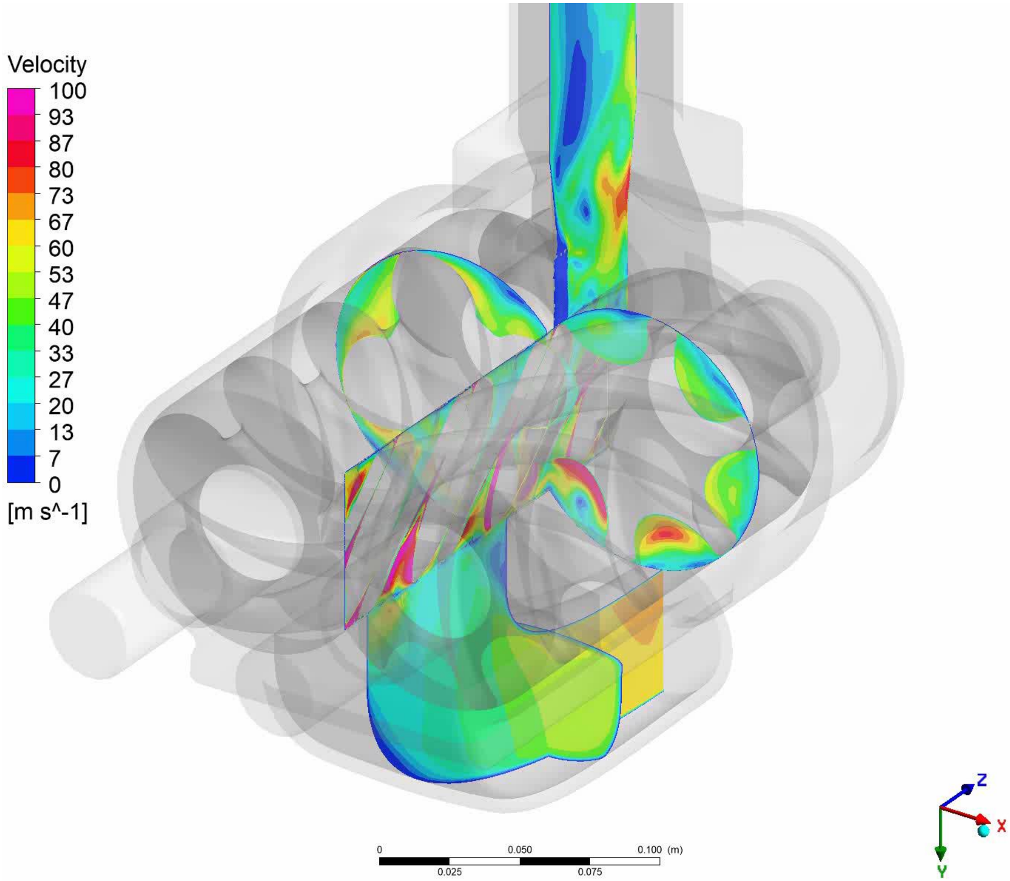
- General
  - CFD simulation with CHT
    - Solver: Ansys CFX
  - Incorporation of fluid and solid domains
  - Fluid: air ideal gas
  - Turbulence model: SST
- Boundary conditions

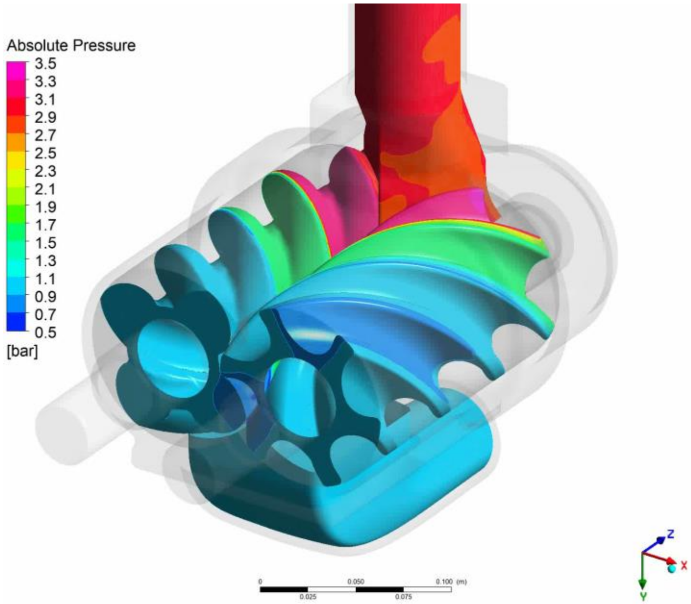
Angle increment (male rotor)	deg	1
Time step	µs	13.51
Rotation speed male	rev/min	1233 3
Rotation speed female	rev/min	8222
Inlet pressure (total)	bar(a)	1
Outlet pressure (static)	bar(a)	3
Inlet temperature	C	20
Outlet temperature	C	160
Rotor shaft temperature	C	70
Ambient temperature	C	20
Heat transfer coefficient for outer casing walls	W/(m² K)	10

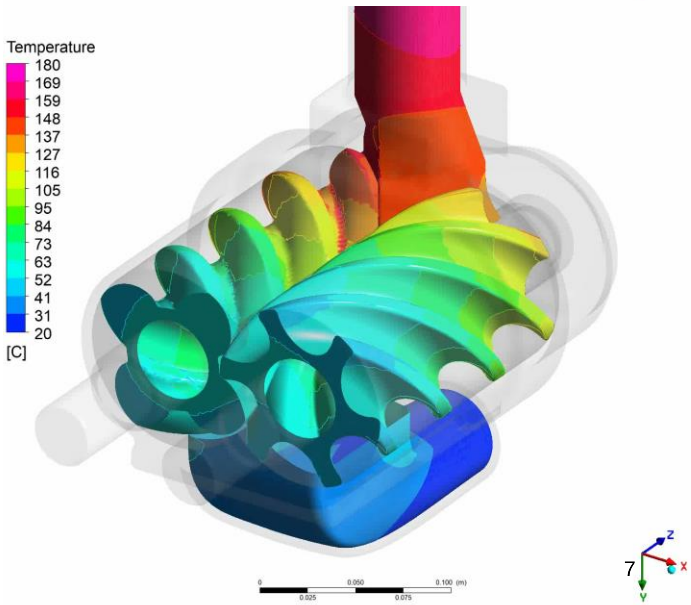


Simulation results (CFD)

- 3D fields flow quantities
  - Results allow to analyze local flow variables as well as integral values over time.







Simulation results (CFD)

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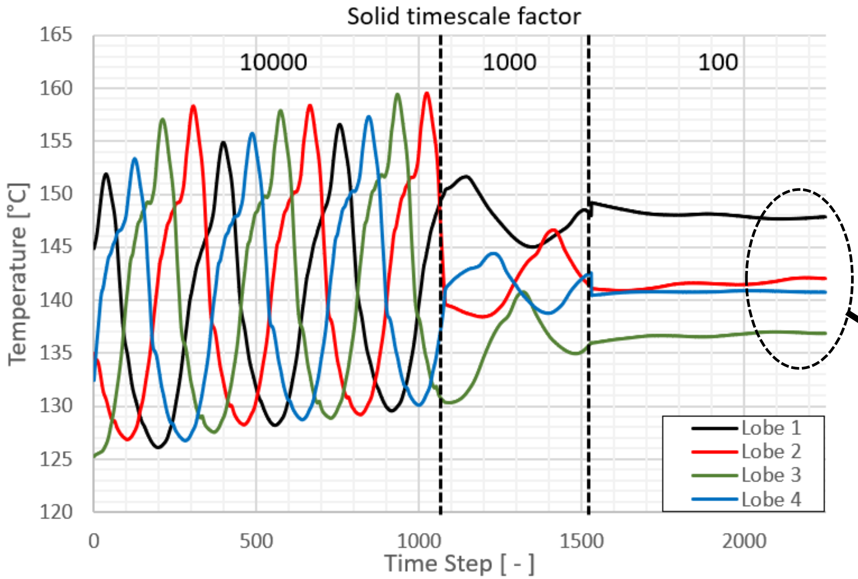
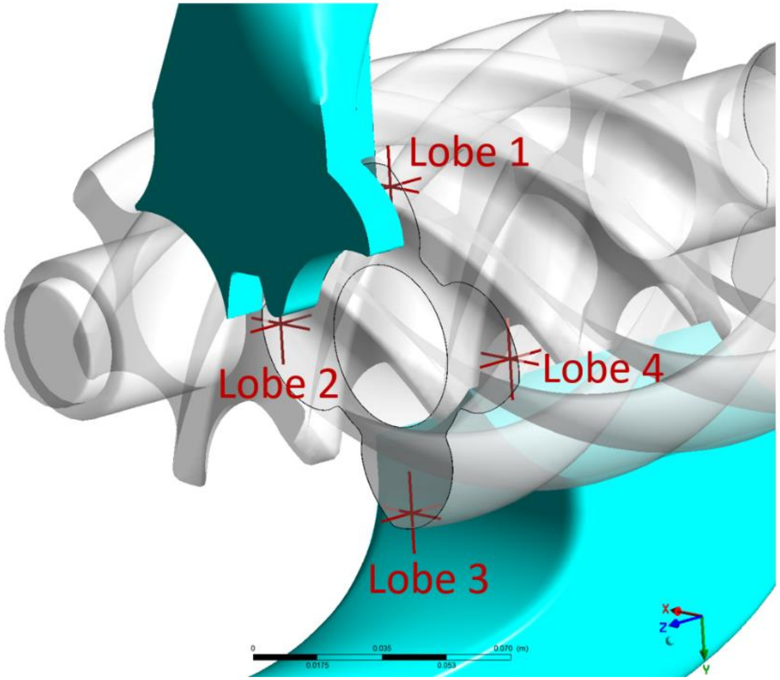
- Temperature at 4 monitor points
  - Structural heating (rotor and casing) takes place on a much larger timescale compared to fluid timescale.
    - Unfeasible amount of revolutions would have to be calculated.
  - Workaround: calculation with large timescale factor for solids; decreasing the factor step by step





Temperature probes at male rotor lobes (pressure side)

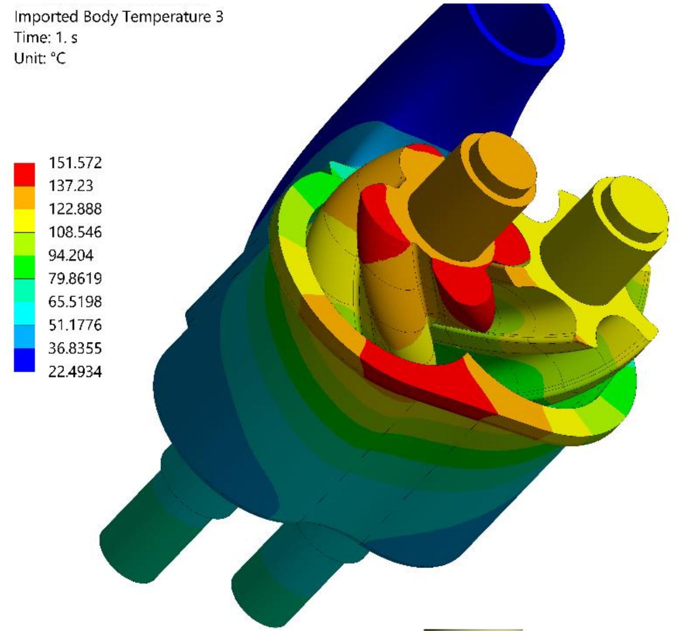
„Freeze“ of values for timescale factor 100

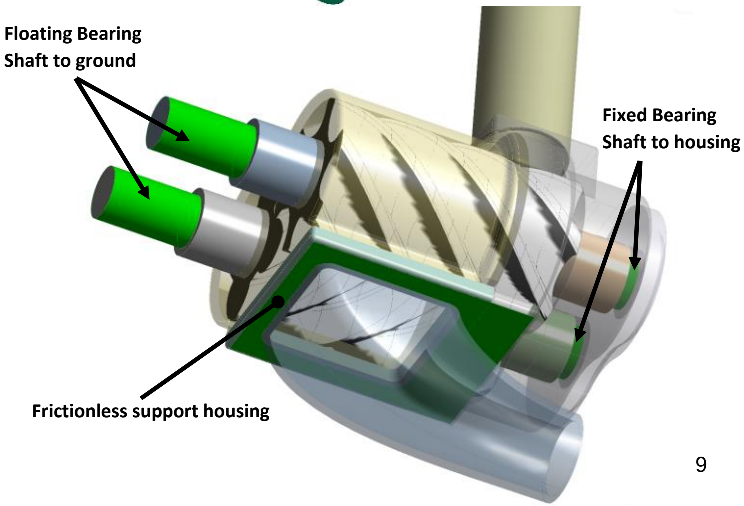
Simulation setup (structural)

- General
  - Static structural analysis
    - Solver: Ansys Mechanical (APDL)
  - Incorporation of solid bodies for rotors and casing
  - Imported loads (temperature and pressure) from CFD result
    - For one point in time
    - Interpolation onto mechanical mesh
  - Specified supports (fixed vs. floating)
    - Bearing stiffness (radial): 500 kN/mm
  - Material: steel
- Material data of structural steel

Density	kg/m^3	7850
Young's modulus	GPa	200
Poissons ratio	-	0.3
Coefficient of thermal expansion	1/K	$1.2 \cdot 10^{-5}$

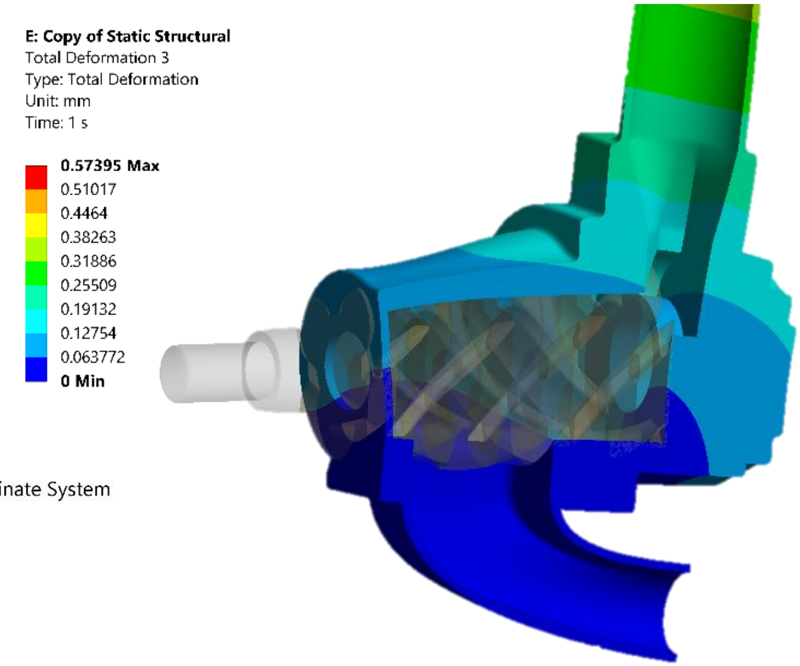
Imported temperature field (CFD result)

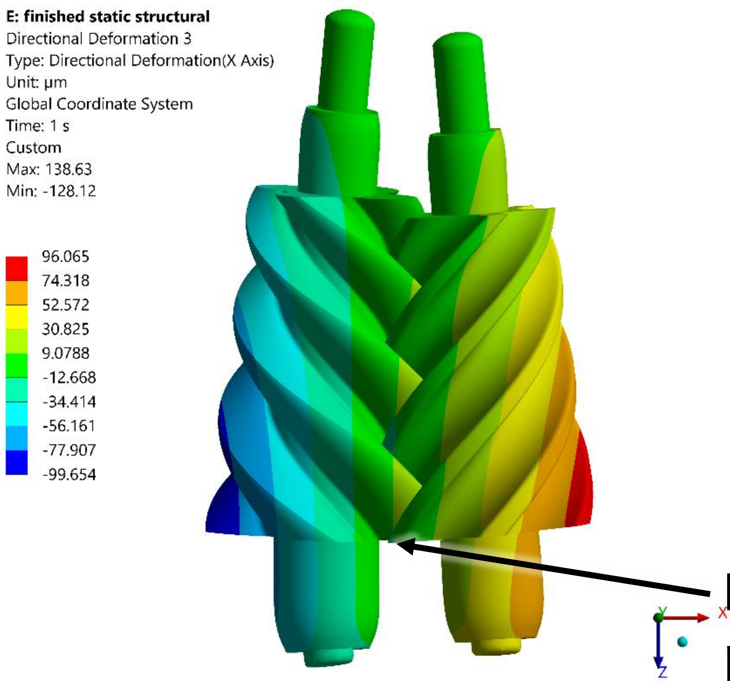


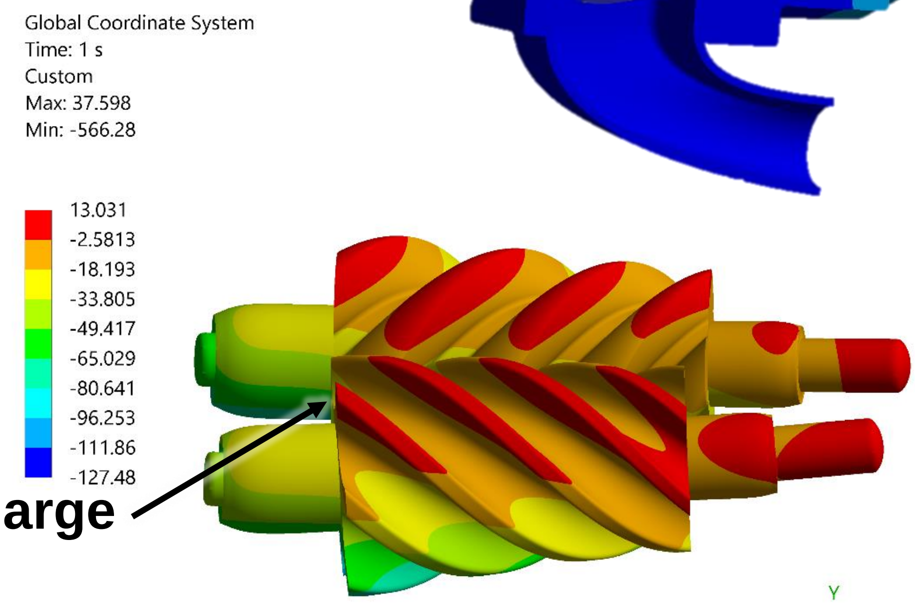


- 3D deformations of rotors and housing
  - Mainly due to temperature gradients
    - more than 10x larger deflections than caused by pressure gradients
  - Visualized with scale factor 500

➔ Will affect clearance sizes







Geometry adaption (clearance change)

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- Change of clearances due to deformation of rotors and casing

Structural Analysis

Simplification ➔

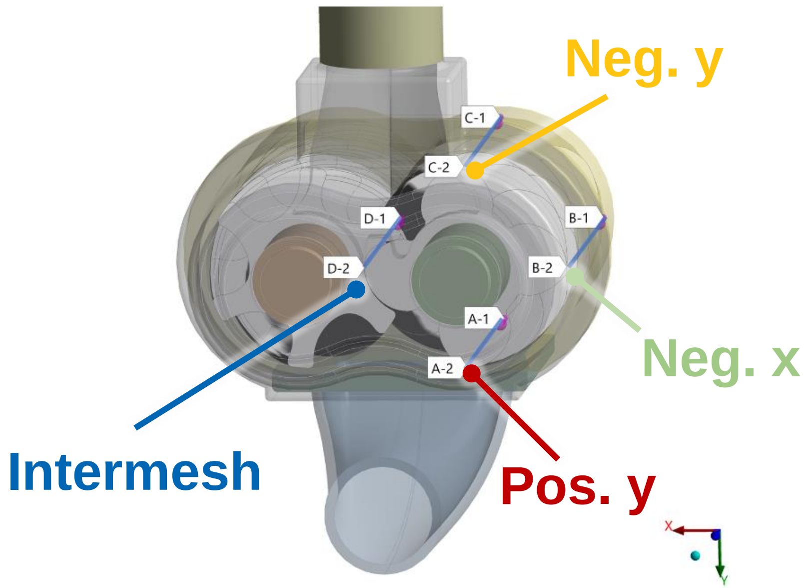
Realized deformations in the CFD mesh

3D deformations of rotors and housing

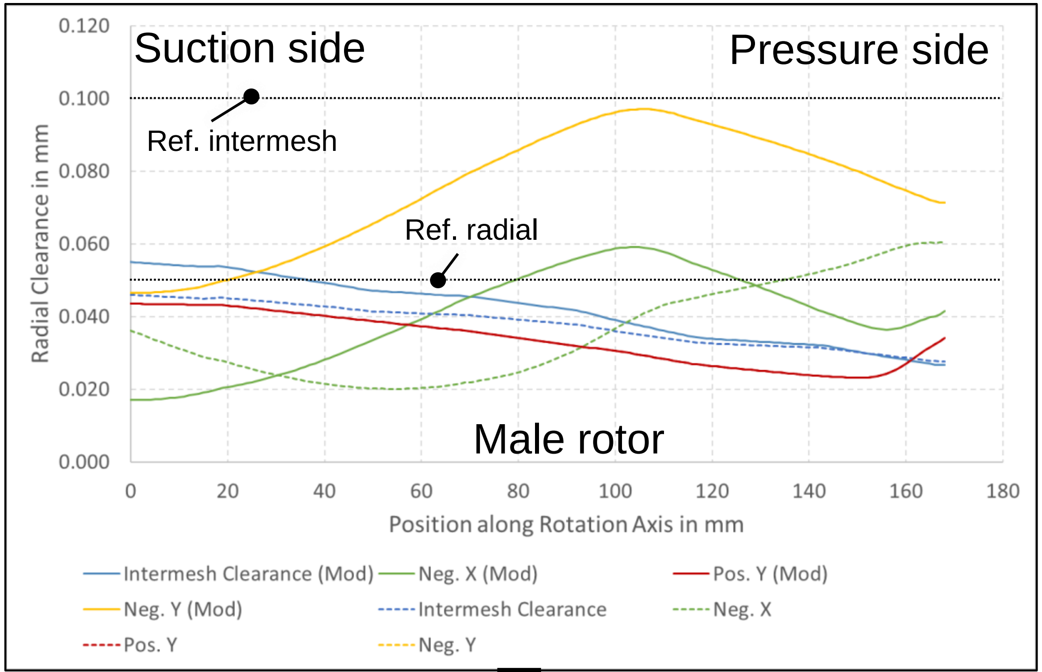
- **Superposition of rotor and casing deflection:**
  ➔ Only rotor walls are deformed in the mesh (target is the resulting gap cross section)
- **Only deformations in radial direction**

Geometry adaption (clearance change)

- Evaluation of the deflection in radial direction (dx, dy)
  - Export of dx and dy along paths in axial direction (paths A, B, C and D)



Paths for deformation values (exemplaric for male rotor)



Dashed lines = Target deflection
bold lines = realized deflection in mesh

➔ Deviation for intermesh gap and neg. x gap
➔ Compromise due to meshing approach

Geometry adaption (CFD results)

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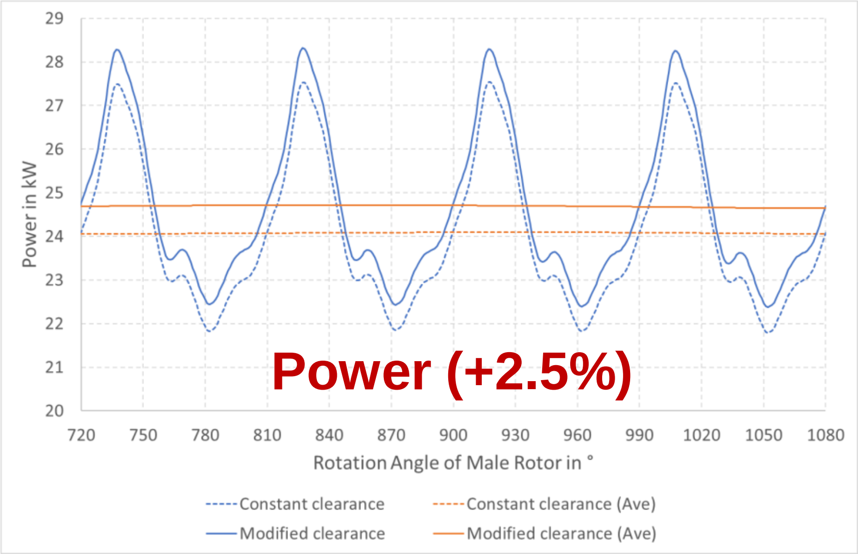
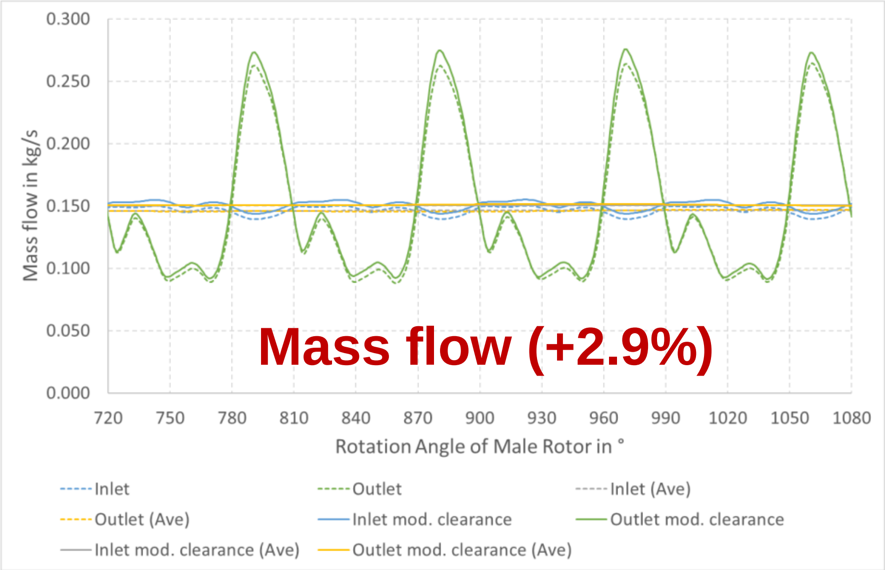
- Rerun with deformed rotor geometry
  - Working chamber grids are re-generated, taking deflections in radial direction into account.

➔ Increase in flow rate and power
  - Mass flow and thus volumetric efficiency increase about 2.9%
  - Shaft power increases about 2.5%





Conclusion

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- Simplified approach at first
  - Feasibility, challenges, limits?
- No direct coupling between fluid and structure calculations is realized
  - Instead: Separate calculations for fluid and structure
- Uncertainties are present for this approach
  - Severity of simplifications, e. g.
    - only taking deflections along paths in radial directions
    - Deviation from exact deformations from structural results (target vs. realized gaps)
    - Calculation of deformations only for an (arbitrary) point in time
  - Only generic compressor model; no experimental validation
- Goals
  - Be closer to real operating conditions
  - Identify trends to gain knowledge or improve compressor performance
  - Achieve good compromise between simulation effort and accuracy

Thank you for your attention!

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