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

<table>
<thead>
<tr>
<th></th>
<th>Male rotor</th>
<th>Female rotor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lobes</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>Length</td>
<td>mm</td>
<td>168.1</td>
</tr>
<tr>
<td>Tip diameter</td>
<td>mm</td>
<td>101.9</td>
</tr>
<tr>
<td>Root diameter</td>
<td>mm</td>
<td>58.7</td>
</tr>
<tr>
<td>Rotor Wrap angle</td>
<td>deg</td>
<td>300</td>
</tr>
<tr>
<td>Center distance</td>
<td>mm</td>
<td>80</td>
</tr>
<tr>
<td>Inner volume ratio</td>
<td>-</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Introduction

- Workflow 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?
• 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
Rotor chamber modeling

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

<table>
<thead>
<tr>
<th>Clearances in µm</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial male (uniform)</td>
<td>50</td>
</tr>
<tr>
<td>Radial female (uniform)</td>
<td>50</td>
</tr>
<tr>
<td>Axial male (equal for pressure and suction side)</td>
<td>100</td>
</tr>
<tr>
<td>Axial female (equal for pressure and suction side)</td>
<td>100</td>
</tr>
<tr>
<td>Intermesh</td>
<td>100</td>
</tr>
</tbody>
</table>
Simulation setup (CFD)

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

- **Boundary conditions**

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

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Simulation results (CFD)

- 3D fields flow quantities
  - Results allow to analyze local flow variables as well as integral values over time.
Simulation results (CFD)

- 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td>7850</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>GPa</td>
<td>200</td>
</tr>
<tr>
<td>Poissons ratio</td>
<td>-</td>
<td>0.3</td>
</tr>
<tr>
<td>Coefficient of thermal expansion</td>
<td>1/K</td>
<td>1.2·10⁻⁵</td>
</tr>
</tbody>
</table>

Imported temperature field (CFD result)
Simulation results (structural)

- 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

Global Coordinate System
Time: 1 s
Custom
Max: 37.598
Min: -566.28

Discharge port

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Geometry adaption (clearance change)

- Change of clearances due to deformation of rotors and casing

**Structural Analysis**

- 3D deformations of rotors and housing

**Simplification**

**Realized deformations in the CFD mesh**

- 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

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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%
• 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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