Optimization and preliminary design of a high-temperature, low pressure-ratio sCO$_2$-compressor for a wide operating range

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Motivation

- Experimental facility set up within the CARBOSOLA project (supercritical carbon dioxide as alternative working fluid for bottoming cycle and solar thermal application)
- First rig configuration without expansion device → pure fluid circulation at low pressure difference
- Design of a centrifugal compressor to provide fluid circulation over a wide operating range

Baseline impeller design

- First impeller design based on the rig boundary conditions
- Parametrized geometry model using the design software CFturbo providing a direct export to CFD

Optimization criteria

- Geometry optimization by varying 20 design parameters using a multi-objective genetic algorithm
- Numerical evaluation of each design in terms of a 3D, single blade passage CFD-model
- Operating range of each design estimated at the design point by the equivalent diffusion factor from 1D impeller theory:
  \[ D_{eq} = \frac{w_{max}}{w_2} = \frac{1}{2} \cdot w_2 \cdot \left( w_1 + w_2 + \frac{2\pi \cdot d_2 \cdot u_2 \cdot l_2}{z_{eq} \cdot l_B} \right) \]
- Full optimization target:
  \[ \min(D_{eq}) \land \min(w_2) \Pi_{tot} \geq 1.036 \]

Optimization results

- Evaluation of 1067 designs in total
- Selection of 4 designs with various $D_{eq}$ to verify the optimization target

- Comparison of performance lines validates suitability of $D_{eq}$ to be used as an indicator for a wide operating range
- Differences for impeller 728 and 87 shows that $D_{eq}$ is an indicator but not a guarantee for a wide and stable range
- Impeller design 728 shows the best compromise of a wide operating range and high values for $\Pi_{tot}$

Optimized design

- Based on the selected impeller a solid model and a stage design were created for further evaluation

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