CFD Simulation of a Screw Compressor Including Leakage Flows and Rotor Heating

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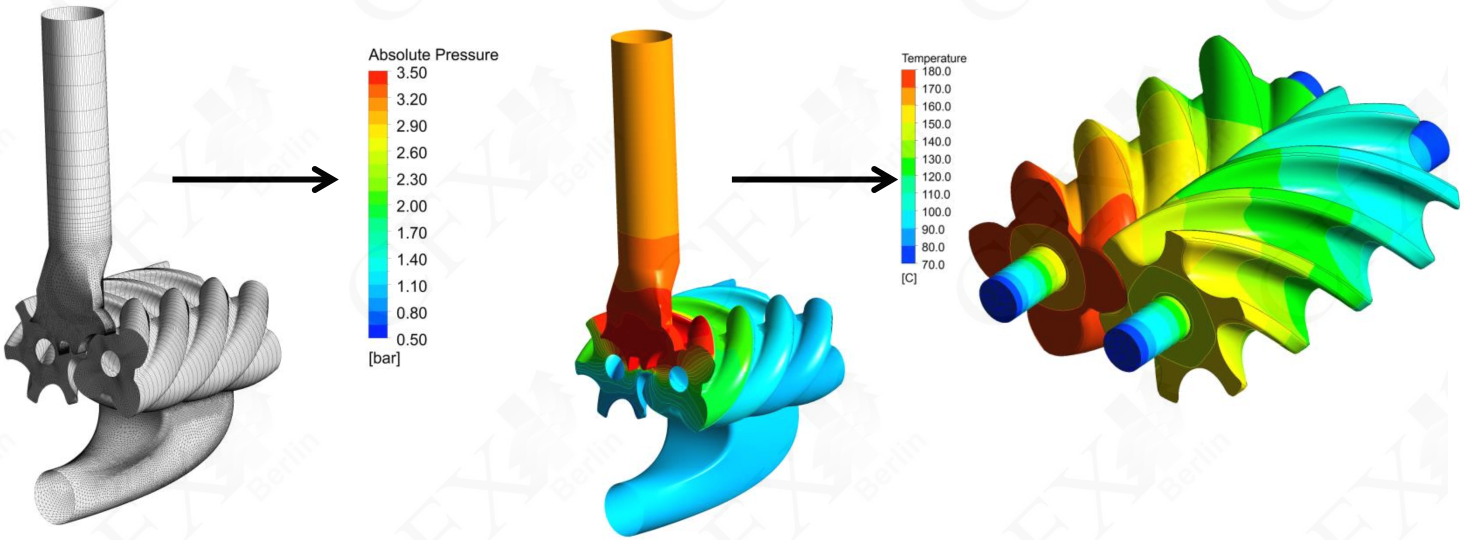
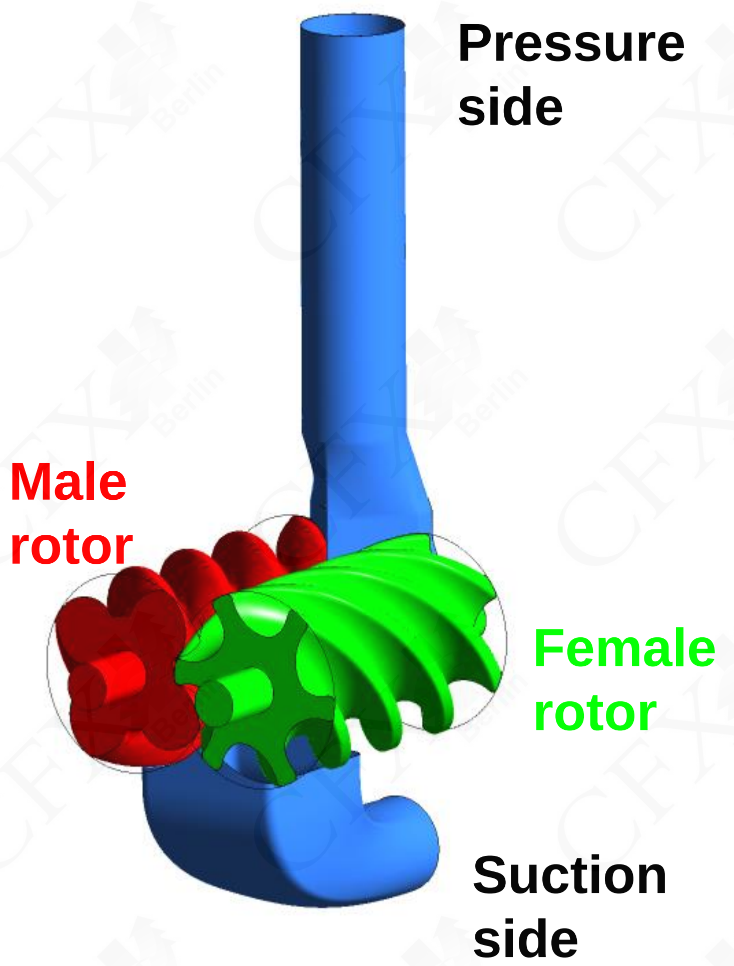
Dr. Andreas Spille-Kohoff
Jan Hesse
Ahmed El Shorbagy

CFX Berlin Software GmbH
Karl-Marx-Allee 90 A
10243 Berlin, Germany



Introduction

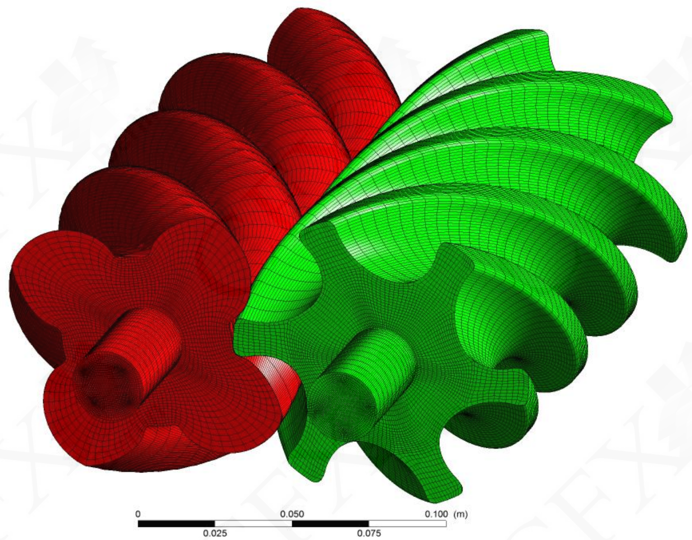
- Example case is from Master‘s Thesis of Ahmed El Shorbagy:
  - *“Auslegung, Konstruktion und numerische Simulation eines trockenlaufenden Schraubenverdichters und Vergleich der Simulationsergebnisse mit den Entwurfsanforderungen“*
    Technical University Berlin, 2014
  - Design, construction, and numerical simulation of a dry-running screw compressor
    - Design: SRM profile 4+6 with rotor profile after „Schraubenverdichter“ by Lorenz Rinder (1979)
    - Construction: suction and pressure side with 3 different pressure ports
    - Simulation: setup, solution, and post-processing with ANSYS CFX
  - Extended by axial gaps and CHT in solids

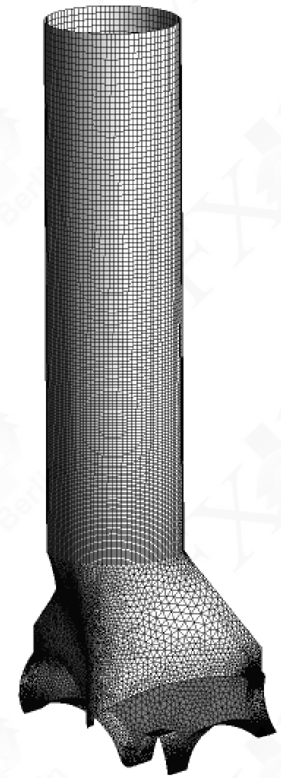


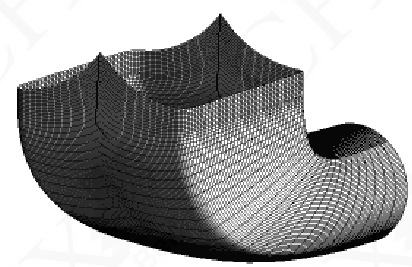
Software and Workflow

Software and workflow:

- Meshing
  - TwinMesh for chamber meshes
  - ANSYS Meshing for stator and solid meshes
- Pre-processing
  - Session file from TwinMesh
  - ANSYS CFX-Pre
- Solution
  - ANSYS CFX Solver with User Fortran for reading of rotor meshes at run-time
  - ANSYS Structural for deformations
- Post-Processing
  - ANSYS CFD-Post



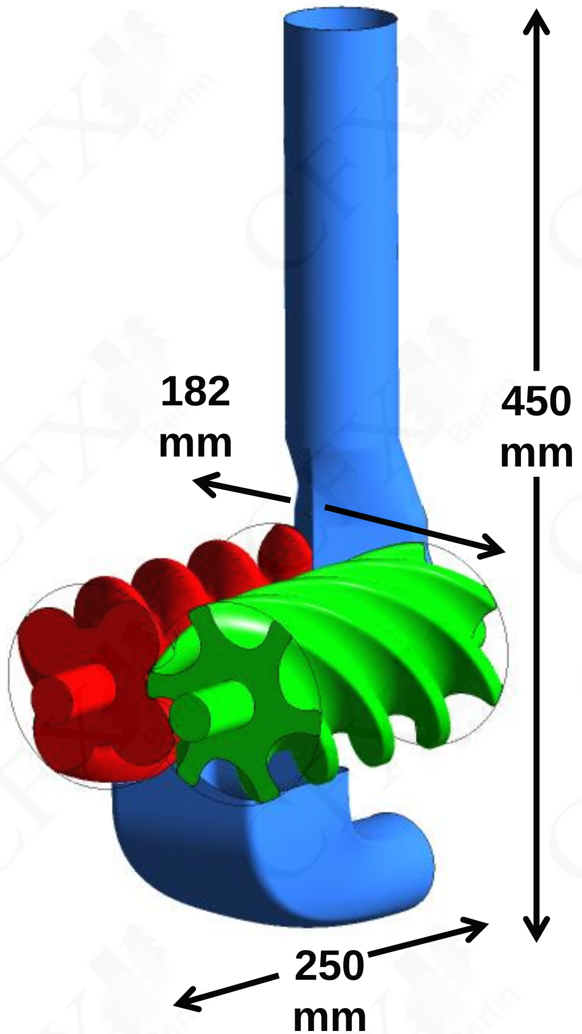




Geometry and Dimensions

Geometry and dimensions:

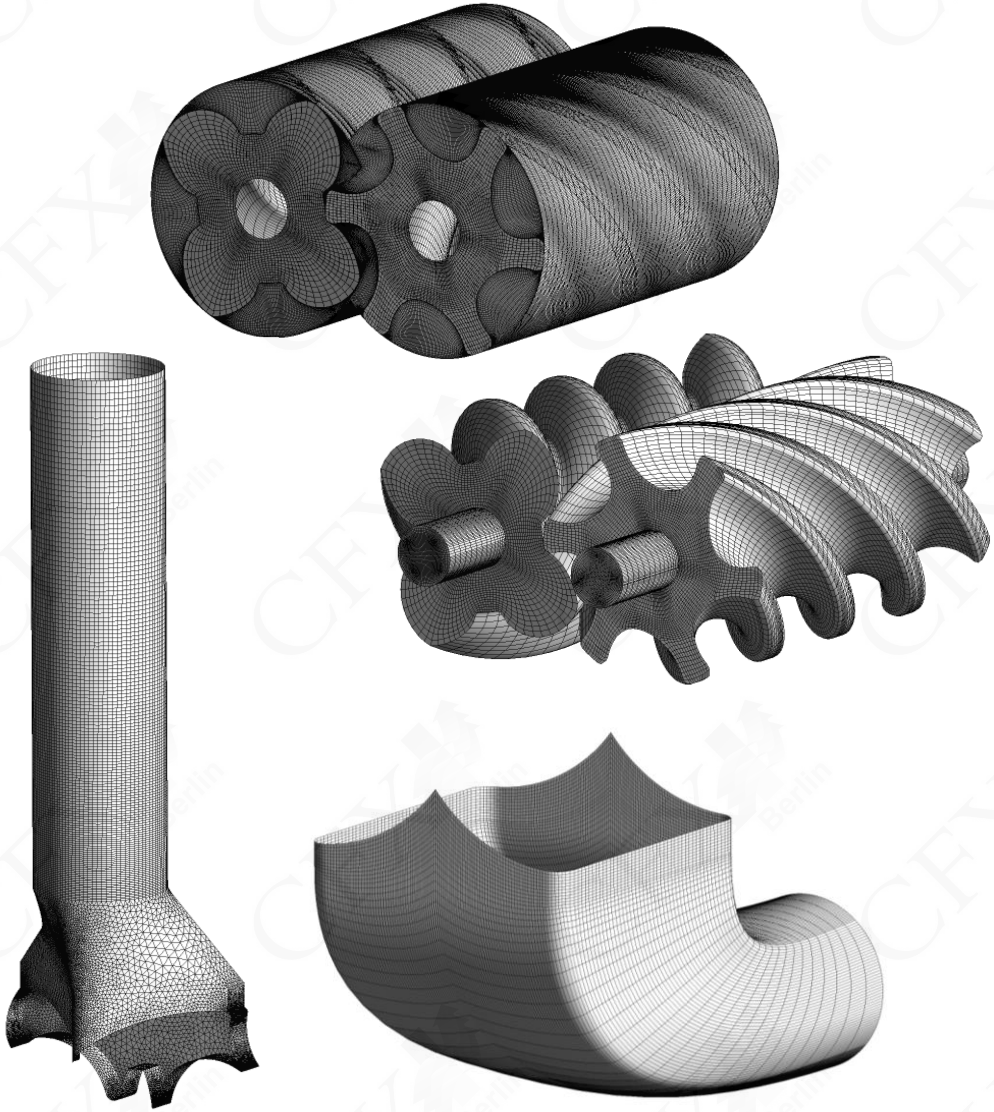
- Rotors:
  - Male: 4 lobes, ∅ 102 mm, wrap angle 300°
  - Female: 6 lobes, ∅ 101.2 mm, wrap angle 200°
  - Length: 168.3 mm
  - Shafts: length 248.3 mm, ∅ 24 mm
  - Distance of rotation axes: 80 mm
  - Clearances: radial 50 µm, interlobe 100 µm, axial 100 µm
- Ports:
  - Radial suction port
  - Axial and radial pressure port in 3 variations for volume ratio 2.2, 2.7 and 3
  - Ending in pipes with ∅ 50-55 mm



Meshing

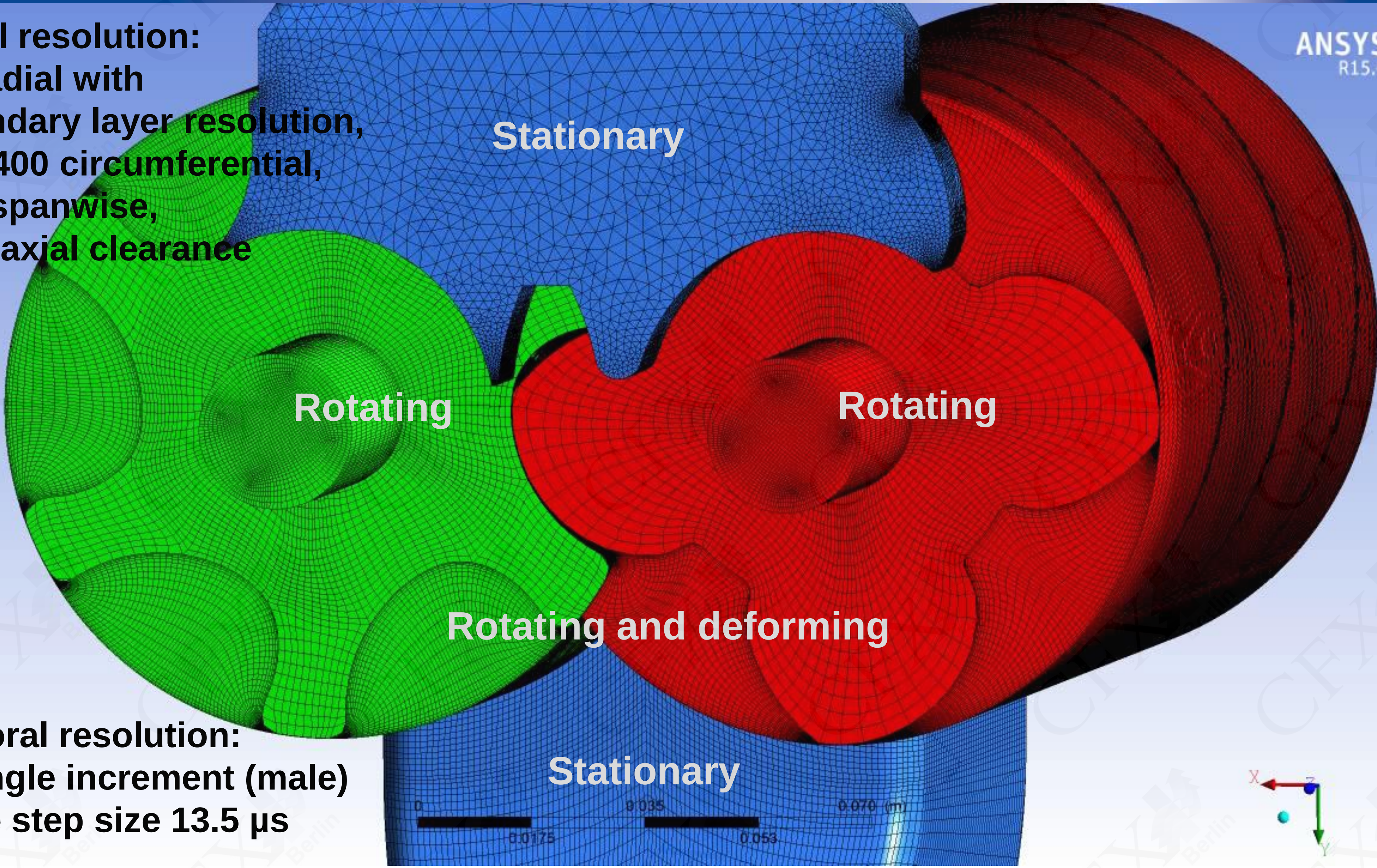
Meshing:

- Rotors:
  - Hexahedral meshes, each appr. 550 000 nodes, for rotating and deforming fluid regions around rotors including clearances from TwinMesh for each time step
  - Hexahedral meshes, each appr. 300 000 nodes, for solid rotors
- Stator parts:
  - Mixed mesh with hexahedrons, tetrahedrons and prisms (1 mio nodes)
- Total mesh:
  - 2.7 mio nodes
  - 3.5 mio elements



Meshing cont.

Spatial resolution:
- **20 radial with boundary layer resolution,**
- **300-400 circumferential,**
- **130 spanwise,**
- **5-10 axial clearance**

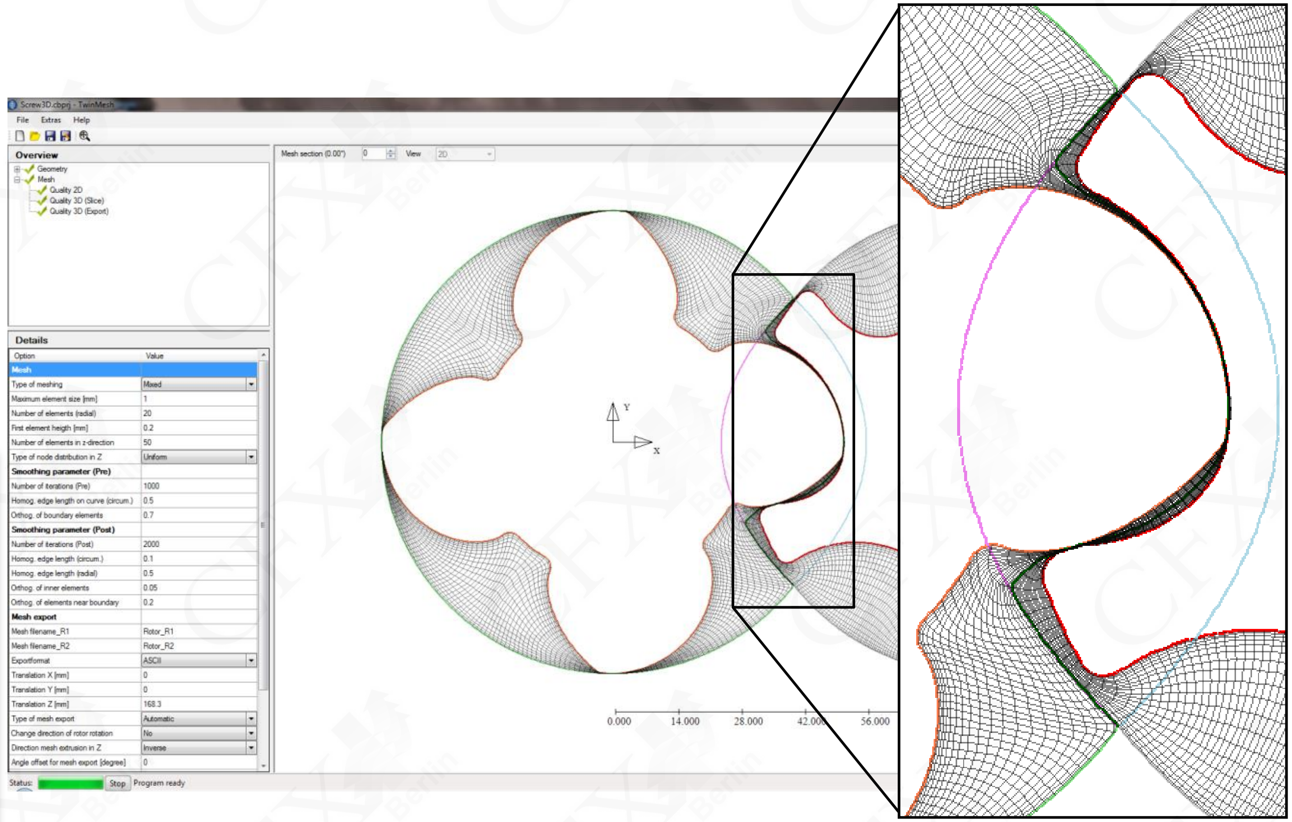


Temporal resolution:
- **1° angle increment (male)**
- **Time step size 13.5 µs**

Meshing with TwinMesh

CAD

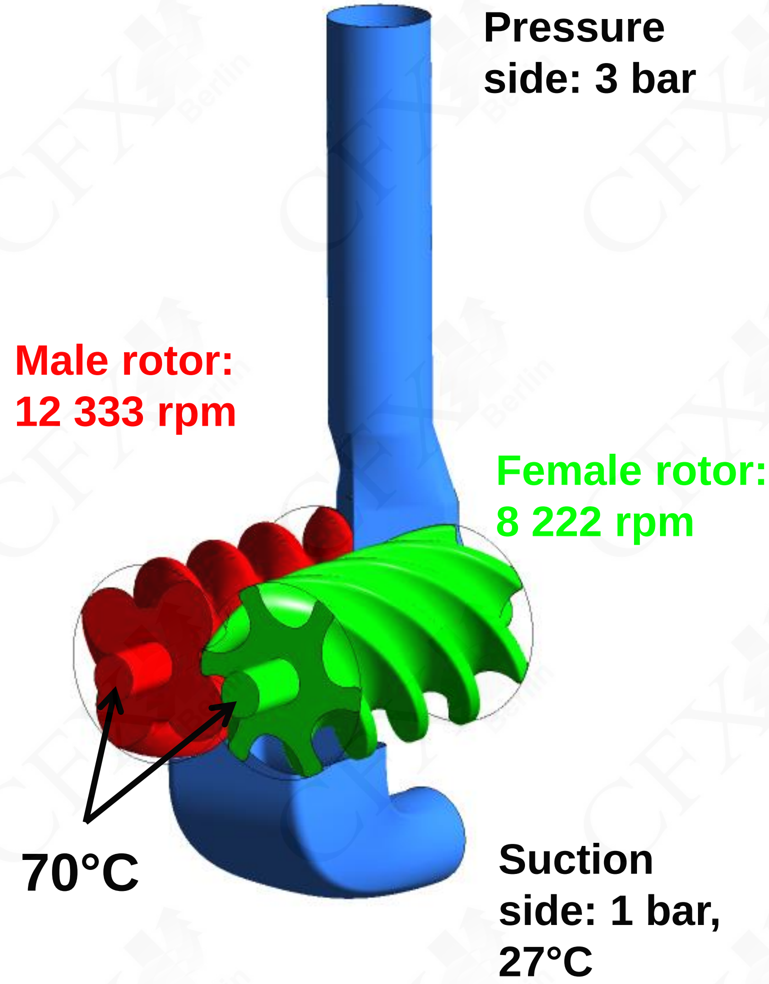
1. Import geometry
2. Set boundary conditions
3. Generate interfaces
4. Apply mesh settings
5. Check mesh quality
6. Generate meshes
7. Export meshes



- **Intuitive and comfortable GUI**
- **High quality structured meshes**
- **Gap sizes down to 1 µm**
- **Individual node distribution**

Setup

- Materials:
  - Fluid: Air as Ideal Gas (dry compressor)
  - Solid: Steel
- Models:
  - SST turbulence model
  - Total energy model with viscous dissipation and CHT into solids
  - User Fortran for rotor meshes at run-time, mesh deformation for solid rotation
- Boundary conditions:
  - Rotation speed (male): 12 333 rpm
  - Suction side: opening at 1 bar and 27°C
  - Pressure side: opening at 3 bar
  - Non-reflecting boundary conditions
  - Adiabatic casing except shaft ends at 70°C
- Solver:
  - ANSYS CFX for 90 time steps of 1°
  - Restart with interpolation

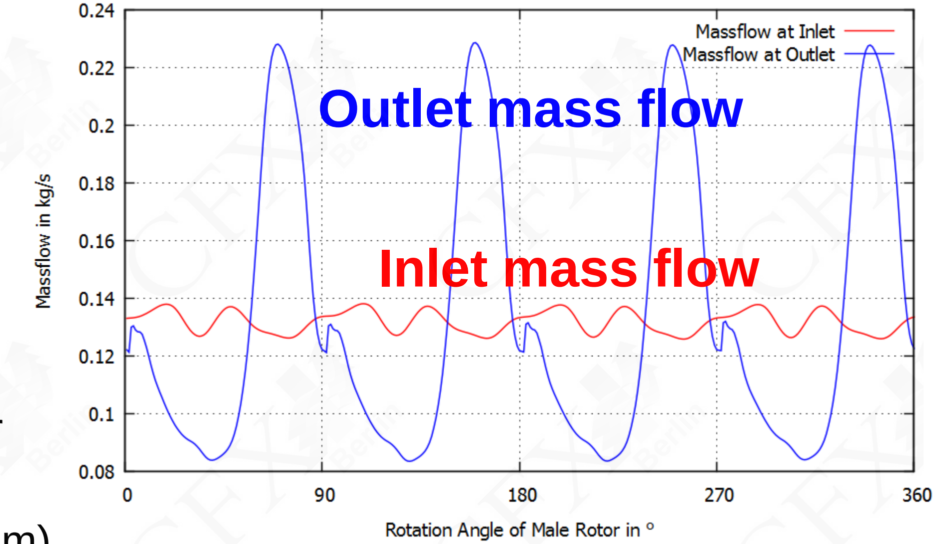


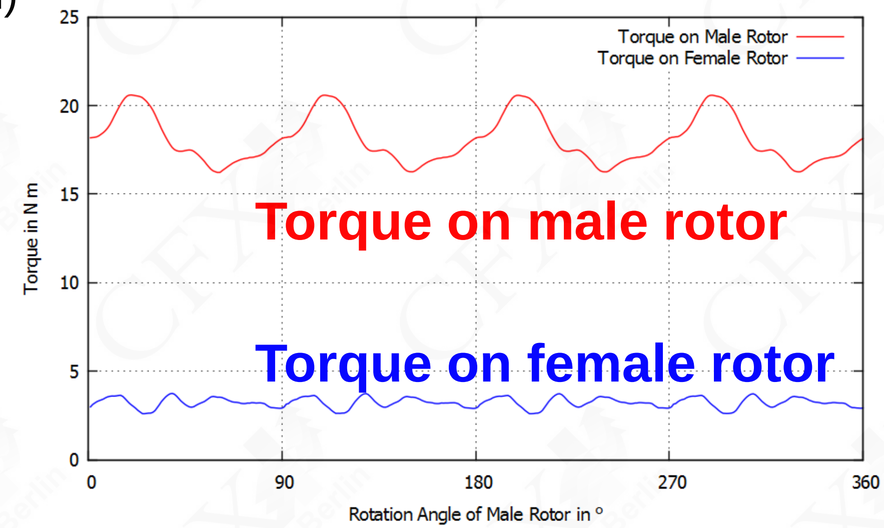
Result Overview

Quantitative Results

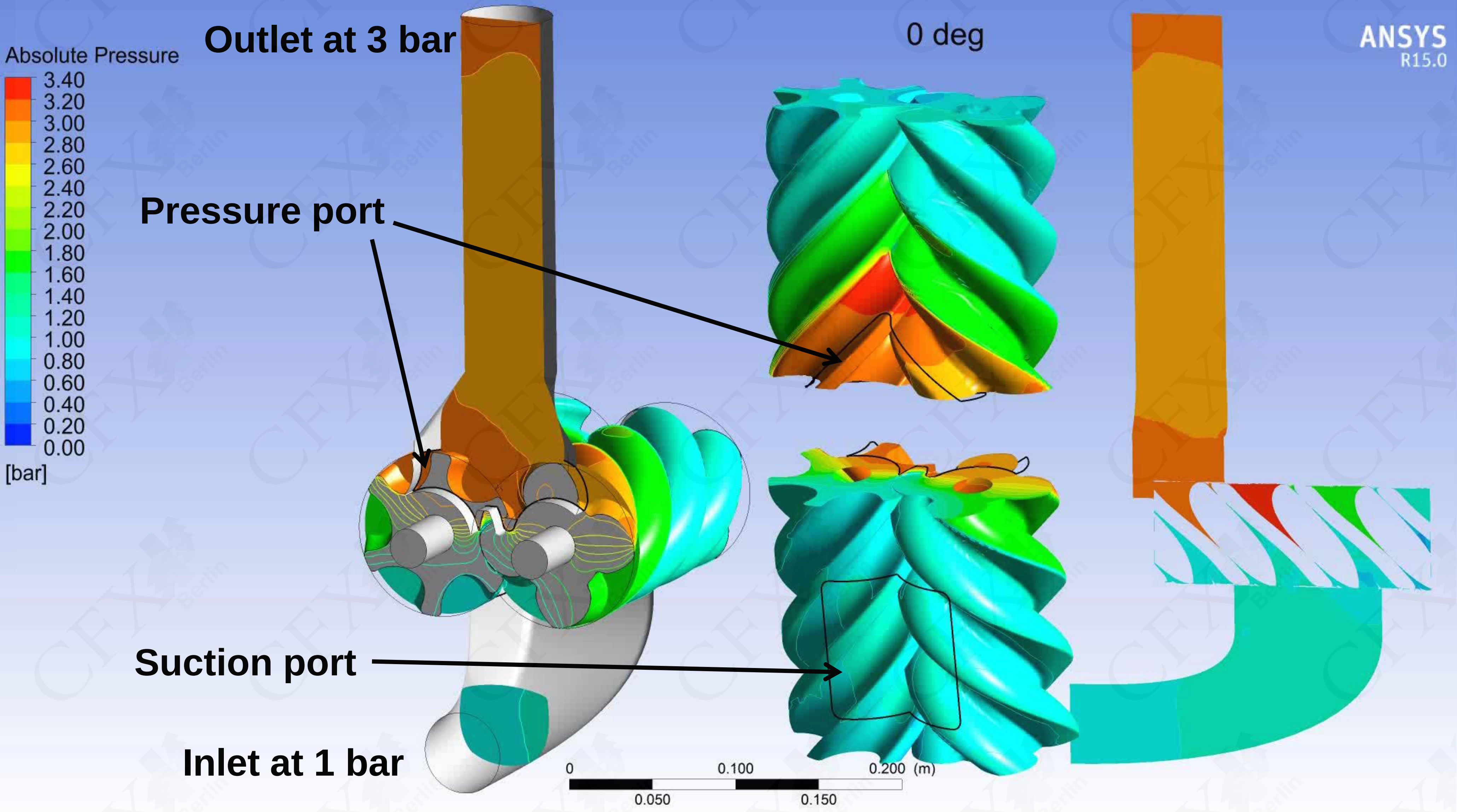
Quantitative results:

- Mass flow:
  - Average mass flow: 0.13 kg/s
  - Almost constant at inlet
  - High fluctuation at outlet
- Torque:
  - High, almost constant torque on male rotor (average 18.2 Nm)
  - Low torque on female rotor (average 3.2 Nm)
- Power:
  - Total power consumption 25.1 kW
- Computation time:
  - ANSYS CFX-15.0.7 with MeTiS partitioning
  - 9 hours for 90° on 8 cores Intel Xeon E5-2637 v2 with Platform MPI
  - 20 GB memory for double precision solver



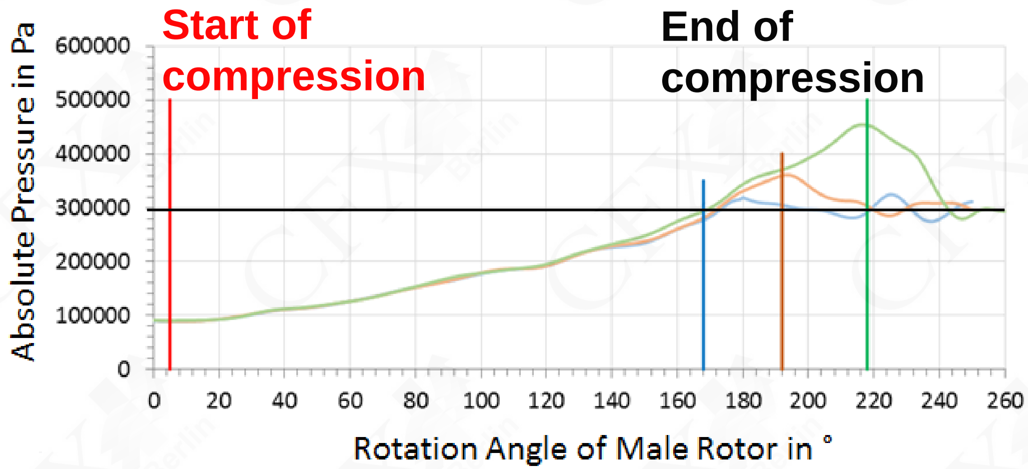


Absolute Pressure



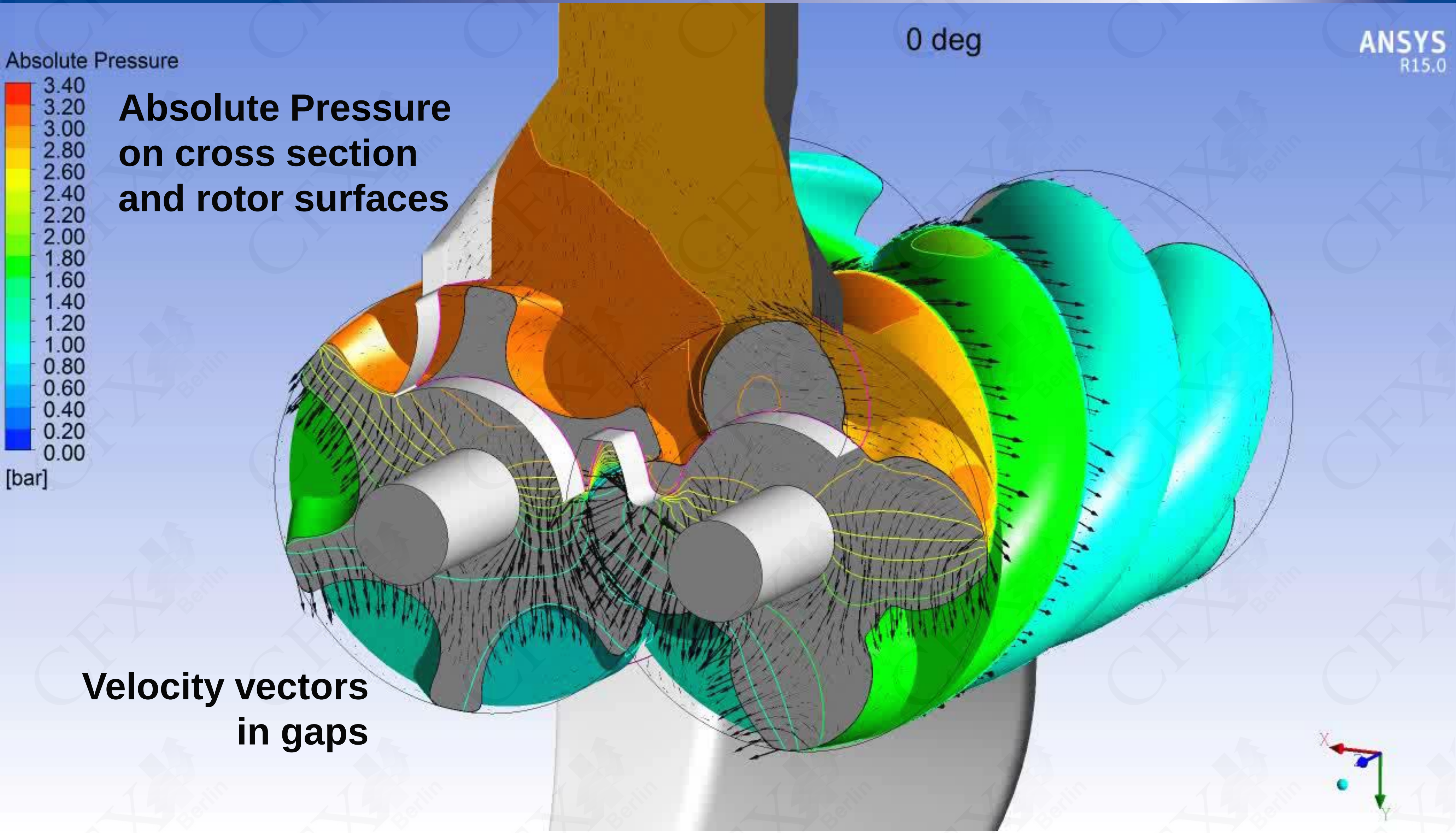
Chamber Pressure

- Chamber pressure for different pressure ports:
  - Absolute pressure for monitor point in male rotor chamber over male rotor angle
  - Almost identical pressure increase during compression
  - Pressure port for estimated pressure ratio 3 shows undercompression
  - Pressure ports for estimated pressure ratios 4 and 4.6 show overcompression
  - Slight higher pressure during compression for 4.6 due to increased gap flow



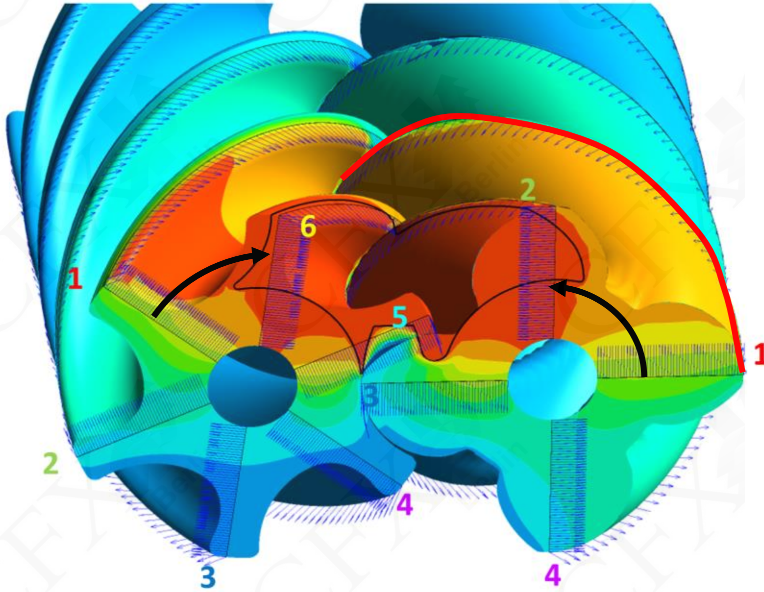
Pressure port for pressure ratio

Flow through Axial and Radial Gaps



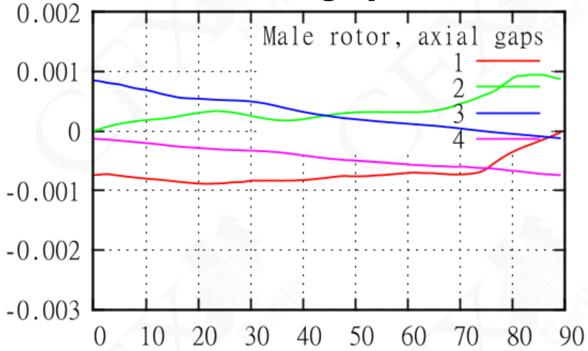
Evaluation of Gap Flow

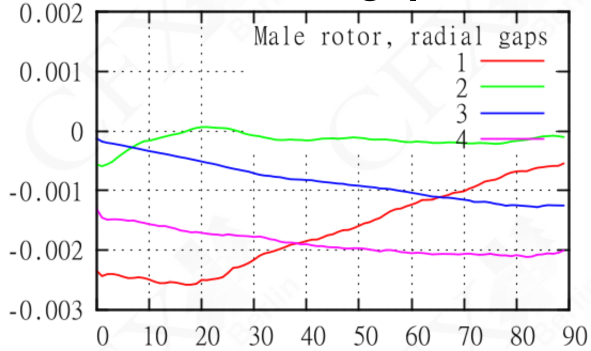
- Evaluation of gap flow:
  - Generation of surfaces in axial and radial gaps allow evaluation of gap mass flow
  - Positive means: mass flow in rotation direction



Axial gaps

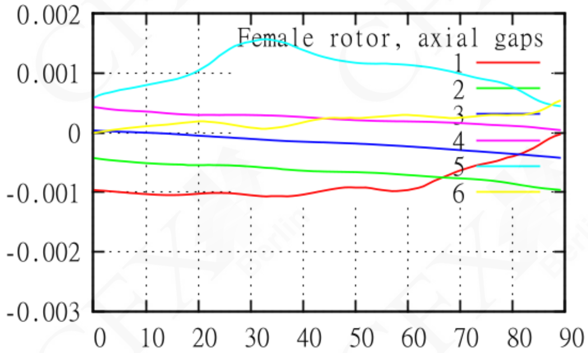
Radial gaps

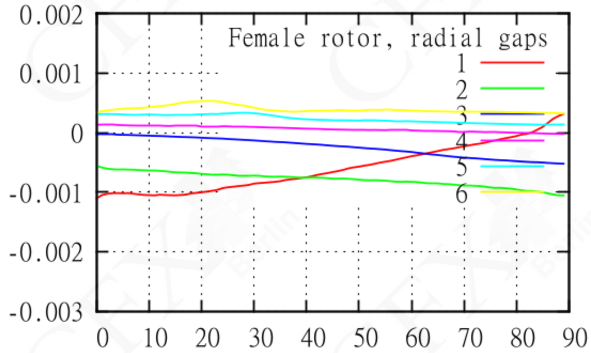




Male rotor

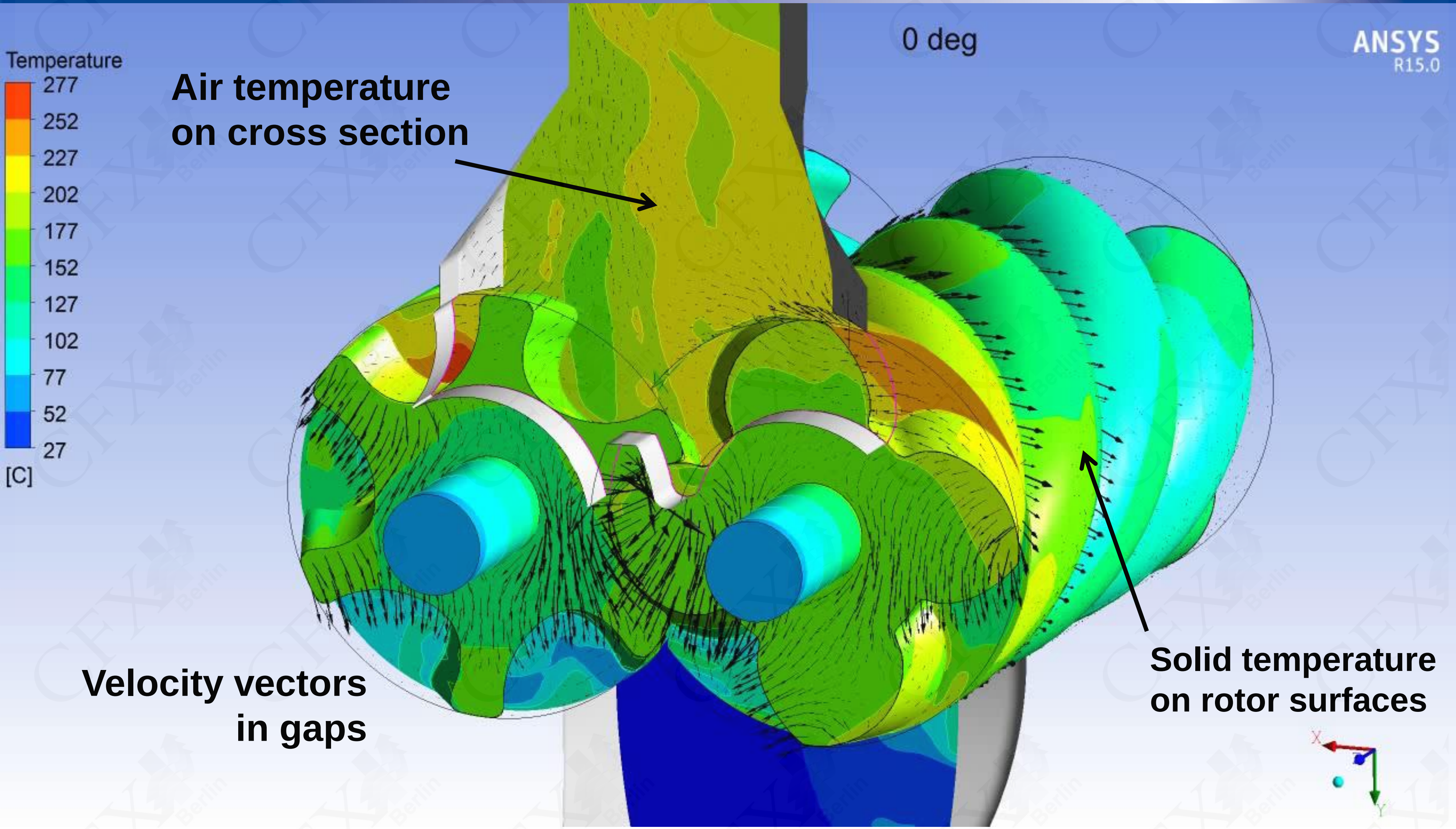
Average mass flow through compressor: 0.13 kg/s





Female rotor

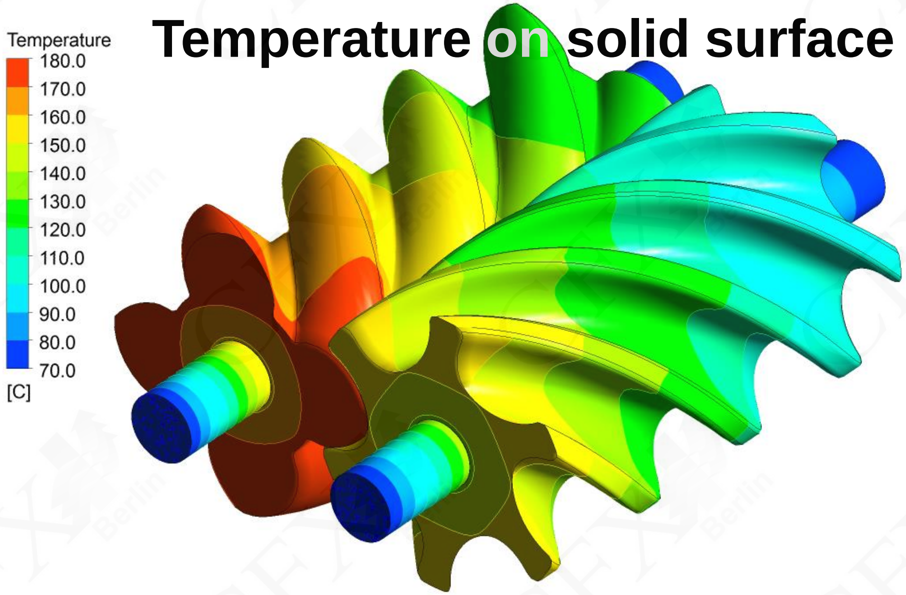
Temperature



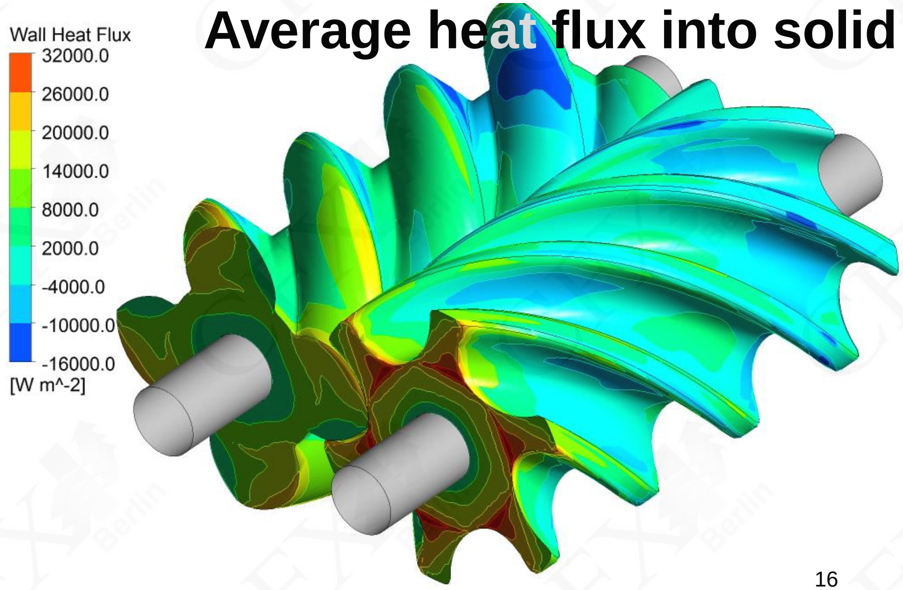
Heat Exchange between Air and Solid

- Heat exchange:
  - Compression of air increases air temperature
  - Heat flux from hot air into cold solids heats solids
  - Equilibrium typically after several minutes
  - Simulation by iterative coupling of fluid/solid simulation (some ms) and heat load transfer to pure solid simulation (some min)
- Equilibrium:
  - Male rotor heats up to 180°C, female up to 160°C due to 560 W heat flox at pressure side
  - Cold gas at suction side is heated up with 380 W
  - 180 W leave solid at shaft ends (fixed at 70°C)

Temperature on solid surface



Average heat flux into solid



Summary

- Efficient workflow from design to results
  - Design from basic literature and construction in Master‘s Thesis
  - High-quality meshes with TwinMesh and ANSYS Meshing
  - Setup, simulation, and post-processing with ANSYS CFX
  - Simulation of solid heat-up by iterative coupling of fluid/solid and pure solid simulation
  - Structural simulation of deformation by thermal and pressure loads
- Deep insight into complex physics of screw compressors
  - Visualisation of compression process by looking at pressures, velocities, temperatures, heat fluxes on surfaces, cross sections, etc.
  - Evaluation of compression process by looking at chamber pressures, mass flows, torque, power, or gap flows
  - Comparison of different designs or operating points
- TwinMesh and ANSYS CFD for
  - **Better and innovative designs** by a better understanding of complex phenomena
  - **Speed and flexibility at reduced costs** by massive use of virtual prototyping

Outlook
Oil Injected Screw Compressor

Oil injected screw compressor (SRM)

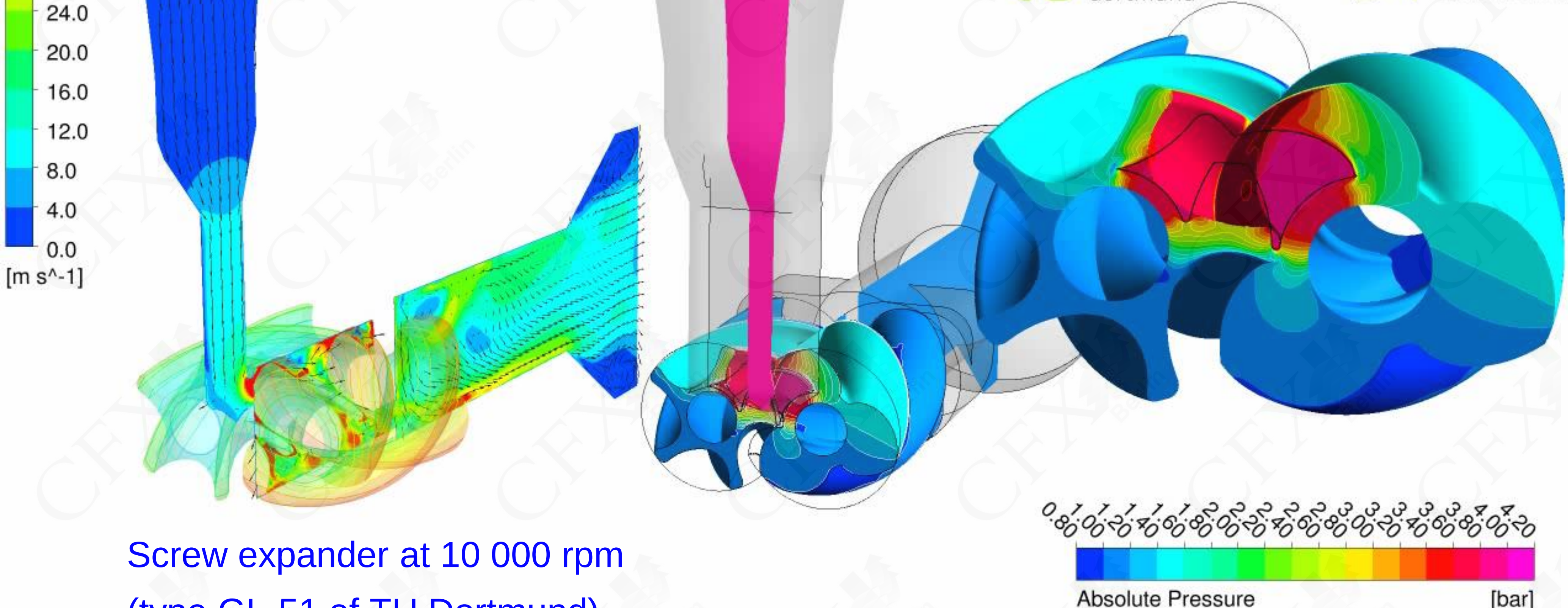
Outlook
Screw Expander at 10 000 rpm

CFX Berlin

TwinMesh™ by CFX BERLIN

technische universität dortmund

Fachgebiet Fluidtechnik

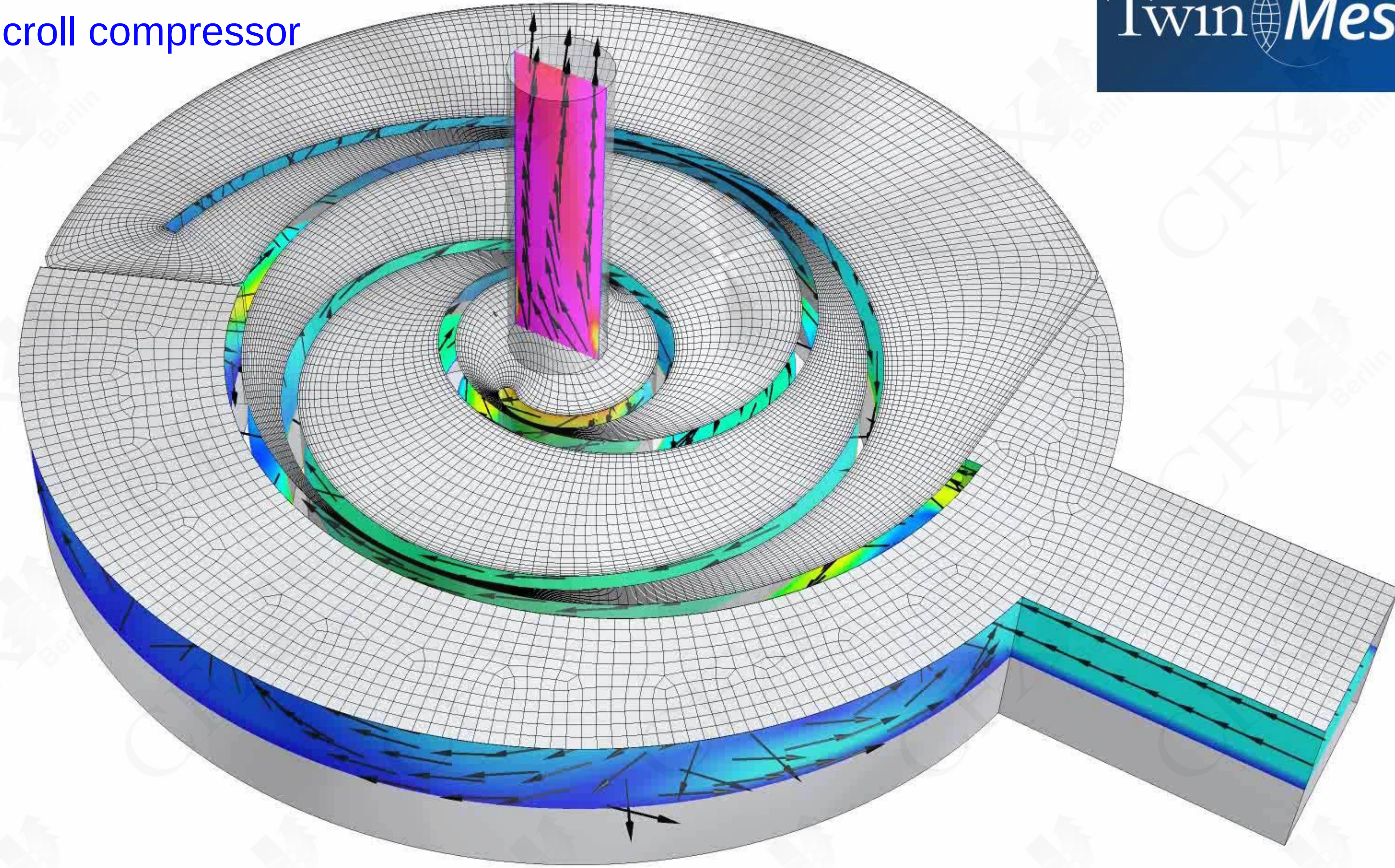


Screw expander at 10 000 rpm

(type GL-51 of TU Dortmund)

Outlook
Scroll Compressor

Scroll compressor



Thank you for your attention!