TwinMesh Grid Generator
and
CFD Simulation with ANSYS CFX

2nd Short Course on CFD in Rotary Positive Displacement Machines

London, 5th – 6th September 2015

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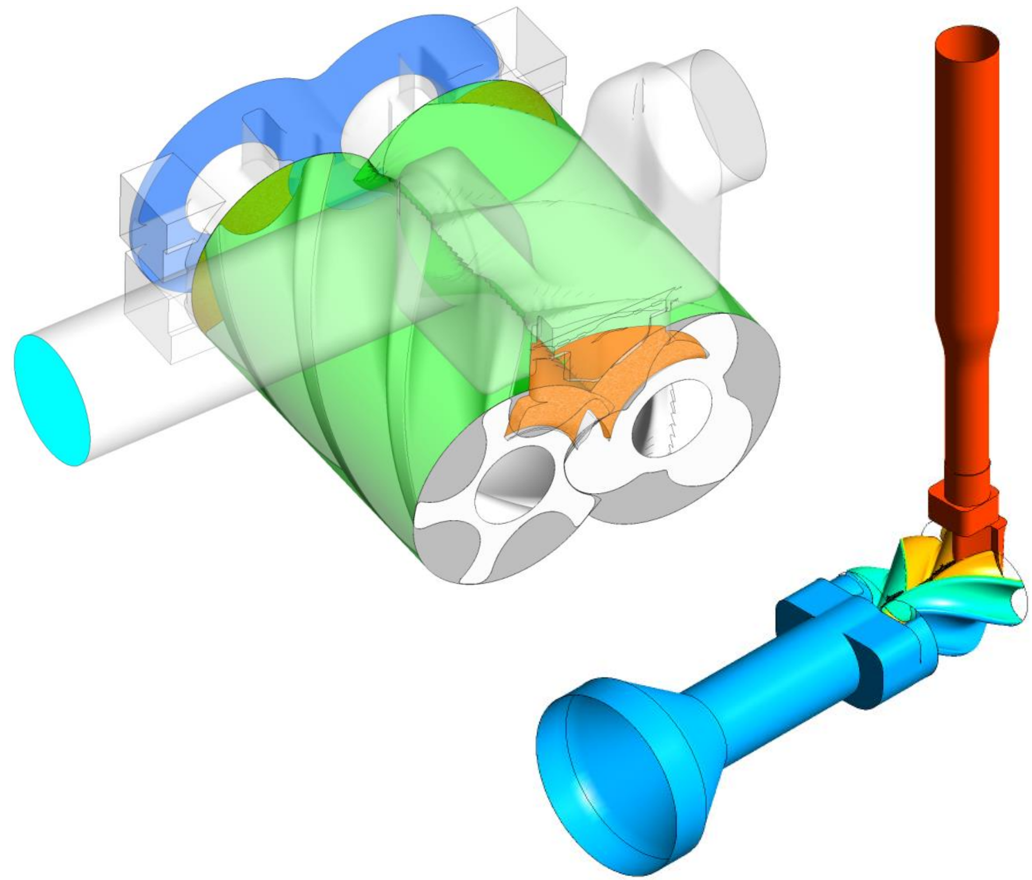
Contents

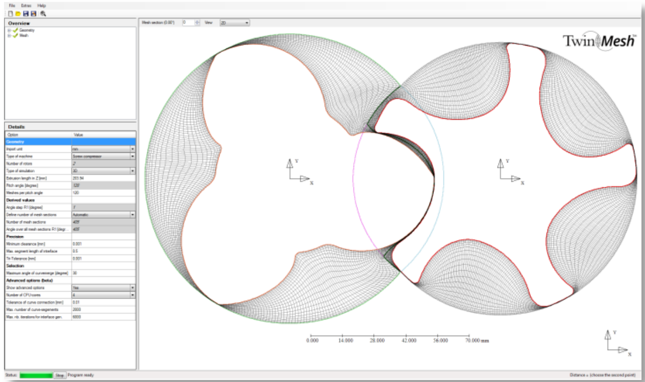
- TwinMesh grid generator
- Numerical Simulation of the 3/5 Lobed Twin Screw Compressor Test Case



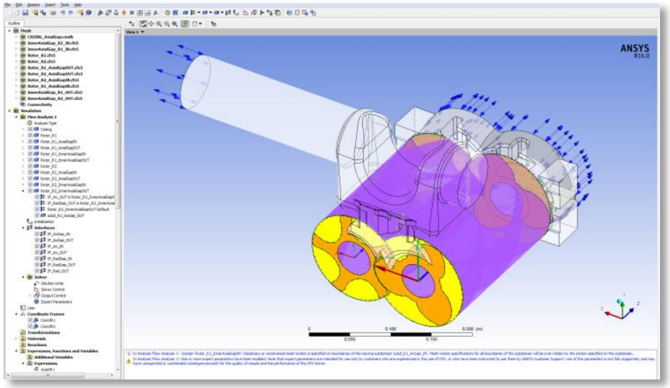
TwinMesh Grid Generator Overview

- Software overview
  - Meshes are generated in **ANSYS Meshing** and **TwinMesh**
  - Simulations are performed using **ANSYS CFX**
- Workflow overview
  - **Meshing**: Pre-generate all meshes
  - **Pre-processing**: boundary conditions and solver settings
  - **Solution**: Read mesh files for rotor positions during the simulation run
  - **Post-processing**: evaluation and illustration of the simulation results

Meshing
TwinMesh (rotors) and ANSYS Meshing (stator)

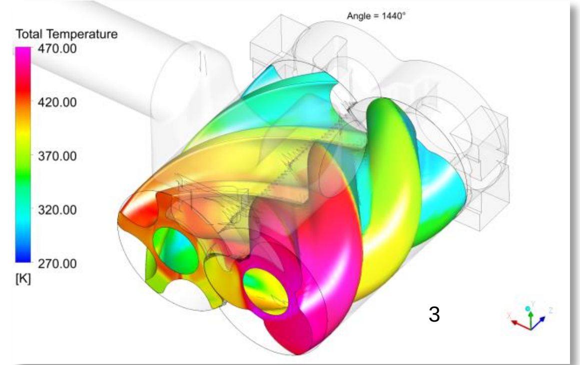


Simulation setup
ANSYS CFX-Pre



Simulation
ANSYS CFX with User Fortran

Simulation results
ANSYS CFD-Post



TwinMesh Grid Generator
TwinMesh Workflow

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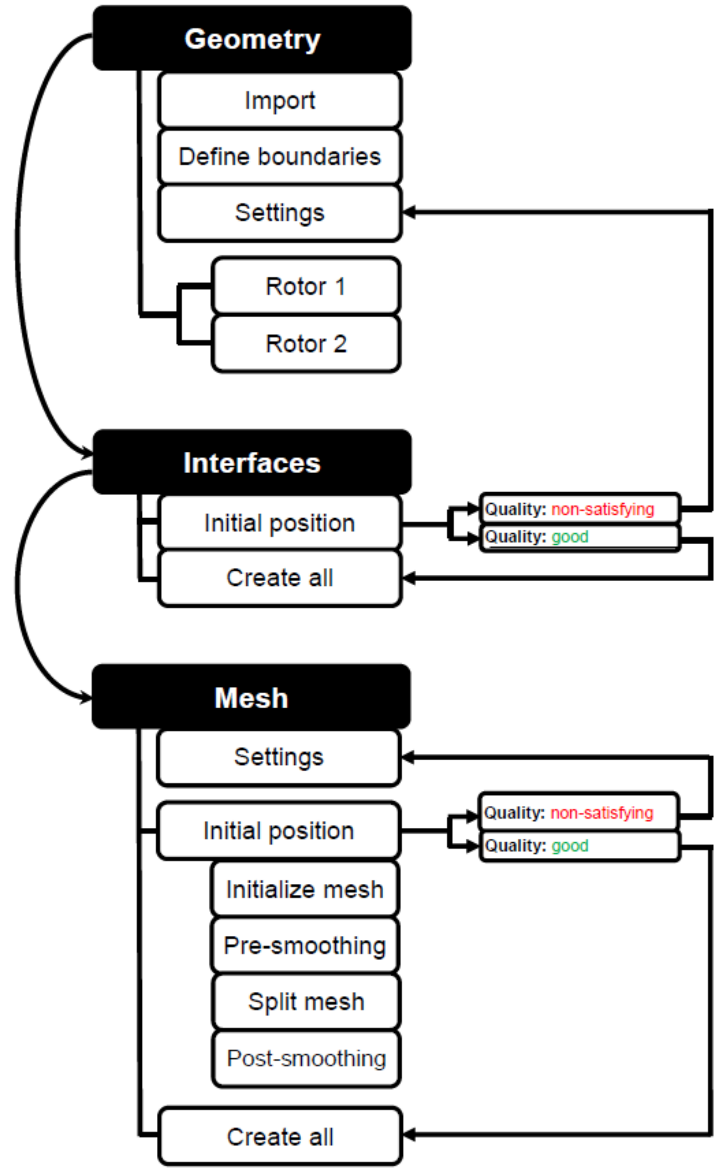
CAD

TwinMesh™

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

ANSYS®



TwinMesh Grid Generator
Import Geometry

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CAD

1. Import geometry
2. Set boundary conditions
3. Generate interfaces
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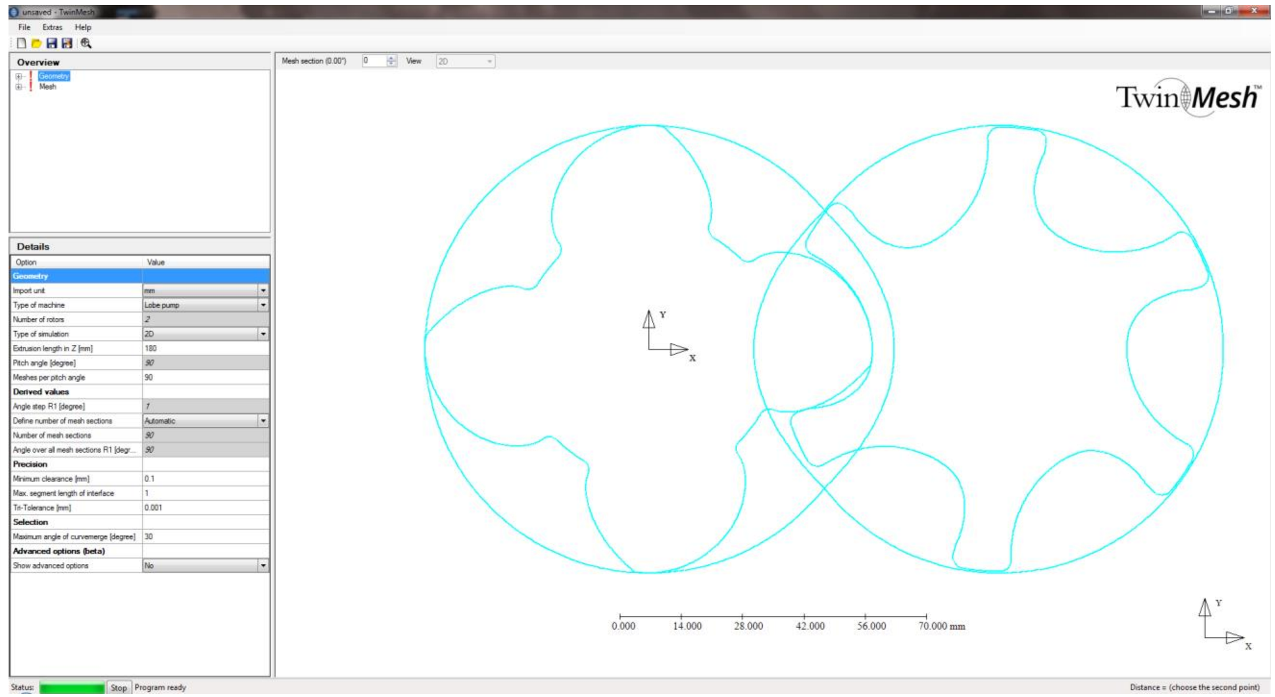
7. Export meshes

ANSYS



- **Import curves for rotors and casing as IGES or ASCII point data**

TwinMesh Grid Generator
Set Boundary Conditions

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CAD

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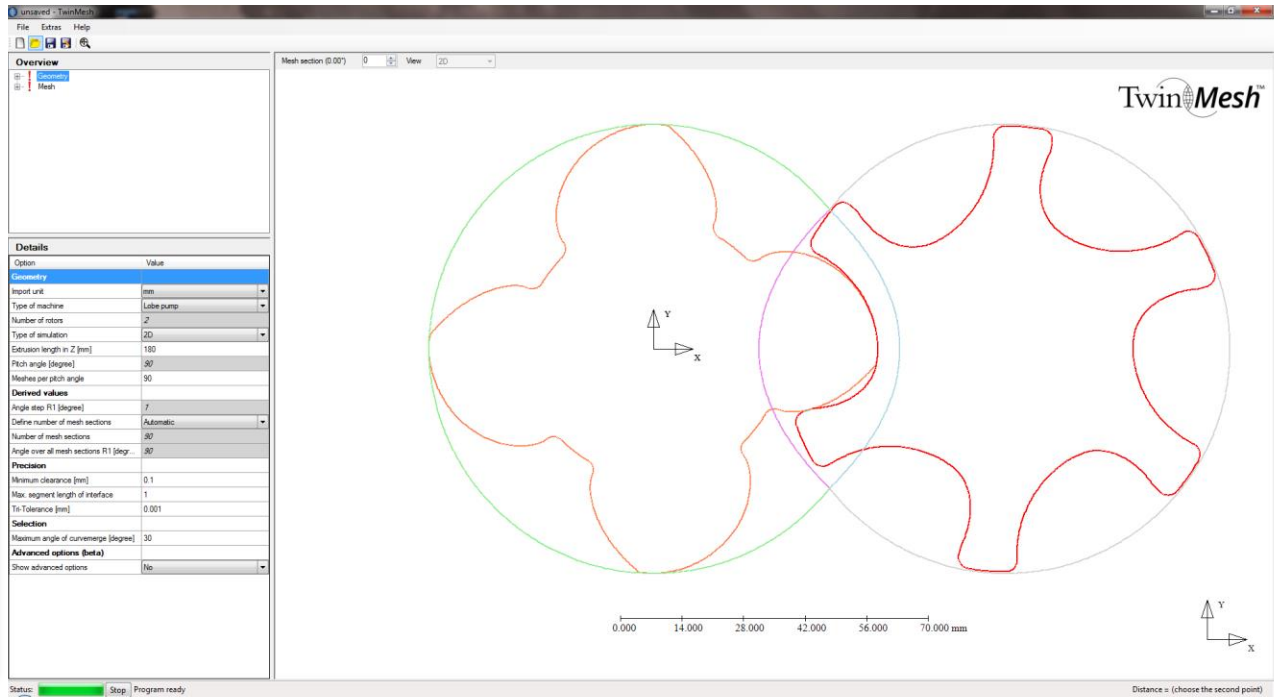
7. Export meshes

ANSYS



- **Assign curves to rotor 1, rotor 2, casing and interface region**

CAD

TwinMesh™

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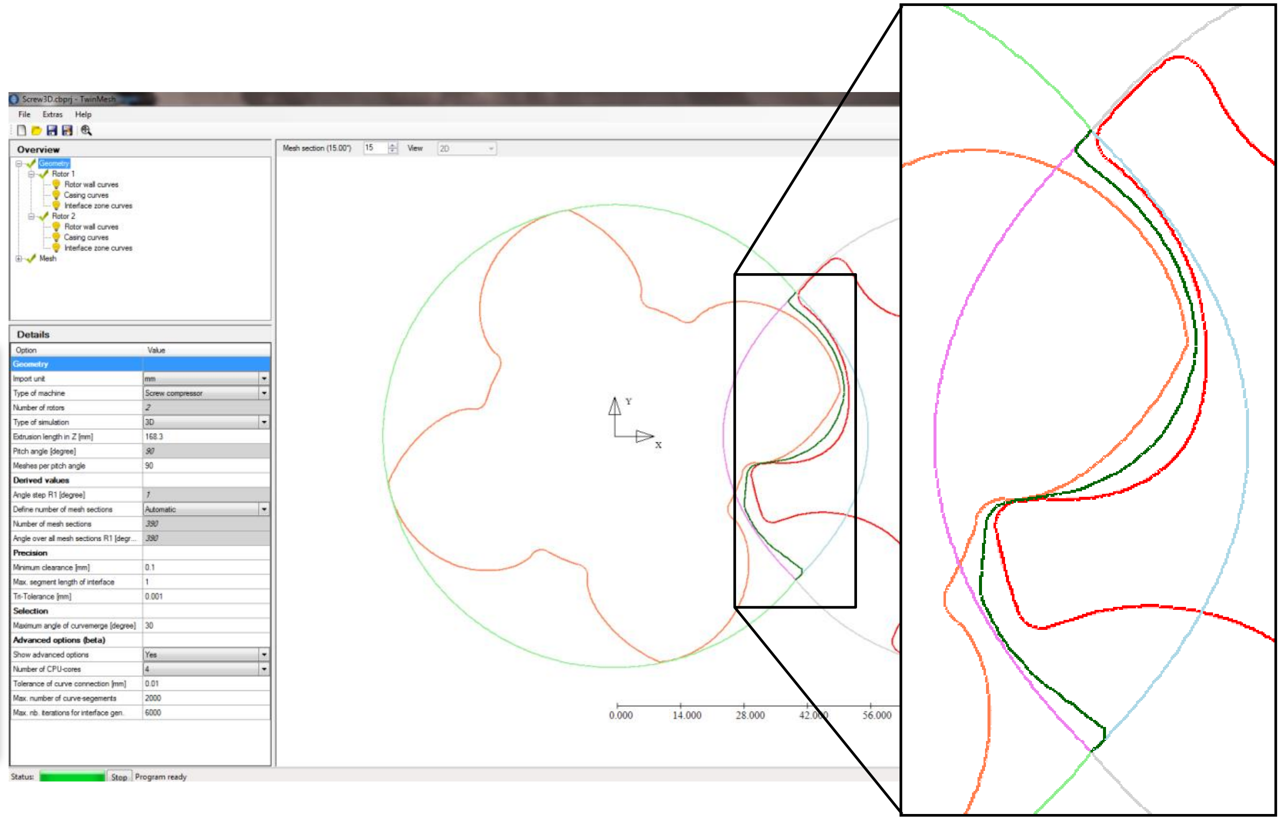
7. Export meshes

ANSYS®

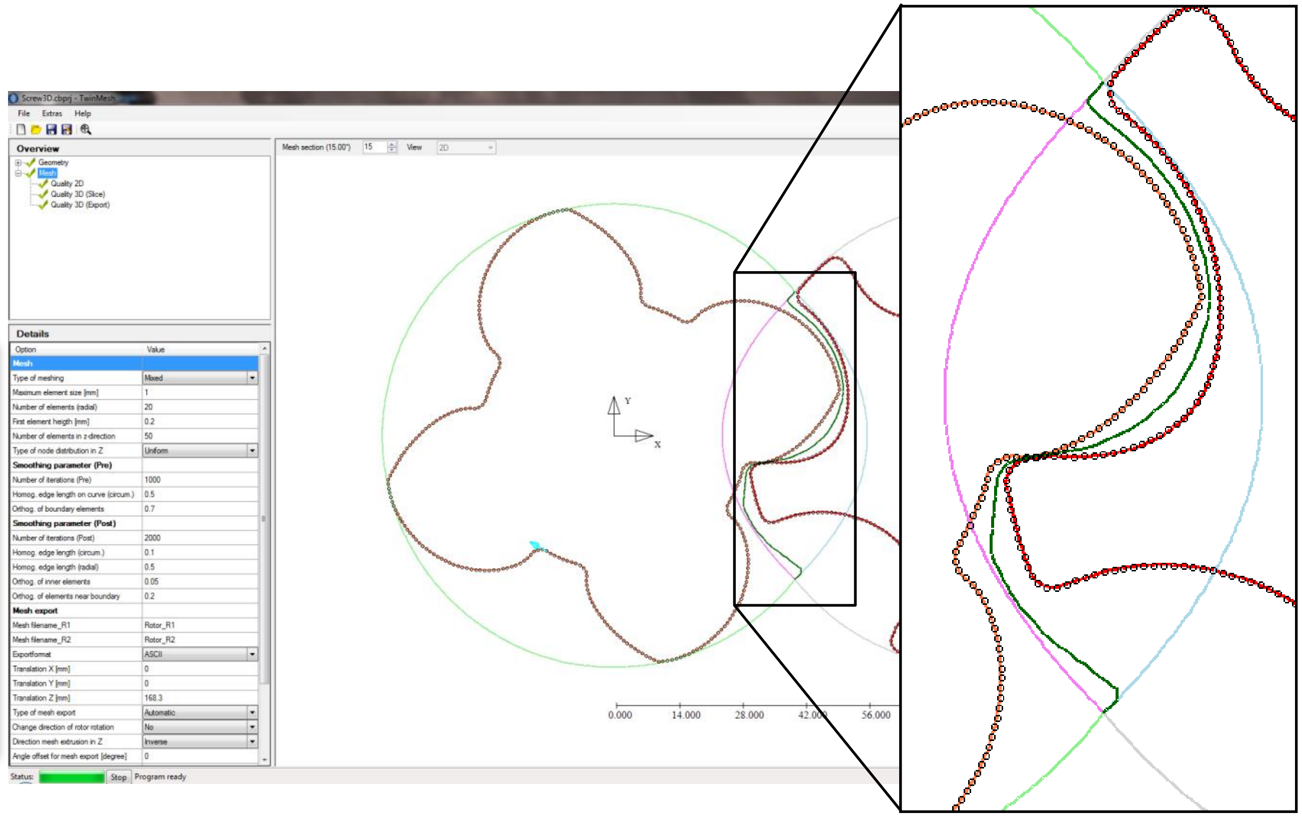


- **Define further geometry details (extrusion length, scaling, center points)**
- **Automatically generate interfaces between rotors**

TwinMesh Grid Generator
Apply Mesh Settings

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



- **Set mesh strategy (fixed on inner or outer curves)**
- **Define mesh properties (number of elements, first element height, ratio)**

TwinMesh Grid Generator
Apply Mesh Settings Cont.

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CAD

1. Import geometry
2. Set boundary conditions
3. Generate interfaces
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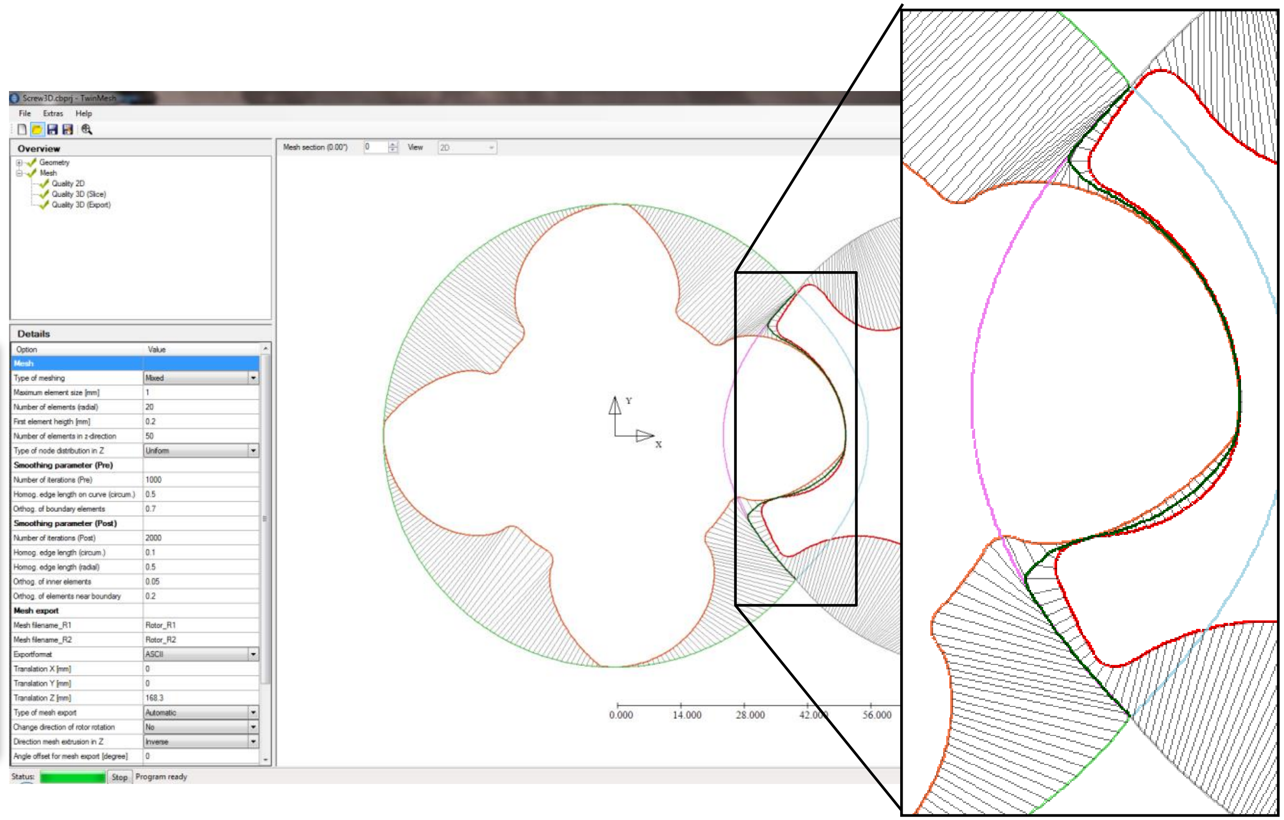
7. Export meshes



- **Apply circumferential mesh distribution**
- **Apply pre-smoothing**

TwinMesh Grid Generator
Apply Mesh Settings Cont.

CAD

1. Import geometry
2. Set boundary conditions
3. Generate interfaces
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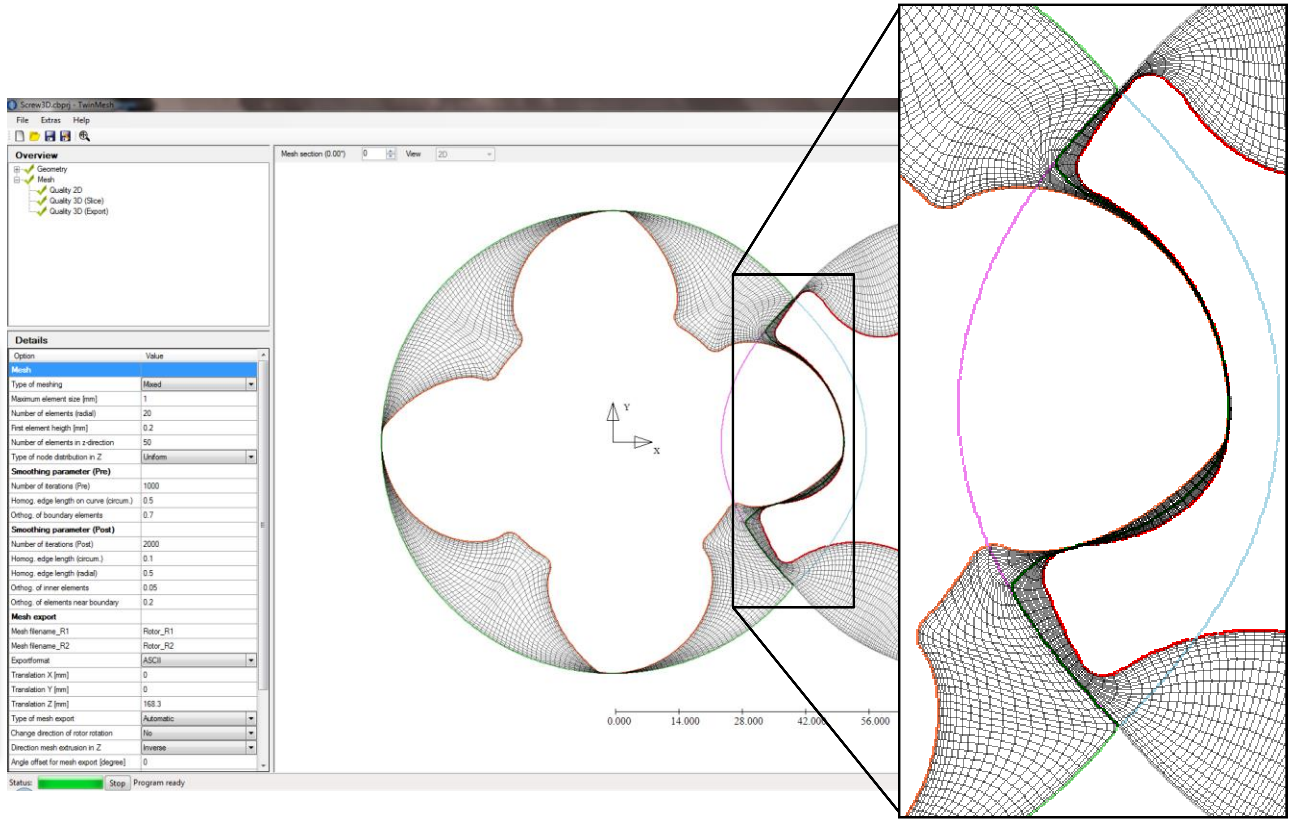

- **Apply radial split of elements**
- **Apply post-smoothing to get high internal angles (normal at walls) and small volume changes**

TwinMesh Grid Generator
Check Mesh Quality

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CAD

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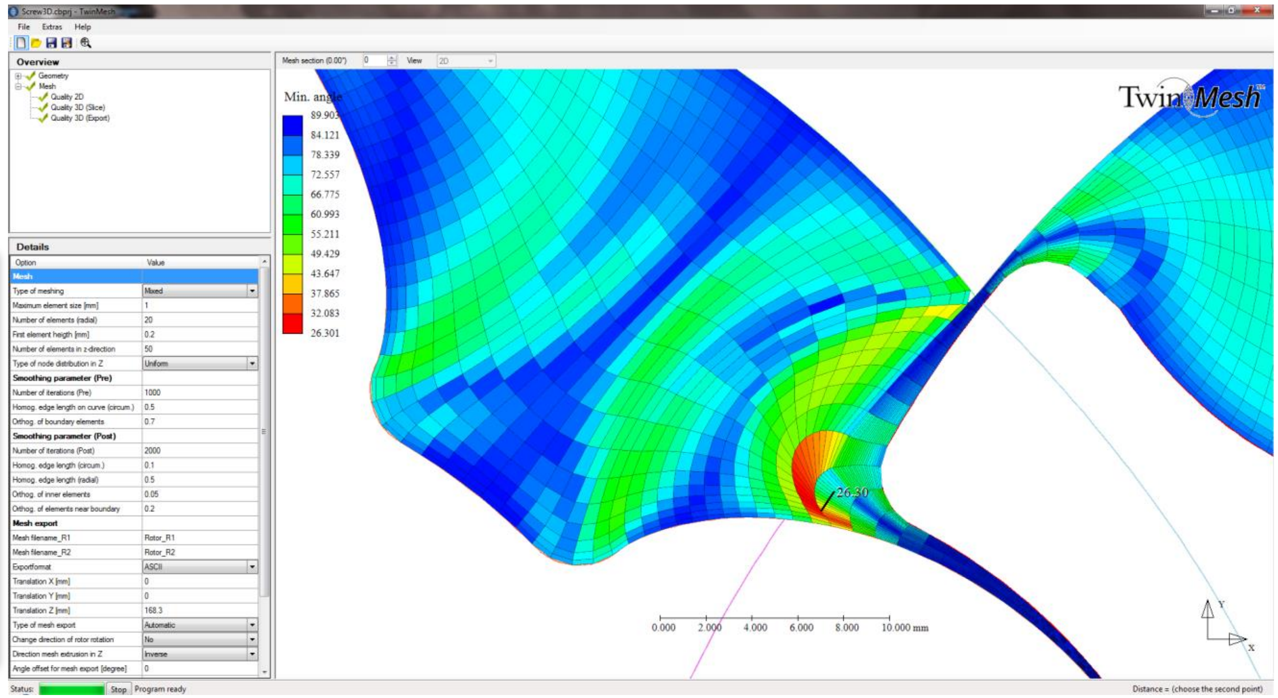
7. Export meshes

ANSYS



- **Check mesh quality: minimum angle, aspect ratio, volume change, determinant for some rotor positions**
- **if necessary, adjust mesh settings**

TwinMesh Grid Generator
Generate Meshes

CFX Berlin

CAD

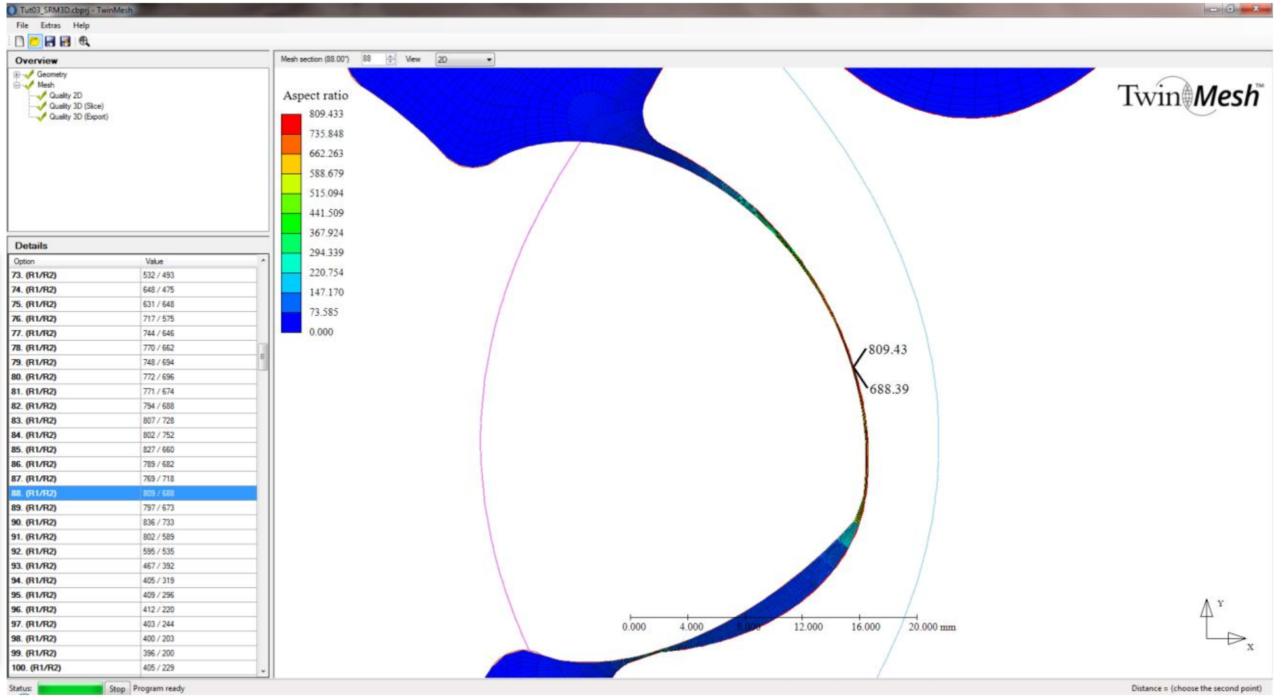
↓

TwinMesh

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

↓

ANSYS



- **Automatically generate all 2D meshes**
- **Check mesh quality for all 2D meshes (table summarizes worst values)**

TwinMesh Grid Generator
Export Meshes

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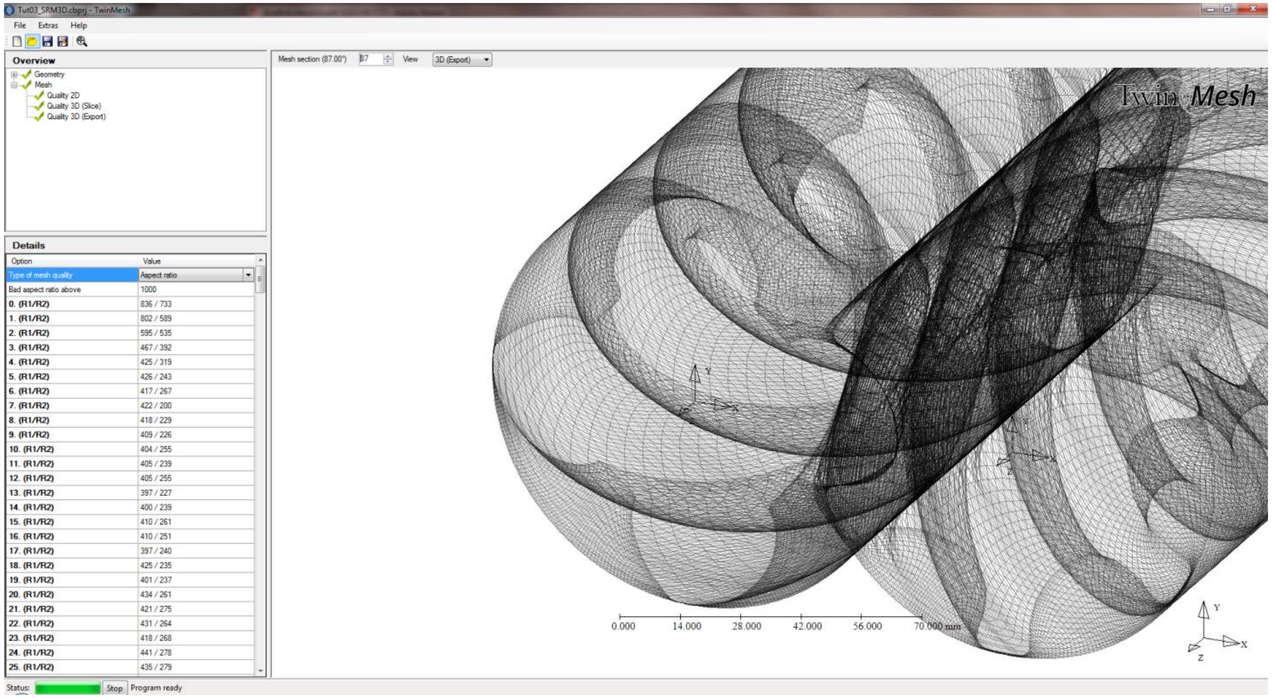
TwinMesh™

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

ANSYS®



- **Check mesh quality for all 3D meshes**
- **Export meshes as binary or ASCII files**
- **Export session file for ANSYS CFX-Pre with basic setup**

TwinMesh Grid Generator
Comparison of Methods

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Comparison to other methods for chamber modeling:

- Immersed Solids
  - Insufficient wall treatment
  - Insufficient gap resolution
  - No multiphase, no compressible gases

TwinMesh™

+ Fine wall resolution possible
+ Very fine gap resolution possible
+ All physical models available

- Mesh deformation / remeshing
  - Mesh deformation may cause bad mesh quality on run-time
  - Automatic remeshing only with tetrahedra / prisms
  - Interpolation errors after remeshing
  - Small gaps increase element number

TwinMesh™

+ Pre-generation ensures high quality meshes at run-time
+ Pure hexahedral meshes with well-resolved boundary layers
+ No interpolation necessary
+ User-definened element number

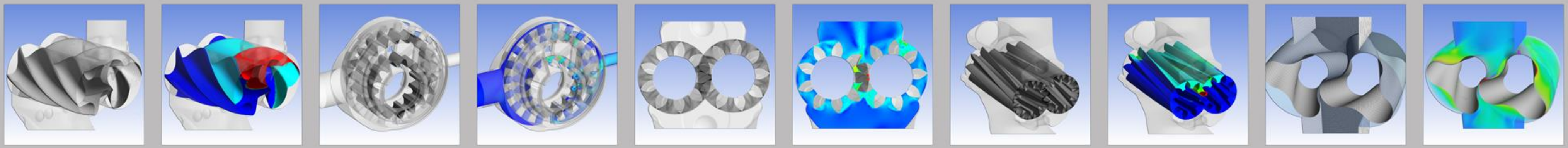
- Manual pre-generation
  - High manual effort
  - Needs days to weeks hand time

TwinMesh™

+ Highly automated but flexible mesh generation
+ Needs hours to days computing time

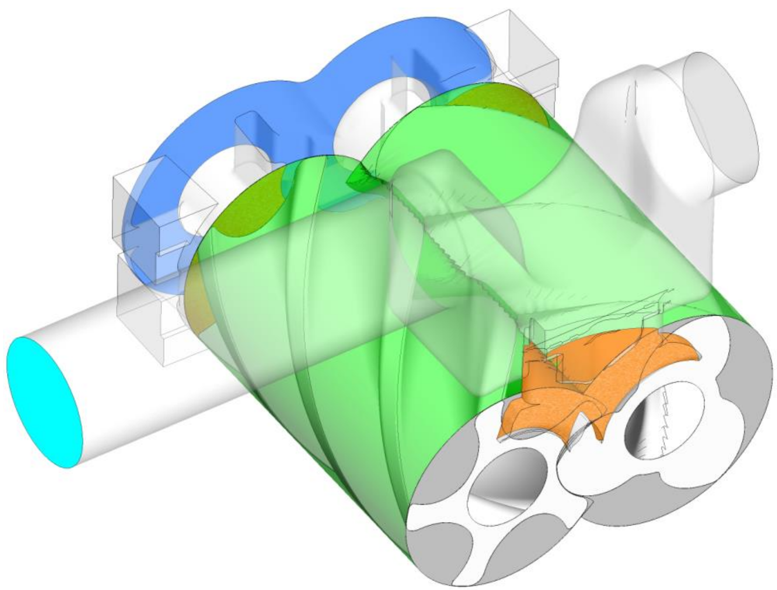
TwinMesh Grid Generator
Key Features

- Key features of TwinMesh:
  - Easy to use (comfortable GUI)
  - Works for many different PD machine types
  - Generation of high quality structured meshes with smoothing algorithm
  - Allows gap sizes down to 1 µm
  - Individual node distribution and rotation angle steps
  - Efficient workflow for ANSYS CFX software
- Further development by CFX Berlin:
  - New machine types, e.g. Scroll compressor
  - Integrated meshing of axial gaps and solids
  - User Defined Functions for ANSYS FLUENT



Contents

- TwinMesh grid generator
- Numerical Simulation of the 3/5 Lobed Twin Screw Compressor Test Case
- Gap flow and mesh resolution
- Numerical Simulation of a Twin Screw Expander
- Conclusions and Outlook

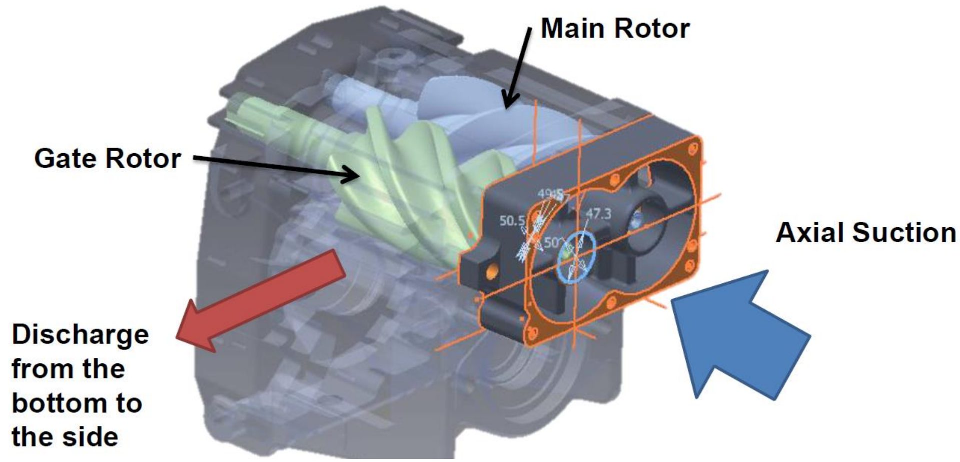


3/5 Screw Compressor Introduction

- Test case was provided by City University London in May 2015
  - Description as PDF
  - Data from experimental measurements as XLS for discharge pressure 2 bar at 3 operating points:
    - 6000 rpm
    - 7000 rpm (not used here)
    - 8000 rpm
  - Geometry as
    - SoLiDworks PaRT file
    - Parasolid file x_b
    - txt files for rotor profiles
- Work has been done at CFX Berlin by Rainer Andres in appr. 50 hours working time

3/5 Lobed Twin Screw Compressor

CITY UNIVERSITY LONDON



Measurements

CITY UNIVERSITY LONDON

Results from computations of Leakage flow cases can be compared with measurements*

Results need to be presented in Normalised form if used for comparison.

No	Speed	Discharge Pressure	Flow	Torque	Indicated Power	Specific Power	Discharge Temperature	Adiabatic Efficiency	Volumetric Efficiency
	rpm	bar	m3/min	Nm	kW	kW/m3/min	K	%	%
1	6000	2.0	7.051	25.397	15.945	2.148	402.6	56.81	67.59
2	7000	2.0	8.733	27.011	19.796	2.153	402.3	57.76	71.92
3	8000	2.0	10.362	28.204	23.631	2.166	406.9	60.03	75.31

3/5 Screw Compressor Rotor Geometry

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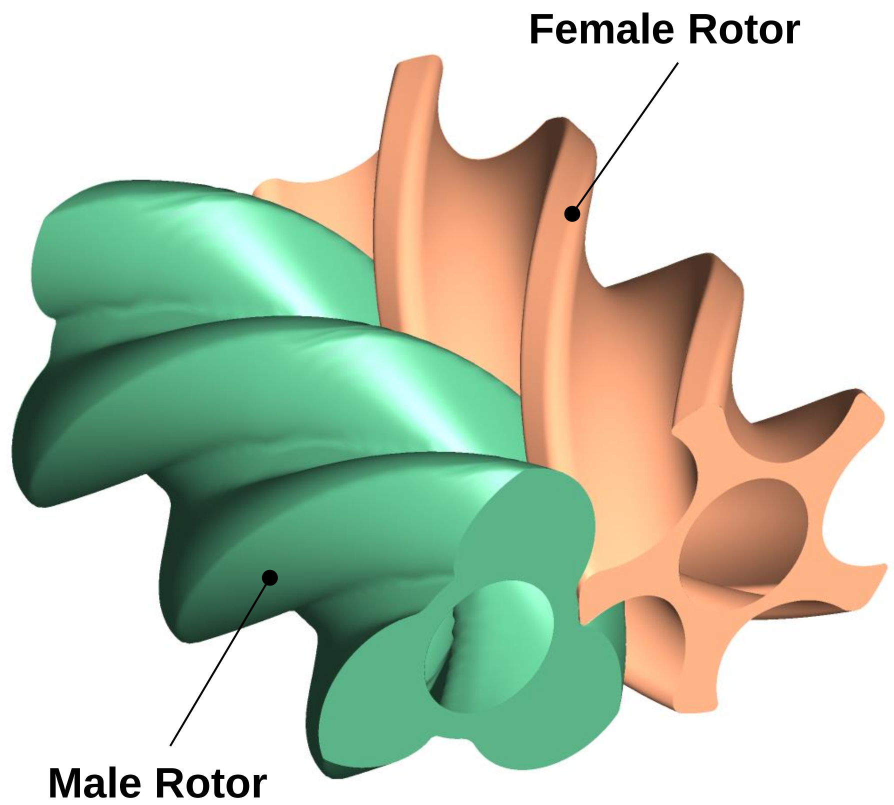
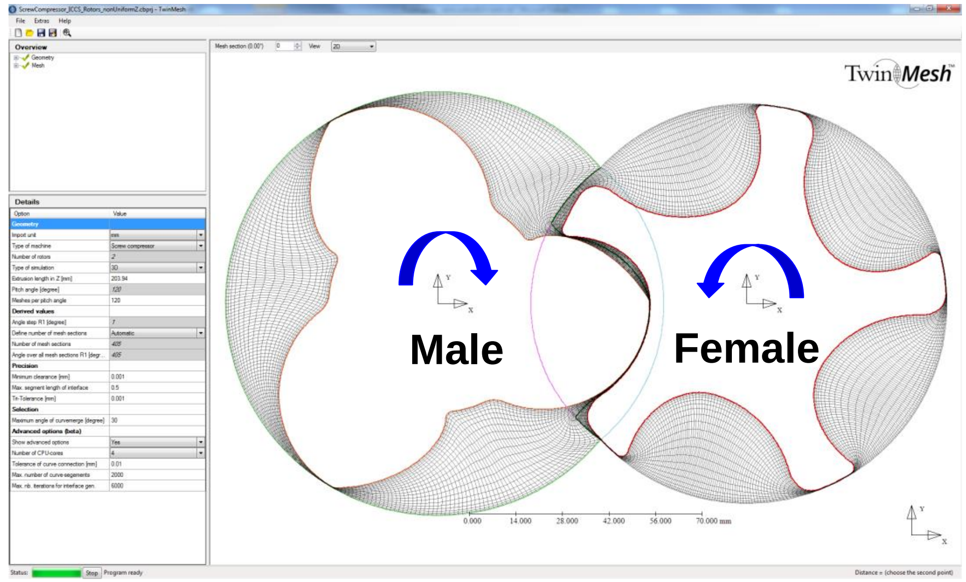
- Rotor geometry
  - Import of provided CAD models in ANSYS DesignModeler and TwinMesh

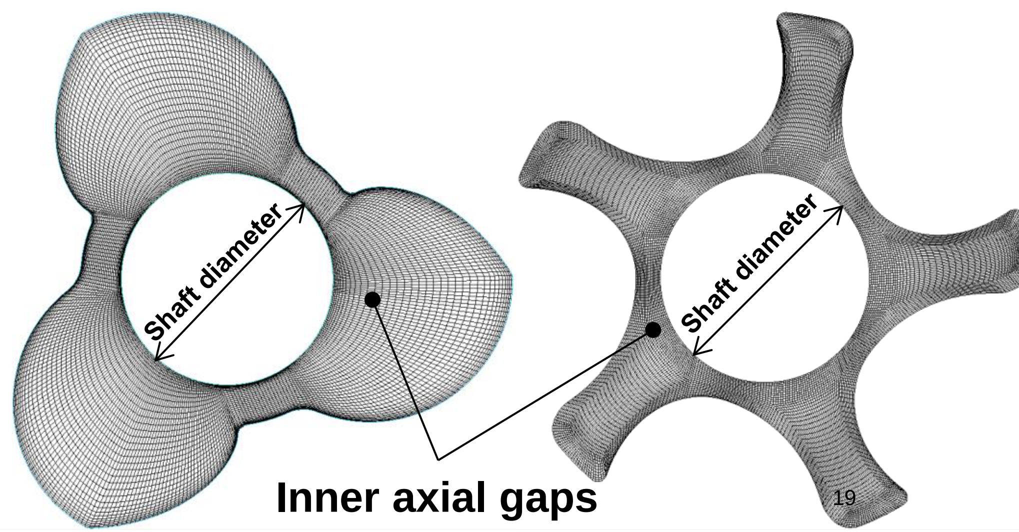
Parameter	Value on main rotor
Center distance	93 mm
Wrap angle	285 deg
Interlobe clearance	160 µm
Radial clearance	180 µm
Axial clearance at suction port	150 µm
Axial clearance at discharge port	120 µm
Shaft diameter	47.30 mm



3/5 Screw Compressor Rotor Grids in TwinMesh

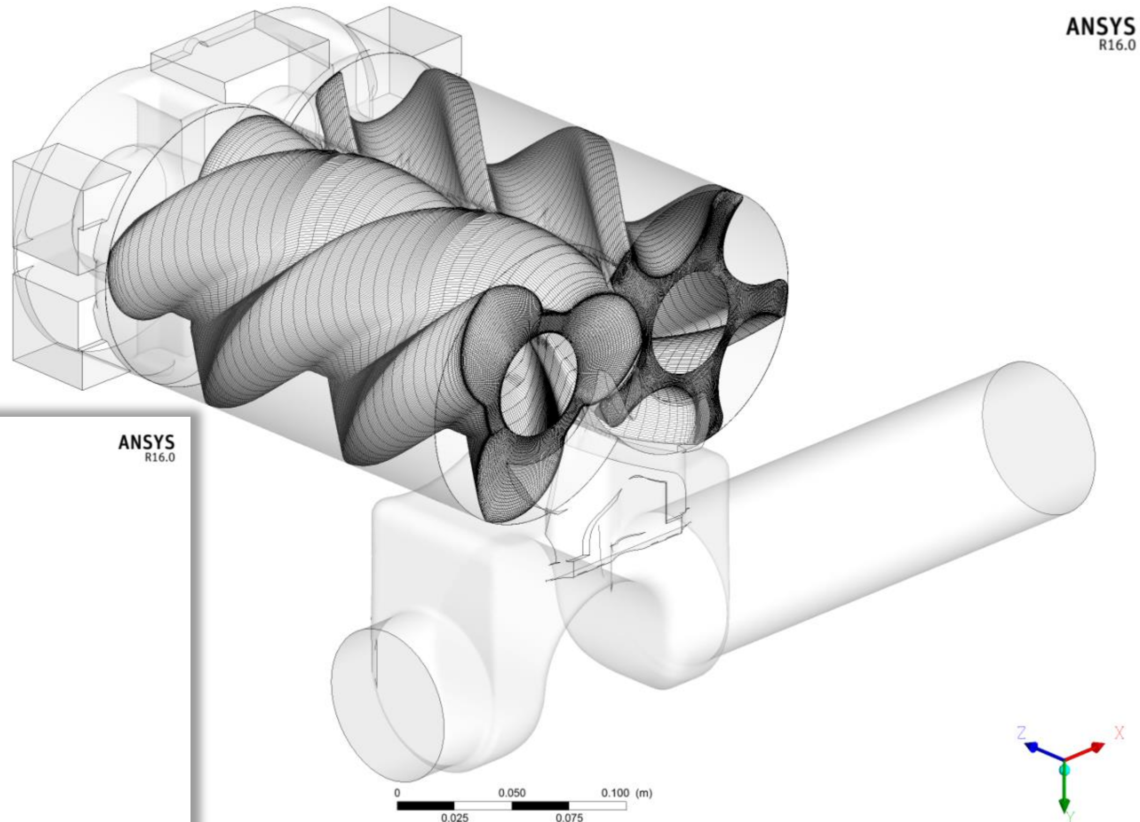
- Rotor representation in TwinMesh
  - Grids for the flow volume between rotors and casing (chambers)
  - Grids for the outer axial gaps
  - Generated and exported from TwinMesh for 120 rotor positions with 1° male rotor angle increment
- Inner axial gaps
  - Inner axial gaps are meshed in ICEM CFD congruent to the rotor solid

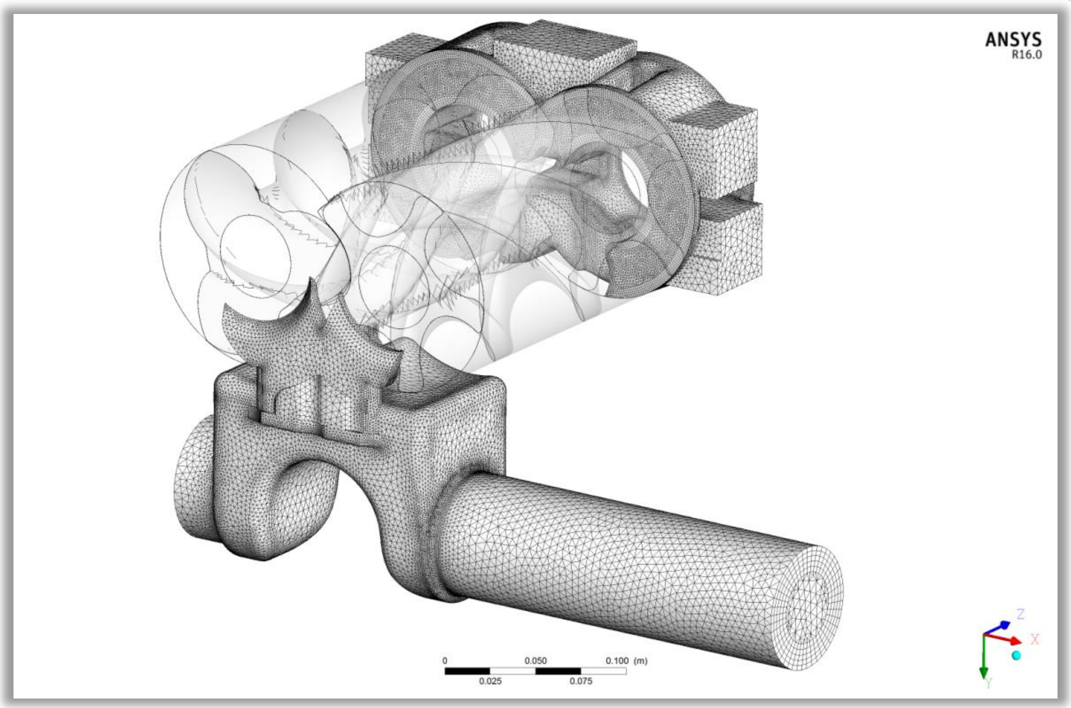




3/5 Screw Compressor Mesh Assembly

- Mesh assemby
  - Structured grids for the rotors with TwinMesh
  - Unstructured grid for the stator with ANSYS Meshing





3/5 Screw Compressor
Mesh Statistics for Rotors

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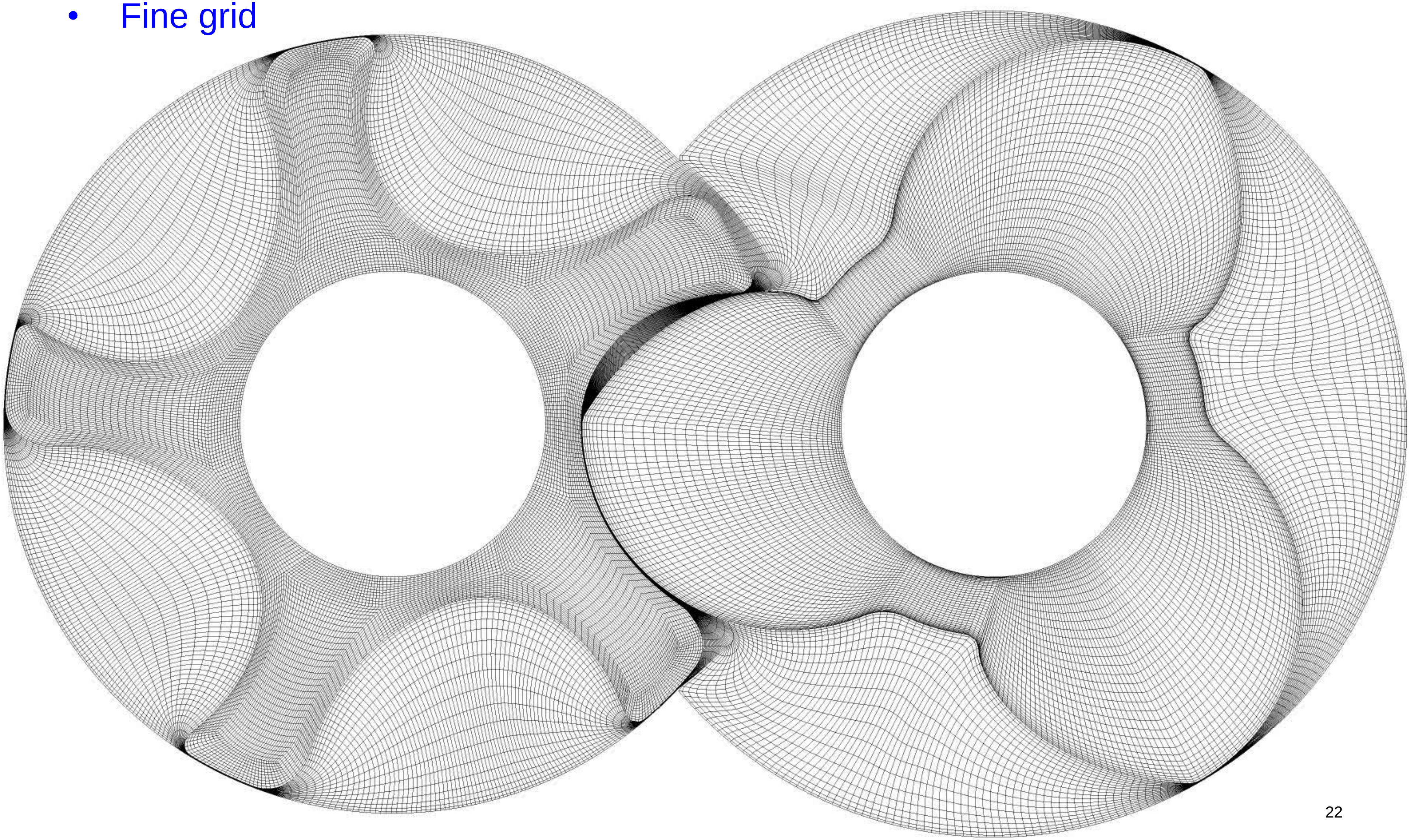
- Rotor meshes
  - Two different mesh resolutions

Number of Elements	Fine Grid		Coarse Grid	
	male rotor	female rotor	male rotor	female rotor
Circumferecial direction	375	473	120	200
Radial direction	20	20	8	8
Axial direction	60	60	60	60
Total (2D)	7 500	9 460	960	1 600
Total (3D)	450 000	567 600	57 600	96 000

factor 6 - 8

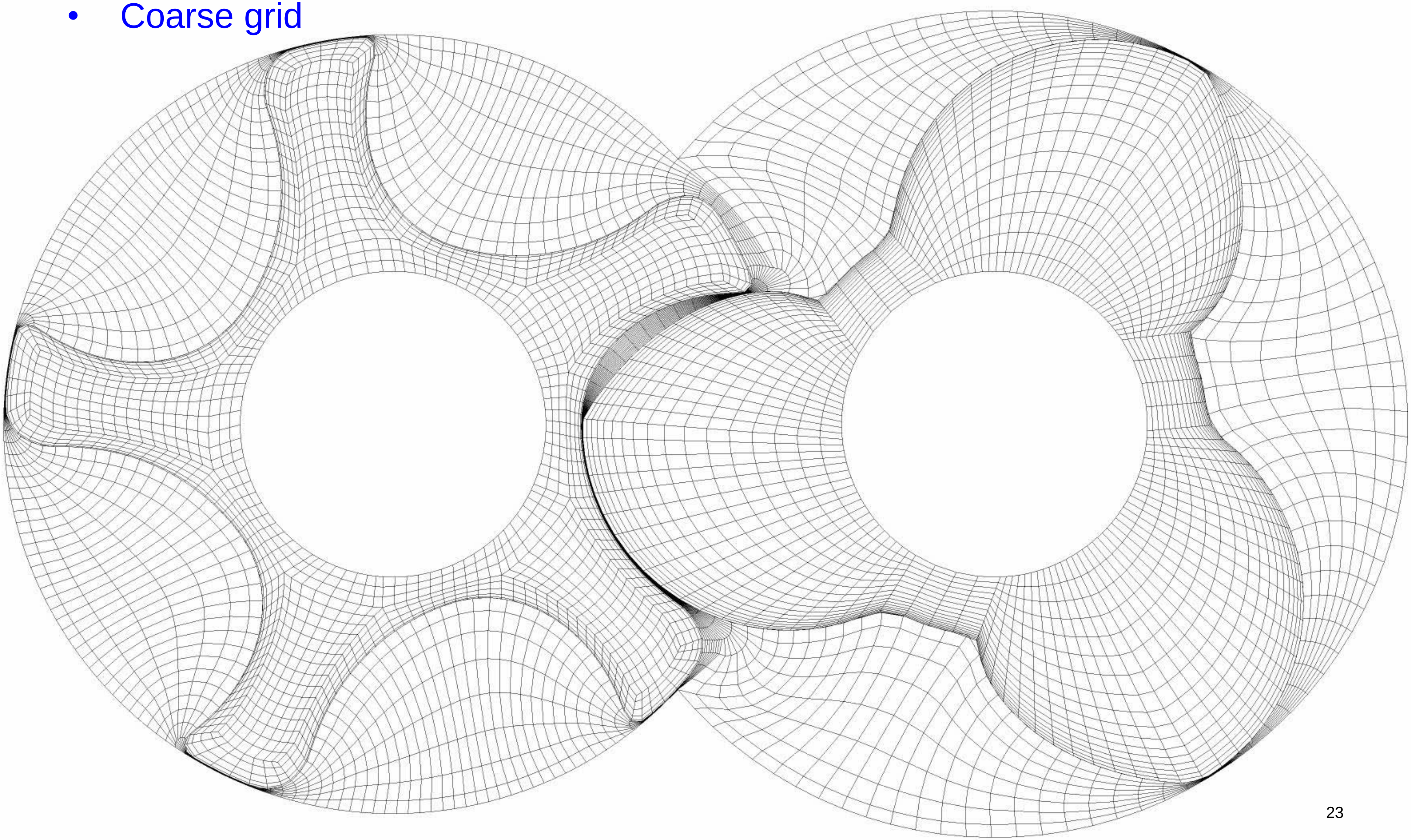
3/5 Screw Compressor
Fine Rotor Grids

- Fine grid



3/5 Screw Compressor
Coarse Rotor Grids

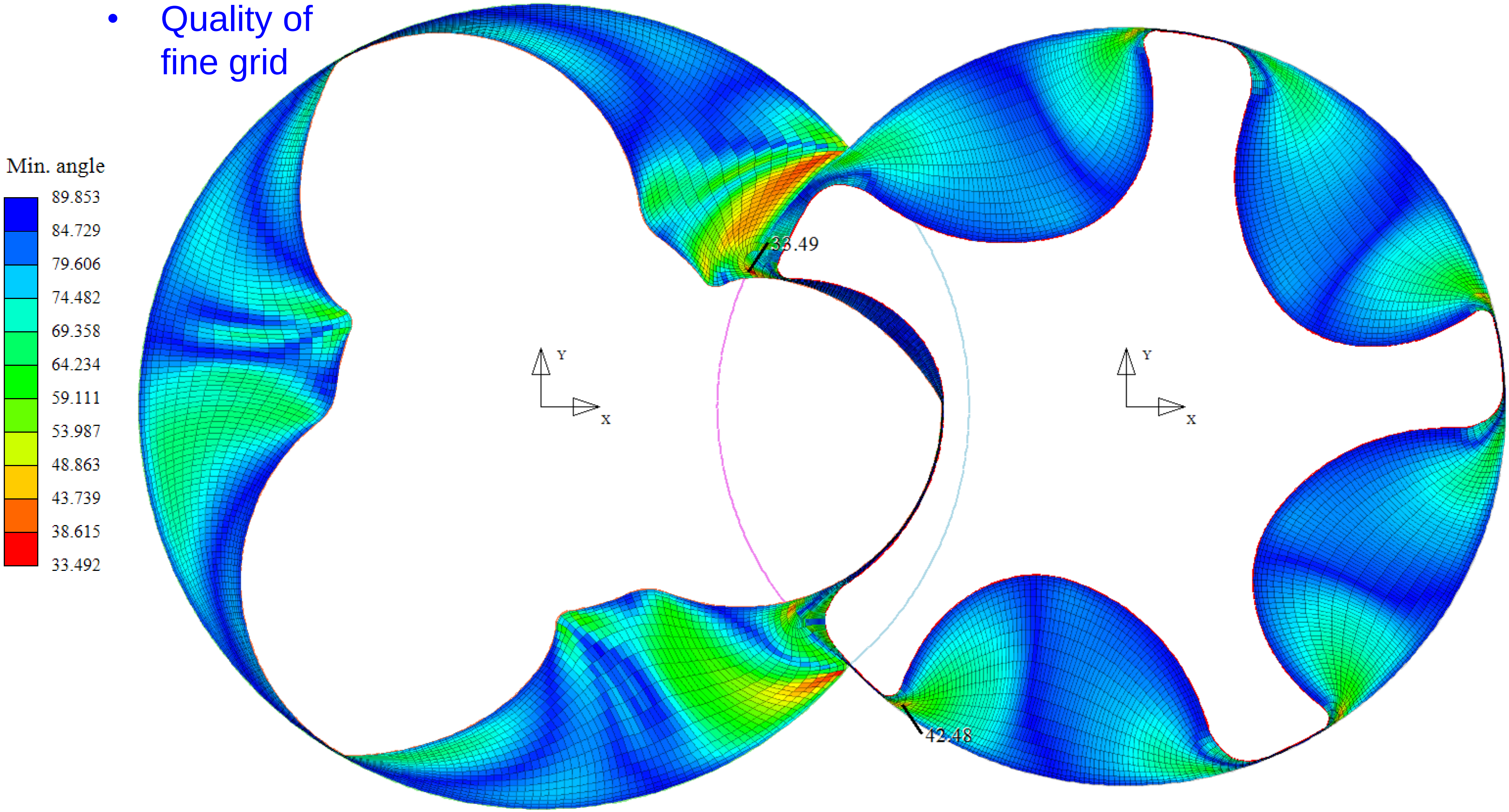
- Coarse grid



3/5 Screw Compressor
Quality of Fine Rotor Grids

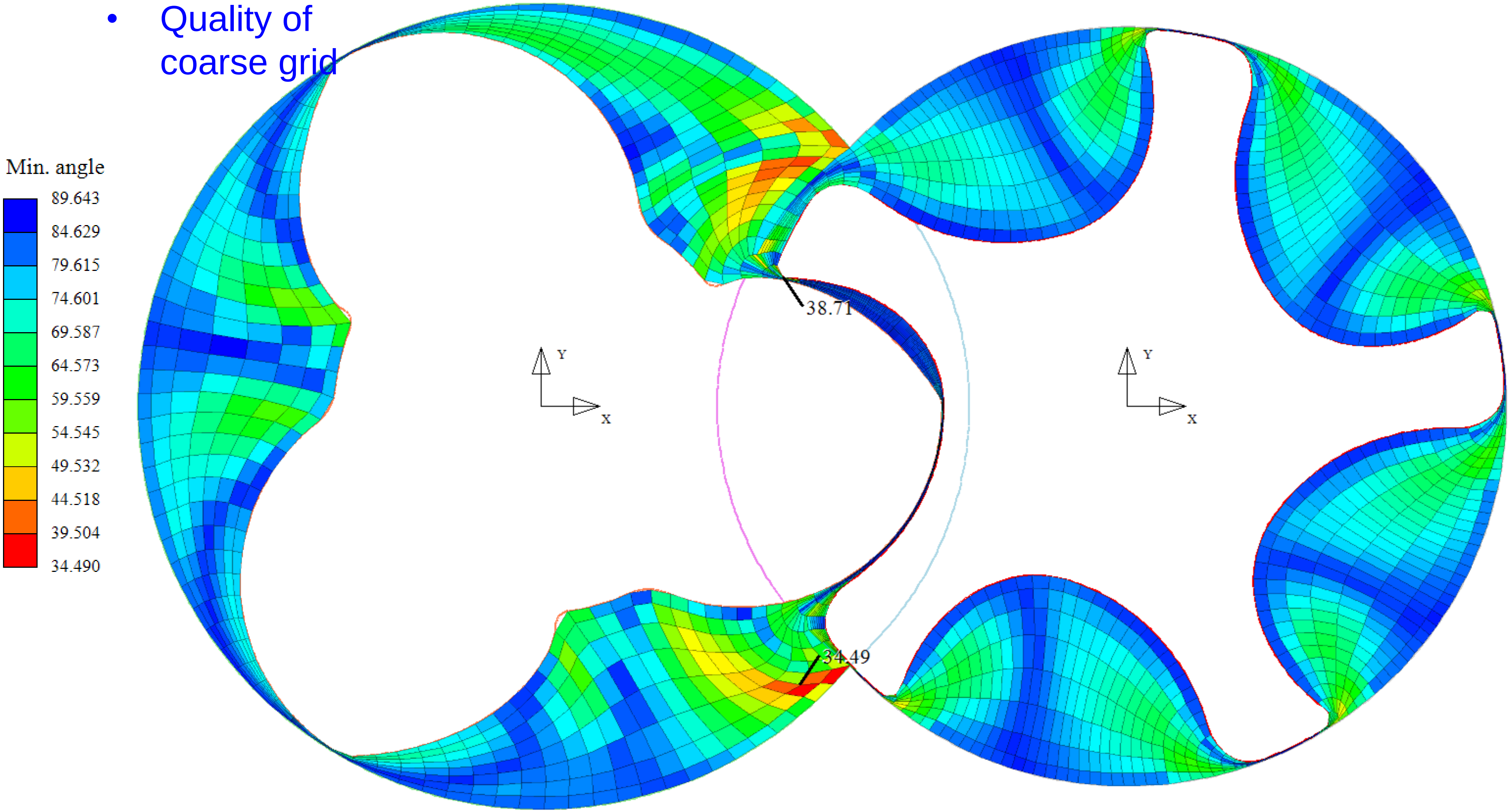
CFX Berlin

- Quality of fine grid



3/5 Screw Compressor
Quality of Coarse Rotor Grids

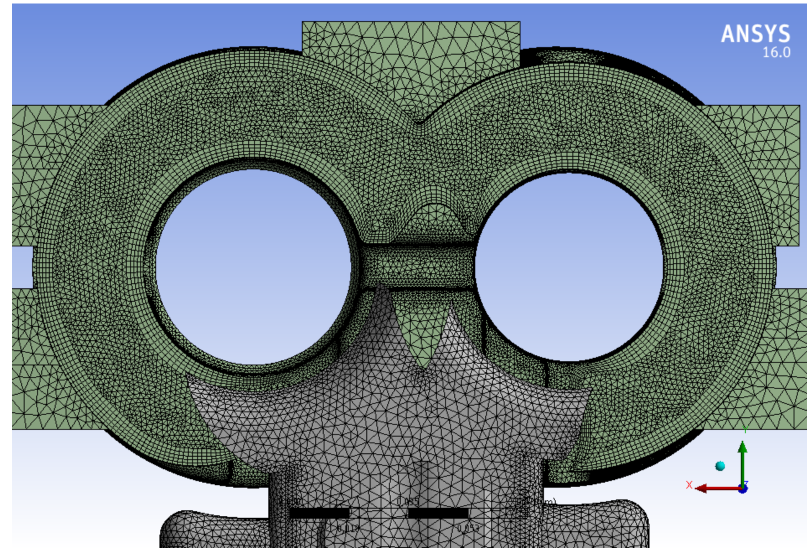
- Quality of coarse grid

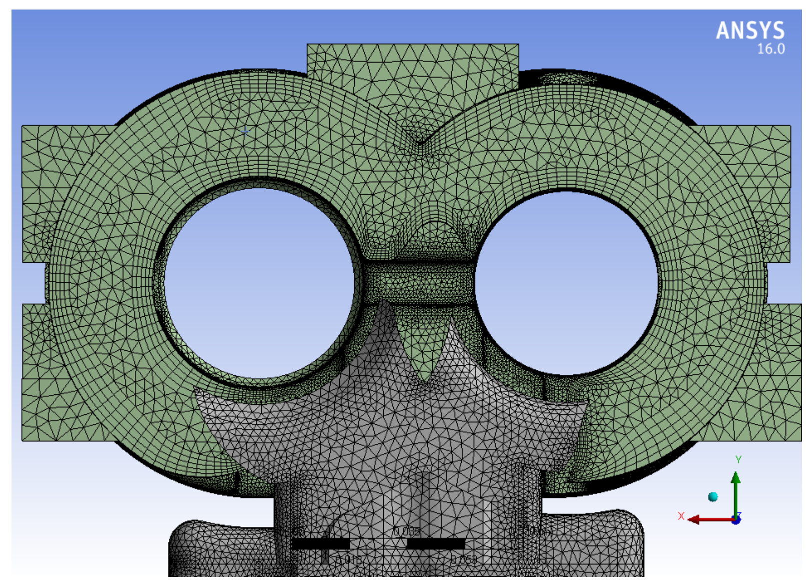


3/5 Screw Compressor Stator Meshes

- Stator mesh for fine rotor grids
  - 1.2 mio elements (tetrahedrons, prisms)
  - 380 000 nodes

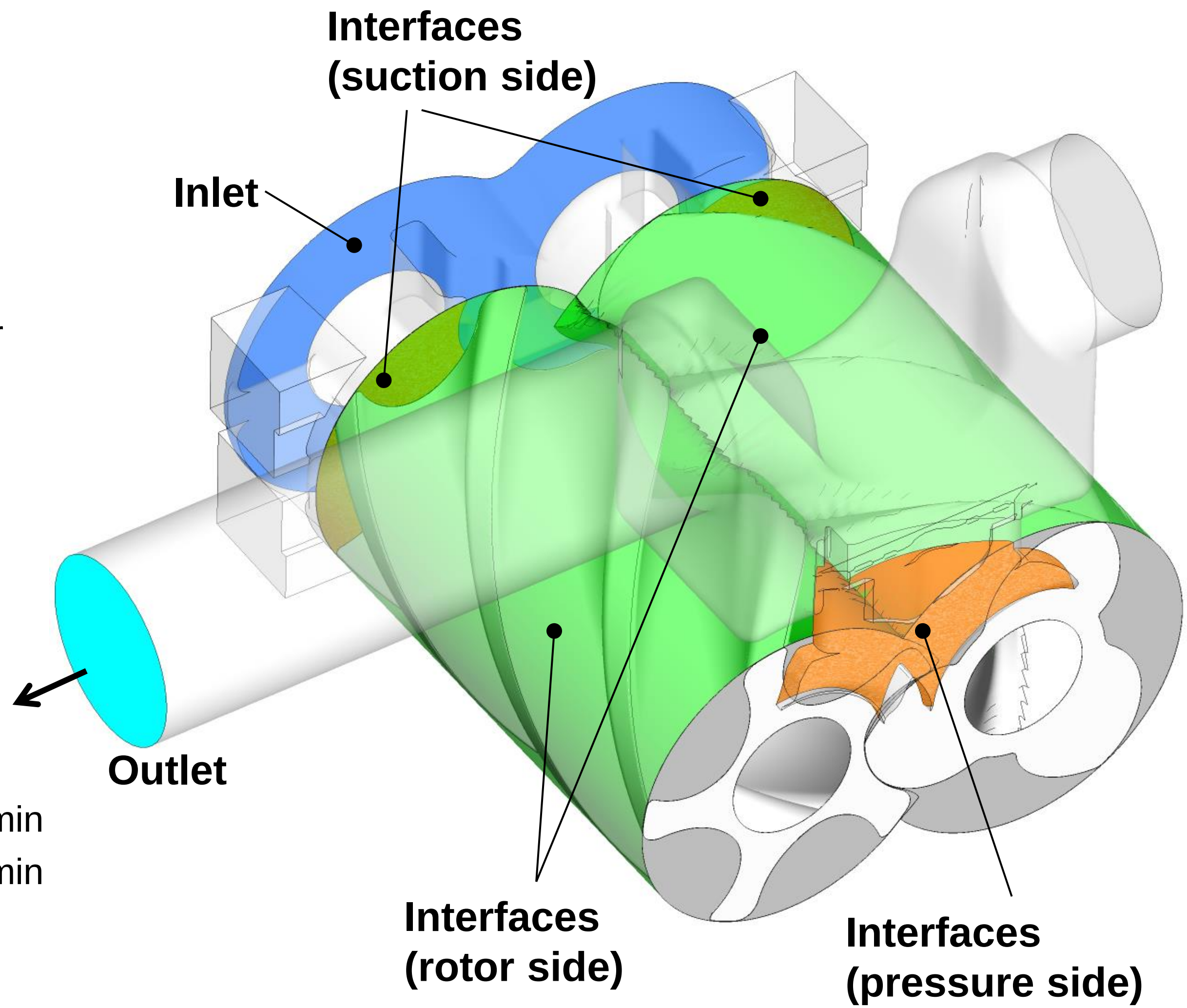
- Stator mesh for coarse rotor grids
  - Increased element size at rotor-stator interfaces
  - 900 000 elements (tetrahedrons, prisms)
  - 320 000 nodes





3/5 Screw Compressor Boundary Conditions

- Boundary conditions
  - Inlet (opening)
    - Absolute pressure = 1 bar
    - Temperature= 300 K
  - Outlet (opening)
    - Absolute pressure = 2 bar
    - Temperature 1 = 402.6 K
    - Temperature 2 = 406.9 K
  - Interface
    - Interface between rotors and stator (GGI)
  - Walls
    - No slip walls, adiabatic
  - Rotors
    - Rot. speed 1 = 6 000 rev/min
    - Rot. speed 2 = 8 000 rev/min
    - Angle step = 1°
  - Fluid
    - Air as ideal gas



3/5 Screw Compressor Solving

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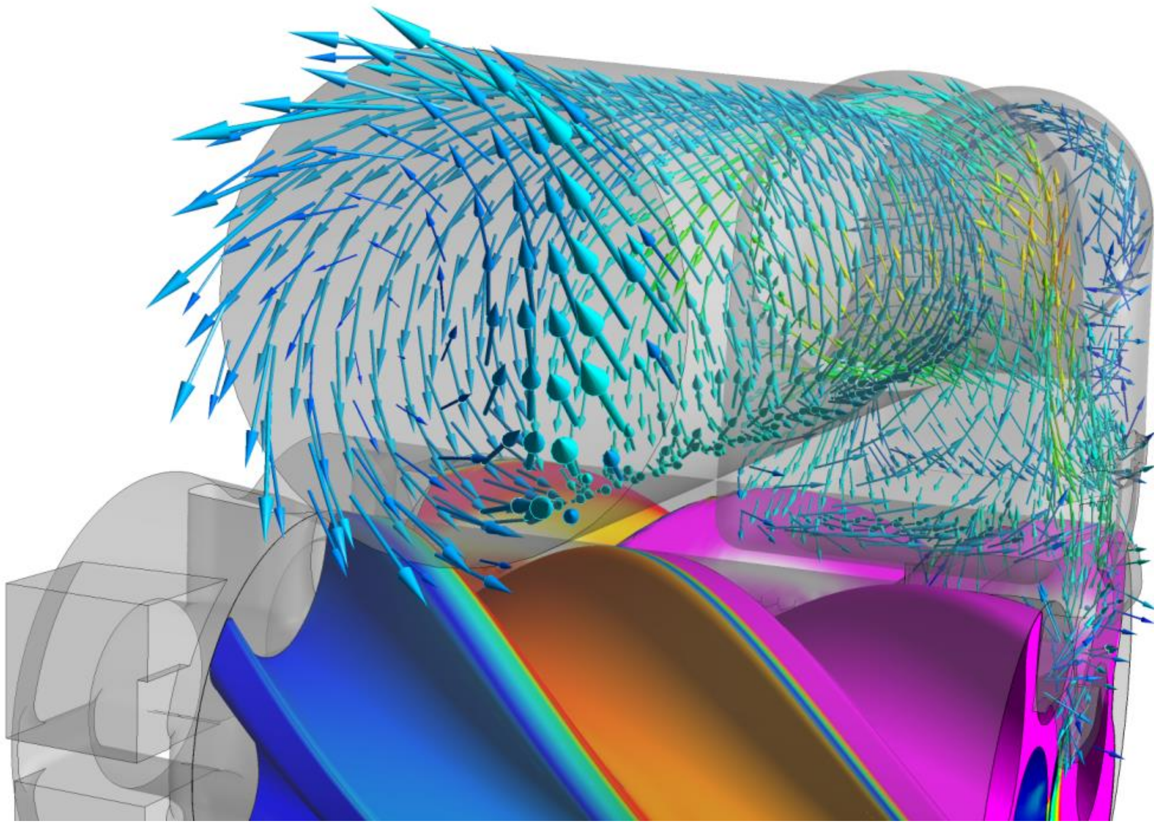
- Mesh motion
  - TwinMesh grids are read in prior to each time step during run-time via User Fortran
  - after 120° male rotor rotation, simulation is restarted with interpolation from previous results
- Convergence
  - Achieved convergence
    - RMS < 10^{-3}
    - max. number of coefficient loops: 5 to10
  - Conservation target
    - < 1 %
  - Simulation duration
    - ≈30 hours per revolution (male rotor, finest mesh)
  - Hardware
    - 2 x 4 - Quad Core Intel Xeon(R) E5-2637 v2
    - 3.50 GHz

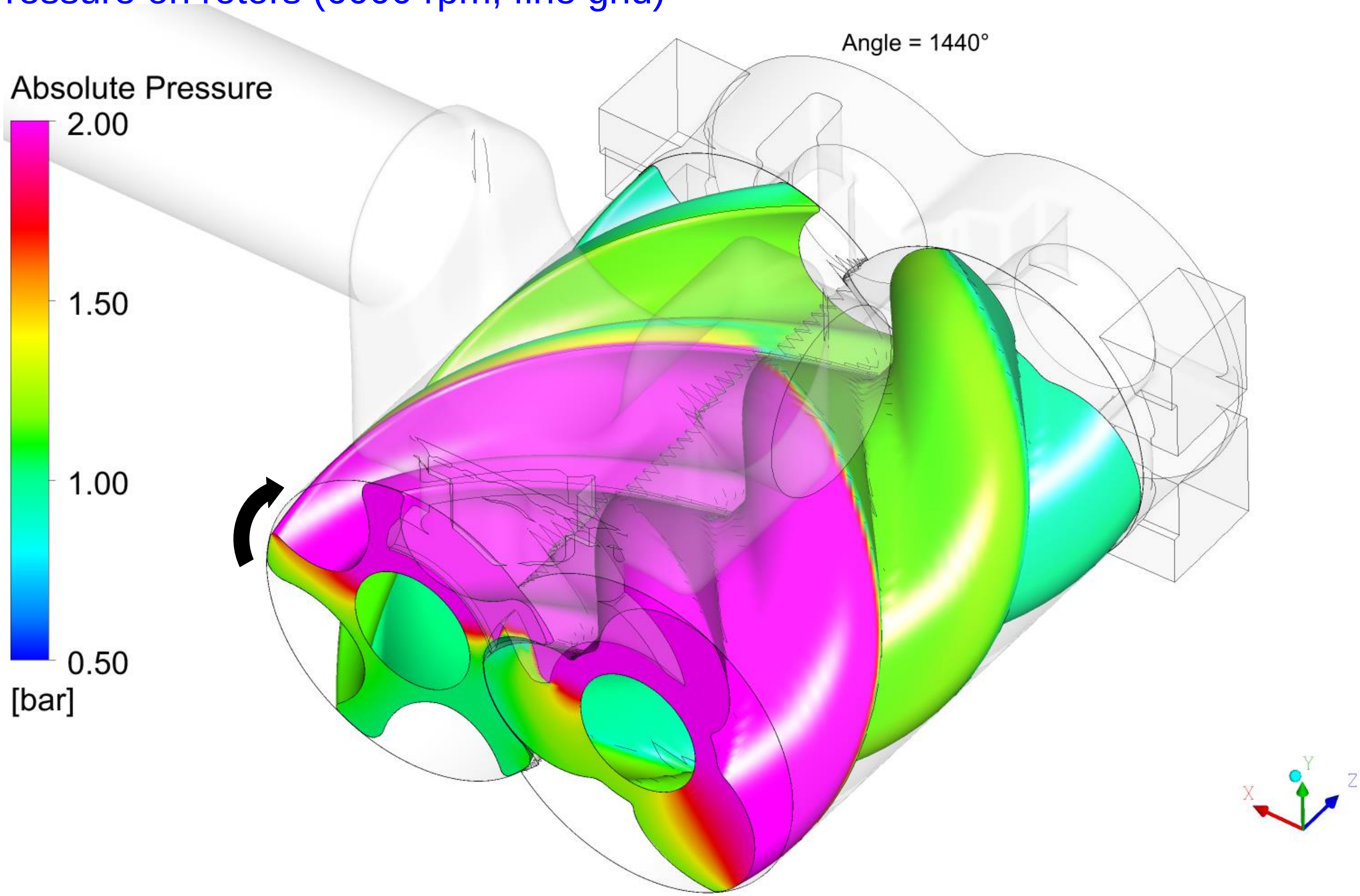
3/5 Screw Compressor
Results Overview

- Results
  - Qualitative evaluation of the flow field
    - Pressure field
    - Velocity field
    - Temperature field
  - Evaluation of integral values:
    - Volume flow rate [m³/min]
    - Power [kW]



3/5 Screw Compressor
Pressure on Rotors

Pressure on rotors (6000 rpm, fine grid)



3/5 Screw Compressor
Pressure on Casing

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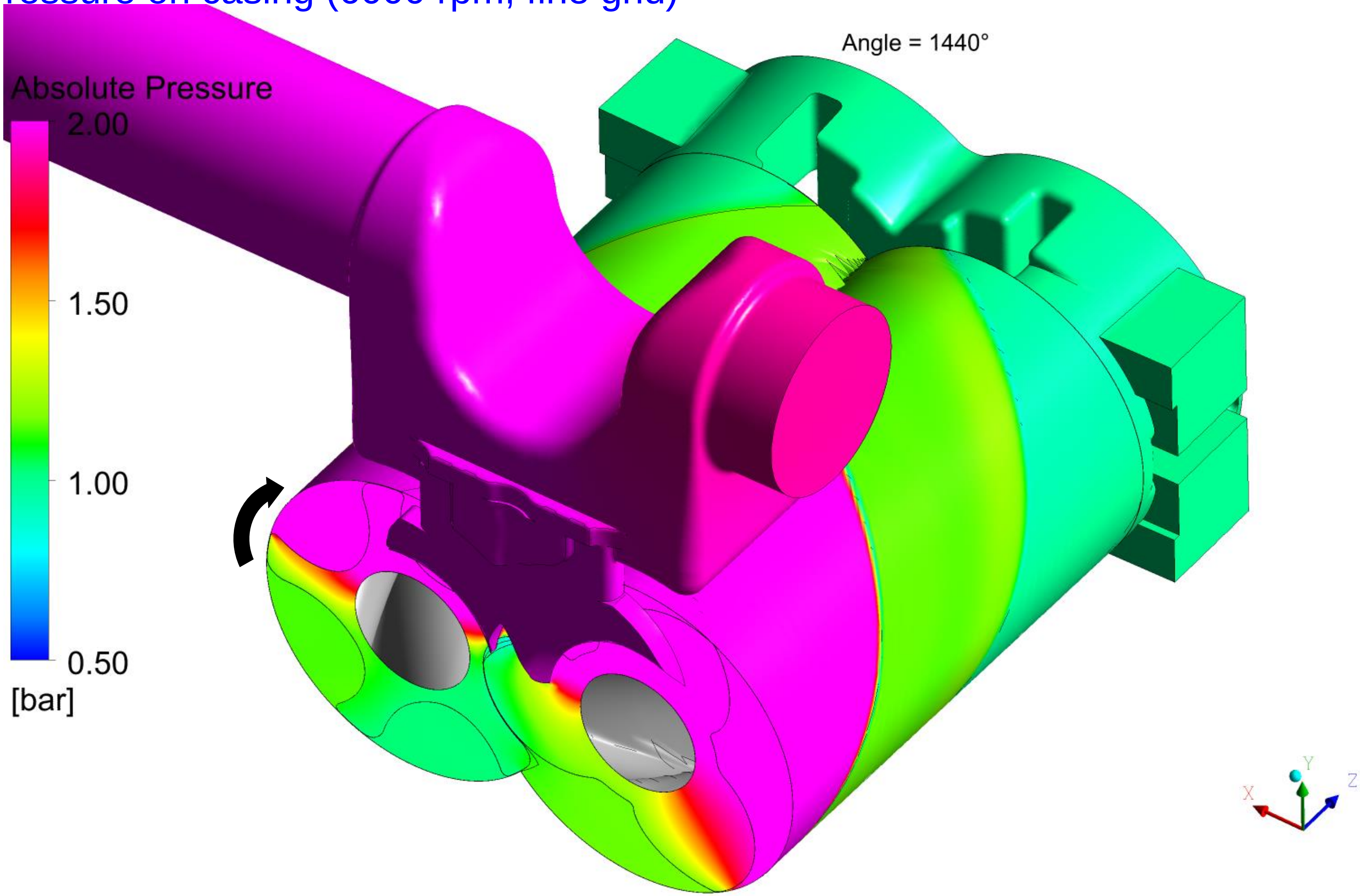
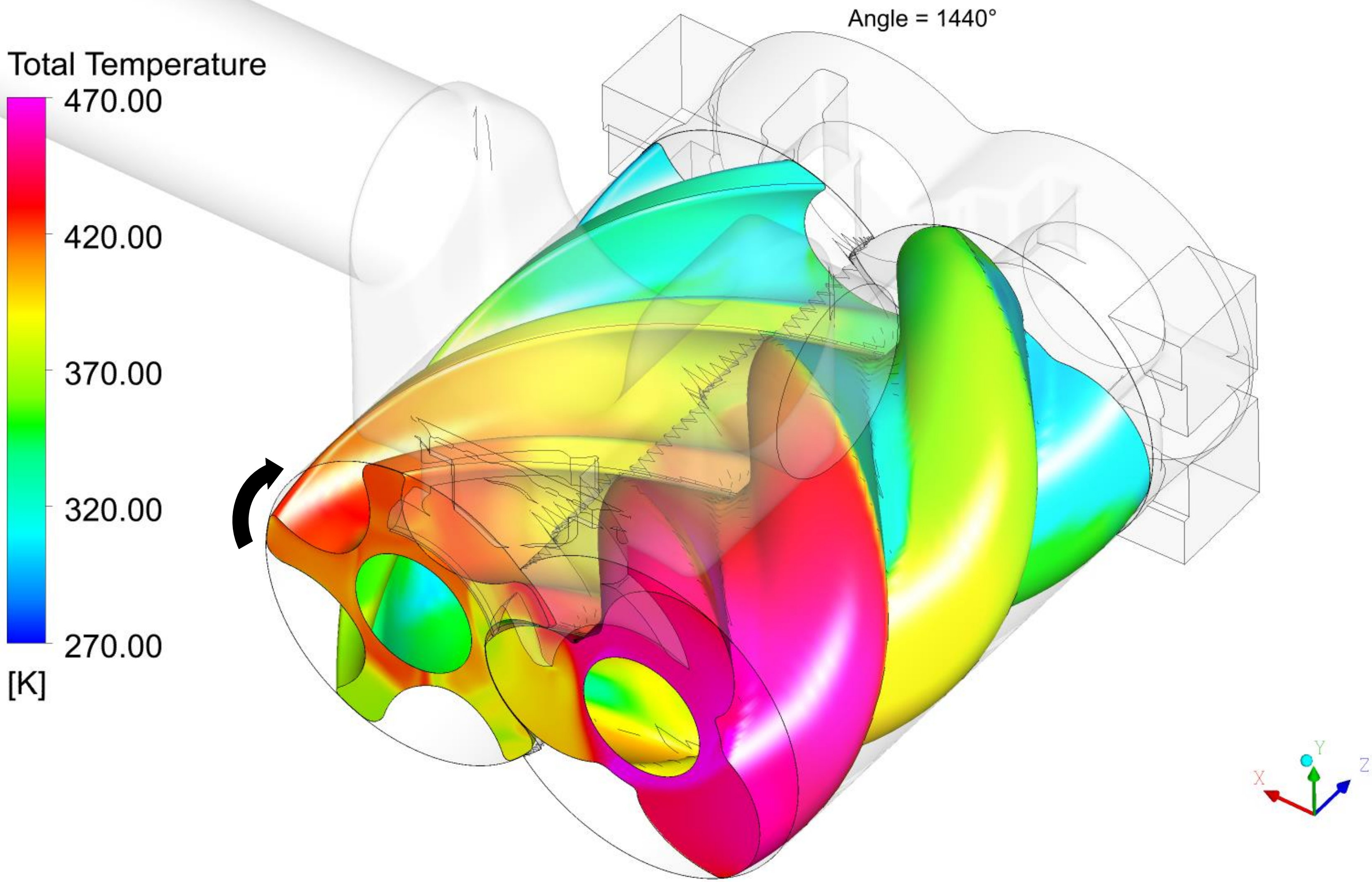
Pressure on casing (6000 rpm, fine grid)



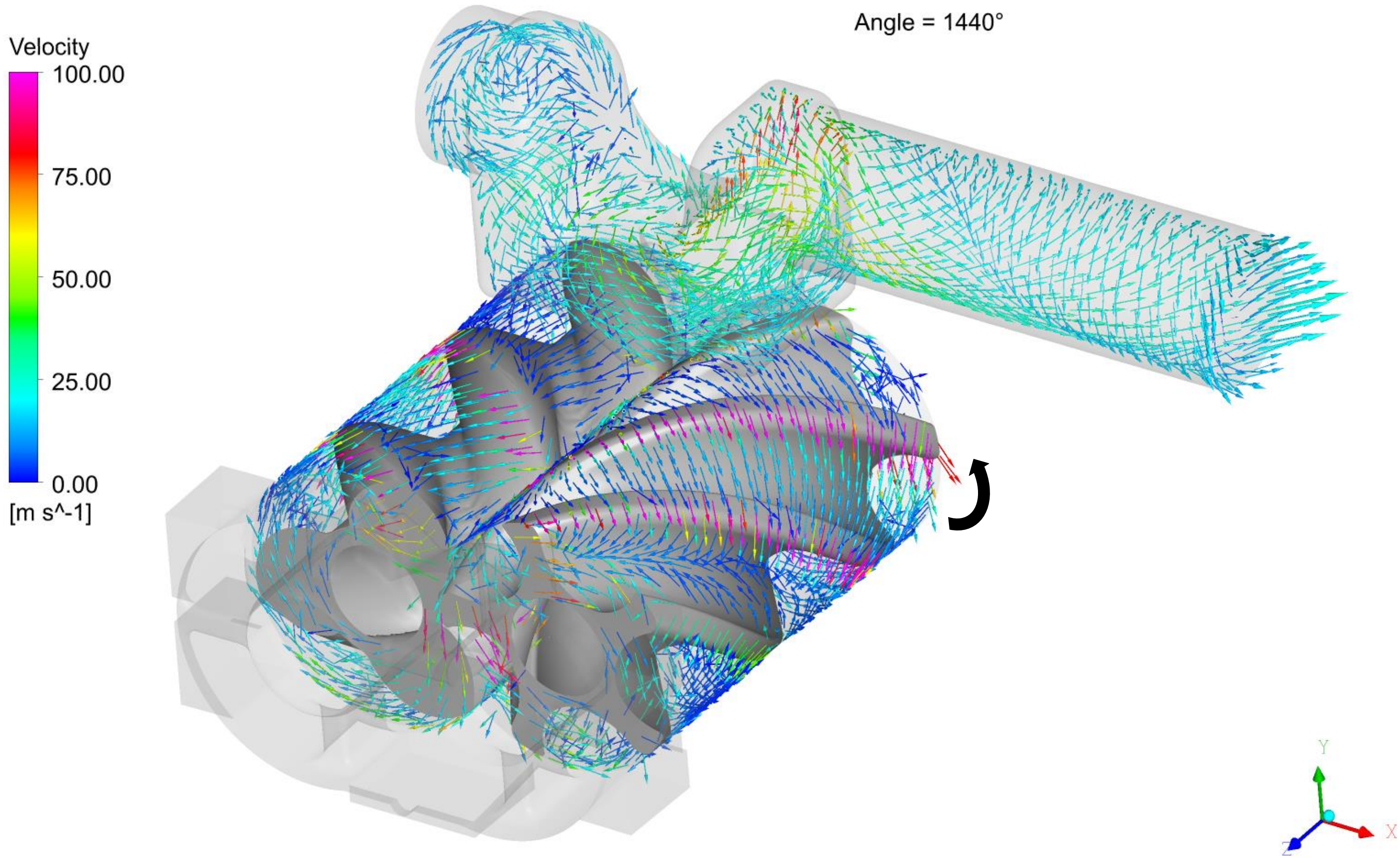
3/5 Screw Compressor
Temperature on Rotors

Temperature on rotors (6000 rpm, fine grid, adiabatic boundary)



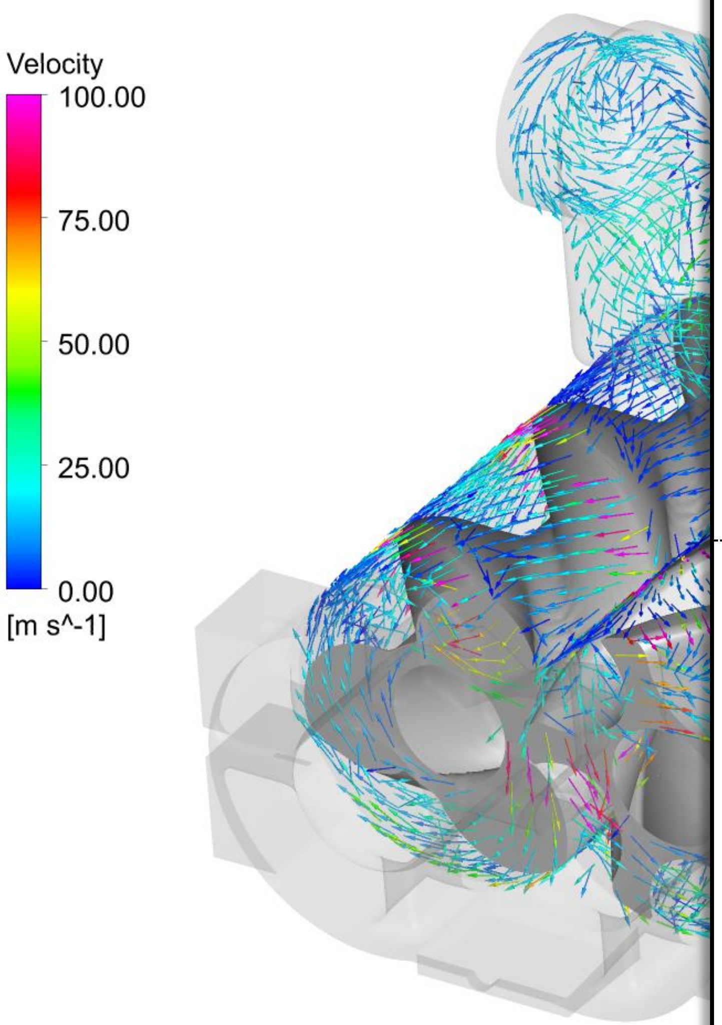
3/5 Screw Compressor
Velocity in Clearances

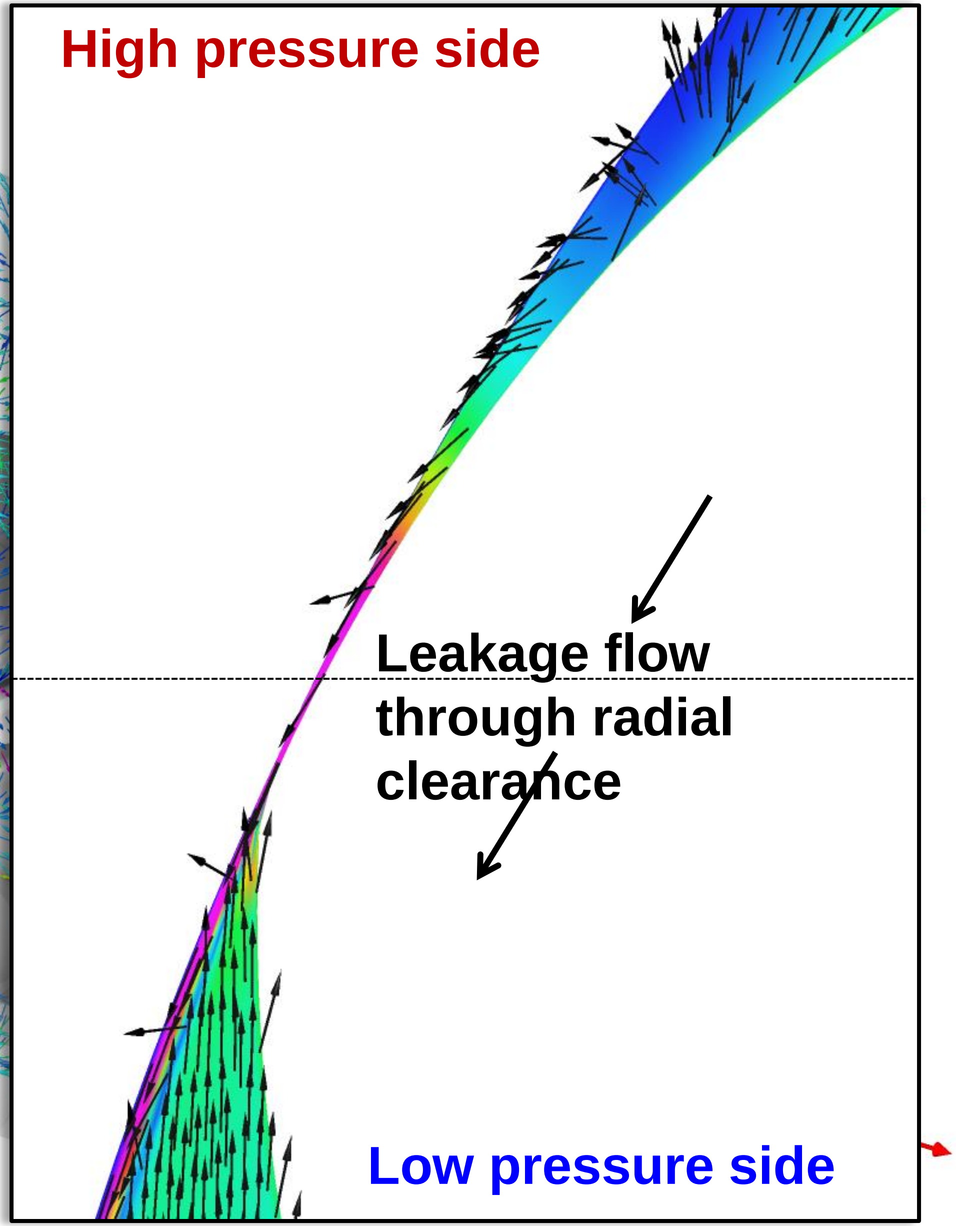
Velocity vectors in clearances and pressure side (6000 rpm, fine grid)



3/5 Screw Compressor Velocity in Clearances

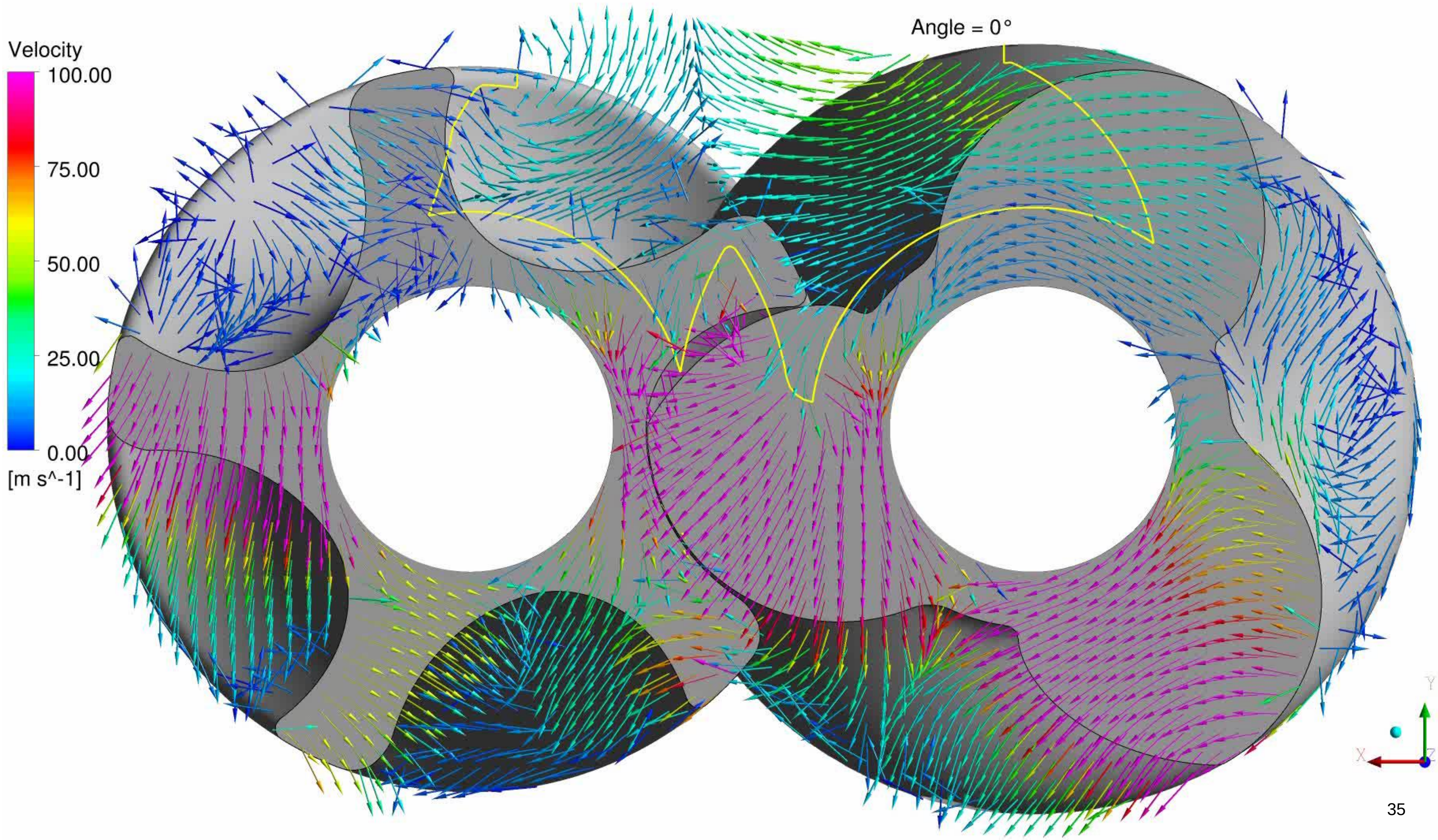
Velocity vectors in clearances and



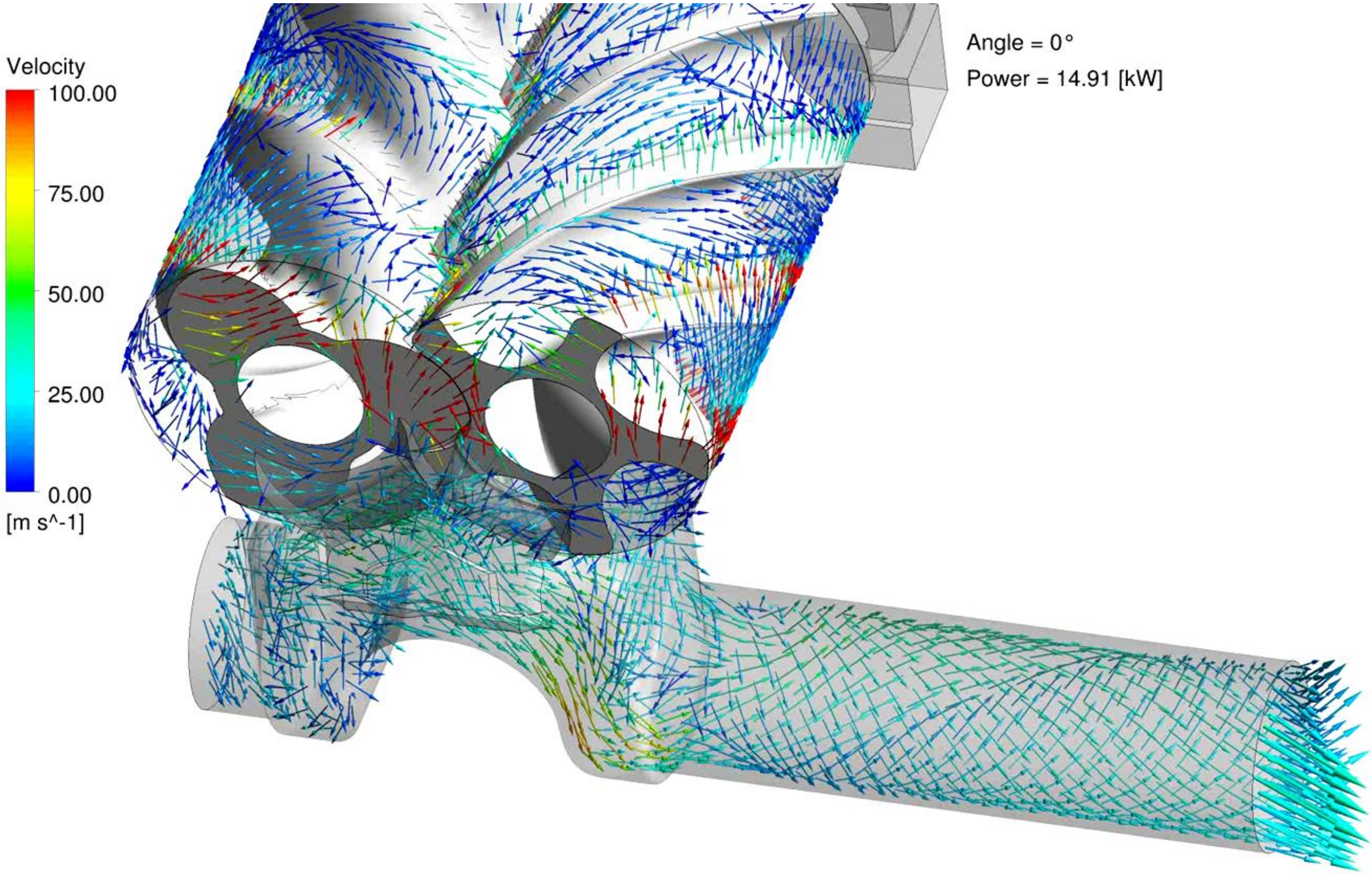


3/5 Screw Compressor
Velocity in Axial Clearance

Velocity vectors in the axial clearance, pressure side (6000 rpm, fine grid)



3/5 Screw Compressor
Velocity



3/5 Screw Compressor
Velocity on Cross Section

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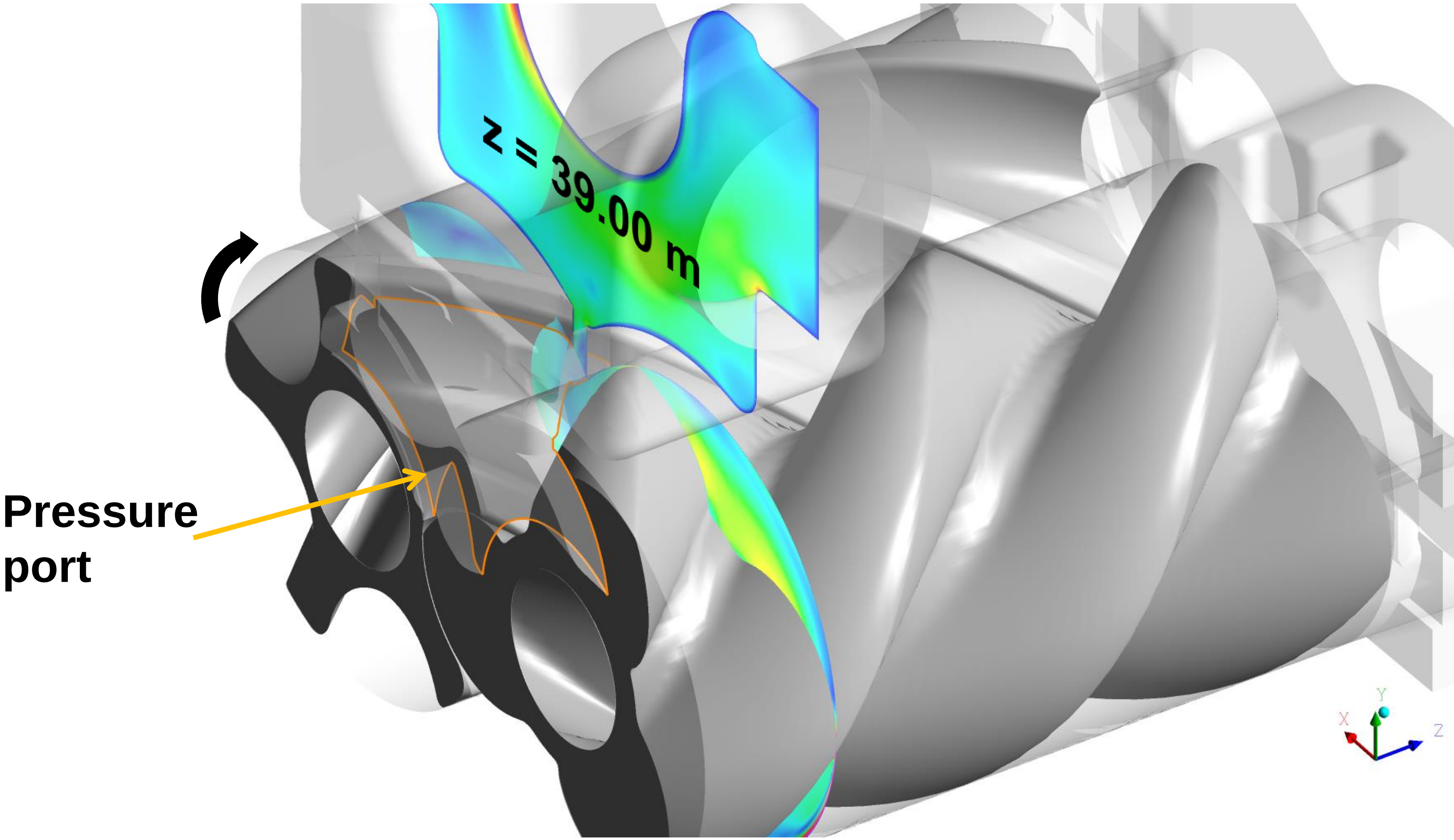
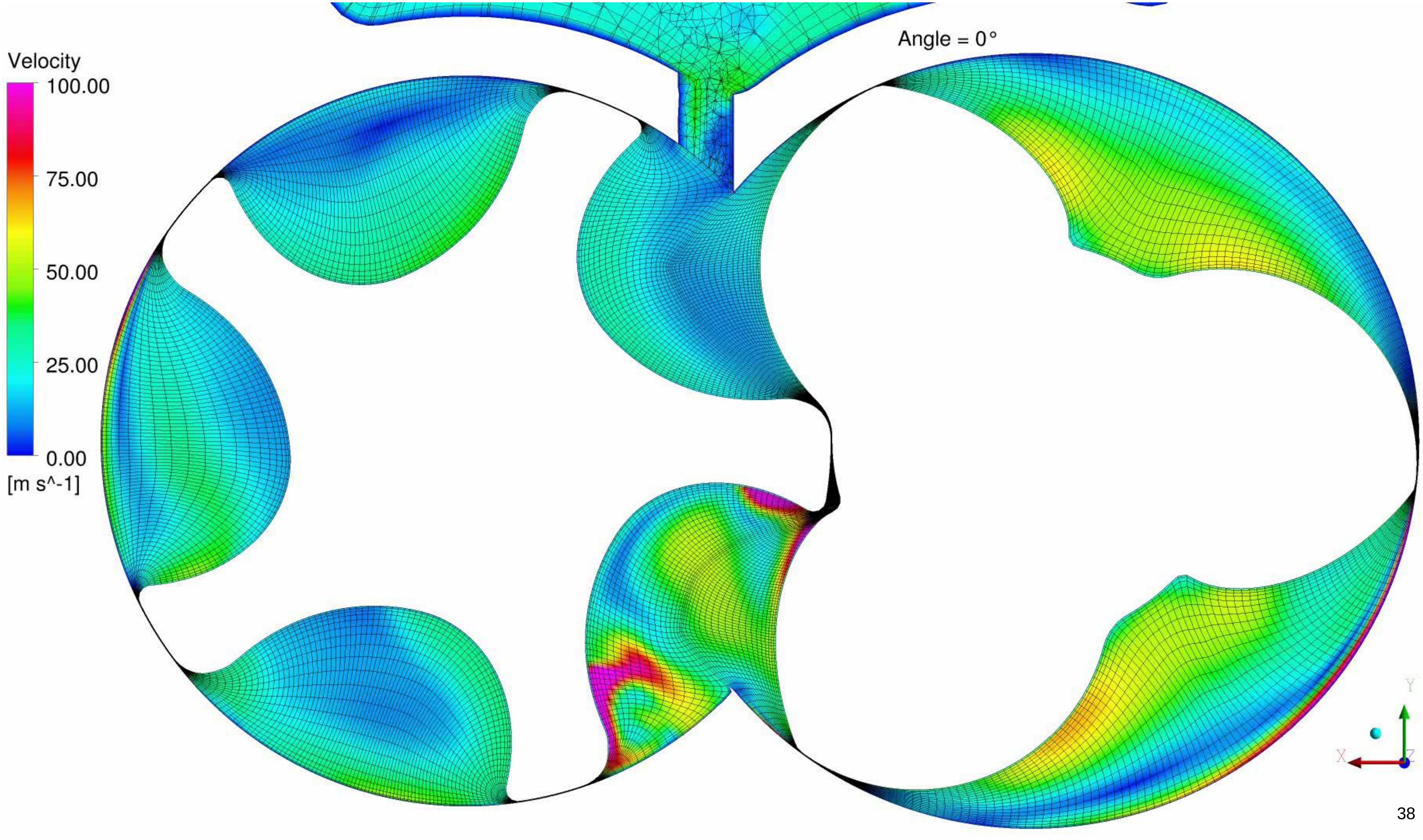
Velocity at z = 39.00 mm:
Comparison between fine and coarse grid



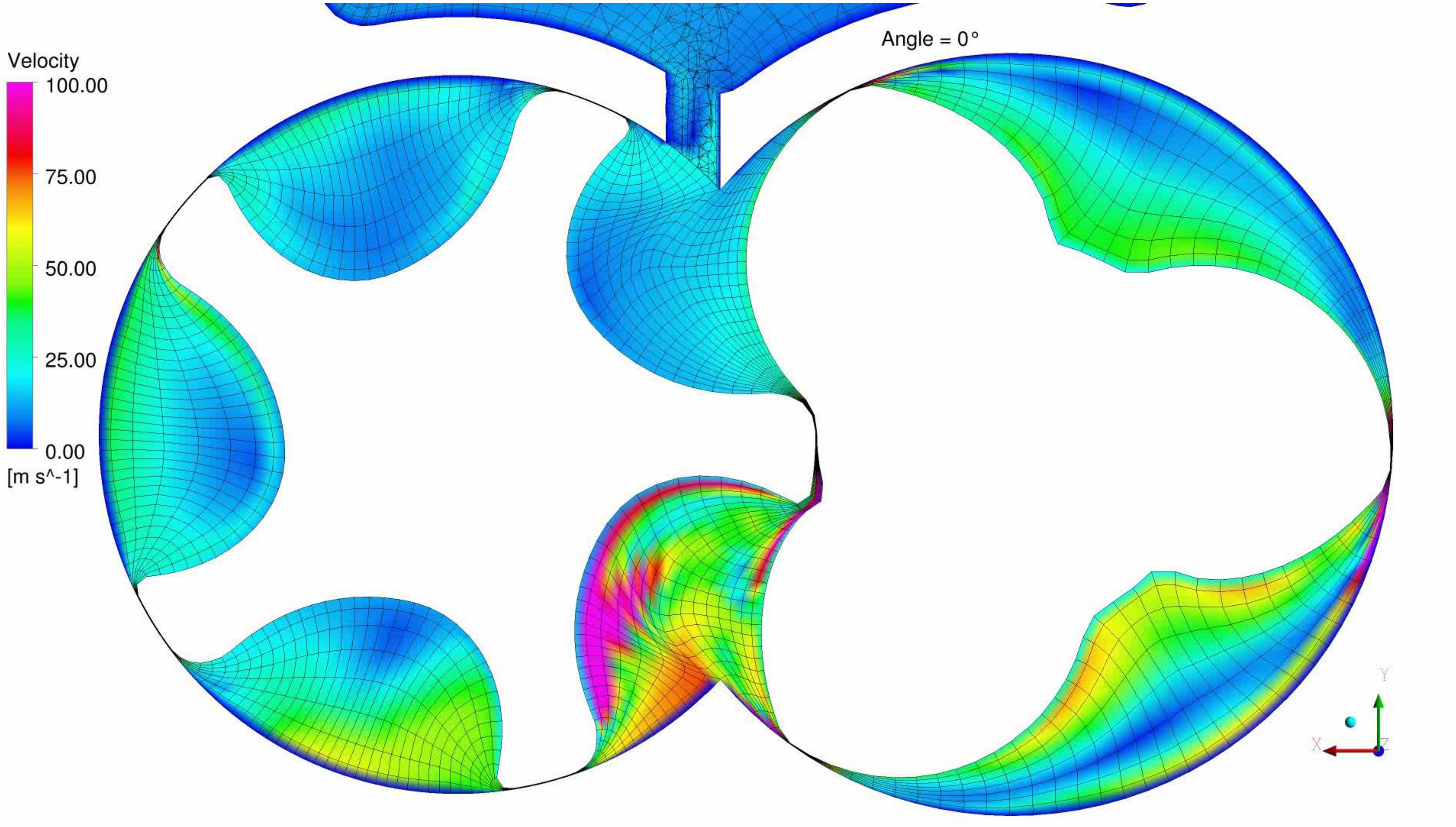
3/5 Screw Compressor
Velocity on Cross Section

Velocity for z = 39.00 mm (6000 rpm, fine grid)



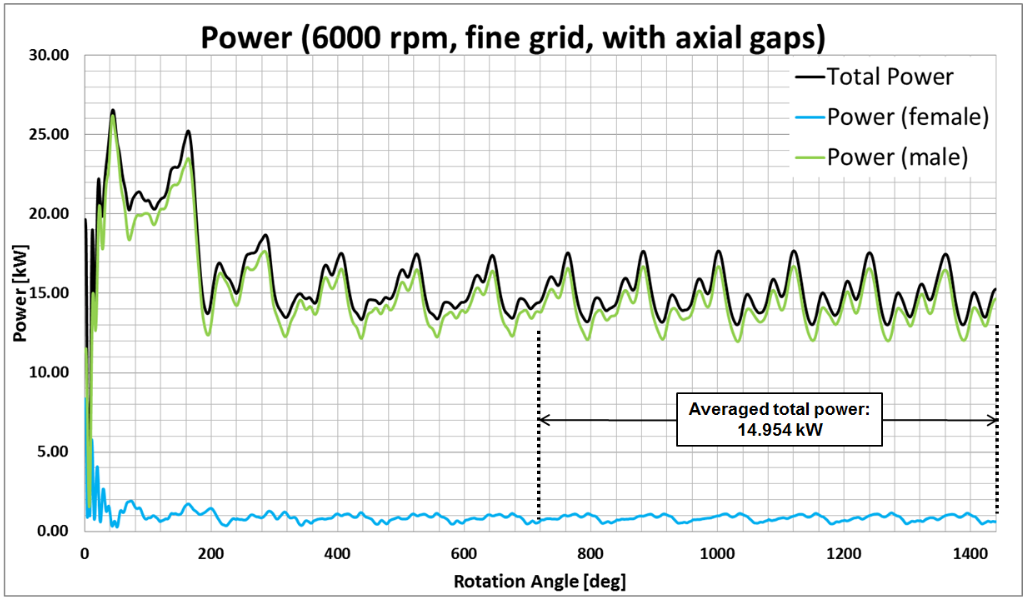
3/5 Screw Compressor
Velocity on Cross Section

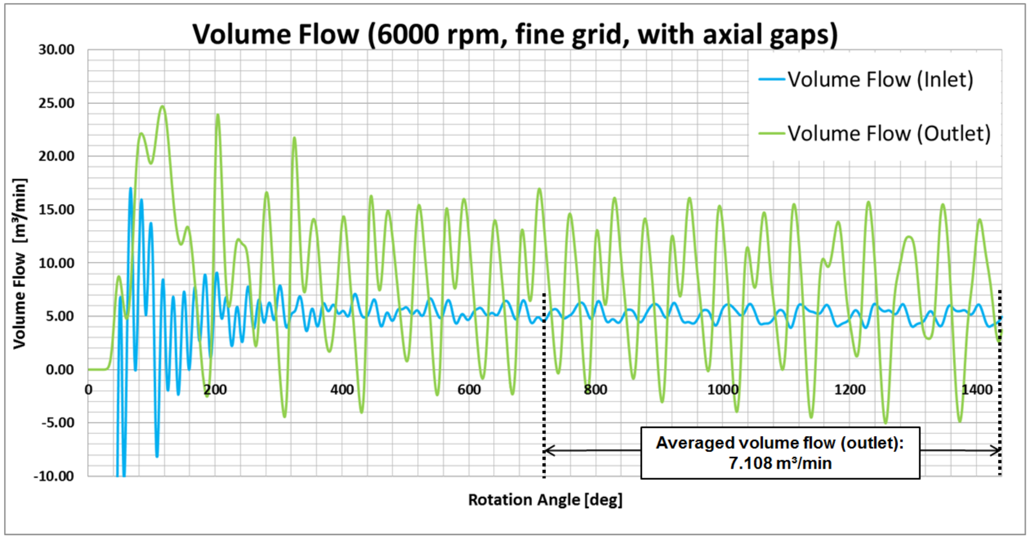
Velocity for z = 39.00 mm (6000 rpm, coarse grid)



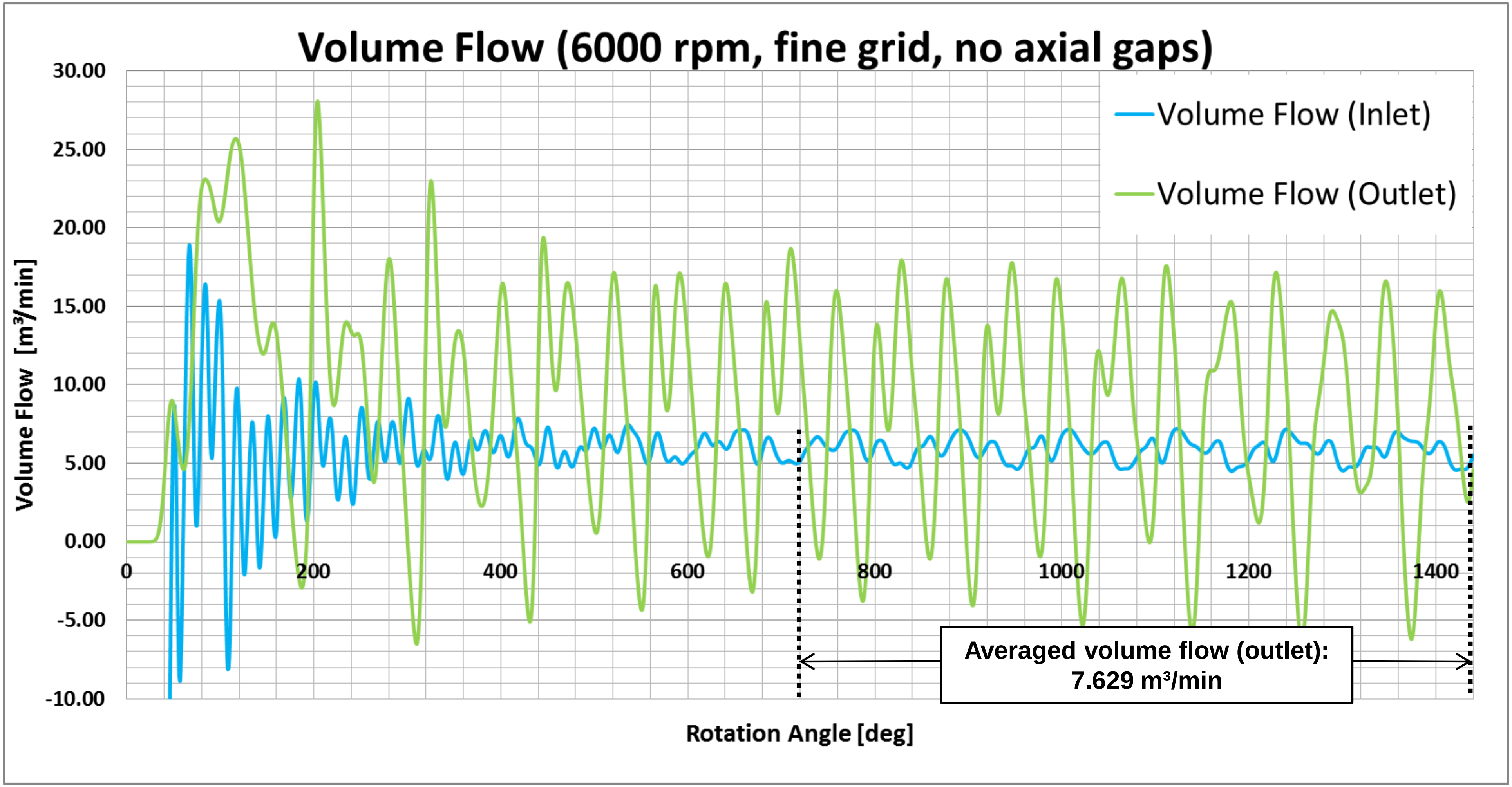
3/5 Screw Compressor Quantitative Results Overview

- Power and volume flow
  - Starting from neutral initialization
  - Two revolutions as start-up phase
  - Averaging over two revolutions (720°-1440° male rotor angle)
- Comparison between
  - Cases with and without axial clearance
  - 6000 rpm and 8000 rpm
  - Fine and coarse mesh resolution

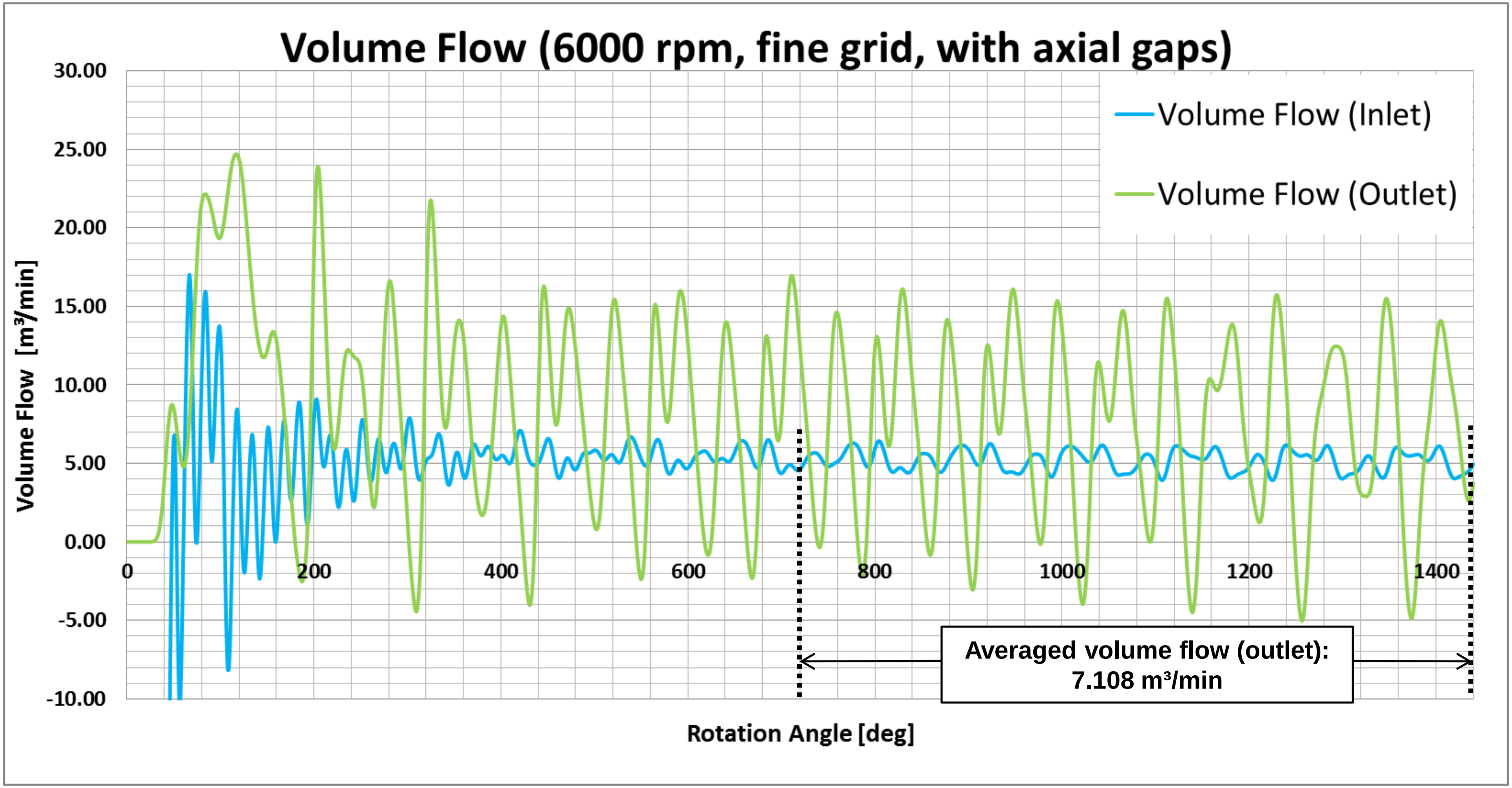




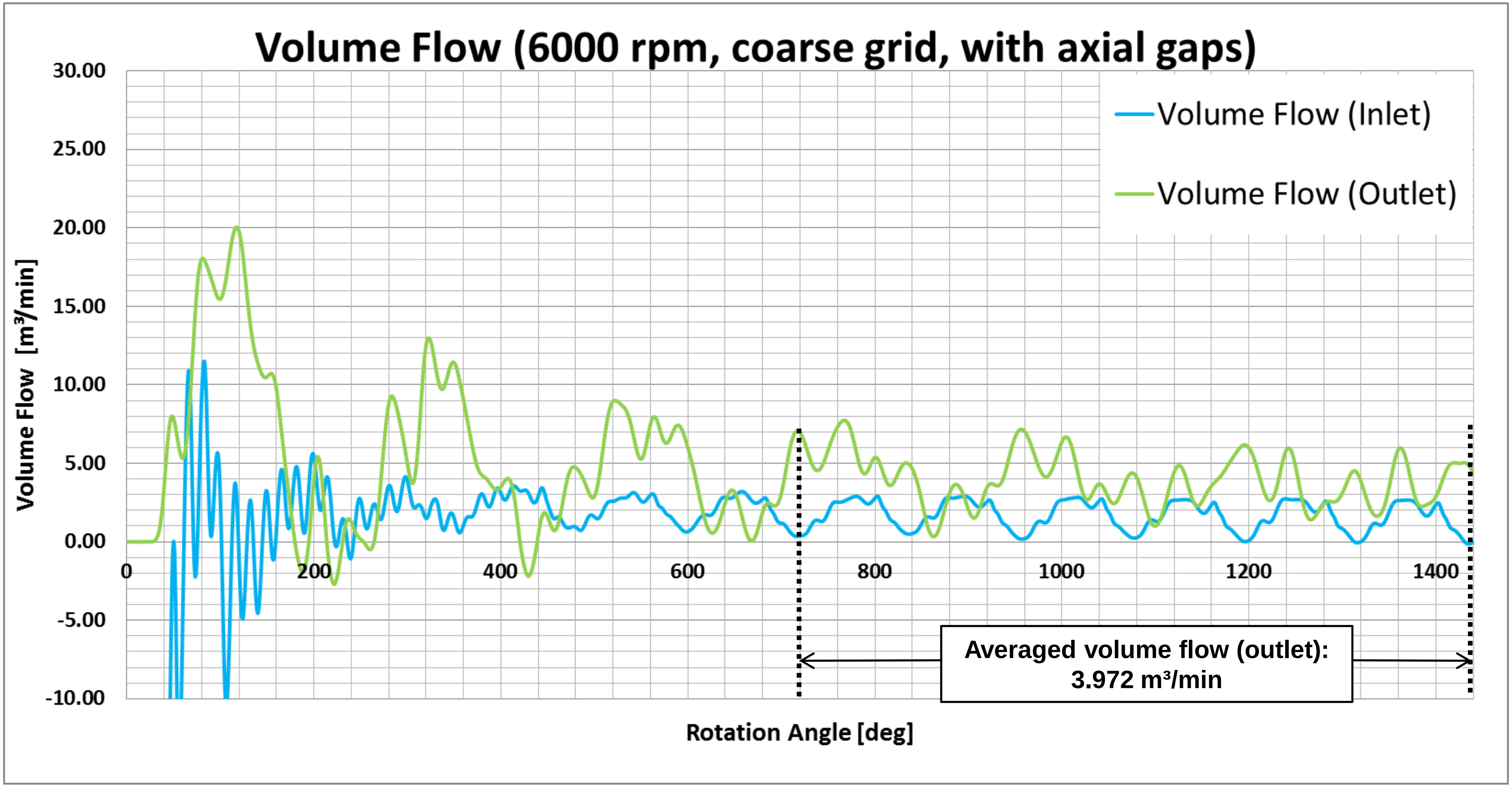
3/5 Screw Compressor Volume Flow



3/5 Screw Compressor
Volume Flow



3/5 Screw Compressor Volume Flow



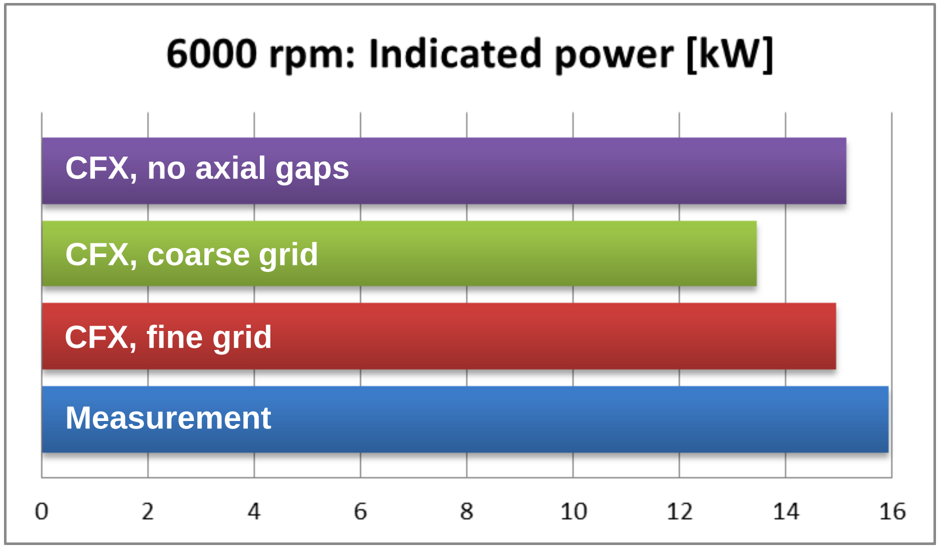
3/5 Screw Compressor Quantitative Results

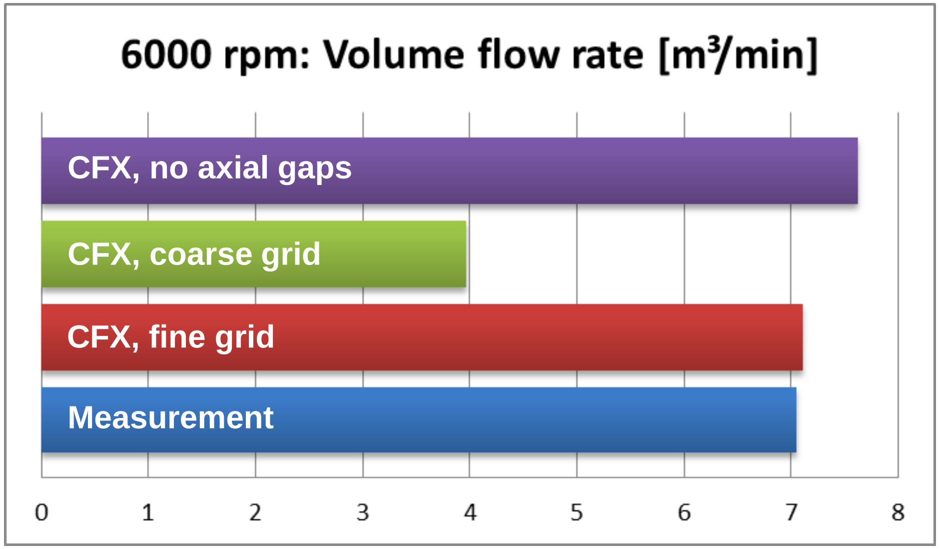
CFX Berlin

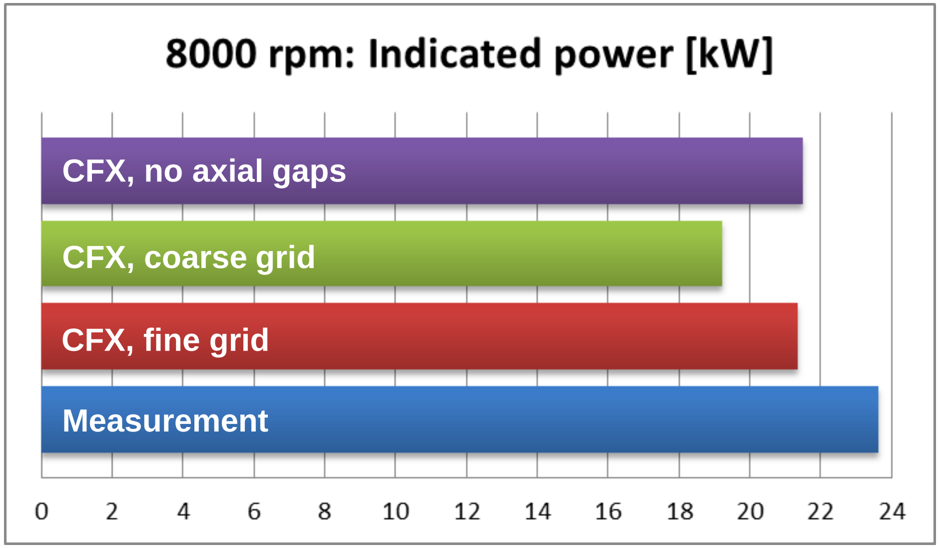
- Comparison
  - Comparison of measurements with simulation results for two operating points (OP): Rotor speed: 6 000 and 8 000 rpm
  - Three simulation cases per operating point:

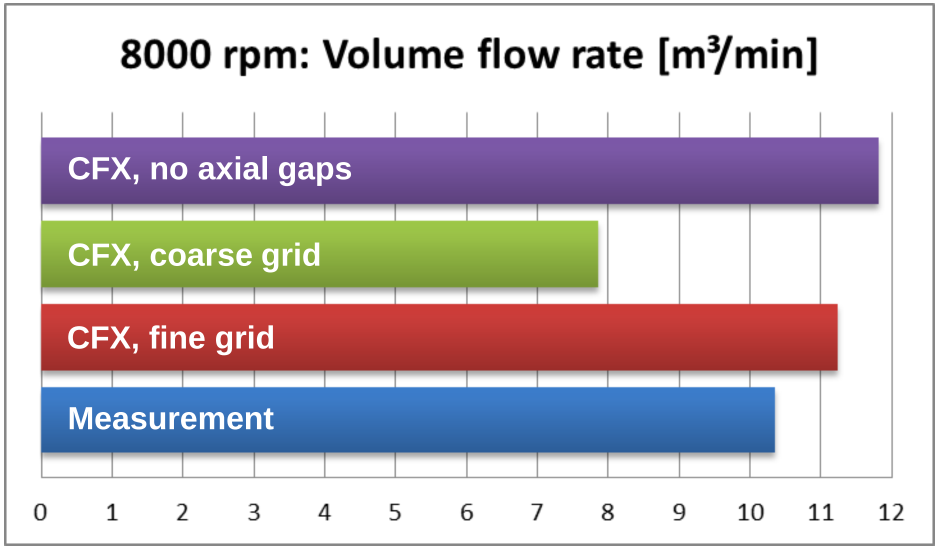
	OP	Speed	Discharge Pressure	Flow	Torque	Indicated Power	Specific Power
		rpm	bar	m³/min	Nm	kW	kW/m³/min
Measurement	1	6 000	2	7.051	25.397	15.945	2.148
CFX (fine grid)	1	6 000	2	7.108	24.696	14.954	2.104
CFX (coarse grid)	1	6 000	2	3.972	22.632	13.451	3.386
CFX (no AxGaps)	1	6 000	2	7.629	24.991	15.151	1.986
Measurement	2	8 000	2	10.362	28.204	23.631	2.166
CFX (fine grid)	2	8 000	2	11.242	26.452	21.351	1.899
CFX (coarse grid)	2	8 000	2	7.862	24.253	19.215	2.444
CFX (no AxGaps)	2	8 000	2	11.829	26.567	21.497	1.817

3/5 Screw Compressor Quantitative Results









3/5 Screw Compressor
Conclusions

Conclusions:

- Very good agreement at 6000 rpm for volume flow, slightly underestimation of the total power (shaft output)
  - Bearing friction losses are not included in the numerical model, thus a lower indicated power (for a compressor) seems plausible
- Increasing deviation from measurements at 8000 rpm regarding volume flow and power
  - Is it realistic that clearances at 6000 and 8000 rpm are the same?
- Clear demonstration of the effect of an axial clearance
  - Neglecting axial gaps results in 5 to 7% higher volume flow
  - Detailed analysis of the leakage flow pattern possible (axial and radial)
- Severe impact of mesh resolution on the volume flow for both operation points
  - Volume flows 30-45%, power 10% smaller on coarse grid
  - No reliable results using the coarse mesh

- What is an adequate mesh resolution for small gaps?

Thank you for your attention!