CFD simulation of a two stage twin screw compressor including leakage flows and comparison with experimental data

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Introduction

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- CFD Simulation of a two stage twin screw compressor (oil free)
- Sample screw compressor from Sullair A Hitachi Group Company
- Comparison with experimental data
  - Characteristic curve for volumetric flow rate and power
  - Solver: ANSYS CFX

Introduction

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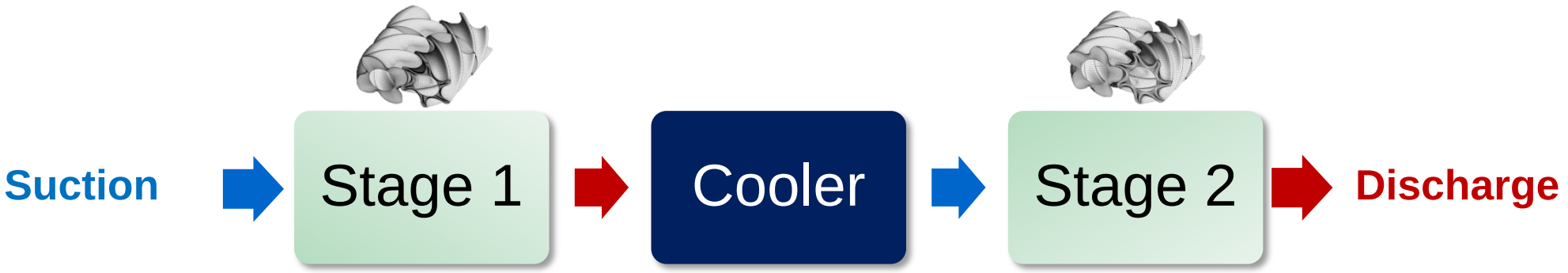
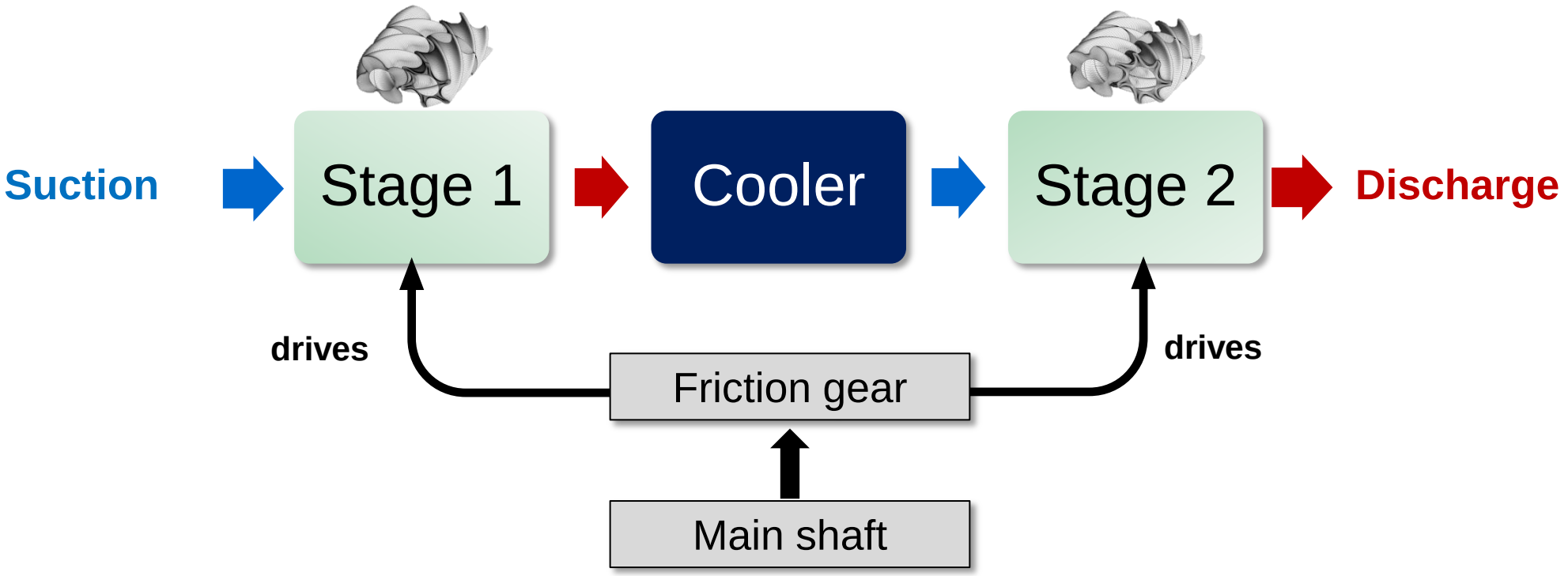
- Feasibility study:
  - Direct coupling of the stages regarding flow field, i. e. no requirement to elaborate adequate boundary conditions at discharge port (1st stage) and suction port (2nd stage)
- Challenges:
  - Time dependent change of complex rotor chambers
  - Coupling of two compressor stages in one simulation setup
  - Different rotational speeds and pitch angles for each stage whereas simulated time step is the same for the entire model
  - Modeling of cooler between stages

Compressor setup



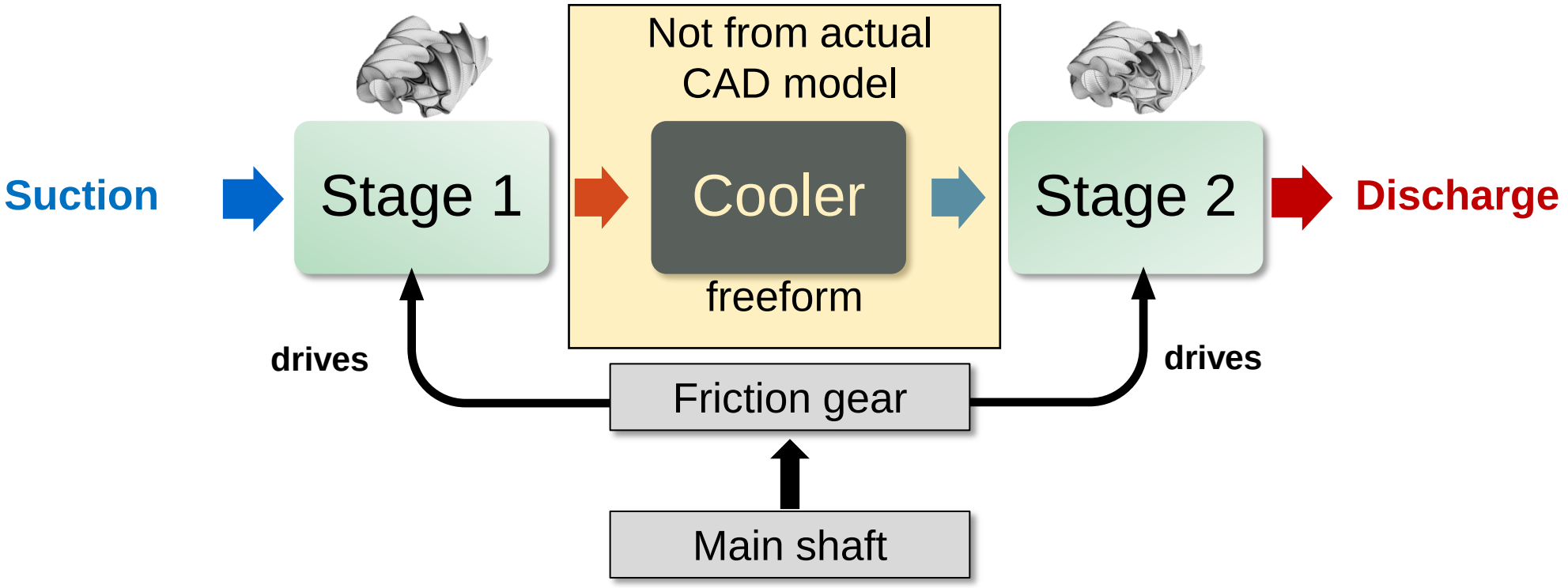
Compressor setup



MS/Male S1= 6.226
S2 Male /S1 Male= 1.53

1490 rev/min
1790 rev/min
2100 rev/min

Compressor setup



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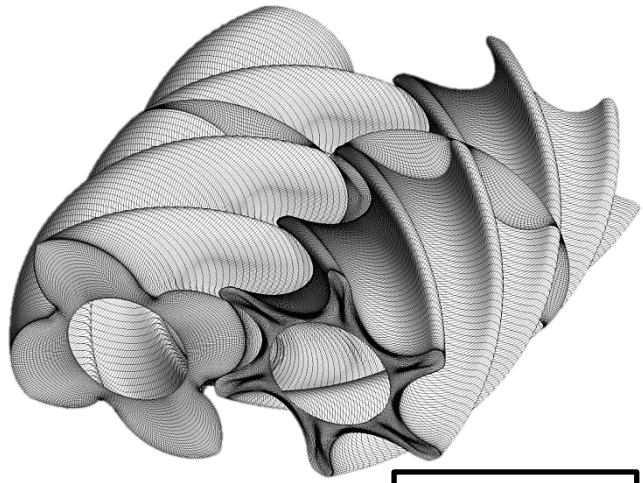
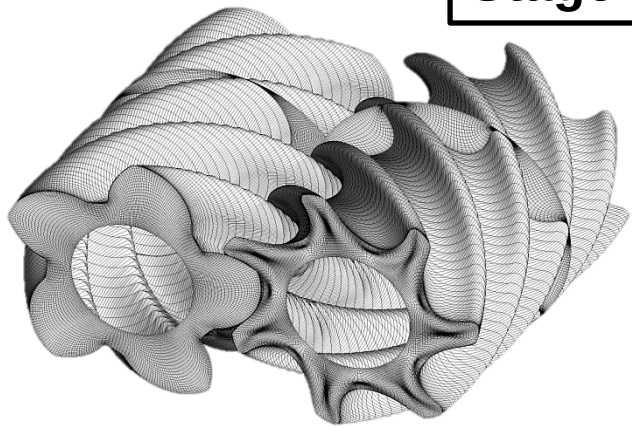
Meshing

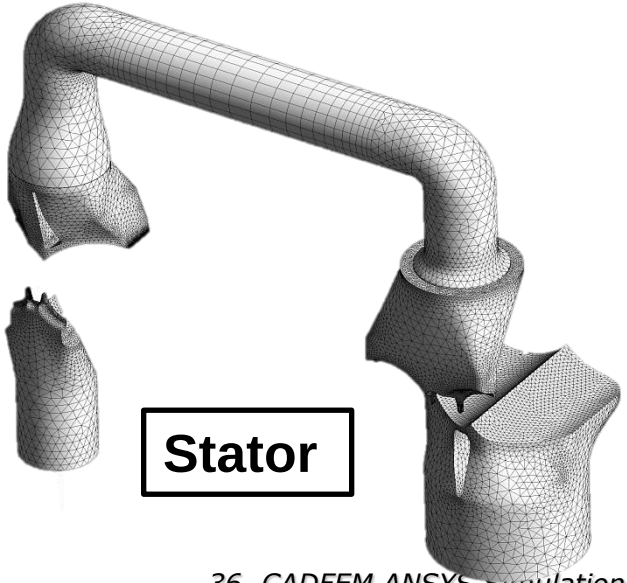
- Stator volumes meshed with ANSYS Meshing
  - 591 625 elements in total
- Rotor volumes meshed with TwinMesh
  - 3 266 560 elements in total



Stage 1

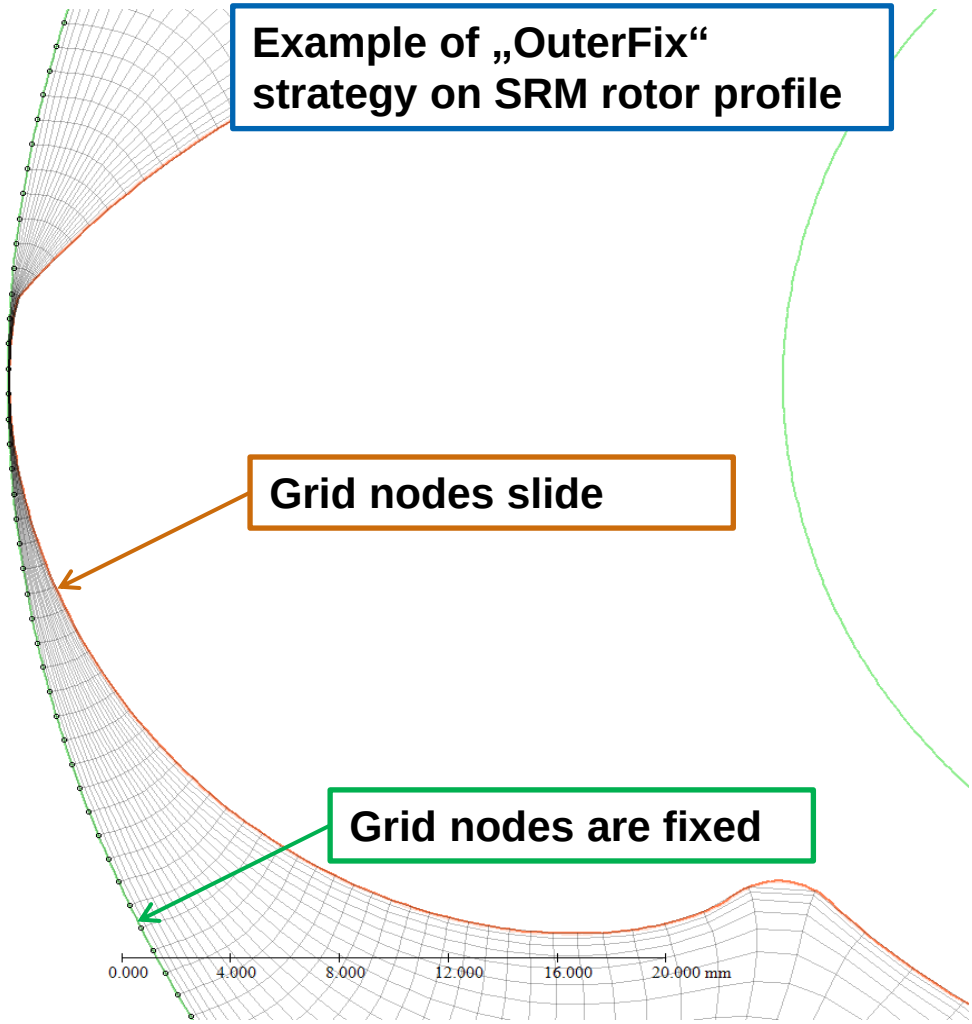


Stage 2



Stator

- Meshing strategy (Rotors)
  - Nodes are fixed on stator curves and can slide along rotor curves („OuterFix“)
  - After a completed pitch (360°/number of male rotor lobes) angle, nodes have the same position as for the initial position
  - CFD solver needs no interpolation between pitch angles



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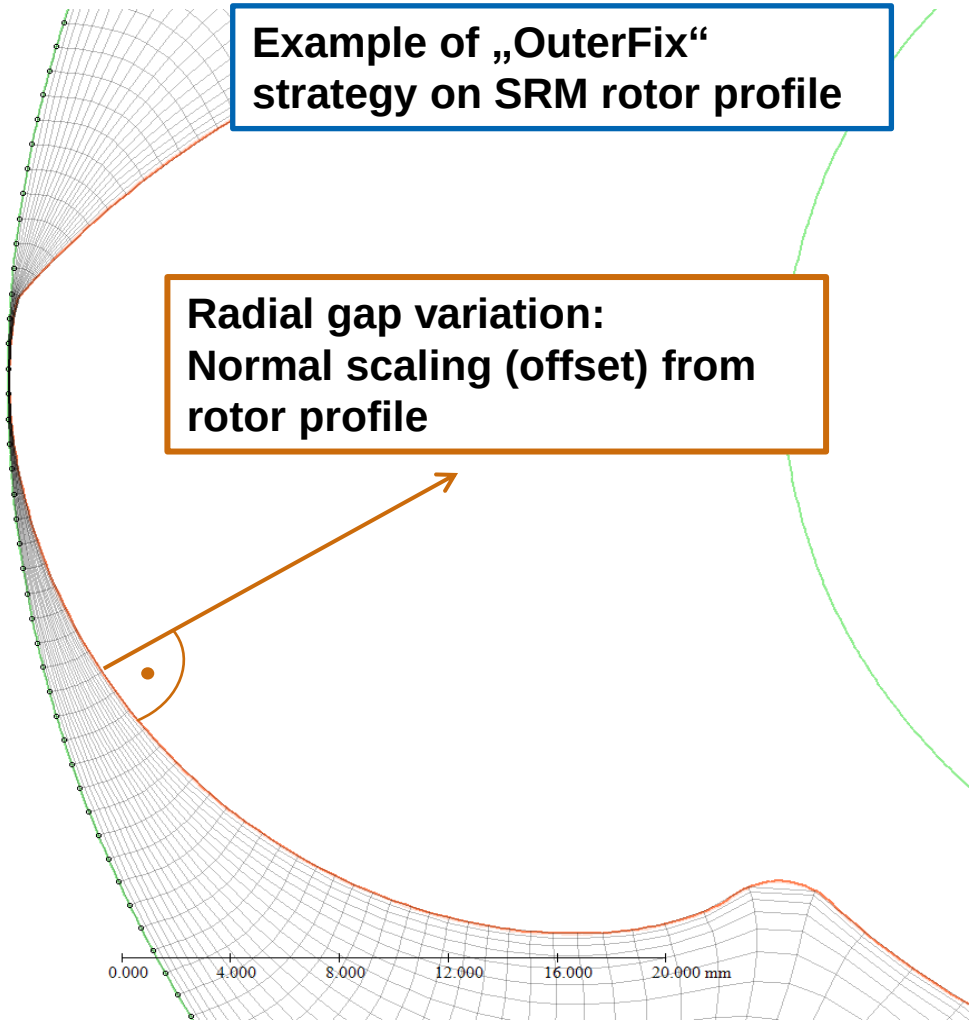

Meshing

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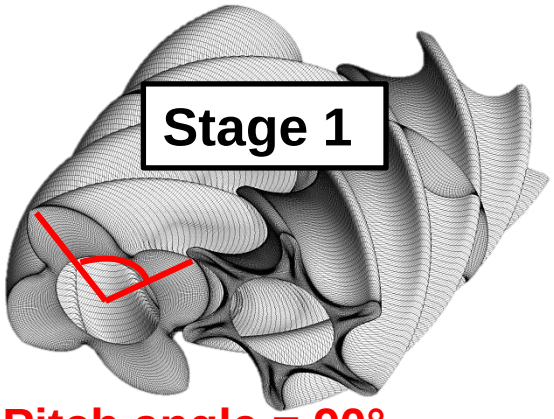
- Coupling of both stages
  - Generation of rotor chamber grids prior to simulation run
  - Grid set for a single pitch angle to run any desired amount of revolutions
  - Angle increments of stages according to real machine gear ratio
  - Time step can be set according to rotational speed of 1st stage male rotor

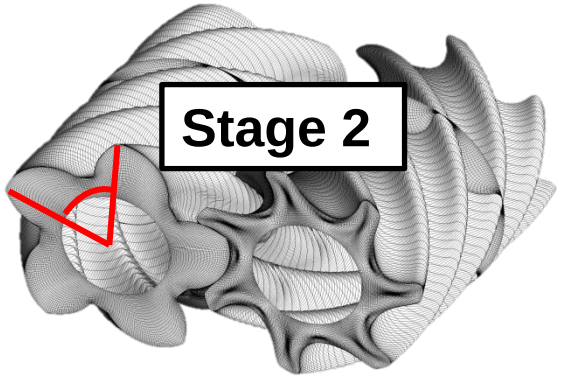
	Stage 1	Stage 2
Speed ratio (Stage 2/Stage 1)	1.530	
Lobe count (male)	4	5
Lobe count (female)	6	7
Pitch angle	90°	72°
Number of grids per pitch angle	90	47
Angle increment	1°	1.532°
Angle increment ratio (Stage2/Stage1)	1.532	

Meshing

- Coupling of both stages



Pitch angle = 90°



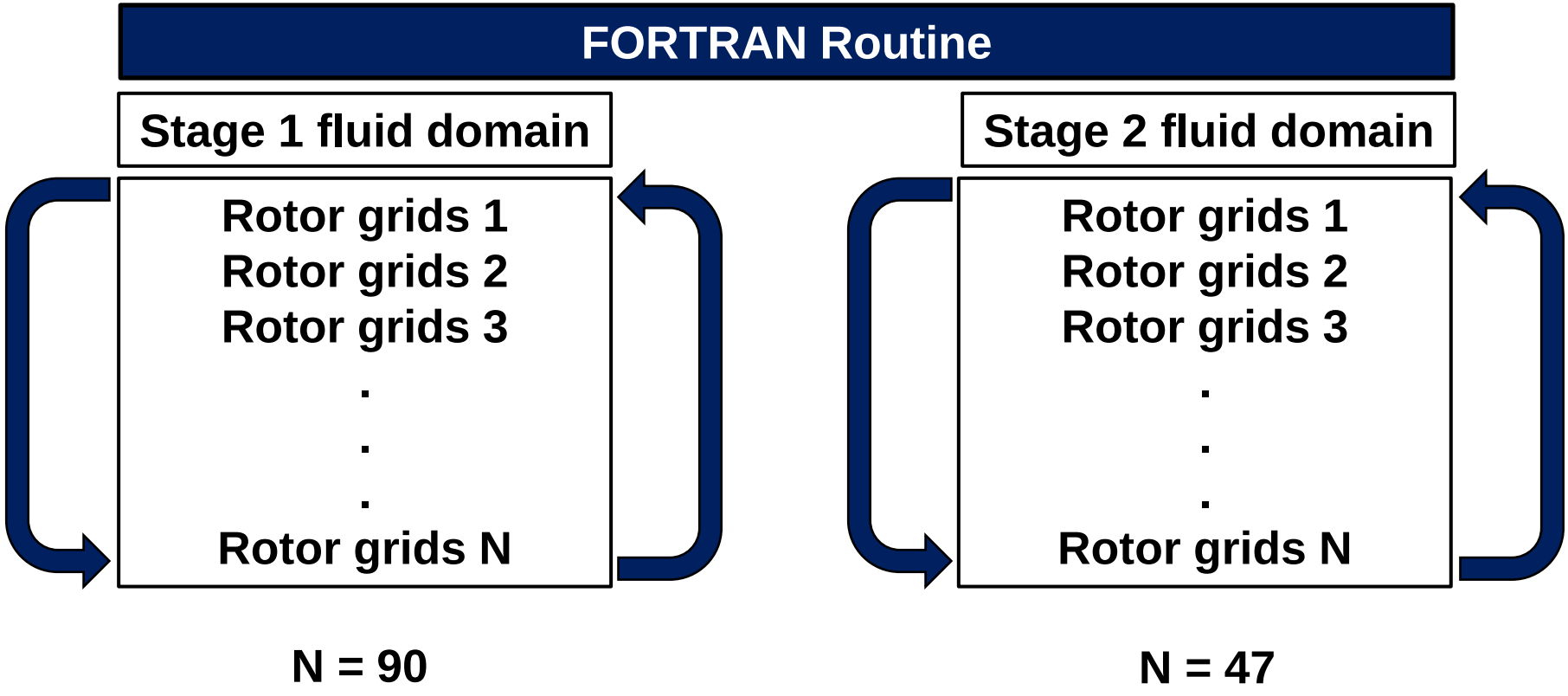
Pitch angle = 72°

90 meshes for 90° pitch angle = 1°/Δt

47 meshes for 72° pitch angle = 1.532°/Δt

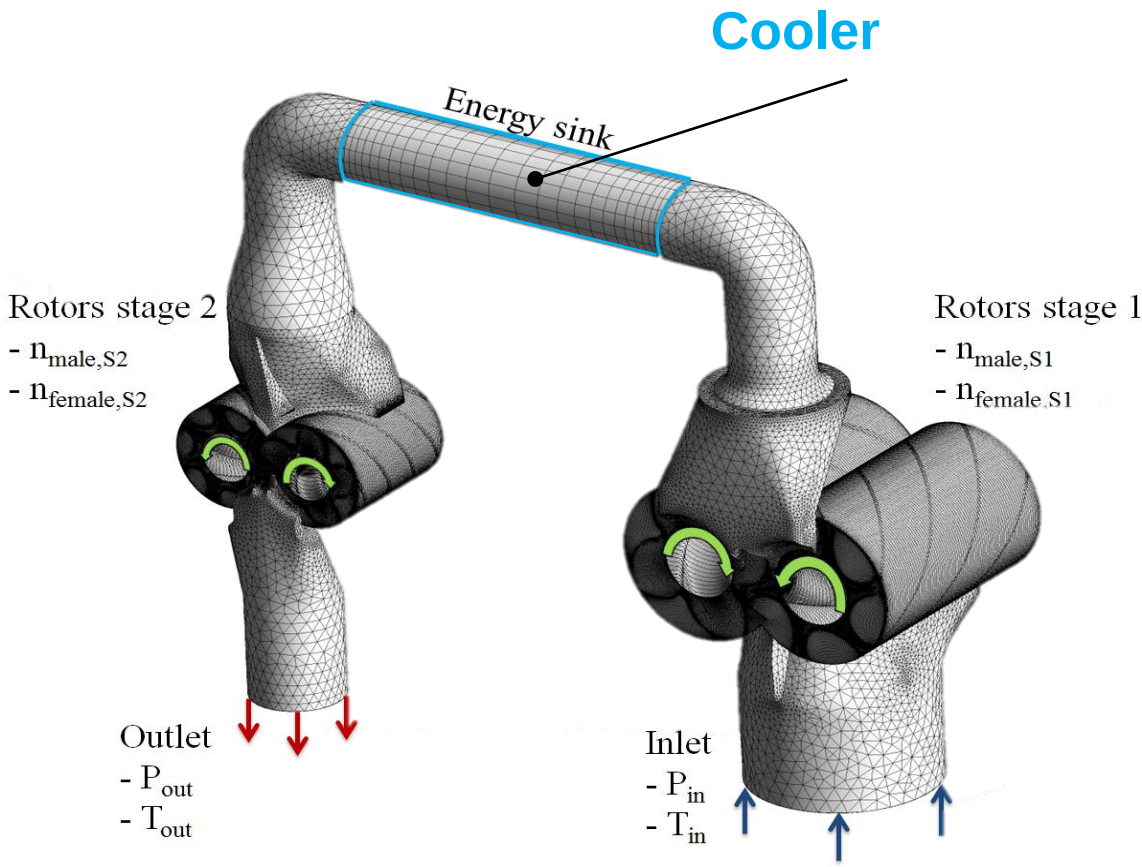
Representation of two rotational speeds with a fixed time step

- Coupling of both stages



Boundary Conditions

- Rotational speeds
  - For each rotor based on gear ratios
- Inlet
  - Absolute Pressure
  - Temperature
- Outlet
  - Absolute Pressure
  - Temperature
- Cooler
  - Energy sink controller with target temperature



Boundary Conditions

- Simulated operating points (OP)
  - Fluid: Air ideal gas
  - Angle increment of 2° (rotor grids generated with 1° steps)
  - No additional pressure loss modeled for cooler
  - Adiabatic walls
  - SST turbulence model

Case	Main shaft speed [rev/min]	Inlet Pressure [bar(a)]	Outlet pressure [bar(a)]	Inlet temp. 1st stage [C]	Inlet temp. 2nd stage [C]	Outlet temp. 2nd stage [C]
OP1	1480	1.0	7.98	30.8	31.9	136.1
OP2	1780	1.0	7.98	28.6	34.1	143.0
OP3	2100	1.0	7.98	27.0	37.9	150.8
OP4	1780	1.0	7.89	28.6	34.1	143.0
(Decreased radial clearances)	Housing clearances uniformly by 20%, intermesh closest point by 50%					

Boundary Conditions

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- Simulation time and hardware
  - CPU type: Intel Xeon E5-2637 v2
  - CPU cores: 16
  - Memory requirement: 30 GB RAM
  - Simulation time: approx. 19 hours/revolution (male 1st stage)
    - Angle increment: 2°/time step
    - 12 Coefficient loops/time step
  - Calculated revolutions: 30
  - Hard drive space required:
    - approx. 3.4 GB for full result file
    - approx. 300 MB for intermediate results

Simulation Results

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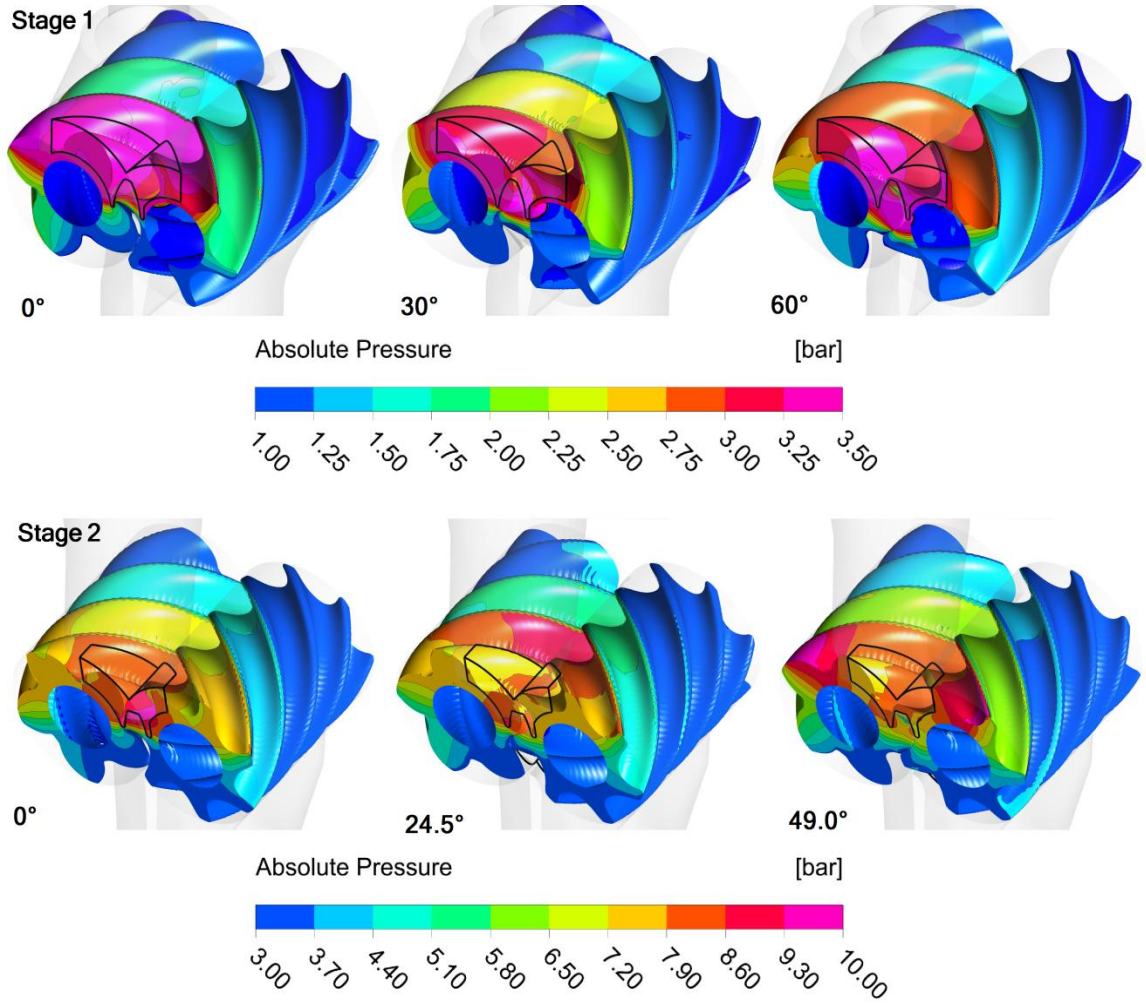
- Static pressure (OP2)
  - Instantaneous pressure on rotors
  - Cycle over one pitch angle for each stage (repetitive scheme)



Simulation Results

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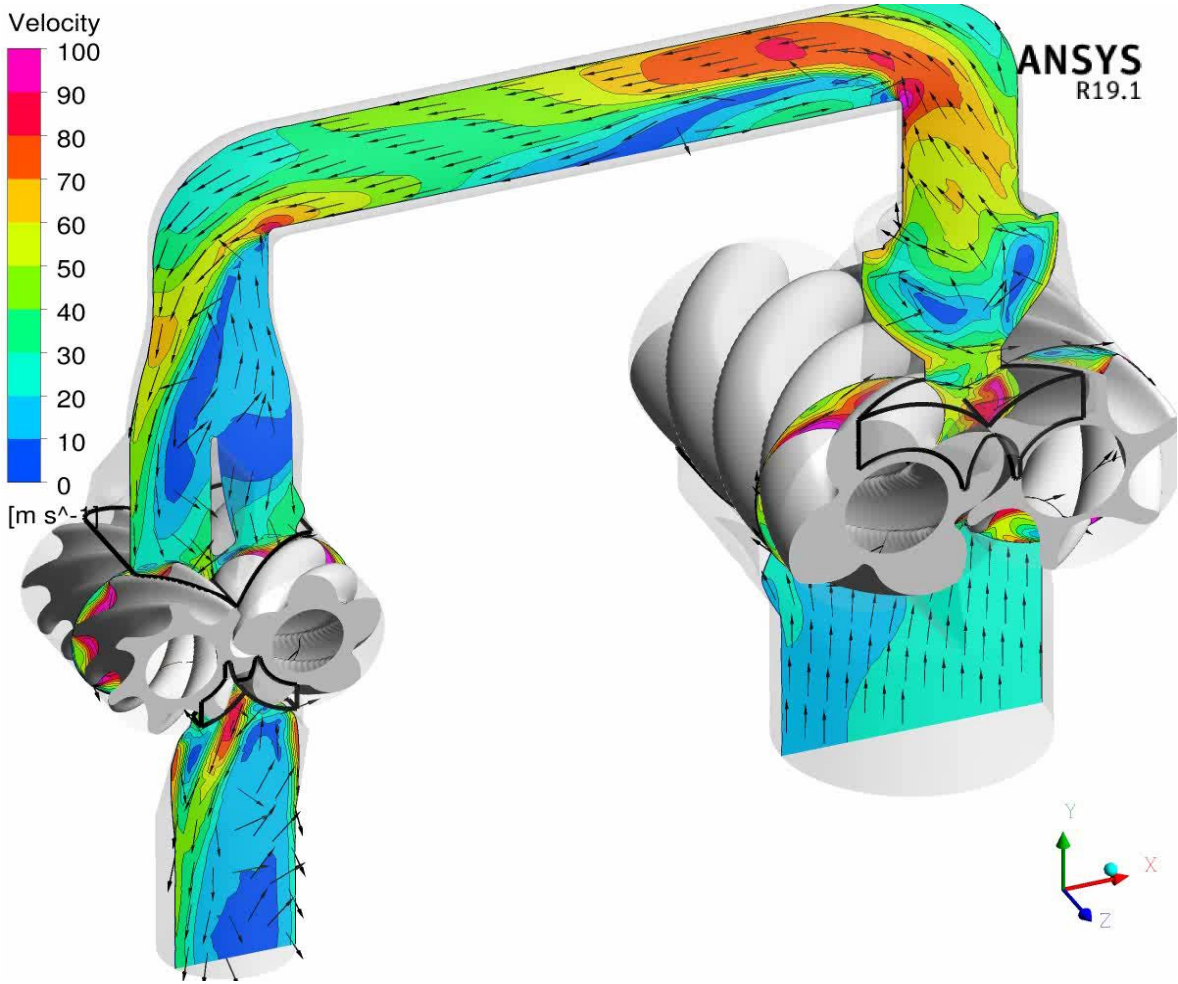
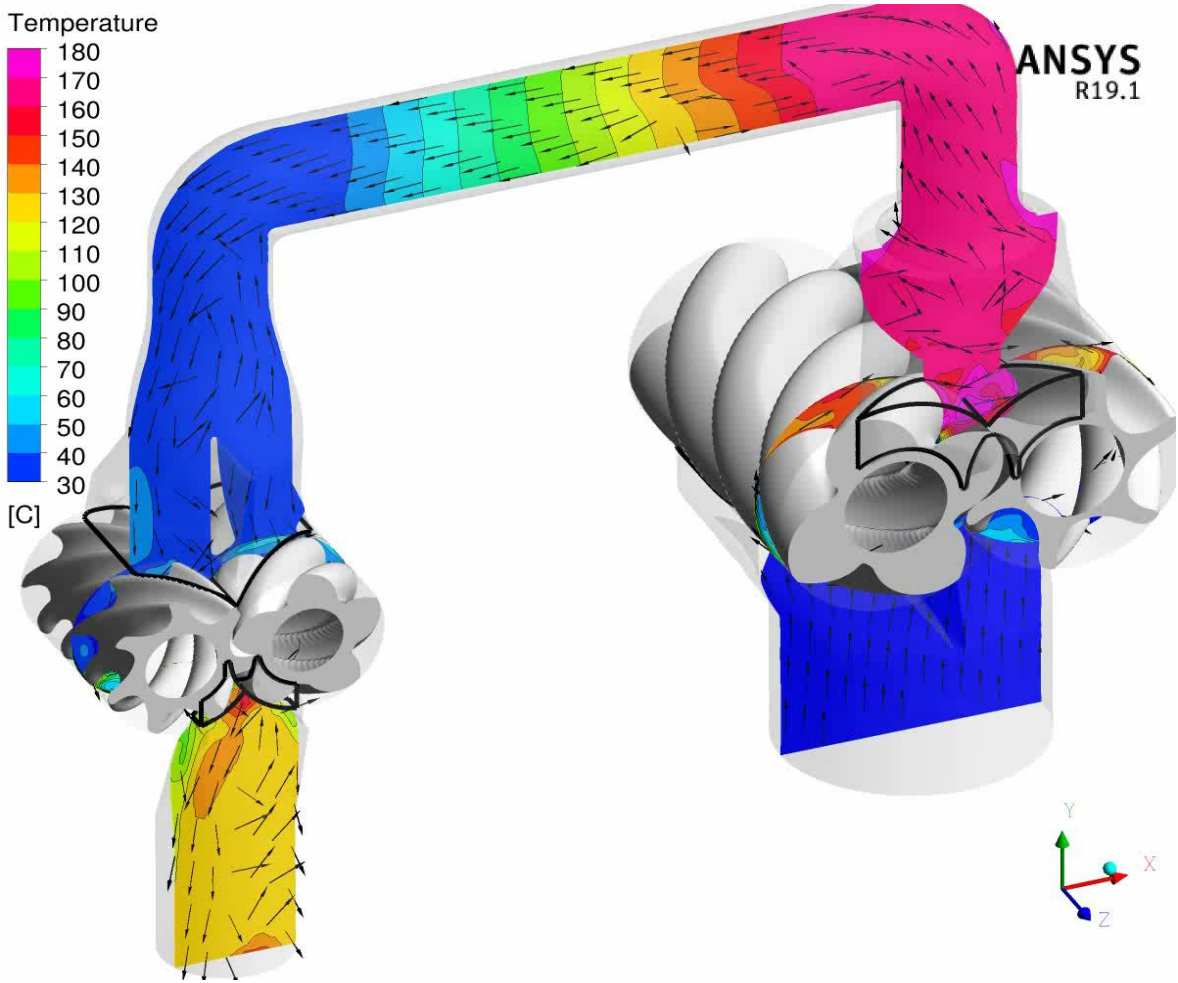
- Velocity (OP2)
  - Velocity field on a cross section plane through both stages and cooler
  - Animation over 1 revolution of 1st stage male rotor



Simulation Results

CFX BERLIN

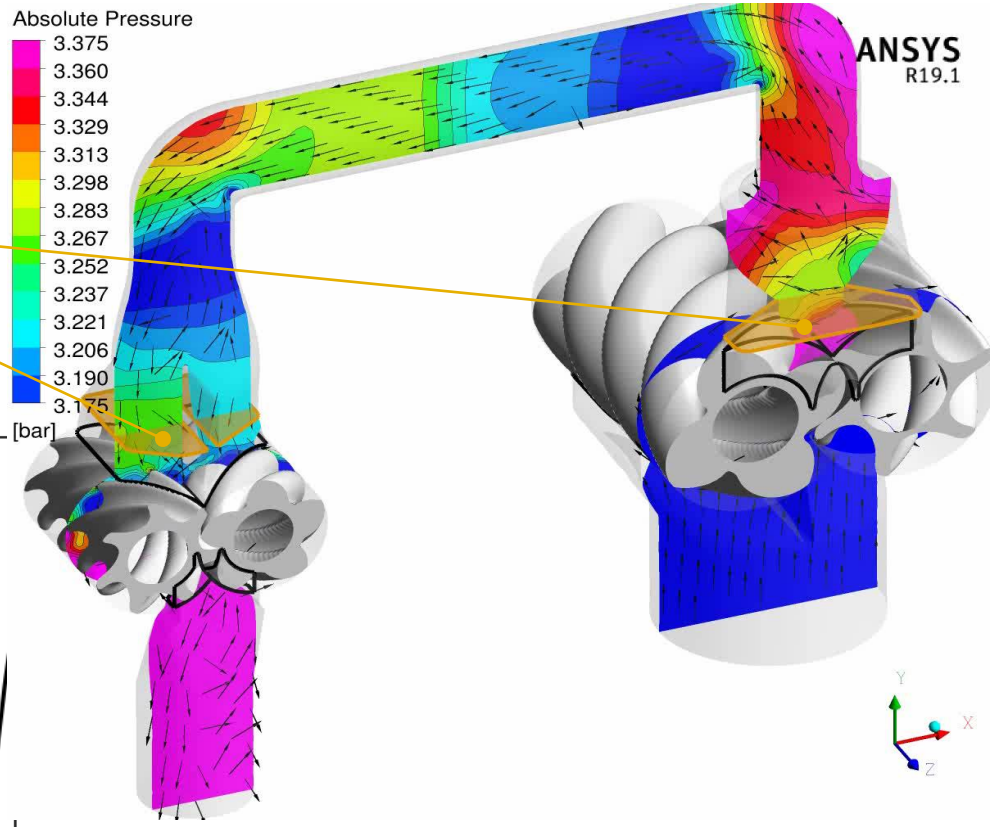
- Temperature (OP2)
  - Temperature field on a cross section plane through both stages and cooler
  - Animation over 1 revolution of 1st stage male rotor

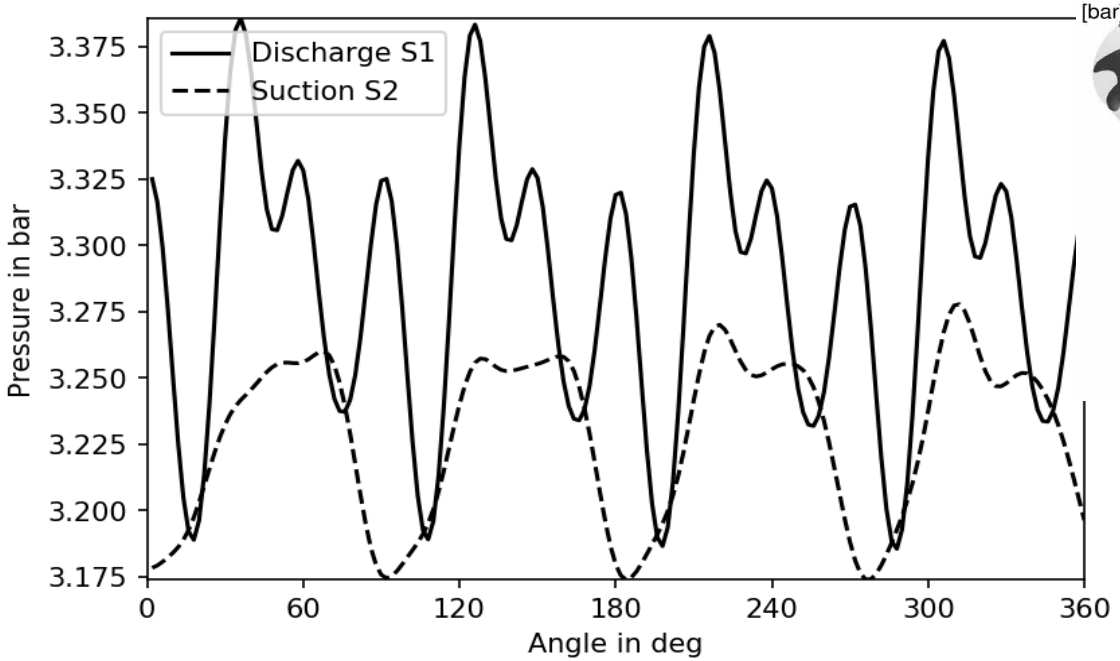


Simulation Results

CFX BERLIN

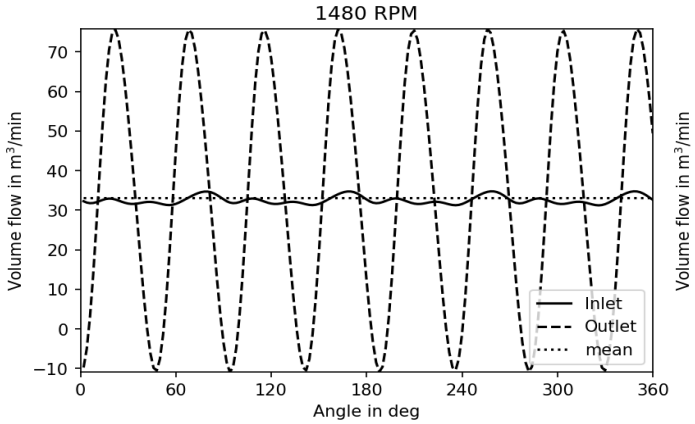
- Static pressure (OP2)
  - Area averaged absolute pressure over time on cross sections

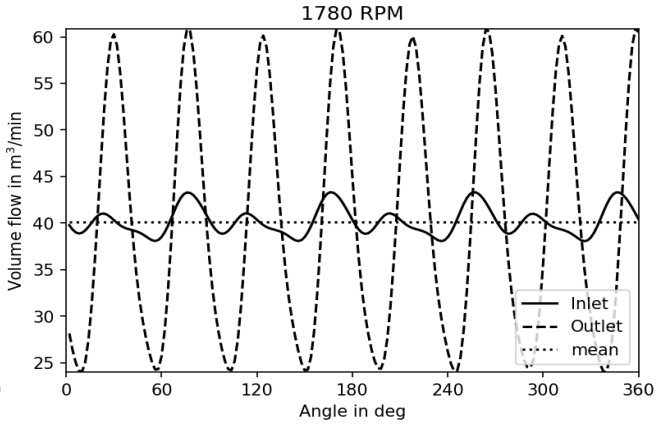




- Volumetric flow rate (OP2)
  - Time resolved over 360° of 1st stage male rotor

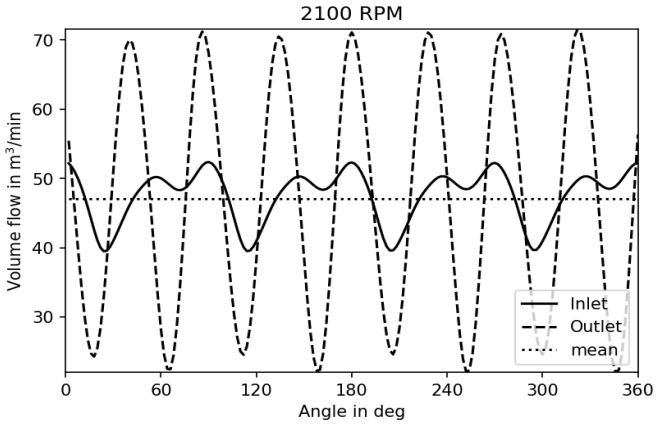
OP1

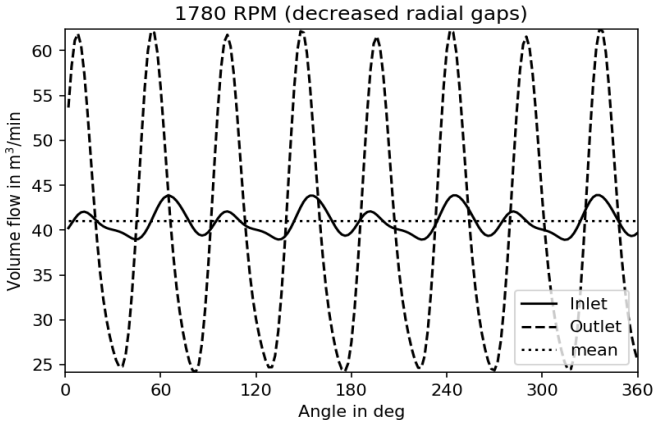




OP2

OP3



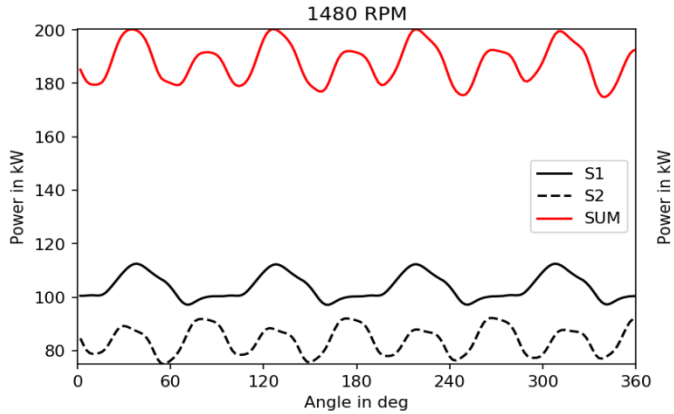


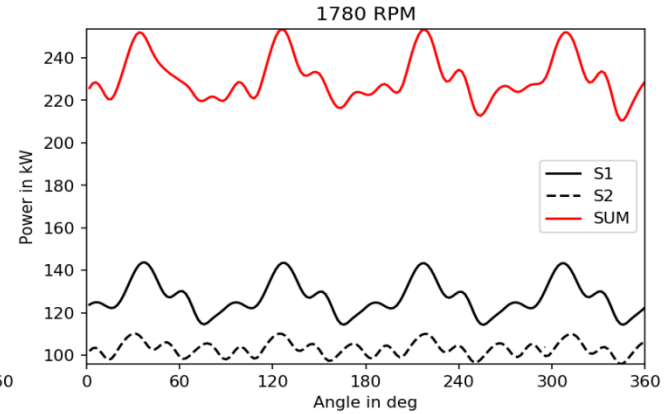
OP4

Simulation Results

- Power (OP)
  - Time resolved over 360° of 1st stage male rotor

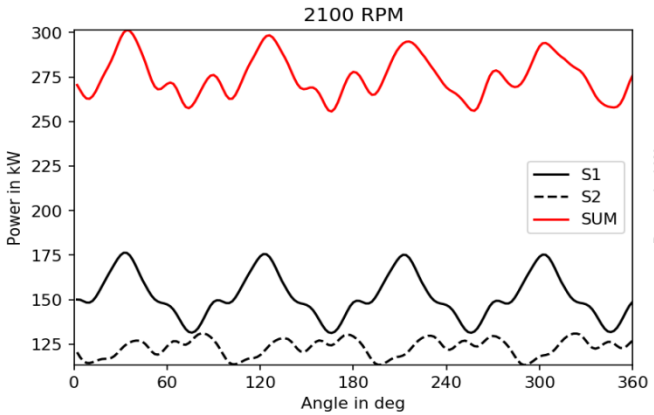
OP1

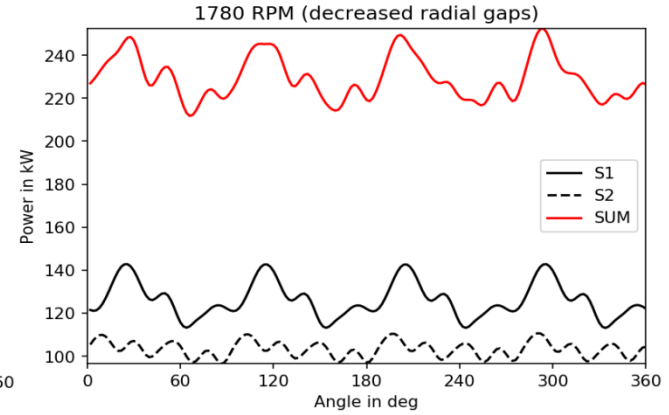




OP2

OP3



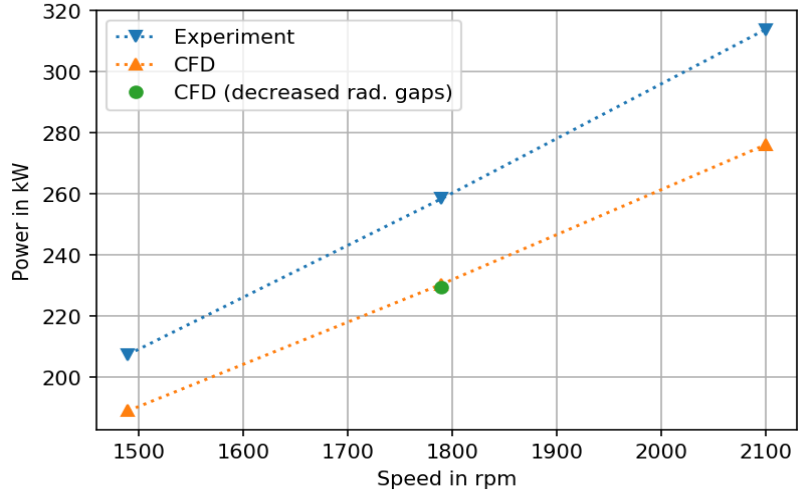


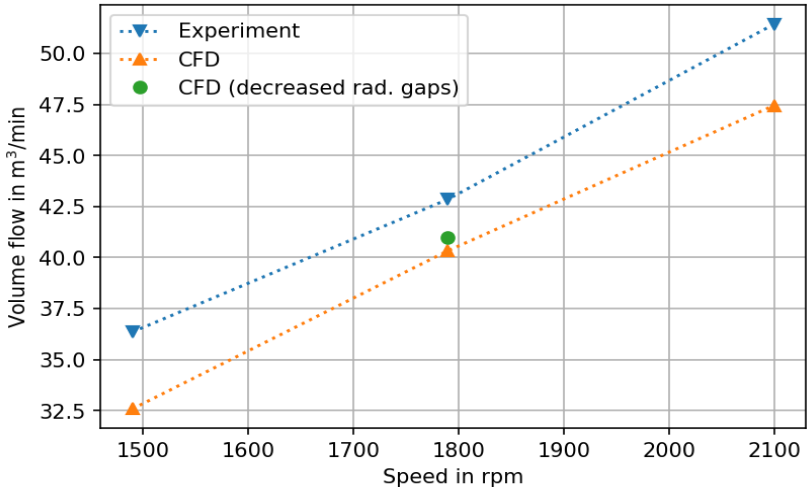
OP4

Simulation Results

- Comparison with measurements
  - Volumetric flow rate, power and specific power (power/flow rate)

	Relative Deviation (CFD from experiment)		
	Flow Rate [%]	Power [%]	Specific Power [%]
OP1	-10.4%	-9.4%	1.1%
OP2	-5.9%	-10.8%	-5.3%
OP3	-7.7%	-12%	-4.7%
OP4	-4.4%	-11.2%	-7.1%





Conclusion

- Successful coupling of both compressor stages within one simulation setup
  - Reasonable results and good match with experimental data
  - Different rotational speeds modeled with fixed time step
  - Interstage cooler modeled with energy sink
- Uncertainties
  - Overestimation of specific power for OP1
  - Little influence of performed clearance change
  - Clearance sizes while compressor is running (manufacturing clearances modelled)
  - Simplification of cooler and interstage geometry respectively

Outlook

- Presented approach enables to enhance the setup and analyze discrepancies between experiment and simulation
  - Leakage flow investigation
  - Impact of meshing strategy on gap resolution
  - Enhanced cooler modeling with respect to pressure loss
  - Incorporation of rotor and housing solids (CHT analysis)
  - Analysis with non-reflective boundary conditions
  - Investigate feasibility regarding other gear ratios