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CFD Simulation of Cavitation in an Internal Gear Pump

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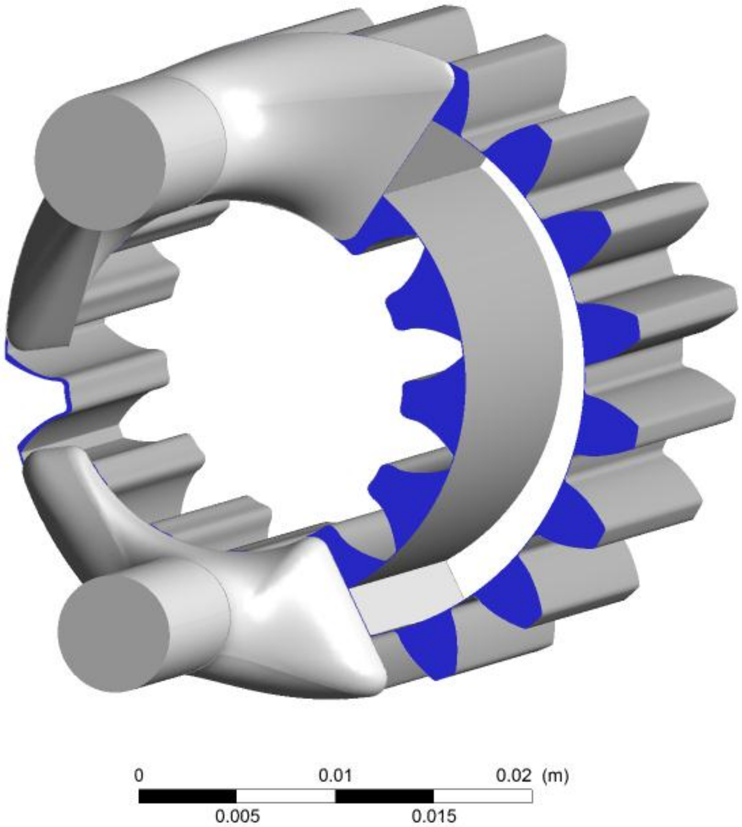

Introduction into internal gear pumps:

- Positive displacement machine:
  - Liquid is displaced between large exterior gear and small interior gear
  - Crescent divides low and high pressure side (as a seal)
  - Suction / discharge can be in radial or axial direction
- Advantages:
  - Liquids with wide viscosity range, even with particles
  - Discharge rate almost independent of pressure conditions

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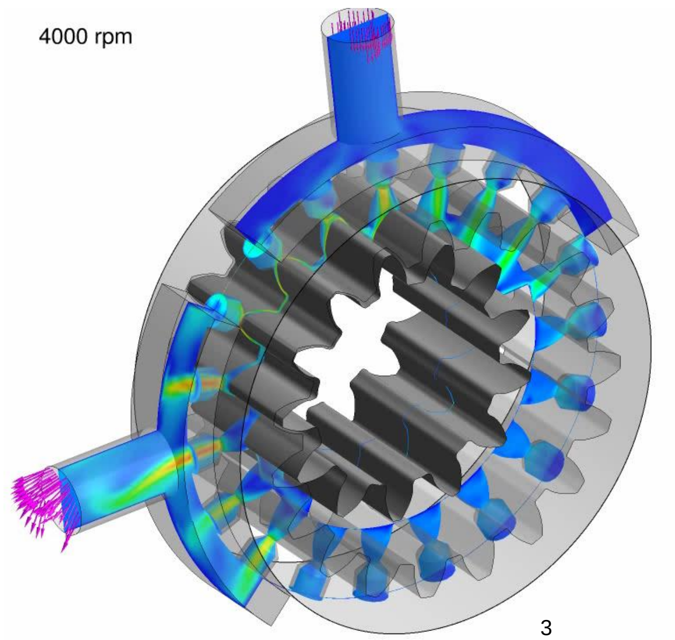
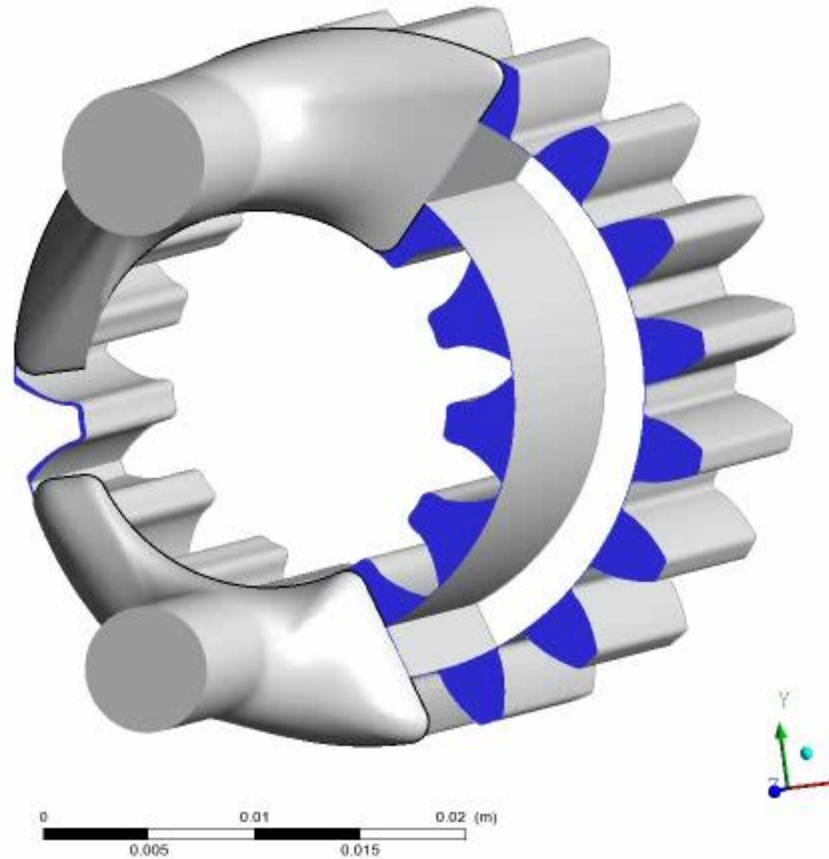


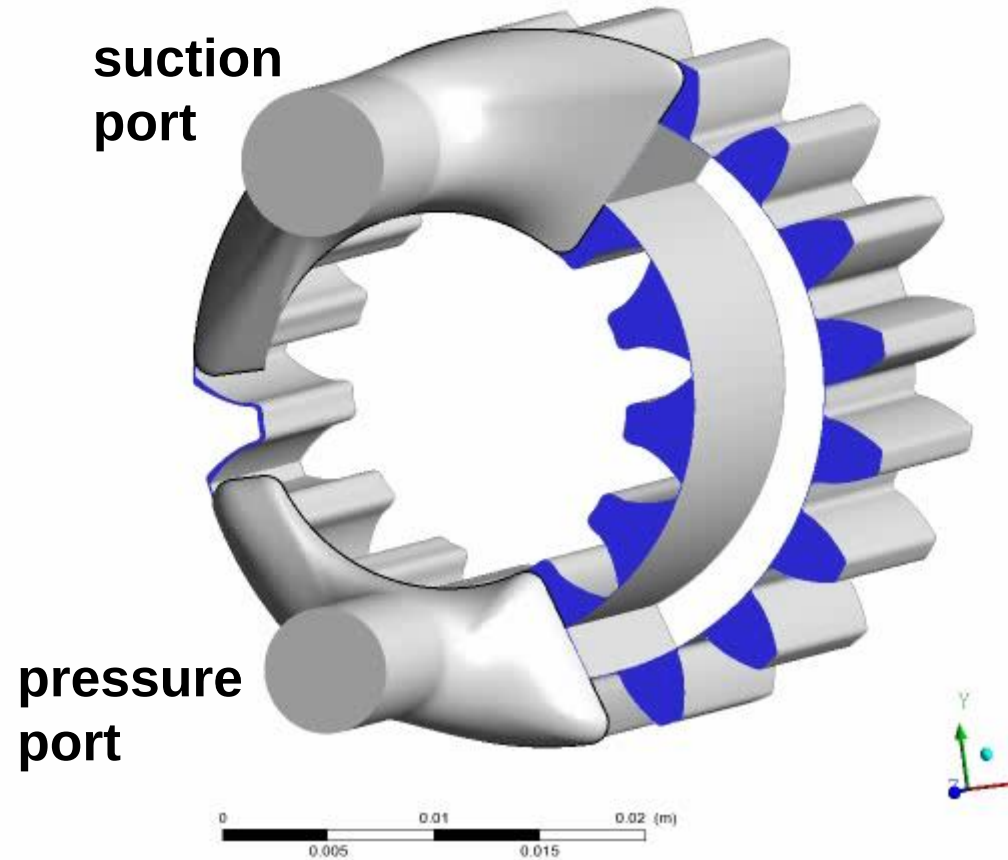
Geometry of internal gear pump:

- Inner rotor:
  - 13 teeth
  - 24.4 mm outer diameter
- Outer rotor:
  - 19 teeth
  - 34.0 mm outer diameter
- 4.77 mm eccentricity
- 16.1 mm thickness
- Suction / discharge in axial direction



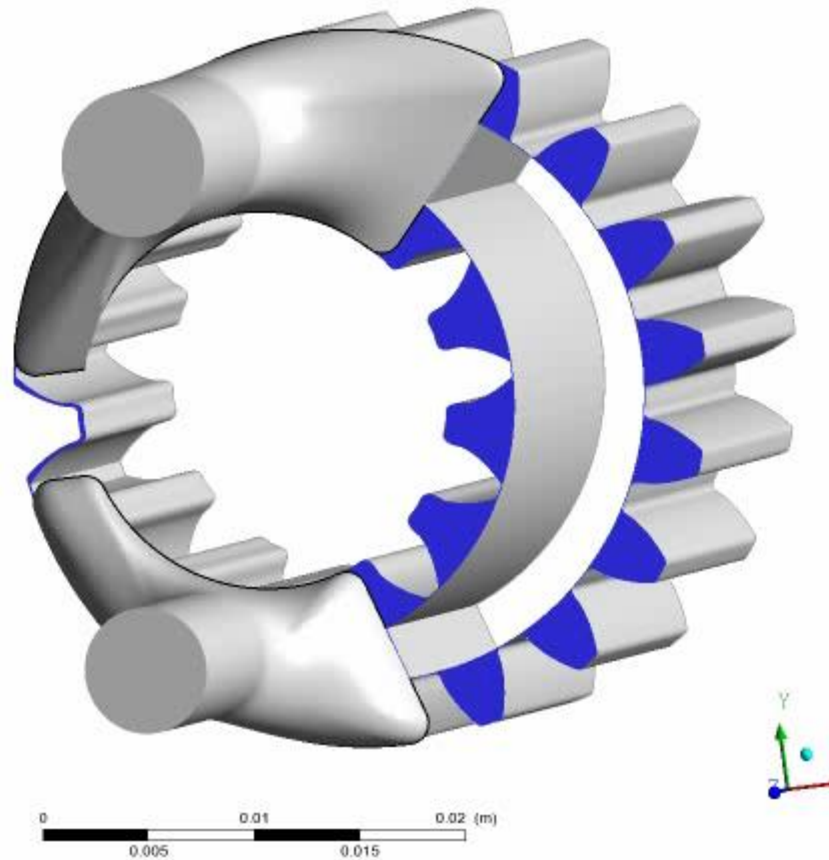
Geometry of internal gear pump:

- Stationary part:
  - suction and pressure port with
    6 mm diameter and
    10 mm length



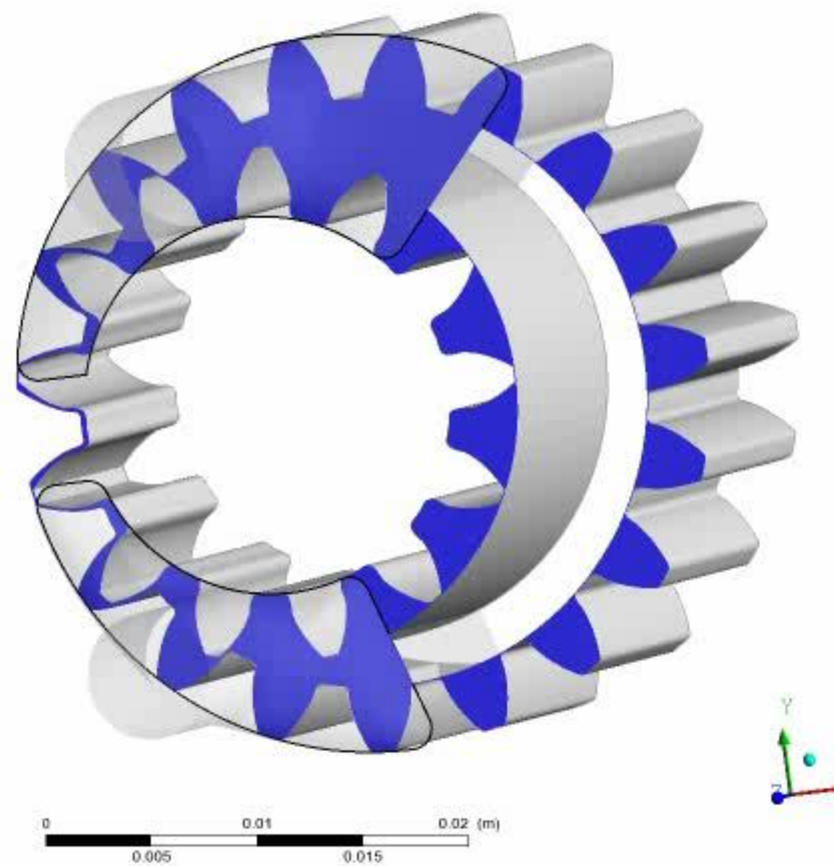
Geometry of internal gear pump:

- Stationary part:
  - suction and pressure port with 6 mm diameter and 10 mm length
  - axial interfaces between ports and rotors
  - crescent to separate chambers



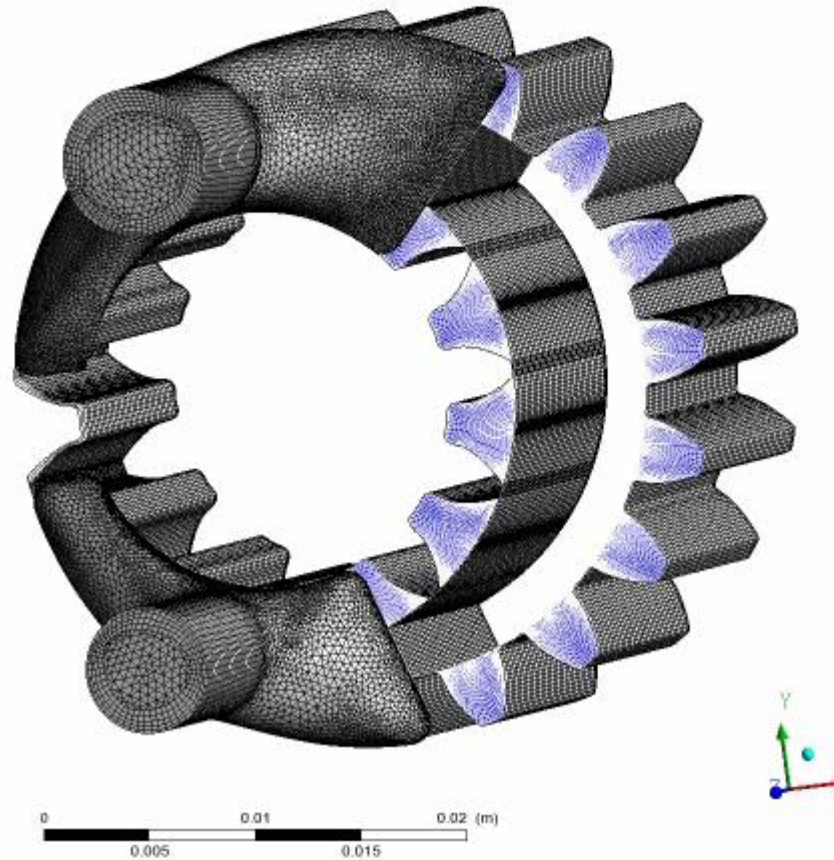
Geometry of internal gear pump:

- Radial clearances:
  - internal gear to crescent: 65 µm
  - external gear to crescent: 50 µm
  - between gears: >100 µm
    (no contact point)
- Axial clearances can
  be included



Mesh:

- Stationary part:
  - ANSYS Meshing for hybrid mesh
  - 800,000 elements, 280,000 nodes
- Rotating parts:
  - TwinMesh for hexahedral meshes
  - 20 radial x 30 axial x 46 per tooth
  - internal gear 360,000 elements
  - external gear 520,000 elements



What is TwinMesh?

- Challenges in geometry
  - two intermeshing gears
  - size-changing chambers
  - very small clearances (5-50 µm)
- Challenges in flow modelling:
  - transient with mesh deformation
  - strong gradients and high velocities in small gaps
- ➢ Challenges in mesh generation:
  - high mesh quality
  - constant mesh topology to avoid interpolation
  - ensure continuous mesh motion
  - small manual effort, but flexible

SpaceClaim / DesignModeler

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TwinMesh™

1. Import geometry
2. Set boundary types
3. Generate interfaces
4. Define mesh settings
5. Generate all meshes
6. Check mesh quality
7. Export all meshes
8. Generate Pre script

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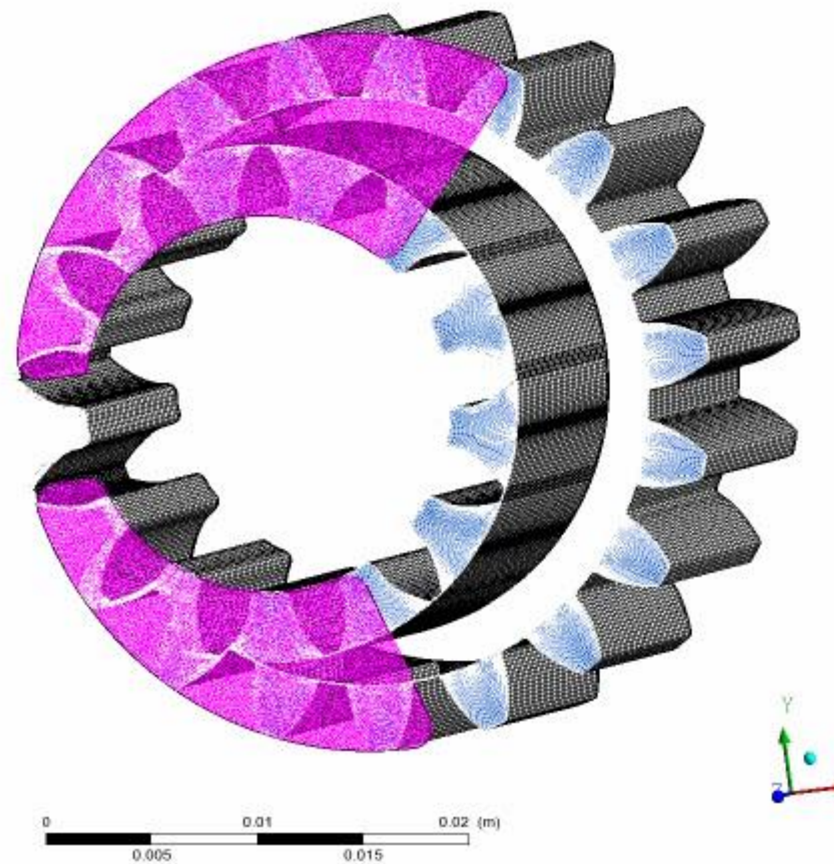
ANSYS

1. Apply Pre script with initial mesh
2. Read further meshes at run-time

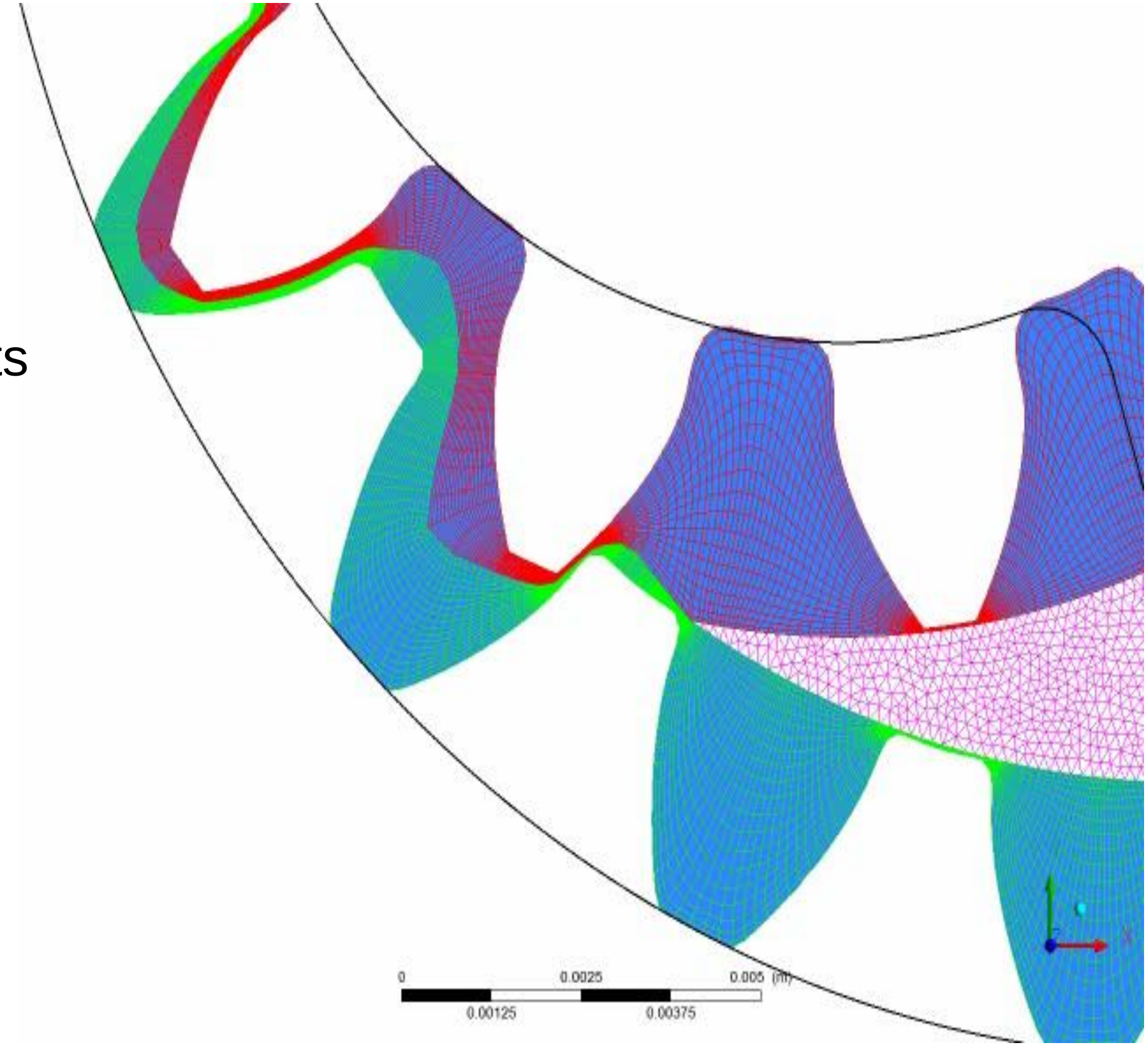
Mesh:

- Grid interfaces
  - GGI between rotating and stationary parts



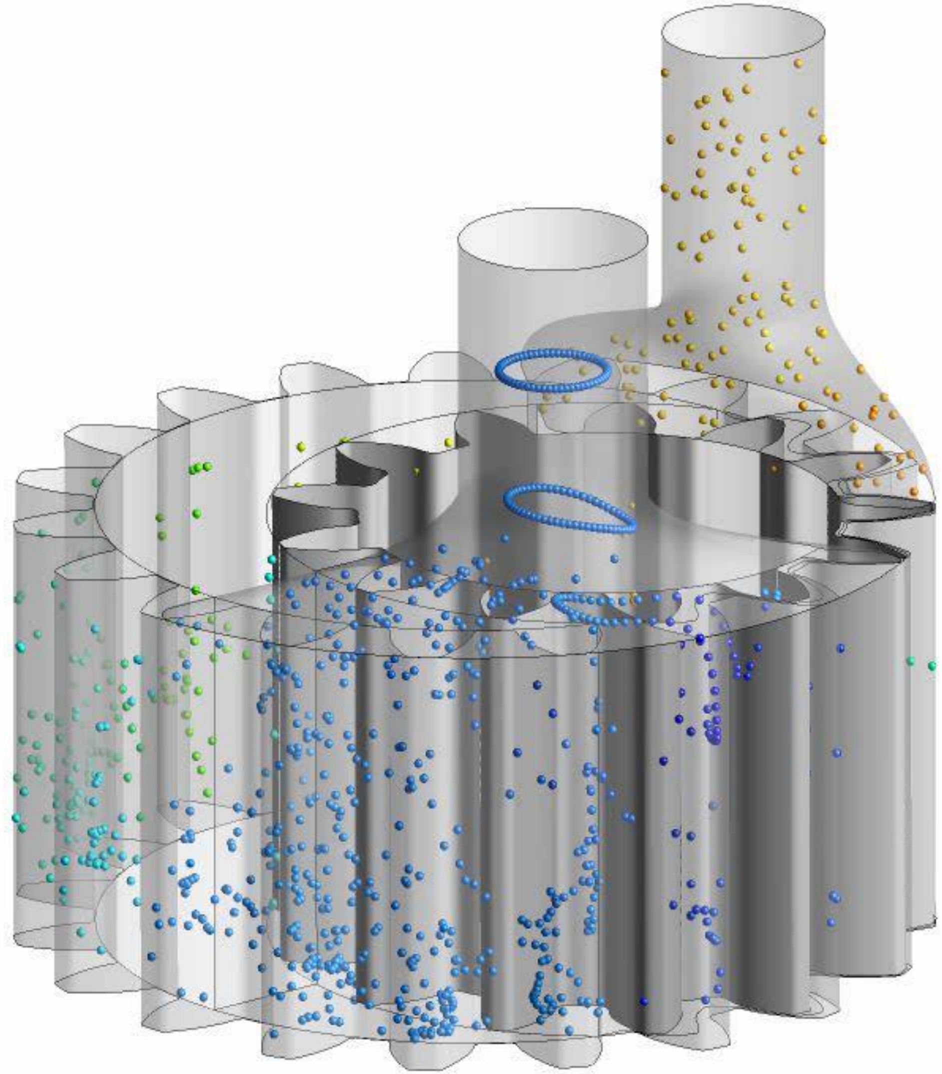
Mesh:

- Grid interfaces
  - GGI between rotating and stationary parts
  - GGI between rotating parts



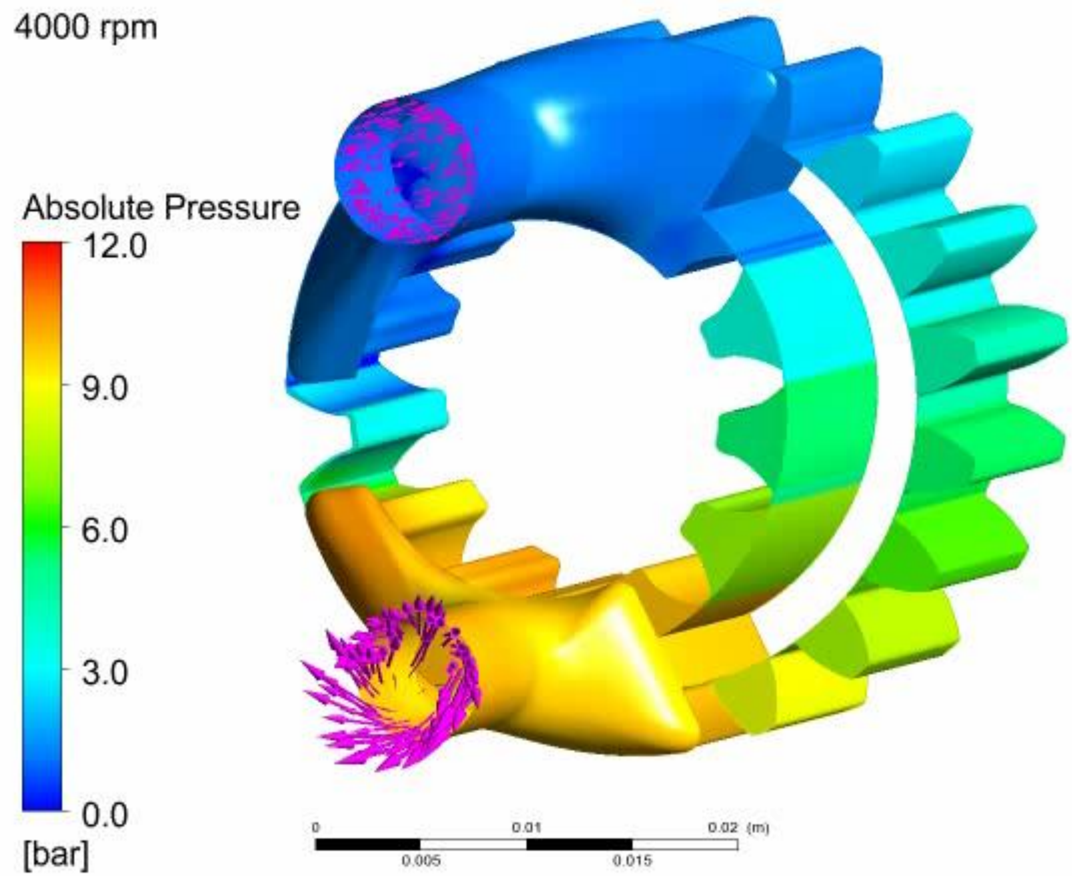
Simulation setup:

- Single-phase flow: water at 25°C
- transient simulation with 500 to 10,000 rpm for internal gear
- 20 to 200 meshes per tooth
- SST turbulence model
- suction and pressure side as opening with total pressures of 1 bar and 10 bar
- no-slip walls
- ➢ approx. 3 hours on 8 cores for 40 time steps (one tooth)



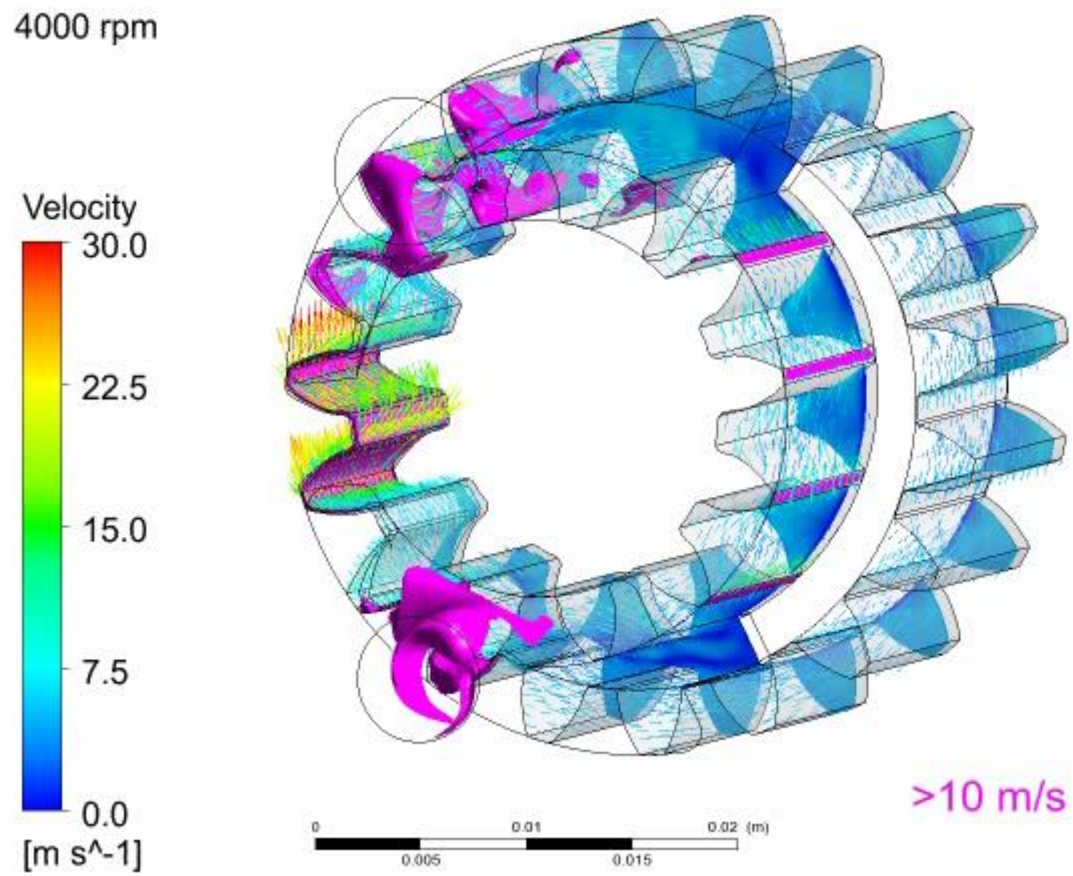
Single-phase results:

- Pressure:
  - linear pressure increase at crescent
  - sharp pressure increase between gears
  - pressure peaks <1 bar and >10 bar in intermeshing region



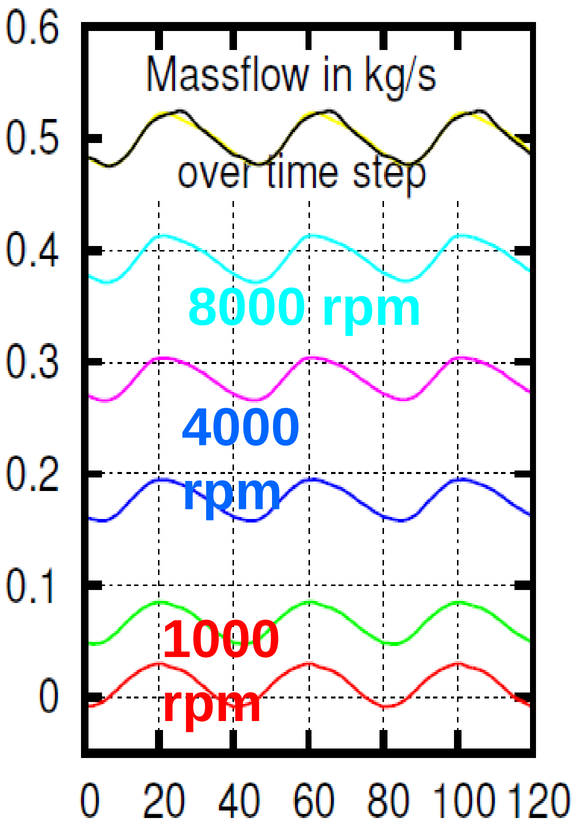
Single-phase results:

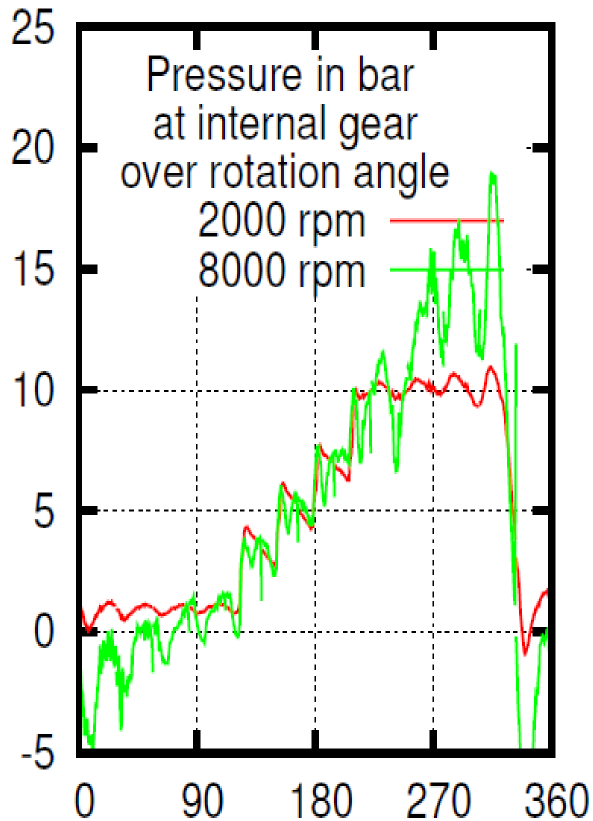
- Velocity:
  - fluid is displaced in chambers towards pressure side (rotational speed < 5 m/s)
  - backflow in radial clearances with >10 m/s, in intermeshing clearance with >30 m/s

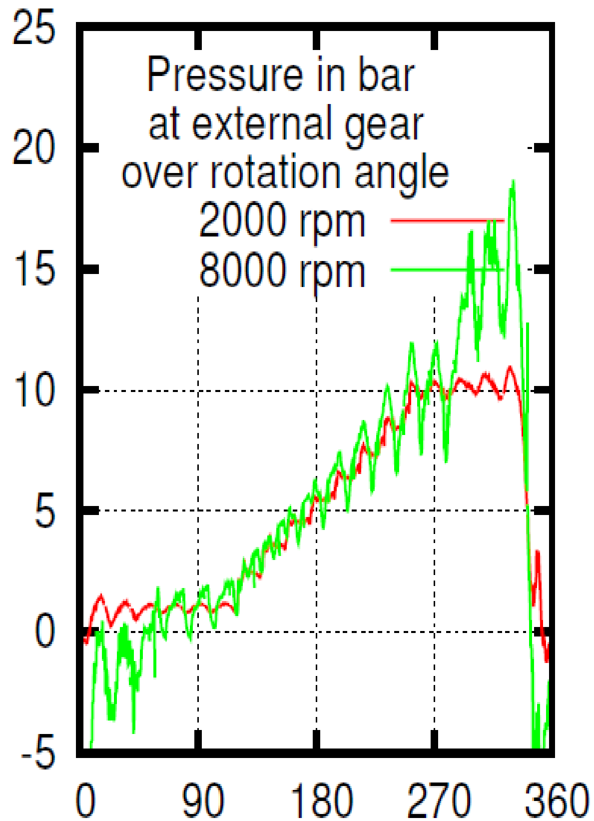


Single-phase results:

- Time-resolved results (40 meshes per tooth)

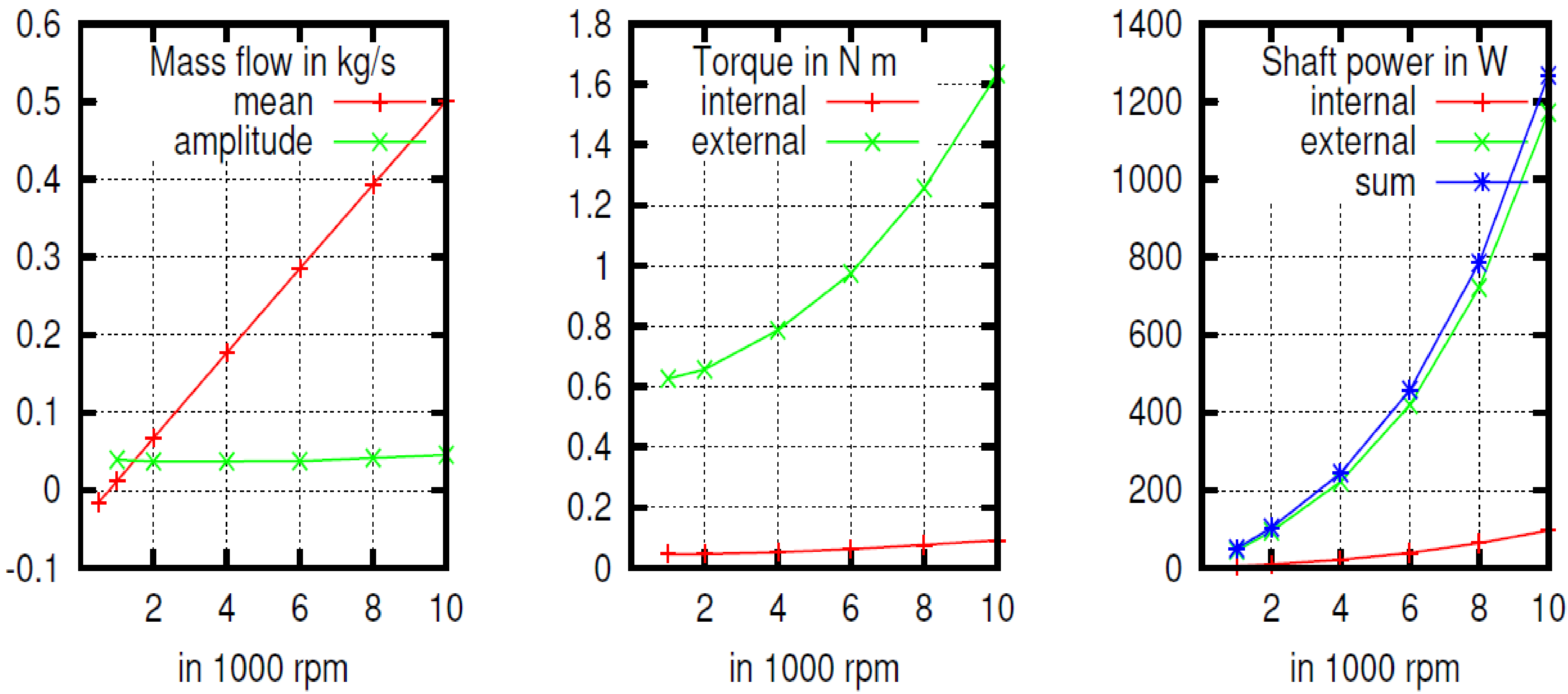






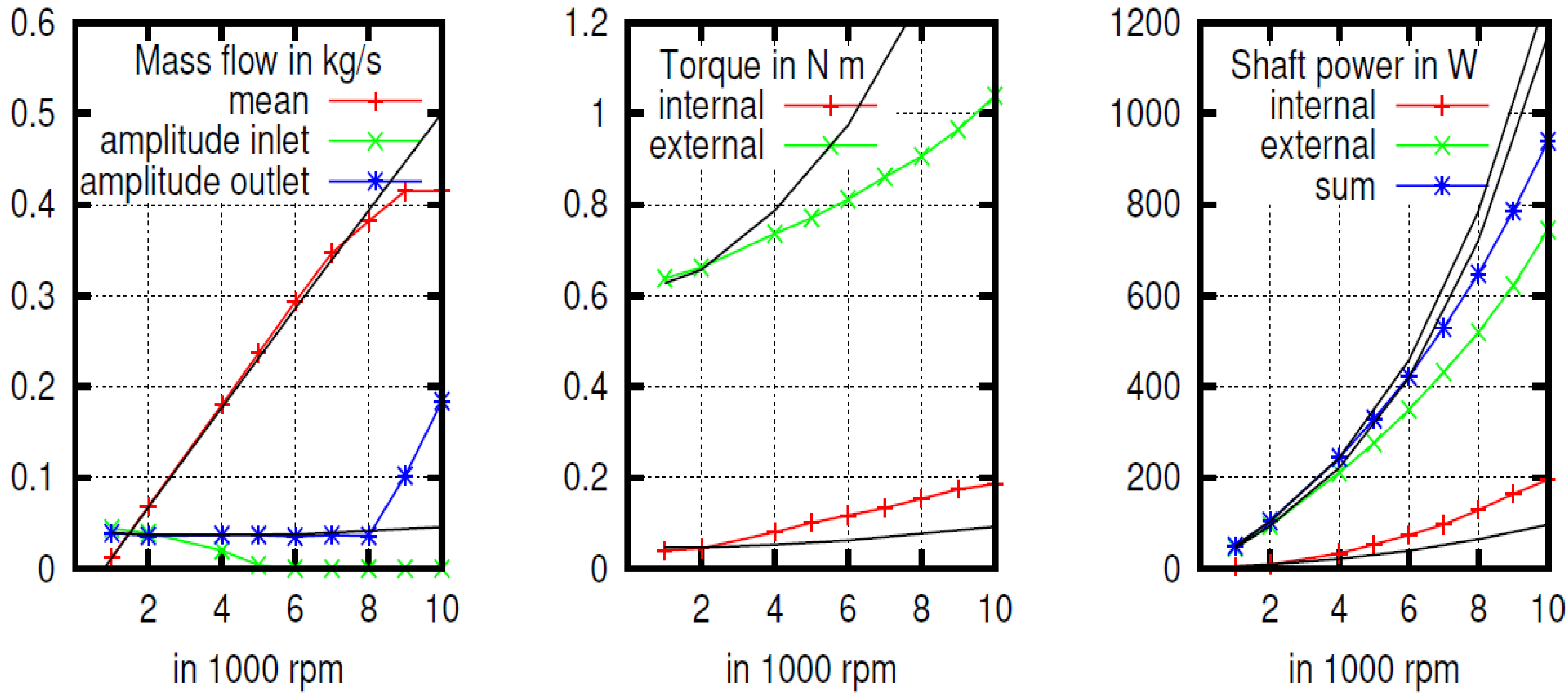
Single-phase results:

- Time-averaged results



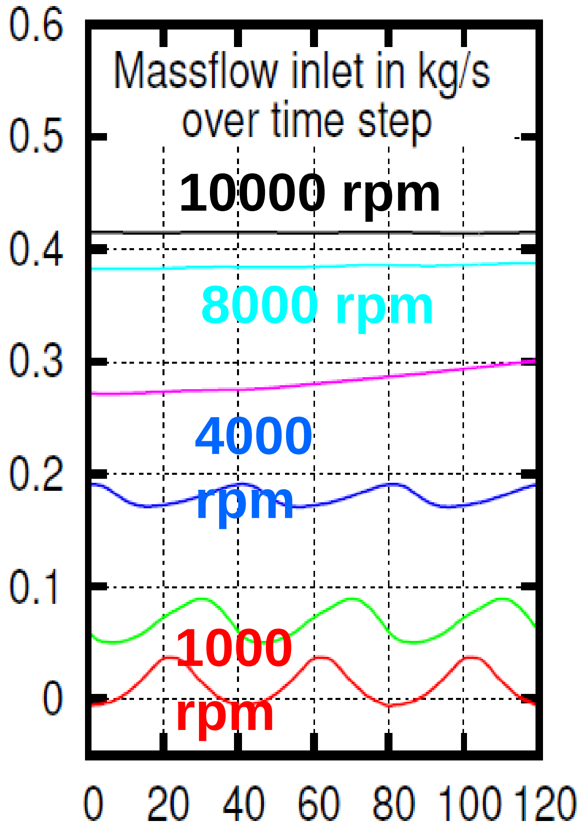
Results with cavitation:

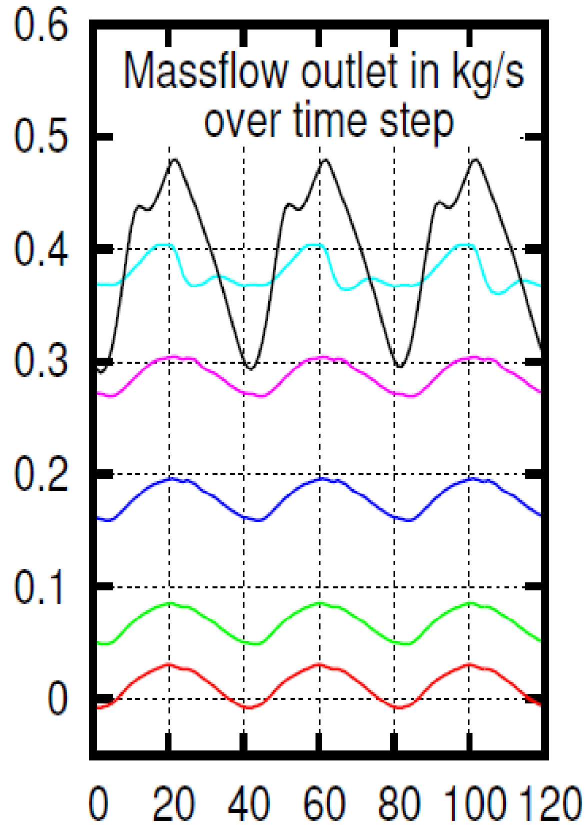
- Time-averaged results

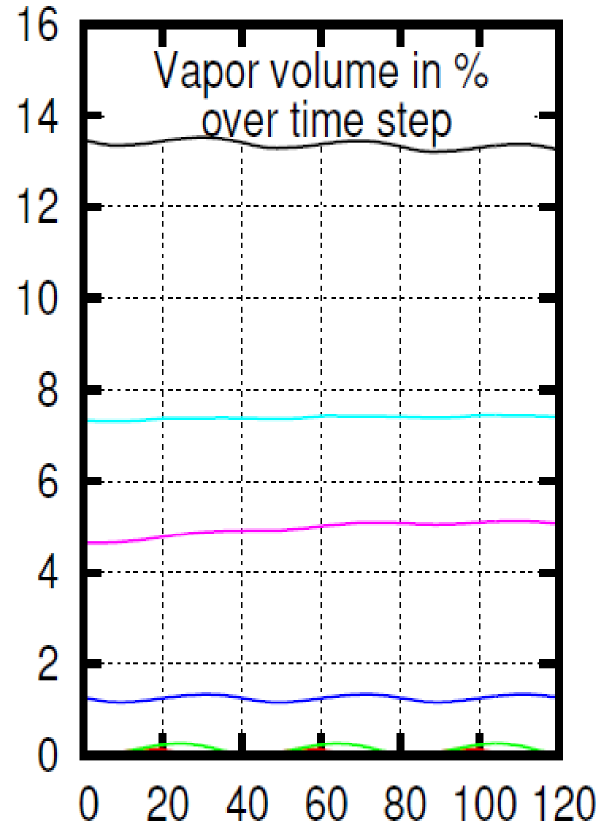


Results with cavitation:

- Time-resolved results (40 meshes per tooth)

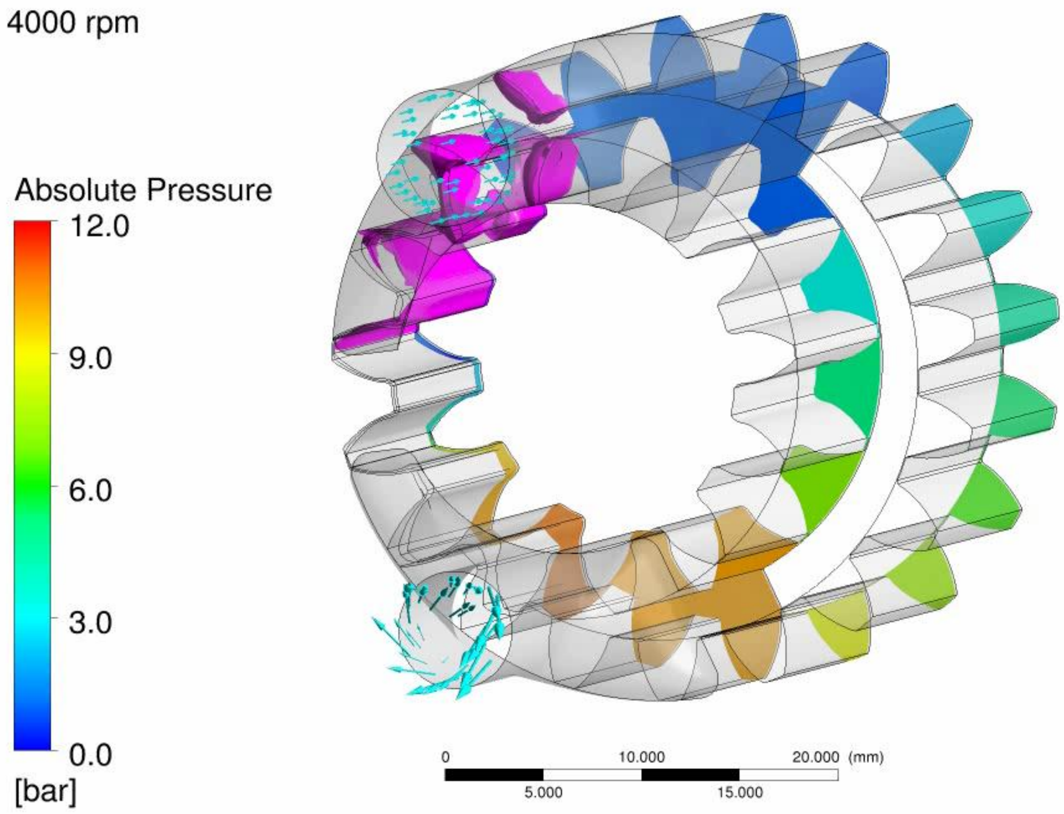






Results with cavitation:

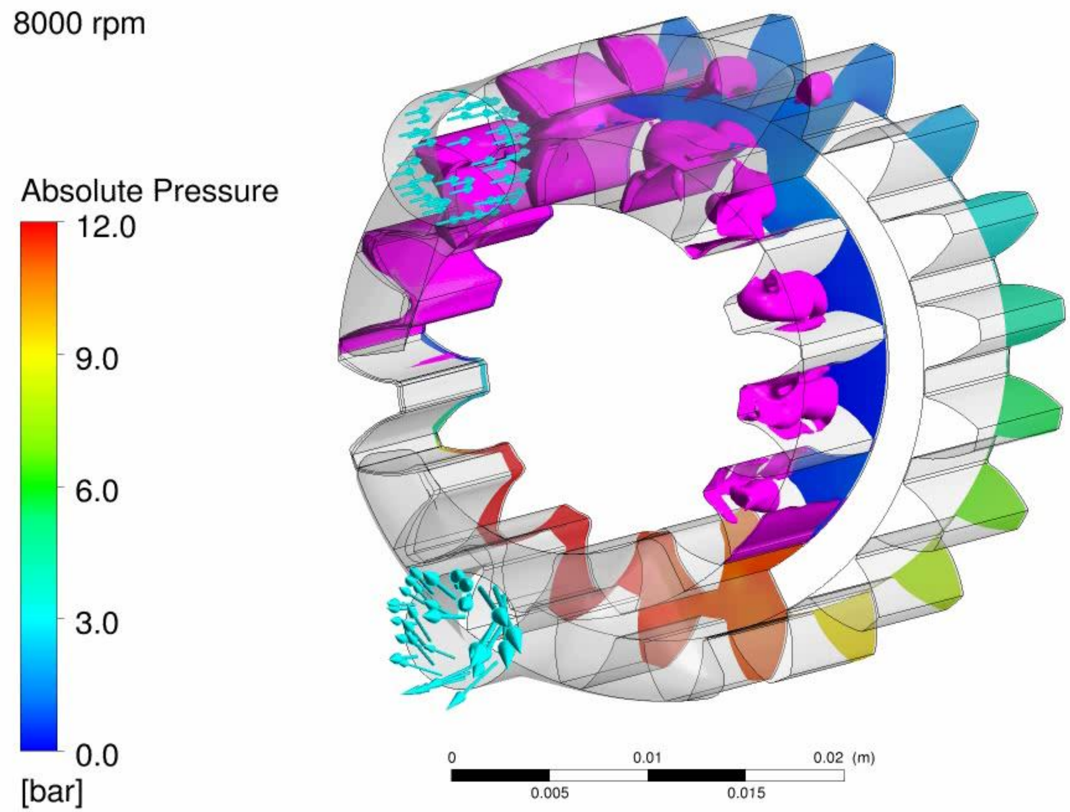
- Animation for 4000 rpm:
  - vapor is generated where teeth separate
  - vapor condensates before crescent
  - only water is displaced along crescent
  - same massflow as single-phase case



>10% vapor volume fraction

Results with cavitation:

- Animation for 8000 rpm:
  - vapor is generated where teeth separate
  - vapor stays at internal gear along crescent
  - water and vapor are displaced along crescent
  - less massflow as single-phase case



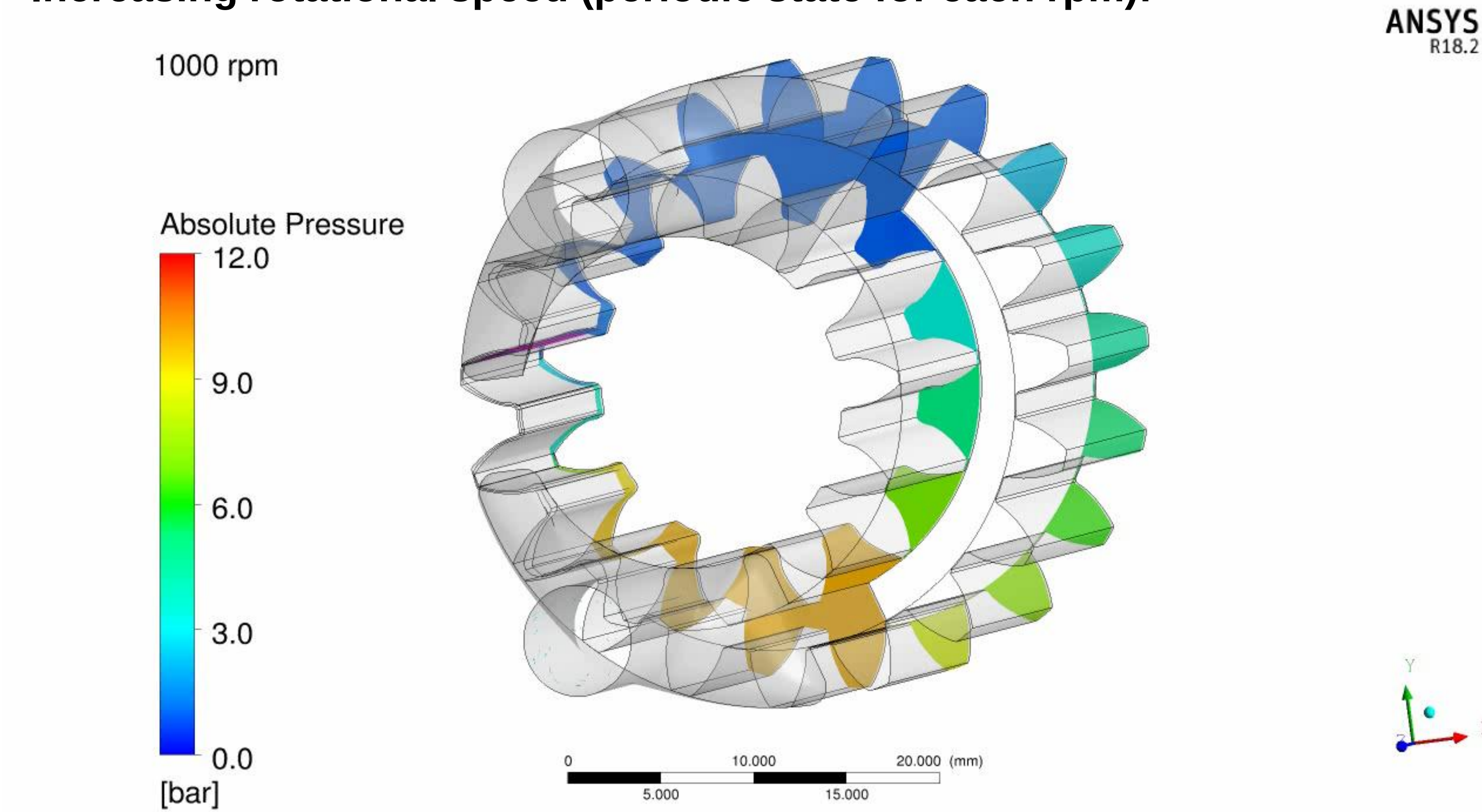
>10% vapor volume fraction

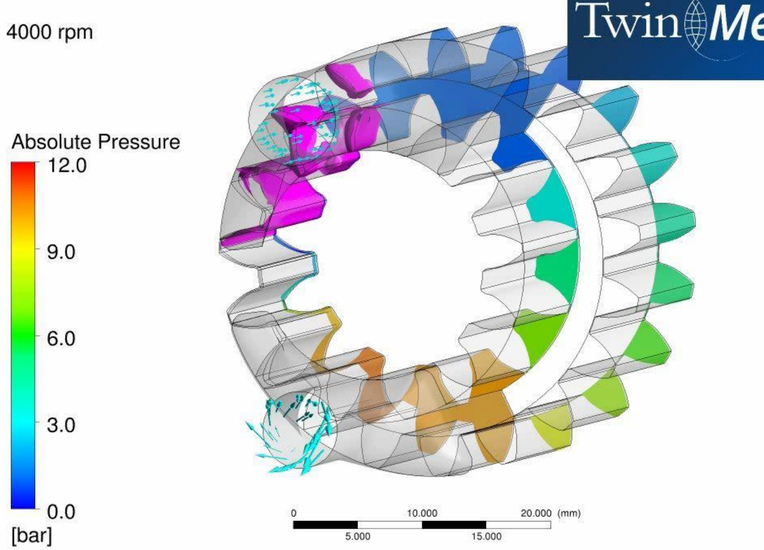
Cavitation with Rayleigh-Plesset model:

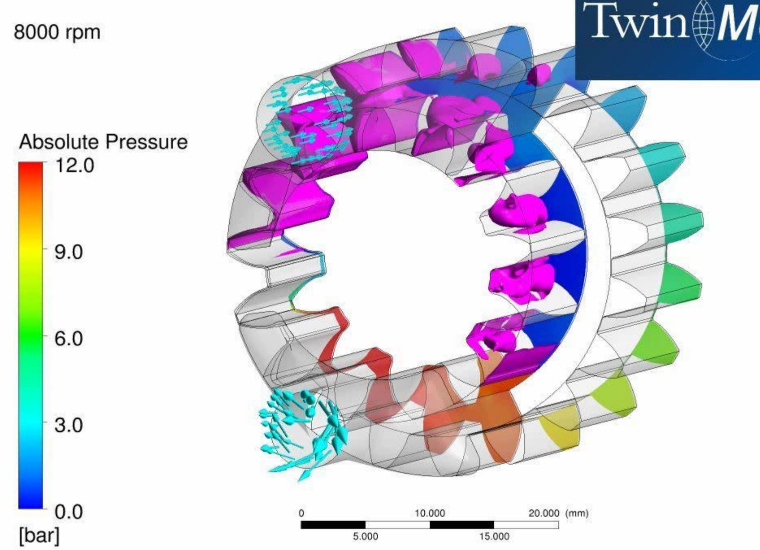
- Homogeneous Euler-Euler multi-phase simulation
  - Condensation if $p>p_v$:
    $$\dot{m}_{fg}=F\,\frac{3\,r_g\,\rho_g}{R_B}\sqrt{\frac{2}{3}\,\frac{|p_v-p|}{\rho_f}}$$
  - Evaporation if $p<p_v$:
    $$\dot{m}_{fg}=F\,\frac{3\,r_{nuc}(1-r_g)\,\rho_g}{R_{nuc}}\sqrt{\frac{2}{3}\,\frac{|p_v-p|}{\rho_f}}$$
- New expert parameter in ANSYS CFX-18.1:
  - accelerates convergence and mass conservation, but less stable
  - `cavitation finite pcoef factor=0` (old behaviour: 1)
  - Combination with „Cavitation Pressure Coefficient Factor“ possible
- But pressure in simulation still drops below p_v, even below 0 Pa!
  - model coefficients calibrated on hydrofoils and ship propellers
  - second order term and surface tension neglected in derivation of RP model
  - vapor assumed incompressible at saturation pressure → ideal gas law
  - outgassing of dissolved gas neglected → full cavitation model

p_v = 3574 Pa
R_{nuc} = R_B=1 µm
r_{nuc} = 5E-4
F_{vap} = 50
F_{cond}= 0.01

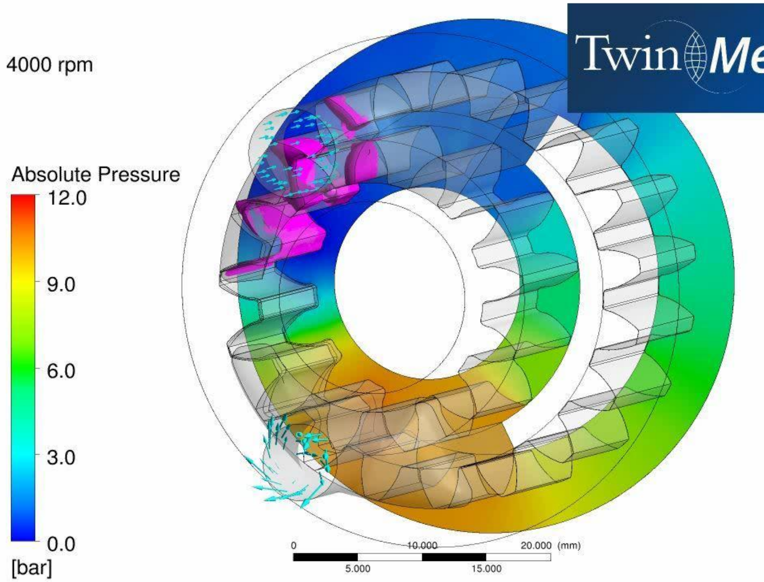
Increasing rotational speed (periodic state for each rpm):

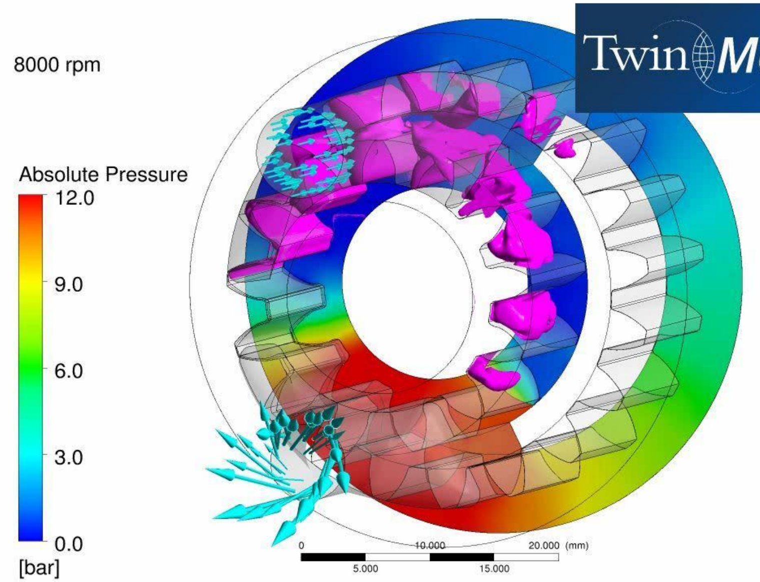






No axial gaps





Axial gaps with 20 µm width

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Summary and conclusions

- TwinMesh and ANSYS CFD
  - simulation of PD machines
  - high quality meshing, easy setup
- Simulations of single-phase flow
  - backflow through radial clearances
  - pulsations of massflow
- Cavitation simulations
  - blockage effect of cavitation: vapor is displaced in the chambers
  - massflow decreases
- Cavitation model needs further improvements

For more information, visit our stand!