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
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

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

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

35. CADFEM ANSYS Simulation Conference 2017
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

![Graphs showing mass flow, torque, and shaft power versus rpm for internal and external conditions.](image-url)
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 \( \rightarrow \) ideal gas law
  - outgassing of dissolved gas neglected \( \rightarrow \) full cavitation model

\[
\begin{align*}
p_v &= 3574 \text{ Pa} \\
R_{nuc} &= R_B = 1 \, \mu\text{m} \\
r_{nuc} &= 5 \times 10^{-4} \\
F_{vap} &= 50 \\
F_{cond} &= 0.01
\end{align*}
\]
Increasing rotational speed (periodic state for each rpm):

1000 rpm

Absolute Pressure

12.0
9.0
6.0
3.0
0.0
[bar]

0 5,000 10,000 20,000 (mm)
Axial gaps with 20 µm width

No axial gaps
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!