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Content

• Introduction

• Hydraulic Axial Pumps
  – Variable Displacement Pumps
  – Pressure Peaks
  – Compensation Chamber

• Coupled FEA and CFD Simulation
  – Simulation Models
  – Simulation Results

• Summary and Outlook
Hydraulic Axial Pumps
Hydraulic Axial Pumps

• Research project in the Department of Hydraulics and Pneumatics at Gdansk University in Poland.

• A new axial pump with a cam-driven commutation unit (called PWK-pump) was developed.

• Constant displacement pump with very good performance:
  – Working pressure up to 55 MPa
  – Efficiency of 94%
  – Good power density
Hydraulic Axial Pumps

- To control the fluid amount **variable displacement** pumps are used, which usually have to be controlled by a complicated hydraulic servomechanism.

- The main advantage of the new pump is that it can be controlled by a low-energy actuator.

- Reduces pump’s cost and dimensions drastically.

- For displacement control a special planetary gearbox was developed to provide control over fast rotating parts.
Variable Displacement Pumps
Hydraulic Axial Pumps

Main elements of the pump:
Hydraulic Axial Pumps

Prototypes have been built and tested, e.g. in lifting devices on ships in an extreme temperature environment.
Pressure Peaks
When the cylinder chamber is disconnected from the outtake and intake channels harmful pressure peaks were observed in the pump.

High Noise Emission

Damage of the Pump
Pressure Peaks

- Average pumping pressure
- Oil compressibility
- Volume of the fluid in the chamber
- Deformation of pump’s elements
- Temperature
- Displacement adjustment
- Rotational speed
- Leakage

Amplitude of Pressure Peaks
Pressure Peak Compensation
Pressure Peak Compensation

Compensation Chamber:
Shortens period of disconnection and gives fluid more room.

Pressure Peak reduction by 50%, not affecting the pump’s efficiency.

Optimize shape, elasticity and volume of the chamber while minimizing pressure peaks.
Coupled CFD and FEA Simulation
Coupled CFD and FEA Simulation

CAD model of a pump with seven chambers (right) and a symmetric model of a simplified pump with two chambers (left). Movable parts are shown in red.
CFD model in FLUENT

- Hexahedral elements and dynamic layering method for moving mesh between the pistons.
- Motion of the pistons and the bridge (connecting the cylinder volume with the intake or outtake channels) is realized via user defined functions.
- The hydraulic oil is assumed to be slightly compressible.
- A coupled solver (for pressure and velocity) and the Spalart-Allmaras turbulence model are used.
- High pressure 10 MPa, low pressure 0.2 MPa. (pressure in- and outlet).
- Two cycles of the pump (depending on the configuration) take 0.08s.
- Time step size is 1e-05 or 5e-06.
CFD model in FLUENT

One cylinder chamber in Fluent: walls are colored blue, interfaces green and symmetry planes yellow.

The two pistons are quite close to each other leading to a small volume of the cylinder chamber.
FEA model in Abaqus

- Shell model of the membrane with S4 elements.
- Boundary conditions: left and right sides of the chamber wall are fixed in space.
- Thickness of elastic wall: 1.5 mm
- Isotropic elastic material with
  - Young’s modulus: $E = 2.1 \times 10^9$ Pa
  - Poisson ratio: $\nu = 0.35$
  - Density: $\rho = 7800$ kg/m$^3$
FEA model in Abaqus

• Solid model (consisting of hexahedral elements) of the pump was developed as well for comparison with shell results.

• Solved with Abaqus/Explicit (nonlinear geometry) with a fixed time increment.

• Abaqus loads are ramped linearly over the time step.
Fluid-Structure Interaction

Hydraulic oil exerts wall force on the membrane.  

Membrane deforms under load.  

Modeled in Fluent.  

Simulated in Abaqus.  

FSI coupling with MpCCI
Fluid-Structure Interaction

• MpCCI – Fraunhofer SCAI’s Multifysics Code Coupling Interface:
  – Automatic and fast coupling methods
  – Orphan filling
  – Flexible: many supported codes, API
  – Usage of fast socket communication
  – Under-relaxation of quantities
  – Visualization of results
  – Easy usage via GUI or batch
Pressure contours on the CFD model during two pump cycles.

The pressure change in the compensation chamber can be seen when the chamber is connected to the channels.
Simulation Results

Displacement of the FEM model (shells modeled in Abaqus).

The force exerted by the hydraulic oil leads to a slight deformation of the membrane wall.
Simulation Results

Von-Mises Stress on the FEM model (shell elements in Abaqus)
Simulation Results

Von-Mises Stress on the FEM model (displaced volume elements in Abaqus)

The boundary conditions, i.e. the fixation of the compensation chamber, is shown in this picture.
Simulation Results

**CFD (FLUENT)**

**Pressure Plots** at three discrete points of the pump.
Simulation Results

**CFD (FLUENT)**

**FSI (Abaqus-MpCCI-Fluent)**

**Pressure Plots** at three discrete points of the pump.
Simulation Results

Time sensitivity of the FSI solution: time step size 1e-04
Simulation Results

Time sensitivity of the FSI solution: time step size 3e-05
Summary

• **FSI simulation during the design process of the new axial hydraulic pump:**
  – Much better understanding of occurrence of pressure peaks.
  – Helped in finding an optimal design for the compensation chamber.
  – Significant differences between CFD stand-alone and FSI simulations: FSI simulations agreed considerably better with experimental results.

• **Further investigations:**
  – Include leakage in the numerical simulation.
  – Fatigue simulation of pump.

Thank you for your attention.
Any questions?
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