Splash lubrication simulation using CFD

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Content

- Background
  - Why is splash lubrication simulation important?

- Method development and validation
  - Can we trust the results?

- Applications
  - How can the method be useful?

- Summary
  - What can the model do today and how can we improve it?
Background

- **Purpose of the lubrication system**
  - Provide adequate lubrication and cooling of important components, such as bearings, gear contacts, clutches, synchronizers, etc., ...  
  - ... with minimum losses in the transmission.
- **Many transmissions work without a controlled, pressurized, lubrication system.** Instead they rely on splash lubrication where the oil flow is driven by the rotation of the gears and guided to important positions.
- **Splash lubrication is difficult to predict due to the chaotic nature of the flow.**
- **The transmission housing plays a major role in guiding the flow.**

Background

- **Development of the lubrication system is still done experimentally in rig tests.**
  - Measurement of flow to important positions.
  - Visualization of the flow by plastic housings.
- **Transmission housings are long-lead time items.**
  - Difficult to obtain feedback in early design stages when hardware is not available.
  - Difficult/expensive to introduce design changes once the hardware is in place.
**Product Development Process**

**Front loaded math based development process, assuring low development cost and shortest leadtime**

- Requirement driven, all parts and systems optimized towards their individual technical and functional requirements
- A math-based process assures a minimum need of development prototypes
- No order of prototypes prior confirmation that a part is meeting all requirements
- Low cost and Short lead time

**Math-based development**

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**Physics**

\[
\frac{d^2\theta}{dt^2} + \frac{d\phi}{dt} \frac{d\theta}{dt} = \frac{1}{J} \left( \tau - \tau_0 - \tau_1 \right)
\]

\[
\frac{d\phi}{dt} \frac{d\theta}{dt} = \frac{1}{\tau} \left( \tau - \tau_0 - \tau_1 \right)
\]
Method development and validation
- Validation methodology

Problem reduction

Drag torque and oil flow Measurements

Flow Field Validation @Chalmers

Problem separation

Method development and validation
- Churning losses

- Churning loss was measured on single components:
  - Cylinder
  - Spur gear
  - Helical gear
- To understand influence of gear teeth.
- Losses can be predicted well
  - the major uncertainty is the effect of temperature since the thermal field is not included in the simulation.
Method development and validation
- Oil splashing behaviour

- Filming with high-speed camera shows that ...
  - splashing behind the gear
  - wetting of the gear
  - air bubbles between the teeth
  ... is captured well in the simulation.
- The simulation can capture the major features of the flow.

Method development and validation
- Flow field measurements

- PIV measurements show details about the flow
  - Velocity field (fluctuations and mean values)
  - Boundary layer profile

- Simulations give qualitatively good results.
Method development and validation
- Internal shaft flow

- Rig measurements of oil flow through a shaft were performed for various temperatures and rotational speed.
- The oil flow behaviour is predicted well.
- Important flow phenomena such as choking of the shaft is predicted.

Applications
- Minimization of losses
Applications
- Thermal effects

- Thermal effects can be accounted for by changing the global temperature of the oil.
- The function of the lubrication system can be evaluated at cold and warm conditions.
- The temperature field is not included in the simulation due to long simulation times.

Applications
- Lubrication system development
Applications
- Transmission housing design

Lubrication

Manufacturing

Structure & NVH

Topology optimization

1st-time-right Housing design!

Summary
A CFD method for splash lubrication has been developed and applied
- Transient two-phase flow (oil and air)
- Rotating geometries
- Complete transmissions can be simulated

The method is useful for
- Minimization of losses
  - Understanding geometrical effects
  - Minimize oil-level
- Lubrication system
  - Understanding oil-flow to components under different driving conditions (temperature, external forces, angle of inclination, ...)
  - Design collector system and compare alternative solutions

Future improvements
- Temperature field and heat transfer
- Meshing gears
- Additional component validation
  - Bearings
  - Clutches
  - Synchronizers
- Simulation time

The method is used today for Vicura’s customers

2011-11-09 16 Torbjörn Kvist
Thank you!

Movie

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