Experimental and Numerical Results of Gearbox Flow at Chalmers

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Motivation

• Stricter worldwide regulations to mitigate the environmental impact of the CO2 emissions.

• Development of energy- and installation-efficient drive system platform that can be utilized for full-electric medium-heavy (18-30 tonnes) buses and trucks.

• Gearbox studies important for predicting performance of transmissions in the powertrain system.

• Churning losses understanding. Few studies of relevant cases in literature.

• Faster and efficient designing of gearboxes and transmissions without tests.
Metodology

- Measurements of the torque drag via experiments in gearbox rig and CFD simulations.
- Visualization of the oil splashing pattern.
- Use a standard FZG test rig with spur gears in vertical position.
- Use a realistic gearbox shape and gear.
Vertical FZG gearbox
Test settings

- 4 configurations
- 3 oil levels
- 3 RPMs in CFD / 6 in exp.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Wheel (rotating)</th>
<th>Pinion (stationary)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Disc</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>Gear</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>Disc</td>
<td>Disc</td>
</tr>
<tr>
<td>4</td>
<td>Gear</td>
<td>Disc</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rotational speed (rpm)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil height (mm)</td>
<td>45</td>
<td>59</td>
<td>89</td>
</tr>
<tr>
<td>Submerged wheel part (%)</td>
<td>13</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>
• Experimental data for Torques of Config. 3 (gear wheel with cylinder pinion)

Mechanical losses included

Mechanical losses excluded
• Config. 1 (cylinder wheel without pinion)
• Config. 2 (cylinder wheel without cylinder pinion)
• Config. 4 (gear wheel with cylinder pinion)
• Mechanical losses are excluded.

13% of wheel submerged

25%
• Config. 1 (cylinder wheel without pinion)
• Config. 3 (gear wheel without pinion)
• Mechanical losses are excluded
- 13% of wheel is submerged in oil.

Config. 1
(gear wheel without pinion)

Config. 4
(gear wheel with cylinder/disc pinion)
Numerical method

• Lattice-Boltzmann method is used for CFD simulations.
• The computational domain and gear/disc geometries are the same as in the experimental rig.
• Test matrix:
  • 4 configurations
  • 3 oil levels
  • 3 rpm.
Vertical velocity

Config. 1  |  Config. 2  |  Config. 3  |  Config. 4
---|---|---|---
500 rpm  |  (a)  |  (b)  |  (c)  |  (d)
1000 rpm  |  (e)  |  (f)  |  (g)  |  (h)
2000 rpm  |  (i)  |  (j)  |  (k)  |  (l)
Comparison of Experiments and Simulations

Vertical velocity
Conclusions

• 4 gearbox configurations are designed based on a vertical FZG rig, which is more representative for real gearboxes.

• The configurations are investigated at
  • 3 rpms (numerically) and 6 rpms (experimentally)
  • 3 oil levels, i.e., 13%, 25% and 50% of the wheel submerged into the oil.

• The experimental and numerical results show consistent flow patterns.

• Gear teeth is effective to increase torques.

• The installed pinion
  • significantly increased torques above approx. 1000 rpm for 13% submerged level;
  • a similar phenomenon at 2000 rpm for 25% submerged level;
  • however, this effect is not obvious for 50% submerged level.

• Oil levels play an important role in the torque generation.

• A test rig for helical gearboxes has been constructed.
Simplified Gearbox Rig with single helical gear
Test settings

- 3 configurations
- 1 oil level
- 5 RPMs in exp

Baseline case

Modification 1

Modification 2

Oil height = 44 mm
Experimental Results

\[ C_m = \frac{2M}{0.5\rho r^5 \omega^2} \quad Re = \frac{\omega r^2}{\nu} \]
Power losses

![Bar chart showing power losses at different RPMs for Baseline, Modification 1, and Modification 2. The chart indicates that Modification 2 has the highest power losses, followed by Baseline and then Modification 1.]
CFD Simulations (2 approaches)

**Lattice Boltzmann Method**

The computational domain and gear geometry are the same as in the experimental rig.

- Test matrix:
  - 3 configurations
  - 1 oil level
  - 4 speeds
  - Meshless
  - Voxelized

**Volume of Fluid (FVM)**

The computational domain and gear geometry are the same as in the experimental rig.

- Test matrix:
  - 3 configurations
  - 1 oil level
  - 3 speeds
  - ~ 14M cells
  - K-omega SST low-Re
  - StarCCM+
Results CFD and Experiments

\[ C_m = \begin{cases} 3.87 & Re^{-0.5} \\ 2.67 & Re^{-0.5} \end{cases} \]
Oil distribution (LBM-experiments)
Conclusions

• 3 gearbox configurations are designed based on a real geometry.
• The configurations are investigated at
  • 3 and 4 speeds (numerically) and 5 rpms (experimentally)
  • 1 oil level, i.e., 44 mm oil height.
• Experimental results show better performance of the base case for the medium and high speeds.
• Experimental results show that deflector works best at low speeds, not at high speeds.
• Influence of the gearbox shape on the gearbox efficiency tends to be more important as the speed increases. Looks like a quick oil return to the sump is not of benefit for the efficiency.
• Numerical methods with insufficient accuracy and need improvement for future cases. However, Torque trends are not completely in disagreement with experimental methods.

Suggested Work

• Perform investigation of the influence of different turbulence models. Ongoing.
• Analys direction rotation, different oil redirection, positioning of the gear.
• Increase numerical accuracy of the models. Robustness. New methods?
Thanks