Efficiency optimisation of heavy duty axles

A collaborative project

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ETI Lower Drivetrain Parasitic Loss Reduction Project

Introduction

- Romax Technology leads 4-year project funded by the UK Energy Technologies Institute (ETI)

- The aim of this Project is to develop cost effective platform technologies targeting vehicle level efficiency improvements of 2-5%

- Lead Partner – System simulation, gear design for efficiency, advanced lubrication control

- Oil churning simulation and method development (CFD)

- Development of new oil technology platform

- Development of efficient bearings and gear surface coatings

- Tilt and axle rig set up and testing (subcontractor)

- The demonstrator application is a heavy duty articulated truck centre axle
Project Objectives

- Consortium to work collaboratively to achieve loss reduction

- Development of new oil technology platform increasing efficiency

- Improved lubrication management to reduce churning losses

- Development of efficient bearings and gear surface coatings

- Reduction of gear mesh losses through enhanced gear geometry

[Caterpillar/Magna/Klingelnberg]
ETI Lower Drivetrain Parasitic Loss Reduction Project

Project Overview

- **2013**
  - Baseline testing
    - Understand the current system

- **2014**
  - Modelling and Validation
    - Create validated simulation of the system that we can modify and optimise
  - Sensitivity study, Select optimal solution
    - See how the system can be optimised to gain robust improvements

- **2015**
  - Detail design and prototype manufacturing
    - Confirm the design, get it made

- **May 2016**
  - Confirmation testing
    - Test the new design to confirm improvement

Current status
Content

- Baseline testing of axle (Romax)
- Role of CFD in reducing churning losses (Ansys)
- Development of Fuel Efficient bearings (Timken)
- Development of new oil (Castrol)
- Project overview (Romax)
Baseline testing of axles

- Test setup for efficiency measurement
- Torque-to-turn and efficiency results
- Break down of losses
- Drive cycle efficiency performance
- Summary
Baseline testing - overview
From simple to complex; From component to system level

- The baseline fluid properties are confirmed
- Friction performance is evaluated, parameters for input to efficiency model are obtained

- Oil flow investigation on single crown wheel
- Oil flow investigation on bevel stage using tilt rig, variation of fill level, temperature, roll and tilt angle

- A combination of no-load and loaded tests is applied to facilitate a break down of losses between major components and sub-assemblies
- Efficiency maps measured
Test outline

No-load tilt rig:
- Speed, temperature and fill level variation
- Torque-to-turn measurements
- Oil sump and ambient temperature logged
- Oil flow investigation using high speed camera

Loaded rig:
- Effect of run-in
- Oil temperature variation
- Break down of losses for bevel stage + wheel hubs
- Oil sump and ambient temperature logged
- In addition to input and output torque transducers a range of temperature sensors was installed
Tilt rig set up

- Torque-to-turn measurement and oil flow visualisation
Torque to turn results

- Measurements conducted for different oil sump temperatures
- At low temperature repeatability affected by temperature increase
- Repeatability very good at higher temperatures
- Non-linear torque-speed dependency at low temperature, linear above 50degC
Torque to turn comparison

- Viscosity/temperature most significant parameter
- Fill level influence comparable over temperature range
- Results with oil drained (h=0.0) similar for all temperatures due to temperature increase in bearings (quasi-static temperature reached)
Break down of no-load losses

- T=75degC, centre fill h=1
- Centre stage bearings significant over speed range
- Bevel pinion head&tail bearings dominating due to size and preload
- Gear churning losses important above 900rpm, cause 50% of no load losses at full speed
- Wheel hub bearings less significant
Axle rig mechanical set up

- Test rig commissioned at mi Technology: 250kW motor, 9-spd transmission, 700kW EC-dyno
- Water spray and fan cooling utilised to control axle oil sump temperature
- Axles tested with and without wheel hubs installed
- Repeatability ±2Nm on 5000Nm input torque range (with complete axle)
Axle rig – Axle 1 results

Repeatability

T=75°C
Test 1

T=75°C
Test 2

T=50°C

T=100°C
Sensitivity to fill level/temperature variation

- Standard conditions 75degC, centre fill h=1
- Temperature/viscosity most significant parameter → potential for low viscosity lubricant/dry sump system and fuel efficient bearings

Improvement through:
- Fill level halved h=1.0 → h=0.5
- Viscosity reduction 35→18 cSt (-16%)

max. theoretical improvement with dry sump (-50%)
Break down of losses for selected op. points

- Oil sump temp. $T=75\,\text{degC}$, fill level $h=1$
- Break down between no-load and loaded losses based on torque-to-turn measurements
- Centre/Bevel stage test results used to facilitate break down between loaded losses of bevel stage and wheel hubs
Comparison experimental and simulated efficiency maps
Drive cycle efficiency simulation

- Oil sump temperature $T=75\,\text{degC}$, centre fill $h=1.0$
- Axle input speed/torque overlayed on calculated efficiency map

Loaded cycle efficiency 90.9%

Unloaded cycle efficiency 86.0%
Summary of initial testing

• Test rigs and test methodology developed, very good repeatability achieved
• Measurements conducted to quantify influence of torque, speed, temperature and fill level
• Temperature and thus viscosity major factor influencing efficiency
• Break down of losses confirmed:
  o Bevel pinion head/tail bearings dominate bearing losses
  o Churning of bevel gear and transfer gears becomes significant above 900rpm
  o Gear mesh losses dominate under high loads
• Good agreement found between measurement results and calculation
• Drive cycle efficiency analysis confirmed potential of low viscosity oils and FE bearings to reduce losses, further potential for improvement in gear mesh losses
Energy Technologies Institute – Heavy Duty Vehicle Efficiency Project

Stephen Silvester - ANSYS UK
Maik Hoppert - Romax Technology
Heavy Duty Off-Highway Axle Efficiency Improvement:
Design for Efficiency Through Fuel-Efficient Bearings and System Optimization
Development of low viscosity oil – Castrol
Project Overview: Current Technology

• Project start saw Romax carry out an extensive literature survey on methods and projects for the optimisation of driveline efficiency
  o 300 full text publications were processed

• Conclusion:
  o Projects typically approach efficiency optimisation from one view point
    • Bearings
    • Oil
    • Surface finish
    • Gear design
    • Churning

• The target of this project is to pull together all of these approaches to achieve efficiency improvement which is “greater than the sum of the parts”
Project Overview: Collaborative Working

Reducing friction in contacting surfaces

Reducing churning drag

Component Geometry

Surface Finish

Lubricant Definition

Manufacturing Control

Dry Sump (no churning)

Wet Sump (churning used to propel oil to contacting surfaces)

Critical Case

Generic Crown/Pinion

Rexona

Castrol
Summary

- HDV collaboration is pulling together leaders in their given fields with the intention of achieving significant reductions in CO\textsubscript{2} emissions

- The output will lead to:
  - Improved oil and bearing products
  - Improved software functionality (with working case studies)

- Collaborative offering aims to deliver more than just the standard offering of each individual member
Any Questions?