Efficiency Improvement through Reduction in Friction and Wear in Powertrain Systems

Mike Killian
February 28, 2008

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Efficiency Improvement through Reduction in Friction and Wear in Powertrain Systems

<table>
<thead>
<tr>
<th>Project ID/Agreement ID</th>
<th>Program Structure</th>
<th>Sub-Program Element</th>
<th>R&amp;D Phase</th>
<th>Date</th>
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<tr>
<td>DE-FC26-04NT42263 / A000</td>
<td>Vehicle Systems</td>
<td>HV Systems Optimization</td>
<td>Exploratory Research</td>
<td>02/28/08</td>
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PURPOSE

To conduct research and development to reduce friction and parasitic energy loss by 30-50%, in truck transmissions and axles used in class 3-8 trucks, is the purpose of this project. Increased efficiency will improve fuel economy by 2-4%, producing a savings of 390 to 780 gallons per vehicle annually, without compromising performance and durability.
Technical Approach: Formulate an IMPLEMENTATION STRATEGY

1. Churning losses
2. Surface roughness – super finishing
3. Lubrication effects
4. Coatings
5. Texturing
BARRIERS / RISKS

- Risk of gear and bearing damage with dry, low fill sumps
- Excessive gear pitting, wear and noise from low viscosity lubricants
- Hard debris from delamination and disbond of coatings
- Loss of oil film with excessively smooth, super finished surfaces
- Cost of the technology
- Convincing fleet users the technology provides a tangible benefit
LESSONS LEARNED

Advanced sumps to reduce churning loss (24-31%)
- Old “dry sump” hardware with spray tubes
- Low volume sump with electronic oil injection
- RISK: gear and bearing damage on inclines

Lubricant additives for friction reduction (24-42%)
- Additives to bulk oil
- Demand based additive injection
- RISK: gear pitting and wear

Gear coatings for friction reduction (??%)
- PVD diamond like carbon, AlMgB, MoN-Cu
- RISK: coating delamination, disbond, debris

Three dry sumps 1/5 of the lube
COMPARISON OF DYNAMOMETER TORQUE FOR FULL FILL VERSUS DRY SUMP FOR ROADRANGER SAE 50 REV 7 LUBRICANT

Churning Loss Reduction - Transmission

- 31% Overdrive
- 24% Direct

24 – 31% reduction
Parasitic torque for four Caterpillar oils tested at 30 degrees C (86 degrees F). For high viscosity Oil #20, the reduction in parasitic torque due to the dry sump exceeds 30 percent.
Parasitic torque for four Caterpillar oils tested at 90 degrees C (194 degrees F). For baseline Oil #18, the reduction in parasitic torque due to the dry sump exceeds 47 percent.
FZG tested lubricants

New Lubricant (#20) vs. year 2 selection (#1 and #11) and baseline (#18),
More validation of Lube (#20) is planned
LUBRICANT APPROACHES

Alternatives to Roadranger Rev 7

• PAO base oil
• Friction modifiers
• Anti-wear additives
• RFY4 oil
• RIM 5 oil; New Castle tester

Reduce friction coefficient for Roadranger Rev 7

• Introduce friction modifiers
• Introduce solid lubricants
• Rev 7 with RJK5 additive blended in oil
• RJK5 dosing additive
### Falex Fixed 4-Ball Test

<table>
<thead>
<tr>
<th>TEST NO.</th>
<th>LUBRICANT</th>
<th>FRICTION COEFFICIENT (average)</th>
<th>WEAR SCAR DIAMETER (mm)</th>
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</thead>
<tbody>
<tr>
<td>H142 Baseline</td>
<td>Eaton Roadranger SAE 50 Rev 7</td>
<td>0.066</td>
<td>0.44</td>
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<tr>
<td>H143</td>
<td>R7L5</td>
<td>0.066</td>
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<td>H145</td>
<td>R7L7</td>
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<td>H146</td>
<td>R7H7</td>
<td>0.079</td>
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<td>C230</td>
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<tr>
<td>H154</td>
<td>Mobil SHC 50</td>
<td>0.123</td>
<td>0.64</td>
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</tbody>
</table>

High contact stress: >150,000 psi

COMMERCIAL (August 2006)

COMMERCIAL

June 5, 2007
<table>
<thead>
<tr>
<th>TEST NUMBER</th>
<th>DESIGN CODE</th>
<th>TEST METHOD CODE</th>
<th>COMPOSITION</th>
<th>FRICTION COEFFICIENT</th>
<th>WEAR SCAR DIAMETER (mm)</th>
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<tr>
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<td>H204</td>
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<td>Durasyn 168 + CK3D + RFF2 + RFY2 + H121</td>
<td>0.038</td>
<td>0.33</td>
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<tr>
<td>H205</td>
<td>RFY5</td>
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<td>Durasyn 168 + CK3D + RFF2 + RFY3 + H121</td>
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<tr>
<td>H189</td>
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<tr>
<td>H200</td>
<td>RFV3</td>
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<td>96-Durasyn 168 + 1-CK3D + 2-RFF2 +1-RFV2</td>
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<tr>
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<td>H188</td>
<td>RFN4</td>
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<td>96-FCB3 Dursyn 168 PAO + 1-CK3D + 2-RFF2 TechGARD 740 + 1 RFN2 Elco 103</td>
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</table>

*Lubes from Ann Arbor Testing & Development, Inc
# H204 Oil Functional Breakdown

<table>
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<td>Roadranger SAE 50 Rev 7 Baseline</td>
<td>0.066</td>
<td>0.44</td>
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<tr>
<td>H154</td>
<td>RFN4</td>
<td>Mobil SHC 50 tested 5/25/07</td>
<td>0.123</td>
<td>0.64</td>
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<tr>
<td>H204</td>
<td>RFY4</td>
<td>PAO + CK3D + RFF2 + RFY2 + H121</td>
<td>0.038</td>
<td>0.33</td>
</tr>
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</table>

- PAO + CK3D + RFF2 + RFY2 + H121
- 96 PAO Base oil + 1 Friction Modifier + 2 Gear Oil Pkg + 1 Zn Additive
EATON: SWITCHING OIL ON-THE-FLY

STANDARD ➔ NEW ADDITIVE ➔ STANDARD

SAE 50 Rev 7

Bulk oil: Rev 7 & RJK5 oil

25%

Injected RJK5 additive

New additive reduces friction by 25%

Time (hrs)

Torque (inch-lbs)

0 Days, 0h ➔ 0 Days, 2h ➔ 0 Days, 4h ➔ 0 Days, 6h
PVD COATING CHALLENGES

Challenges have been identified when PVD (physical vapor deposition) processing is used for coating gears:

- Gear geometry
- Limited temperature processing
- Surface finish
- Cost
PVD GEAR COATING

Eaton spur gear, contact fatigue rollers and Falex ring that have been coated with Diamond-Like Carbon by physical vapor deposition
ROLLING CONTACT FATIGUE RESULTS

Roughness

Wear & Polishing

Test duration (hrs.)

Roughness, $R_a$ (micro-in)

- Shaved, LR
- Shaved, SR
- CBN ground, LR
- CBN ground, SR
- Superpolished, LR
- Superpolished, SR

LR

SR
SURFACE TEXTURING

Quarterly Progress Report Q2 2005

Fricso Vibra-grooved samples. Rings 2 and 4 exhibited lowest coefficient of friction in Falex mailbox pin test. Contact stress: ~13,000 psi.
INTEGRATED GEAR DESIGN MODEL

Deliverables 9, 10 & 12 BP2
Coatings, Gear Design, Strategy
SUMMARY

- Research has enabled an *initial vision of the efficient powertrain* assembly, *whether a transmission or an axle*

- An efficient powertrain assembly includes
  - *Advanced low fill sump with precision oil injection* to the gear mesh and to bearings
  - *Low viscosity synthetic oil*, heavily dosed with friction modifiers and anti-wear additives
  - *Super finished contact surfaces* including gear teeth and rotating elements
  - *Coatings* applied to super finished surfaces
    - Potential to reduce friction and to reduce operating temperature
    - Durability remains an issue requiring further development and testing
A 2-4% improvement in fuel economy correlates to a savings of $1200 to $2400 per vehicle for the fleet.

More importantly, a 2-4% improvement in heavy truck miles per gallon yields a savings of 390 to 780 gallons of diesel fuel per vehicle.

Assuming a population of 2.5 million active heavy trucks in the US and saving 500 gallons per vehicle annually, the fuel savings reaches 1.25B gallons of diesel fuel. This amount of diesel fuel comes from 7.5B gallons of crude oil, roughly 180M barrels.

If only 20% of the trucks were updated, the savings would be 250M gallons of diesel fuel or 1.5B gallons of crude, about 36M barrels.
END
Fuel Economy: miles per gallon; 120,000 miles annually, at 6 mpg = 20,000 gallons of fuel; 2.0% improvement target

- 2% fuel economy improvement: \(0.02 \times 6 \text{ mpg} = 0.12 \text{ better mpg}\)
- Improved mpg = 6.12 mpg
- 120,000 miles / 6.12 mpg = 19,608 gallons
- 20,000 gallons – 19,608 gallons = 392 gallons saved
- 392 gallons \(*\$3.00 \text{ to } \$3.50 \text{ / gallon} = \$1,176 \text{ to } \$1,372 \text{ savings annually}\)
- 1,000 vehicle fleet \(*\$1,000+ \text{ savings } = >\$1M \text{ annually}\)
- Swift Transportation Co., Inc – 18,000 tractors
Coating thickness / adhesion (micro-blasting method)

8206 large gear, micro-blasting test results
68 psi air pressure, 50 micron glass beads
(calibration: 7.5 sec.)

Coating: CemeCon TiAlN

Gear Tooth – coating thickness distribution

Deliverable 9 & 14 BP2
**POWERTRAIN EFFICIENCY**

**Business Strategy**

- Medium and heavy duty trucks; off-highway equipment
- Eaton dominates NA HD truck market, >90% market share
- MD truck market share is 20%, an opportunity for growth
- Fuel savings for fleet customers; 2% improvement in mpg from transmission; additional 2% from axles; $1200 to $2400 savings per vehicle for fleet