Analysis of Power Distribution in a Mid-Size Agricultural Tractor through Modeling

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Analysis of Power Distribution in a Mid-Size Agricultural Tractor through Modeling

Research motivation

Auxiliary hydraulic functions
Traveling service
Steering
Braking
Power beyond

Ag. Tractor Standards
Guarantee
State of The Art Architectures
Load Sensing

Competitive Machine Operation

How to know?
Optimal Behavior
All working maneuvers?
Research goal

We know: Different sources of power loss existing [load sensing]

• Feasible and cost-effective solutions for significant increase of energy efficiency of such system to improve overall system efficiency.
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Research approach

Experimental Characterization

Validated AMESim Model

Classification of Energy Losses

Machine Instrumentation → Steady State Testing → Dynamic Testing (Real Drive Cycles)

Solution Proposal
Analysis of Power Distribution in a Mid-Size Agricultural Tractor through Modeling

**Research approach**

- **Experimental Characterization**
- **Steady State Testing**
- **Dynamic Testing (Real Drive Cycles)**
- **Valuated AMESim Model Testing**

**Solution Proposal**

- Improved? Yes!
- Improved? No
- Delivered?
Reference hydraulic circuit

Variable Displacement Load Sensing Pump

Hitch Control Valve

EHR Control Valve 1

EHR Control Valve 2
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System modeling

Variable Displacement Load Sensing Pump

Flow Compensator

Pressure Compensator

Control Piston

Shaft speed

Low pressure circuit port

Pump supply port

LS signal port

Pump drain port
System modeling

Pressure Compensator

Orifice equation: \( Q = c_q \cdot A \cdot \sqrt{\frac{2|\Delta p|}{\rho}} \cdot \text{sign}(\Delta p) \)

Internal volumes: \( \frac{dp}{dt} = \frac{B(p) \cdot Q(p)}{V(p)} \)

Spool equilibrium: \( F = F_s + F_{jet} \)

Viscous friction force: \( f = -b \cdot v \)

Jet forces: \( F_{jet} = K \cdot 2 \cdot c_q \cdot A \cdot \Delta p \cdot \cos \theta \)

\[ K = k_{jet} \cdot \frac{1}{2} \left[ \tanh \left( \frac{2(\chi_{lap} - \chi_{min})}{\chi_{min}} \right) + 1 \right] \]
Model validation

- Pressure-flow compensator dynamic test: SAE STANDARD J745 JUN2009

![Graph showing FC Recovery Time with pressure values]

<table>
<thead>
<tr>
<th></th>
<th>Load Pressure</th>
<th>Deadhead Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure Compensator</td>
<td>95.08</td>
<td>99.29</td>
</tr>
<tr>
<td>Flow Compensator</td>
<td>99.79</td>
<td>83.22</td>
</tr>
</tbody>
</table>

Load Pressure:
- Model = 158.77 bar
- Experiment = 159.11 bar

Standby Pressure:
- 13.43 bar
- 11.50 bar
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Experimental tests set up

- Maha Test plan:
  - Based on real tractor testing standards.
  - Contains specific modifications for energy consumption analysis.
  - Versatile & easily adjustable to larger or smaller size tractors.

<table>
<thead>
<tr>
<th>EHR Test Summary</th>
<th>Number of Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Remote</td>
<td>224</td>
</tr>
<tr>
<td>Multiple Remotes</td>
<td>48</td>
</tr>
<tr>
<td>TOTAL</td>
<td>272</td>
</tr>
</tbody>
</table>
Experimental tests set up
System Model Tests

Test Plan for EHR and Hitch

100% Flow Command
EHR: (Retraction/Extension, High/Low $T_{oil}$)
HITCH: (Rising, High/Low $T_{oil}$)

<table>
<thead>
<tr>
<th>Load</th>
<th>0% Load</th>
<th>50% Load</th>
<th>75% Load</th>
<th>90% Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow command</td>
<td>50%</td>
<td>75%</td>
<td>90% Load</td>
<td></td>
</tr>
</tbody>
</table>

90% Load
EHR: (Retraction/Extension, High/Low $T_{oil}$)
HITCH: (Rising, High/Low $T_{oil}$)

<table>
<thead>
<tr>
<th>Load</th>
<th>25%</th>
<th>50%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow command</td>
<td>75%</td>
<td>90%</td>
<td>75%</td>
</tr>
</tbody>
</table>
System model validation results

- Different load settings
- Full command
- Retraction
- High \( T_{oil} \)
- High RPM

Single Remote Test Results Comparison

![Graph showing pressure and flow rate comparison](image)

- \( p/p_{ref} \) vs. Load setting [%]
- \( Q/Q_{ref} \) vs. Load setting [%]
System model validation results

Hitch with Single Remote Test Results Comparison

- Different load settings on remote
- Hitch cylinder raising
- Full command
- Extension
- High $T_{oil}$
- High RPM
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System power distribution

Power Distribution Comparison Between Different Loads for Single Remote Test

*Full command, Retraction, High RPM, High oil temperature*

<table>
<thead>
<tr>
<th>Load Setting [%]</th>
<th>90%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power distribution in the system [%]</td>
<td>55.99</td>
<td>52.64</td>
</tr>
<tr>
<td>Useful power on remote</td>
<td>20.33</td>
<td>9.42</td>
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<tr>
<td>TF pump</td>
<td>4.37</td>
<td>5.56</td>
</tr>
<tr>
<td>EHR local compensator</td>
<td>2.99</td>
<td>8.25</td>
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<tr>
<td>EHR main spool</td>
<td>2.11</td>
<td>8.74</td>
</tr>
<tr>
<td>EHR lock check valve</td>
<td>14.21</td>
<td>15.40</td>
</tr>
<tr>
<td>Back pressure and quick coupling</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Power Distribution Comparison Between Different Loads for Dual Remotes Test

*Full command, Retraction, High RPM, High oil temperature*

<table>
<thead>
<tr>
<th>Load Setting [%]</th>
<th>75%</th>
<th>50%</th>
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</thead>
<tbody>
<tr>
<td>Power distribution in the system [%]</td>
<td>29.07</td>
<td>13.13</td>
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<tr>
<td>Useful power on remote</td>
<td>0.75</td>
<td>0.61</td>
</tr>
<tr>
<td>TF pump</td>
<td>4.33</td>
<td>4.33</td>
</tr>
<tr>
<td>EHR local compensator</td>
<td>0.31</td>
<td>0.61</td>
</tr>
<tr>
<td>EHR main spool</td>
<td>11.06</td>
<td>7.19</td>
</tr>
<tr>
<td>EHR lock check valve</td>
<td>15.40</td>
<td>13.13</td>
</tr>
<tr>
<td>Back pressure and quick coupling</td>
<td>14.21</td>
<td>11.06</td>
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Introduction

Model development

Experimental tests

Model validation

Power distribution

Current

- Auxiliary hydraulic functions
- Travelling service
- Steering
- Braking

Independent Metering
Flow Sharing Control

Increased Control + Performance

E-Load Sensing
Hybrid Components

$EHR_1^{cmd}$ $EHR_2^{cmd}$ $Q_{pump}$ $Q_{EHR1}$ $Q_{EHR2}$
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Conclusion

Rationale & Motivation

Experimental Instrumentation & Testing

Model Development & Validation

Complete Characterization & Technological Improvements

Model validation

Power distribution

Introduction

Model development

Experimental tests
Thank you for your attention!

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