All-Inclusive Simulation Process Development of Piston Pumps with GT-SUITE

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Virtual Product Development
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Agenda

• About Caterpillar
• Project background
• Modeling strategies
• Piston pump models
• Modeling approach
• Simulation validation
• Summary
Products and Industries
Virtual Product Development (VPD)

VPD is a product development approach driven by **physics-based simulation**

Simulation Powered Product Development

- **Velocity**
  Products delivered to market in months rather than years

- **Insight**
  Full understanding of all tradeoffs made during concept phase

- **Customer**
  Global, real world applications fully understood

- **Confidence**
  Simulation is trusted source for information

- **Innovation**
  Fully explored alternatives provide superior innovation

- **Process**
  Imbedded simulation seamlessly drive decision making
Project Background

• Modeling process development for machine cold start

Hydraulic pumps (piston & gear) simulation is one of the major elements in whole machine cold start simulation process.

Caterpillar: Non-Confidential
Machine Cold Start

• Sub-systems in machine

Focus on:
- Parasitic loads
- Power losses
Simulation Process Development

• Modeling strategies

- High Fidelity & Physics-based
- Multi-domain System Modeling
- Dynamic & Transient Analysis
- Model Correlation & Validation
- Simple Model Inputs
- Simulation Accuracy with +/- 15%
- All-inclusive Simulation Process
Simulation Process Development

• 1D modeling tools

Use modeling components analytically defined

Dynasty: Caterpillar in-house 1D code

Benchmark for correlation/validation

Modeling process for product groups
Piston Pump Models

• Cat® machine steering pump: a variable displacement piston pump

Model characteristics:
- **GT-SUITE**: use convenient and dedicated predictive templates
- **Dynasty**: combine mechanical with hydraulic components

Pump parasitic load & power loss:
- pumping work
- fluid compressibility
- leakage loss
- friction & viscous losses
- resistance torque
Modeling Approach

• Piston pump intake & discharge flow area profiles
Modeling Approach

- **Piston torque on the swashplate**
  - Support force – torque $T_s$
    1. $F_s = F_p/cos(\alpha) = P*A/cos(\alpha)$
    2. Torque arm = $r*cos(\theta)/cos(\alpha)$
    
    $T_s = P*A*r*cos(\theta)/cos(\alpha)^2$
  - Inertia force – torque $T_i$
    
    $T_i = -M_p*\omega^2*r^2*tan(\alpha)*cos(\theta)^2/cos(\alpha)$
  - Total torque $T$ from a piston
    
    $T = \left[P*A*r*cos(\theta) - M_p*\omega^2*r^2*sin(\alpha)*cos(\theta)^2\right]/cos(\alpha)^2$
  - References:
Simulation Validation

- Comparison with GT-SUITE – flow rate & pressure

Different pump speeds
(100% Disp, 80°C Oil, and 2500KPa $P_{outlet}$)

Different pump displacements
(1800RPM, 80°C Oil, and 2500KPa $P_{outlet}$)
Simulation Validation

- Comparison with GT-SUITE – flow rate & pressure (cont’d)

Different pump outlet pressures
(1800RPM, 80°C Oil, and 100% Disp)

Different oil temperatures
(1800RPM, 50% Disp, and 2500KPa $P_{\text{outlet}}$)
Simulation Validation

• Correlation with performance test data – efficiency

Volumetric efficiency:
- leakage flow
- fluid compressibility
Simulation Validation

- Comparison with GT-SUITE – variable displacement

**Swashplate angle - torques:**
- upstroke/destroke actuators (spring force & pressure forces)
- pump pistons (support forces & inertia forces)

**Outlet pressure**

**Volumetric flow rate**

**Swashplate angle**

**Total piston torque**
Simulation Validation

• Validation by cold start data – pump torque

Forces (Torque & Power):
- input torque force
- inertial force
- spring force
- pressure force
- friction force
- viscous force
Summary

• Simulation process development
  – The simulation process demonstrates promising modeling capabilities with a high accuracy for a variable displacement piston pump
  – GT-SUITE helps us to do model correlation/validation, and create a high confidence in our all-inclusive (any operating conditions & any performance data) simulation process

• Next steps
  – Work with test teams to expand the modeling process for load sensing control cases
  – Gear pump modeling development
Thank You

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