Low Fidelity [ Fast Running ] Lubrication system model development using GT-SUITE software

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**Event:**
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Agenda:

- Background
- Introduction to Lubrication system model (HF Model)
- Approach of modeling Lube system FRM (LF Model)
- Lube system High Fidelity vs Fast Running Models
- Current Status
- Summary / Conclusion
- Way-forward
Acronym:

- Lube system: Engine Lubrication system
- HF: High Fidelity Model
- LF: Low Fidelity Model
- FRM: Fast Running Model
- PSJ: Piston Spray Jet
- JDPS: John Deere Power System
- PA: Performance Analysis
Typically, the lube system models that are developed are **High Fidelity** due to the need for capturing the flow dynamics of the lubrication system.

Due to the computational demands of the **High Fidelity** models, they run very slowly. [Simulation speed 5000 X times the real time].

The purpose of developing **Low Fidelity [ Fast Running ]** model of the lubrication system is to have a model where pulse dynamics is not as important but is needed to predict key elements of the overall system behavior accurately with fast computational times.

Low Fidelity lube system models will be linked with other engine sub-system models and hence various heat loads on lube system can be modeled.
Introduction to the lubrication system model:

- Steady state models can be used to predict pressure, flow rate and temperature distribution throughout the oil circuit (i.e. ensuring adequate flow to bearings).

- All major components of a lubrication system can be modeled in GT-SUITE including predictive models for bearings, heat exchangers, piston cooling jets, cam phasers, and relief valves.

- Transient runs can be performed to predict system priming (filling), thermal warm-up, and integration with cooling system models.

Reference: GT-SUITE Documents
Existing HF Lube system model:

- Pressure Pump Out pipe
- Pressure Main Oil Gallery pipe
- PRV Oscillation in Engine cycle (Pressure Relief Valve)
- HF Model calibration results

References:
GT-SUITE Documents
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Approach for modeling the Lube system FRM:

- Baseline HF Model
- Generate Mean Value Bearing (MVB) Maps
- GT Model simplification to run with Implicit solver
- Oil Pump and Other mechanical component simplification
- Modeling the engine oil pan (oil reservoir) and its heat loss
- Linking the Engine and Cooling system model
- Input Speed and Torque profile
- GT Model results comparison against the test data

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# Lube system HF vs LF/FRM:

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Criteria</th>
<th>Lube system HF Model</th>
<th>Lube system LF / FRM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Flow paths inclusion</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Oil Cooler model</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Solver</td>
<td>Explicit</td>
<td>Implicit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[ Calculation in CA domain ]</td>
<td>[ Calculation in time domain ]</td>
</tr>
<tr>
<td>4</td>
<td>Capturing the wave dynamics</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>Bearings modeling</td>
<td>Detailed</td>
<td>Simplified</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>[ Map Based ]</td>
</tr>
<tr>
<td>6</td>
<td>Bearing forces</td>
<td>Detailed</td>
<td>Simplified</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>[ Map Based ]</td>
</tr>
<tr>
<td>7</td>
<td>PRV and other valves modeling</td>
<td>Detailed</td>
<td>Simplified</td>
</tr>
<tr>
<td></td>
<td>[ Pressure Regulating Valve ]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Engine operating conditions</td>
<td>Full load, Speed sweep</td>
<td>Variable load, Speed sweep</td>
</tr>
<tr>
<td>9</td>
<td>Run time / Simulation time</td>
<td>5000 X Real Time</td>
<td>1 X - 10 X Real time</td>
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<tr>
<td>10</td>
<td>Oil conditions to oil pump</td>
<td>Imposed (Constant)</td>
<td>Determined during the simulation</td>
</tr>
<tr>
<td>11</td>
<td>Model suitable to run long transient cycle simulations</td>
<td>No</td>
<td>Yes</td>
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<tr>
<td>12</td>
<td>Capturing Lube system thermal loads</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>13</td>
<td>Predict the oil pan (oil) temperature at end of run</td>
<td>No</td>
<td>Yes*</td>
</tr>
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</table>
Salient features of developed Lube system FRM:

- Load dependent MVB Maps
- Imposed bearing / Journal speed
- Oil pump model simplification for G-rotor, Gear Pump and VDOP to simplified oil pump
- Modeling of Oil Pan (Oil Reservoir) and its heat loss
- Lube system FRM linked with Engine Cycle, Engine Cooling and other sub-system models.
- Input data speed and torque profile
- Close loop model all the oil paths are connected back to oil reservoir
- Added calculation for Oil Pump heat load addition
Integration of GT-SUITE Sub-System Models:

- Results from Cooling system model
- Block and head Temp
- Valve train to Oil heat transfer
- Engine Bearings
- MVB Maps
- Cylinder to Oil heat Transfer
- Piston to Oil heat Transfer
- Lube System Fast Running Model
- Oil Pump heat addition
- Calculation
- Turbo charger heat load
- Engine Cycle simulation model
- Oil Cooler Heat Rejection
- Oil Pan to Ambient heat rejection

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Integration of GT-SUITE Sub-System Models:

Engine Cycle Simulation
- Engine operating condition
- Engine to lube system heat load
- Data for generating MVB Maps

Valve Train System
- Data for generating MVB Maps

Heat Transfer between the Engine and Cooling system model

Engine Cooling System
- Oil flow information

Lubrication System HF Model
- 1) Engine Cooling system to Lube system heat transfer
- 1) Model with MVB Maps
- 2) Oil Pump heat addition

Lubrication System Fast Running Model

Gear Train System
- Data for generating MVB Maps
GT Sub-system model accuracy:

### Engine Cycle simulation model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% Error wrt Lab Data</th>
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<tr>
<td>Engine Speed</td>
<td>0.00</td>
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<tr>
<td>Torque</td>
<td>-0.34</td>
</tr>
<tr>
<td>Power</td>
<td>-0.34</td>
</tr>
<tr>
<td>BSFC</td>
<td>0.54</td>
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<tr>
<td>NOx ppm</td>
<td>-5.50</td>
</tr>
<tr>
<td>PeakCylP</td>
<td>-1.66</td>
</tr>
<tr>
<td>AFR</td>
<td>-3.73</td>
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<tr>
<td>EGR%</td>
<td>0.04</td>
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<tr>
<td>GIMEP</td>
<td>-0.34</td>
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<tr>
<td>ExhT</td>
<td>-0.86</td>
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<tr>
<td>Exh Port 1</td>
<td>1.55</td>
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<tr>
<td>Coolant HR</td>
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<tr>
<td>Head T</td>
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<tr>
<td>Piston T</td>
<td>-0.47</td>
</tr>
<tr>
<td>Liner T</td>
<td>2.19</td>
</tr>
</tbody>
</table>

### Cooling System Model

#### Piston to Oil Heat Rejection

- Coolant Model Results
- Engine Model Results

### Lube system HF Vs LF / FRM

- MB Flow
- Rocker Bearing Power
- MB Friction Power
- Idler Bearing flow
- LEB Flow
- MG Pressure
- LEB Friction Power
- Rocker arm Gallery pressure
- Cam B Flow
- BPV Leakage flow
- Cam B Power
- Idler Bearing Power
- Turbo oil flow
- Pump out pressure
- Pump flow
- PRV leakage flow
- PSJ Flow
- Idler Bearing flow
Lube system Fast Running Model results vs test data: Full load and part load condition

- Lube system Fast Running Model is ran 300 sec duration for each operating point and GT model parameters are compared against the test data.
Summary / conclusion:

- Developing the Lube system LF models is new capability development activity for JDPS Performance Analysis (JDPS-PA) group.

- Creating the lower fidelity models will help to simulate overall system behavior quickly without much sacrifice on model accuracy.

- Will be useful while doing the Lube system co-simulations because of faster computational speed.

- Developed Lube system FRM runs 1.12 X Real time [So to simulate 300 sec actual test cycle this model will take 336 sec of CPU computational time].

- The Bearing friction heat loss for the Fast Running model and lube system HF model matches closely.

- This model captures the engine load variations (Engine Torque and Speed) and predicted the oil temperatures accurately for full load and as well as low load engine operating conditions.
Way forward:

Fast Running model future usage:

- Model integration with Engine model, Cooling system model.
- Predict change in Oil temperature at the end of engine run.
- The prediction of power loss from different consumers in an engine oil circuit.
- Thermal warmup of a lubrication circuit, with the engine block initially at low temperature to simulate cold start.
Thank You !!