Creation and Validation of a High-Accuracy, Real-Time-Capable Mean-Value GT-POWER Model

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Outline

• Introduction
• Mean Value Model Approach
• Model Validation
• Brief Model Studies
• Summary/Conclusions
• Future Work
Introduction

• Objective
  – Create and Validate a High-Accuracy, Real-Time-Capable Mean-Value engine model in GT-POWER
  – Model must be capable of simulating next-generation Diesel engine air-handling and fuel systems
Motivation

- **Real Time**
  - Requirement to run in a HIL system

- **High Accuracy**
  - Most parameters within 1% of Detailed Model
  - Enables more accurate controls calibration
  - Permits very quick engine hardware or calibration studies

- **In GT-POWER**
  - Share modeling environment and some parts with detailed models
  - No need for external modeling tools
Mean Value Approach Overview

- Lumped flow component volumes to permit larger time steps
- Mean-value cylinder model
  - One object replaces multiple cylinders
  - Empirical parameters instead of crank-angle resolved models
- Neural Networks
  - In-cylinder processes trained to detailed model using DOE
  - Results Imposed onto Mean Value model
  - Maps used for Indicated Efficiency, Volumetric Efficiency, Exhaust Energy Fraction
Neural Network Training

• Detailed Model Training DOE Setup
  – D-Optimal Latin Hypercube, 2000 points
  – 7 Input Factors: Engine Speed, Fueling Rate, Boost Pressure, Back Pressure, Intake Manifold Temperature, EGR Valve Opening
  – Wide Factor Ranges to accommodate extremes of engine operation

• Neural Network Models
  – Much improved results from new 3-layer Feed-Forward Model – eliminates need for external model calibration tools
300-point independent data set shown for model validation
Mean Value Modeling Approach

- RTCoolerConn objects used for Heat Exchangers
  - Easier to calibrate restriction and heat transfer
- Mapped Calibration Parameters
  - Enables accurate air system response across engine operating regime
    - Restrictions
    - Heat transfer
    - Turbo operation
  - Most results very close to detailed model
Mean Value Model

Inline 6-cylinder DI engine with 2-stage Turbocharging
Very good agreement at Steady-State
13-Mode Point Calibration
21 seconds of HD FTP Cycle

Mean Value Cylinder cannot handle motoring torque

Very good transient agreement is achieved for positive torque
21 seconds of HD FTP Cycle

- Sensor Boost Pressure
- Sensor Back Pressure
- HP Turbo Average Speed
- LP Turbo Average Speed
- Exhaust Manifold Temperature
- Intake Manifold Temperature
Model Execution Speed

- Mean Value Model used 5 CAD maximum time step
- Single-processor 3.2 GHz standard desktop PC
- Other applications open simultaneously
- Faster execution would be possible by increasing time step, disabling in-cylinder pressure prediction, and reducing flowsplit expansion diameters

<table>
<thead>
<tr>
<th>Run Time Statistics</th>
<th>Execution/Clock time Ratio</th>
<th>MV/Detailed Execution Speed</th>
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<tbody>
<tr>
<td><strong>21-second portion of US HD FTP Emissions Cycle</strong></td>
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<tr>
<td>Simulation Environment Elapsed Time</td>
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<tr>
<td>Detailed GT-Power Model</td>
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<td>Mean Value Model in GT-Suite (w/ RLT variables and display windows)</td>
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<td>29.9</td>
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<td>Mean Value Model in GT-Suite (w/o RLT variables or display windows)</td>
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<td>Mean Value Model in GTsuite RT</td>
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<td><strong>1200-second US HD FTP Emissions Cycle</strong></td>
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<td>Mean Value Model in GT-Suite (w/ RLT variables and display windows)</td>
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<tr>
<td>Mean Value Model in GT-Suite (w/ RLT variables but w/o display windows)</td>
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</table>
This study ran in 1 hour 34 minutes using the Detailed Model
This study ran in under 3 minutes using the Mean Value Model
Summary/Conclusions

- A High-Accuracy, Real-Time-Capable Mean-Value engine model has been created and validated in GT-POWER
- The model is capable of simulating next-generation Diesel engine air-handling and fuel systems
- Very good agreement with detailed model has been achieved at steady-state and over brief transient excursions
- The main limitation is the inability to simulate motoring torque
- The high accuracy of the model also permits very quick engine hardware or calibration studies
- A model calibration methodology is now in place to replicate real-time modeling capability for other engines
Future Work

• Improvements Needed
  – GT-POWER Version 6.2 Build 6 Mean Value Cylinder cannot handle motoring (negative) torque
  – New Mean Value Cylinder object in Build 7 should address this problem

• Future Capabilities
  – Real-Time in-cylinder combustion and emissions models
  – Real-Time Aftertreatment models
  – Automated Model Creation and Calibration