Predict Engine Performance over the Product Duty Cycle to Determine the Right Engine for the Market

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Background

- Determine the right fit for market product meeting emission regulations.

- Can an existing Cummins engine meet the requirements?
- Do we need to develop a new engine?
- How can we leverage analysis tools to make the decision?
Engine Displacement Assessment

Technical Profile Requirements

Initial assessment: Key Performance Evaluation of Multiple Engine Displacements Using Detailed GT-POWER model

bsfc vs bsNOx

PCP vs bsNOx

Select Top Options

Engine Option 1

Engine Option 2

Detailed Analysis for Engine Displacement Assessment
Detailed Analysis Approach for Assessment of Engine Options

Multi-step process involving DGM and FRM is repeated for each engine option selected during initial assessment.
Detailed Analysis Approach for Assessment of Engine Options

Multi-step process involving DGM and FRM is repeated for each engine option selected during initial assessment.
Air Handling Optimization

Black Box turbocharger approach was used to determine the turbocharger requirements.

- Torque vs. Speed
- Engine Torque Curve
- Black box Turbocharger simulation results
- Turbocharger options
- Evaluate options in GT-POWER
- Turbocharger for Engine Option 1
- Turbocharger for Engine Option 2
- Optimum air handling system for each displacement.
Detailed Analysis Approach for Assessment of Engine Options

Multi-step process involving DGM and FRM is repeated for each engine option selected during initial assessment.
ECU Calibration Table Development

Objective: Develop Electronic Control Unit (ECU) Calibration table for engine displacement options using detailed GT-POWER Model

- Create Test plan to develop Calibration table
- Run the Test plan in GT-POWER to generate data.
- Use in-house optimization tool to develop ECU calibration table.
- Meet the Engine mechanical constraints.
- Meet ECU calibration table development constraints.
ECU Calibration Table Development

- Start of Injection Calibration Table
- Rail Pressure Calibration Table

Predict Performance Across the Torque Speed Space

ECU Calibration Tables Developed Using GT-POWER Model
Detailed Analysis Approach for Assessment of Engine Options

Multi-step process involving DGM and FRM is repeated for each engine option selected during initial assessment.
Determine Aftertreatment Thermal Management Strategy

Determine Thermal management strategy to meet aftertreatment inlet temperature requirements.

Run a Design of Experiments (DOE) for thermal management strategy for lower loads.

Develop calibration table for thermal management strategy

Run the FRM with the optimized thermal management strategy in transient emission duty cycle regulations.

Increase in aftertreatment inlet temperature in transient emission cycles

Key points

- Increase in exhaust temperature

- Aftertreatment inlet temperature (without thermal management strategy)
- Aftertreatment inlet temperature (with thermal management strategy)

Turbine outlet temperature predictions from calibration tables developed

Increase in aftertreatment inlet temperature in transient emission cycles

Temperature

Time

Torque (Nm)

Speed (RPM)

Turbine outlet Temp

Increase in exhaust temperature
Detailed Analysis Approach for Assessment of Engine Options

Engine Options

Evaluate torque curves, emission target range, air fuel ratio requirement

Optimize Air Handling System

Develop ECU Calibration Tables

Steady State Simulation

Detailed GT-POWER Model (DGM)

Determine Aftertreatment Thermal Management Strategy

Predict Duty Cycle Performance

Fast Running Model (FRM)

Transient Simulation

Evaluate strategies with respect to transient

Fuel Economy Estimates for Each Engine Option

Multi-step process involving DGM and FRM is repeated for each engine option selected during initial assessment.
Fuel Economy Predictions Over Duty Cycle

- **GT-POWER based Calibration table predictions**
- **Control logic**
- **Driving Cycles**
- **Driver Sensitivity**
- **ECU Control Models**
- **Transmission Models**
- **Electrification**

**Challenge**: Understand role of thermal inertia of components during aftertreatment thermal management strategy.
Fuel Economy Predictions Over Duty Cycle

Replicate the actual drive cycle using FRM with inputs coming from developed ECU calibration tables.

Enabled to understand time spent in different regions of thermal management.

Best Engine Option Selected

Duty Cycle Fuel Economy Predictions

Fuel penalty across engine torque speed space.
Summary – Process to Determine Best Engine Fit for Market

1. **Steady State Simulations**
   - Narrow down options based on key performance parameters.

2. **Transient Simulations**
   - Determine the optimum thermal management strategy for different engine options in transient cycle.

3. **FRM Model with ECU tables**
   - Select optimum turbocharger for engine displacement options for AFR and minimum BSFC targets.
   - Simulate vehicle duty cycle to predict fuel economy over actual duty cycle.

4. **Generate ECU Calibration tables for engine displacement options.**

5. **Decision making based on vehicle level fuel economy**
Conclusions

▪ A detailed simulation approach was developed to evaluate performance difference due to displacement change over the entire torque speed space.

▪ A detailed GT-POWER model was used to develop ECU calibration tables in an early phase of the engine program as a cost effective way to predict engine performance across the engine operating range.

▪ Use of Fast Running Models enables to predict engine behavior over real world duty cycle to predict fuel consumption benefit to customer.

▪ The detailed analysis approach that was developed enabled the team to determine the best engine fit for the market requirements using analysis tools.
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