Generating Optimal Engine Calibrations Using Model-Based Calibration Toolbox

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Main Takeaways

- Maximize Product Performance With Modeling and Optimization in Model-Based Calibration Toolbox

- Models From Data Can Be Put In Simulink for HIL

- Model-Based Calibration Toolbox Is a Very General Tool

- We Make It Possible For Regular Engineers to Routinely Do Statistical Models and Design of Experiments

- MathWorks Consulting Can Help You In Your First Application
  - Model-Based Calibration JumpStart 2-Day Service For CI Diesel
  - Model-Based Calibration JumpStart 2-Day Service For SI Gasoline
Topics

- **Green** Economy Marketplace Drivers
- Response to Marketplace Drivers
- Model-Based Calibration Process Overview
- Example CI and SI Engine Calibration Problems
- Customer Application Examples
- Live Demonstration of Optimal CI Engine Calibration
Marketplace Drivers

The **Green** Economy Dictates Stringent Performance, Emissions, and Fuel Economy Requirements:

- Engineers Respond by Adding Many Engine Actuators
- Engineering Resources are Scarce and Expensive
Response to Marketplace Drivers

The Green Economy Dictates Stringent Performance, Emissions, and Fuel Economy Requirements:

- Engineers Respond by Adding Many Engine Actuators
  - Increased Understanding via Accurate Statistical Models
  - Make Numerical Calibration Optimization Accessible

- Engineering Resources are Scarce and Expensive
  - Design of Experiments Tools To Reduce Testing
  - Off-Shelf Software, Promoting Core Business Focus
  - Facilitate Systematic, Repeatable Process
Model-Based Calibration Process Overview

Systematic Calibration Process Execution with Empirical Model-Based Calibration

- Reduced testing over 70% and improved fuel economy over 5% for some customers

Design of Experiments
- Model-Based Calibration Toolbox

Data Modeling
- High-Fidelity Engine Model
- Simulation using analytical engine models and distributed computing tools

Calibration Generation
- Model-Based Calibration Toolbox

Results
- Accurate Engine Model for:
  - Hardware-in-the-Loop
  - Performance and Fuel Economy Study
  - Estimator

Upfront Calibration Process Development with Analytical Model-Based Calibration

The MathWorks
Accelerating the pace of engineering and science
Types Of Models You Can Make

- High Degree-of-Freedom Accurate Steady-State Models For Use in Suitable Transient Applications (e.g. Engine Base Cal)

- High Degree-of-Freedom Accurate Models of Transient Response Characteristics (e.g. Catalyst Light-Off Time)

- Key High Degree-of-Freedom Steady-State Submodels as Part of Larger Dynamic Model (e.g. Powertrain Fuel Economy sim)
Example CI Engine Calibration Problem

- Test Configuration

VGT Position → Brake Torque
EGR Position → Engine Out NO
Main SOI → Exhaust AFR
Pilot SOI → Turbo. Speed
Pilot Mass → Peak Pressure
Fuel Pressure → EGR Fraction

RPM → Total Fuel Mass/Inj
Example CI Engine Calibration Problem

- Optimization Problem Setup

Minimize mode-weighted brake specific fuel consumption, subject to multiple mode-based output constraints.
Example CI Engine Calibration Problem

- Optimal Calibration Results

MAIN SOI Table
MAIN Fuel Table
EGR Mass Fraction Table
Fuel Pressure Table
VGT Rack Position Table
Example SI Engine Calibration Problem

- **Test Configuration**

  - Intake VCP
  - Exhaust VCP
  - Spark Advance
  - RPM
  - AFR
  - Intake Valve Lift
  - VGT Vane Fraction
  - Load Command
  - AFR Command

  **Closed-Loop Load Controller**

  **Temperature-Limited AFR and Spark Control**

  - Brake Torque
  - Turbocharger Speed
  - Intake Manifold Pressure
  - Exhaust Temperature
  - Load
Example SI Engine Calibration Problem

- Optimization Problem Setup: Stoich. Region

Maximize Torque subject to exhaust temperature, turbocharger speed, and user-specified AFR Constraints
Example SI Engine Calibration Problem

- Optimal Calibration Results

Spark Advance
Intake Cam Advance
Exhaust Cam Retard
Air-Fuel Ratio
VGT Open Fraction
Intake Valve Lift
Re-Use Models From MBC in System-Level Simulation and HIL
Customer Application Examples: Ford

Key Point:
- Process to develop optimal multi-inject diesel calibration using Model-Based Calibration

Calibration Process Steps

- Identify designed experiment (DoE) operating points
  - Select load axis
  - Cascade vehicle drive cycles to engine operating points
  - Select speed/load (S/L) break points for DoE
  - Calculate weighting factors for each S/L for each drive cycle
- Determine DoE factors, bounds, and resolution
  - Identify factors to be varied
  - Collect ranges for each factor at each S/L
  - Build DoE runs based on desired model complexity
- Collect and prepare data for MBC
- Build multimodels for engine responses with boundary models
- Optimize calibration
  - Independent S/L optimization
  - Cycle-based optimization
- Export calibration and verify engine responses

Customer Application Examples: Toyota

Key Points:
- Full-Factorial Testing No Longer Feasible for optimal results
- Model-Based Calibration Process Required and Developed

Customer Application Examples: FAW China

Key Points:

- Emerging Market
- Adopting MBC From the Beginning
- SI V12 Single Intake Phaser Calibration Example
Customer Application Examples: John Deere

Benefits

- **Performance optimization given application constraints**
  - 1-3% improvement in application specific fuel consumption compared to conventional techniques

- **Reduction of needed testing and associated expense**
  - Measured in hundreds of thousands of dollars compared to conventional techniques

- **Control of constraint usage to minimize errors**
  - Example – peak firing pressure or exhaust temperature
  - Consistent reliability performance across applications

- **Calibration methodology is controlled**
  - NTE compliance
  - Similar performance output of engine across applications

From: “Analytical Engine Calibration at John Deere” Jason Schneider, John Deere Power System, 2007 SAE COMVEC Panel on Analytical Calibration

Industry Record, Nebraska Test 2005:
Most Fuel Efficient Row-Crop Tractor

- **8430 Series Tractor / 9.0L PowerTech Plus**
  - 8.8% more fuel efficient with 40% less emissions
  - Engine optimization
  - Vehicle efficiency improvement
Customer Application Examples: GM Holden

Key Points:
- Significant reduction in test points compared with ‘one parameter at a time’ or factorial test methods
- Model re-use: MBC models are engine test-bed simulator

Re-Cap

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