MoBEO: Model based Engine Development and Calibration

Innovative ways to increase calibration quality within the limits of acceptable development effort!

Dr. Prakash Gnanam, AVL Powertrain UK Ltd

FPC 2015
Outline

- Challenges
- AVL Approach
- MoBEO: Model Overview
- Model Accuracy
- Application Environment
- Use Cases
Powertrain Development Challenges

- CO2 / Fuel Consumption
- Real Driving Emissions
- Broad Vehicle Portfolio

- Increased system complexity (EAS, OBD, Hybridization)
- Reduction of development costs
- Reduction of development time
- Keep quality standards
AVL APPROACH
Diesel Calibration Methodology and Tools for a more efficient calibration

- Measuring
- Post Processing
- Validation

Extension to the Virtual Environments

MOBEO Methodology

Advanced Test Automation

Advanced Post Processing

Quality Management

Planning / Monitoring

Dataset Management

Test Field Host

Vehicle Data

Test Environments
MOBEO

Model overview
Changing Calibration Paradigm

Overview

• Model based development using a **real time capable engine model**

• Starting from **concept** phase until **SOP** calibration

• Engine model based on semi-physical modeling approach
  
  → **empirical model components derived from AVL experience and test bed data**

  → **physical components increase the range of application due to better extrapolation**

• **Easy usability** due to the use of suitable simulation environments

> Increasing system robustness within given development duration and budget by transferring development from real to virtual testing
DoE and Beyond
The evolution of the methodology approach
## Definitions - Model Accuracy Levels

<table>
<thead>
<tr>
<th>Maturity Level</th>
<th>Description</th>
<th>Use Cases</th>
</tr>
</thead>
</table>
| Level 1        | Only the main geometrical data of the engine are used as input for model set-up |  - Concept study and decision  
                  - ECU algorithm design  
                  - Exhaust gas aftertreatment (EAS) concept |
| Level 2        | Measurement data is used to make a refinement of the model to increase accuracy. |  - Pre-Calibration: the possible calibration tasks depends on focus of the model parameterization  
                  - Used for specific calibration tasks |
| Level 3        | Model is adapted to steady state and transient data, measured at AVL. Highest accuracy which is needed for model based calibration. |  - Variant calibration support  
                  - Ambient correction calibration (altitude/hot/cold)  
                  - EAS calibration strategy  
                  - OBD calibration support  
                  - Robustness investigations  
                  - ECU algorithm verification |
Development Process

Consequent usage of real-time system simulation

- Concept / Layout
- Component and system development
- Endurance testing
- Calibration / Validation

Consequent usage of real-time system simulation

AVL data base, measurements of single components
Data engine test bed
Data vehicle testing

Start of Production

Model quality

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Model Based Development
Modelling Approach

Virtual

Basic model setup
MoBEO

Refined model setup
MoBEO

Semi-physical
Basic Model without measurement data

Empirical static global
HC, CO, Soot, SPL.....
Cameo M&M

Combined model
Increased number of engine specific outputs

Model refinement

Pre-calibration

Testbed results

DoE Test Results

First engine Run
Puma / Cameo T&M

Base engine testbed development
Puma / Cameo T&M

DoE Measurements
Puma / Cameo T&M

Environmental validation

Emission validation

Model-based calibration of various variants
Variant specific hardware change
(e.g. intake piping, ...)
(No combustion HW change)

Robustness analysis

Real

Extension to the Virtual Environments
Advanced Test Automation
Post-Processing

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Model accuracy
MOBEO – Model Based Development

ACCURACY IN DIFFERENT CYCLES

NEDC

<table>
<thead>
<tr>
<th>NOx cum. [%]</th>
<th>CO2 cum. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Chassis Dyno</td>
<td>100</td>
</tr>
<tr>
<td>MoBEO Simulation</td>
<td>106,2</td>
</tr>
</tbody>
</table>

uran 1

extra urban

urban 1

extra urban

NEDC

engine torque [Nm]

engine speed [rpm]

extra urban

urban 1

NEDC

time [s]

Temp. us. TC [°C]

NOx [g/h]

CO2 [kg/h]
MOBEO – Model Based Development

ACCURACY IN DIFFERENT CYCLES

<table>
<thead>
<tr>
<th>WLTC</th>
<th>NOx cum. [%]</th>
<th>CO2 cum. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Chassis Dyno</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>MoBEO Simulation</td>
<td>93.3</td>
<td>96.1</td>
</tr>
</tbody>
</table>

- Engine speed [rpm]
- Engine torque [Nm]
- Temp. us. TC [°C]
- NOx [g/h]
- CO2 [kg/h]
### MOBEO – Model Based Development

#### ACCURACY IN DIFFERENT CYCLES

<table>
<thead>
<tr>
<th>engine speed [rpm]</th>
<th>engine torque [Nm]</th>
<th>time [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>50</td>
<td>400</td>
</tr>
<tr>
<td>1500</td>
<td>100</td>
<td>800</td>
</tr>
<tr>
<td>2000</td>
<td>150</td>
<td>1200</td>
</tr>
<tr>
<td>2500</td>
<td>200</td>
<td>1600</td>
</tr>
<tr>
<td>3000</td>
<td>250</td>
<td>2000</td>
</tr>
</tbody>
</table>

**ARTEMIS gesamt**

<table>
<thead>
<tr>
<th>NOx cum. [%]</th>
<th>CO2 cum. [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Chassis Dyno</td>
<td>100</td>
</tr>
<tr>
<td>MoBE Simulation</td>
<td>104.5</td>
</tr>
</tbody>
</table>

**ARTEMIS gesamt** (Charts)

- **Engine Speed [rpm]**
- **Engine Torque [Nm]**
- **Time [s]**
- **NOx [g/h]**
- **CO2 [kg/h]**
- **Temp. us TC [°C]**

**Graphs showing measurements and simulations vs time [s]**
MOBEO - Model Based Development
Model Accuracy – Commercial Vehicle

Typical deviations of the cycle emissions and fuel consumption as well as achievable temperature accuracy:

- Fuel Consumption < 3%
- NOx Emission < 10%
- Insoluble Particulate Emission < 10%
- Temperature Intake Side < 10°C
- Temperature Exhaust Side < 20°C
MOBEO

Application environment
Changing Calibration Paradigm
The right application environment at the right time

Model in the Loop (MiL)

Advantages
- Simulation faster than real time (app. 5 to 10 times faster)
- No hardware parts needed
- Simulation on normal PC possible

Disadvantages
- Availability of software ECU
- Often not all ECU functionalities available

Hardware in the Loop (HiL)

Advantages
- All ECU functions available
- Pre-Calibration of all ECU functions possible
- Possibility of ECU software and dataset validation

Disadvantages
- Only real time simulation possible
- Need of hardware in the loop test bed

→ Both environments can be used for pre-calibration of specific tasks
WORK ENVIRONMENTS - XIL-STATION

HiL Cabinet, including AVL Load-Drawer + HIL Base System (e.g. dSPACE, ETAS) with RTPC and I/O boards

Operator Station, including 4 x 24inch Monitors

PUMA Testbed Workstation

CAMEO Workstation

HiL Host PC including, HiL Operator Software and ECU Application Software

PUMA
CAMEO
HIL SW
INCA

WORK ENVIRONMENTS - XIL-STATION
Sil System integrating Mobeo

AVL Mobeo Engine Model

Transient Cycle from the Testbed
Sil System integrating Mobeo

ECU Parameters

- : Engine model output
- - : Measurement
Sil System integrating Mobeo

- Reduction of the Demand EGR rate
- Increase of the NOx Emissions

- -- : Engine model output
- - - : Measurement
Sil System integrating Mobeo

Reduction of the ambient pressure (from 1000 to 700 mbar) → Increase of the exhaust gas temperature

- : Engine model output
- - : Measurement
Generic Mobeo – SIL Environment

Import Model
→
Import Calibration Data
→
Run Simulation

- Manual Changes
- Cycle Definition
- Ambient Conditions
- Output Folder

Import
- MoBEO Model
- ECU Software

Calibration
- Cycle Simulation
- Run Simulation

Results Graphics
- Results Summary
- Results Statistics
- Results Group Statistics

Operation progress
- Simulation starten
  - Run 4%
  - Simulation time: 63 seconds
  - Elapsed time: 8 sec
  - Estimated remaining time: 2 min 52 sec

5-10x real time!!
MOBEO

Use Cases
Model Based Development
Concept Investigations

Model based concept investigations

- Assessment of technology route
- Simulation of transient behaviour of engine in early concept phase on MiL environment
- Definition of possible concepts considering the interaction between
  - engine
  - exhaust after-treatment system
  - software and calibration
  - Sensors and actuators
  - environmental conditions

Vehicle & drivetrain simulation
Powertrain Calibration tasks for MiL/HiL:

- RDE – Real Driving Emission evaluation
- EAS Simulation
- Calibration for non-standard ambient conditions
- Calibration of component protection
- In-Use Compliance - PEMS
- Sensitivity studies taking into account system interactions
- OBD – Diagnoses, IUPR
- Software and dataset validation
Model Based Development Calibration of Ambient Corrections

Simulation of full load altitude operation for validation of ambient correction and engine protection functions

970mbar = 350m (Graz)
750mbar = 2500m
660mbar = 3500m
540mbar = 5000m

Limits for component protection
Model Based Development
Calibration of Component Protection Functions

Simulation of engine failure at full load for validation of engine protection functions

Limits for component protection
Borders of applicability for HiL test bed

- Final Calibration Validation
- Certification
- Durability testing
- Pre-calibration of Start and Cold Start
- Idle stability
- Missfire
Changing Calibration Paradigm: Innovative ways to increase xCU calibration quality

AVL model based development methodology is the consequent usage of real-time system simulation from concept to SOP on suitable development environments with smart calibration tools
Thank you for your attention