Model Based Testing of Automotive Control Functions

Real Time
Virtual
Verification
Automotive
Validation
Calibration
Hardware
Quality
Closed-Loop

MBD
Legacy
Frontloading
Software
Code-generation
Concept
Variants
Feedback

System Under Test
Simulation
Variant
System-in-the-Loop
Simulation

Model Coverage
Experiments
Variables
Parameter
Constant

Plant Model
Software-in-the-Loop

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Model Based Testing of Automotive Control Function

Agenda

1. Need for Model Based Testing
2. Conventional Vs MBD Approach
3. Test Environment Description
4. Testing of SUT using MBD Approach
5. System Simulation using Plant Model
6. Results
7. Benefits
8. Summary
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Need for Model Based Testing

1. Increasing Engine Control Complexity
   - Function Complexity increasing → Challenges in maintaining quality
   - Increase in number of calibration → More calibration effort
   - Increase number of ECU → Increased inter domain connectivity

Source: ETAS

New Functions & Variants

Increased inter domain connectivity
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Conventional Vs MBD Approach

Conventional Approach

MBD Approach

System Analysis
Function Model
Source Code
Unit Testing
Func validation

Prototyping through H/W
Function Design
Code generation
Compile/Link
Testing

System Analysis
Concept Eval
PC Environment
Lab Environment

Concept Control Model
Overall Control Model
Control Model
Control Model

Plant Model
Plant Model
Plant Model
Plant Model

ViL
Vehicle
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Closed Loop Test Environment Set-up

Software & Model in Loop

CONTROL MODEL

SUT (System Under Test)

*.dll from legacy code

New Function Model (ML/SL)

Scheduler (DGS Lib)

PLANT MODEL

Intake

Engine

Drive Train

Vehicle

Test Output Verification
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Testing of SUT (System Under Test) using MBD Approach
# Model Based Testing of Automotive Control Function

## Test Case Description

- Engine is in neutral gear
  - Check the engine behaviors with open drive train (neutral gear) without consumer

<table>
<thead>
<tr>
<th>S.No</th>
<th>Test Case Description</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><strong>Unit Testing of Low Idle Speed Governor</strong></td>
<td>• Engine speed settles around the idle speed</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low Idle governor working with speed deviation of around -50 to 50 RPM</td>
</tr>
<tr>
<td>2.</td>
<td><strong>Engine in the Neutral Gear</strong></td>
<td>Engine Speed settles @ Idle Speed</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Engine is in First Gear</strong></td>
<td>Engine speed increase during gear change from neutral → First</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Engine speed settles to idle speed when gear change from first → zero.</td>
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</tbody>
</table>
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Idle Speed Control – Test Results

Inference:
- Mass flow isn’t sufficient to achieve the desired idle speed.
- Therefore, stepper configuration and by-pass valve dimensions need to be calibrated.
Next Step

1) Study of Engine behavior using simulation
   - Throttle & Ignition Sweep for different Engine Speed (800 – 2000 rpm)
     - Based on load variation to determine air mass flow through ISA

2) Component Dimensioning
   Based on air mass flow – Area & Dia. of ISA to be fixed
MSE work package: Model based Testing

Idle Speed Actuator - Component Sizing

**Torque @ Varying throttle and Fixed Speed**

Considering 0.5-1 Nm load variation from electrical loads (magneto) ideal low idle speed could be above 1400 rpm.

**Air Mass flow @ Varying Throttle and Fixed Speed**

Based on the load variation of 0.5 – 1Nm, mass flow of 1.25 Kg/hr through ISA is required.

Torque → Air Mass Flow → Area of By Pass Valve
Component Dimensioning

By pass Valve

<table>
<thead>
<tr>
<th></th>
<th>Old By-Pass Valve</th>
<th>New By-Pass Valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>2.8 mm</td>
<td>3.98 mm</td>
</tr>
</tbody>
</table>

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Stepper motor for low-idle control
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New By-pass Vs Old By-pass valve - Results

- Graph 1: Stepper Area [cm²] vs Stepper Motor Steps [-]
  - Old Stepper
  - New Stepper

- Graph 2: Engine Speed [rpm] vs Time [s]
  - Engine Speed [rpm]
  - Set Point Engine Speed [rpm]

- Graph 3: Engine Speed [rpm] vs Time [s]
  - Engine Speed [rpm]
  - Set Point Engine Speed [rpm]
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Pre-Calibration
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Pre-calibration

Graph 1: Engine Speed Vs Set Point Engine Speed
- Deviation: -100 to 100 rpm

Graph 2: Engine Speed Vs Set Point Engine Speed
- Deviation: -50 to 50 rpm
Benefit of Model Based Development

- Efficiency increase including development cost reduction
- Early evaluation of control models and new control strategies $\rightarrow$ frontloading
- Reduce effort for validation of control models $\rightarrow$ speed-up
  - Do more in virtual environment
  - Reduce dependence on dyno testing
- System Level:
  - Concept evaluation before “make” decision
  - Investigate system behavior/function at early stage
  - Simulate extreme/rare environment conditions, safe experiments
  - Reusing plant models developed for other series project.
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Benefit of Model Based Development

- **ECU-SW Level:**
  - Easier debugging/reproducing of problems on PC
  - No reprogramming/flashing after every change in the functionality
  - Reuse ECU data
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Summary

➔ Desktop PC Simulation of implemented SW-functions together with the available plant models allows a very early pre-calibration of these functions and optimally supports the front-loading process in the area of ECU-SW verification and validation.

➔ The accuracy of the models is sufficient for concept evaluation w/o measurement data and can be improved with measurement results to use it for calibration tasks.

➔ Finally to deploy the virtual environment requires software as well as system knowledge.
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thank you!