NEW APPROACH FOR ENGINE CONTROL SYSTEM SOFTWARE DEVELOPMENT

6th CIMAC CASCADES 2015
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AGENDA

1. Engine control software development: Concept
2. Engine control software development over time
3. New approach: Model based development
   a. Model based development: phases
   b. Model based development: advantages
   c. Model based development: example
4. Conclusions
ENGINE CONTROL SOFTWARE DEVELOPMENT -CONCEPT

- Software to control the complete powertrain system
  - Includes: sensors and actuators needed for control strategies
- Typical control systems for large engines:
  - ✓ Rotational engine speed control
  - ✓ Rail pressure control
  - ✓ Boost pressure control
  - ✓ Monitoring and diagnosis
  - ✓ Emissions optimization
  - ✓ Consumption optimization
Typical example for a large engine: **rotational engine speed control**

- A lever sets an engine speed set point
- The Engine Control Unit (ECU) functionality shall keep the engine speed constant to the demand value
**ENGINE CONTROL SOFTWARE DEVELOPMENT OVER TIME**

Mayor software improvements over time allowing for: shorter development time, reduce costs and increased quality

1. No test of requirements
2. Manual code generation

- Very time consuming
- Poor overview
- Need software experts

1. Open loop test
2. Graphical model overview

- Need software experts 😞
Engine Control Software Development Over Time

3

Open loop test

Auto code generation

• Open loop test ✓
• Graphical overview ✓
• Fast code generation. Code generated without errors ✓

4

Auto code generation

• Closed loop test ✓
• Graphical overview ✓
• Fast code generation. Code generated without errors ✓
NEW APPROACH: MODEL BASED DEVELOPMENT

Working flow:

1. Development of software functions using a graphical programming language (e.g. Simulink) according to the customer requirements

2. Test the software functions in Simulink using a virtual engine model (closed loop test)

3. Generate C code and flash it into the ECU

4. Verification of software functions at engine test bench (closed loop test)
NEW APPROACH: MODEL BASED DEVELOPMENT

- Detailed engine model: Crank angle resolution for cylinder and gas path
- Innovative, numerically-optimized approach and advanced solver technology allows real-time capability
- Multiple applications of real-time engine models in the software development process
MODEL BASED DEVELOPMENT: PHASES

Model-in-the-Loop (MiL)
- ECU concept
- Functions and ECU development

Hardware-in-the-Loop (HiL)
- ECU development
- Pre-calibration, Monitoring, OBD
- Hardware-Tests

Engine test bench
- Verification
- Refinement
MODEL BASED DEVELOPMENT: PHASES

Model-in-the-Loop (MiL)
- ECU concept
- Functions and ECU development

- Entire Simulink environment
- Development of functions
- Virtual engine model interface available for Simulink
- Closed loop test using virtual engine models

Motor model
State of the Art:
No model or very simple model (mean model, map)

AVL-Proposal:
Physical Model (Cylinder and air path in CRK angle resolution)
MODEL BASED DEVELOPMENT: PHASES

Hardware-in-the-Loop (HiL)

- ECU development
- Pre-calibration, Monitoring, OBD
- Hardware-Tests

ECU

Simulink

Computer for data analysis

Real time PC ~ Virtual engine

Actuators

Wiring harness

Lever
MODEL BASED DEVELOPMENT: ADVANTAGES

- Higher maturity of engine control achieved earlier in the development
- No risk of engine-component damage in MiL & HiL environment
- Pre-calibration and validation of control functionality are developed in MiL & HiL environment
- Model based software development saves time and money and improves quality of the software
MODEL BASED DEVELOPMENT: EXAMPLE

- Motor type (~ 1 MW per Cyl.)
  Bore > 300 mm
- Dual Fuel (Diesel, Gas)
- One stage turbo with wastegate
- Motor bypass and compressor bypass valve developed for fine $\lambda$-control
- Variable valve timing
- Generator operation, ship propulsion
MODEL BASED DEVELOPMENT: EXAMPLE

Building the model

Software development

Closed loop test (HiL)

Fuel supply (Gas & Diesel)

Brake, external load

Cylinder & Motor (Wall heat transfer, combustion characteristics, valve lift, flow characteristics, moment of inertia...)

Variable valve timing

Air path (incl. Wastegate, Compressor-Bypass and Motor-Bypass)

Charging & Intercooling

Fuel supply

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MODEL BASED DEVELOPMENT: EXAMPLE

Building the model

Software development

Closed loop test (HiL)

ECS Control Functionality

- Engine speed set point
- Boost pressure set point
- Lambda set point
- Operating point

Speed Controller

- Fuel mass

Boost Pressure Controller

- Waste gate
- Bypass valve

P_{Boost} Demand

Plant Model

- Engine speed
- Lambda
- Boost pressure

Operating point

Demand

Engine

Boost

Lambda

Waste gate

Bypass valve

HiL
MODEL BASED DEVELOPMENT: EXAMPLE

Building the model
Software development

Closed loop test (HiL)

Load is constant (100%)

Engine speed [rpm]
Fuel quantity [g/stk]

Zeit [s]
MODEL BASED DEVELOPMENT: EXAMPLE

Building the model  |  Software development  |  Closed loop test (HiL)

Load is constant (100%)

- Boost pressure
  - Actual value
  - Setpoint

- Lambda
  - Setpoint

- Wg position

Last is constant (100%).

Building the model
Software development
Closed loop test (HiL)
CONCLUSIONS

- Model based software development **saves time and money** and **improves software quality**
- **Innovative, physical real-time engine models** (simulation in crank angle resolution, 0D gas dynamics) allow the observation of various motor phenomena that can not be considered with mean value models
THANK YOU

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