Optimization of a 3-Cylinder CNG Engine within a Hybrid Powertrain

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Outline

Project Description

Project Description; Engine Data

GT Power Engine Model X10XE

FKFS User Cylinder – GTIse Interaction; Model Calibration;

Model Validation; HP-EGR Variation; Phlegmatic Engine

GT Drive Hybrid Modell X10XE

Control Strategy; Shift of Operating Points; SoC during Drive Cycles;

Transmission/FD Variation
Project Description
Project Description

Project Aims

• Mild-HEV based on an Opel Astra Caravan (total mass: 1500 kg)

• CO₂ emissions < 90 g/km performing the NEDC

• Accomplishing future emission standards (Euro 5): NOₓ emissions

Realization:

• Application of a small volume, highly charged ICE (X10XE)

• Fuel: CNG (monovalent)

• Hybrid (Start/Stop, Recuperation, … etc.)
Engine Data

<table>
<thead>
<tr>
<th>Engine Data:</th>
<th>Unit:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Family 0 (1. Gen.)</td>
</tr>
<tr>
<td>Number of Cylinders</td>
<td>3</td>
</tr>
<tr>
<td>Displacement</td>
<td>973 cm³</td>
</tr>
<tr>
<td>Compression Ratio (\varepsilon)*</td>
<td>1:10.6 (TD)</td>
</tr>
<tr>
<td>Connecting Rod length*</td>
<td>132.5 mm</td>
</tr>
<tr>
<td>Stroke*</td>
<td>78.6 mm</td>
</tr>
<tr>
<td>Bore</td>
<td>72.5 mm</td>
</tr>
<tr>
<td>Number of Valves</td>
<td>4 (IV: 2; EV: 2)</td>
</tr>
<tr>
<td>Rated Power*</td>
<td>71 kW (5500 rpm)</td>
</tr>
<tr>
<td>Rated Torque*</td>
<td>160 Nm (2000 - 4000 rpm)</td>
</tr>
<tr>
<td>Rated Engine Speed*</td>
<td>5500 rpm</td>
</tr>
<tr>
<td>Injection Valve</td>
<td>NGI 2 (Bosch)</td>
</tr>
<tr>
<td>ECU*</td>
<td>ME 1.5.5</td>
</tr>
</tbody>
</table>

* modified in comparison to series engine
GT Power Engine Model X10XE
FKFS User Cylinder – GTise Interaction

Starting Conditions:
- Residuals
- Cylinder Pressure
- Mass Mean Temperature
- A/F-Ratio
- Engine Speed

Parameter:
- Spark Timing
- Spark Plug Pos.
- Fuel
- Port-/Direct-Injection
- Engine Turbulence Level

FKFS User Cylinder

Quasidimensional Combustion Model:
- Entrainment
- Combustion Chamber
- Flame Propagation
- Turbulence

Wall Heat Transfer:
- Bargende
- Woschni-Huber

Knock Model:
- Worret

Cylinder Pressure

Burn Rate
Model Calibration: Cyl. Pressure and Burn Rate

Engine:
Typ: X10XE
Cylinder: 3
Displacement: 997cm³
Comp. Ratio: 1:10.6

Operation Point:
Cylinder No.: 1
Engine Speed: 4000 rpm
IMEP: 10 bar
50 % D. P.: 8 ° C A
A/F-Ratio: 1
EGR: 0 %
Model Calibration: Intake- and Exhaust Pressure

Engine:
Typ: X10XE
Cylinder: 3
Displacement: 997 cm³
Comp. Ratio: 1:10.6

Operation Point:
Cylinder No.: 1
Engine Speed: 4000 rpm
IMEP: 10 bar
50 % D. P.: 8 ° C A
A/F-Ratio: 1
EGR: 0 %
Model Validation: Spark Timing

**Engine:**
- Type: X10XE
- Cylinder: 3
- Displacement: 997 cm³
- Comp. Ratio: 1:10.6

**Operation Point:**
- Cylinder No.: 1
- Engine Speed: 2000 rpm
- IMEP: 5 bar
- A/F-Ratio: 1
- EGR: 0%

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PTA
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Quasidim.

**Graphs:**
- Top graph: Pressure vs. Crank Angle for 50% D.P. with different crank angles (01° CA to 25° CA).
- Bottom graph: Burn Rate vs. Crank Angle for 50% D.P. with different crank angles (01° CA to 25° CA).
**HP-EGR Variation**

![Graph of Efficiency vs. EGR Rate]

- **Efficiency [%]**
  - Range: 34.5 to 37.0
  - Points: 0, 5, 10, 15, 20, 25

- **EGR Rate [%]**
  - Range: 0 to 25

**Engine:**
- **Type:** X10XE
- **Cylinder:** 3
- **Displacement:** 997 cm³
- **Comp. Ratio:** 1:10.6

**Operation Point:**
- **Cylinder No.:** 1
- **Engine Speed:** 2000 rpm
- **IMEP:** 5 bar
- **A/F-Ratio:** 1
- **50 % D. P.:** 8 °C A
**Phlegmatic Engine: Theory**

- OP of high TPR can be shifted to lower (wider turbine neck square area)
  - Lower exhaust gas back pressure
  - Better cylinder filling due to reduced internal EGR
  - Higher engine efficiency (reduced PMEP)

- Worse transient behavior of the engine can be compensated by e-motor
Phlegmatic Engine: Turbine/Compressor Variation

- Engine efficiency can be raised up to 3 Percent

![Diagram showing performance metrics]
GT Drive Hybrid Model
Control Strategy (modified ECMS)

\[ V_{\text{REQ}} \rightarrow \text{Driver} \rightarrow T \rightarrow \text{Simulink} \rightarrow \text{Energy Broker} \]

\[ V_{\text{ACT}} \rightarrow \text{Torque Split} \]

\[ T_{\text{ICE}} \rightarrow \text{ICE Control} \]

\[ T_{\text{EM}} \rightarrow \text{EM Control} \]

\[ \text{BMEP} \rightarrow \text{Engine State} \]

\[ \text{Accel. Pos.} \rightarrow \text{Motor/Generator} \]

\[ \text{SoC} \]

\[ T \text{ Torque} \]

\[ u \text{ Torque Split Factor} \]

\[ s \text{ Energy Equivalent} \]

\[ I \text{ Current} \]

\[ \text{SoC State of Charge} \]

Folie 15
Shift of Operating Points (Non-HEV vs. HEV)

Part load OP's are shifted within the HEV Compound to higher loads

Better specific fuel consumption (torque used for generator)

- Engine Speed [1/min]
- Engine Torque [Nm]
- X10XE Basic CNG Engine
- X10XE HEV ECMS
SoC during Drive Cycles

- Multiple drive cycles are possible
- Initial SoC is met to avoid penalization

**NEDC**

| Emissions: 85.1 g\textsubscript{CO}_2/km |
| Δ SoC: 0.001% |

**FTP 75**

| Emissions: 89.8 g\textsubscript{CO}_2/km |
| Δ SoC: 0.001% |
Transmission/Final Drive Variation

- Gearbox WR-ECO/ER using 2 overdrive gears
  - Minimal CO$_2$/NO$_x$ emissions using economical gear boxes
- FD ratio increases from FD1 to FD5
  - Minimal CO$_2$: FD1 / Minimal NO$_x$: FD2
Thank you for your kind attention.