1-D Cycle Simulation

exemplified as a helpful Tool within the
Scope of Truck Engine Development
Overview

1D Cycle Simulation exemplified as a helpful Tool within the Scope of Truck Engine Development

- General Aspects of Cycle Simulation
- Capability of Calculating the Combustion Process
- Post-Calculation of a Euro-3 Engine
- Pre-Calculation of Concepts for Euro-4
Post-Calculation of a Euro-3 Engine: Pumping Loop

Comparison of measured (——) and calculated (⋯⋯) results

1800 rpm, 100 % Load

Graph showing comparison of measured and calculated results for a Euro-3 engine at 1800 rpm and 100% load. The graph illustrates the pressure (pabs bar) over crank angle (degree).
Injection Jet, divided in many zones

- Jet Breakup
- Air Entrainment
- Droplet Evaporation
- Ignition and Combustion

Temperature distribution

Distribution of nitric oxides

Combustion Calculation: Jet Model based on Hiroyasu
Variation of Injection Timing

(Data of Simulation and Testing)

- speed: 1500 rpm
- mep: 9,1 bar
- pRail: 734 bar
Variation of Injection Timing: Fuel Consumption vs NOx at 1500 rpm

(speed: 1500 rpm
mep: 9,1 bar
pRail: 734 bar)
Variation of Injection Timing: bsfc/NOx-Trade-Off at 1200 and 1800 rpm

(Simulation/Testing)

- Speed: 1800 rpm
- mep: 16.4 bar
- pRail: 1040 bar

- Speed: 1200 rpm
- mep: 18.1 bar
- pRail: 640 bar
Variation of Injection Timing: Maximum Cylinder Pressure vs NOx

(simulation/testing)

- Speed: 1500 rpm
- MEP: 9.1 bar
- pRail: 734 bar
Variation of Rail Pressure:
NOx Emission and Fuel Consumption

(speed: 1500 rpm  
mep: 18.2 bar  
EB: 11° b.TDC)

Simulation/Testing
Variation of EGR-Rate
NOx Concentration

(Simulation/Testing)

speed: 1100 rpm
mep: 23,6 bar
pRail: 1650 bar
GT-Power-Model of a Euro-3-Engine with High-Pressure-Loop EGR („A“)
Post-Calculation of a Euro-3 Engine: Maximum Cylinder Pressure

(Simulation/Testing)

Points 1-4
1800 rpm

Points 5 - 8
1500 rpm

Points 9 - 12
1200 rpm

(each 25%, 50%, 75% and 100% Duty)
Post-Calculation of a Euro-3 Engine:
Break Specific Fuel Consumption

(Simulation/Testing)

Points 1-4
1800 rpm

Points 5 - 8
1500 rpm

Points 9 - 12
1200 rpm
(each 25%, 50%, 75 %
and 100% Duty)
Post-Calculation of a Euro-3 Engine: NOx concentration

(Simulation/Testing)

Points 1-4
1800 rpm

Points 5 - 8
1500 rpm

Points 9 - 12
1200 rpm
(each 25%, 50%, 75 % and 100% Duty)
# Cycle Results of the Euro-3-Engine

<table>
<thead>
<tr>
<th></th>
<th>Tested</th>
<th>Calculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx-Emission</td>
<td>4.87</td>
<td>4.80</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>202.0</td>
<td>201.3</td>
</tr>
</tbody>
</table>

each g/kW-h
Boundary Conditions of the Concept Study

Limits:

- \( a/f \geq 23.2 \) at 1800 and 1500 rpm
- \( a/f \geq 20.3 \) at 1200 rpm
- \( p_{\text{max}} < 200 \) bar
- \( T_{\text{vTur}} < 700^\circ \text{C} \)
- Coolers with usual pressure drops
- PM-KAT: approx. 100 hPa
- target NOx-Emission: 3.20 g/kWh
Compressor Map of a Euro-4 Engine
One-Stage Turbocharged

ESC-Operation Points, EGR-Rates about 13%
Euro-4-Engine with High-Pressure-Loop EGR and two-stage turbocharging („B“)
Euro-4-Engine with Low-Pressure-Loop EGR and two-stage turbocharging („C“)
Euro-4-Engine with Mean-Pressure-Loop EGR and two-stage turbocharging („D“)
Compressor Maps of High- and Low-Pressure Stage of Variant C2

LPL-EGR without EGR-Cooler
EGR-Rates of all Variants

A: HPL 1stage
B1: HPL 2stage, Intercooler, EGR-Cooler
B2: like B1, but twin-entry, w/o Intercooler
B3: like B2, but single-entry
C1: LPL with EGR-Cooler
C2: LPL w/o EGR-Cooler
C3: LPL with Filter
D1: MPL with EGR-Cooler
D2: MPL with Filter
Cycle Fuel Consumptions

A: HPL 1stage
B1: HPL 2stage, Intercooler, EGR-Cooler
B2: like B1, but twin-entry, w/o Intercooler
B3: w/o Intercooler, but single-entry
C1: LPL with EGR-Cooler
C2: LPL w/o EGR-Cooler
C3: LPL like C2, with Filter
D1: MPL with EGR-Cooler
D2: MPL with Filter
Thank you for your Attention!

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