INTRODUCTION TO NEAR TERM TECHNOLOGIES FOR LD DIESEL EFFICIENCY

prepared for:
2014 CRC Advanced Fuel and Engine Efficiency Workshop

February 25th 2014
H. Nanjundaswamy\textsuperscript{b)}, B. Holderbaum\textsuperscript{a)}, T. Körfer\textsuperscript{a)}, H. Pieta\textsuperscript{a)}, M. Scassa\textsuperscript{c)}, J. Schaub\textsuperscript{d)}, T. Schnorbus\textsuperscript{a)}, R Van Sickle\textsuperscript{b)}, D. Tomazic\textsuperscript{b)}

\textsuperscript{a)}FEV GmbH, \textsuperscript{b)}FEV Inc., \textsuperscript{c)}FEV Italia, \textsuperscript{d)}VKA
Agenda

- Introduction
- Control Concept
- Technology Approach
  - Base Engine-Out BSFC - NO_x Level
  - NO_x Aftertreatment Conversion Efficiencies
- Simulation of Complete System for Global Optimization
- Outlook and Summary

LEV III/Tier 3 Emission Standards

- NOx+NMOG (g/mile)
- PM phase in (3 mg/mile)

Fuel Economy

Fuel economy limits 2017 – 2025

≈ 8 l/100 km
A Challenging Framework for Highly Fuel-Efficient Diesel Engines
Modern Diesel Engine Design and Layout

Robust, Low Friction Design

• Tailored Peak Firing Pressure
  • < 200 bar for combustion; VCR protected
• Flow-Optimized 4-Valve Cyl. Head w/ VVT (modular functionality)
• Crankcase (AL/CGI) with minimized bore distortion
• Modular crank drive for various ratings
• Variable, adjustable accessories (water pump, oil pump, vacuum pump, alternator,…) *

High-Efficient, Low NOx Combustion

Refined Advanced Combustion Process with high EGR Tolerance

- Optimized Compression Ratio
  - 2-Mode Arrangement (14:1….17:1)
- Variable load-dependent Cyl. Swirl
- Highly-Refined FIE (≤ 2200 bar)
- Optimized Single-Stage TC up to 75 kW/l, dual-stage TC up to 90 kW/l

* electrified, if electrical board net is ≥ 48V
Significant Engine-Out Emissions Reduction to Meet SULEV

~ 70% reduction at engine-out location to maintain current AFT performance at ~ 150k miles

→ Definition of new engine-out targets necessary for best compromise between engine hardware enhancement and exhaust aftertreatment system.
Agenda

- Introduction
- Control Concept
- Technology Approach
  - Base Engine-Out BSFC - NOₓ Level
  - NOₓ Aftertreatment Conversion Efficiencies
- Simulation of Complete System for Global Optimization
- Outlook and Summary
Offsets between steady state and transient emissions and fuel consumption as observed for air mass based control concepts need an additional reduction of steady state emissions with drawbacks in fuel consumption.

→ Advanced emission based control concepts for increasingly complex engine hardware and tailored calibration measures are key points.
Layout of the NO\textsubscript{x} Emission Based Control Concept for Multiple EGR Paths

Rule based optimization of the use of each EGR line according to its reaction times and most fuel efficient use in steady state conditions.
Global Emission Management for Varying Aftertreatment Efficiencies
Agenda

- Introduction
- Control Concept
- Technology Approach
  - Base Engine-Out BSFC - NO\textsubscript{X} Level
  - NO\textsubscript{X} Aftertreatment Conversion Efficiencies
- Simulation of Complete System for Global Optimization
- Outlook and Summary
Boundary Conditions for the Definition of a Robust NO\textsubscript{x} Engine-Out Emission Level with Favorable Fuel Economy

BSFC / Required DeNO\textsubscript{x} Efficiency

- Robust NO\textsubscript{x} engine out level for maintaining tailpipe emission targets
- NO\textsubscript{x} tailpipe target
- Feasible DeNO\textsubscript{x} Efficiency (OBD requirements)
- Attainable NO\textsubscript{x} engine out level
- BSFC NO\textsubscript{x} Trade Off
- Required DeNO\textsubscript{x} Efficiency
Enhanced Combustion System Performance with Valve Train Variabilities

Internal EGR increases the compression temperature and reduces the cylinder charge for low load operation under highest EGR rates.

→ Significant reduction of engine-out HC and CO emissions, in combination with a 40 °C increase of the exhaust temperature with a fuel consumption drawback < 1 %.
Low Pressure EGR systems depict an efficient method to reduce engine out NO\textsubscript{X} emissions for medium and high load operation, which are gaining weight with increased overall gear ratios and the parallel trend for down-speeding to increase fuel economy.

LP EGR systems allow to increase the EGR rate with only minor density losses through multi-stage cooling and improve fuel consumption through reduced gas exchange losses in a wide range of operation.
Enhanced Combustion System Performance with Optimized HP LP EGR

**Significant reduction in NOX Emission.**

- **LP EGR** offers Higher EGR %, Improved distribution, Low thermal footprint
- **HP EGR** offers Faster response time, High capacity
- **HP-LP EGR** with cooling management: Offers the best of both worlds

**At the same time PM level is also reduced.**
Agenda

- Introduction
- Control Concept
- Technology Approach
  - Base Engine-Out BSFC - NO_x Level
  - NO_x Aftertreatment Conversion Efficiencies
- Simulation of Complete System for Global Optimization
- Outlook and Summary
Potential Exhaust Aftertreatment Configurations for SULEV Complex Control and Aftertreatment Management Functions

<table>
<thead>
<tr>
<th>Layout</th>
<th>Size / Volume</th>
<th>Main Features</th>
</tr>
</thead>
</table>
| ![Diagram 1](image1.png) | **DOC**: 1.25l  
**SDPF**: 3l  
**SCR**: 4l | Close-coupled SDPF, innovative AdBlue® injection system with reduced mixing length, under-floor SCR as backup catalyst |
| ![Diagram 2](image2.png) | **LNT**: 1.25l  
**SDPF**: 4l  
**SC**: 1l | Close-coupled LNT and SDPF with reduced mixing length, SC eliminates HC and NH₃ breakthrough |
| ![Diagram 3](image3.png) | **LNT**: 1.25l  
**CDPF**: 3l  
**SCR**: 4l | Close-coupled LNT and CDPF, under-floor SDPF |

SC: Slip Catalyst
Simulated NO$_x$ and HC Emissions for DOC/SDPF/SCR and LNT/cDPF/SCR System

- Engine Out emissions [g/mi]
- Tailpipe emissions [mg/mi]

VVT 
- Engine Out emissions
  - DOC/SDPF/SCR: very high
  - LNT/SDPF/SCR: very high
  - LNT/cDPF/SCR: very high

T2B2 NOx Limit
T2B2 NMOG Limit
Impact of Aftertreatment Configuration on Fuel and AdBlue® Consumption

![Graph showing the impact of aftertreatment configuration on fuel and AdBlue consumption. The graph compares different configurations such as FC w/o DPF regeneration, FC w/ DPF regeneration, and AdBlue consumption. The configurations are categorized by VVT (very high) and include DOC/SDPF/SCR and LNT/SDPF/SC. The graph indicates a significant reduction in fuel consumption and AdBlue consumption with different configurations.]
Agenda

- Introduction
- Control Concept

- Technology Approach
  - Base Engine-Out BSFC - NO\textsubscript{X} Level
  - NO\textsubscript{X} Aftertreatment Conversion Efficiencies

- Simulation of Complete System for Global Optimization

- Outlook and Summary
Outlook and Summary

- In order to fulfill the upcoming LEV III and CAFE regulations a holistic optimization of engine and aftertreatment systems in conjunction with an upgraded engine management system is required.

- Engine-out thermal management with reduced THC slip is key to fulfill aftertreatment efficiencies and cold start emissions slip

- Optimized air management for improved process efficiencies is key for efficient combustion control

- The SCR based system (DOC/SDPF/SCR) together with VVT achieves the tailpipe emission target under ideal conditions, which is quite challenging to maintain over life time.

- The LNT/SCR combinations provide a good compromise between fuel consumption penalty and AdBlue® consumption with slight fuel consumption advantages for the LNT/CDPF/SCR due to the available CRT effect.