Research in motion
Diesel exhaust system aftertreatment modeling with the perspective on hybrid vehicle strategies

Dipl.-Ing. M. Sosio
Dr.-Ing. M. Grill
Dipl.-Ing. G. Hitzler
Prof. Dr.-Ing. M. Bargende

GT-User Conference - Frankfurt, 25.10.2010
Overview

- Introduction
- Diesel exhaust aftertreatment: state of art
- FKFS: test benches and simulations go together
  - Diesel oxidation catalyst: 1D GTI-Model
  - Diesel particle filter: 1D GTI-Model
  - Selective catalytic reduction: 1D GTI-Model
- Hybrid engine & exhaust aftertreatment
- Summary
Exhaust aftertreatment. Not a question anymore.

Worldwide stricter engine exhaust regulations

+ people’s spread awareness about health importance

= Simulation of exhaust aftertreatment imperative
Exhaust aftertreatment. Not a question anymore.

Technology made giant steps ahead in the last years:

from simple lambda probe and catalyst…

…to a complex DOC-DPF-SCR aftertreatment system.

IAV – Automotive Engineering
Diesel exhaust aftertreatment: complexity

Multiple elements are developed to eliminate the different combustion products, CO-HC, NOx and PM.

**Diesel Oxidation Catalyst (DOC)**

**Diesel Particle Filter (DPF)**

**Selective Catalytic Reduction catalyst (SCR)**

**Combustion efficiency improvement**
Diesel exhaust aftertreatment: complexity

The duality of PM and NOx inside the Diesel exhausts lead to a trade-off trend that produces different solution opportunities

Even the interaction among the multiple aftertreatment modules has to be investigated to reach the consumption and emission target.

Not only what, but mainly how.
Diesel exhaust aftertreatment: complexity

**Past**
- One engine
- One design
- Easier calibration

**Today & Future**
- Individual design & calibration of the exhaust aftertreatment for each engine, gearbox & vehicle combination
- The engine calibration strongly depends on the individual exhaust aftertreatment system

⇒ **Complexity increases significantly**

---

**Today & Future**
- One engine
- One design
- Multiple calibration
GT-Power: Simulation of supercharging methods

“Classical” duty of GT-Power

Classical single-stage
Maximum power set-up
Fast DOC light-off temperature

Alternative two-stage
Small turbo covering lower RPM
Fast response characteristic
Wider operating range
Slow DOC light-off temperature
FKFS activities covers the main subject areas, thanks to experience on:

Test bench analysis 1D/3D-CFD simulation
Diesel exhaust aftertreatment: 1D GTI-Model

**Diesel oxidation catalyst (DOC)**

- Temperature, pressure, mass flow and exhausts at DOC are measured at the test bench

- Measured geometrical characteristics are defined into the GT-Power surface
Diesel exhaust aftertreatment: 1D GTI-Model

**Diesel oxidation catalyst (DOC) – Light-off test**

- **Introduction**
- **State of art**
- **GT-Power**
- **FKFS know-how**
- **Exhaust analysis**
  - **DOC**
  - **DPF**
  - **SCR**
- **Hybrid strategies**
- **Conclusions**
Diesel exhaust aftertreatment: 1D GTI-Model

Diesel oxidation catalyst (DOC) – Light-off test

Introduction
State of art
GT-Power
FKFS know-how
Exhaust analysis
  DOC
  DPF
  SCR
Hybrid strategies
Conclusions
Diesel exhaust aftertreatment: 1D GTI-Model

Diesel oxidation catalyst (DOC) Light-off test

Measurements

Precious metal loading

Simulations

Different activation temperatures

Introduction
State of art
GT-Power
FKFS know-how
Exhaust analysis
  DOC
  DPF
  SCR
Hybrid strategies
Conclusions
Diesel exhaust aftertreatment: 1D GTI-Model

**Diesel particle filter (DPF)**

- Temperature, pressure, mass flow and exhausts at DPF are measured at the test bench

- Measured geometrical characteristics are defined into the GT-Power surface
Diesel exhaust aftertreatment: 1D GTI-Model

**Diesel particle filter (DPF) – Loading test**

- ECU Simulation
- Simulation GTI (33.9g)
- Weighted mass (33.7g)

**Graphical Representation**

- Deposited soot mass [g]
- Time [s]
- CRT-Effect
- Great influence of the activation temperature in the thermal layer

**Exhaust Wall Flow**

- Thermal layer
- Catalytic layer
- Substrate layer

**Sections**

- Introduction
- State of art
- GT-Power
- FKFS know-how
- Exhaust analysis
  - DOC
  - DPF
  - SCR
- Hybrid strategies
- Conclusions
Diesel exhaust aftertreatment: 1D GTI-Model

Diesel particle filter (DPF) – Passive regeneration

Introduction
State of art
GT-Power
FKFS know-how
Exhaust analysis
  DOC
  DPF
  SCR
Hybrid strategies
Conclusions
Diesel exhaust aftertreatment: 1D GTI-Model

Diesel particle filter (DPF) – Regeneration

Introduction
State of art
GT-Power
FKFS know-how
Exhaust analysis
   DOC
   DPF
   SCR
Hybrid strategies
Conclusions

- ECU Simulation (6,4g)
- Simulation GTI (4,6g)
- Weighted mass (4,6g)

Weighted mass
During the regeneration will drop to idle:
- Lower mass flow, but enough oxygen to burn soot
- Increasing DPF-temperatures - Up to cracking!
Selective catalytic reduction (SCR)

- Temperature, pressure, mass flow and exhausts at SCR are measured at the test bench

- Measured geometrical characteristics are reproduced in GT-Power
Hybrid Driving Strategies for SI-HEVs

Driving Strategies for SI-HEVs:

Shifting of operating points (boosting, electric driving, hybrid driving) ➔ minimizing fuel consumptions
Absolutely important to consider the emissions and the exhaust aftertreatment (e.g. CAT warm-up) in the "cost function" of the ECMS driving strategy.
Hybrid Driving Strategies for Diesel-HEVs

New complexity and new possibilities

- It is necessary to include emission penalty function in the driving strategy, e.g. depending on additional fuel consumption for DPF regeneration
- It is possible to avoid active DPF regeneration with post injections and increased fuel consumption
  - using passive DPF regeneration with CRT-Effect
  - shifting operating points to high loads (hybrid drive, loading of the battery)
    - high exhaust temperature and DPF regeneration without post injections
  - reducing engine out raw emission (e.g. acceleration)
    - active regeneration less frequently necessary
- Driving strategy for fast DOC Light-off (hybrid drive at high loads)
Hybrid Driving Strategies for Diesel-HEVs

New complexity and new possibilities

With special driving strategies it might be possible to save parts of the exhaust aftertreatment system

Example: replacing SCR thanks to Diesel-HEV

Simulation of exhaust gas aftertreatment is essential for the assessment of different concepts
Conclusions

Simulation of Diesel exhaust aftertreatment: one must

- **1D-CFD Simulation** is the reliable tool to handle the massive study needed to improve engines quality.

- **Integrated modeling and simulation tool like** GT-SUITE is ideal for investigation of Diesel HEV
  
  - **GT-Power**: engine, turbocharging, gas-dynamics
  - **GT-Power**: exhaust aftertreatment
  - **GT-Drive**: HEV
Thank you for your kind attention!