EURO VI and US Tier 4 – a big challenge for all IC engine developers @ ASAM Open Technology Forum

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18.05.2011
Michael Mühlöger ASAM Open Technology Forum, May 2011

Why should it fly?
- We have a heterogeneous Tool Chain
- We need homogeneous Data

Common Requirement Management

Common Dataware, Modelware, Testware

Virtual World
- Office Simulation
- MIL/SIL Testing
- HIL Testing
- Battery TestBed Testing
- E-Motor TestBed Testing

Engine TestBed Testing

Real World
- AWD TestBed Testing
- Chassis Dyno TestBed Testing
- Road Testing

Consistent, comparable results

AVL OPEN DEVELOPMENT PLATFORM
OVERVIEW REQUIREMENTS

- EURO VI, US EPA Tier 4 – demanding emission limits, new components and test conditions
- EURO VI - PN measurement as proven, compact and industrial solution
- EURO VI - PN measurement in addition to PM requires smart integrative solutions
- Verification of NH$_3$ and NO$_2$ limits for EURO VI compliance
- EPA CFR Part 1065 compliance at PFD-PM measurement and filter handling / weighting
- EPA / EU HD In-Use Emission Testing
- Test bed automation to support new duty cycles at laboratory emission testing
US EPA HD-Diesel Engines – NRMM Application
Emission limits, components, test conditions

**Tier 3:** ISO 8178 C1 Test Cycle

**Interim Tier 4**

**Tier 4:** NRSC – 8 Mode Discrete or Ramped Mode test Cycle

**NO_x + NMHC / PM [g/kWh]**

**NO_x / NMHC / PM [g/kWh]**

**kW**

- **< 8**
  - 7.5 / 0.4
- **8 – 19**
  - 7.5 / 0.4
- **19 – 37**
  - 7.5 / 0.3
  - - 90% - 7.7 / 0.03
- **37 – 56**
  - Option 1: 4.7 / 0.03
  - Option 2: 4.0 / 0.3
  - - 92.5% - 1.97 / 0.019 / 0.04
- **56 – 75**
  - 4.7 / 0.4
  - - 95% - 1.79 / 0.19 / 0.02
- **75 – 130**
  - 4.0 / 0.3
  - 3.4 / 0.197 / 0.02
  - - 88% - 0.4 / 0.19 / 0.02
- **130 – 560**
  - 4.0 / 0.2
  - 2.0 / 0.1 / 0.01
  - - 80% - 0.4 / 0.19 / 0.02
- **> 560**
  - 6.4 / 0.2
  - 3.5 / 0.19 / 0.04
  - - 50% - 3.5 / 0.19 / 0.04

**Weighting 5/95%**

- **2008**
- **2009**
- **2010**
- **2011**
- **2012**
- **2013**
- **2014**
- **2015**
- **2016**
EU HD-Diesel Engines – OnRoad Application
Emission limits, components, test conditions

- **Euro III** ESC/ETC 2000
  - NO\textsubscript{x} \(5.0\) g/kWh
  - PM \(0.1/0.16\) g/kWh

- **Euro IV** ESC/ETC 2005
  - NO\textsubscript{x} \(3.5\) g/kWh
  - PM \(0.02/0.03\) g/kWh

- **Euro V** ESC/ETC 2008
  - NO\textsubscript{x} \(2.0\) g/kWh
  - PM \(0.02/0.03\) g/kWh

- **Euro VI** WHSC/WHTC 2013
  - NO\textsubscript{x} \(0.4/0.46\) g/kWh
  - PM (mass) \(0.01\) g/kWh
  - PN (number) \(8/6\) E11 #/kWh
  - NH\textsubscript{3}, NO\textsubscript{2}
  - On-board measurement

- ≤ EURO V: GVW > 3.5 ton
- EURO VI and later: Reference mass >2610 kg
PM / PN measurement w/wo CVS System
AVL product portfolio
PN measurement - APC 489
A proven, compact and industrial solution

Dilution Tunnel (CVS)

Dilution air in

C HEPA

Evaporation Tube

PND1
Particle number diluter 1

PND2
Particle number diluter 2

PNC: Particle Number Counter
Condensation Particle Counter (CPC) for particle counting

VPR: Volatile Particle Remover

Expansion Tube

Secondary Diluter (PND2)

AVL Primary Diluter PND1
Smart AVL solutions for combined PN- and PM measurement

ADD-ON SAMPLING
@ AVL PF-PSS
Smart Sampler (SPC) for AVL Particle Counter (APC)

Particle Counting with FF-PSS
AVL FF-Dilution PSSi60 combined with integrated AVL Particle Counter (APC)

- Compact solution
- No additional space needed in test cell for PM#
- Short sample line with min. losses
- Service-, operation friendly and safe solution (e.g. Butanol)

Feed-back of extracted flow up-stream of filter to minimize dilution error
Verification of NH\textsubscript{3} and NO\textsubscript{2} emission limits for EURO VI compliance

Ammonia (NH\textsubscript{3}) slip 10ppm

- Reduced from 25 to 10ppm
- NH\textsubscript{3} is now a Limit, before it was a technical requirement
- Specification for NH\textsubscript{3} measurement defines FTIR measurement principle (heated sampling)

Limit for maximum fraction of NO\textsubscript{2} within NO\textsubscript{x} emissions, or a NO\textsubscript{2} limit

Some engine concepts and exhaust after-treatment systems produce lower NO\textsubscript{x} (NO\textsubscript{x} = NO + NO\textsubscript{2}) emissions, while the fraction of NO\textsubscript{2} gets much higher. Air quality legislation and ambient air measurements are very much concerned about NO\textsubscript{2}. NO\textsubscript{2} limits will decrease 2010, some cities will get problems. Likely to be similar to fine particulate discussion in 2005.

Proposal that max. 45% of NO\textsubscript{x} is allowed to be NO\textsubscript{2}
EPA CFR Part 1065 compliant PFD-PSS(PM) and particulate filter handling / weighting

Allowance of PFD PM systems for both steady state and transient testing

Title 40: Protection of Environment
PART 1065—ENGINE-TESTING PROCEDURES
Subpart B—Equipment Specifications

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§ 1065.140 Dilution for gaseous and PM constituents.
(5) Partial-flow dilution (PFD). You may dilute a partial flow of raw or previously diluted exhaust before measuring emissions. Section 1065.240 describes PFD-related flow measurement instruments. PFD may consist of constant or varying dilution ratios as described in paragraphs (k)(2) and (3) of this section. An example of a constant dilution ratio PFD is a "secondary dilution PM" measurement system.

(1) Applicability. (i) You must use PFD to extract a proportional raw exhaust sample for any batch or continuous PM emission sampling over any transient duty cycle, any steady state duty cycle, or any ramped modal cycle.

AVL Smart Sampler fully approved for EPA compliant testing (development and certification)!

Particulate filter preparation and weighting

Fulfillment of EPA 1065 specified thermo-dynamic conditions at PF preparation and gravimetric mass determination

<table>
<thead>
<tr>
<th>Performance data</th>
<th>Unit</th>
<th>PSSi60 EPA (1065)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleanroom Class (working area)</td>
<td>ISO 14644-1 Fed. Standard</td>
<td>Class 6 Class 1000</td>
</tr>
<tr>
<td>Temperature set-point range</td>
<td>°C</td>
<td>21-25</td>
</tr>
<tr>
<td>Temperature stability</td>
<td>K</td>
<td>&lt; ±1</td>
</tr>
<tr>
<td>Humidity set-point range</td>
<td>g/kg</td>
<td>7.0 – 10.0</td>
</tr>
<tr>
<td>Humidity stability</td>
<td>% rh</td>
<td>&lt; ±3</td>
</tr>
</tbody>
</table>

PSSi60 Clean Work Bench
Heavy Duty In-Use Testing (HDIUT)
Emission verification at real operating conditions

- EPA / EU PEMS regulations requests vehicle manufacturers to report compliance to legal emission limits during real-world driving conditions
- Need of robust measurement modules and suitable mounting hardware for on-road and non-road testing

Solution: AVL M.O.V.E PEMS
Test bed automation to support of new duty cycles at laboratory emission testing

**World-harmonized cycles at EURO VI testing**

**Transient / Ramped testing at Tier 4 testing**

Off Cycle Emissions (OCE) - WNTE

- 9 modes for engines < 3000 rpm
- 12 modes for engines > 3000 rpm

WNTE emission limits shall apply at:
- all atm. pressures ≥ to 82.5 kPa
- all temperatures ≤ to T determined by equation at the specified atm. pressure:
  \[ T = -0.4514 \times (101.3 - p_b) + 311 \]
  
  \( T \) is the ambient air temperature, K
  
  \( p_b \) is the atmospheric pressure, kPa

AVL SW Suite / Engine Test Systems

AVL SW Suite

AVL SW SuiteAir

AVL ConsysAir

AVL SW Suite
SUMMARY

- For EURO VI emission dev. & cert. the PMP approved **AVL Particle Counter APC489** is capable to be flexibly used in smart combination with Full-Flow Dilution PM-PSS System (PSSi60) and Partial-Flow Dilution PM-PSS System (SPC472)

- Both the currently defined additional gaseous emission measurements **NH₃** and **NO₂** but also new upcoming components are covered by the **AVL iGeneration Emission Test System**

- **Allowance of AVL SPC472 for EPA 1065** for transient measurement application

- **AVL emission measurement instruments** (Gas, PM) do address both the laboratory and the mobile, in-vehicle test application

- **AVL Engine Test Systems** with **AVL Suite** are supporting EURO VI and EPA Tier 4 development and certification
Thank you very much for your attention