The continuous rise of Real Driving Emissions

November 2017, Markus Böck (HORIBA GmbH)
Agenda

1. Introduction
2. RDE for LDV in EU
3. RDE for HD in EU
4. RDE for HD in US
5. RDE for NRMM in EU
1. Introduction
### Introduction

PEMS are not new!

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
<th>Regulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEXA-1340AFM</td>
<td>Real world tests</td>
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<tr>
<td>MEXA-1440AFM</td>
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<td>OBS-1000</td>
<td>Real world tests and environmental modelling</td>
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<td>US / EU HDD, LDV regulation</td>
<td>CFR 1065 Subpart J</td>
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<td>OBS-ONE-PM</td>
<td>US HDD regulation</td>
<td>CFR 1065 Subpart J</td>
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<tr>
<td>OBS-ONE-PN</td>
<td>LDV regulation</td>
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<tr>
<td>MEXA-1360AFM</td>
<td>Real world tests</td>
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<table>
<thead>
<tr>
<th>Year</th>
<th>Equipment</th>
<th>Description</th>
<th>Regulation</th>
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<td>Real world tests</td>
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<tr>
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<tr>
<td>1982</td>
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<td>2005</td>
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<td>2013</td>
<td>MEXA-1360AFM</td>
<td>Real world tests</td>
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</tr>
</tbody>
</table>
Introduction

Application

Certification LDV and HDV
RDE LDV legislation (EU)
US HDV legislation CFR 1065 Subpart J
EU HDV legislation No 582 / 2011 (EU)
64 / 2012
2016 / 1718

In-Service Conformity (ISC)
Survey of exhaust gas values during use

Research and Development
Engine / vehicle calibration
Road to rig
Environmental research

NRMM
Non road mobile machinery
2.
RDE for LDV in EU
RDE-LDV Legislation

Four regulatory packages

1st Package
Development of basic technical test procedure w/o quantitative requirements

2nd Package
- Definition of not-to-exceed (NTE) emission limits for RDE testing
- Trip Dynamics
- Cumulative positive elevation gain

3rd Package
- PN PEMS testing
- Vehicle cold start
- Regeneration event
- RDE testing for hybrids
- CoC (certificate of Conformity)

4th Package
- In-use-conformity testing by OEMs and authority
- Surveillance testing by “third party”
### Implications of 1st Regulatory package

#### Boundary conditions and test procedure

<table>
<thead>
<tr>
<th><strong>Altitude</strong></th>
<th><strong>Road Trip Requirements</strong></th>
<th><strong>DPF Regeneration</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate : &lt; 700m</td>
<td>Time: 90 – 120 min</td>
<td>Test voided if regeneration occurs</td>
</tr>
<tr>
<td>Extended : 700 – 1300m</td>
<td>Road Type Contributions (% dist.)</td>
<td>Possibility to repeat</td>
</tr>
<tr>
<td>• Correction (1.6)</td>
<td>- Urban: 34 ± 10% (never &lt; 29%)</td>
<td>Should regeneration occurs in the test repetition, then pollutants emissions are valid measurements</td>
</tr>
<tr>
<td></td>
<td>- Rural: 33 ± 10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Motorway: 33 ± 10%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Etc…</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Temperature (*)</strong></th>
<th><strong>Fuel</strong></th>
<th><strong>Exhaust flow measurement</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderate : 0 to 30 °C</td>
<td>Market fuels</td>
<td>EFM must be used for TA</td>
</tr>
<tr>
<td>Extended : - 7 to 35 °C</td>
<td></td>
<td>ECU based exhaust flow can be used for other PEMS tests</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>NOx correction factor</strong></th>
<th><strong>Road Conditions</strong></th>
<th><strong>Road Speed</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not applicable</td>
<td>Daylight conditions</td>
<td>Urban &lt; 60 km/h</td>
</tr>
<tr>
<td></td>
<td>Only on paved road (not off road)</td>
<td>Rural 60 – 90 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Motorway &gt; 90 km/h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Max. speed &lt; 145 km/h (can be exceeded by up to 15 km/h for &lt; 3% of total duration of motorway driving)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Etc…</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Fuel</strong></th>
<th><strong>Cold start</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Market fuels</td>
<td>Must be recorded but excluded from data evaluation</td>
</tr>
</tbody>
</table>
Implications of 2\textsuperscript{nd} Regulatory package

Requirements introduced in two steps

\textbf{1\textsuperscript{st} step}

- From 1\textsuperscript{st} September 2017 for new models
- From 1\textsuperscript{st} September 2019 for new vehicles

Conformity Factor for NOx = 2.1

Vehicles will be allowed for exceeding the applicable NOx emissions limit (i.e. 80 mg/km for EU6) by 110%.

The aim is to give manufacturers time to gradually adapt to the new RDE rules.

\textbf{2\textsuperscript{nd} step}

- From 1\textsuperscript{st} January 2020 for new models
- From 1\textsuperscript{st} January 2021 for new vehicles

Conformity Factor for NOx = 1.0 + 0.5 Error Margin

Vehicles will be allowed for exceeding the applicable NOx emissions limit (i.e. 80 mg/km for EU6) by 50%.

This CF will be annually reviewed to take into consideration technical improvements to test equipment.
Implications of 3rd Regulatory package
PN-PEMS (Portable Emission Measurement System for Particle Number)

JRC RDE PN-PEMS program assessing performance of various PN-PEMS equipment
Phase I (2013): Feasibility study
Inter-laboratory correlation exercise – ILCE (2015)  (reports still to be issued soon …)

What is confirmed

- **Conformity Factor for PN = 1.0 + 0.5**
- From 1st September 2017 for new models
- From 1st September 2018 for new vehicles
Implications of 3rd Regulatory package

Vehicle Cold Start (*)

**Background**

As part of the 1st RDE package, cold start (*) emissions are recorded but excluded from data evaluation.

Reasons: No Vehicle conditioning requirements, poor repeatability, small share of the overall emissions

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**Revisions for Including Cold Start**

- Vehicle Conditioning (5.3)
  - Driven for > 30 min
  - 6 – 56 h at moderate or extended conditions
  - No harsh conditions
- Requirement to start the trip with urban part (6.2)
- Limited Idling (7.6)

**Approved**

- Cold start included in data evaluation
- Using a correction factor (1.6) if vehicle has been conditioned for >3 h in extended conditions
- Additional Warm Start test

(*) The cold start period covers the first 5 minutes after initial start of the combustion engine. If the coolant temperature can be reliably determined, the cold start period ends once the coolant has reached 343 K (70 °C) for the first time but no later than 5 min after initial engine start.
Implications of 3\textsuperscript{rd} Regulatory package

Periodically regenerating systems

What is confirmed

- All results will be corrected with the $K_i$ factors
- Possible results:
  - Vehicle below the limit → pass ✓
  - Vehicle above the limit → Check if regeneration occurred
  - If not → failed ✗
  - If yes → remove $K_i$ factor, if now below the limit → pass ✓
  - If yes → remove $K_i$ factor, but still above the limit → complete regeneration and repeat the test once
Implications of 3rd Regulatory package
Testing of Hybrids

(*) Moving Averaging Windows/ Standardize Power Frequency

Background
RDE data evaluation methods (MAW/SPF)\(^(*)\) verifies normality of test conditions with the assumption that CO\(_2\) is a reliable proxy of work/power

Approach is valid for conventional ICE vehicles but may not be applicable to hybrid vehicles yielding biased results

What is confirmed

- New appendix 7c for OVC-HEVs (Off-vehicle charging hybrid electric vehicles)
- Only OVC-HEVs are included
- Recommended to start in charge-sustaining mode
- Minimum use of the combustion engine in urban conditions
- Need to be reviewed to create a more complete method
4th Regulatory package

**In-use-conformity testing**
- To be done by OEM and Type Approval (TA) authority
- To assess durability of emission control systems over certain periods of use
- Similar philosophy as type I in-use-conformity laboratory testing

**Surveillance testing**
- Done by a “third party” e.g. NGO(s), authority not involved in initial TA
- Decisive for the effectiveness of RDE-LDV regulation requirement
- At Type Approval, this requirement is only demonstrated, not proven

« RDE-LDV regulation is based on the legal requirement that NTE emission limits are not exceeded for a whole variety of different PEMS trips »
Definition of window

a) Window = half of CO₂ total mass [g] emitted by the vehicle over WLTP cycle

b) Every 1 Hz a new window is build

\[ \frac{1}{2} \text{ CO₂ (WLTC)} [\text{g}] \]
3. RDE for HD in EU
**EU HD PEMS**

Already a long experience

<table>
<thead>
<tr>
<th>Regulation EC No</th>
<th>PEMS for EURO VI HD engine In-Service-Conformity</th>
<th>PEMS ISC test as part of the Type Approval</th>
<th>HD PN-PEMS program (2015) application date 1/9/2018?</th>
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<tbody>
<tr>
<td>582/2011</td>
<td></td>
<td></td>
<td>dropped</td>
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<tr>
<td>64/2012</td>
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<tr>
<td>2016/1718</td>
<td>Step D</td>
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<td></td>
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<td></td>
<td>1.9.2018 for new types</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.9.2019 for new vehicles</td>
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<td></td>
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</table>
EU HD PEMS
Main Changes in Step D

Low Power Vehicle Operation
- Reducing the % of engine power threshold down from 20% to 10%
- CF 90th percentile reporting retained

Influence of vehicle payload
- 10 – 100 % payload at the nomination of the Type Approval Authority
  (before 50-60%)

Minimum Sampling Duration
- 5xWTHC – 4-7xWHTC Work or CO2 reference.

Cold Start Emissions
- Still excluded from Validation, Start of measurement 70-30°C

Influence of the test route
- Urban -> Rural -> Motorway order mandated
EU HD PEMS
Aver. Real-world Nox emissions (g/km) for LD and HD diesel Veh. Euro 5/V and Euro 6/VI

- Euro 6 and Euro VI (2014)

- "Success" for HDDs from Euro V to Euro VI
- Euro 6 diesel cars more than 2 x Euro VI diesel trucks

Source: Rachel Muncie, Int. Council on Clean Transportation 6 Jan 2017
http://www.greencarcongress.com/2017/01/20170105-icct.html
4.

RDE for HD in US
HDIUT Regulation
Manufacturer-Run Heavy-Duty In-Use Testing (HDIUT) Overview

History
- The HDIUT program was established as a CARB and EPA joint regulatory effort
- Purpose: To assure that engines meet applicable emission standards throughout their useful life
- 2005-6 gaseous pilot years, manufacturers had to conduct testing and report data, but no enforcement
- 2007 first gaseous enforceable year and particle mass (PM) pilot

Details
- EPA/CARB annually select engine families and send test orders to manufacturers
- Manufacturers recruit trucks from existing customers
- PEMS installed on vehicles prior to planned operation
- Vehicles must be operated by customer provided drivers on regular routes
- Test validity: 3+ hours non-idle vehicle operation with PEMS fully functioning
- Evaluation method: NTE >90% pass ratio

General Reference: CARB Heavy-Duty In-Use Compliance/Testing/Not-to-Exceed Workgroup February 22, 2017 staff presentation
(https://www.arb.ca.gov/msprog/hdlownox/hdlownox.htm)
HDIUT Regulation

Explanation of NTE

NTE Boundaries (Zone)
- > 30% max power
- > 30% max torque
- > 15% European Stationary Cycle speed

Temperature Conditions
- > 250 degC exhaust temperature (if SCR)
- > minimum intake manifold or coolant temperatures

NTE Validity = minimum 30 consecutive seconds while in the NTE zone and meeting the temperature conditions

5.
RDE for NRMM in EU
13 April 2017: EU Stage V Regulation (EU) 2016/1628 for Non-Road Mobile Machinery (NRMM) engines were published in the Official Journal (OJ) – Came into force on 3rd May 2017. 2016/1628 is supplemented by:

- 2017/654: technical requirements ref emission limits and type-approval of NRMM engines
  - test methods relating to emission limits
  - EU type-approval procedures for internal combustion engines for NRMM
  - arrangements with regard to conformity of production
  - The requirements and procedures relating to technical services for those engines.

- 2017/655: monitoring of gaseous pollutant emissions from in-service engines installed in NRMM
  - arrangements with regards to the selection of engines
What Does NRMM Legislation Cover?

Overview
## EU Non Road Engines

### Emission Limits Stage V

**REGULATION (EU) 2016/1628 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 September 2016**

<table>
<thead>
<tr>
<th>Category</th>
<th>Ignition</th>
<th>Net Power</th>
<th>Date</th>
<th>CO</th>
<th>HC</th>
<th>NOx</th>
<th>PM</th>
<th>PN</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>kW</td>
<td></td>
<td>g/kWh</td>
<td>n/kWh</td>
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<td>0.19</td>
<td>3.50</td>
<td>0.045</td>
<td>-</td>
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**Categories for In Service Monitoring**
Issues for PEMS for NRMM

Packaging
Virtually no space in the operator cab area so external mounting on the vehicle is most likely
Use of enclosures that are rain/splash proof and also sealed against dust
**Anti-vibration** / shock mounting is necessary for off-road
(need to make preparatory evaluation of the In Service Monitoring application)

Lack of signals for engine power determination
Some NRMM category vehicles may not have the necessary ECU signals for the determination of engine power
So cannot calculate emissions on g/kW.hr base
Alternative expressions of specific exhaust emissions necessary
(g/kg fuel or g/kg CO2)

PEMS Operation
Vehicle operator cannot operate the PEMS system and the vehicle Remote control and monitoring using wireless communications with “chase” vehicles
Contact
Markus Böck
HORIBA GmbH
Kaplanstraße 5
3430 Tulln
Austria
E-mail: markus.boeck@horiba.com
web: http://www.horiba.com