HORIBA
Portable Emissions Measurement Systems (PEMS)

PEMS for Light Duty Vehicle Workshop
DAIMLER Stuttgart
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Introduction

- PEMS for Gaseous Measurements
  OBS-2200

- PEMS for PM Mass and Transient PM
  OBS-2000TRPM
Vacuum flow scheme to reduce power & size

- All components can be measured in wet condition
- All detector are semi-vacuum type (saving power & pump size, improving response time)

Explore the future
Dimension & Weight

Dimension: 350(W) X 330(H) X 500(D)

Weight: 29kg

Power consumption:
480W
Including 191 degC
5m sample line (after warm up)
Problems of WET Type Heated NDIR

Influences of H2O on NDIR measurement

Spectral Overlap
Spectral overlap of H2O spectrum and measured component spectrum

Molecular Interaction
Influence of H2O molecule on spectrum of measured components
**H2O interference of heated-NDIR**

- **H₂O interference at ZERO point**
  - Spectral overlap

Before compensation  After compensation

![Graph](image)
H2O interference of heated-NDIR

- H2O interference of CO detector at SPAN point

After compensation

Before compensation

After compensation

H2O coexisting effect (RS%)

H2O concentration (vol%)

Explore the future
H2O interference of heated-NDIR

- H2O interference of CO2 detector at SPAN point
  >>>molecular interaction

Before compensation  After compensation

![Graph showing H2O interference effect before and after compensation.](image)
Correlation with Lab Analyzer

- **CO**:
  - OBS-2200 CO [vol%] vs. MEXA-7000 CO [vol%]
  - Equation: $Y = 0.00476 + 1.01409X$
  - $R^2 = 0.9967$

- **CO$_2$**:
  - OBS-2200 CO$_2$ [vol%] vs. MEXA-7000 CO$_2$ [vol%]
  - Equation: $Y = 0.00476 + 1.01409X$
  - $R^2 = 0.996$

- **THC**:
  - OBS-2200 THC [ppm] vs. MEXA-7000 THC(Wet) [ppm]
  - Equation: $Y = 1.22861 + 0.99374X$
  - $R^2 = 0.9991$

- **NOx**:
  - OBS-2200 NOx [ppm] vs. MEXA-7000 NOx(Wet) [ppm]
  - Equation: $Y = 0.50281 + 0.98178X$
  - $R^2 = 0.996$
Regulation Compliance of OBS-2200

- **CFR-1065  Subpart J**
  **Target spec of PEMS**
  - Spec of each detector (interference, relative response,)
  - Spec of linearization,
  - Response time, Noise, Repeatability, Accuracy

- **CFR-86  Subpart T**
  Manufacture-Run In-Use Testing Program for Heavy-Duty Diesel Engine
  **Test procedure of Field testing (NTE test)**

- **EU EURO VI – Regulation 582/2011**
  - Requirement and Tests for In Service Testing
Exhaust Gas: Pitot Tube Flow Meter

\[ P_{exh} = K \sqrt{\frac{P_{exh}}{101.3[kPa]}} \times \frac{293.15[K]}{T_{exh}} \times \frac{\Delta h}{\gamma} \]

\[ H = \sqrt{\frac{P_{exh}}{101.3[kPa]}} \times \frac{293.15[K]}{T_{exh}} \times \frac{\Delta h}{\gamma} \]
Pulsation flow at idling (gasoline engine)

Measured by fast response differential pressure sensor (2kHz)
Pitot flow meter square root error

Average of pulsation in diff. pressure dimension \neq \text{Average of pulsation in flow dimension}
Pitot flow meter square root error

- Calculated exhaust flow rate [L/min.]
- Filtered response frequency [Hz]
- Measured exhaust flow rate
- Pulsation frequency
Comparison with ultrasonic and SAO tracer flow meters
Pitot flow meter root square error

1.6L gasoline engine (FTP75 HT)
(response frequency of diff. pressure; 1.6Hz)

1.6L gasoline engine (FTP75 HT)
(response frequency of diff. pressure; 2kHz)

Explore the future
**Correlation with chassis dyno / CVS**

3.5L Gasoline Vehicle --50% level of 2005 regulation--

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**CVS-CO2 [g/km]**

- 2000 regulation (10・15mode; 0.08g/km)
- 2005, 2009 regulation (JC08 mode; 1.15g/km)

**CVS-CO [g/km]**

- 2000 regulation (10・15mode; 0.67g/km)
- 2005, 2009 regulation (JC08 mode; 0.05g/km)

**CVS-THC [g/km]**

- 2000 regulation (10・15mode; 0.08g/km NMHC)
- 2005, 2009 regulation (JC08 mode; 0.05g/km)

**CVS-NOx [g/km]**

- 2000 regulation (10・15mode; 0.08g/km)
- 2005, 2009 regulation (JC08 mode; 0.05g/km)

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Explore the future
PEMS PM Mass Measurement

- PM Mass Measurement
  - EPA and EU have requested that real time PM mass measurement systems are required for the OB application so that emissions can be compared with the legislative procedure (gravimetric PM from diluted exhaust)

- “Real Time Measurement or PM Mass . . . Choose One”
  - Practically very difficult to have a true real time PM mass measurement system that correlates perfectly with the legal PM measurement method from full flow CVS from low -> high PM levels
  - PM mass using a Miniaturised Partial Flow Dilution System (PFDS) is possible, using the exhaust flow signal from OBS, but this system cannot provide real time data for vehicle NTE analysis
  - Real time measurements can be made for soot using a variety of techniques (opacity, laser scatter, LII, PASS, Diffusion Charger, Solid Particle Counting)

- US EPA and EU have investigated PM techniques for OB application
PEMS Real Time PM Mass Measurement

Technical Difficulties

- Accuracy / Correlation To Legislative Method
  - Specifically, correlation to the filter based gravimetric measurement principle that is used currently for all engine / vehicle certification. And in real time.

- Sensitivity
  - Requires higher sensitivity than filter gravimetric principle
    - Laboratory has whole test cycle for PM loading, real time can have as little as 30 seconds of PM mass loading.

- Traceability
  - Calibration method
  - Traceability to a mass standard

- Repeatability / Reproducibility
  - Short term and long term drift potential

- PM Sensitivity to Fuel Composition, After-Treatment, Test Cycle, Ambient Conditions, Vehicle Pre-Conditioning/History etc
  - PM mass / composition can change with the above

- Rugged and Practical for On Board Use
  - Insensitive to vibration, ambient temperature change, altitude, ambient humidity
  - Size, power consumption, control signals etc

Explore the future
PM is a complex, variable mixture of several components

Soot: Carbonaceous Solid (Combustion Generated)
SOF: Heavy HC condensed/absorbed on soot (Unburned fuel, Oil, Compounds formed during combustion)
$SO_4^2-$: (Sulfur from the Fuel and Oil) combined with $H_2O$
Nitrate: Formed as by-product from some exhaust after-treatments
Ash: solid particles formed from combustion of oil or additives in fuel
Combination of PFDS and Real Time Detector

**Filter Gravimetric Method**

**Advantage**
- Conventional Method
- Gravimetric result

**Disadvantage**
- Low Sensitivity
- Batch result

**Real Time Instruments**

**Disadvantage**
- Correlation ?
- Traceability ?

**Advantage**
- High sensitivity
- Real time result
OBS-2000TRPM Schematic

1. Proportional Sampling
   Exhaust flow rate signal from Gaseous PEMS flow meter (or analog signal) used to control proportional flow diluter

2. Real Time Measurement
   DCS-100 is a real-time particle sensor, based on diffusion charge principle
   DCS-100 signal is calibrated to actual PM mass post test using the gravimetric method.

3. Filter Collection:
   PM mass collected on filter using an exhaust-proportional partial flow dilution system

4. Mass Calculation
   Filter mass is used to calibrate DCS-100 integrated signal. Then DCS signal is used to calculate real time PM mass.
DCS-100 Real Time Particle Sensor
OEM version of EAD from TSI Inc

**Specification:**
- Measurement range: 0 ... 2500 mm/cm³
- Sensitivity limit: 0.01 mm/cm³
- Sample flow: 2.5 liters/min. (approx.)
OBS-2000TRPM
Issues for Light Duty Vehicle Testing

- Size / power not main issues for on-road HDVs
  - sufficient space for all modules, generators etc

- For LDVs: issues to be resolved / improved
  - size/power especially with real time PM mass capability
    - Must use batteries: no space / location for on-board generator
  - support gases
    - Zero, FID fuel, compressed air for PM mass (if installed)
  - access holes into the vehicle for the heated sample line & pipes / cables incl GPS sensor
  - Adaptors / mounting / piping for exhaust flow meter
    - Connections to exhaust (twin pipes !)
    - Sufficient pipe length for exhaust flow stability: depends on vehicle
  - Local legal / health & safety / public liability issues ref on road testing
  - data calculations
    - NTE for the USA
    - Moving work window for the EU
    - what method would be applied for LDVs?
HORIBA Future PEMS Activities / Research

- DCS-100 improvement for real time PM determination
  - For sensitivity to small particles emitted during regeneration
  - Extending service life / resistance to contamination on high emitters

- ECU connections for Light Duty Vehicle Testing
  - Not necessary for base g/km
  - Parameters for LDVs to be finalised

- Size / power reduction
  - Especially for the OBS-2000TRPM for application to the Light Duty Vehicle

- On-Board Particle Number Counting
  - Applicable to vehicles with PN based emissions standards
  - Solutions to the various problems of its application for HD and LD Vehicles
  - OR use an alternative parameter with reliable, consistent correlation to PN

- Additional gaseous compounds
  - As required by legislation in the future
Thank you

And

Any Questions?