50th PMP Meeting 3 - 4 April 2019
03 April 2019, 10:00-17:00H

Centre Albert Borschette, Brussels
Rue Froissart 36, Brussels, Belgium

DRAFT Meeting Minutes

► 3d April 2019 @ 10:00H

1. Welcome & Introduction

- Welcome by Giorgio Martini. Introduction
- Meeting Minutes from 49th on PMP site.

2. Roadmap to robust regulatory procedure for Sub23nm particles

- EU Com: wants to change to sub 23nm for next regulatory step. Revision of limit value would be second step

3. Light duty Sub23nm

- Round Robin - Tero LAHDE (JRC)
  Variability 10-20% for sub 23nm and 23nm were at same level
  Sub 23nm excess particles: highest for PMP system (26±20%)
  CS1 low (4-6%) variability CS2 higher (13-15%) variability
  Japan (May 2019); China (Q2/Q3 2019)
  No clear benefit of CS vs ET can be drawn from RR

- Update on Horizon 2020 projects on sub-23 nm particles
  - DownToTen (John Anderson)
    Instrumentation and sampling for down to 10nm
    New engine technologies to be investigated
    Investigated excess particles from 10 to 23 nm and from 3 to 23 nm
    Extension of project by 3 months until Dec 2019
    - CS can be used, if possible. CS shows best and robust removal
    - Most technologies with 10nm are compliant with 6E11 limit
    - Sometimes increased sub 23 nm, but at low level not exceeding the 6E11 limit
  - Pems4nano (Horiba Phillip Kreutziger))
    23 nm efficiency transferred to PEMS. 50% CPC efficiency at 10nm
    Modification of 10nm CPC: temperature adjusted and tubing diameter adjusted
  - Surreal (CERTH)
    Sub 23 fraction ca 30%. Investigated fuel effects
    Artefact at 6nm if ET at 400C. No such effect with CS
    PEMS tests were driven around Thessaloniki, Torino and Paris on RDE routes
    Comment by Catalytic Instruments: CS also works at 150-200C.

4. Calibration

- Calibration Material / Generation Introduction (Tero, JRC)
  Minimum concentration needed for calibration (5000cm-3?)

Material/ generation

- "EC/OC content of the soot generated by miniCAST soot generator" (Lianpeng JING; JING Ltd.)

- Operation of soot particle formation from N2 quenching
- Change of gas flows: 200nm – 100nm – 30 nm
- Fuel rich/lean operation of CAST leads to variation of particle size distribution.
- N2 quench gas of 7 lpm recommended. 3 lpm N2 leads to very high OC/EC ratios

Particle size change of less 1.5 nm in 120 min. Day to day variability measured.

- "Sub 20 nm generation of soot particles using the VSP-G1 nanoparticle generator" (VSPARTICLE - M. Kamp)
  - Spark generator principle generates very small particles
  - particle mass production is about mg into gas flow
  - Spark gap is kept constant.
  - Size distribution around 30-50 nm

- "Towards a stable mass and number generator for repeatable and traceable calibration of PMP devices" (Catalytic Instruments GmbH – Mr Scholz?)
  - Silver particle generation by evaporation and condensation. Particle generation of particles below 20 nm; high stability over 24h regarding size and PN concentration.
  - On/off of furnace: new design with on/off performance- perhaps 5-10%?
  - Narrow size distribution?
  - Catalytic stripper: redesign to 99-98% removal at lower temperature.

- "Proposal for a universal calibration standard for 10nm" (BMW, A. Terres)
  - Proposal for full system performance calibration at 15nm 40-80% 23 nm 60-90%.
    10 nm could be omitted as calibration point.
  - Omit the PCRF definition at for example 15nm and calculation of overall PCRF
  - CPC is only calibrated for linearity. CPC efficiency not needed, it is covered by overall efficiency
  - Calibration: need to define single aerosol: a.) CAST or b.) spark generator at least down to 15 nm
  - System calibration tried-out for 23 nm method. Not yet done for sub-23nm method

- "AIP approach on Traceable Particle Number calibrations" CPC. AIP Automotive, A. Trommer
  - PN-PEMS efficiency calibration for 23nm method
  - CPC calibrations with CAST as aerosol source – worked well

- "AVL APC CPC calibration to 10nm: status and challenges" (Thanasis MAMAKOS – AVL)
  - PCRF setup: Mini CAST + CS 350C – Kr-85 – DMA – Mixer – 10nm CPC
  - 10nm CPC: Counting efficiency for soot vs emery oil identical.
  - 23 nm counter shows higher counting with emery oil.
  - Proposal: 10nm: 50% +-12%; 23nm: >90nm efficiency
  - VPR penetration PCRF15/PCRF100 remain at 2
  - k-factor consideration: counting efficiency should be stated in relation to the plateau counting.

- CPC calibration material: not critical. Not needed to limit to soot-like particles at this point in time.

- "kf influence on CPC calibration" (VW, Stefan Carli)
  - Different efficiency curves with different manufacturer counters
  - Application of kf has to be specified
  - PMP requirements have to be met

- Decision on the DRAFT sub-23 nm calibration procedure (Theo G., JRC)
  - Question to CPC manufacturers will be sent: Is efficiency at 10nm (50%), 23nm (90%) realistic? CPC manufacturers should provide CPC data.

5. Adaptation of current methodology or optimized system (Tero L. JRC)

- Discussed feasibility of the current methodology PN-systems on Sub23nm measurements (10nm)
  - Procedure should allow existing systems upgraded and optimization for particle losses. Horiba recommends modification to existing instruments
  - Agreed: Keep PCRF concept: Details need to be defined, for example, if an additional PCRF value at 15nm is required in addition to the PCRF three-point averaging (old) process
  - There is an incentive to optimize systems for instrument manufacturers to improve variability (HORIBA)

- DRAFT Decision on CS or VPR next steps
  - PMP23 nm calls for ET tube, but this could also be a CS which is essentially an ET.
  - <u>Agreed:</u> Use CS, or VPR. Write specification such that artefacts are mostly reduced. Use current CS performance as DRAFT specification

- Calibration material

  HORIBA: Emery oil (consistent with Electrometer calibration)

  AVL : Emery oil

  <u>No Agreement</u> on specific material. Reference material needed, to which a transfer function would be defined. Could be squerical singly charged particles, like emery oil

6. PN-PEMS 10nm

- Not discussed

7. Update on raw exhaust sampling

- ACEA/JRC presentation on ***"PN Counting from Raw Exhaust via Fixed Dilution and round robin project"*** provided by JRC
  - Tailpipe sampling HD –update. Uncertainty against CVS, or PFDS
  - Golden APC compared with 23nm and 10nm: very similar.
  - Repeatability of 10nm similar to 23nm
  - TP (CS) vs PFDS (ET) compared well
  - Sub-23nm can be substantially higher than 23 nm
  - Golden TP vs PFDS +-20%

- PCRF: old 23nm calibration was used. No new calibration procedure was applied.

8. The effect of fuel characteristics on PN emissions

- Not discussed

GRPE Meeting in May 2019 (not June 2019).

- No PMP meeting. Web PMP meeting to prepare

End of Day 1 @ 17:30H

► 4th April 2019 @ 09:00H

1. **Welcome & Introduction**

Non-exhaust emissions are getting relatively more important with decreasing exhaust emissions. PMP is asked to continue method development. Not clear by now, if implemented. In May 2019 GRPE mandate has to be submitted and approved. Non-exhaust part: end of 2020 proposal for brake regulatory method

Tires: current work is on labelling abrasion rate. Later PMP could get involved for determination of PM10 emission rate.

2. **Step 1 – Development of a novel braking test cycle**

- **Update on the work done by the dedicated TF and update on the on-going round robin (Theodoros GRIGORATOS – JRC/TF1)**
  RR objectives: WLTP cycle was run at different labs. Speed traces could be well reproduced.
  Provide to TF 2 recommendations for important parameters to do repeatable measurements.
  Report of data and statistics (Q4/19). Recommendation for TF2 will take some more time and provided to TF1. It will be included into TF1 Report (Q4/19).

- **Initial results and findings from Interlaboratory evaluation of WLTP-brake cycle using dynamometer testing (TF1) (Carlos AGUDELO - Link Engineering)**
  Speed/Time traces are not consistent over the participating (7) labs. Analysis of speed violations. Some labs have very low deviations, other much higher deviations.
  Analysis of temperature deviations to vehicle temperature data from proving ground measurement. Analysis of torque / distance; analysis deceleration
  Break temperature evaluation (Jarek Grochowicz)
  Temperature is a very important parameter for brake particle emissions. Observed Delta Max-Min temperature: up to 45°C. Possible reasons: a.) different energy, however same inertia, time traces and driving resistances were used in the labs. b.) different cooling conditions
  Need: better control of temperature, i.e. defined cooling air temperature, and cooling air speed
  Developed some DRAFT recommendations: for example shorten stand still times, if cooling at dyno is higher than vehicle.

- **Japanese Analysis of Japan Data and WLTP cycle**
  Hiroyuki Hagino presented JARI analysis (see presentation)
  - Detection Sensitivity for PN and PM
    Reproducibility of JARI Sampling System
    Cycle Pattern Analysis for World Harmonization
  - Conclusions and Next Steps:
  - Modification of air flow for PN measurement using uniform sampling JARI/JASIC model design.
  - Reproducibility of PN emissions
  - How much do the differences of the speed-deceleration distribution contribute to PN and PM emission levels.

- **Analysis of Japanese driving data in relation to the WLTP derived Braking** Cycle – Heinz Steven
  - Japanese brake events somewhat higher at low speed. Deceleration in good agreement.
  - HS marked the brake short trips according to low, medium, high, and extra high.
  - HS concluded that WLTC also represents well the Japanese driving data available.

- JARI will take presentation to Japan government and discuss if cycle is also acceptable to Japan. It would have to be investigated if omitting >110 km h^{-1} event would have impact on brake wear PM/PN emission.
- HS will clarify if in JARI presentation the deceleration data included deceleration without braking

3. Steps 2&3 – Selection of the most suitable sampling method and the most suitable methodology for brake particles measurement and characterization

- ***Exploratory Brake Emissions Benchmarking – a Design of Experiments*** **(Matt ROBERE – GM)**
  - Regional brake material difference based upon regionally extreme requirements. NAO in US and Japan, low metallic in EU.
  - Comparison of cooling rate of from 400°C at dyno and vehicle at different air flows.
  - Setup DoE to identify main factors: Effect on Brake temperature, Effect on mass loss of brake disc.
  - NAO had 2-3x lower brake PM kg/km than LowMet. PN emissions reported. 4x WLTP not sufficient to reach steady emission. Rather 6x WLTP repeats are recommended.
  - CPC PN counting is not with thermal treatment, i.e. data includes volatile particles
  - Fading test (PN = ca 10E12 #/km) is a severe run-in test with lots of energy dissipation. Not relevant to costumer usage.

- ***Measurement of brake wear PM emissions under realistic conditions" from a collaborative Project of AUDI and HORIBA*** **(Dmytro LUGOVYY – HORIBA)**
  - Studied impact of air flow (38 -> 13km/h) on PM mass. 0.2 mg PM per cycle collected on filter.
  - PM depends upon air flow and temperature.
  - Comparison of temperature data from Audi/Ford dyno and Ford vehicle tests.
  - Audi cooling is faster than other facilities. Consider ratio of duct diameter/volume enclosure ratio. Increased flow rate: PN events are still visible.

- ***Brake Dust PM Results measured on a Dyno running the Novel Test Cycle"*** **from AVL and TU Ilmenau (Thanasis MAMAKOS – AVL)**
  - Identify optimal settings for PM measurement. Tunnel air flow was at 170 m^3/h.
  - Brake run-in: 20 x WLTP. PM-PEMS investigation of ECE pads (= ca 2.2 mg/km) NAO pads (= 0.5 mg/km). No effect of PM2.5 cyclon on PM or PN. Collected 0.3-3.0 mg PM on filter paper.
  - Discussion around including a PM10 cyclone to avoid sampling of large PM flakes.
  - Note: R-83 Exhaust regulation requires pre-classifier in the PM10-PM2.5 size range with 99% reduction efficiency.

- ***"Preliminary Results for Brake Wear Particle Emission PN and PM Concentration and Size Distribution Measurements"*** from Dekati, ITT and Airmodus (M. Moisio – Dekati and A. Sin – ITT)
  WLTP cycle; ELPI+, E-Filter, Airmodus A20 CPC.
  - Brake emission peaks were identified by different instruments. ELPI+ and CPC and other instruments correlated well.
  - Background was 2000 part/m^3 pointing to some outside air leakage.

- ***Measurement of brake wear PN emissions under realistic conditions" from a collaborative Project of AUDI and HORIBA*** **(Dmytro LUGOVYY – HORIBA)**
  - Horiba solid particle counter (with dilution and CS): ca 4x10E10 part/km (WLTP cycle); WLTP Class 3: ca. 1x10E11 part/km
  - Size distributions showed: coagulation observed dependent on dilution air Note: experiments were done without thermal treatment and AK Master cycle. PM size includes volatile particles and condensation/nucleation effects
  - Brake pads stabilized after 8-10 cycles

- Discussion on coagulation.

- ***Sensitivity and Reproducibility of Brake Wear Particle Emission Measurements using JARI System* (JARI - Dr. H. Hagino)**
  - See presentation and above.
    Description of JARI sampling system. No significant difference in PM and PN for 1 - 4 m^3/min flow rates. Tunnel background 10 ug / filter; 10 #/cm^{-3}
  - Regen Braking showed 67% PM reduction and 40% PN reduction on NAO pads
  - Reproducibility was ±0.4 mg/km

4. Other brake related topics

- ***High-fidelity modelling and characterization of dynamometer enclosure interactions using a DOE approach for brake emissions measurements from an on-going project of LINK and University of Michigan* (Carlos AGUDELO – LINK & Jesse CAPACELATRO – University of Michigan)**
  - Single particle inception simulation, 400-1000 m^3/h air flow. Residence time simulation: 0.2 s.
  - CFD is an important tool: Air flow and brake speed are important factors
  - Q: Inject Arizona Dust to verify model?

- ***CARB/CALTRANS Emission Factors update and enhancements* (Sonya COLLIER – CARB)**
  Presented via phone – see slides.
  - Ambient PM2.5 has be decreasing to 10-15 ug/m^3 over past years
  - Environmental Justice regulation: gap of BC is closing 1.0 vs 0.5 ug/m^3
  - PM2.5 brake wear projection to 2040. ZEV mandate will introduce regen braking. Expect brake wear contribution to PM2.5 decrease.
  - Planned test program with ERG/LINK: 6-7 x LDVs, on-road driving data collection, real world usage, drive cycle w final temperature, Brake wear emission testing with validated enclosed brake dyno. Including Regen braking vehicles. 4x HDV testing.
  - Anticipated results: speed dependent emission factors, for PM and PN. Repeatability and chemical analysis.
  - At CARB: In-house testing by chassis dyno at SHED test chamber
  - Health effects study: EPI study with UCLA looking on negative birth weight.
  - Q: Could CARB also run a few tests on WLTP cycle for comparison? CARB: Not clear yet, might consider.

5. Arrangements for the next meeting

Provide new mandate for approval. Giorgio M + Rainer V will rephrase the mandate and circulate to PMP group for comment
No physical PMP meeting around GRPE meeting in May 2019. Anticipate Web-conference
Next PMP meeting 29/30.10.2019 potentially in Brussels, or ISPRA.

End of Day 2 @ 17:00H