



PMP IWG

BRAKE PARTICLE EMISSIONS

BRAKE EMISSION TASK FORCE 2 (TF2)












MINIMUM SPECIFICATIONS FOR TESTING

Theo Grigoratos and TF2 members
PMP Webconference 15 July 2021

Task Force 2 – Definition of Minimum Specifications

Define a set of minimum specifications for measuring brake wear particle emissions in a repeatable and reproducible manner --- **Completed Q3/2021**

Apply these specifications in the upcoming Interlaboratory Study (ILS) and come up with final technical specs --- **On-going expected to be finalized by the end Q4/2021**

Parameter #1	Parameter #2	Parameter #3	Parameter #4	Parameter #5	Parameter #6	Parameter #7	Parameter #8	Parameter #9	Parameter #10	Parameter #11
Testing Cycle	Cooling Air-speed Adjustment	Background Check	Dynamometer Climatics	Temperature Measurement	Bedding-in Procedure	Enclosure Design	Duct Losses	PM Measurement	PN Measurement	Test Reports
										

The document "PMP Brake Protocol - Testing Specifications" has been submitted and can be found on the PMP's website <https://wiki.unece.org/display/trans/PMP+Web+Conference+15.07.2021>

Task Force 2 – Minimum Specifications

1. Testing cycle (WLTP-Brake Cycle)

The testing cycle will be the WLTP-Brake Cycle profile. The 1Hz speed traces of the cycle can be found at <https://data.mendeley.com/datasets/dkp376g3m8/1>

- ***Initial temperature of 40°C shall be applied for every trip of the cycle when performing emission measurements.*** Trip #1 shall commence at ambient temperature. This will allow for a significant reduction of the soak time during testing.
- ***A maximum 10% of speed violations are allowed during the execution of the WLTP-Brake Cycle.*** A speed violation occurs whenever the actual speed of the dynamometer exceeds the upper or lower speed trace tolerance compared to the nominal speed as per clause 6.5 of the GRPE-81-12.
- More details regarding the application of the WLTP-Brake Cycle are included to the attached document and the GRPE-81-12 protocol “Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle”.

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2. Incoming cooling-air adjustment (Current Proposal)

To determine the appropriate airstream speed for testing the emissions of a given brake, labs shall follow the steps described below:

- **Classify the tested brake according to its Wheel Load to Disc Mass (WL/DM) ratio.** Four different Groups have been identified based on the WL/DM ratio (≤ 45 ; $>45 \& \leq 65$; $>65 \& \leq 85$; >85).
- Run Trip #10 of the WLTP-Brake cycle to obtain *i. The Average Temperature of the Trip, ii. The Average Initial Brake Temperature (IBT) of six predefined brake events, iii. The Average Final Brake Temperature (FBT) of the same six events.*
- **Check the temperatures measured in the previous step for compliance with the default temperature metrics and limits** as defined in the Table included to the attached document.
- **If all three temperature criteria are fulfilled the adjustment of the cooling air speed is considered successful.** If not, appropriate adjustments shall be made to meet all defined criteria.

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3. Background concentration check

Each lab shall follow the recommendations described below regarding the background concentration check.

- The cooling air entering the brake enclosure during a brake particle emission test shall pass through a medium capable of reducing particles of the most penetrating particle size in the filter material by **at least 99.95%**, or through **a filter of at least class H13** as specified in EN 1822.
- **The background concentration shall be defined on a PN basis.** Each laboratory shall report their background concentration for each cooling setting. The background concentration shall not exceed the maximum allowed value of ***X particles/km (to be defined after the ILS)***.
- The background check shall be performed at two levels. **The first level foresees the system installation** (or when there are indications of malfunction), while **the second level foresees regular background checks** before and after the execution of a brake emissions test.

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4. Dyno climatics

The incoming cooling air temperature and relative humidity (RH) shall be set to 20°C and 50%, respectively.

- Emission tests shall be considered successful when the average temperature of the incoming cooling air during the test falls within $\pm 2^\circ\text{C}$ with respect to the target value (i.e. $20 \pm 2^\circ\text{C}$) **AND** when the average relative humidity of the incoming cooling air during the test falls within $\pm 5\%$ of the target value (i.e. $50 \pm 5\%$).
- The temperature and relative humidity of the incoming cooling air are allowed to oscillate between $20 \pm 5^\circ\text{C}$ and $50 \pm 10\%$, respectively, for no longer than the 10% duration of the cycle ***provided that the average targets as defined above are met.***
- The same temperature and relative humidity requirements for the incoming cooling air as described above shall apply during the ***bedding procedure*** as well as during the ***cooling air adjustment procedure.***

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5. Brake temperature measurement method

Embedded thermocouples shall be used for measuring brake disc and drum temperature. Disc temperature shall be used to control the test temperatures and initiate individual trips of the WLTP-Brake Cycle. It shall also be used to define target parameters during cooling adjustment

- ***The disc thermocouple shall be located in the outboard plate rubbing surface recessed (0.5±0.1) mm deep into the face of the disc.*** The drum thermocouple shall be located at the centre of the friction path (0.5±0.1) mm deep in the inside surface of the brake drum.
- ***Brake pad or shoe temperature measurement is also recommended in parallel to the disc measurement.*** It is recommended to embed one thermocouple at a depth of 1.0 mm near the center of the friction surface on each pad or in case of drum brakes near the centre of the friction surface of the most heavily loaded shoe.
- Sliding thermocouples may be used for research or other purposes; however, always complementary to the embedded thermocouples.

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6. Definition of bedding-in procedure

Bedding shall be long enough to ensure the stabilization of the brake's emission behavior. However, there needs to be a compromise to keep test duration at reasonable levels.

- It is recommended to apply **5 WLTP-Brake Cycles for bedding disc/pad couples and drum brakes**. The number of cycles required might be revised after the ILS.
- The 5 WLTP-based novel cycles shall run consecutively without any interruption. **Soak times shall not apply between the individual trips during the bedding procedure. Each repetition shall commence at 40°C** (1st repetition at ambient temperature).
- **The bedding procedure shall take place on the same dynamometer as the actual emissions measurement without disassembling the parts between the two procedures.** This is to avoid modifying the contact points and subsequently the emissions behaviour.
- **An alternative protocol of 10 repetitions of Trip #10 of the WLTP-Brake Cycle will be tested at the ILS for its suitability as a bedding procedure.**

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7. Brake enclosure design

Design requirements for the enclosure are defined with the aim of achieving maximum transport efficiency, maximum particle distribution/uniformity, and minimum residence time.

- The brake enclosure shall incorporate good aerosol sampling practice that includes the use of smooth internal surfaces and ***the avoidance of sharp bends and abrupt changes in cross-section.***
- The brake enclosure shall come in ***dimensions which allow for measurements of all common sizes of LDV brake assemblies.***
- It is recommended to ***install the caliper at the upper part of the disc in a position between 1 and 2 o'clock or 10 and 11 o'clock*** considering the direction of evacuation.
- ***The brake disc shall rotate in the direction of the evacuation (CW or CCW) independently of the orientation of the duct works*** (horizontal or vertical).

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8. Estimation of duct and sampling train losses

Each lab shall report the estimation of the particle losses in the duct and the sampling train (from the tip of the sampling nozzle to the entry port of the given instrument or sampling device) based on calculations performed in house. Available options include but not limited to.

- Estimation of the losses by means of LINK PALS Macro (Optional).
- CFD studies (Optional)
- Particle size distribution (Optional)

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9. PM mass measurement

Brake PM₁₀ and PM_{2.5} mass emissions shall be measured gravimetrically. Minimum specifications and recommendations on the following aspects have been defined.

- ***Transport and Extraction*** – Include specs about the positioning of the sampling plane, the selection and positioning of nozzles to ensure isokinetic sampling, the measurement of air-speed, the use of flow splitters, etc.
- ***PM Sampling Devices and Media*** – Including specs about the potential use of pre-classifiers and classifiers, their minimum requirements, the types of filters and substrates depending on the PM sampling device, etc.
- ***Weighing Procedure*** – Including specs about the pre-sampling and the post-sampling conditioning of the substrates, the weighing room and balance, the storage and transfer conditions, the use of reference filters, etc.

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10. PN concentration measurement

The Particle Number (PN) measurement system shall consist of a pre-classifier, a sampling line, a diluter, and a Condensation Particle Counter (CPC). Minimum specifications have been defined for these

- ***A pre-classifier with a cut-off point between 2.5-10 μm (recommendation to select one with a low cut-off) shall be used to protect the PN system from contamination.***
- ***The diluter shall ensure that sufficient dilution is employed to avoid CPC saturation.*** The CPC concentration during tests shall not exceed the maximum concentration employed during linearity calibration.
- ***The CPC shall be full flow and in accordance with the specifications of GTR15 for 10 nm measurements.*** These include a counting efficiency of 65% ($\pm 15\%$) at 10 nm and $>90\%$ at 15 nm.
- ***It is recommended to also measure Solid PN (SPN) in parallel to the total PN concentrations.*** Thermal treatment of the sample should be done following the specifications described in GTR 15.

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11. Minimum parameters to be registered and test reports

The two main outputs of the brake inertia dynamometer test shall be the EEC and EED files. Labs shall collect continuously and automatically the following channels at 10Hz during the WLTP-Brake Cycle:

- Brake torque, pressure, equivalent linear speed, disc or drum temperature, pads or shoe temperature, cooling air temperature, cooling air relative humidity, cooling airstream speed or cooling airflow. ***Deceleration rate and friction coefficient shall be calculated at 10Hz for the entire WLTP-Brake cycle and reported within the EED file***
- ***EEC Files – Labs shall use the VDA 305/EKB 3008 standard to generate a CSV or MS Excel™ file for the entire test. This file shall include one row for each brake deceleration event.*** More information regarding the EEC file is included in Annex C of the Informal Document GRPE-81-12.
- ***EED files - Labs shall use the VDA 305/EKB 3008 standard to generate a CSV or MS Excel™ file for the entire test. This file shall include data sampling at 1Hz.*** More information regarding the EED file is included in the Informal Document GRPE-81-12.

Task Force 2 – Overview

- AUDI (S. Gramstat), AVL (T. Mamakos, M. Arndt), BMW (K. Kolbeck, J. Von-Wild, T. Schroeder), BREMBO (M. Federici, G. Perricone), CARB (Q. Yao, S. Yoon), CONTI (A. Reich, S. Fischer), DEKATI (M. Moisio), DRIV (M. Morbach, C. Koelsch), FORD (R. Vogt, J. Grochowicz, M. Mathissen), GM (M. Robere), HORIBA (G. Kanae Filler, D. Lugovyy), ITT (A. Sin, S. Ansaloni), JARI (H. Hagino), JRC (T. Grigoratos, B. Giechaskiel), LINK-EU (A. Hortet, C. Schmidt), LINK-US (C. Agudelo, R. Vedula), STELLANTIS (O. Bausch), TMD (P. Nyhof), TSI-EU (S. Percot), TSI-US (B. Anderson, F. Romay), TU ILMENAU (D. Hesse)
- **35 full group meetings plus several preparation bilateral and smaller group meetings.** Minutes of the meetings, technical presentations on brake emission measurements, and other material related to the testing specifications are available on the PMP website.
- The final output of the TF2 "PMP Brake Protocol - Testing Specifications" has been submitted at the PMP Virtual Meeting on 15.07.2021 and can be found on the PMP's website <https://wiki.unece.org/display/trans/PMP+Web+Conference+15.07.2021>

Thank you



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