PMP IWG – BRAKE PARTICLE EMISSIONS

DEVELOPMENT OF A COMMONLY ACCEPTED METHOD FOR MEASURING BRAKE PARTICLE EMISSIONS

BRAKE EMISSION TASK FORCES PROGRESS UPDATE

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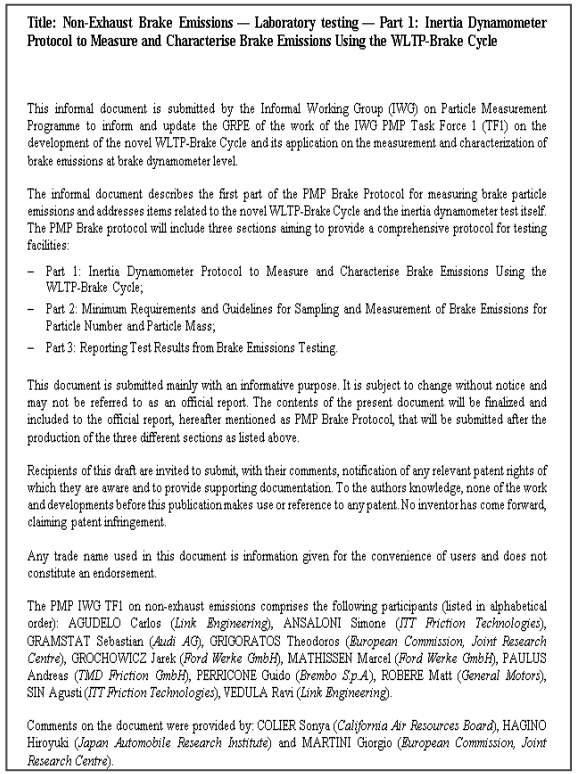
20 May 2020

Brake Emissions – Outlook

- ✓ **Task Force 1 – Brief overview**
- ✓ **Task Force 2 – Brief overview**
- ✓ **Task Force 2 – Development phase**
- ✓ **Task Force 2 – Future activities and timeline**

Brake Emissions – Task Force 1

TF1 activities can be separated in three distinct phases. The first phase included the ***WLTP-Brake Cycle development***. The second phase involved the ***validation of the WLTP-Brake Cycle*** at vehicle and dyno level. The third phase includes the ***reporting of results, lessons learnt and recommendations***.



Title: Non-Exhaust Brake Emissions — Laboratory testing — Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle

This informal document is submitted by the Informal Working Group (IWG) on Particle Measurement Programme to inform and update the GRPE of the work of the IWG PMP Task Force 1 (TF1) on the development of the novel WLTP-Brake Cycle and its application on the measurement and characterization of brake emissions at brake dynamometer level.

The informal document describes the first part of the PMP Brake Protocol for measuring brake particle emissions and addresses items related to the novel WLTP-Brake Cycle and the inertia dynamometer test itself. The PMP Brake protocol will include three sections aiming to provide a comprehensive protocol for testing facilities:

- Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle;
- Part 2: Minimum Requirements and Guidelines for Sampling and Measurement of Brake Emissions for Particle Number and Particle Mass;
- Part 3: Reporting Test Results from Brake Emissions Testing.

This document is submitted mainly with an informative purpose. It is subject to change without notice and may not be referred to as an official report. The contents of the present document will be finalized and included to the official report, hereafter mentioned as PMP Brake Protocol, that will be submitted after the production of the three different sections as listed above.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation. To the authors knowledge, none of the work and developments before this publication makes use or reference to any patent. No inventor has come forward, claiming patent infringement.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

The PMP IWG TF1 on non-exhaust emissions comprises the following participants (listed in alphabetical order): AGUDELO Carlos (*Link Engineering*), ANSALONI Simone (*ITT Friction Technologies*), GRAMSTAT Sebastian (*Audi AG*), GRIGORATOS Theodoros (*European Commission, Joint Research Centre*), GROCHOWICZ Jarek (*Ford Werke GmbH*), MATHISSEN Marcel (*Ford Werke GmbH*), PAULUS Andreas (*TMD Friction GmbH*), PERRICONE Guido (*Brembo S.p.A.*), ROBERE Matt (*General Motors*), SIN Agusti (*ITT Friction Technologies*), VEDULA Ravi (*Link Engineering*).

Comments on the document were provided by: COLIER Sonya (*California Air Resources Board*), HAGINO Hiroyuki (*Japan Automobile Research Institute*) and MARTINI Giorgio (*European Commission, Joint Research Centre*).

What were the main activities of TF1 during the last months?

- ✓ TF1 submitted the Informal Document GRPE-81-XX entitled "***Non-Exhaust Brake Emissions — Laboratory testing — Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle***"
- ✓ The document is the first part of the overall protocol (*PMP Brake Protocol*) and addresses items related to the novel WLTP-Brake Cycle and the inertia dynamometer test itself. Parts of the protocol might be subject of revision based on data availability
- ✓ TF1 will soon submit a statistic analysis of the RR results along with a publication of a paper in a peer-reviewed journal

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Brake Emissions – Task Force 2

TF2 activity and progress depend on the availability and quality of experimental data. Different phases are not so distinct as in TF1 and the strategy has been modified since the beginning.

Preparation Phase

- ✓ Included the decision on the test method approach at the PMP level (brake dynamometer) as well as the merging of sampling and measurement discussion to a common group --- Completed

Understanding Phase

- ✓ Included the presentation and discussion on existing and state-of-the-art configurations for brake particles sampling and measurement --- Completed

Development Phase

- ✓ Aim is to define a set of minimum requirements related to the measurement of brake particle emissions. The aim is to apply these requirements in a RR exercise and come up with final decisions on technical specifications --- On-going (Expected to be finalized by the end of Q3/2020)

Task Force 2 – Development phase

The aim of this phase is to define a set of minimum requirements related to the measurement of brake particle emissions. The following parameters have been considered partially or exclusively in TF2:

1. Defined Cycle (WLTP-Brake Cycle)
2. Background Concentration
3. Dyno Climatics
4. Brake Temperature Measurement
5. Definition of bedding-in procedure
6. Brake Enclosure Design
7. PM Measurement
8. PN Measurement
9. Other topics

Task Force 2 – Development phase

1. Defined Cycle (WLTP-Brake Cycle) --- Topic closed

Decision is to run the time based WLTP-Brake Cycle profile. The aim is to adjust the cooling air volume for the different dynos.

- ***IBT 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. IBT of exactly 40°C shall be applied when performing the cooling air flowrate adjustment by means of trip #10 of the WLTP-Brake Cycle.
- More details regarding the application of the WLTP-Brake Cycle (including the adjustment of the cooling air flowrate) are included to the protocol "***Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle***".

Task Force 2 – Development phase

2. Background Concentration --- Topic closed

Each laboratory 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;
- It is encouraged that the cooling air entering the brake enclosure during an emission test passes through a ***charcoal (or activated carbon) filter*** with the aim of removing volatile organic species.
- ***The background concentration shall be defined on a PN basis.*** Each laboratory shall report their background concentration which shall not exceed the maximum allowed value of ***X particles/cm^3***;
- It is recommended to perform the BG check 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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Task Force 2 – Development phase

3. Dyno Climatics – Defined range of incoming cooling air temperature and RH --- Topic closed

Volume flow should be constant during the test. Brake/caliper orientation relative to incoming cooling air plays a major role (see Brake Enclosure Design).

- ***Volume flow*** as well as ***its measurement point(s)*** need to be reported in order to avoid wrong comparisons.
- ***Cooling air temperature and Relative Humidity shall be adjusted to 20±2°C and 50±5%, respectively.*** Labs need to make sure they stay as close to the target values as possible (20°C and 50% RH). The same values apply for the adjustment of the cooling air flowrate during trip #10. ***20±5°C and 50±10% RH are allowed for no longer than the 10% duration of the cycle.***

Task Force 2 – Development phase

4. Brake Temperature Measurement --- Topic closed

A common protocol describing the temperature measurement is required to ensure repeatable and comparable measurements.

- ***Only embedded thermocouples shall be used for recording brake temperature regimes.*** Sliding thermocouples might also be used in addition but shall not be considered for lab-to-lab comparison purposes.
- ***The disc thermocouple should be located in the outboard plate rubbing surface, radially positioned 10 mm outwards of the center of the friction path, and recessed ½ mm deep into the face of the disc.*** On vented discs the thermocouple should be centered between two fins of the disc plate.
- More details regarding the measurement method have been included to the protocol ***"Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle"***

Task Force 2 – Development phase

5. Definition of bedding-in procedure --- Topic closed

Bedding shall be long enough to ensure the ***stabilization of the friction couple behavior***. However, there needs to be a compromise in terms of the stabilization in order to reach a ***reasonable testing time***.

- 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 RR exercise.
- It is recommended that the 5 WLTP-based novel cycles run consecutively without any interruption. ***Soak times shall not apply between the individual trips during the bedding procedure***. However, each repetition shall commence with IBT of 40°C (1st repetition at ambient temperature).

Additional Elements

JRC invites the labs to run a campaign with the aim of comparing the bedding of a brake couple with the application of 5 WLTP-Brake Cycles as described above against the following alternatives:

- ✓ The application of 5 repetitions of the WLTP-Brake Cycles WITH soak times
- ✓ The application of ten repetitions of trip #10 of the WLTP-Brake Cycle

Task Force 2 – Development phase

6. Brake Enclosure Design (1/2) --- Topic closed

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 ***avoidance of sharp bends and abrupt changes in cross-section*** and the use of smooth internal surfaces (i.e. curved edges) to reduce flow recirculation zones. ***Gradual changes in the cross-section are permitted***; however, it is recommended to apply smooth transition angles to overcome these cross-section changes and ***avoid application of 90 degrees – and larger – bends***;

- The brake enclosure shall come in dimensions which allow for measurements of ***all common sizes of LDV brake assemblies***. However, it is strongly recommended to ***avoid oversized enclosures due to higher residence times and increased particle losses***. Maximum dimensions might be specified in the future when more data become available;

Task Force 2 – Development phase

6. Brake Enclosure Design (2/2) --- Topic closed

- The use of ***electropolished surfaces*** (i.e. stainless steel), or other electrically conductive material ***to avoid particle losses by electrostatic deposition***, is recommended;
- The enclosure shall be designed in such a way that a ***maximum particle residence time of X sec is ensured*** (value to be agreed after the experimental RR phase). Every lab shall report the maximum residence time for their setup based on their specific design for a given cooling air flow rate.
- The caliper shall be positioned in a way to minimize a potential interference with the incoming cooling air. Depending on the orientation of the duct works (horizontal or vertical), 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*** (CCW) independently of the orientation of the duct works (horizontal or vertical).

Task Force 2 – Development phase

7. PM Measurement --- Topic to be addressed

PM ($PM_{2.5}$ and PM_{10}) should be measured gravimetrically. Great care needs to be taken to ensure isokinetic sampling. TF2 members have been requested to carefully study the corresponding chapter drafted by Brembo-Dekati-JRC and come back with suggestions.

Topics for consideration

- ✓ Detailed specifications for the cyclone, the filter media + efficiency, the weighting method etc. are required
- ✓ Recommendations for minimizing coarse particles losses and ensuring accurate and reproducible PM_{10} measurement are needed
- ✓ Other topics (?)

Task Force 2 – Development phase

8. PN Measurement --- Topic to be addressed

PN down to 10 nm should be measured directly preferably by means of a full-flow CPC or OPC technique. Indirect measurements, conversions, and corrections shall be avoided. Specifications for measurement of both total PN and solid only PN shall be prepared and provided.

Topics for consideration

- ✓ How should one deal with volatile background? How does it affect PN measurement in both cases (Solid vs. Total)
- ✓ The calibration procedure has not been discussed yet. Are there any preliminary proposals for both cases (Solid vs. Total)?
- ✓ Other topics (?)

Task Force 2 – Development phase

9. Other Topics --- Topic to be addressed

- Minumum parameters to be registered and commonly acceptable format. A first proposal for some of the parameters have been included to the protocol "***Part 1: Inertia Dynamometer Protocol to Measure and Characterise Brake Emissions Using the WLTP-Brake Cycle***"
- Cleaning procedure of the test bench after testing. How should this be done? How often? Any other considerations?
- System size and spacing considerations. Some partners have expressed concerns regarding the overall required space for the brake dyno and the necessary equipment
- Discussion on what happens if a test is interrupted between the different cycle repetitions or within the same cycle between the different trips
- Other topics (?)

Brake Emissions – Task Force 2 – Next Steps

Testing Phase

- ✓ A RR campaign will take place in the next months. TF2 members and external labs able to follow the specified requirements will participate. The campaign will start in Q4 2020 and finish by the end of Q1 2021. Details about the campaign will become available at the next F2F PMP Meeting

Assessment Phase

- ✓ This phase will include the assessment of the RR results. TF2 will develop the final specifications for the brake emissions measurement method. This task is expected to be completed by Q3 2021

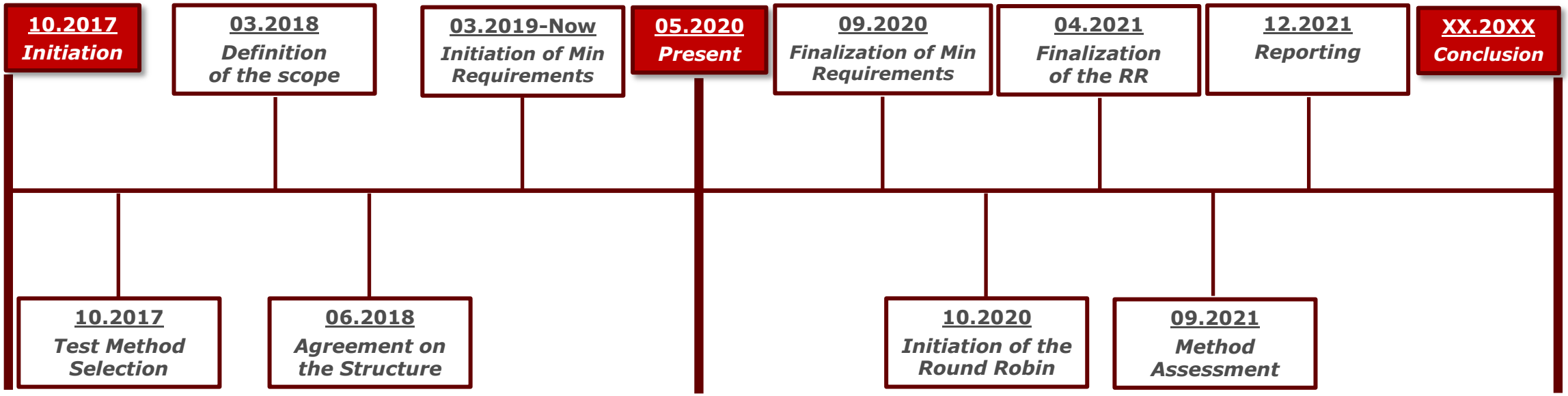
Reporting Phase

- ✓ Parts 2 "Minimum Requirements and Guidelines for Sampling and Measurement of Brake Emissions for Particle Number and Particle Mass" and 3 "Reporting Test Results from Brake Emissions Testing" of the PMP Brake Protocol will be published at Q4 2021

The next steps as described above will rely on labs which will be available within the indicated timeframe.

Decisions regarding the final method will rely only on available experimental data

Task Force 2 – Timeline



- ✓ It is possible that a monitoring phase to understand PM and PN EFs will be required after the development of the measurement method;
- ✓ At the same time possible adjustments to include other vehicle types and categories to the general methodology will be required.

Thank you

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