Chapter 1: Introduction and definition of the scope

1 Rationale

There is a sharp increase in interest internationally to better characterize brake wear emissions due to concerns of their increasing importance relative to exhaust pollution and possible toxicological concerns due to their high metal content. Several aspects should be considered when studying brake particle emissions including brake pad materials, vehicle type and driving behavior. For some of these aspects available literature data are sufficient to draw conclusions since there is a general consensus among the scientific community (Informal document GRPE-69-23). However, there are many other aspects for which the current knowledge is not sufficient to reach sound conclusions. This is due to either scarcity of data (brake particle emissions is a relatively new topic of research), or in most cases inconsistency of the reported results due to the employment of different testing procedures (sampling methodologies and measurement techniques). A summary of the level of knowledge and the still existing gaps has been provided in the Informal document GRPE-69-23 (69th GRPE, 5-6 June 2014).

Based on the Terms of Reference (ToR) and rules of procedure for the Particle Measurement Programme Informal Working Group (PMP IWG), published in June 2016, the PMP IWG should work towards the ***"Development of a suggested common test procedure for sampling and assessing brake wear particles both in terms of mass and number"***. The need for the development of a commonly accepted test procedure relates to the lack of a standardized approach for investigating brake particle emissions. This lack has led to a variety of experimental and roadside measurement results, which are difficult to compare or apply more generally. The proposed methodology should simulate real world conditions to the greatest extent possible and at the same time create comparable and harmonized measurement systems for Research and Development (R&D) and scientific purposes. The proposed setup should enable an accurate and reproducible measurement of desired parameters and let the end users decide which values to measure in accordance with the aim of their work and research focus. ***The overall objective of the proposed methodology is to provide guidance for the harmonization of future wear studies and thus improve the comparability of the results worldwide.*** The chosen methodology for rigorous sampling and characterization of brake wear particulate is the enclosed brake dynamometer. This method allows for the sampling of brake wear PM without interferences from other sources and allows for the minimization of particle losses. It offers a flexible platform to test various brake pads and configurations and simulate different driving conditions and vehicle loads.

Three steps were identified in the ToR in order to achieve the development of this commonly accepted methodology: (a) ***Selection or development of a test cycle appropriate for the investigation of brake wear particles***; (b) ***Investigation and selection of the appropriate methodologies for particle generation and sampling,*** in this case the enclosed brake dynamometer; and (c) ***Investigation and selection of the appropriate instrumentation for the measurement and characterization of brake wear particles***. Two Task Forces (TF) were created in the framework of the PMP IWG with the aim of addressing the identified working items. TF1 was created in November 2016 with the aim of accelerating the work with regard to the development of the new braking schedule (Step (a)). TF2 was created in September 2017 and has been working since then on the sampling and measurement specifications of the proposed methodology. Steps (b) and (c) of the ToR

have been modified and are handled by TF2 as one individual working item. Information regarding the TF are provided in the Annex of the current document.

2 Definition of the Scope

Members of TF2 have independently experimented with the concept of measuring brake wear PM using a brake dynamometer and synthesized their design concepts and preliminary results. They initially presented their own findings in order to reach a common understanding and agreement regarding the definition of the scope and the following questions were distributed to the members of the TF2 and discussed in detail in several TF2 meetings:

- ✓ ***Q1: Is it possible to develop a methodology for PM_{10}, $PM_{2.5}$ and PN concentration measurements using as a basis the existing configurations?***
- ✓ ***Q2: If yes, are simultaneous measurements feasible using the same sampling system or do we need to develop two different methods, one for PM_{10} and one for $PM_{2.5}$ and PN?***
- ✓ ***Q3: Is it necessary/desirable to have PM and PN size distribution measurements in addition to concentrations without changing sampling configuration?***
- ✓ ***Q4: If yes, are simultaneous measurements feasible using the same sampling system or do we need to develop different methodologies for concentrations and distributions?***
- ✓ ***Q5: Would it be possible to collect PM_{10} by using filters?***
- ✓ ***Q6: Is there any other parameter that should be considered and included in the measurement scheme?***

Table 1 summarizes the answers provided by the TF2 participants to the questions listed above. The way answers are presented ensures the anonimity of the participants as it is out of the scope of the document to expose the individual opinion of each participant. “Y” stands for positive while “N” for negative answers to the respective question. The “?” stands for no opinion on the specific question. Asterisk is related to answer followed by some comment. A more detailed analysis on the comments regarding specific questions follows.

Table 1: Overview of answers to the questions related to the definition of the scope

	Q1	Q2	Q3	Q4	Q5	Q6
Partner #1	Y	Y	Y	Y	Y	Y
Partner #2	Y	Y	N	Y	Y	Y*
Partner #3	Y	Y	Y	N	Y	N
Partner #4	Y	Y	Y	Y	Y	N
Partner #5	Y	Y	N	Y	Y	N
Partner #6	Y	Y	Y	Y	Y	N
Partner #7	Y	Y	N	Y	Y	N
Partner #8	Y	Y	Y*	Y	Y	N
Partner #9	Y	Y	Y	?	?	N

Partner #10	N	N	Y	N	Y	N
Partner #11	Y	Y	Y*	N	Y	N
Partner #12	Y*	Y*	Y*	Y*	Y	N
Partner #13	Y	Y	Y	Y	Y	N
Partner #14	Y	?	N	?	Y	N
Partner #15	Y	Y	Y	Y	Y	Y*
Partner #16	Y	Y	?	Y	Y	Y

Question 1 – Is it possible to develop a methodology for PM_{10}, $PM_{2.5}$ and PN concentration measurements using as a basis the existing configurations? Based on the feedback from TF2 Members it seems that **it is possible to develop a methodology for PM_{10}, $PM_{2.5}$ and PN concentration measurements using as a basis the existing configurations.** However, an optimization of existing configurations will be required. All modifications will be done after a joint review of specifications and boundary conditions.

Several technical comments/issues were raised by the TF2 members. There have been concerns regarding the selection of the sampling locations with respect to the different metrics, the handling of cooling air flowrate in order to maintain realistic brake temperature, the uniformity of the sample inside the sampling tube, the influence of the nucleation mode, etc. One partner stated that that there are big challenges in measurement of PM_{10}, and for that reason it would be extremely difficult to include PM_{10} in the scope. It was agreed that these points would be addressed individually at a later stage during the technical discussion.

Question 2 – If yes (referring to Q1), are simultaneous measurements feasible using the same sampling system or do we need to develop two different methods, one for PM_{10} and one for $PM_{2.5}$ and PN? This question has already been answered in the context of Q1. **Overall, it seems that it is possible to conduct simultaneous measurements using the same sampling system but different methodologies for PM and PN.**

Very few technical comments/issues were raised by the TF2 members. There have been concerns regarding the selection of the sampling locations with respect to the different metrics and the handling of cooling air flowrate in order to maintain realistic brake temperature. It was also stated that measurements should be performed with best available instruments and not aim to necessarily obtain both measurements with the same instrument. There is a consensus among TF2 Members that PM should be measured gravimetrically (and not calculated through indirect methods), whereas PN should be determined with the best available measurement technologies. Some members raised the concern that there may be a need for separate experimental runs to determine both PM and PN concentrations.

Question 3 – Is it necessary/desirable to have PM and PN size distribution measurements in addition to concentrations without changing sampling configuration? Based on the feedback from TF2 Members the **decision is to investigate the possibility of measuring PM and PN size distributions as optional items without including them in the scope.** The consensus is that both distributions are desirable for R&D work, while PN distribution is helpful to study the effect of nucleation. However, future routine testing emphasizing total PM mass may not require size

distribution measurement. The primary reason to include it as optional relates to the already challenging and complicated nature of addressing Q1 and Q2 and thus it wouldn't be feasible for TF2 to commit to an additional difficult task in such a short timeframe.

Question 4 – If yes (referring to Q3), are simultaneous measurements feasible using the same sampling system or do we need to develop different methodologies for concentrations and distributions? This question has already been answered in the context of Q3. Following the decision to include PM and PN distributions as optional items, TF2 Members believe that simultaneous measurement is feasible. The idea of having different methodologies is complex and costly for the interested parties. On the other hand, keeping this opportunity as optional will allow end users to decide if they need it and if they are willing to take over the cost.

Question 5 – Would it be possible to collect PM_{10} by using filters? This question has already been answered in the context of Q1 and Q2. **There is a consensus that the collection of PM_{10} (and $PM_{2.5}$) in filters is the proposed methodology to determine PM concentrations**. There are certain technical aspects to be considered such as the use of cyclones for larger particle collection and the subsequent sampling losses, handling of high and low particle emissions are recorded (high emissions could block the filters due to too much wear debris, whereas at low concentrations there is certainly a concern about filter media and filter handling), validation of the methodology, etc. It was agreed for these points to be addressed at a later stage during the technical discussion.

Question 6 – Is there any other parameter that should be considered and included in the measurement scheme? There are some additional parameters which have been proposed by TF2 Members with real-time PM and PN measurements and chemical analysis of the collected filters being the most important. **It was decided that these parameters will be considered but they will not become a part of the scope of the proposed methodology.** In other words, TF2 will describe the best practices for filter handling and real time measurements but will not develop any methodology as part of the scope of the TF2.

Based on the opinion of TF2 the development of a methodology capable of providing meaningful and reproducible measurement results for PM_{10}, $PM_{2.5}$ and PN concentrations as well as distributions is very challenging and complicated. For that reason it was decided to limit the scope of the current project to the measurement of PM_{10}, $PM_{2.5}$ and PN concentrations and keep the rest of the parameters as optional. The proposed methodology should simulate real world conditions to the greatest extent possible and at the same time create comparable and harmonized measurement systems. The overall objective of this document is to provide guidance for the harmonization of future wear studies and thus improve the comparability of brake wear PM measurement results worldwide.

3 Topics not addressed in the proposed methodology

Several technologies are available for the measurement of PM and PN concentrations. Some of these methods are based on a direct measurement of the targeted parameter (i.e. gravimetric measurement of mass or measurement of particle number concentration via a particle counter technique), while others base their measurement principle on indirect methods (i.e. convertion of the PN concentration to mass concentration). Since there is not sufficient data in the literature regarding brake wear particle density, no indirect methodology will be taken into account for the

development of the proposed methodology. Furthermore, the calculation of the density of the brake wear particles will not be considered as it is a complex task and is out of the scope of the PMP IWG.

Chemical analysis of the collected brake wear particles is a very important task which will help researchers better understand the properties and further assess possible health effects of these particles on humans. For that reason TF2 will describe the best practices for filter handling in the proposed methodology. However, further details regarding chemical analysis is out of scope of the TF2 and will not be provided.

Health effect studies are under the responsibility of the WHO (World Health Organisation) and outside the scope of the PMP group. Therefore, the proposed methodology is not related by any means to health related issues.