Preliminary Outline

1. **Introduction, rationale, scope and list of topics not addressed**
    1.1. Rationale
    1.2. Definition of the scope
    1.3. Topics not addressed in the proposed methodology

2. **Nomenclature, definitions, and terminology, including ISO and EN standards**
    2.1. Particulate matter
    2.2. Brake dynamometer testing
    2.3. Calibration and validation

3. **Brake dynamometer capabilities**
    3.1. General
    3.2. Fast rate automatic data collection
    3.3. Slow rate automatic data collection
    3.4. Brake emissions data collection
    3.5. Cooling air
    3.6. Test conditions and sample preparation
    3.7. Brake test fixture

4. **Sampling system**
    4.1. Cooling air speed/airflow and climatic conditioning for air temperature and relative humidity (measurement of background concentration)
    4.2. Enclosure[1] and guidelines for duct size, shape[2], and material (including surface finish in wet areas)
    4.3. Conditioning for sampling air (dilution, temperature, etc.)
    4.4. Layout and losses (acceptable levels for PN, PM metrics)
    4.5. Cooling air settings[3] and temperature regimes using the WLTP based reference brake cycle (LowMet vs NAO)

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[1] F-M: Two parameters that should be considered: **a. Complete flow around the brake system most probably will be required.** Decoupling a partial sampling current on the brake system by suction on the brake caliper or similar seems barely controllable and comparable, since losses can hardly be quantified and are likely to depend on the cooling air speed, etc. Loss detection through a numerical simulation of such structures has very limited validity and credibility. Risk of uncontrollable, undefined experimental conditions! **b. Isokinetic aerosol removal from the duct must be ensured.** Compliance with isokinetics depends on the cooling air speed (short sample line, as few as possible 90° bends). Uniform tube cross sections. Hoses made of conductive material (conductive silicone rubber).

[2] Horiba: Enclosure and duct size and shape should provide reproducible and repeatable results for wide range brake disk sizes used in passenger cars (12-19 inch). Attention should be paid to pads temperature – for small pipe diameter they will be overheated. Maybe consider defining cooling efficiency or time for pads/disk cooling rather than duct size and shape. It should be comparable to real world conditions. Otherwise, one can expect over- or underestimation of both PM and PN.

[3] Horiba: Air speed should be comparable to real world conditions (10 km/h < X < 100 km/h). Reasonable cooling time as well as sufficient dilution ratio and distance to sampling L will provide homogenous mixture of probe.

5. Brake emissions mass measurement system

5.1. Mass measurement methods

5.2. Minimizing transport losses

5.3. Sampling procedures

5.4. Weighing procedure

5.5. Calculation

5.6. Calibration and verification procedures

5.7. Real time measurement instruments

6. Brake emissions number measurement system

6.1. Particle number measurement principle

6.2. Data output and sampling rates

6.3. Handling of volatiles (assumptions, removal, correction)

6.4. Particle measurement system (from sampling point to measurement) specifications

6.5. Calibration and verification procedures

7. System calibration, validation, and sign-off[4]

7.1. Standard losses estimation numerical tools (spreadsheets, calculators, computational fluid dynamics[5] with physical validation)[6]

7.2. Standard calibration process[7] for particle measurement with reference aerosols, filters, and use of approved reference brakes

7.3. Standard procedures for replicate tests and uncertainty calculations[8]

7.4. Data calculation principles (open data handling, documented calculation procedures for both instrument result and sampling loss etc. determination)

7.5. Checklists for installation, validation, calibration, and regular check-ups

8. Appendixes

8.1. Dynamometer approved test cycle

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[4] Could this Chapter be removed and its topics migrate to existing Chapters?

[5] AVL: This looks like an overkill. We should evaluate the necessity of requiring losses calculations and corrections. Ideally it would be sufficient to establish proper limits (penetrations, residence times) to restrain the losses to low levels

[6] Spreadsheets/calculators are available for particle loss simulation in sample lines. [Horiba]: Has to be moved to Appendix. Results for particle losses will strongly depend on physical and chemical properties of brake airborne.

[7] AVL: Considering that the challenges are different for PM and PN it would make sense to have this section segregated. Considering the importance of this topic, we would suggest to include this as subsections in chapters 5 and 6 respectively. We should refer as much as possible to existing procedures and standards. [Horiba]: We have to define first what kind of particles we have and afterwords think about calibration. Even for exhaust measurements there are a few approaches for calibration of instruments.

[8] JARI: Wouldn't it make sense to address in Item 8.3. "Uncertainty of measurement". Since this aims to check correation between different laboratories, e.g. supplier and OEM. [Horiba]: Can be moved to appendix and or considered by definition of test procedure Chapter 8.

8.1.1. Vehicle loading conditions (Definition based on available statistics)

8.1.2. Front and rear brake loading conditions (70% of load on front brakes)

8.1.3. Tabular cycle with speed and deceleration as a function of time/temperature (at least 1 Hz), allowing clear separation of journeys and optional cycles (low, medium, high energy or city, urban, highway, etc.)

8.2. Coagulation estimates[9] (how to handle bimodal lognormal distributions[10])

8.3. Uncertainty of measurement

8.4. Size distribution measurements

8.4.1. Charging probabilities and applicability to the specifics of brake wear particles (are these the same for those produced by friction and those produced thermally[11])

8.4.2. Morphology, effective particle density (are these properties constant or do they depend on the formation mechanism and the size range?)

8.4.3. Transparent inversion procedures (How does raw signal translate to mass or number concentration?)

8.4.4. Validation of transient performance

8.5. Material density and porosity correction[12]

9. References

9.1. Applicable EPA, ISO, EN, SAE standards

9.2. Literature

9.3. Technical Papers

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[9] F-M: Bimodal size distributions and coagulation can occur for a variety of reasons: e.g. Property of the braking system or property of the test setup or any mixture thereof. Coagulation processes are 1. Extremely strongly dependent on the particle number concentration (~ N^2) and need 2. Possibly more time than required to move the aerosol from the brake system to the meter and 3. Preferably take place between dissimilar partners (small and large particles). I think this point can only be treated after a better data situation (much more measurement data). [Horiba: This is one big topic “particle losses” and should not be considered separately].

[10] [AVL]: This is excessive. We do not thing there is a need for such a placeholder as of yet, especially since size distribution measurements are not mandated. [Horiba]: Depends on type of pads materials. The topic has to be addressed to equipment supplier.

[11] [Horiba]: How can we distinguish between particle produced by friction and thermally? There are specific questions that have to be addressed to equipment supplier and not to TF2

[12] [F-M]: Applies to conversion between number-based and mass-based measures. High risk of systematic errors due to incorrect assumptions in the conversion; [AVL]: With respect to what? Here comes the benefit of dealing with total particle counts (of properly conditioned aerosol) and total gravimetric mass; [Horiba]: We never discussed conversion results of PN based measurements to PM or vice versa. Why should we need such complicated conversion if we agree to do both PN and PM measurements?