Title: Proposal for a new UN GTR on Laboratory Measurement of Brake Emissions for Light-Duty Vehicles

This informal document is submitted by the Informal Working Group (IWG) on Particle Measurement Programme (PMP) to inform the GRPE of the work of the IWG PMP on the development of a new UN GTR for the measurement and characterization of brake emissions of Light-Duty vehicles at brake dynamometer level. The submission of this document follows the request of the GRPE group according to the ECE/TRANS/WP.29/2021/150.

The informal document describes the technical details of the proposed PMP Brake Protocol for sampling and measuring brake particle emissions from full friction brakes. It also foresees placeholders for the introduction of the specific methodology for measuring brake particle emissions from brakes with regenerative capability. The informal document includes fourteen paragraphs aiming to provide a comprehensive protocol for testing facilities.

This document is submitted with the aim of collecting feedback from the GRPE stakeholders. The contents of the present document – including the final structure – will be finalized and included to the official working document that will be submitted to the GRPE after the end of the feedback process.

Recipients of this draft are invited to submit, with their comments, a 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 existent patent.

Submitted by the Informal Working Group on non-exhaust for Particulate Measurement Programme on 11.07.2022.

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# Statement of technical rationale and justification

1. Introduction

1. Over recent years there has been a sharp increase in the international interest to characterise non-exhaust emissions of particles from road transport. Until recently, exhaust sources dominated road transport emissions, and all regulatory efforts have been aiming at their reduction. As exhaust emissions were reduced due to increasingly stringent regulations, the relative contribution of non-exhaust emissions to overall ambient concentrations of particulate matter increased.

2. Most manufacturers produce vehicles for a global clientele, or at least for several regions. Since manufacturers tend to cater to the preferences, needs, and lifestyles of specific geographic regions, vehicle designs will vary worldwide. As compliance with different emission standards in each region can create burdens from an administrative and vehicle design point of view, vehicle manufacturers tend to have a strong interest in harmonising brake emission test procedures and performance requirements on a global scale. Global harmonisation is also of interest to regulators as it offers more efficient development and adaptation to technical progress, potential collaborations with market surveillance, and facilitates the exchange of information between regulatory authorities.

3. In this context, stakeholders launched the work for this United Nations Global Technical Regulation (UN GTR) on Worldwide harmonised Light vehicle Test Procedures (WLTP) for particle emissions from brake wear. This UN GTR aims to harmonise test procedures for emissions from Light-Duty Vehicles (LDV) to the extent possible. Laboratory test procedures need to represent real driving conditions as much as possible and to enable a direct comparison between the performance of vehicles during certification procedures and in real life. However, this aspect puts some limitations on the level of harmonisation to be achieved. Furthermore, different countries will show varying levels of development, population densities, and costs associated with braking system technology. Consequently, the regulatory stringency of legislation is expected to vary from region to region for the foreseeable future. Therefore, the definition of emission limit values is not part of this UN GTR.

4. UN GTRs are intended to be implemented into regional legislation by as many Contracting Parties as possible. The selection of vehicle categories to be covered by the scope of regional legislation represents a challenge as it depends on regional conditions that cannot be anticipated. However, according to the provisions of the 1998 UN ECE agreement, a UN GTR being implemented by a Contracting Party must apply to all vehicles, conditions, and equipment falling under its formal scope. Therefore, care must be taken in developing the scope of the UN GTR, as an unduly large formal scope may prevent or hamper its implementation into regional legislation. For this reason, the formal scope of this UN GTR is limited to Light-Duty vehicles up to 3500 kg. This limitation does not, however, indicate that the scope of this UN GTR should not be applied to a larger group of vehicle categories when implemented into regional legislation. Indeed, Contracting Parties are encouraged to do so if this is feasible and appropriate from a technical, economical, and administrative point of view.

5. A harmonised approach for measuring brake particle emissions would allow manufacturers to better understand the behaviour of different brake systems, reduce inconsistencies in results and; therefore, compare them more efficiently, and develop strategies to decrease brake emissions.

6. This version of the UN GTR does not contain test requirements specific to other types of vehicles e.g. heavy-duty vehicles, off-road or special purpose vehicles. Thus, these vehicles are not included in the scope of the UN GTR. However, Contracting Parties may apply the provisions within this UN GTR to such vehicles to the extent possible from a technical point of view, and complement them with additional provisions in regional legislation e.g. brake emission testing with different types of friction materials or mating parts.

1. Procedural background and future development

7. In 2013, following the submission of informal documents by the Russian Federation, UNECE WP.29 agreed with the GRPE decision to task the Informal Working Group on Particle Measurement Programme (IWG on PMP) to investigate the issues concerning the emissions of non-exhaust emissions of particles from road transport. The main objective of the IWG on PMP was to investigate whether there is a need to extend particle measurement procedures to additional sources such as brake, tyre, and road wear.

8. The IWG on PMP identified brake and tyre wear as the most relevant sources of non-exhaust emissions of particles from road transport and selected them as the main topics for future investigation (Informal document GRPE-69-23). With regards to brake wear emissions, the primary task of the IWG on PMP has been to define a set of “normal” or “typical” driving conditions, investigate the suitability of existing driving cycles for studying brake particle emissions, and develop a novel test cycle reproducing the driving and braking activity of Light-Duty vehicles in real-world conditions. Other main tasks included the broadening of the IWG on PMP to include non-exhaust experts, the development of guidelines and best practices for sampling and measuring brake wear particles, and the establishment of minimum requirements to report test results.

9. Following the approval by AC.3 of the first mandate of the IWG on PMP regarding non-exhaust emissions in June 2013, the IWG on PMP aimed to accomplish the following objectives, which were completed by June 2016:

1. Conduct a literature survey summarising the current knowledge on the physical/chemical nature, mass, number, and size distribution of non-exhaust particle emissions (JRC 89231 – EUR 26648);
2. Identify and report the main knowledge gaps and the needs for future research. These findings were included in a report submitted to the 69th GRPE session (Informal Document GRPE-69-23);
3. Establish a group of experts in the field of non-exhaust emissions, sharing information and ongoing research on topics related to non-exhaust emissions;
4. Analyse the WLTP database to define normal and extreme driving conditions, and gather information on existing methodologies for sampling and measuring non-exhaust emissions;
5. Consider the most suitable testing approach for brake emissions, and define the pros and cons of different available options (brake test rig, full vehicle chassis dyno, vehicle on-road, etc.).

10. In the context of point (e), the IWG on PMP extensively discussed several options for a standardised method to sample and characterise brake wear particles, and eventually selected an approach based on a fully-enclosed brake dynamometer. This method allows the sampling of particles from brake wear without interferences from other sources and minimises particle losses over the entire sampling and measurement line. Furthermore, brake dynamometers offer a flexible platform to test different friction couples under various driving conditions and vehicle loads. The laboratory setup needs to enable repeatable and reproducible measurements at least for a defined set of core parameters. An appropriate installation of the laboratory setup will then allow the end-user to select additional values worth measuring, within the capabilities of the system.

11. A second mandate for the IWG on PMP with specific reference to non-exhaust emissions was approved in June 2016 by AC.3. The IWG on PMP was mandated to develop a commonly accepted test procedure for sampling and assessing brake wear particles both in terms of mass and number. The methodology would aim to provide the necessary tool to support future studies on brake emissions that can be easily compared. During the reporting period of the mandate (2016-2019) the following items were addressed:

1. Development and validation of a novel test cycle appropriate for the investigation of brake wear particles;
2. Investigation and selection of the appropriate methodologies for particle generation and sampling;
3. Investigation and selection of the appropriate instrumentation for the measurement and characterisation of brake wear particles.

12. After completing a thorough analysis regarding the suitability of existing brake cycles, the IWG on PMP decided to proceed with the development of a novel test cycle appropriate for the investigation of brake wear particles. Therefore, the IWG on PMP decided to create a dedicated Task Force (TF1) to accelerate the development of a test cycle in October 2016. In September 2017, the IWG on PMP decided to create a dedicated Task Force (TF2) to investigate and select the appropriate methodologies and instrumentation for the measurement of brake wear particles. TF2 initiated its activities in October 2017.

13. During the reporting period (2016-2019), the IWG on PMP aimed to accomplish the following objectives:

1. Selection of the brake test rig methodology for the generation and sampling of brake wear particles;
2. Agreement on the method’s target measurement parameters. TF2 agreed unanimously that both PM (PM10 and PM2.5) and PN (≥10 nm) emissions shall be addressed;
3. Development and publication of the WLTP-Brake cycle. The cycle is based on real-world data extracted from the WLTP database and is considered representative of real-world applications;
4. Validation of the WLTP-Brake cycle through an interlaboratory accuracy study exercise which was completed in 8 different laboratories in Europe and the United States;
5. A thorough analysis of the existing methods and setups for the sampling and measurement of brake particle emissions. Agreement on the need of defining a set of minimum specifications and requirements for sampling and measurement of brake particle emissions.

14. The mandate for the IWG on PMP regarding non-exhaust emissions was further extended in June 2019 by AC.3. The revised mandate included an additional item compared to 2016, which foresaw the validation of the proposed methodology for the measurement and characterisation of brake wear particles. During the reporting period (2019-2020), the IWG on PMP aimed to accomplish the following objectives:

1. Update the GRPE of the work of the IWG on PMP (TF1) on the development of the novel WLTP-Brake cycle and its application in the measurement and characterisation of brake emissions at brake dynamometer level;
2. A first discussion on how to address future technologies took place at the IWG on PMP level following the request of several GRPE stakeholders.

15. The mandate for the IWG on PMP regarding non-exhaust emissions was further extended in June 2020 by AC.3. Following the discussion at the IWG on PMP level, the revised mandate included the extension of the proposed methodology to future technologies. In June 2020, several GRPE Contracting Parties urged the IWG on PMP to start considering a possible use of the proposed method as a regulatory tool. Therefore, the IWG on PMP was requested to start looking at the necessary changes and adaptations to extend the method to all existing technologies and other vehicle categories.

16. Stakeholders and Contracting Parties discussed the possible approaches to regulate brake particle emissions in a workshop in January 2021. The main topics discussed during the workshop include:

1. The ideal scheme for regulating brake emissions from conventional ICE Light-Duty vehicles;
2. How to handle non-conventional Light-Duty vehicles (i.e. HEVs, PEVs) in a possible future regulatory approach;
3. Heavy-Duty vehicle brake emissions and possible approaches.

17. As a follow-up of the workshop, the interested Contracting Parties and the IWG on PMP recommended that a UN GTR on brake PM and PN emissions from all types of Light-Duty vehicle brake systems is developed under a new mandate. Therefore, the representatives of the European Union, the UK and Japan sought and obtained authorisation from AC.3 to develop a new UN GTR on brake PM and PN emissions from all types of LDVs brake systems.

1. Background on the technical work of the PMP group

18. The IWG on PMP decided to create a dedicated Task Force (TF1) to accelerate the development of a test cycle in October 2016 (PMP 41st Session). The TF1 main tasks included the definition of testing parameters such as dynamometer climatic controls, the definition of the temperature measurement method, the development of a methodology for adjusting the cooling airflow based on real-world vehicle data, the support for the development of a novel test cycle, and the validation of the novel test cycle through an Inter-Laboratory Study. The novel WLTP-Brake cycle was developed in July 2018 and presented to the IWG on PMP in November 2018 (PMP 48th Session). The WLTP-Brake cycle was validated through an Inter-Laboratory Study 1 (ILS-1) with the participation of eight testing facilities. The results of the validation were presented to the IWG on PMP in April 2019 (PMP 50th Session). TF1 concluded its activities in October 2019 having completed 30 meetings.

19. The IWG on PMP decided to create a dedicated Task Force (TF2) to investigate and select the appropriate methodologies and instrumentation for sampling and measurement of brake wear particles (PMP 43rd Session). TF2 main tasks included the definition of the appropriate test setup for sampling and measuring brake particle emissions, the definition of the appropriate instrumentation for sampling and measuring particulate mass emissions, the definition of the appropriate instrumentation for sampling and measuring particle number emissions,. The TF2 submitted its recommendations for the minimum specifications for testing brake particle emissions to the IWG on PMP in July 2021 (PMP Web Conference 15.07.2021). TF2 recommendations were applied to the Inter-Laboratory Study 2 (ILS-2) to test their suitability and improve the proposed protocol. TF2 resumed its activities after the completion of the ILS-2 to finalise the protocol and prepare a proposal for the draft UN GTR to the IWG on PMP. The proposal was presented to the IWG on PMP in June 2022 (PMP Web Conference 15.06.2022). TF2 concluded its activities in June 2022 having completed 45 meetings.

20. The IWG on PMP decided to create a dedicated Task Force (TF3) to organise and execute the ILS-2 in March 2021 (PMP Web Conference 24.03.2021). The TF3 main tasks included the organisation and execution of the ILS-2, the verification of the feasibility and applicability of the defined specifications for sampling and measuring brake particle emissions, the examination of the repeatability and reproducibility of PM and PN emission measurements with the application of the defined specifications, and the preparation of recommendations to the TF2 on further improving and/or extending the set of the defined specifications. The ILS-2 was launched in September 2021 and finalised in January 2022. The results of the ILS-2 were presented to the IWG on PMP in March 2022 (PMP Web Conference 29.03.2022). TF3 concluded its activities in April 2022 having completed 6 meetings.

21. [PLACEHOLDER – REFERENCE TO THE TF4 ACTIVITIES]

22. This UN GTR provides all the information necessary to carry out brake particle emissions testing in the laboratory. The main elements of the protocol contained in this GTR include:

1. References, definitions, and terminology applying to the methodology for sampling and measuring particles from brake wear emissions;
2. General requirements and capabilities of the required test setup. Main test conditions for the different elements of the overall setup;
3. A detailed description of the WLTP-Brake cycle;
4. A detailed description of the different sections of a brake emissions test, including cooling airflow adjustment, bedding procedure, and emissions measurement;
5. Minimum requirements to report results from the dynamometer test including actual emissions measurements and metrics.

23. Future work to further expand the protocol contained in this UN GTR might address:

1. Adaptation of the proposed methodology to include non-friction braking and future technologies;
2. Adaptation of the proposed methodology to address brake emissions from heavy-duty vehicles.

# Text of the GTR

## Purpose

This Global Technical Regulation (GTR) provides a worldwide harmonised methodology for the measurement of brake wear particle and particulate emissions from Light-Duty vehicles.

This GTR defines the test cycle, minimum system requirements, test conditions, and equipment preparation to execute the WLTP-Brake cycle using brake dynamometers. This GTR also provides requirements for the design and set up of test systems to measure brake emissions, including requirements on calibration and validation of test equipment.

## Scope and application

This GTR applies to vehicles using some type of mechanical braking, using a combination of dry friction materials and a mating brake disc or brake drum.

This GTR applies to category 1-1 and category 2 vehicles with a fully laden mass below 3500 kg.

The Contracting Parties shall make a decision about the applicability of this GTR to Small Volume Manufacturers for their jurisdiction.

## Definitions

### **Vehicle and Brake Dynamometer settings**

#### "*Category 1 vehicle*" means a power-driven vehicle with four or more wheels designed and constructed primarily for the carriage of one or more persons.

#### "*Category 1‒1 vehicle*" means a category 1 vehicle comprising not more than eight seating positions in addition to the driver's seating position. A category 1‒1 vehicle may not have standing passengers.

#### "*Category 2 vehicle*" means a power-driven vehicle with four or more wheels designed and constructed primarily for the carriage of goods. This category shall also include (a) Tractive units and (b) Chassis explicitly designed to be equipped with special equipment.

#### "*Mass in running order*" is the mass of the vehicle, with its fuel tank(s) filled to at least 90 per cent of its capacity, including the mass of the driver, fuel, and liquids, fitted with the standard equipment in accordance with the manufacturer's specifications and, when they are fitted, the mass of the bodywork, the cabin, the coupling and the spare wheel(s) as well as the tools.

#### "*Mass of the driver*" means a mass rated at 75 kg located at the driver's seating reference point. In the context of the current regulation, the term "mass of additional 0.5 passengers" means a mass rated at 37.5 kg.

#### "*Maximum vehicle load*" means the technically permissible maximum laden mass minus the mass in running order, 25 kg, and the mass of the optional equipment.

#### "*Optional equipment*" means all the features not included in the standard equipment fitted to a vehicle under the manufacturer's responsibility and that the customer can order.

#### "*Standard equipment*" means the basic configuration of a vehicle equipped with all the features required under the regulatory acts of the Contracting Party, including all features that are fitted without giving rise to any further specifications on configuration or equipment level.

#### "*Vehicle test mass*" means the mass in running order plus the mass of the optional fitted equipment to an individual vehicle (kg) on which the tested brake is mounted plus:

#### 37.5 kg that corresponds to an additional mass of 0.5 passengers for category 1‒1 vehicle (or M1 vehicle category);

#### 25 kg plus 28 per cent of the Maximum Vehicle Load (MVL) for category 2 vehicles with a fully laden mass below 3.5t (or N1 vehicle category).

#### "*Road Loads*" means the total force or power required to move the vehicle on a level and smooth surface at a specified speed and mass. Road loads take account of transmission friction, rolling friction, and air resistance. In this GTR, a reduction of the brake nominal inertia by a fixed percentage of 13 per cent is considered to account for road loads in full-friction brakes emissions testing.

#### *"Tyre dynamic rolling radius"* means the tyre radius that equates to the revolutions per kilometre (or revolutions per mile) published by the tyre manufacturer for the specific tyre size (mm).

#### *"Brake force distribution"* means the ratio between the braking force of each axle and the total braking force expressed as a percentage for each axle.

#### *"Nominal Wheel load"* means the (equivalent) rotating mass as a function of the total vehicle test mass, the axle under test (front or rear), and the brake work distribution among the two axles. It represents the load at the brake corner under testing before accounting for vehicle road loads.

#### *"Test wheel load"* means the (equivalent) rotating mass as a function of the total vehicle test mass, the axle under test (front or rear), and the brake work distribution among the two axles. It represents the load at the brake corner under testing after accounting for vehicle road loads. Also referred to as *"Applied wheel load"*.

#### *"Brake nominal inertia"* means the inertia of the wheel load at the radius of gyration equal to the tyre dynamic rolling radius, which imposes the same kinetic energy on the brake as in the actual vehicle before subtracting the total road loads for the vehicle.

#### *"Brake test inertia"* means the inertia of the wheel load at the radius of gyration equal to the tyre dynamic rolling radius, which imposes the same kinetic energy on the brake as in the actual vehicle after subtracting the total road loads for the vehicle. Also referred to as *"Brake applied inertia"*.

#### *"Brake torque"* means the product of the frictional forces resulting from the tangential actuating forces in a brake assembly and the distance between the points of generation of these frictional forces and the axis of rotation. The brake torque is a function of the hydraulic piston area, apparent friction coefficient, and the effective brake radius of the brake corner.

#### *"Hydraulic pressure"* means the net pressure supplied by the brake to generate clamping force between the brake and friction material. The hydraulic pressure, combined with the brake's friction coefficient and the effective brake radius, induces the actual brake torque output.

#### *"Threshold pressure"* means the minimum hydraulic pressure to overcome the internal friction and seal forces, move the brake calliper's piston or drum wheel cylinder, and onset brake torque output.

#### *"Piston diameter**"* means the diameter of the hydraulic piston(s) in the calliper or drum wheel cylinder and is used to calculate the total piston(s) area. Also referred to as *"Hydraulic piston diameter"*.

#### *"Piston area**"* means the active area of all hydraulic pistons acting on one side of the brake calliper or drum brake cylinder.

#### *"Effective brake radius**"* means for a disc brake, the distance between the centre of rotation and the centerline of the calliper piston(s) when assembled on the fixture. For drum brakes, the effective radius is half of the drum's inner diameter.

#### *"Friction* *coefficient "* means the ratio between the tangential force and the normal force acting between the brake pad and the disc or the brake shoe and the drum. For a disc brake, the apparent friction coefficient value from the brake under testing is a function of braking torque, effective brake radius, and the piston area. The apparent coefficient of friction is a calculated (mathematical) value and is not directly measurable. Also referred to as "*Brake effectiveness*".

#### *"Brake fluid displacement"* means the transient (volumetric) use of hydraulic fluid by the brake calliper or the brake wheel cylinder during a brake deceleration event.

#### *"Average by time"* means the averaging method for a given measurand where the sampling frequency is a unit of time (between data points) through a braking event. The resultant value yields the same result as the integration between two points in time.

#### *"Average by distance"* means the averaging method for a given measurand where the sampling frequency is a unit of vehicle distance (between data points) travelled (or driven) during a braking event. The resultant value yields the same result as the integration between two distance points.

#### *"Fast sampling rate"* means the sampling rate for the data collection system greater than or equal to 250 Hz. The "fast sampling rate" applies to the dynamometer channels.

#### *"Slow sampling rate"* means the sampling rate for the data collection system that is less than or equal to 10 Hz. The "*fast sampling rate*" applies to the dynamometer channels.

#### *“sampling rate”* represents the number of events that are measured within 1 second. It is given in the unit [Hz]. Also referred to as “sampling frequency”.

*“sampling rate”* represents the number of events that are measured within 1m of distance, if it refers to distance instead of time. It is given in the unit [1/m]. Also referred to as “sampling frequency”.

#### *“recording rate”* represents the number of events that are recorded within 1 second. It is given in the unit [Hz]. Also referred to as “recording frequency”. It is used e.g. for the storage of data in files.

### **Test setup**

#### *"Brake dynamometer"* means a technical system that imposes, controls, and records the mechanical and electrical work from the brake under testing while operating with a pre-programmed test procedure.

#### *"Torque measurement sensor"* means the electromechanical device that converts the torsional strain on the brake assembly into the equivalent voltage output. The equivalent torque derives from the angular deceleration rate and the effective brake inertia.

#### *"Servo controller"* means a system that modulates the braking torque or hydraulic pressure to the intended (setpoint) value. The servo controller also provides the algorithm to control the release of braking torque or pressure at the end of the brake deceleration events.

#### *"Climatic conditioning unit"* means the air handling system which provides clean, conditioned, and controlled cooling air into the transport duct and the brake enclosure.

#### *"Cooling air"* means the clean, conditioned, and controlled air provided to the brake assembly by the climatic conditioning unit during the test through the ducting as required and described in this UN GTR.

#### *"Cooling air temperature"* means the temperature of the cooling air stream measured near the entry to the brake enclosure.

#### *"Cooling air relative humidity"* means the amount of water vapour present in the cooling air stream expressed as a percentage of the amount needed for saturation at the same temperature. It is measured near the entry to the brake enclosure.

#### *"Cooling air absolute humidity"* represents the grams of water per kilogram of dry air.

#### *"Cooling airspeed"* means the average speed of the cooling airstream measured in real-time in a length of a straight duct with constant shape and cross-sectional area.

#### *"Cooling airflow"* means the average flow of the cooling airstream provided to the brake assembly.

#### *"Brake enclosure"* means a sealed chamber that is passed by the cooling air and prevents untreated air from entering the air flowing around the brake assembly. The brake enclosure shrouds the brake assembly.

#### *"Sampling Tunnel"* means a rigid duct connecting the brake enclosure to the sampling plane and continuous to the airflow measurement device. It represents the part of the tunnel where the brake particles emitted inside the brake enclosure travel towards the sampling and measurement devices.

### **Brake hardware**

#### *"Brake under testing"* means the friction brake assembly and its associated vehicle parameters used by the test facility to measure brake particle emissions according to this UN GTR. Vehicle parameters include those from the power-train and other systems that are required to calculate the share of friction braking.

#### "*Brake assembly"* in the case of disc brakes means the set of matching brake discs, brake pad assemblies, brake calliper, and associated hardware for a given vehicle and axle application. In the case of drum brake systems, the hardware set comprises the brake drum, brake shoes, drum assembly parts, and brake mounting plate for a given vehicle and rear axle application. The brake assembly mounts on a brake fixture to adapt and connect to the brake dynamometer.

#### *"Service brake"* means the (friction or regenerative) braking system allowing the driver to control, directly or indirectly and in a graduated manner, the speed of a vehicle during normal driving or to bring the vehicle to a halt (standstill).

#### *"Full-friction brake"* means the service brake mounted on a vehicle with an internal combustion engine.

#### *"Brake fixture**"* means a mechanical device or jig to mount the brake assembly by connecting the tailstock (or non-rotating surface) to the brake dynamometer shaft (rotating). The tailstock side (or non-rotating surface) absorbs the braking torque and associated tangential forces. The rotating shaft transmits the kinetic energy from the brake test inertia to the brake assembly.

#### *"Universal style fixture"* means a brake fixture cylindrical and symmetrical without additional extensions or protrusions different from those needed to mount the brake assembly. A wheel hub is not included in the assembly.

#### *"Post style fixture"* means a dynamometer fixture that uses round and stiff tubing and adaptors, instead of the vehicle knuckle, to mount the brake assembly. A wheel hub is attached to complete the assembly.

#### *"Brake calliper**"* means a mechanical device that converts driver brake pedal input into a clamping force on the brake pads to generate braking torque.

#### *"Brake disc**"* means a rotating, wearable device against which the brake calliper clamps the brake pads in a disc brake system. This device acts as the primary heat absorption and dissipation device as the brake corner transforms vehicle kinetic energy into heat.

#### *"Brake pad**"* means a wearable device that mounts onto the brake calliper consisting of a structural (metal) pressure plate and a friction material element. The brake pads clamp against the brake disc, generating a retarding friction force and thus the brake torque.

#### *"Brake drum**"* means a rotating, wearable mechanism against which the brake wheel cylinder clamps the brake shoes in a drum brake system. This device acts as the primary heat absorption and dissipation device as the brake corner translates vehicle kinetic energy into heat.

#### *"Brake shoe"* means a wearable device consisting of an arced structural metal shoe and a (bonded or riveted) friction material. The brake shoe is clamped against the drum to generate friction and thus brake torque.

#### *"Friction material part number"* means the unique edge code to identify the specific friction material supplier, formulation, and environmental marking.

#### *"Disc or drum part number"* means the unique code labelled by the manufacturer to identify the specific disc or drum.

#### *"Lateral runout"* means the change in the axial distance (from a datum plane) to the braking surface of the brake disc during one complete revolution at a given radial position.

#### *"Running clearance"* means the axial distance between the braking surface of the disc and the brake pad during one complete revolution with the brake released. For drum brakes, it is the radial distance between the inner diameter of the drum and the brake shoe.

### **WLTP-Brake Cycle**

#### *"Driving cycle"* means a series of data points representing the speed of a vehicle versus time. The driving cycle consists of individual trips and each trip consists of a series of separate and consecutive events. These events include brake dwell, acceleration, cruising, and deceleration.

#### *" WLTP-Brake cycle"* means the driving cycle derived from the vehicle activity of the Worldwide Light vehicle Test Procedure database with a total duration of 15 826 seconds plus the cooling sections in-between trips. The cycle comprises ten trips and 303 brake deceleration events.

#### *"Brake emissions test"* means a sequence of three sections (cooling air adjustment, brake bedding, and brake emissions measurement) to characterise the particle emissions of the brake under testing, which in general are performed in consecutive order.

#### *"Cooling air adjustment"* means the section that follows a procedure with the brake under testing to define the appropriate incoming cooling airflow for the bedding and emissions measurement sections. Also referred to as “cooling adjustment section”.

#### *"Brake bedding"* means the section with a sequence of braking events to develop a friction couple with a stable transfer layer, brake effectiveness, and brake emissions behaviour before conducting the brake emissions measurement section. Also referred to as the "*Bedding procedure*" or “bedding section”.

#### *"Brake emissions measurement"* means the section of the brake emissions test where PM and PN emissions are sampled and measured. Also referred to as “emission measurement section”.

#### *"Brake acceleration event"* means a measurable period during which the linear speed increases to a predetermined set value at a known rate. This event always precedes a brake cruising or a brake deceleration event.

#### *"Brake cruising event"* means a measurable period during which the (non-zero) linear speed is constant.

#### *"Brake dwell event"* means a measurable and predictable brake pause at zero speed during the cycle.

#### *"Brake deceleration event"* means a measurable period during which the linear speed decreases at a known rate to a predetermined release speed during the cycle.

#### *"Deceleration rate**"* means the total rate of reduction in the linear speed of the vehicle induced by the application of the service brake, the road loads, and the regenerative torque from the electric machine.

#### *"Brake stop"* is the generic term denoting a brake deceleration event that brings the vehicle to a halt or standstill.

#### *"Brake snub"* means the generic term used to denote a brake deceleration event that reduces the vehicle speed to a non-zero level.

#### *"Soaking section"* means the section in-between trips when the brake is rotating at low speed (approximately five or fewer revolutions per minute) waiting for the brake to cool down and the initial brake temperature to reach the predefined level for commencing the next cycle trip.

#### *"Initial speed"* means the speed at the start of a brake deceleration event.

#### *"Release speed"* means the speed at the end of a brake deceleration event.

#### *"Nominal linear speed"* means the target (or set) speed at the time *i* per the WLTP-Brake cycle.

#### *"Actual linear speed"* means the linear speed at the time *i* during the test cycle execution. Also referred to as *"Measured speed"*

#### *"Speed violation"* means any instance when the actual dynamometer speed trace exceeds the speed trace tolerances prescribed in this GTR during the WLTP-Brake cycle.

#### *"Initial brake temperature"* means the bulk temperature of the brake disc or brake drum at the start of a given brake event during the WLTP-Brake cycle.

#### *"Final brake temperature"* means the bulk temperature of the brake disc or brake drum at the end of a given brake event during the WLTP-Brake cycle.

#### *"Average brake temperature"* means the unfiltered average of the time-resolved brake disc or brake drum temperature during a predetermined period.

#### *"Peak brake temperature"* means the highest unfiltered temperature measured using the time-resolved temperature during a predetermined period.

### **PM and PN Measurement**

#### The term "particle" is conventionally used for the matter being characterised (measured) in the airborne phase (suspended matter), and the term "particulate matter" for the deposited matter.

#### "*Particle number emissions*" (PN) means the number of particles emitted from the brake under testing and quantified according to the dilution, sampling, and measurement methods specified in this UN GTR.

#### "*Total Particle number emissions*" (TPN) means the number of total particles (i.e. solids and volatiles) emitted from the brake under testing.

#### *“TPN10”* means the total particle number emissions as defined and quantified according to the dilution, sampling and measurement methods specified in this UN GTR, using analysers with a nominal cut-off at 10nm aerodynamic mobility diameter.

#### "*Solid Particle number emissions*" (SPN) means the number of solid particles emitted from the brake under testing

#### *“SPN10”* means the solid particle number emissions as defined and quantified according to the dilution, sampling, and measurement methods specified in this UN GTR, using analysers with a nominal cut-off at 10nm aerodynamic mobility diameter.

#### "*Particulate matter emissions*" (PM) means the mass of any particulate matter from the brake under testing quantified according to the dilution, sampling, and measurement methods specified in this UN GTR.

#### "*PM2.5* emissions" means the PM with an aerodynamic mobility diameter of approximately ≤2.5 µm or less.

#### "*PM10* emissions" means the PM with an aerodynamic mobility diameter of approximately ≤10 µm or less.

#### *"Sampling plane"* means the fixed plane (perpendicular to the sampling tunnel axis) where the entry of the sampling nozzle(s) are located.

#### *"Sampling probe"* means a thin-walled stainless steel tube designed to extract and transfer a representative portion of aerosol from the sampling tunnel to the sampling system.

#### *"Sampling nozzle"* means a thin-walled stainless steel cylinder with a knife-edge nozzle tip that mounts at the inlet of a sampling probe and aims to extract isokinetically aerosol from the sampling tunnel.

#### *"Sampling nozzle tip"* means the outer edge at the entry of the sampling nozzle.

#### *"PM Sampling system"* means the series of elements where aerosol travels after entering the sampling probe. It includes in the direction of flow the PM sampling probe, PM separation device, PM sampling line, and filter holder.

#### *“PM separation device”* means a device that separates the relevant portion of PM from the aerosol according to the specifications of this UN GTR

#### *“Filter holder”* means a device that allows the collection of PM on filters, which are used to determine the PM emission factors according to this UN GTR.

#### *"PN Sampling system"* means the series of elements where aerosol travels after entering the sampling probe. It includes in the direction of flow the PN sampling probe, PN pre-classifier, particle transfer tube, flow splitting device (if applicable), and the PN measurement system.

#### *"PM Sampling line"* means the rigid or flexible tubing connecting the outlet of the PM separation device to the inlet of the filter holder.

#### *"Particle transfer tube"* means the flexible tubing connecting the PN sampling probe’s outlet to the pre-classifier’s inlet. When the pre-classifier is directly connected to the PN sampling probe’s outlet, the particle transfer tube means the flexible tubing connecting the pre-classifier’s outlet to the sample conditioning system’s inlet.

#### *“pre classifier”*

#### *"PN measurement system*" means the system that allows the determination of the particle number concentrations according to this UN GTR. It includes the sample conditioning system, the PN internal transfer lines, and the particle number counter.

#### *“internal transfer lines”*

#### *“sample conditioning system”* means the parts of the PN measurement systems that dilutes and conditions the aerosol to be provided to the particle number counter to determine TPN10 and SPN10, respectively.

#### *“particle number counter”* means a condensation particle counter according to the specifications of this UN GTR to determine either TPN10 or SPN10.

#### *"Standard conditions"* means pressure equal to 101.325 kPa and temperature corresponding to 293.15 K.

#### *"Background emissions"* means the measurement of particle number concentration using the same instrumentation as for emission testing when the environmental conditioning system and the dynamometer cooling air are running under the test conditions, without any brake applications or brake rotation to influence the result.

### **Test system**

#### "*Calibration*" means the process of setting a measurement system's response so that its output agrees with a range of reference signals.

#### "*Major maintenance*" means the adjustment, repair, or replacement of a component or module that could affect the accuracy of a measurement.

#### "*Reference value*" means a value traceable to a national or international standard.

#### "*Setpoint*" means the target value a control system aims to reach.

#### "*Verification*" means evaluating whether a measurement system's outputs agree with applied reference signals within one or more predetermined thresholds for acceptance.

#### "*Response time*" means the difference in time between the change of the component to be measured at the reference point and a system response of 90 per cent of the final reading (t90) with the sampling probe being defined as the reference point, whereby the change of the measured component is at least 60 per cent full scale (FS) and takes place in less than 0.1 seconds. The system response time consists of the delay time to the system and of the rise time of the system.

#### “delay time” tbd

#### “rise time” tbd

#### “Fall time” means the difference in time between t90 and t10, where the change of the component to be measured at the reference point falls from 90% of initial reading to 10% of initial reading, if the change of the set signal takes place in less than 0.1 second.

#### “drift” means the change of the measured signal of time due to external influences (such as time, temperature, pressure, voltage, current, etc.) although the setpoint stays stable.

### **Reserved [Pure electric, pure ICE, hybrid electric]**

#### *"Regenerative braking"* means the decelerating of the vehicle when the vehicle energy management system diverts part of the kinetic energy at the wheel to charge the rechargeable energy storage system (REESS).

#### "*Electric machine*" means an energy converter transforming between electrical and mechanical energy.

#### "*Category of propulsion energy converter*" means (i) an internal combustion engine, or (ii) an electric machine.

#### "*Hybrid electric vehicle*" (HEV) means a hybrid vehicle where one of the propulsion energy converters is an electric machine.

#### "*Hybrid vehicle*" means a vehicle equipped with a powertrain containing at least two different categories of propulsion energy converters and at least two different categories of propulsion energy storage systems.

#### "*Not off-vehicle charging hybrid electric vehicle*" (NOVC-HEV) means a hybrid electric vehicle that cannot be charged from an external source.

#### "*Off-vehicle charging hybrid electric vehicle*" (OVC-HEV) means a hybrid electric vehicle that can be charged from an external source.

#### "*Pure electric vehicle*" (PEV) means a vehicle equipped with a powertrain containing exclusively electric machines as propulsion energy converters and exclusively rechargeable electric energy storage systems as propulsion energy storage systems.

#### "*Pure ICE vehicle*" means a vehicle where all propulsion energy converters are internal combustion engines.

#### *"Rechargeable energy storage system – REESS"* means the rechargeable energy storage system that provides electric energy for electric propulsion.

#### “non-friction braking” means the decelerating of the vehicle by different technical means without using the mechanical braking system, e.g. such as regenerative braking.

#### “friction braking” means the deceleration of the vehicle by using the mechanical braking system. If several braking methods are used in combination, it refers to the residual mechanical braking

## Abbreviations and Symbols

Table 4.1   
**Abbreviations**

| *Abbreviation* | *Definition* | *Unit* | *Paragraph* |
| --- | --- | --- | --- |
| *CFD* | Computational fluid dynamics | - | 7.3 |
| *CSV* | Comma-separated values | - | 13.1 |
| *DM* | Disc mass before testing | kg | 8.1 |
| *DOP* | Dioctyl phthalate | - | 12.1 |
| *ECE* | Economic Commission for Europe | - | 8.1 |
| *EF* | Emission factor | - | 12.1 |
| *EN* | "European Norm" - European technical standard | - | 7.2 |
| *FA* | Vehicle front axle | - | 8.1 |
| *FBT* | Final brake temperature at the end of the braking event | °C | 10.1 |
| *GTR* | Global technical regulation | - | 8.1 |
| *H13* | High-efficiency air filter with a filtering efficiency of at least 99.95% | - | 7.2 |
| *HEPA* | High-efficiency particulate filter | - | 12.1 |
| *IBT* | Initial brake temperature at the start of the braking event | ℃ | 10.1 |
| *IR* | Isokinetic ratio | - | 12.1 |
| *L0-P* | Post style brake fixture with wheel hub connection | - | 8.1 |
| *L0-U* | Universal tyle brake fixture without wheel hub connection | - | 8.1 |
| *LHC* | The left-hand corner of the vehicle | - | 8.1 |
| *LRO* | Lateral runout | µm | 8.1 |
| *MRO* | Mass in running order | kg | 8.1 |
| *MS* | Microsoft | - | 13.1 |
| *MVL* | Maximum vehicle load | kg | 8.1 |
| *OD* | Disc/drum outer diameter | mm | 8.1 |
| *Plane A* | Vertical plane aligned with the enclosure’s inlet | - | 7.3 |
| *Plane A1* | Horizontal level aligned with the axis of rotation of the brake assembly and the duct axis | - | 7.3 |
| *Plane B* | Vertical plane at the end of the transition from the inlet duct to the central section of the enclosure, perpendicular to the duct axis | - | 7.3 |
| *Plane C* | Vertical plane tangential to the largest brake for M1, N1 vehicle category, perpendicular to the duct axis | - | 7.3 |
| *Plane D* | Vertical plane aligned with the axis of rotation of the brake assembly | - | 7.3 |
| *PND1* | Primary particle number diluter | - | 12.2 |
| *PND2* | Secondary particle number diluter | - | 12.2 |
| *PAO* | poly-alpha-olefin | - | 12.1 |
| *PBT* | Peak brake temperature of the braking event | ℃ | 13.1 |
| *PCRF* | Particle number concentration reduction factor | - | 12.2 |
| *PM* | Particulate matter mass | mg, mg/m3, mg/km | 6.0 |
| *PM2.5* | Particle mass for aerosols with aerodynamic diameter below 2.5 µm | mg, mg/m3, mg/km | 7.1 |
| *PM10* | Particle mass for aerosols with aerodynamic diameter below 2.5 µm | mg, mg/m3, mg/km | 7.1 |
| *PN* | Particle number concentration | #/m³, #/km | 6.0 |
| *PNC* | Particle number counter | - | 12.2 |
| *PTFE* | Poly tetra fluoroethylene | - | 12.1 |
| *PTT* | Particle transfer tube | - | 12.2 |
| *RA* | Vehicle rear axle | - | 8.1 |
| *RH* | relative humidity | % | 7.2 |
| *RHC* | right-hand corner of the vehicle | - | 8.1 |
| *RR* | Tyre dynamic rolling radius | mm | 8.1 |
| *SPN10* | Solid particle number concentration | #/cm3 | 7.1 |
| *SAE* | Society of Automotive Engineers | - | 12.3 |
| *SEE* | Standard error of estimate | - | 14.3 |
| *TPN10* | Total particle number concentration | #/cm3 | 7.1 |
| *ULPA* | Ultra-low particulate air | - | 12.1 |
| *VPR* | Volatile particle remover | - | 12.2 |
| *WLTP* | World-wide harmonized light vehicle test procedure | - | 6.0 |

Table 4.2   
**Symbols**

| *Symbol* | *Definition* | *Unit* | *Paragraph* |
| --- | --- | --- | --- |
| *a* | Transition angle of the brake enclosure | ° | 7.3 |
| *a1* | The minimum distance between the sampling probes/ and between the sampling probes and the tunnel walls | mm | 7.6 |
| *a* | Deceleration rate | m/s² | 13.2 |
| *A1…3* | Metrics for vehicle or target temperatures | ℃ | 10.1 |
| *B1…3* | Metrics for dynamometer temperatures | ℃ | 10.1 |
| *C1…3* | Metrics for the temperature difference between vehicle/target and dynamometer | K | 10.1 |
| *d* | Total distance travelled (driven) during Trip #10 or the WLTP-Brake cycle | km | 12.1 |
| *di* | Sampling tunnel inner diameter. Used as reference diameter where there is a requirement in the minimum number of duct diameters for length or radii. | mm | 7.1 |
| *dn* | Sampling nozzles inner diameter (applies to both PN and PM) | mm | 12.1 |
| *dn-PM2.5* | The inner diameter of the isokinetic nozzle for sampling PM2.5 | mm | 12.1 |
| *dn-PM10* | The inner diameter of the isokinetic nozzle for sampling PM10 | mm | 12.1 |
| *dn-SPN10* | The inner diameter of the isokinetic nozzle for sampling SPN10 | mm | 12.2 |
| *dn-TPN10* | The inner diameter of the isokinetic nozzle for sampling TPN10 | mm | 12.2 |
| *dpiston* | Calliper piston mean or hydraulic diameter | mm | 8.1 |
| *dp* | Sampling probes inner diameter (applies to both PN and PM) | mm | 12.1 |
| *ds* | The inner diameter of the PM sampling line | mm | 12.1 |
| *dtl* | The inner diameter of the PN internal transfer line | mm | 12.2 |
| *dtt* | The inner diameter of the PN transfer tube | mm | 12.2 |
| *dx* | Electrical mobility diameter | µm | 14.5 |
| *η* | Brake calliper or drum efficiency | % | 8.1 |
| *f* | Brake rotational speed | rev/min | 9.4 |
| *fr (dx)* | PCRF for each particle of electrical mobility diameter dx | - | 14.5 |
| *fr-SPN10* | Arithmetic averaged PCRF for the SPN10 measuring device | - | 12.2 |
| *fr-TPN10* | Arithmetic averaged PCRF for the TPN10 measuring device | - | 12.2 |
| *hB* | Length of plane B (enclosure) | mm | 7.3 |
| *hD* | Length of plane D (enclosure) | mm | 7.3 |
| *He* | The point that defines the end of the mandatory horizontal part in the layout | - | 7.1 |
| *Hs* | The point that defines the start of the mandatory horizontal part in the layout | - | 7.1 |
| *In* | Brake nominal inertia | kg·m² | 8.1 |
| *It* | Brake test inertia | kg·m² | 8.1 |
| *lA1* | Length of plane A1 (enclosure) | mm | 7.3 |
| *li* | Length of inlet or outlet transition of brake enclosure | mm | 7.3 |
| *L1* | Minimum length of the straight duct upstream of the inlet of the brake enclosure | mm | 7.1 |
| *L2* | Minimum length from the last disturbance upstream of the sampling plane to the sampling plane | mm | 7.1 |
| *L3* | Minimum length from the sampling plane to the next disturbance downstream of the sampling plane | mm | 7.1 |
| *L4* | Minimum length from the last disturbance upstream of the airflow measurement element to the airflow measurement element | mm | 7.1 |
| *L5* | Minimum length from the airflow measurement element to the next disturbance downstream of the airflow measurement element | mm | 7.1 |
| *μ* | Average by distance friction variable for disc brakes (Friction Coefficient) | (unitless) | 13.1 |
| *MMix* | The molar mass of air in the balance room | g/mol | 12.1 |
| *Mveh* | Vehicle test mass to simulate on the dynamometer | kg | 8.1 |
| *ν* | Kinematic viscosity of air | m2/s | 7.3 |
| *Nin(dx)* | Upstream PN concentration for particles of electrical mobility dx | #/cm3 | 14.5 |
| *Nout(dx)* | Downstream PN concentration for particles of electrical mobility dx | #/cm3 | 14.5 |
| *NQ* | Average normalised cooling airflow | Nm³/h | 7.2 |
| *NQPM2.5* | Average normalised PM2.5 sampling flow | Nl/min | 12.1 |
| *NQPM10* | Average normalised PM10 sampling flow | Nl/min | 12.1 |
| *NQTPN10* | Average normalised TPN10 sampling flow | Nl/min | 12.2 |
| *NQSPN10* | Average normalised SPN10 sampling flow | Nl/min | 12.2 |
| *NQs* | Average normalised flow in the sampling nozzle (applies to both PN and PM) | Nm³/h | 12.1 |
| *Pb* | Atmospheric pressure in the balance room | kPa | 12.1 |
| *Pbrake* | Brake pressure | kPa | 13.2 |
| *Pr* | Particle penetration | % | 14.5 |
| *pthreshold* | Threshold pressure or minimum pressure required to develop braking torque | kPa | 8.1 |
| *PM2.5-Mass* | PM2.5 filter load from a given brake emissions test corrected for buoyancy | µg, mg | 12.1 |
| *PM10-Mass* | PM10 filter load from a given brake emissions test corrected for buoyancy | µg, mg | 12.1 |
| *PMCorrected* | Buoyancy-corrected filter mass | µg, mg | 12.1 |
| *PMUncorrected* | Filter mass without buoyancy correction | µg, mg | 12.1 |
| *Q* | Average measured (actual) cooling airflow | m3/h | 7.2 |
| *Qset* | Nominal (or set) cooling airflow | m3/h | 7.2 |
| *QPM2.5* | PM2.5 sampling flow (actual) | l/min | 12.1 |
| *QPM2.5-set* | Nominal (or set) PM2.5 sampling flow | l/min | 13.2 |
| *QPM10* | PM10 sampling flow (actual) | l/min | 12.1 |
| *QPM10-set* | Nominal (or set) PM10 sampling flow | l/min | 13.2 |
| *rb* | Bending radius of the cooling air duct | mm | 7.4 |
| *reff* | Brake effective radius | mm | 8.1 |
| *rP* | Bending radius of the sampling probe or sampling line | mm | 12.1 |
| ρ*a* | Density of air | kg/m3 | 12.1 |
| ρ*f* | The density of PM filter material | kg/m3 | 12.1 |
| ρ*w* | The density of the PM microbalance calibration object | kg/m3 | 12.1 |
| *R* | Molar mass constant | J/kg/mol | 12.1 |
| *SPN10#* | Average normalised and PCRF-corrected SPN10 concentration | #/*N*cm3 | 12.2 |
| *SPN10back* | Average normalised SPN10 concentration during background check | #/*N*cm3 | 7.2 |
| *SPN10b EF* | Average SPN10 count per unit distance driven during the background check | #/km | 7.2 |
| *Sp* | Output signal for cooling air pressure | kPa | 7.1 |
| *SQ* | Output signal for cooling airflow | m³/h | 7.1 |
| *SRH* | Output signal for cooling air relative humidity | % | 7.1 |
| *St* | Output signal for cooling air temperature | ℃ | 7.1 |
| *tbrake* | The total duration of the deceleration event (stop duration) | s | 13.1 |
| *t90* | Response time of particle number counter | s | 12.2 |
| τ*brake* | Brake torque | N·m | 9.4 |
| τ*brake-avg* | Time-averaged brake torque | N·m | 13.1 |
| *T* | Cooling air temperature | ℃ | 7.2 |
| *Ta* | Air temperature in the balance room | ℃ | 12.1 |
| *Tavg* | Average brake temperature | ℃ | 10.1 |
| *Tbrake* | Brake (disc/drum) temperature | ℃ | 8.3 |
| *TPN10#* | Average normalised and PCRF-corrected TPN10 concentration | #/*N*cm3 | 12.2 |
| *TPN10back* | Average normalised TPN10 concentration during background check | #/*N*cm3 | 7.2 |
| *TPN10b EF* | Average TPN10 count per unit distance driven during the background check | #/km | 7.2 |
| *U* | Average cooling airspeed | km/h, m/s | 7.2 |
| *Us* | Average airspeed of air entering the sampling nozzle | km/h, m/s | 12.1 |
| *V* | Average actual linear speed of the WLTP-Brake cycle | km/h | 12.2 |
| *Vset* | The average nominal linear speed of the WLTP-Brake cycle (=43.7 km/h) | km/h | 7.2 |
| *Wf* | Weight specific Friction work | J/kg | 9.4 |
| *WLn* | Nominal wheel load without accounting for vehicle road loads or any other type of losses | kg | 8.1 |
| *WLt* | Test wheel load after accounting for vehicle road loads or any other type of losses | kg | 8.1 |

## General Requirements

### **Compliance Requirements**

The compliance of a brake system with this GTR shall be evaluated against the regional emission limits as defined by each Contracting Party. The compliance shall be demonstrated by testing the worst-performing representative of a brake family according to paragraphs 6-14 of this UN GTR.

### **Definition of Brake Family**

A brake family shall be composed of brake systems that may be used in the same vehicle category and that are the same in terms of the following emission characteristics and technical criteria (Criteria based on UNR 13 to be further elaborated and finalized before the submission of the final working document):

[PLACEHOLDER]

The manufacturer shall identify the worst performing brake system in terms of emissions and submit it to the authority as a candidate for testing. The authority shall approve the selection if appropriate and may also select any member of the family for testing. The maximum number for testing during type approval is two brake systems per family.

### **Rounding Requirements**

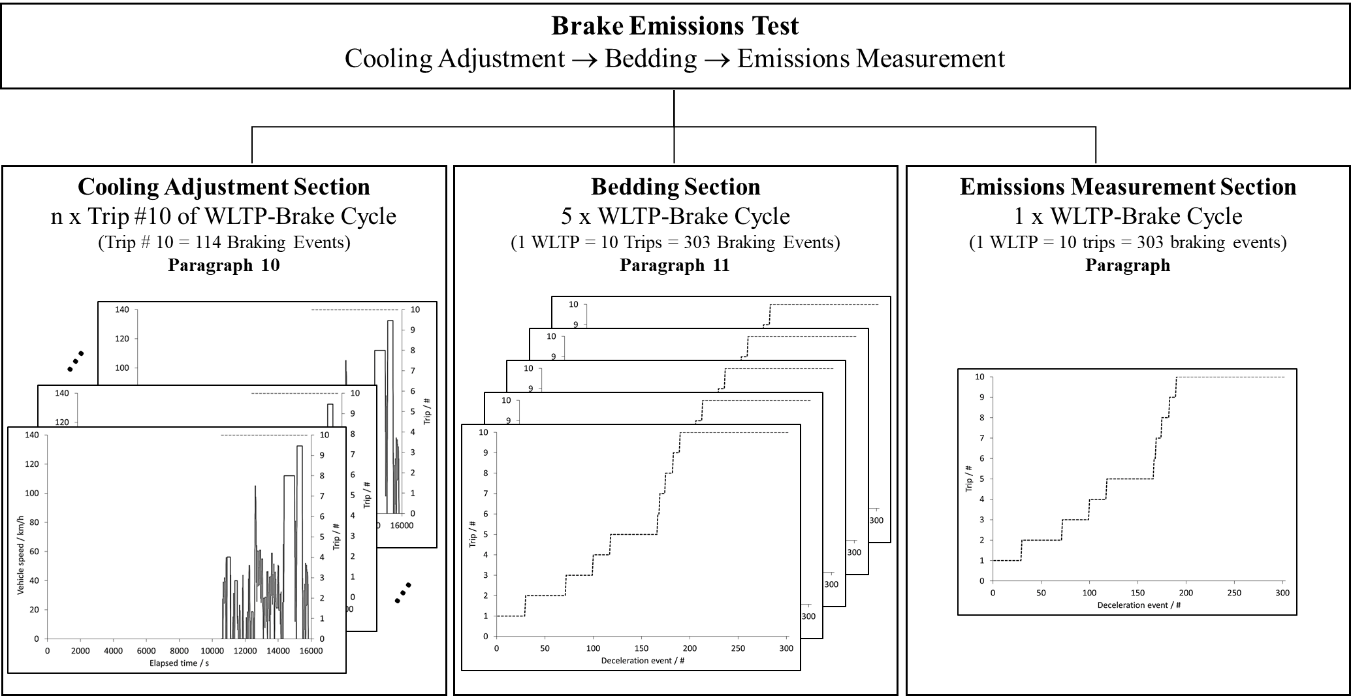
Rounding of data in the data exchange file is not permitted. In the pre-processing file, the data may be rounded to the same order of magnitude of the accuracy of the measurement of a respective parameter and based on the number of decimals defined for the parameter in paragraph 13 of this GTR.

## General Overview

A brake emissions test includes three test sections. Each section contains one or more trips with a series of events. The main events which induce brake work and generate brake emissions are the deceleration events. Figure 6.1 provides a schematic overview of a brake emissions test. The three sections of the brake emissions test are:

* Brake cooling adjustment. This section uses Trip #10 of the WLTP-Brake cycle. The cooling adjustment section is described in detail in Paragraph 10;
* Brake bedding. This section uses five repetitions of the WLTP-Brake cycle. The bedding section is described in detail in Paragraph 11;
* Brake emissions measurement. This section includes one performance of the WLTP-Brake cycle. The emissions measurement section is described in detail in Paragraph 12.

Figure 6.1  
**Structure of the brake emissions tests for vehicles with full-friction braking**

****

The correct execution of a brake emissions test requires the test facility to conduct and document the following steps:

1. Ensure the test system meets the requirements defined in Paragraph 7 regarding the system layout, cooling airflow, temperature, and humidity control, brake dynamometer capabilities, brake enclosure design, sampling tunnel design, and sampling plane design;
2. Meet all requirements defined in Paragraph 8 for test preparation involving the verification of the correct input parameters, test setup, measurement of brake temperature, and brake positioning in the enclosure;
3. Be capable of executing the WLTP-Brake cycle per Paragraph 9 and demonstrate compliance with the quality checks;
4. Perform the brake cooling adjustment section as defined in Paragraph 10;
5. Perform the brake bedding section for all types of brakes as defined in Paragraph 11;
6. Execute all items from Paragraph 12 for the brake emissions measurement, including particulate mass, particle number, and mass loss of the wearable brake hardware;
7. Report the results of the test following Paragraph 13;
8. Comply with Paragraph 14 for minimum calibration requirements and periodic evaluations of the used instrumentation and setup.

## Test System Requirements

### **Overall Test System Layout**

This GTR defines a standard dynamometer test method aiming for repeatable and reproducible measurements of particle emissions from brakes equipped in category 1-1 vehicles and category 2 vehicles with a fully laden mass below 3500 kg. The technical system to perform brake emissions tests requires a system approach. The execution of a valid brake emissions test requires a robust integration of several subsystems to ensure the drive cycle, cooling air, dynamometer control, brake enclosure, sampling tunnel, aerosol sampling train, and the data collection, altogether meet the requirements specified in this GTR.

Figure 7.1 provides a layout that includes the minimum required subsystems to carry out a brake emissions test using a brake dynamometer. The illustrated layout features a climatic conditioning unit with variable flow fan(s) that supplies the setup with conditioned air. The conditioned air enters a brake enclosure designed to fit the entire assembly of the brake under testing. The brake dynamometer enables and controls the testing of the brake. The enclosure is directly connected to the sampling tunnel near the end of which four sampling probes are mounted. The sampling probes are used to extract aerosol from the tunnel towards the PM and PN measurement setup. A flow measurement device is installed in the tunnel downstream of the sampling plane. The positioning and dimensions of the different elements are indicative and are provided for illustration purposes; therefore, exact conformance with Figure 7.1 is not required.

There are several accepted configurations to lay out the air handling and control subsystems. All designs can use the same (not depicted) brake dynamometer, control software, data acquisition, and brake fixture. However, the testing facility shall ensure that all configurations include at the least the subsystems and characteristics laid down in Table 7.1. Details regarding the different elements of the setup are given in the corresponding paragraphs of this GTR as indicated in Table 7.1.

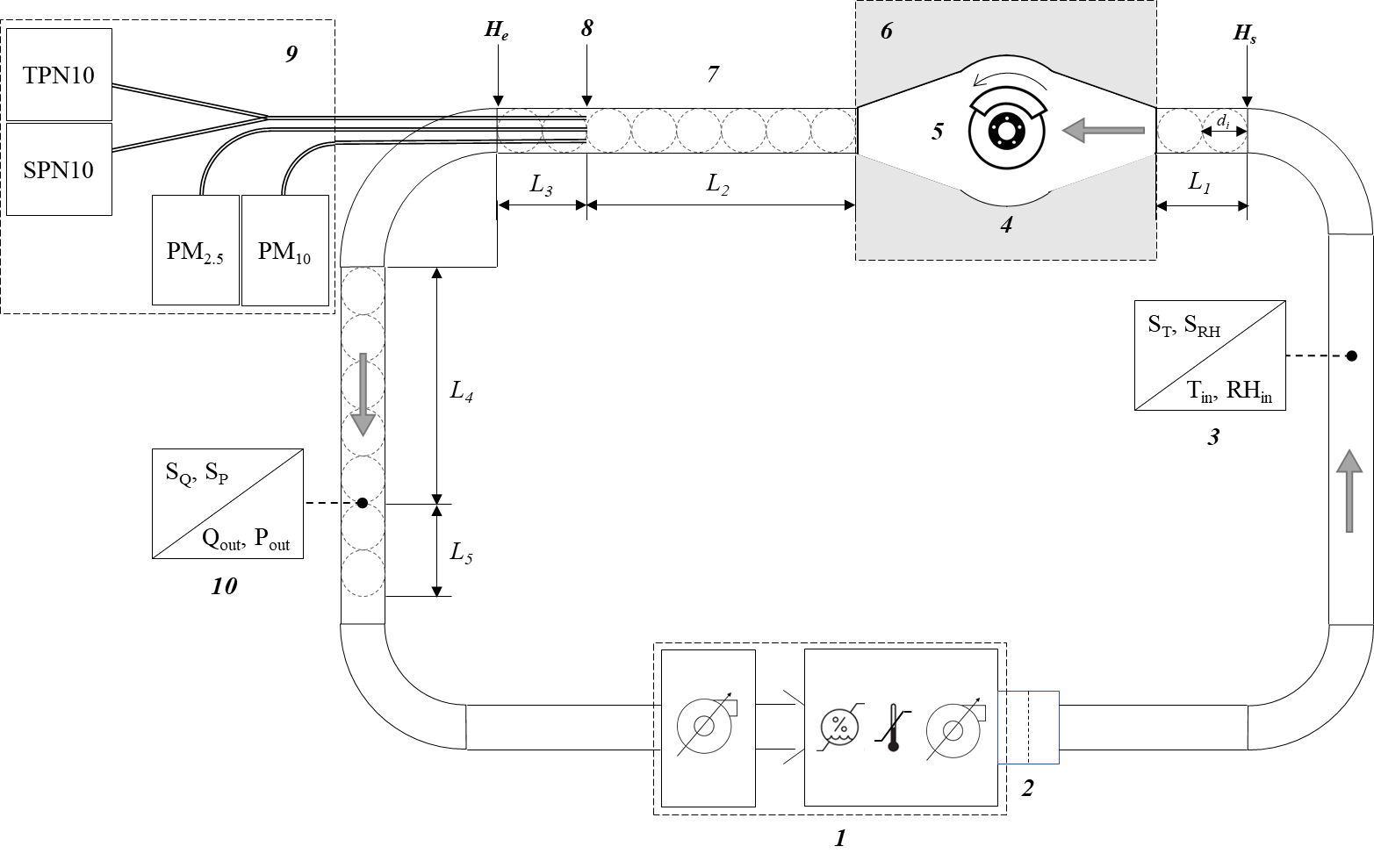
Figure 7.1  
**Indicative layout for performing brake emissions test in the laboratory**The layout has the sampling tunnel connected directly to the brake enclosure and four sampling probes . A layout with a bend in the sampling tunnel is also feasible i.e. downstream of the enclosure and upstream of the sampling plane. The brake dynamometer is not depicted but only denoted (gray area) – a graphical representation of the brake dynamometer is given in Figure 7.2

Table 7.1  
**Subsystems and characteristics required for the brake emissions testing setup** **as depicted in Figure 7.1**

|  |  |
| --- | --- |
| *Element* | *Subsystem* |
| 1 | Climatic conditioning unit with variable flow blower(s), air temperature, and air humidity control per paragraph 7.2.1 |
| 2 | Cooling air filtering medium per paragraph 7.2.2.1 |
| 3 | Cooling air temperature and humidity sensors placed upstream of the brake enclosure per paragraphs 7.2.1.1 and 7.2.1.2 |
| 4 | Brake enclosure per paragraph 7.4 |
| 5 | Brake assembly connected to the brake dynamometer per paragraph 8.4.1 |
| 6 | Brake dynamometer (not depicted but only denoted in gray) per paragraph 7.3 |
| 7 | Sampling tunnel per paragraph 7.5 |
| 8 | sampling plane with the corresponding PM and PN sampling probes per paragraph 7.6 |
| 9 | Instruments to collect PM mass and measure PN concentrations per paragraphs 12.1 and 12.2, respectively |
| TPN10, SPN10 | Systems to control, measure, and output signals of TPN10 and SPN10 per paragraph 12.2 |
| PM2.5, PM10 | Systems to control sampling flow, sample particulate mass on filters, and output signals per paragraph 12.1 |
| 10 | Airflow measurement element placed downstream of the sampling plane per paragraph 7.2.3 |
| *Symbol* | Characteristic |
| L1 | Minimum length of the straight duct at the inlet of the brake enclosure per paragraph 7.4.2 |
| L2 | Minimum length from the last disturbance and upstream of the sampling plane per paragraph 7.6 |
| L3 | Minimum length to the next disturbance and downstream of the sampling plane per paragraph 7.6 |
| L4 | Minimum length from the last disturbance and upstream of the airflow measurement element per paragraph 7.2.3 |
| L5 | Minimum length to the next disturbance and downstream of the airflow measurement element per paragraph 7.2.3 |
| SQ, SP, ST, SRH | Output electronic signals for cooling airflow, pressure, temperature, and humidity per paragraphs 7.2.1 and 7.2.3 |
| di | Reference duct diameter where there is a requirement in the minimum number of duct diameters for length or radii. |
| Hs, He | Points that define the beginning (Hs) and the end (He) of the mandatory horizontal part in the layout (in the direction of the flow) per paragraph 7.4.2 |

### **Climatic Conditioning Unit and Cooling Air**

The conditioned cooling air a) provides clean and continuous cooling to the brake assembly and b) transports the aerosol from the enclosure into the sampling tunnel and the PM/PN sampling probes. The cooling air needs to be under stable conditions for temperature and humidity following the specifications described in paragraph 7.2.1, clean with low background concentration values as defined in paragraph 7.2.2, and at a constant flow to ensure repeatable and reproducible test conditions following the specifications described in paragraph 7.2.3.

The conditioned cooling air is supplied to the testing setup by the climatic conditioning unit. A typical system configuration includes cooling devices to cool and dehumidify the air, heating devices to increase the temperature of the air, and steam or water mist generators to increase the humidity in the air. Integral to the unit are the closed-loop proportional integral derivative controls, alarms, and sensors to monitor the condition of all devices and interfaces. The system shall consist of a variable flow blower able to supply the layout with conditioned cooling air over a wide range of airflows. The system can also combine two-variable flow blowers (one to push and one to pull) to provide a slight negative pressure inside the sampling tunnel (approximately 0.5kPa below ambient). The climatic conditioning unit control shall be capable of providing the necessary interfaces to the operator and the dynamometer.

#### Cooling Air Conditioning

The testing facility shall continuously monitor and control the temperature and humidity of the conditioned cooling air. For that reason, the testing facility shall install temperature and humidity sensors in the last segment of the duct before entering the brake enclosure. Positioning the sensors upstream of the brake enclosure avoids influencing the feedback signals with the thermal load from the braking events. Figure 7.1 provides an indicative position for the temperature and air humidity sensors (element 3).

The temperature sensor shall have an accuracy of ±1 °C. The relative humidity sensor shall have an accuracy of ±5 per cent of the nominal value. The testing facility shall use the signals from these sensors to assess the stability of the cooling air’s temperature and humidity. Table 7.2 summarises the requirements for the cooling air’s temperature, humidity, and flow described in paragraphs 7.2.1 and 7.2.3.

Table 7.2   
**Summary of the main cooling air temperature, humidity, and flow** **requirements**

| *Parameter* | *Cooling air*  *temperature* | *Cooling air*  *relative humidity* | *Cooling*  *airflow* |
| --- | --- | --- | --- |
| Nominal value | 20 ⁰C | 50 % | Set value (Qset) as  defined in paragraph 10 |
| Average value: Maximum permissible tolerance | ±2 ⁰C | ±5 % | ±5 % of Qset |
| Instantaneous values (1Hz): Maximum permissible tolerance | ±5 ⁰C | ±30 % | ±5 % of Qset |
| Instantaneous values (1Hz): Permissible deviation beyond the maximum permissible tolerance | Not defined | Not defined | ±10 % of Qset |
|  |  |  |  |

##### Cooling Air Temperature

Cooling air temperature at the measurement point shall be constant throughout the entire brake emissions test. The testing facility shall carry out the following steps:

1. Set the cooling air temperature at 23 °C. The average cooling air temperature shall not deviate more than ±2 °C of the set (nominal) value.
2. Calculate and report the average cooling air temperature in all sections as defined in Table 13.6 in paragraph 13.4;
3. The instantaneous cooling air temperature shall not deviate more than ±5 °C of the nominal value;
5. If the average or the instantaneous cooling air temperature falls out of the limits specified in this paragraph, the test is invalid.

##### Cooling Air Humidity

The absolute humidity of the cooling air should be kept between 5 and 11g of water per kg dry air.

Cooling air relative humidity shall be constant throughout the entire brake emissions test. The testing facility shall carry out the following steps:

1. Set the relative humidity of the cooling air to a nominal value of 50 per cent. The average cooling air humidity shall not deviate more than ±5 per cent of the nominal value.
2. Calculate and report the average relative humidity of the cooling air in all sections as defined in Table 13.6 in paragraph 13.4;
3. The instantaneous cooling air relative humidity shall not deviate more than ±30 per cent of the nominal value;
5. If the average or the instantaneous relative humidity or the absolute humidity falls out of the predefined limits specified in this paragraph, the test is invalid.

#### Cooling Air Cleaning

##### Cooling Air Filtering

The cooling air entering the test system shall pass through a medium capable of reducing particles of the most penetrating particle size in the filter material by at least 99.95 per cent or through a filter of at least class H13 as specified in EN 1822. Any other type of filter applied to remove volatile organic species (charcoal, activated carbon, or equivalent) shall be installed upstream of the H13 (or equivalent) filter. The testing facility shall follow the filter manufacturer’s specifications and ensure the installation of the filter does not negatively affect the flow rate and the airflow distribution. Figure 7.1 provides an indicative position for the air filtering device (element 2).

##### Particle Background Verification

The particle background in the overall layout shall be defined at a PN concentration basis.The testing facility shall measure the particle background using the same instrumentation used for the PN emissions measurements. Details regarding the PN measurement system are provided in paragraph 12.2. The testing facility shall measure and report both TPN10 and SPN10 background concentrations at two levels: System-level and brake emissions test level.

7.2.2.2.1. Particle Background Verification at the System Level

The first level concerns the system background check upon the installation of the setup, after any major maintenance, or when there are indications of a system malfunction. The testing facility shall apply the following steps for a complete background verification at the system level:

1. Perform the background verification with neither the brake fixture nor any brake components installed inside the brake enclosure;
2. Perform the background verification with the TPN10 and SPN10 measurement systems operating at the minimum certified dilution ratio;
3. Commence the background verification at least five minutes after the cooling airflow is stabilised to the average values per paragraph 7.2.3 (for the nominal value at each level) for cooling airflow stability, and to the average values per paragraph 7.2.1 for cooling air temperature and relative humidity;
4. Perform the background verification at three different cooling airflow settings representing the entire operating range of the test facility. Apply the minimum, 50 per cent, and maximum operational airflow of the system. The test facility may use the nozzle size, which fulfils the isokinetic requirements at 50% for sampling TPN10 and SPN10 during the system background verification when applying different airflow settings;
5. The background verification shall run for approximately 30 minutes to allow the background concentration to stabilise. The background concentration is stable when its average value is below the maximum permissible level per paragraph 7.2.2.2.3 for at least five minutes or when the one-minute average does not vary by more than ±2 #/*N*cm³.

##### 7.2.2.2.2. Particle Background Verification at the Test Level

The second level concerns the background verification before and after the execution of a brake emissions test. The testing facility shall carry out the following steps for the pre-test verification:

1. Perform the regular background pre-test before the bedding section with the brake assembly mounted. The disc/drum shall not rotate and the pads/shoes shall be fully retracted. Do not apply braking during the background concentration check procedure (zero brake pressure);
2. Perform the pre-test verification with the TPN10 and SPN10 measurement systems operating at the dilution ratio(s) selected for the brake emissions test;
3. Commence the background pre-test check at least five minutes after the cooling airflow is stabilised to the average values per paragraph 7.2.3 (for the nominal value at each level) for cooling airflow stability, and to the average values per paragraph 7.2.1 for cooling air temperature and relative humidity;
4. Perform the background pre-test check for at least 5 min, or as long as it takes for the background concentration to stabilise at the airflow setting of the given emissions test. The background concentration is stable when its average value is below the maximum limit defined in paragraph 7.2.2.2.3 for at least five minutes or when the one-minute average does not vary by more than ±2 #/*N*cm³.

The testing facility shall carry out the following steps for the post-test verification:

1. Perform the regular background post-test before purging and with the brake assembly mounted. The disc/drum shall not rotate and the pads/shoes shall not be disturbed. Do not apply braking during the background concentration check procedure (zero brake pressure);
2. Perform the post-test verification with the TPN10 and SPN10 measurement systems operating at the dilution ratio selected for the brake emissions test;
3. Commence the background post-test check right after the emissions test and with the cooling airflow stabilised to the average values per paragraph 7.2.3 (for the nominal value at each level) for cooling airflow stability, and to the average values per paragraph 7.2.1 for cooling air temperature and relative humidity;
4. Perform the background post-test for at least 5 min, or as long as it takes for the background concentration to stabilise at the airflow setting of the emissions test. The background concentration is stable when its average value is below the maximum limit defined in paragraph 7.2.2.2.3 for at least five minutes or when its value does not vary by more than ±2 #/*N*cm³ for at least one minute.

##### 7.2.2.2.3. Calculation and Reporting of the Particle Background

The background shall be measured and reported at a TPN10 and SPN10 concentration basis at standard conditions (273.15 K and 101.325 kPa). The testing facility shall apply the following procedure:

1. Perform a zero verification of the particle number counter. Apply a filter of appropriate performance at the PN measurement device inlet and record the PN concentration. The reading shall not exceed 0.2 #/cm³. Upon removal of the filter, the PN measurement device shall show an increase in measured concentration and a return to ≤ 0.2 #/cm³ on the replacement of the filter. The PN measurement device shall not report any errors;
2. Measure the average value of both TPN10 (TPN10b#) and SPN10 (SPN10b#) background concentrations at the system and test levels following paragraphs 7.2.2.2.1 and 7.2.2.2.2. Report the background values in particle number concentration (#/*N*cm3) as specified in Table 13.6 in paragraph 13.4;
3. The average background concentration in the tunnel shall not exceed the maximum limit of 20 #/*N*cm³ for each TPN10 and SPN10. The limit of 20 #/*N*cm3 applies to the background concentration at both system and test levels as described in paragraphs 7.2.2.2.1 and 7.2.2.2.2;
4. Failure to comply with the particle background limits defined in point (c) of this paragraph results in an invalid test;
5. The test facility shall not subtract the background concentration values when reporting the TPN10 and SPN10 concentration values of the brake emissions measurement section per paragraph 12.2.4.

The testing facility shall also report the background expressed as the number of particles per distance driven to reflect the changes in the cooling air settings when testing different brakes. The calculation of the background as the number of particles per unit distance driven is determined by equations 7.1 and 7.2:

|  |  |
| --- | --- |
|  | (Eq. 7.1) |
|  | (Eq. 7.2) |

Where:

is the TPN10 background in #/km in the sampling tunnel;

is the SPN10 background in #/km in the sampling tunnel;

is the average normalised and PCRF-corrected TPN10 background concentration in #/*Ncm*³ in the sampling tunnel;

is the average normalised and PCRF-corrected SPN10 background concentration in #/*N*cm³ in the sampling tunnel;

is the average normalised airflow in the sampling tunnel in *N*m³/h;

is the average nominal linear speed of the WLTP-Brake cycle in km/h.

1. The PN background concentrations (TPN10b# and SPN10b#) correspond to the average normalised and PCRF-corrected TPN10 and SPN10 values calculated throughout the background check from the given parameters in the Time-Based file;
2. Calculate the normalised average cooling airflow (*N*Q) during the background verification procedure from the given parameter in the Time-Based file;
3. The average nominal linear speed of the WLTP-Brake cycle equals to 43.7 km/h (Vset = 43.7 km/h);
4. Calculate and report the background particle concentration values per distance driven only at the test level both pre- and post-test as specified in Table 13.6 in paragraph 13.4.

#### Cooling Airflow

The testing facility shall measure and report the cooling airflow throughout the entire brake emissions testing procedure. The measurement of the cooling airflow shall meet the following requirements:

1. The method of measuring cooling airflow shall be such that measurement is accurate to ±2 per cent under all operating conditions;
2. Measure the cooling airflow downstream of the sampling plane. Figure 7.1 provides an indicative position for the flow measurement device (element 10);
3. For a single-point measurement, locate the flow measurement element at the centre of the duct, at least five duct diameters downstream and two duct diameters upstream of any flow disturbance. Duct diameter refers to the inner diameter of the duct where the flow measurement device is located;
4. For a multi-point measurement, install the flow measurement element perpendicular to the flow direction, at least five duct diameters downstream and two duct diameters upstream of any flow disturbance. Duct diameter refers to the inner diameter of the duct where the flow measurement device is located;
5. Use a flow measurement device calibrated to report airflow at both operating and standard conditions. The temperature sensor shall have an accuracy of ±1 °C. The pressure measurements shall have precision and accuracy of ±0.4 kPa;
6. When using air filters to protect the airflow measurement device from contamination, install the filter at least five duct diameters upstream of the flow measurement device. Follow the recommendations regarding the type and specifications of the filter from the manufacturer of the flow measurement device.

The testing facility shall ensure that the cooling airflow is constant throughout the entire brake emissions testing procedure as follows:

1. The set (nominal) value for the cooling airflow (Qset) shall be the same and constant as determined during the cooling adjustment section during for the bedding section and the emission measurement section, including soaking..;
2. During the cooling adjustment section, the average measured cooling airflow shall be within ±5 per cent of the set value defined at the beginning of the test;
3. During the bedding section, the average measured cooling airflow shall be within ±5 per cent of the nominal value defined during the cooling adjustment section for the given brake;
4. During the emissions measurement section, the average measured cooling airflow shall be within ±5 per cent of the nominal value defined during the cooling adjustment section for the given brake;
5. Calculate and report the average measured cooling airflow in all sections as defined in Table 13.6 in paragraph 13.4;
6. In case the average nominal or measured cooling airflow does not meet all of the requirements defined in this paragraph, the test is invalid;
7. The instantaneous cooling airflow can deviate more than ±5 per cent and up to ±10 per cent of the nominal value for no longer than 5 per cent of the duration of the cycle, provided that the average measured cooling airflow meets the requirements defined in this paragraph. This applies to the cooling adjustment and the emissions measurement section:
8. For the cooling adjustment section, the instantaneous cooling airflow can deviate between ±5 and ±10 per cent of the set value for no longer than 264 s;
9. For the emissions measurement section, the instantaneous cooling airflow can deviate between ±5 and ±10 per cent of the set value for no longer than 792 s (soaking sections not included).
10. In addition to the compliance to the average and instantaneous limits defined in this paragraph, the cooling airflow in combination with the airflow in the PM and PN sampling lines shall meet the isokinetic requirements per paragraphs 12.1.2.3 and 12.2.3.2, respectively;
11. If a device with a flow control feature (e.g. critical orifice, pressure regulator, feedback controller, or other) is used to ensure a stable cooling air flow the accuracy value shall be within ±2 per cent of the set value;
12. A system leak check covering the ductwork and the enclosure shall take place before testing. Set the cooling airflow at 50 per cent of the test setup’s maximum capacity and measure for at least 2 min after the flow is stabilised. If the average measured flow in the sampling tunnel is within ±5 per cent of the set value proceed with the testing. If the flow fluctuates beyond ±5 per cent of the set value cease testing activities, verify the flow measurement device, identify possible sources of the leak(s), take corrective action to resolve the issue, and resume testing by first performing a successful leak check.

The testing facility shall report the cooling airflow in the Time-Based file of the brake emissions test as follows:

1. When the cooling airflow is measured, report both the actual and normalised values as defined in Table 13.6 in paragraph 13.4;
2. Calculate the corresponding cooling airspeed using the measured airflow and the duct diameter based on equation 7.3. Report the calculated cooling airspeed as defined in Table 13.6 in paragraph 13.4;

|  |  |
| --- | --- |
|  | (Eq. 7.3) |

Where:

is the average cooling airspeed m/s per Table 13.2;

is the average measured cooling airflow in m³/s per Table 13.2;

is the sampling tunnel diameter in m per Table 7.1.

1. When the cooling airspeed is measured, report the values as defined in Table 13.6 in paragraph 13.4;
2. Calculate the corresponding actual cooling airflow using the measured cooling airspeed and the duct diameter based on equation 7.4. Report the actual and normalised cooling airflow values as defined in Table 13.6 in paragraph 13.4

|  |  |
| --- | --- |
|  | (Eq. 7.4) |

### **Brake Dynamometer and Automation Systems**

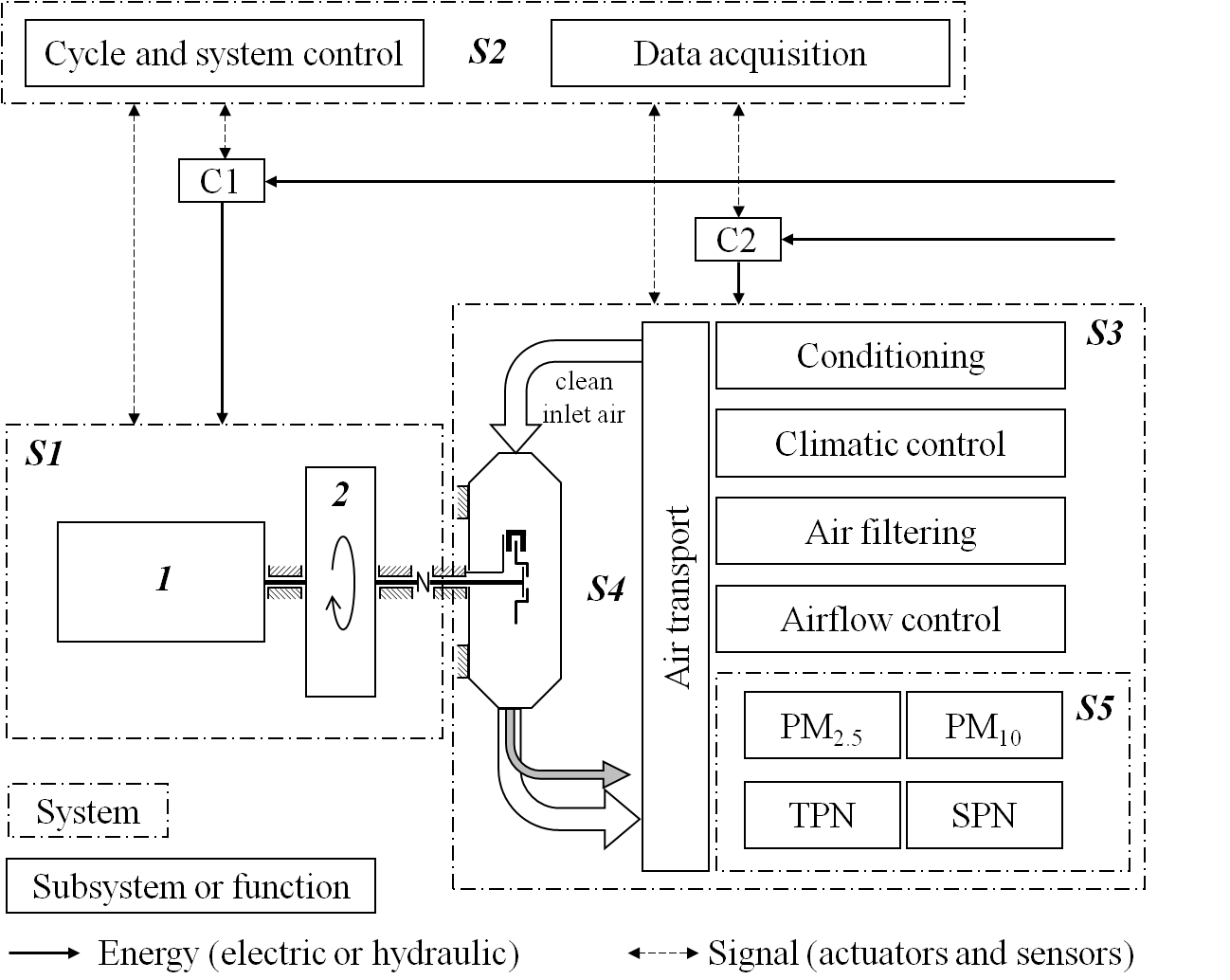
The brake dynamometer is a technical system that provides the controlled kinetic energy to the brake under test. It primarily transforms rotational kinetic energy into thermal energy (Figure 7.2‒S1). Other energy transformations (not part of this UN GTR) include vibration or noise. The brake dynamometer shall consist of at least the following elements:

1. A variable speed electric motor to accelerate or keep the rotational speed constant. It also modulates the test inertia in real driving conditions and simulates non-friction braking;
2. A servo controller (hydraulic or electric) to actuate the brake under testing;
3. A mechanical assembly to mount the brake under testing, allow free rotation of the disc or drum, and absorb the reaction forces from braking;
4. A rigid structure to mount all the mandatory subsystems. The structure shall be capable of absorbing the forces and moments generated by the brake under testing;
5. Sensors and devices to collect data and monitor the operation of the test system.

Figure 7.2 provides a layout of the test system with the brake dynamometer and shows the interactions with the minimum subsystems required to execute a brake emissions test following this GTR. Integral to the test system is the automation, controls, and data acquisition system (Figure 7.2‒S2). It continuously controls the rotational speed of the motor (Figure 7.2‒1) as well as the operation and the interactions between the different systems (Figure 7.2‒S3, S4, S5). Subsystems S3, S4, and S5 are described in detail in paragraphs 7.2, 7.4-7.5, and 9.1-9.2, respectively. The different elements and subsystems in Figure 7.2 are indicative; therefore, exact conformance with the figure is not mandatory.

Figure 7.2

**Brake dynamometer and automation systems in the overall test layout**

S1: Brake dynamometer, S2: Automation, control, and data acquisition system, S3: Air handling system, S4: Brake enclosure and sampling plane, S5: Emissions measurement system. C1 and C2: Testing facility energy controls and monitoring system. The grey arrow represents the particle emissions sample from the brake under testing, 1: electric motor to simulate the vehicle / drive the brake system, 2: rotating mass simulation r rotation mass equivalent

The automation, control, and data acquisition system perform all the functions that enable the brake emissions test. It accelerates the brake during acceleration events, maintains constant speed during cruise events, and modulates the frictional torque during deceleration events to reduce the kinetic energy of the rotating masses (Figure 7.2‒2). Additionally, the automation, controls, and data acquisition system provide an interface to the operator, stores the data from the test, and handles the interfaces with other systems in the testing facility. The automation system shall be capable of using active torque control on the electric motor to increase or decrease the total effective test inertia during deceleration events. The electric motor shall also be capable of absorbing part of the kinetic energy equivalent to the road loads and the non-friction braking from the vehicle’s powertrain. The software that operates the test system shall be capable of performing at least the following functions:

1. Execute the driving cycle automatically by operating all the closed-loop processes (mainly for brake controls, cooling air handling, and emissions measurements instruments);
2. Continuously record data from all relevant sensors to generate the outputs defined in paragraph 13 of this UN GTR;
3. Monitor signals, messages, alarms, or emergency stops from the operator and the different systems connected to the test system.

### **Brake Enclosure Design**

#### General

The brake enclosure is defined as the test chamber where the brake assembly is installed during brake emissions testing. It is a sealed chamber that prevents untreated air from entering and contaminating the air flowing around the brake assembly. The brake enclosure directs uniform conditioned air to cool the brake and transport aerosol into the sampling tunnel. Design requirements for the enclosure aim at providing general guidelines to ensure systems’ comparability related to brake cooling and particle transport efficiency. Figure 7.1 provides an indicative position for the brake enclosure (element 4).

#### Setup and Elements

An indicative shape of the enclosure is illustrated in Figure 7.3. The enclosure is defined by one horizontal and four vertical planes. Plane A1 represents the horizontal level aligned with the axis of rotation of the brake assembly and the axis of the inlet and outlet ducts. A represents the vertical plane aligned with the enclosure’s inlet. B represents the vertical plane at the end of the transition from the inlet duct to the central section of the enclosure. Plane C shall be defined by the largest brake system applied on the vehicles that fall within the scope of this UN GTR or any brake with similar dimensions. D represents the vertical plane aligned with the axis of rotation of the brake assembly.

The inlet transition volume (Figure 7.3 – 1) is defined as the section of the enclosure between planes A and B and is illustrated with a grey colour. The transition angle “α” (Figure 7.3 – 2) defines how smoothly the transition area develops in the enclosure. In Figure 7.3, the cooling air flows from right to left.

Figure 7.3  
**Indicative schematic representation of the brake enclosure**

#### Design Specifications

The following general specifications for the design of the brake enclosure and the verification of proper mixing and flow uniformity therein shall be met:

1. The brake enclosure shall have two conical or trapezoidal sections intersecting with a cylinder at the centre concentric to the axis of rotation of the brake assembly;
2. The transition from plane A to plane B shall be smooth and continuous with no abrupt changes. The requirements apply to the vertical plane, along the duct axis, and to the horizontal plane A1 to the sides of the enclosure’s centre section (intersecting cylinder);
3. Design the inlet and outlet cross-sections, ensuring smooth transition angles (15° ≤ α ≤ 30°) to avoid sudden changes in cross-section shape or size;
4. The transition points between the segments shall not have any imperfections or features that may collect brake particles that could become airborne later during the test;
5. If fasteners are applied at the transition points, they shall not protrude into the enclosure area;
6. The cooling air shall enter and exit the enclosure only in the horizontal direction (i.e. the central axis of the enclosure defined by plane A1 shall align with the airflow direction). The tunnel shall be horizontal and straight for at least two duct diameters (2∙di) upstream of the enclosure’s inlet. The tunnel ducting shall also be horizontal and straight after the enclosure at least until two duct diameters (2∙di) downstream of the sampling plane;
7. The surfaces of the brake enclosure that come into contact with the aerosol shall have a seamless construction. Use stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface and to enhance corrosion resistance;
8. Select all materials (including seals) to ensure sufficient protection against the media used (e.g. brake fluid) during setup. All enclosure gaps and interfaces shall be air-tight sealed using gasket linings or equivalent;
9. The airflow at the entrance of the enclosure shall remain turbulent with a Reynolds number of at least 4000 for all airflow testing settings to ensure sufficient mixing. Calculate the Reynolds number for a given brake emissions test using equation 7.5;

|  |  |
| --- | --- |
|  | (Eq. 7.5) |

Where:

is the Reynolds number for the given brake emissions test (unitless);

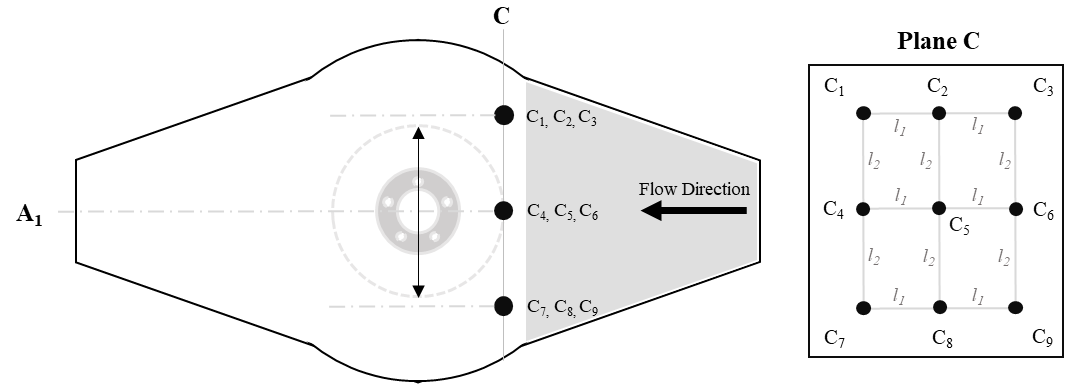
*U* is the average cooling airspeed in m/s per Table 13.2;

is the sampling tunnel diameter in m per Table 7.1;

is the kinematic viscosity of air (use default value of 1.48×10−5 m²/s).

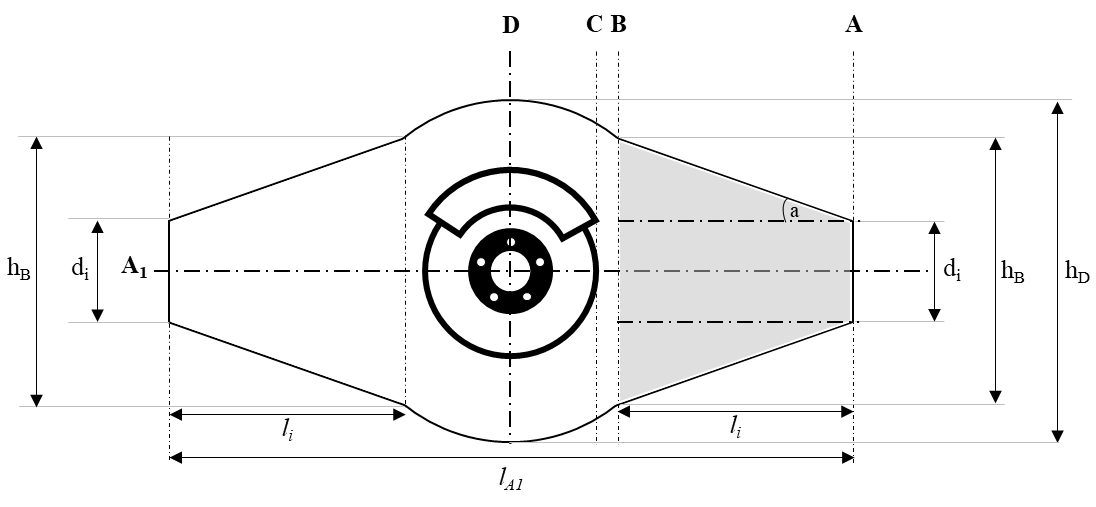
1. Design the cross-section area at the inlet so that the airspeed at plane C remains below the maximum permissible tolerance for speed uniformity defined in point (l) of this paragraph. If necessary, use flow straighteners or diffusion plates at the inlet’s side between planes A and B to ensure the highest possible level of uniform flow;
2. Calculate the airspeed values at nine positions in plane C as defined in Figure 7.4. Plane C is tangential to a disc diameter of 450 mm. Point C5 shall be the centre of plane C and the shared vertex of four imaginary rectangles. The remaining 8 points represent the vertices of these rectangles. Lines C5-C2 and C5-C8 are the longer sides of the rectangles with dimensions of 250 mm (*l2* = 250 mm). Lines C5-C4 and C5-C6 are the shorter sides of the rectangles with dimensions of 150 mm (*l1* = 150 mm);
3. Apply Computational Fluid Dynamics (CFD) to calculate the airspeed values at the nine positions of plane C. Carry out the computation at three different cooling airflow settings representing the minimum, 50 per cent, and the maximum of the operational airflow range of the test system. The simulation time shall be of sufficient duration to detect any instability in the airspeed pattern that may affect the airspeed values. Conduct the simulation without a brake assembly or a brake fixture installed. Airspeed at each position shall not vary by more than ±20 per cent of the arithmetic mean of all measurements for a given flow;
4. It is required that the testing facilities conduct physical measurements additional to the CFD simulations to verify the uniformity of the airspeed using the nine positions defined in points (k) and (l) of this paragraph;
5. Cleaning and maintenance of the brake enclosure shall follow the specifications provided by the manufacturer regarding the frequency and means. In any case, the testing facility shall ensure that the enclosure is clean before commencing a brake emissions test.

Figure 7.4  
**Reference positions for airspeed verification**

Left-hand side – Verification of proper mixing and flow uniformity using plane C for a disc with 450 mm outside diameter. Right-hand side – Distribution of calculation or measurement positions on plane C (view in the direction of flow-

#### Dimensions

The testing facility shall exercise due diligence to design the brake enclosure to fit the largest brake system applied to vehicles that fall within the scope of this UN GTR. In addition, the testing facility shall verify the selection is within the capabilities for speed, brake test inertia, and brake torque expected during the test. An indicative layout with the principal dimensions of the enclosure is illustrated in Figure 7.5.

Figure 7.5  
**Indicative schematic representation of the brake enclosure and main dimensions**

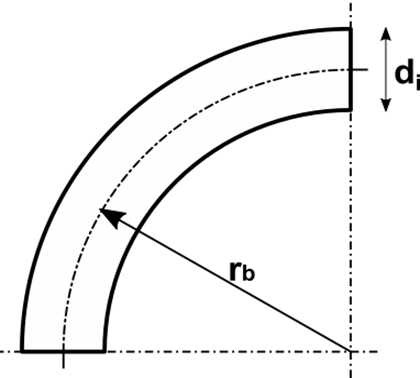
The minimum specifications related to the dimensions of the brake enclosure are described below. In addition to the dimension specifications described in this paragraph, the testing facility shall ensure the selected dimensions provide a design that meets all requirements defined in paragraph7.4.2.

1. Design the brake enclosure symmetrically to plane A1. The length of plane A1 (*lA1*) represents the most extended length of the enclosure along the flow direction. Plane A1’s length shall be between 1200 mm and 1400 mm (1200 mm ≤ *lA1* ≤ 1400 mm);
2. Design the brake enclosure symmetrically to plane D. The length of plane D (hD) represents the longest distance (height) of the enclosure perpendicular to the flow direction. Plane D’s height shall be between 600 mm and 750 mm (600 mm ≤ hD ≤ 750 mm);
3. The distance from plane C to plane D is as long as the radius of the largest market available brake on vehicles within the scope of this GTR (i.e. approximately 200-250 mm). Plane C’s position in Figure 7.5 is given for illustration purposes and does not correspond to any actual dimension specification;
4. Design the height at plane B (hB) such that the hB/hD ratio is always greater than 60 percent (hB/hD > 60 %). Design the cross-section’s transition depth at plane B to equal the axial depth of the enclosure as defined in (g) of this paragraph;
5. Design the outlet’s transition length (*li*) and height (hB) such that they equate to the inlet’s transition length (*li*) and height (hB);
6. The inlet and outlet diameters (di) shall equal to the diameter of the duct in the sampling tunnel as specified in paragraph 7.5;
7. The maximum axial depth of the brake enclosure at plane D (parallel to the brake rotation axis) shall be between 400 mm and 500 mm.

### **Design of the Sampling Tunnel**

The sampling tunnel is defined as the part between the outlet of the brake enclosure and the inlet of the sampling probes. Figure 7.1 provides an indicative position for the sampling tunnel in the overall layout (element 7). There are two possibilities for the design of the sampling tunnel: a layout without a bend and a layout with one bend. The testing facility shall ensure the design of the sampling tunnel meets the following requirements:

1. The cooling air shall flow through round ducts with an inner diameter di between the enclosure exit and the sampling plane;
2. Use stainless steel with an electropolished finish (or equivalent) for the surfaces of the tunnel that come into contact with the aerosol;
3. Any transition between adjacent sectors shall not have imperfections or features that may accumulate brake particles. Whenever this is not feasible, ensure the transitions are engineered to minimise the accumulation of brake particles in the size range that is relevant for brake emissions testing;
4. Ducts shall have a constant inner diameter di as defined in 3.5.xxx(?). The inner duct diameter di is defined as shown in Figure 7.6;
5. A maximum of one bend of 90° or less may be applied in the sampling tunnel (i.e. downstream of the brake enclosure and upstream of the sampling plane) provided that the specifications described in (f) and (g) are met;
6. If a bend is applied in the sampling tunnel, the bending radius rb shall be at least two times the duct diameter (2∙di). The bending radius is defined as shown in Figure 7.6;

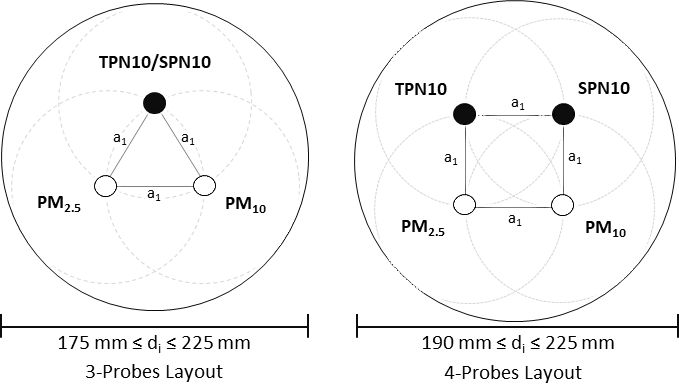
Figure 7.6  
**Definition of duct diameter (di) and bending radius (rb)**

1. If a bend is applied in the sampling tunnel, a straight duct with a length of at least six times the duct diameter (6∙di) shall follow the bend before locating the sampling plane. Additionally, a straight duct with a length of at least two times the duct diameter (2∙di) shall follow the sampling plane before placing any flow disturbance (e.g. a second bend in the setup);
2. If there is no bend in the sampling tunnel, a straight duct with a length of at least six times the duct diameter (6∙di) shall follow the exit of the enclosure before locating the sampling plane. Additionally, a straight duct with a length of at least two times the duct diameter (2∙di) shall follow the sampling plane before placing any flow disturbance (e.g. a bend in the setup or a filter to protect the airflow measurement device from contamination);
3. The provisions for the ducts described in points (a), (c), and (d) of this paragraph shall apply at least to the tunnel ducting from two duct diameters (2∙di) upstream of the enclosure’s inlet to two duct diameters (2∙di) downstream of the flow measurement device.

### **Sampling Plane**

The sampling plane is defined as the vertical plane in the sampling tunnel where the inlet of the sampling probes is placed. Figure 7.1 provides an indicative position for the sampling plane in the overall layout (element 8). The following specifications apply to the sampling plane:

1. PM and PN sampling shall take place in the same cross-section area in the sampling tunnel. Reference paragraphs 12.1.1.1 and 12.2.1.1 for PM and PN sampling, respectively;
2. Figure 7.7 illustrates the proper positioning of the PM and PN sampling probes for the four sampling probes layout;
3. Place the sampling probes/nozzles equally spaced around the central longitudinal axis of the sampling tunnel with a minimum distance between them of 50±2.5 mm. Measure the distance using the outer diameter of the nozzle tips. A longer distance between the probes/nozzles can be applied provided that the nozzle-to-duct distance meets the specifications described in point (d) of this paragraph;
4. Place the sampling probes/nozzles ensuring a minimum distance from the tunnel wall (nozzle-to-duct distance) of 50±2.5 mm. Measure the nozzle-to-duct distance using the outer diameter of the nozzle tips;

Figure 7.7  
**Graphic representation of the spacing of the probes in the tunnel**View of the vertical part in the direction of flow in the sampling tunnel that defines the sampling plane. White dots represent the PM sampling probes (PM2.5/PM10). Black dots represent the PN sampling probes (TPN10/SPN10).

## Test Preparation Requirements

### **Input Parameters**

#### Full-friction brakes

The following parameters related to the brake – and the vehicle on which the brake under testing is mounted – shall be available to the testing facility to carry out brake emissions testing with full-friction brakes following this UN GTR.

Table 8.1  
**Required test parameters for full-friction brakes**

| *Serial No.* | *Parameters and Inputs* | *Short description* | *Symbol* | *Unit* |
| --- | --- | --- | --- | --- |
| 1 | Vehicle make and model | The vehicle make and model where the brake under testing is mounted |  | [-] |
| 2 | Vehicle axle | The axle on the vehicle, front or rear, where the brake under testing is mounted | VFA or VRA | [-] |
| 3 | Brake mounting position in the vehicle | The location of the brake under testing on the vehicle, right-hand corner or left-hand corner | RHC or LHC | [-] |
| 4 | Vehicle test mass | The vehicle mass to be simulated on the brake dynamometer as defined in point (a) in this paragraph | Mveh | [kg] |
| 5 | Brake force distribution | The ratio between the braking force of each axle and the total braking force on the vehicle as described in point (b) in this paragraph | FA or RA | [-] |
| 6 | Fixture style | The support fixture of the brake assembly per paragraph 8.4.1. | L0-U or L0-P | [-] |
| 7 | Part number for the disc or drum | The code labelled by the brake manufacturer on the disc/drum |  | [-] |
| 8 | Part number for the friction material | The code labelled by the friction manufacturer on the pads/shoes |  | [-] |
| 9 | Nominal Wheel Load | The load at the brake corner under testing before accounting for vehicle road loads or any other type of losses as defined in point (c) in this paragraph | WLn | [kg] |
| 10 | Test (or applied) Wheel Load | Load at the brake corner under testing after accounting for vehicle road loads or any other type of losses as defined in point (d) in this paragraph | WLt | [kg] |
| 11 | Tyre dynamic rolling radius | Tyre radius that equates to the revolutions per distance driven as published by the tyre manufacturer for the specific tyre size | RR | [mm] |
| 12 | Brake Effective radius | The distance from the axis of rotation of the brake to the theoretical center of the friction material as defined in point (e) in this paragraph | reff | [mm] |
| 13 | Brake nominal inertia | Wheel load with a gyration radius that equals the tyre dynamic rolling radius which imposes the same kinetic energy on the service brake as in the actual vehicle. It is defined in point (f) in this paragraph | In | [kg·m2] |
| 14 | Brake test (or applied) inertia | Nominal brake inertia after subtracting the decelerating forces induced by vehicle road loads or any other type of losses as defined in point (g) in this paragraph | It | [kg·m2] |
| 15 | Disc/Drum maximum outer diameter | The largest diameter of the disc or drum under testing | OD | [mm] |
| 16 | Disc Mass | Mass of the disc before testing – It is used for the allocation of the brake under testing to a nominal wheel load to disc mass group as described in Paragraph 10 | DM | [kg] |
| 17 | Number of pistons per side | Number of pistons (or “pots”) on one side of the brake calliper |  | [#] |
| 18 | Piston Mean (or hydraulic) Diameter | The diameter of the piston of the brake under testing as defined in point (h) in this paragraph |  | [mm] |
| 19 | Disc calliper bolt tightening torque (if applicable) | Bolt tightening suggested torque if specified by the brake manufacturer |  | [N·m] |
| 20 | Brake calliper or brake drum efficiency (if applicable) | Efficiency to account for friction losses, piston travel, etc. if specified by the brake manufacturer. If not specified, use 100 per cent |  | [%] |
|  |  |  |  |  |
|  |  |  |  |  |

The following considerations shall be taken into account when calculating some of the required testing parameters provided in Table 8.1:

1. Vehicle Test Mass (Mveh): It is the mass in running order (MRO) of the vehicle (kg) on which the tested brake is mounted plus:
2. 37.5 kg that corresponds to an additional mass of 0.5 passengers, for category 1-1 vehicles;
3. 25 kg plus 28 percent of the Maximum Vehicle Load (MVL), for category 2 vehicles with a fully laden mass below 3500 kg.
4. .

Brake Force Distribution represents the ratio between the braking force of each axle and the total braking force on the vehicle, respectively. FA represents the share of the braking force applied to the front axle; RA represents the braking force share applied to the rear axle. The summation of the brake force ratios for the front and rear axle does equal 100 per cent. The brake force distribution (FA/RA) shall be provided by the vehicle manufacturer.

1. Nominal Wheel Load (WLn) represents the load at the brake under testing before accounting for vehicle road loads or any other type of losses. It is a function of the vehicle test mass and the brake force distribution and is calculated from equation 8.1. The nominal wheel load is used only to classify the brake under testing into a nominal wheel load to disc mass group according to its (WLn/DM) ratio when adjusting the cooling settings as specified in Paragraph 10.

|  |  |
| --- | --- |
|  | (Eq. 8.1) |

Where:

is the nominal wheel load in kg per Table 8.1;

is the vehicle test mass in kg per Table 8.1;

is the brake force share of the front brake.

1. Test (or applied) Wheel Load (WLt) represents the load at the brake corner under testing after accounting for vehicle road loads or any other type of losses. It is a function of the Nominal Wheel Load and is calculated from equation 8.2. For full-friction brakes, the WLt is reduced by 13 per cent compared to the WLn to account for the road loads of the vehicle during real-world operation. The WLt is applied during the entire brake emissions test including cooling adjustment, bedding, and emissions measurement sections. If the vehicle uses additional non-friction technologies, the Wheel Load shall be calculated to [Reference on according paragraph in appropriate chapter].

|  |  |
| --- | --- |
|  | (Eq. 8.2) |

1. Brake Effective Radius (reff) is defined as the distance from the axis of rotation of the brake (disc or drum) to the theoretical center of the friction material. A circle drawn with this radius would be placed at the centre of the disc-pads or drum-shoes contact surface.

For disc brakes, the brake effective radius shall be provided by the brake manufacturer. For a drum brake, the effective radius is half of the drum's inner diameter.

1. Brake Nominal Inertia (In) represents the wheel load with a radius of gyration equal to the tyre dynamic rolling radius which imposes the same kinetic energy on the brake system as in the actual vehicle. It is a function of the nominal wheel load and the tyre dynamic rolling radius and is calculated from equation 8.3:

|  |  |
| --- | --- |
|  | (Eq. 8.3) |

Where:

is the brake nominal inertia in kg·m2 per Table 8.1;

is the nominal wheel load in kg per Table 8.1;

is the tyre dynamic rolling radius in m per Table 8.1.

1. Brake Test (or applied) Inertia (It) represents the brake nominal inertia after subtracting the decelerating forces induced by vehicle road loads or any other type of losses. The brake test inertia is the primary source of kinetic energy during braking. It is a function of the Brake Nominal Interia and is calculated following equation 8.4. For full-friction brakes, the brake test inertia is reduced by 13 per cent compared to the brake nominal inertia to account for the vehicle road load losses during real-world operationand applies to the entire brake emissions test including cooling adjustment, bedding, and emissions measurement sections. If the vehicle uses additional non-friction technologies, the brake nominal inertia applies to the cooling adjustment and the bedding. Whereas the applied brake interia for emissions testing shall be calculated to [Reference on according paragraph in appropriate chapter].

|  |  |
| --- | --- |
|  | (Eq. 8.4) |



#### Regenerative Brakes

[placeholder – reserved]

### **Test Setup Preparation**

#### Testing procedure of Full-Friction Braking

The testing facility shall perform the following tasks before commencing a brake emissions test:

1. Verify the availability of all the test documentation, brake information, control program, dynamometer capabilities, and test conditions;
2. Update or upload the corresponding control program, test parameters and conditions, and brake information onto the brake dynamometer control system;
3. Install the brake assembly onto the test fixture and the dynamometer tailstock following the specifications described in paragraph 8.4.1. Connect with the adaptors to the main dynamometer shaft;
4. Install the brake pads or brake shoes and perform a thorough brake bleed to remove air bubbles from the brake lines spanning from the master cylinder up to the brake;
5. Measure the lateral run out (LRO) using a dial indicator while manually rotating the brake installed on the dynamometer. Verify that the LRO is less than 50 μm. Check for running clearance between pads/shoes and disc/drum;
6. Perform a visual inspection of the brake under testing, brake fixture, thermocouple wires, and hydraulic brake lines to ensure proper routing and connections;
7. Ensure all the instruments and filter media are available per the standard operating procedure;
8. Perform brake static applies at brake pressures in the range of 3-30 bar to verify fluid displacement curve for bleed check and visual inspection of any fluid leak inside the enclosure;
9. Close the brake enclosure, turn on the environmental conditioning system, and verify the operation of the cooling air system following the specifications defined in paragraph 7.2;
10. Perform acceleration events to reach different linear speeds (5 km/h, 50 km/h, and 135 km/h) and record residual torque during the acceleration to the set speed and after cruising at the target speeds for 10 seconds (at zero brake pressure). Verify that this spinning torque remains less than 20 N·m (excluding the torque absorbed by the dynamometer bearings). If the spinning torque exceeds this value check again the LRO, running clearance (including thermocouples wiring), and brake bleed, in that order of diagnosis;
11. Repeat the first brake event of the WLTP-Brake cycle three times to verify data collection, test parameters, brake test inertia, and overall system operation;
12. When the cooling airflow for the axle and brake type under test is not known adjust to a known value used for similar brakes as described in paragraph 10.2.4. Verify that the selected cooling airflow meets the specifications defined in Paragraph 10. If not, adjust its value following the instructions in paragraph 10.2.4. until the nominal value is defined;
13. Verify the pre-test background emissions levels are within the acceptable limits as defined in paragraph 7.2.2.2.2 using the nominal cooling airflow;
14. Verify all instruments and devices for brake emissions measurements are enabled and running without any errors and warning. operational;
15. If no issues arise, continue with the bedding and emissions measurement sections following the standard operating procedures;
16. When the testing facility carries out the cooling adjustment section with a different brake assembly than the one used for testing, all steps in this paragraph except for point (l) shall apply.

#### Regenerative Brakes

[placeholder – reserved]

### **Brake Temperature Measurement**

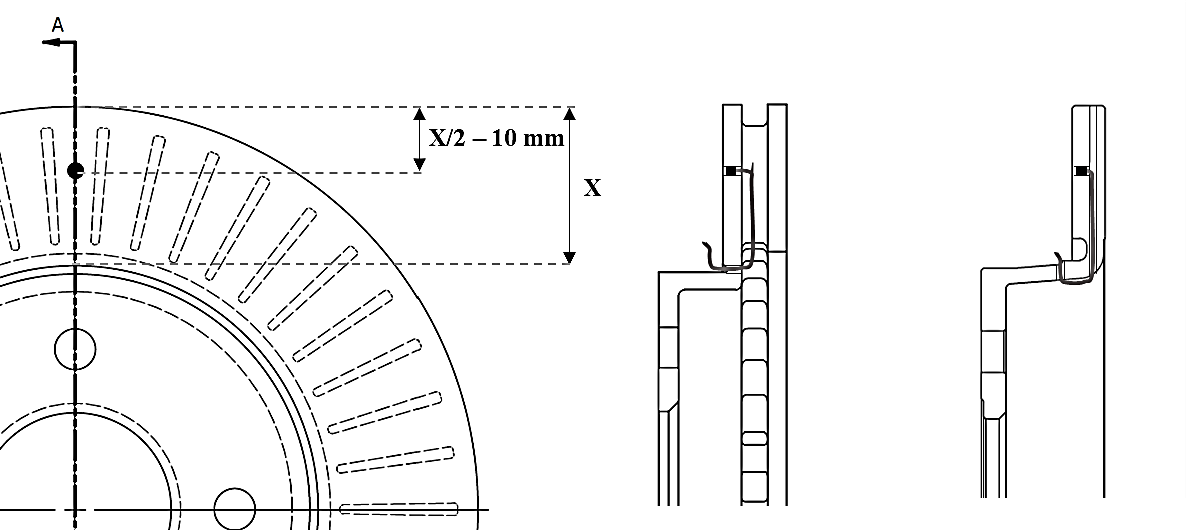
The testing facility shall use embedded thermocouples for the measurement of the brake disc or drum temperature. The following specifications apply:

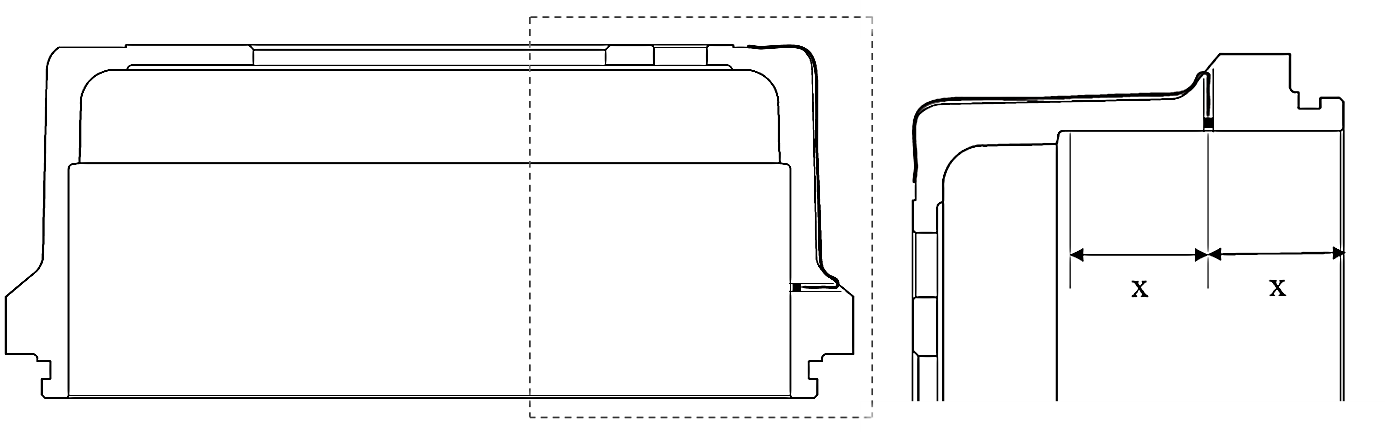
1. Use commercially available temperature sensors containing Nickel-chromium (Chromel) and Nickel-aluminum (Alumel) conductors (Type K thermocouples);
2. Use embedded thermocouples with a measurement temperature range of (0 to 1260) °C and a maximum permissible error (tolerance) of ±2.2 °C or ±0.75 per cent of the measured value;
3. Use embedded thermocouples with a solid tip readily installed to embed them onto the brake components.

Additionally, the following specifications for placing the embedded thermocouples onto the brake components apply:

1. Disc brakes: Locate the embedded thermocouple in the outboard plate rubbing surface – radially positioned 10 mm outwards of the centre of the friction path – and recessed (0.5 ± 0.1) mm deep below the surface of the disc. On vented discs, centre the thermocouple between two fins of the disc plate. Figure 8.1 illustrates the proper installation of embedded thermocouples on brake discs;
2. Drum brakes: Locate the embedded thermocouple at the centre of the friction path recessed (0.5 ± 0.1) mm below the inside surface of the brake drum. Figure 8.2 illustrates the proper installation of embedded thermocouples on brake drums;
3. The installation of embedded or other types of thermocouples for measuring brake pad or shoe temperature during brake particle emissions tests in the context of this UN GTR is strongly discouraged. If the installation of the thermocouple is not possible as required in this UN GTR for technical reasons, the testing facility may prove equivalency of the alternative method with the requirements of this UN GTR together with the technical authority.

Brake temperature shall be recorded in the Time-Based file and reported as described in Table 13.6 in paragraph 13.4. The testing facility shall use the 1Hz temperature readings of the embedded thermocouples in the Time-Based file (Tbrake) to check the correct application of the initial temperature at the individual trips of the WLTP-Brake cycle following the specifications described in paragraph 9.2.

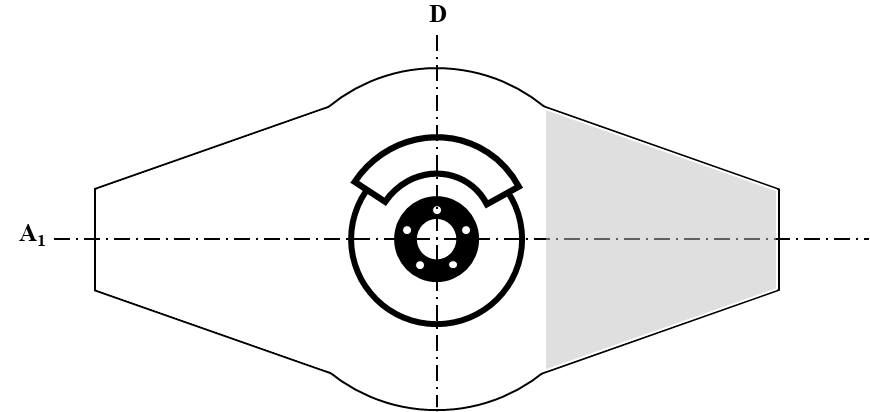
****Figure 8.1  
**Schematic installation of embedded thermocouples for brake discs**

****Figure 8.2  
**Schematic installation of embedded thermocouples for brake drums**

### **Brake Positioning**

#### Brake Assembly

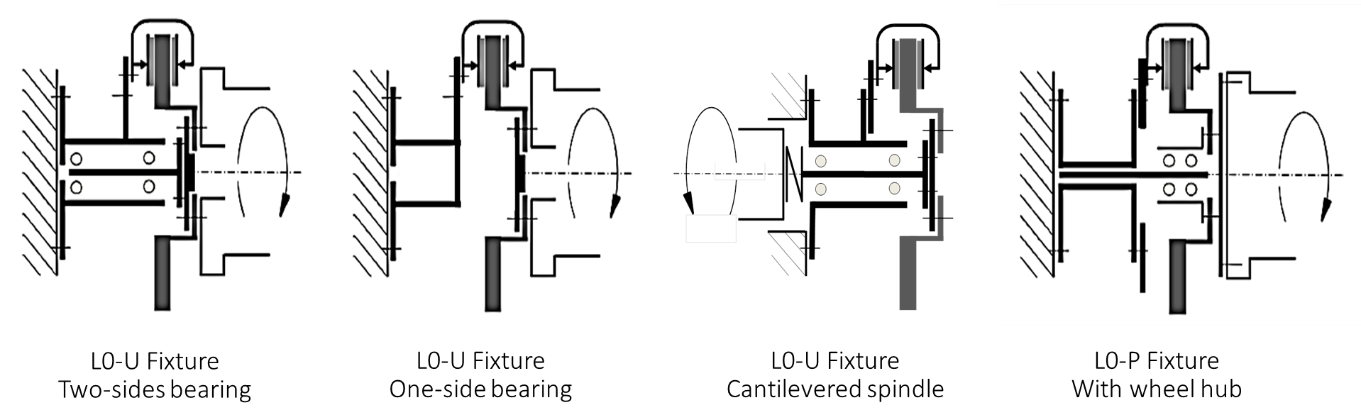
The installing position of the brake assembly defined the axis of rotation of the brake assembly and at the same time the location of planes A1 and D of the enclosure. Proper installation is illustrated in Figure 8.3 with A1 and D perpendicularly intersection in the axis of rotation.

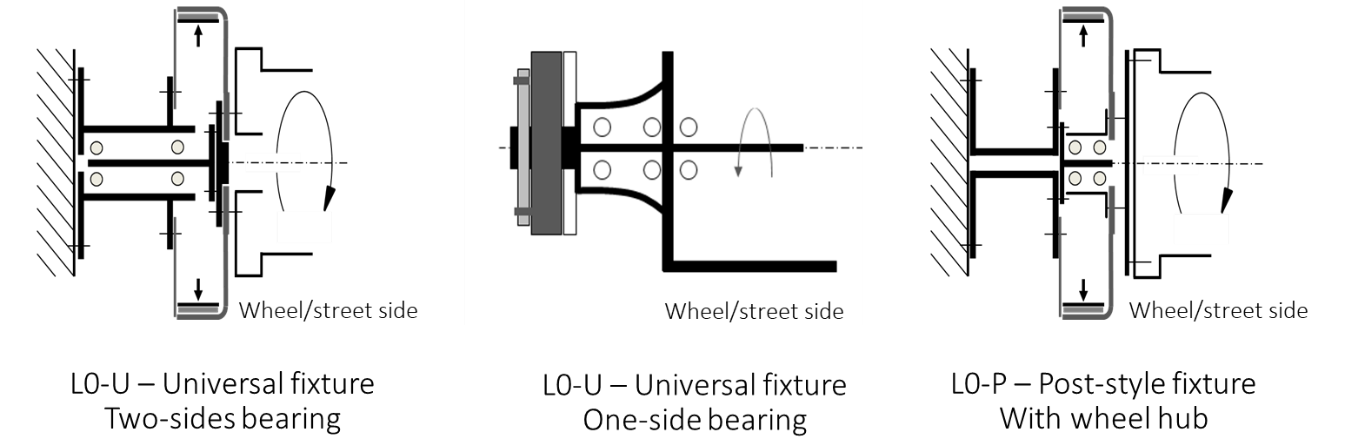
****Figure 8.3  
**Installation position of the brake assembly and the calliper**

#### The testing facility shall use a suitable brake fixture to mount the brake assembly by connecting the tailstock (non-rotating side) to the brake dynamometer shaft (rotating side). The minimum subsystems of the dynamometer brake fixture shall include:

1. Mounting components to attach the brake test fixture to the (non-rotating) tailstock;
2. Structural components to transfer the braking torque and forces to the tailstock;
3. Mounting components to take the brake calliper or the backing plate assembly for drum brakes;
4. Rotating parts to mount the brake disc or brake drum onto;
5. Rotating components to connect the shaft of the brake dynamometer to the brake disc or brake drum.

The support fixture of the brake assembly shall allow the brake to freely rotate by 360° with low friction and without exhibiting vibration or oscillations during testing. The testing facility shall mount the brake assembly on the dynamometer using a universal style (L0-U) or post style (L0-P) brake fixture. The L0-U allows for directly attaching the brake assembly onto the dynamometer driveshaft without a wheel hub. The L0-P allows for the installation of the specific vehicle’s bearing. Figures 8.4 and 8.5 illustrate some examples of the fixture style schematics for disc and drum brakes, respectively.

****Figure 8.4  
**Example of allowed fixture styles schematics for disc brakes**

****Figure 8.5  
**Example of allowed fixture styles schematics for drum brakes**

Any variant of these fixtures (one side bearing right or left or both sides bearing) may be applied provided they use an L0 style fixture as a reference (i.e. cylindrical and symmetrical base without additional extensions or protrusions different from those needed to mount the calliper assembly). For example, Figure 8.4 illustrates three different versions of an L0-U fixture: With two side bearings, one side bearing, and a cantilevered spindle. Unique brake mounting systems for braking technologies that the L0-U or the L0-P cannot accommodate may deviate from this requirement. In such a case, the testing facility shall submit the proper documentation demonstrating the need for their use and prove equivalency of the alternative method with the requirements of this UN GTR together with the technical authority.

The testing facility shall install the brake assembly such that it always rotates in the evacuation direction when driving forward as shown in Figure 8.6. When the cooling air flows in a direction from right to left (Figure 8.6 left-hand side), the disc shall rotate in a counter-clockwise direction (CCW). When the cooling air flows in a direction from left to right (Figure 8.6 right-hand side), the disc shall rotate in a clockwise direction (CW). Although the direction of airflow is opposite to the flow direction at the vehicle, alternative rotation directions are not allowed and will invalidate the test.

Figure 8.6  
**Schematic representation of disc rotation for the use case of a left hand side brake (left) and a right hand side brake (right).**

#### Calliper Orientation

The testing facility shall position the calliper to minimise potential interference with the incoming cooling air. Install the calliper above the disc with the center of the calliper in a 12-o’clock position as illustrated in Figure 8.6 irrespective of the mounting position at the vehicle. Other calliper orientations (i.e. vehicle’s mounting position) or configurations are not allowed and will invalidate the test. The parking brake shall be always dismounted for carrying out a brake emissions test. Alternatively, a calliper without the parking brake feature shall be selected for the test.

## WLTP-Brake Cycle

### **General Information**

The testing cycle for all types of brake systems shall be the time-based WLTP-Brake cycle. The WLTP-Brake cycle demands the continuous control of the equivalent linear speed on the brake dynamometer. Figure 9.1 illustrates the time-resolved speed trace of the WLTP-Brake cycle. In summary, the WLTP-Brake cycle includes:

‒ Ten (10) individual trips (Trips #1 - #10) that represent different driving and braking conditions. The trips are separated by cooling sections. The trips’ numbers are indicated on the right-hand side Y-axis in Figure 9.1;

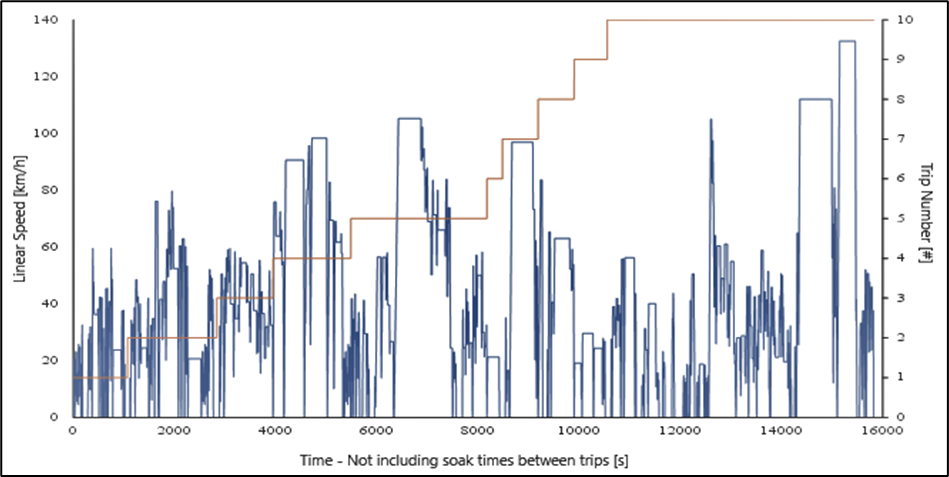
‒ 15 826 seconds of active speed control, without including the cooling sections between the individual trips of the cycle;

‒ 303 brake deceleration events. The main properties of the brake deceleration events are described in the “Brake Events Information” tab in the “ WLTP-Brake cycle“ file[[1]](#footnote-2);

‒ 192 km of total distance driven with an average speed of 43.7 km/h and a maximum speed of 132.5 km/h representing the 95-percentile of normal driving according to the WLTP database;

‒ An average brake deceleration rate of 0.97 m/s². A maximum brake deceleration rate of 2.18 m/s²;

‒ An average brake duration of 5.7 s. A maximum brake duration of 15 s.

Figure 9.1  
**Time-resolved vehicle speed for the WLTP-Brake cycle and the classification of trip numbers**

### **WLTP-Brake Cycle Application**

#### Cooling Adjustment Section

The cooling air adjustment for testing different brakes shall be carried out using Trip #10 of the WLTP-Brake cycle as described in paragraph 10 of this GTR. Specific provisions related to the brake temperature at the beginning of Trip #10 apply to the cooling adjustment section. The testing facility shall perform the following steps:

1. Set the cooling airflow to the nominal value determined in paragraph 10;
2. Warm the brake to (40±1) °C following a sequence of brake events #190 to #196 of Trip #10 with a subsequent cooling phase down to (40±1) °C;
3. Commence Trip #10 of the WLTP-Brake cycle at a brake temperature of (40±1) °C;
4. Run Trip #10 of the WLTP-Brake cycle without any interruption. Paragraph 9.3.1 describes the necessary actions in case of interruptions.

Failure to comply with the described brake temperature provisions shall result in an invalid cooling adjustment. In this case, the testing facility shall repeat the cooling adjustment section. The same brake parts are allowed for repeating the cooling adjustment.

#### Bedding Section

The bedding procedure consists of five consecutive runs of the WLTP-Brake cycle as described in paragraph 11 of this GTR. The correct execution of each WLTP-Brake cycle involves the performance of all ten trips in succession. Specific provisions related to the brake temperature at the beginning of each WLTP-Brake cycle apply to the bedding procedure. The testing facility shall carry out the following steps:

1. Set the cooling airflow to the nominal value for the brake under testing following the procedure described in paragraph 10;
2. Commence the first run of the WLTP-Brake cycle at a brake temperature of (23 ± 2) °C;
3. Do not apply soaking sections between the individual trips of the WLTP-Brake cycle during the bedding procedure;
4. Commence each of the subsequent four WLTP Brake cycle as soon as the brake temperature at the end of the previous WLTP-Brake cycle is below 40.0°C and above 30.0°C, without any intervention to warm the brake;
5. If the brake temperature at the end of the previous WLTP-Brake cycle is below 30 °C, discontinue the bedding section and identify discrepancies in the test execution or repeat the cooling adjustment. After fixing the issue, repeat the bedding section from the beginning;
6. Run the five individual WLTP-Brake cycles consecutively without any interruption. Paragraph 9.3.2 describes the necessary actions in case of interruptions.

The minimum threshold temperature of 30 °C specified in this paragraph applies to all tested brake assemblies. Failure to comply with the described brake temperature provisions shall result in an invalid bedding test and the testing facility shall repeat the bedding section. A new set of brake parts shall be used in case of repeating the bedding procedure.

#### Emissions Measurement Section

The correct execution of the WLTP-Brake cycle involves the performance of all ten trips in succession. Soaking sections are mandatory between the individual trips of the WLTP-Brake cycle during the execution of the emissions measurement section. Specific provisions related to the brake temperature at the beginning of each trip of the WLTP-Brake cycle apply to the emissions measurement. The testing facility shall carry out the following steps:

1. Set the cooling airflow to the nominal value for the brake under testing following the procedure described in paragraph 10;
2. Commence Trip #1 of the WLTP-Brake cycle at a brake temperature of (23 ± 2) °C, without conducting any warm-up stops or snubs;
3. For Trips #2-10, if the brake temperature at the end of the previous trip is between 30 °C to 40 °C, commence the subsequent trip immediately without any intervention to warm the brake disc; if the temperature is above 40°C soak until the brake temperature falls below 40.0°C
4. For Trips #2-10, if the brake temperature at the end of the previous trip is below 30 °C, discontinue the emissions test and identify discrepancies in the test execution or repeat the cooling adjustment. After fixing the issue, repeat from the beginning of the bedding section using a new set of brake parts;
5. Run the WLTP-Brake cycle without any interruption. Paragraph 9.3.3 describes the necessary actions in case of interruptions.

The minimum threshold temperature of 30 °C specified in this paragraph applies to full-friction brake systems equipped on all vehicles within the scope of this GTR. A minimum threshold temperature of 23 (25) °C applies to brakes equipped on vehicles within the scope of this GTR that feature regenerative braking systems.

### **WLTP-Brake Cycle Interruptions**

#### Cooling Adjustment Section

#### If the test is interrupted (or the dynamometer faults) during the cooling adjustment section, the testing facility shall discontinue the test and restart the cooling adjustment procedure from the beginning. In that case, after performing a data review and a visual inspection without disturbing the brake assembly, the testing facility shall use the same brake assembly to continue the cooling adjustment. If upon inspection there are reasons to compromise the test (loose components, brake fluid leakage, incorrect mounting, excessive vibration, etc.), the testing facility shall mount a new brake assembly and repeat the procedure following the specifications described in 8.2.1.

#### Bedding Section

#### If the test is interrupted (or the dynamometer faults) during the bedding section, the testing facility shall continue bedding from the point of interruption considering the last recorded timestamp in the Time-Based file with non-zero values for the braking parameters. . Disassembling of the brake or replacing parts of the brake assembly is not permitted. If this is required for technical reasons the bedding procedure must be repeated from the beginning, If the replacing or reassembling of the brake may have effect on the temperature behaviour of the brake the cooling adjustment section shall be repeated as well.

#### Emissions Measurement Section

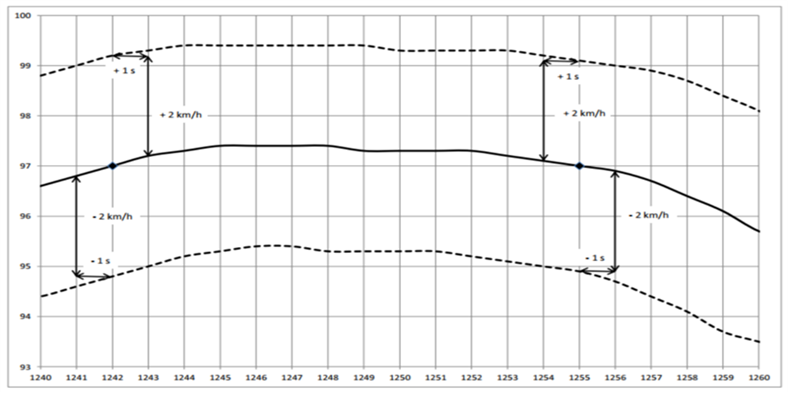
#### If the emission measurement test is interrupted due to malfunction of the dynamometer or the measurement equipment, the test is invalid, and the section shall be repeated as a new test.

### **WLTP-Brake Cycle Quality Checks**

The following quality checks shall be carried out to verify the correct execution of the WLTP-Brake cycle. A valid emissions test shall comply with all the criteria described below.

#### Speed Violations Check

##### The speed violations quality check is necessary to ensure that the brake dynamometer has correctly executed the WLTP-Brake cycle speed trace. A speed violation occurs whenever the actual speed of the dynamometer exceeds the speed trace tolerances defined by the prescribed (nominal) speed. Figure 9.2 depicts the upper and lower speed tolerance limits.

Figure 9.2  
**Tolerance limits for speed violations during WLTP-Brake cycle [UN GTR No 15]**

‒ Upper-speed tolerance: 2.0 km/h higher than the nominal linear speed trace within ±1.0 second of the given point in time;

‒ Lower-speed tolerance: 2.0 km/h lower than the nominal linear speed trace within ±1.0 second of the given point in time.

1. During the cooling adjustment section, the number of speed violations shall not exceed 158 for each complete Trip #10 of the WLTP-Brake cycle. This corresponds to 3 per cent of the Trip #10 duration;
2. During the bedding section, the number of speed violations shall not exceed 475 for each complete WLTP-Brake cycle. This corresponds to 3 per cent of the WLTP-Brake cycle duration and applies to all five repetitions of the WLTP-Brake cycle;
3. During the emissions measurement section, the number of speed violations shall not exceed 475 for each complete WLTP-Brake cycle. This corresponds to 3 per cent of the WLTP-Brake cycle duration. Soaking sections shall not be included in the calculation;
4. Calculate and report the number of speed violations in all sections as defined in Table 13.6 in paragraph 13.4. The computation of speed violations shall include all types of events (dwell, acceleration, cruising, and deceleration);
5. Failure to run Trip #10 of the WLTP-Brake cycle (cooling adjustment section) during any section ( (cooling air adjustment, bedding or emissions measurement section) within the speed tolerances defined in this paragraph shall result in an invalid brake emissions test.

#### Number of Deceleration Events

##### This quality check examines the number of executed brake events. It is necessary to ensure that all 303 brake events of the WLTP-Brake cycle were applied during the emissions measurement section. A violation of this criterion occurs whenever the actual number of applied brake events is not equal to the nominal value (i.e. 303).

##### The testing facility shall verify the number of applied brake events as defined in Table 13.6 in paragraph 13.4. The parameters “Stop Duration” and “Deceleration Rate - Distance Averaged” shall be cross-checked and verified that both include 303 numerical and non-zero values that correspond to the respective 303 brake events of the WLTP-Brake cycle.

##### This quality check applies only to the emissions measurement section. Failure to perform the 303 braking events of the WLTP-Brake cycle during the emissions measurement section as defined in this paragraph shall result in an invalid test.

#### Kinetic Energy Dissipation

This quality check is necessary to ensure the application of the correct amount of friction work (Wf) during the execution of the WLTP-Brake cycle. It is also an additional quality check that other input parameters (e.g. brake test inertia) have been calculated and applied correctly.

##### A violation occurs whenever the sum of the calculated friction work of all brake events throughout Trip #10 of the WLTP-Brake cycle (for the cooling adjustment section) and the entire WLTP-Brake cycle (for the bedding or emissions measurement sections) exceeds the defined tolerances:

‒ Trip #10 upper-friction work tolerance: 278 J/kg higher than the nominal friction work value of 5555 J/kg. Thus, the upper-friction work tolerance is 5833 J/kg;

‒ Trip #10 lower-friction work tolerance: 278 J/kg lower than the nominal friction work value of 5555 J/kg. Thus, the lower-friction work tolerance is 5277 J/kg if no non-friction braking method is applied;

‒ WLTP-Brake cycle upper-friction work tolerance: 799 J/kg higher than the nominal friction work value of 15983 J/kg. Thus, the upper-friction work tolerance is 16782 J/kg;

‒ WLTP-Brake cycle lower-friction work tolerance: 799 J/kg lower than the nominal friction work value of 15983 J/kg. Thus, the lower-friction work tolerance is 15184 J/kg if no non-friction braking method is applied.

1. During the cooling adjustment section, the calculated friction work over Trip #10 shall be between 5277 J/kg and 5833 J/kg. This corresponds to ±5 per cent of the nominal value;
2. During the bedding section, the calculated friction work over the WLTP-Brake cycle shall be between 15184 J/kg and 16782 J/kg. This corresponds to ±5 per cent of the nominal value and applies to all five repetitions of the WLTP-Brake cycle;
3. During the emissions measurement section, the calculated friction work over the WLTP-Brake cycle shall be between 15184 J/kg and 16782 J/kg if no non-friction braking method is applied. This corresponds to ±5 per cent of the nominal value. Soaking sections shall not be included in the calculation;
4. If no non-friction braking method is applied, the testing facility shall calculate the friction work by applying the integrals for torque and angular speed over time for each braking event using the submitted Event-Based file of the brake emissions test as defined in Table 13.6 in paragraph 13.4. The calculation requires also the use of the test wheel load (WLt) and follows equation 9.1:

|  |  |
| --- | --- |
|  | (Eq. 9.1) |

Where:

is the friction work in J/kg;

is the rotational speed per Table 13.1;

is the brake torque per Table 13.1;

is the stop duration per Table 13.1;

is the test (or applied) wheel load per Table 8.1.

1. Equation 9.1 provides the friction work for each one of the 114 and 303 brake events of Trip #10 and the WLTP-Brake cycle, respectively. The testing facility shall calculate the total friction work by summing the calculated friction work from the individual brake events. The total friction work shall be compared to the prescribed (nominal) friction work value as described in points (a)-(c) of this paragraph;
2. Failure to complete any of the sections of the brake emissions test with a total friction work within the tolerances defined in this paragraph shall result in an invalid test. The kinetic energy dissipation quality check applies only to full friction brakes equipped on vehicles within the scope of this GTR. It does not apply to brakes equipped on vehicles with regenerative braking capabilities.

## Cooling Airflow Adjustment

Different test systems can embody different combinations of brake enclosure design and size, airflow or airspeed levelsThis paragraph establishes the proper methodology to adjust the airstream speed to provide comparable brake thermal regimes across the testing facilities.

### **Method Description**

#### Definition of Brake assembly Groups and Verification Parameters

To determine the appropriate cooling airflow for the brake assembly under test, the testing facility shall first classify the tested brake into a nominal wheel load (WLn) to disc or drum mass (DM) group according to its (WLn/DM) ratio.

The WLn/DM ratio is calculated by dividing the WLn (kg) with the pre-test disc or drum mass (kg). The testing facility shall determine the WLn following paragraph 8.1.1 (c). Four different WLn/DM groups are defined based on the WLn/DM ratio:

‒ Group 1: WLn/DM ≤ 45;

‒ Group 2: 45 < WLn/DM ≤ 65;

‒ Group 3: 65 < WLn/DM ≤ 85;

‒ Group 4: WLn/DM > 85.

The testing facility shall apply the test wheel load (WLt) described in paragraph 8.1.1 (d) – and not the nominal wheel load (WLn) – during the execution of all sections of the brake emissions test.

Three check parameters have been defined for the cooling air adjustment of the brake under testing. The target values and allowed tolerances for these parameters differ for each WLn/DM group. The testing facility shall use the following parameters as a reference against which the cooling adjustment test results shall be compared:

1. Average brake temperature over Trip #10 of the WLTP-Brake cycle (Tavg);
2. Average initial brake temperature of six selected brake events from Trip #10 of the WLTP-Brake cycle (IBT) applying full-friction braking;
3. Average final brake temperature of six selected brake events from Trip #10 of the WLTP-Brake cycle (FBT) applying full-friction braking;

The brake events referred to (b) and (c) of this paragraph are #46, #101, #102, #103, #104, and #106 of Trip #10. The details of the target brake events are specified in Table 10.1. When the entire WLTP-Brake cycle is considered, the brake events’ corresponding sequence numbers are #235, #290, #291, #292, #293, and #295.

Table 10.1  
**Specific brake events from Trip #10 of the WLTP-Brake cycle**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *Parameter* | *Unit* | *Deceleration event* | | | | | |
| *#46* | *#101* | *#102* | *#103* | *#104* | *#106* |
| Start time | s | 2088 | 4438 | 4459 | 4494 | 4522 | 4903 |
| End time | s | 2092 | 4447 | 4467 | 4503 | 4529 | 4918 |
| Brake duration | s | 4.0 | 9.0 | 8.0 | 9.0 | 7.0 | 15.0 |
| Initial speed | km/h | 97.4 | 112.0 | 68.2 | 80.9 | 73.4 | 132.5 |
| Final speed | km/h | 82.7 | 56.1 | 12.0 | 35.3 | 39.3 | 34.0 |

#### Verification of Parameters and Tolerances for Brake Temperature

The target values and the corresponding tolerances for the three check parameters are given in Table 10.2 for the case that full friction braking is applied.

Table 10.2  
**Default temperature metrics and tolerances for brakes during Trip #10 of the WLTP-Brake cycle**

|  |  |  |  |
| --- | --- | --- | --- |
| *Group* | *Tavg [A1]* | *IBT [A2] ± Tolerance* | *FBT [A3] ± Tolerance* |
| *WLn/DM* ≤ 45 | ≥ 50 °C | 60 ± 20 °C | 90 ± 30 °C |
| 45 < *WLn/DM* ≤ 65 | ≥ 55 °C | 70 ± 20 °C | 110 ± 30 °C |
| 65 < *WLn/DM* ≤ 85 | ≥ 60 °C | 80 ± 20 °C | 125 ± 30 °C |
| *WLn/DM* > 85 | ≥ 65 °C | 90 ± 20 °C | 145 ± 30 °C |

1. The target values and the corresponding tolerances for the three check parameters apply to all types of front brake systems mounted in all types of vehicles within the scope of this GTR if full-friction braking is applied;
2. For rear disc brakes, the nominal (or set) cooling airflow defined for the corresponding front brake application (i.e. same vehicle data) shall be applied. In this case, the allocation of the brake in a WLn/DM category described in paragraph 10.1.1 shall be carried out using the front brake data;
3. For rear drum brakes, the nominal (or set) cooling airflow defined for the corresponding front brake application (i.e. same vehicle data) shall be applied. In this case, the allocation of the brake in a WLn/DM category described in paragraph 10.1.1 shall be carried out using the front brake data.

#### Computation of Verification Parameters and Acceptance Criteria

##### Once the brake is classified to its WLn/DM Group per paragraph 10.1.1, the testing facility shall run Trip #10 of the WLTP-Brake cycle with new brake parts to obtain the values of the check parameters to populate the cells in Table 10.3. The test shall be carried out according to paragraph 10.1.4. The testing facility shall apply the WLt as defined in paragraph 8.1.1 (d) for the allocation of the brake to a WLn/DM group. The measured values for the check parameters shall be calculated using the produced test report files as follows:

1. Average brake temperature over Trip #10 of the WLTP-Brake cycle (Tavg):
2. The target value (A1) depends on the WLn/DM Group and is defined in Table 10.2;
3. The measured value (B1) is calculated from the Time-Based file of the brake emissions test as defined in Table 13.6 in paragraph 13.4;
4. B1 equals the average of all brake temperature entries corresponding to the entire duration of Trip #10 (5272 s).
5. Average initial brake temperature of selected brake events from Trip #10 of the WLTP-Brake cycle (IBT):
6. The target value (A2) and tolerances depend on the WLn/DM Group and are defined in Table 10.2;
7. The measured value (B2) is calculated from the Event-Based file of the brake emissions test as defined in Table 13.6 in paragraph 13.4;
8. B2 equals the average temperature value of the individual IBT values recorded for each of the six selected brake events described in Table 10.1. The testing facility shall calculate B2 as shown in Table 10.3 (B2 = AVERAGE (Y1:Y6)).
9. Average final brake temperature of selected brake events from Trip #10 of the WLTP-Brake cycle (FBT):
10. The target value (A3) and tolerances depend on the WLn/DM Group and are defined in Table 10.2;
11. The measured value (B3) is calculated from the Event-Based file of the brake emissions test as defined in Table 13.6 in paragraph 13.4;
12. B3 equals the average temperature value of the individual FBT values recorded for each of the six selected brake events described in Table 10.1. The testing facility shall calculate B3 as shown in Table 10.3 (B3 = AVERAGE (Z1:Z6)).

##### After the execution of the cooling adjustment test with the selected air flow, the testing facility shall compare the recorded temperature values of the check parameters to the corresponding target values defined in Table 10.2. The difference between target and test results for the check temperature parameters shall be calculated as follows:

1. Difference (C1) in average brake temperatures B1 and A1 as defined above (B1-A1) and shown in Table 10.3;
2. Absolute difference (C2) in average IBT of the selected events B2 and A2 as defined above (|A2-B2|) and shown in Table 10.3;
3. Absolute difference (C3) in average FBT of the selected events B3 and A3 as defined above (|A3-B3|) and shown in Table 10.3.

The testing facility shall compare the obtained results with the acceptance criteria as defined in Table 10.3.

Table 10.3  
**Calculation of brake temperature metrics [°C] and acceptance criteria during Trip #10**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| *Trip #10 Event* | *Metric* | *Target Temperature* | *Cooling Adjustment*  *Test Temperature* | *Difference* | *Acceptance Criteria* |
| *‒* | *TAVG* | *A1* | *B1* | *C1=B1 ‒ A1* | *C1 ≥ 0 °C* |
| *‒* | *Average 5 % IBT* | *A2* | *B2 = Average (Y1:Y6)* | *C2=|A2 ‒ B2|* | *C2 ≤ 20 °C* |
| #46 |  |  | Y1 | N/A | N/A |
| #101 | Y2 |
| #102 | Y3 |
| #103 | Y4 |
| #104 | Y5 |
| #106 | Y6 |
| ‒ | *Average 5 % FBT* | A3 | B3 = Average (Z1:Z6) | C3=|A3 *‒* B3| | C3 ≤ 30 °C |
| #46 |  |  | Z1 | N/A | N/A |
| #101 | Z2 |
| #102 | Z3 |
| #103 | Z4 |
| #104 | Z5 |
| #106 | Z6 |

1. All three criteria shall be fulfilled for successful completion of the cooling airflow adjustment section;
2. In case the cooling adjustment test does not meet all metrics from Table 10.2, the testing facility shall repeat the procedure adjusting the cooling airflow accordingly;
3. If there is no suitable cooling airflow meeting all metrics from Table 10.2, the testing facility shall select the cooling airflow that fulfils the acceptable criteria for at least two parameters, always including the average Trip #10 temperature;
4. In case of (c), the testing facility shall submit the reporting files for the non-successful cooling adjustment tests. In the case of brakes with calculated temperatures lower than the lower threshold values of the target temperatures, the testing facility shall demonstrate that the minimum operational airflow of the setup was applied and full compliance with the target parameters was not possible. In the case of brakes with calculated temperatures higher than the higher threshold values of the target temperatures, the testing facility shall demonstrate that the maximum operational airflow of the setup was applied and full compliance with the target parameters was not possible.

#### Brake Dynamometer Testing to Adjust the Cooling Airflow

The testing facility shall carry out the following steps to adjust the cooling airflow when testing a brake for the first time.

1. Follow the test setup preparation specifications described in paragraph 8.2.1;
2. Adjust the cooling airflow to a known value used for similar brakes. In the absence of a useful reference, use an airflow of 50 per cent of the maximum test setup capacity to start the test;
3. Conduct one run of Trip #10 of the WLTP-Brake cycle starting at a brake temperature of 40 °C. Warm up the brake to 40 °C following the instructions given in paragraph 9.2.1;
4. Alternatively, program a series of tests at different cooling airflow levels starting each test at an initial temperature of 40 °C;
5. Perform the calculations using paragraph 10.1.3 and assess the results and deviations for the target parameters;
6. If the test run meets all the metrics from Table 10.2, finish the process and prepare the test report following the specifications described in paragraph 13;
7. proceed with the subsequent sections of the brake emissions test ensuring the application of the same dynamometer settings as in the cooling adjustment procedure. The same set of brakes shall be used for brake emissions testing;
8. If the test run does not meet all the metrics from Table 10.2, use sound engineering judgement to determine a new cooling airflow level and repeat the process from step (a). The same set of brakes can be used for repeating the cooling airflow adjustment section.

## Bedding Section

The bedding procedure is necessary to appropriately precondition the brake assembly and stabilise its emission behavior before performing emissions measurement. The bedding procedure shall be carried out with a completely new brake assembly.

### **Front Brakes**

The testing facility shall perform the bedding procedure for all types of brakes equipped at the front axle of the vehicles that fall within the scope of this GTR following the specifications described below:

1. Set the cooling airflow according to the adjustment of the cooling settings for the brake under testing as specified in paragraph 10.1;
2. Define all relevant testing parameters and dynamometer settings (testing wheel load, brake test inertia, etc.) same as in the cooling adjustment and emissions measurement sections;
3. Apply five repetitions of the WLTP-Brake cycle for complete bedding of the front brake under testing;
4. The five WLTP-Brake cycles shall run consecutively without any interruption. If the test is interrupted during the bedding section, the testing facility shall follow the instructions defined in paragraph 9.3.2;
5. Run each repetition of the WLTP-Brake cycle without the application of soaking sections between the individual trips of the WLTP-Brake cycle. Soaking sections shall apply only between the five repetitions of the WLTP-Brake cycle (i.e. between the end of brake event #303 of Trip #10 of a given WLTP-Brake cycle and the start of brake event #1 of Trip #1 of the following WLTP-Brake cycle);

Commence the first WLTP-Brake cycle of the bedding section at a brake temperature of (23 ± 2) °C. Commence the subsequent four repetitions of the WLTP-Brake cycle at a brake temperature fulfilling the provisions described in paragraph 9.2.2 apply to the bedding procedure of front brakes;

1. Perform the bedding section on the same dynamometer as for the emissions measurement section. Do not disassemble the brake parts between the two sections of the test to avoid modifying the contact points. If the brake parts are disassembled after the beginning of the bedding procedure, they are no longer suitable for completing bedding and emissions measurements. In that case, the testing facility shall replace with new brake parts and repeat the bedding procedure from the beginning.

Failure to comply with any of the provisions described in this paragraph shall result in an invalid bedding procedure. In this case, it is not possible to proceed with the emissions measurement section. The testing facility shall perform the bedding procedure from the beginning using new brake parts.

### **Rear Brakes**

The testing facility shall perform the bedding procedure for all types of brakes equipped at the rear axle of the vehicles that fall within the scope of this GTR following the specifications described below:

1. Use the cooling airflow according to the adjustment of the cooling settings for the corresponding front brake as specified in paragraph 10.1.2;
2. Define all relevant testing parameters and dynamometer settings (testing wheel load, brake test inertia, etc.) same as in the emissions measurement section;
3. Apply five repetitions of the WLTP-Brake cycle for complete bedding of the rear brake under testing;
4. The five WLTP-Brake cycles shall run consecutively without any interruption. If the test is interrupted during the bedding section, the testing facility shall follow the instructions defined in paragraph 9.3.2;
5. Run each repetition of the WLTP-Brake cycle without the application of soaking sections between the individual trips of the WLTP-Brake cycle. Soaking sections shall apply only between the five repetitions of the WLTP-Brake cycle (i.e. between the end of brake event #303 of Trip #10 of a given WLTP-Brake cycle and the start of brake event #1 of Trip #1 of the following WLTP-Brake cycle);
6. Commence the first WLTP-Brake cycle of the bedding section at a brake temperature of (23 ± 2)) °C. Commence the subsequent four repetitions of the WLTP-Brake cycle at a brake temperature fulfilling the provisions described in paragraph 9.2.2 apply to the bedding procedure of rear brakes;
7. Perform the bedding section on the same dynamometer as for the emissions measurement section. Do not disassemble the brake parts between the two sections of the test to avoid modifying the contact points. If the brake parts are disassembled after the beginning of the bedding procedure, they are no longer suitable for completing bedding and emissions measurements. In that case, the testing facility shall replace with new brake parts and repeat the bedding procedure from the beginning.

Failure to comply with any of the provisions described in this paragraph shall result in an invalid bedding procedure. In this case, it is not possible to proceed with the emissions measurement section. The testing facility shall perform the bedding procedure from the beginning using new brake parts.

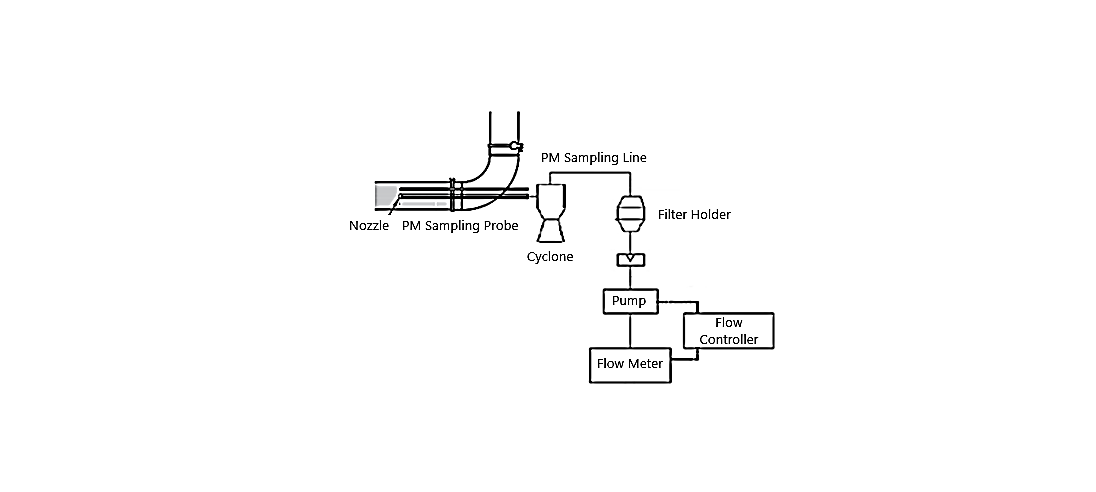
## Particle Number and Particulate Emissions Measurements Section

### **Measurement of Particulate Matter Mass (PM)**

This paragraph describes the specifications for the PM emissions measurement during a brake emissions test. The PM sampling system enables the quantification of the particle mass generated by the brake assembly during the test. The PM emissions and the parameters from the test provide the emissions factors for the brake under testing in mass per unit of distance driven. The test system shall measure brake PM10 and PM2.5 emissions gravimetrically using separate sampling systems for each cut-off diameter (2.5 μm and 10 μm). Each PM sampling system shall consist of the following elements:

1. Two PM sampling probes are located in the tunnel. The specifications for the design of the PM probes are described in paragraph 12.1.1.2;
2. An appropriate sampling nozzle is installed at the tip of the PM sampling probe. The specifications for the design of the nozzles are described in paragraph 12.1.1.3;
3. A cyclone is applied as a PM separation device. The specifications for the cyclone are described in paragraph 12.1.2.1;
4. A particle sampling line transfers the aerosol from the PM separation device to the filter holder. The specifications for the design of the sampling line are described in paragraph 12.1.2.2;
5. A filter holder collects the particulate matter. The specifications for the filter holder are described in paragraph 12.1.3.1;
6. One or more pumps with means to control the flow rate in real-time and the corresponding sensors. The specifications for the sampling flow are described in paragraph 12.1.2.3.

Figure 12.1 illustrates an indicative setup of the PM sampling unit. The positioning and dimensions of the different elements are provided for illustration purposes; therefore, exact conformance with the figure is not required.

****Figure 12.1  
**Indicative setup of the PM sampling unit**

#### Particulate matter Extraction

##### Sampling Plane

The design of the sampling plane shall follow the specifications described in paragraph 7.6. The following additional specifications apply to the sampling plane for the installation of the PM sampling probes:

1. Apply two sampling probes with the corresponding sampling nozzles for the PM measurements, one for PM2.5 and one for PM10. White dots in Figure 7.7 indicate the PM sampling probes for the four sampling probes layout;
2. place the two PM sampling probes (PM2.5 and PM10) at the same horizontal plane to the lower part of the tunnel as shown in Figure 7.7 (right-hand side);
3. Do not use flow splitters for PM measurements anywhere in the sampling and measurement system.

##### PM Sampling Probes

Appropriate sampling probes shall be used to transport the aerosol from the tunnel to the separation device. The testing facility shall select sampling probes meeting the following design requirements:

1. Use probes appropriately designed to minimise particle losses from the nozzle tip to the separation device;
2. Use probes made of stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface;
3. Select probes with a constant inner diameter (dp) of at least 10 mm and a maximum of 18 mm ensuring a laminar flow (10 mm ≤ dp ≤ 18 mm);
4. Design the sampling probes aiming for the shortest possible length to minimise losses and possible tubing pollution. The overall length of the probes from the sampling nozzle tip to the inlet of the PM separation device shall not exceed 1 m;
5. A maximum of one bend of 90° may be applied to the probes provided that the specifications for the design of the bend described in point (f) of this paragraph are met; The bend shall be in the horizontal direction.
6. If a bend is applied to the probes, the bending radius rp shall be at least four times the inner diameter (4∙dp) of the probes;
7. Inspect and clean the inner walls of the sampling probes frequently following the specifications of their manufacturer regarding the cleaning frequency and means. If no such specifications are provided clean the probes at least once every six months.

##### PM Sampling Nozzles

Appropriate nozzles to ensure isokinetic sampling for PM10 and PM2.5 (paragraph 12.1.2.4) shall be used. The testing facility shall select sampling nozzles meeting the following requirements:

1. Use nozzles compatible with the PM sampling probes used by the testing facility for brake emissions testing;
2. Use nozzles made of stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface;
3. Use the appropriate nozzles to achieve an isokinetic ratio (*IR*) as close as possible to 1.0 following the specifications described in paragraph 12.1.2.4. The average isokinetic ratio in a brake emissions test shall be between 0.90-1.15 (0.90 ≤ *IR* ≤ 1.15);
4. Select the nozzle size depending on the applied sampling flow. Do not use nozzles with an inner diameter (dn) lower than 4 mm;
5. The nozzles shall have a constant internal diameter along a length equal to at least one internal diameter or at least 10 mm from the nozzle tip, whichever is greater;
6. Use nozzles with a thin wall at the tip to minimise distortion of flow. These shall have an outer to inner diameter ratio lower than 1.1 at the nozzle tip;
7. Any variation in bore diameter of the nozzles shall be tapered with a conical angle less than 30°;
8. Place the nozzles with their axis parallel to that of the dilution tunnel making sure that the aspiration angle remains lower or equal to 15°;
9. Clean the nozzles before every brake emissions test following the specifications defined by their manufacturer regarding the cleaning means.

#### PM sampling

##### PM Separation Device

Single cyclonic separators followed by gravimetrical filter holders shall be used for the collection of the PM10 and PM2.5 samples. The testing facility shall select cyclonic separators that meet the following specifications:

1. The PM10 and PM2.5 cyclones shall fulfill the specifications for the separation efficiency described in Tables 12.1 and 12.2, respectively;
2. Place the cyclonic separators with horizontally flow inlet at the outlet of the sampling probe. Connect the cyclonic separator directly at the outlet of the sampling probe using appropriate fittings made of conductive stainless steel. Do not use any kind of sampling tubes between the probe and the cyclonic separator;
3. Inspect and clean the inner walls of the cyclones frequently following the specifications of the instrument manufacturer regarding the cleaning frequency and means.

Table 12.1   
**Separation efficiency specifications of PM10 cyclones**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *PM10* | *4 μm* | *8 μm* | *12.5 μm* | *20 μm* |
| Separation Efficiency | < 20 % | < 50 % | > 60 % | > 90 % |

Table 12.2   
**Separation efficiency specifications of PM2.5 cyclones**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *PM2.5* | *1.5 μm* | *2 μm* | *3 μm* | *4 μm* |
| Separation Efficiency | < 20 % | < 50 % | > 60 % | > 90 % |

##### PM Sampling Line

The testing facility shall ensure that the design of the sampling line that transfers the aerosol from the cyclonic separator to the filter holder meets the specifications described below:

1. appropriately designed to minimise particle transport losses between the outlet of the cyclonic separator and the inlet of the filter holder;
2. made of conductive stainless steel and apply the appropriate fittings. Alternatively, flexible antistatic PTFE sampling lines may be used;
3. a constant inner diameter (ds) of at least 10 mm and a maximum of 20 mm (10 mm ≤ ds ≤ 20 mm). A sampling line with a constant inner diameter close to 15 mm is recommended;
4. The overall length of the sampling line from the outlet of the cyclonic separator to the tip of the filter holder shall be as short as possible. Sampling lines longer than 1 m are not allowed;
5. Design the sampling train outside the tunnel (the part of the sampling train that includes the cyclonic separator and the PM sampling line) in a way that no condensation of water can occur. The temperature inside the sample train shall always remain above 15 °C;
6. A bend may be applied to the sampling lines provided that the bending radius rp shall be at least twenty-five times the inner diameter (25∙ds) of the sampling line.

##### PM Sampling Flow

The testing facility shall apply the following provisions for the regulation and measurement of the sampling flow:

1. The method of measuring the flow of the sampling system (QPM2.5 and QPM10) shall have a maximum permissible error of ±2.5 per cent of the reading or ±1.5 per cent of the full-scale, whichever is the smallest, under all operating conditions;
2. Use a flow measurement device calibrated to report flow at both operating and standard conditions. The temperature sensor shall have an accuracy of ±1.0 °C. The pressure measurements shall have precision and accuracy of ±1.0 kPa;
3. The set (nominal) value for the sampling volumetric flow (QPM2.5-set and QPM10-set) shall be constant during the emissions measurement section of a specific brake system;
4. The average sampling volumetric flow shall be within ±2 per cent of the set value for the given brake emissions test. Use a device with a flow control feature (e.g. critical orifice, pressure regulator, feedback controller, or other) to ensure a stable flow through the filter medium;
5. Calculate and report the deviation of the average measured sampling volumetric flow from the set value for both PM10 and PM2.5 using the data of the given parameters in the Time-Based file as defined in Table 13.6 in paragraph 13;
6. Set the sampling flow such that the isokinetic ratio is as close as possible to 1.0. The average isokinetic ratio during the emissions measurement section of a specific brake system shall be between 0.90-1.15 (paragraph 12.1.2.4). Calculate and report the average isokinetic ratio for both PM2.5 and PM10 following the procedure described in paragraph 12.1.2.4;
7. Check for possible leaks by sealing the nozzle and starting the suction device. The flow rate shall be at most 2 per cent of the normal flow rate at the maximum vacuum reached during sampling. Perform the leak check upon the system installation and after every maintenance or upgrade. The leak check shall be carried out at least once every year;
8. In case the sampling volumetric flow and/or the isokinetic requirements set out in this paragraph are not met, the test is invalid;
9. The PM sampling device shall operate continuously during the brake emissions measurement section. This includes also the soaking sections between the individual trips of the WLTP-Brake cycle where the PM sampling flow shall not be paused or bypass the main sampling line.

##### Isokinetic Ratio

Sampling is defined as isokinetic when the airspeed in the tunnel and the sampling nozzle are equal. The airspeed is calculated from the airflow values in the tunnel and the nozzle taking into account their inner diameters (di and dn, respectively). Equations 12.1 and 12.2 apply for the calculation of the airspeed in the tunnel and the sampling nozzle:

|  |  |
| --- | --- |
|  | (Eq. 12.1) |
|  | (Eq. 12.2) |

Where:

is the average airspeed in the tunnel in km/h per Table 13.2;

is the average speed of the sampling air entering the nozzle in km/h;

is the average airflow in the tunnel in m³/h per Table 13.2;

is the average airflow in the sampling nozzle in m³/h;

is the inner diameter at the nozzle tip in m;

is the sampling tunnel inner diameter in m per Table 7.1.

The isokinetic ratio is defined as the ratio of the airspeed in the sampling nozzle to the airspeed in the tunnel. Equation 12.3 provides the means to calculate the isokinetic ratio by combining equations 12.1 and 12.2. The airflow values in the sampling tunnel and the nozzle shall refer to the same temperature and pressure conditions; therefore, normalised values shall be used to ensure comparability also between different testing facilities:

|  |  |
| --- | --- |
|  | (Eq. 12.3) |

Where:

is the isokinetic ratio;

is the average normalised airflow in the sampling nozzle in *N*m³/h;

is the average normalised airflow in the sampling tunnel in *N*m³/h per Table 13.2;

is the inner diameter at the nozzle tip in m;

is the sampling tunnel inner diameter in m per Table 7.1.

Converting the sampling flow units from [*N*m³/h] to [*N*l/min] and the inner diameter units from [m] to [mm] to reflect conventional units, equation 12.3 becomes equation 12.4.

|  |  |
| --- | --- |
|  | (Eq. 12.4) |

Where:

is the isokinetic ratio;

is the average normalised airflow in the sampling nozzle in *N*l/min;

is the average normalised airflow in the sampling tunnel in *N*m³/h per Table 13.2;

is the inner diameter at the nozzle tip in mm;

is the sampling tunnel inner diameter in mm per Table 7.1.

1. Use equation 12.4 to calculate the average isokinetic ratio at the emissions measurement section of a brake emissions test for both PM2.5 and PM10, separately;
2. Use the corresponding values for the isokinetic nozzle inner diameters for PM2.5 (dn-PM2.5) and PM10 (dn-PM10) sampling;
3. Use the data of the average normalised tunnel flow (*N*Q) and the average normalised sample flows (*N*QPM2.5 and *N*QPM10) in the Time-Based file;
4. Report the calculated values as specified in Table 13.6 in paragraph 13.4.

#### Sampling Media

##### Filter Holder

The PM samples shall be collected on 47 mm single filters per test mounted within a dedicated holder. The filter holder shall be located as close as possible to the cyclonic separator’s outlet. The testing facility shall follow the specifications described below for the filter holder assembly:

1. Select a filter holder made of inert and non-corroding material such as stainless steel or anodized aluminium;
2. Use a filter holder suitable for the insertion of circular filters. The diameter of the exposed area through which the sampled air passes shall be between 34 mm and 44 mm;
3. Use a filter holder that provides an even flow distribution across the filter stain area;
4. Design the filter holder arrangement in a way that no condensation of water can occur. The temperature at the filter holder shall follow the specification for the entire sample path defined in 12.1.2.2 and shall always remain above 15 °C during the entire brake emissions test.

##### Multifilter-Holder

The usage of multifilter-holders is allowed to improve the measurement quality and time-of-use of the brake emission test-rig.

For these holders the following requirements apply:

The manufacturer has to provide information that no negative effect on PM emission factors exist. This may be done by correcting losses or provide according and appropriate measurement data.

All holders shall be mounted in the same housing under the same conditions

The same flow shall be used for the sampling of different filters

The limit of consecutively used filtersshall be three to allow measuring for approx. 12h to 16h

Only one filter shall be used at a time

…additional provisions to be discussed

##### Sampling Filters

Fluorocarbon-coated glass fibre filters or fluorocarbon membrane filters shall be used for the PM10 and PM2.5 measurements. All filter types shall have a 0.3 μm DOP (Dioctyl phthalate) or PAO (poly-alpha-olefin) CS 68649-12-7 or CS 68037-01-4 collection efficiency of at least 99 per cent at a gas filter face velocity of 5.33 cm/s measured according to one of the following standards:

1. U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 102.8: DOP-Smoke Penetration of Aerosol-Filter Element;
2. U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 502.1.1: DOP-Smoke Penetration of Gas-Mask Canisters;
3. Institute of Environmental Sciences and Technology, IEST-RP-CC021: Testing HEPA and ULPA Filter Media.

The efficiency requirements for the sampling media described in this paragraph shall be certified by the filter supplier.

#### Weighing Procedure

Only the filter shall be weighed and not any other part of the measurement equipment. The sampling facility shall ensure that the different steps of the weighing procedure are carried out according to the following requirements:

1. Weighing room – The weighing room environment shall be free of any ambient contaminants (such as dust, aerosol, or semi-volatile material) that could contaminate the particle filters. Regulate the weighing room environmental conditions at (22 ± 2) °C and (45 ± 8) per cent RH. Make sure that the air flow for the air exchange does not influence the balance stability;
2. Weighing balance – Use the same microbalance for both pre-sampling and post-sampling weighing in a given brake emission test. Isolate the balance from vibrations, electrostatic forces, and air streams. Place the balance in a controlled environment – the weighing chamber or room – following the specifications described in point (a) of this paragraph. The balance resolution shall be of at least 1 μg. Use certified calibration weights to verify the stability and the proper function of the microbalance regularly. The microbalance shall fulfill the calibration requirements described in paragraph 14.4;
3. Static electricity effects – Nullify the effects of static electricity by grounding the balance through placement upon an antistatic mat and neutralizing the particle sampling filters before weighing using a polonium neutralizer or a device of similar effect. Alternatively, nullify static effects through equalization of static charge;
4. Pre-sampling conditioning and weighing – Condition/stabilise the filters at (22 ± 2) °C and (45 ± 8) per cent RH for a minimum of 2 hours before sampling. Weigh the filter at the end of the stabilization period following the procedure described in (g) of this paragraph and register its weight in all relevant test sheets. No deviation from the conditions specified in this paragraph is permitted during the weighing operation. Store the filter in a closed petri dish (or equivalent) or sealed filter holder until testing. Install the filter within 2 hours of its removal from the weighing chamber (or room) at the test rig;
5. Post-sampling conditioning and weighing – Take the filters to the conditioning room within 60 hours after the final test is completed. Condition/stabilise the filters at (22 ± 2) °C and (45 ± 8) per cent RH for a minimum of 12 hours. Weigh the filter at the end of the stabilization period following the procedure described in (g) of this paragraph and register its weight in all relevant test sheets. No deviation from the conditions specified in this paragraph is permitted during the weighing operation. Store the filter in a closed petri dish (or equivalent) or sealed filter holder;
6. Reference filter weighing – Use reference filters to validate PM weighing. Select at least two Fluorocarbon coated glass fibre or fluorocarbon membrane reference filters that match each sampled filter media. Weigh the reference filters at the beginning and the end of a weighing session (before pre-sampling and after post-sampling weighing) and register the weighings in the PM-Mass Measurement File. The average difference between the initial and final measurement for the reference filter shall remain within ±10 µg. Furthermore, the average difference between the reference filters and their moving average (min 1 day – max 15 days) shall be within ±10 µg. Replace the reference filters at a maximum every 30 days and in such a manner that no sample filter is weighted without comparison to a reference filter that has been present in the weighing chamber (room) for at least one day;
7. Sample filter weighing – Weigh each filter twice and register the weighings in the PM-Mass Measurement File. If the difference between the first and second measurements is lower than 30 µg use the average to report PMUncorrected and calculate PMCorrected following point (h) of this paragraph. When the difference between the first and second measurements is higher than 30 µg weigh the sampled filter for the third time. If the difference between the second and third measurements is lower than 30 µg use the average of the two measurements to report PMUncorrected and calculate PMCorrected following point (h) of this paragraph. If the difference between the second and third measurements is higher than 30 µg consider the measurement invalid and the filter void. This procedure applies to both pre- and post-sampling filters;
8. Buoyancy correction – Correct the sample and reference filter weights for their buoyancy in air. The buoyancy correction is a function of sampling filter density, air density, and the density of the balance calibration weight, and does not account for the buoyancy of the particulate matter itself.

Use the following values for the density of the filter material (pf)when it is not known: (a) Fluorocarbon coated glass fibre filter: 2300 kg/m³; (b) Fluorocarbon membrane filter: 2144 kg/m³.

Use a density (pw) of 8000 kg/m³ for stainless steel calibration weights or the known density for different calibration weight materials. Follow the International Recommendation OIML R 111-1 Edition 2004(E) (or equivalent) from the International Organization of Legal Metrology on calibration weights.

Use the uncorrected average filter mass measurement to calculate the buoyance-corrected average filter mass measurement for PM2.5 and PM10 filters (pre- and post-sampling) following equation 12.5. Register the corrected measurements in the PM-Mass Measurement File:

|  |  |
| --- | --- |
|  | (Eq. 12.5) |

Where:

is the corrected mass for each filter in mg;

is the uncorrected mass for each filter in mg per Table 12.4;

is the density of air in the balance room per equation 12.6 in kg/m³;

is the density of the calibration balance weight per paragraph (e);

is the density of the (unsued) sampling filter per paragraph (e).

Use the conditions in the balance room at the time of weighing to calculate the density of air, following equation 12.6.

|  |  |
| --- | --- |
|  | (Eq. 12.6) |

Where:

is the density of air in the balance room in kg/m³;

is the atmospheric pressure in the balance room in kPa;

is the molar mass of air in the balance room, 28.836 g mol–1;

is the molar mass constant, 8.3144 J mol–1 K–1;

is the air temperature in the balance room in K.

1. Filter load – Subtract the average pre-sampling filter mass measurement from the post-sampling filter mass measurement. Use the buoyance-corrected average filter mass measurements calculated in point (h) of this paragraph. Calculate and register both PM2.5 (PM2.5-Mass) and PM10 (PM10-Mass) filter loads in the PM-Mass Measurement File. Report the PM2.5 and PM10 filter loads as specified in Table 13.6 in paragraph 13.4;
2. Storage and transfer conditions – Keep weighed filters in appositely made filter boxes designed to host the specific filter size. Use stainless steel forceps or tongs for filter handling. Minimise filter movement within the Petri dishes/bags and transport as much as possible. Carefully install the particle sample filter into the filter holder. Rough or abrasive filter handling will result in erroneous weight determination.

#### PM Emission Factor Calculation

The testing facility shall report the PM emissions in particulate matter mass per distance driven. Calculate the PM2.5 and PM10 emission factors following equations 12.7 and 12.8, respectively.

|  |  |
| --- | --- |
|  | (Eq. 12.7) |
|  | (Eq. 12.8) |

Where:

is the PM2.5 emissions in particulate matter mass per distance driven in mg/km;

is the PM10 emissions in particulate matter mass per distance driven in mg/km;

is the PM2.5 filter mass load in mg per Table 13.3;

is the PM10 filter mass load in mg per Table 13.3;

is the average normalised airflow in the sampling tunnel in *N*m³/h per Table 13.2;

is the average normalised airflow in the PM2.5 sampling nozzle in *N*l/min per Table 13.2;

is the average normalised airflow in the PM10 sampling nozzle in *N*l/min per Table 13.2;

is the total distance driven during the WLTP-Brake cycle in km per Table 13.2.

1. Calculate the PM masses (PM10-Mass and PM2.5-Mass) as specified in paragraph 12.1.4 (i) after correcting the values for buoyancy as specified in paragraph 12.1.4 (h);
2. Report the PM2.5 and PM10 EFs as specified in Table 13.6 in paragraph 13.4.

### **Measurement of Particle Number (PN) Concentration**

This paragraph describes the specifications for the PN emissions measurement during brake emissions testing. The PN sampling and measurement systems enable the quantification of the number of particles generated by the brake assembly during the test. The measured PN emissions along with the parameters from the test provide the emissions factors for the brake under testing in the number of particles emitted per unit of distance driven. The test system shall be capable of measuring Total-PN (TPN10) and Solid-PN (SPN10) at a nominal particle size of approximately 10 nm electrical mobility diameter and larger.

Figure 12.2 illustrates an indicative PN sampling and measurement setup. The positioning and dimensions of the different elements are provided for illustration purposes; therefore, exact conformance with the figure is not required.

Figure 12.2  
**Indicative setup of the PN sampling and measurement unit**

The TPN10 sampling and measurement systems shall consist of the following elements:

1. A PN sampling probe extracts a sample in the sampling plane from the sampling tunnel. The specifications for the design of the PN sampling probe are described in paragraph 12.2.1.2;
2. An appropriate PN sampling nozzle is installed at the tip of the PN sampling probe. The specifications for the design of the nozzle are described in paragraph 12.2.1.3;
3. A suitable tube (Particle Transfer Tube – PTT) transfers aerosol from the outlet of the sampling probe to the inlet of the pre-classifier. When the pre-classifier is directly mounted to the outlet of the sampling probe, the PTT may be used to transfer the particles from the outlet of the pre-classifier to the inlet of the dilution system. The specifications for the design of the PTT are described in paragraph 12.2.1.4;
4. A pre-classifier is applied to remove bigger particles. The specifications for the pre-classifier are described in paragraph 12.2.2.1;
5. A dilution system that incorporates one or more dilution stages. The specifications for the design of the dilution system are described in paragraph 12.2.2.2;
6. An internal transfer line transfers the particles from the outlet of the dilution system to the inlet of the particle number counting device. The specifications for the design of the outlet line are described in paragraph 12.2.2.3;
7. A Particle Number Counter (PNC) measures the TPN10 concentration. The specifications for the PNC are described in paragraph 12.2.3.1.

The SPN10 sampling and measurement systems shall consist of the following elements:

1. A PN sampling probe extracts a sample in the sampling plane from the sampling tunnel. The specifications for the design of the PN sampling probe are described in paragraph 12.2.1.2;
2. An appropriate PN sampling nozzle is installed at the tip of the PN sampling probe. The specifications for the design of the nozzle are described in paragraph 12.2.1.3;
3. A suitable PTT transfers aerosol from the outlet of the sampling probe to the inlet of the pre-classifier. When the pre-classifier is directly mounted to the outlet of the sampling probe, the PTT may be used to transfer the particles from the outlet of the pre-classifier to the inlet of the volatile particle remover system. The specifications for the design of the PTT are described in paragraph 12.2.1.4;
4. A pre-classifier is applied to remove bigger particles. The specifications for the pre-classifier are described in paragraph 12.2.2.1;
5. A Volatile Particle Remover (VPR) dilutes the sample and removes volatile particles before the measurement device. The specifications for the design of the VPR are described in paragraph 12.2.2.2;
6. An internal transfer line transfers the aerosol from the outlet of the VPR to the inlet of the PNC. The specifications for the design of the outlet line are described in paragraph 12.2.2.3;
7. A PNC measures the SPN10 concentration. The specifications for the PNC are described in paragraph 12.2.3.1.

TPN10 and SPN10 sampling shall use different probes as specified in 12.2.1.1 (a). The same sampling probe can be used provided that the applied flow splitter fulfils the requirements specified in paragraph 12.2.1.1 (b-e).

#### Sample Extraction

##### Sampling Plane

The design of the sampling plane shall follow the specifications described in paragraph 7.6. The following additional specifications apply to the sampling plane for the installation of the PN sampling probes:

1. Apply two sampling probes for the PN emissions measurements, one for TPN10 and one for SPN10. Black dots in Figure 7.7 (right-hand side) indicate the PN sampling probes for the four sampling probes layout;
2. Alternatively, use a single sampling probe for both TPN10and SPN10 applying an appropriate flow splitting device as specified in points (c-e) of this paragraph.
3. When applying a flow splitting device it shall be made from stainless steel and an electropolished interior to minimise the contamination of the sample;
4. When applying a flow splitting device, keep the change in the flow angle within 20⁰ (≤ 20⁰) for each outlet to ensure similar flow velocities in all branches.
5. .

##### PN Sampling Probes

Appropriate PN sampling probe(s) shall be used to extract the sample from the tunnel to the inlet of the particle transfer tube or the pre-classifier. The testing facility shall select PN sampling probe(s) meeting the following design requirements:

1. Use probe(s) appropriately designed to minimise particle losses from the nozzle tip to the inlet of the particle transfer tube;
2. Use probe(s) made of electrically conductive materials that do not react with brake particles. Use probe(s) made of stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface;
3. Select probe(s) with a constant inner diameter (dp) of at least 10 mm and a maximum of 18 mm ensuring a laminar flow (10 mm ≤ dp ≤ 18 mm) under all operating conditions;
4. The overall length of the probe(s) from the sampling nozzle tip to the inlet of the particle transfer tube shall not exceed 1 m;
5. The residence time from the inlet of the nozzle tip to the inlet of the particle transfer tube or the pre-classifier shall be below 3s;
6. A maximum of one bend of 90° may be applied to the probes provided that the bending radius rp is at least four times the inner diameter (4∙dp) of the PN sampling probe(s).

##### PN Sampling Nozzles

Appropriate nozzles to ensure isokinetic sampling based on the total extracted sampling flow and the average cooling airflow shall be used. The testing facility shall select sampling nozzles meeting the following requirements for both TPN10 and SPN10 sampling:

1. Use nozzles made of stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface;
2. Use the appropriate nozzles to achieve an isokinetic ratio in the range of 0.6 to 1.5;
3. Select the nozzle size depending on the applied flow to keep the isokinetic ratio (paragraph 12.1.2.4) within the specifications defined in point (b) of this paragraph. Do not use nozzles with an inner diameter lower than 4 mm;
4. The nozzles shall have a constant internal diameter along a length equal to at least one internal diameter or at least 10 mm from the nozzle tip, whichever is greater;
5. Use nozzles with a thin wall at the tip to minimise distortion of flow. These shall have an outer to inner diameter ratio lower than 1.1 at the nozzle tip;
6. Any variation in bore diameter of the nozzles shall be tapered with a conical angle less than 30°;
7. Place the nozzles with their axis parallel to that of the dilution tunnel making sure that the aspiration angle remains lower or equal to 5°;
8. Clean the nozzles before every brake emissions test following the specifications defined by their manufacturer regarding the cleaning means.

##### Particle Transfer Tube

When the pre-classifier is not directly connected to the probe’s outlet, a suitable particle transfer tube (PTT) shall be used to transfer aerosol from the probe’s outlet to the pre-classifier’s inlet. When the pre-classifier is directly connected to the probe’s outlet, the PTT shall be used to transfer aerosol from the pre-classifier’s outlet to the sample conditioning system’s inlet. In any case, only a single PTT may be used and the testing facility shall ensure that its design meets the following requirements for both TPN10 and SPN10 sampling:

1. Use transfer tubes appropriately designed to minimise particle transport losses between the pre-classifier’s outlet and the sample conditioning system’s inlet;
2. Use transfer tubes made of electrically conductive materials that do not react with brake aerosol components;
3. Select transfer tubes with a constant inner diameter (dtt) of at least 4 mm ensuring a laminar flow under all operating conditions;
4. The length of the transfer tubes to sample flow ratio shall be below 60000 s/m²;
5. The particles' residence time inside the transfer tubes shall be below 1 s;
6. A bend may be applied to the transfer tubes provided that the bending radius rp shall be at least twenty-five times the tube diameter (25∙dtt).

#### Sample Treatment and Conditioning

##### Pre-classifier

The testing facility shall use a single cyclonic separator to protect the dilution system and the VPR from possible contamination. The following specifications apply to the pre-classifier for both TPN10 and SPN10 sampling and measurement:

1. Use two cyclonic separators when applying different sampling probes for the TPN10 and SPN10 emissions measurements;
2. When a single sampling probe is used for both TPN10 and SPN10, use one cyclonic separator when placed upstream of the flow splitting device. Alternatively, use two cyclonic separators when placed downstream of the flow splitting device;
3. Place the cyclonic separator anywhere between the outlet of the sampling probe and the inlet of the sample conditioning system;
4. Use commercially available cyclonic separators with a 50 per cent cut point particle diameter between 2.5 µm and 10 µm at the volumetric sample flow rate that passes through the cyclonic separator;
5. The cyclone shall achieve a minimum penetration efficiency of 80 per cent for a particle diameter of 1.5 µm;
6. Inspect and clean the inner walls of the cyclones frequently following the specifications of the instrument manufacturer regarding the cleaning frequency and means.

##### Sample Conditioning

The aerosol entering the PN system shall undergo conditioning before entering the PNC. The testing facility shall ensure the sample conditioning system meets the following requirements depending on the measured parameter:

TPN10

A dilution system is mandatory and shall comprise at least one particle diluter. A dilution system like the VPR for SPN10 described in the next paragraph may be used. In this case, any active heating of the evaporation tube and the diluters shall be deactivated. The following specifications apply to the dilution system for conditioning aerosol when measuring TPN10:

1. All parts of the dilution system that come in contact with the sample shall be made of electrically conductive materials, shall be electrically grounded to prevent electrostatic effects, and shall be designed to minimise deposition of the particles;
2. It shall be capable of diluting the sample in one or more stages to achieve a PN concentration below the upper threshold of the single-particle count mode of the PNC. The dilution system shall be capable of providing a dilution factor of at least 10:1;
3. It shall be capable of keeping the dilution factor constant throughout the entire emissions test;
4. It shall be capable of maintaining the diluted gas temperature at the inlet to the PNC below 38 °C;
5. It shall be supplied with dilution air filtered through a HEPA filter of at least class H13 (EN 1822:2008), or equivalent performance;
6. It shall achieve a particle concentration reduction factor (PCRF) for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters not higher than 100 per cent, 30 per cent, and 20 per cent, respectively, compared to particles of 100 nm electrical mobility diameter for the system as a whole. Additionally, it shall achieve a PCRF for particles of 15 nm, 30 nm, and 50 nm not lower than 5 per cent than that for particles of 100 nm for the system as a whole. The calculation of the PCRF at different sizes shall follow the method described in paragraph 14.5.1;
7. It shall monitor the dilution factor variation in real-time to report the arithmetic average PCRF (fr-SPN10) at a frequency of 1 Hz. The calculation of the arithmetic average PCRF shall follow the method described in paragraph 14.5.1;
8. It shall report PCRF-corrected TPN10 concentrations at standard conditions at a reporting frequency of 1 Hz;
9. It shall achieve a total particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;
10. It shall be capable of operating at sample pressures in the (850 to 1050) mbar range and relative pressure differences from ambient in the ±50 mbar range.

SPN10

The volatile particle remover (VPR) shall comprise at least one particle number diluter (PND1) and an evaporation tube. A second diluter (PND2) may be optionally installed in series with the PND1 and the evaporation tube. The following specifications apply to the VPR for conditioning particles when measuring SPN10:

1. All parts of the VPR that come in contact with the sample shall be made of electrically conductive materials, shall be electrically grounded to prevent electrostatic effects, and shall be designed to minimise deposition of the particles;
2. It shall be capable of diluting the sample in one or more stages to achieve a PN concentration below the upper threshold of the single-particle count mode of the PNC. The overall system shall be capable of providing a dilution factor of at least 10:1;
3. It shall be capable of maintaining the gas temperature at the inlet to the PNC below a maximum allowed inlet temperature specified by the PNC manufacturer;
4. It may include an initial heated dilution stage which outputs the sample at a wall temperature between 150 °C and 350 °C. The wall temperature set point shall not exceed the wall temperature of the evaporation tube. The diluter shall be supplied with air filtered through a HEPA filter of at least class H13 (EN 1822:2008), or equivalent performance;
5. It shall include a catalytically active evaporation tube which is controlled to a wall temperature greater than or equal to that of the PND1. The wall temperature of the evaporation tube shall remain at a fixed nominal operating temperature of 350 °C;
6. It shall control heated stages to constant nominal operating temperatures to a tolerance of ±10 °C. Additionally, the VPR system shall indicate whether heated stages are at their correct operating temperatures;
7. It shall achieve a PCRF for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters not higher than 100 per cent, 30 per cent, and 20 per cent, respectively, compared to particles of 100 nm electrical mobility diameter for the VPR as a whole. Additionally, it shall achieve a PCRF for particles of 15 nm, 30 nm, and 50 nm not lower than 5 per cent than that for particles of 100 nm for the VPR as a whole. The calculation of the PCRF at different sizes shall follow the method described in paragraph 14.5.1;
8. It shall monitor the dilution factor variation in real-time to report the arithmetic average PCRF (fr-SPN10) at a frequency of 1 Hz. The calculation of the arithmetic average PCRF shall follow the method described in paragraph 14.5.1;
9. It shall report PCRF-corrected SPN10 concentrations at standard conditions at a reporting frequency equal to or greater than 0.5 Hz;
10. It shall achieve more than 99.9 per cent vaporization of tetracontane (CH3(CH2)38CH3) particles with a count median diameter larger than 50 nm and mass above 1 mg/m³, by means of heating and reduction of partial pressures of the tetracontane;
11. It shall achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;
12. It shall operate at sample pressures in the (850 to 1050) mbar range and relative pressure differences from ambient in the ±50 mbar range.

##### PN Internal Transfer Line

The testing facility shall select lines that transfer the aerosol from the dilution system (TPN10) and the VPR (SPN10) to the inlet of the PNC meeting the specifications described below:

1. Use internal transfer lines appropriately designed to minimise particle transport losses between the dilution system (TPN10) or the VPR (SPN10) and the inlet of the PNC;
2. Use internal transfer lines made of electrically conductive materials that do not react with brake aerosol components;
3. Select internal transfer lines with a constant inner diameter (dtl) of at least 4 mm ensuring a laminar flow under all operating conditions;
4. The overall length of the internal transfer lines from the exit of the dilution system (TPN10) or the VPR (SPN10) to the inlet of the PNC shall not exceed 1 m;
5. The particles’ residence time inside the internal transfer lines shall be below 1 s;
6. A bend may be applied to the PN internal transfer lines provided that the bending radius rp is at least twenty-five times the inner diameter (25∙dtl) of the internal transfer line.

#### Particle Measurement

##### Particle Number Counter

Particle Number Counters (PNC) shall be applied for the measurement of the TPN10 and SPN10 concentrations. The testing facility shall ensure that the PNC meets the following requirements for both TPN10 and SPN10:

1. Operate under full flow operating conditions;
2. Have a counting accuracy of ±10 per cent across the range from 1 #/cm³ to the upper threshold of the single-particle count mode of the PNC against a traceable standard;
3. Have readability of at least 0.1 #/cm³ at concentrations below 100 #/cm³;
4. Have a linear response to particle concentrations over the full measurement range in single-particle count mode;
5. Have a t90 response time over the measured concentration range of less than 5 s;
6. Incorporate an internal calibration factor from the linearity calibration against a traceable reference which shall be applied to determine the PNC counting efficiency. The counting efficiency shall be reported including the calibration factor according to the specifications provided in paragraph 14.6;
7. The PNC calibration material shall be 4 cSt polyalphaolefin (Emery oil), soot-like particles (e.g. flame generated soot or graphite particles), or silver particles;
8. Have counting efficiencies at nominal particle sizes of 10 nm and 15 nm electrical mobility diameter of (65 ± 15) per cent and above 90 per cent, respectively. These counting efficiencies may be achieved by internal (e.g. control of instrument design) or external (e.g. size pre-classification) means;
9. If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

##### PN Sampling Flow

The PN measurement system shall meet the following provisions for the regulation and measurement of the sampling flow (i.e. flow at the PN sampling probe). These apply to both TPN10 and SPN10 sampling:

1. The method of measuring the flow of the sampling and measurement system shall have a maximum permissible error of ±5 per cent of the reading under all operating conditions;
2. Use a flow measurement device calibrated to report flow at both operating and standard conditions). The temperature sensor shall have an accuracy of ±1.0 °C. The pressure measurements shall have precision and accuracy of ±1.0 kPa;
3. The actual normalised sampling flow (*N*QTPN10 and *N*QSPN10) shall not deviate more than ±10 per cent of the average value for the given test. Use a device with a flow control feature (e.g. critical orifice, pressure regulator, feedback controller, or other) to ensure a stable flow;
4. Register the actual normalised sampling flow and report it at a frequency of 1Hz in the Time-Based file. Report the average actual normalised sampling flows as specified in paragraph 13.4;
5. Ensure the average isokinetic ratio during the emissions measurement section of a specific brake system is between 0.60 and 1.50;
6. Use equation 12.4 to calculate the average isokinetic ratio for both TPN10 and SPN10. Use the corresponding values for the isokinetic nozzle inner diameters for TPN10 and SPN10 sampling. Use the data of the average normalised tunnel flow (*N*Q) and the average normalised sample flows (*N*QTPN10 and *N*QSPN10) in the Time-Based file. Report the calculated values as specified in Table 13.6 in paragraph 13.4;
7. If the sampling flow or the isokinetic requirements set out in this paragraph are not met, the test is invalid;
8. The PN sampling devices shall operate continuously during the brake emissions measurement section. This includes also the cooling sections between the individual trips of the WLTP-Brake cycle where the PN sampling flow shall not be paused or bypass the main sampling line.

#### PN Emissions Calculation

The testing facility shall report PN emissions in the number of particles per distance driven. The calculation of PN emission factors for TPN10 and SPN10 follows equations 12.9 and 12.10, respectively.

|  |  |
| --- | --- |
|  | (Eq. 12.9) |
|  | (Eq. 12.10) |

Where:

is the number of TPN10 per distance driven in #/km;

is the number of SPN10 per distance driven in #/km;

is the average normalised and PCRF-corrected TPN10 emissions in #/*N*cm³ per Table 13.2;

is the average normalised and PCRF-corrected SPN10 emissions in #/*N*cm³ per Table 13.2;

is the average normalised airflow in the sampling tunnel in *N*m³/h per Table 13.2;

V is the average actual velocity of the WLTP-Brake cycle in km/h per Table 13.2.

1. Calculate the average normalised and PCRF-corrected TPN10 and SPN10 emissions from the given parameters in the Time-Based file;
2. Calculate the average normalised tunnel flow (*N*Q) and the average velocity of the WLTP-Brake cycle (V) over the emissions measurement section from the given parameters in the Time-Based file;
3. Report the TPN10 and SPN10 EFs as specified in Table 13.6 in paragraph 13.4;
4. In case the measured TPN10 or SPN10 emissions are out of the specified measurement range of the PNC device(s), the test shall be considered invalid.

#### PN System Verification Procedures

The testing facility shall apply the following PN system check procedures to verify the whole system is fully operational:

1. The flow into the PNC shall have a measured value within 5 per cent of the PNC nominal flow rate when checked with a calibrated flow meter. Here the term ‘nominal flow rate’ refers to the flow rate stated in the documentation of the last calibration for the PNC. The testing facility shall perform this check every month;
2. A zero check on the PNC, using a filter of appropriate performance at the PNC inlet, shall report a concentration of ≤0.2 #/cm³. Upon removal of the filter, the PNC shall show an increase in measured concentration and a return to 0.2 #/cm³ or less on replacement of the filter. The PNC shall not report any errors. The testing facility shall perform this check for every brake emissions test;
3. The particle counter shall report a measured concentration of less than 0.5 #/cm³ when a HEPA filter of at least class H13 (EN 1822:2008), or equivalent performance, is attached to the inlet of the sample conditioning system. The testing facility shall perform this check before each brake emissions test;
4. Before the start of each brake emissions test, the testing facility shall confirm that the measurement system indicates that the sample conditioning system has reached its correct operating temperatures.

### **Mass Loss Measurement**

The mass loss of the brake under test provides helpful information regarding the robustness and correctness of the overall test procedure. It can be used as an indicator of possible issues during the execution of the brake emissions test. The testing facility shall measure the initial and final mass of the brake couple under test ensuring the following:

1. Inspect all brake parts for burs, cracks, voids, or detachments and record accordingly. If there are no problems with the brake under testing, measure the brake disc or drum and the brake pads or shoes mass before commencing the brake emissions test;
2. Vacuum clean the parts before conducting the measurements to remove any possible contamination;
3. Measure the mass of each part separately with the thermocouple installed and the thermocouple connector removed (in the case of discs and drums). Report the mass in the PM-Mass Measurement File;
4. Measure the brake friction material including the anti-noise shims, pad-shim springs, and other elements when part of the product assembly. Report the masses in the PM-Mass Measurement File;
5. Use a weighing scale of a resolution of at least 0.1kg or better for parts below 30 kg of total weight. Install the weighing scale in a room with controlled air and humidity to laboratory conditions of (22 ± 2) °C and (45 ± 8) per cent RH;
6. Ensure the brake parts are cool down to a temperature of 30 °C or below before measuring their final mass;
7. Clean the parts to remove any grease or contamination before performing the final mass measurements;
8. Measure the brake disc or drum and the brake pads or shoes mass after the completion of the brake emissions test. Report the masses in the PM-Mass Measurement File. Make sure not to disrupt the brake assembly during the brake emissions test;
9. Calculate the mass loss of the disc or drum and the brake pads or shoes by subtracting the final from the initial total mass, respectively. Report the mass loss of each part of the assembly in the PM-Mass Measurement File following the instructions defined in Table 13.5;
10. Calculate the overall mass loss of the brake assembly by summing the values for the individual parts calculated in (i) of this paragraph. Report the overall mass loss following the instructions defined in Table 13.5;
11. Calculate the averaged weight loss emission factor by dividing the total mass loss calculated in (j) of this paragraph by the total distance driven during the brake emissions test considering all sections (including cooling air adjustment) tested using the brake couple. Report the averaged weight loss emission factor following the instructions defined in Table 13.5.

## Test Report

This section describes the four main outputs of a brake emissions test. These are summarised in the following:

1. Event-Based file. A detailed description of the file and the required parameters is provided in paragraph 13.1;
2. Time-Based file. A detailed description of the file and the required parameters is provided in paragraph 13.2;
3. PM-Mass measurement file. A detailed description of the file and the required parameters is provided in paragraph 13.3;
4. Reporting file. A detailed description of the file and the required parameters is provided in paragraph 13.4.

### **Event-Based File**

The testing facility shall generate a CSV or MS Excel™ Event-Based file for the brake emissions test. The file shall include the necessary data for each brake deceleration event throughout the entire brake emissions test. This file format is agnostic to the control technology and software and allows control authorities to have direct access to the test outputs. Each section of the brake emissions test shall be reported in a separate tab as follows:

1. Tab 1 titled “Test ID – EBF – Raw Data” shall include all raw data registered by the brake dynamometer throughout the entire test;
2. Tab 2 titled “Test ID – EBF – Cooling” shall include the registered data and the reporting parameters specified in this paragraph for the cooling adjustment section;
3. Tabs 3-7 titled “Test ID – EBF – Bedding 1-5” shall include the registered data and the reporting parameters specified in this paragraph for the bedding section. Each tab shall correspond to one repetition of the WLTP-Brake cycle. Tabs 3-7 shall not include data from the soaking sections applied between the repetitions of the WLTP-Brake cycle;
4. Tab 8 titled “Test ID – EBF – Emissions” shall include the registered data and the reporting parameters specified in this paragraph for the brake emissions measurement section. Tab 8 shall not include data from the soaking sections applied between the individual trips of the WLTP-Brake cycle.

The testing facility shall continuously and automatically register and/or calculate the parameters listed in Table 13.1. Details regarding the applied units, number of decimals, and the registration frequency of each parameter are given in Table 13.1. Registration frequency in the context of this GTR is the frequency in which the automation system measures and registers the various parameters. In the Event-Based File, the parameters are always reported for each braking event; therefore, the registered values are averaged to calculate a unique value for the given brake event. Table 13.1. also provides a short description of each parameter and the symbol used throughout the text (where applicable).

Table 13.1.   
**Necessary parameters for registration and reporting at the Event-Based file of a brake emissions test**

| *Measurand* | *Symbol* | *Unit* | *Decimals* | *Description* | *Registration*  *Frequency* | *Column in the File* |
| --- | --- | --- | --- | --- | --- | --- |
| Test Section | - | # | [N/A] | A three digits “ABC” identification code for each deceleration event. “A” represents the cycle’s serial number in a given brake emissions test (A=1 for cooling adjustment, A=2-6 for bedding, A=7 for emissions measurement). BC represents the trip’s serial number (B=01-10) | Calculated  1Hz | A |
| Trip Stop Number | - | # | [N/A] | The serial number of the deceleration event within the individual trip (Can take values between 1 and 114) | Registered  1Hz | B |
| Cycle Stop Number | - | # | [N/A] | The serial number of the deceleration event within the WLTP-Brake cycle (Can take values between 1 and 303) | Registered  1Hz | C |
| Stop Duration | tbrake | s | [1] | The total duration of the deceleration event | Registered  1Hz | D |
| Time of Stop | - | hh:mm:ss | [N/A] | Time at the beginning of the deceleration event registered by the brake dynamometer | Registered  1Hz | E |
| Date of Stop | - | yy-mm-dd | [N/A] | Date at the beginning of the deceleration event registered by the brake dynamometer | Registered  1Hz | F |
| Brake Speed Setpoint | - | km/h | [1] | The nominal linear speed at the beginning of the deceleration event as defined in the WLTP-Brake cycle | Registered  1Hz | G |
| Brake Speed | - | km/h | [1] | The actual linear speed at the beginning of the deceleration event registered by the brake dynamometer | 1Hz | H |
| Release Speed Setpoint | - | km/h | [1] | The nominal linear speed at the end (release) of the deceleration event as defined in the WLTP-Brake cycle | Registered  1Hz | I |
| Release Speed | - | km/h | [1] | The actual linear speed at the end (release) of the deceleration event registered by the brake dynamometer | Registered  250Hz | J |
| Rotational Speed – Time Averaged | *f* | rpm | [1] | Time-averaged rotational brake speed registered by the brake dynamometer | Registered  250Hz | K |
| Deceleration Setpoint | - | m/s2 | [2] | Nominal deceleration rate of the event as defined in the WLTP-Brake cycle | Registered  1Hz | L |
| Deceleration rate – Distance Averaged | - | m/s2 | [2] | Deceleration rate of the given brake event as calculated from parameters in columns D, H, and J | Registered  1Hz | M |
| Brake Torque – Distance Averaged | - | Nm | [1] | Distance averaged brake torque registered by the brake dynamometer | Registered  250Hz | N |
| Brake Torque – Time Averaged | τbrake-avg | Nm | [1] | Time-averaged brake torque registered by the brake dynamometer | Registered  250Hz | O |
| Brake Pressure – Distance Averaged | - | bar | [2] | Distance averaged brake pressure registered by the brake dynamometer | Registered  250Hz | P |
| Friction Coefficient – Distance Averaged | μ | - | [3] | Distance averaged friction coefficient as a function of braking torque, effective brake radius, and the piston area | Registered  1Hz | Q |
| Initial Brake Temperature | IBT | °C | [1] | Brake temperature at the beginning of the deceleration event measured as defined in paragraph 8.3 | Registered  250Hz | R |
| Final Brake Temperature | FBT | °C | [1] | Brake temperature at the end of the deceleration event measured as defined in paragraph 8.3 | Registered  250Hz | S |
| Peak Brake Temperature | PBT | °C | [1] | Peak brake temperature of the deceleration event measured as defined in paragraph 8.3 | Registered  250Hz | T |
| Friction Work | Wf | J/kg | [1] | The actual friction work applied to the brake in the given deceleration event calculated from parameters in columns D, K, and O using equation 10.1 | Calculated  1Hz | U |

### **Time-Based File**

The testing facility shall generate a CSV or MS Excel™ Time-Based file for the brake emissions test. The file shall include information about specific testing parameters registered throughout the entire brake emissions test. Each section of the brake emissions test shall be reported in a separate tab as follows:

1. Tab 1 titled “Test ID – TBF – Raw Data” shall include all raw data registered by the brake dynamometer, the sampling instruments, and the measurement devices as specified in this paragraph;
2. Tab 2 titled “Test ID – TBF – Cooling” shall include the data for the parameters specified in this paragraph collected during the cooling adjustment section;
3. Tabs 3-7 titled “Test ID – TBF – Bedding 1-5” shall include the data for the parameters specified in this paragraph collected during the bedding section. Each tab shall correspond to one repetition of the WLTP-Brake cycle. Tabs 3-7 shall not include data from the soaking sections applied between the repetitions of the WLTP-Brake cycle;
4. Tab 8 titled “Test ID – TBF – Emissions” shall include the data for the parameters specified in this paragraph collected during the brake emissions measurement. Tab 8 shall not include data from the soaking sections applied between the individual trips of the WLTP-Brake cycle;
5. Tab 8 titled “Test ID – TBF – Background” shall include the data for the necessary parameters for the calculation of the pre- and post-test background emissions during the brake emissions measurement. Although the template is the same, the testing facility is requested to register and report only the relevant parameters necessary for the calculation of the background emissions as specified in paragraph 7.2.2.

The testing facility shall continuously and automatically register and/or calculate the parameters listed in Table 13.2. Details regarding the applied units, number of decimals, and the registration frequency of each parameter are given in Table 13.2. Registration frequency is the frequency in which the automation system measures and registers the various parameters. In the Time-Based file, the parameters are always reported at 1Hz; therefore, the registered values are averaged to calculate the 1Hz values. Table 13.2. also provides a short description of each parameter and the symbol used throughout the text.

Table 13.2.   
**Necessary parameters for registration and reporting at the Time-Based file of a brake emissions test**

| *Measurand* | *Symbol* | *Unit* | *Decimals* | *Description* | *Registration*  *Frequency* | *Column in the File* |
| --- | --- | --- | --- | --- | --- | --- |
| Timestamp | - | sec | [0] | Timestamp in the brake emissions test | Registered  1Hz | A |
| Linear Speed Nominal | Vset | km/h | [1] | Nominal linear speed at the given point in time as defined in the WLTP-Brake cycle | Registered  1Hz | B |
| Linear Speed Actual | V | km/h | [1] | Actual linear speed registered by the brake dynamometer at the given point in time | Registered  10Hz | C |
| Driven Distance | d | km | [1] | Total distance driven in the cycle until the given point in time | Registered  1Hz | D |
| Deceleration Rate | α | m/s2 | [2] | Deceleration rate registered by the brake dynamometer at the given point in time | Registered  10Hz | E |
| Brake Torque | τbrake | N·m | [1] | Brake torque registered by the brake dynamometer at the given point in time | Registered  10Hz | F |
| Brake Pressure | Pbrake | bar | [2] | Brake pressure registered by the brake dynamometer at the given point in time | Registered  10Hz | G |
| Friction Coefficient | μ | - | [3] | Instantaneous friction coefficient calculated at the given point in time | Registered  10Hz | H |
| Brake Temperature | Tbrake | °C | [1] | Brake temperature at the given point in time | Registered  10Hz | I |
| Cooling Airflow Set | Qset | m3/h | [1] | Set (nominal) cooling airflow for the given brake emissions test | Registered  1Hz | J |
| Cooling Airflow Actual | Q | m3/h | [1] | Measured cooling airflow at the given point in time | Registered  10Hz | K |
| Cooling Airflow Actual Normalised | *N*Q | *N*m3/h | [1] | Normalised cooling airflow at standard conditions at the given point in time | Registered  10Hz | L |
| Cooling Airspeed Actual | U | km/h | [1] | Cooling airspeed at the given point in time (measured or calculated) | Registered  10Hz | M |
| Cooling Air Temperature | T | °C | [1] | Temperature of the cooling air at the given point in time | Registered  10Hz | N |
| Cooling Air  Relative Humidity | RH | % | [1] | Relative humidity of the cooling air at the given point in time | Registered  10Hz | O |
| Cooling Air  Pressure | P | kPa | [1] | Pressure of the cooling air at the given point in time | Registered  10Hz | P |
| PM2.5 Sampling Airflow Set | QPM2.5-set | l/min | [2] | Set (nominal) PM2.5 sampling airflow for the given brake emissions test | Registered  1Hz | Q |
| PM2.5 Sampling Airflow Actual | QPM2.5 | l/min | [2] | PM2.5 sampling airflow measured at the given point in time | Registered  10Hz | R |
| PM2.5 Sampling Airflow Actual Normalised | *N*QPM2.5 | *N*l/min | [2] | Normalised PM2.5 sampling airflow at standard conditions at the given point in time | Registered  10Hz | S |
| PM10 Sampling Airflow Set | QPM10-set | l/min | [2] | Set (nominal) PM10 sampling airflow for the given brake emissions test | Registered  1Hz | T |
| PM10 Sampling Airflow Actual | QPM10 | l/min | [2] | PM10 sampling airflow measured at the given point in time | Registered  10Hz | U |
| PM10 Sampling Airflow Actual Normalised | *N*QPM10 | *N*l/min | [2] | Normalised PM10 sampling airflow at standard conditions at the given point in time | Registered  10Hz | V |
| TPN10 Sampling Airflow Actual Normalised | *N*QTPN10 | *N*l/min | [2] | TPN10-related sampling airflow measured at the given point in time and reported at standard conditions | Registered  1Hz | W |
|  |  |  |  |  |  |  |
| TPN10 Concentration Normalised - PCRF Corrected | TPN10# | #/*N*cm3 | [1] | TPN10 normalised concentration at standard conditions measured by the PNC and corrected for the PCRF at the given point in time | Registered  10Hz | Y |
| SPN10 Sampling Airflow Actual Normalised | *N*QSPN10 | *N*l/min | [2] | SPN10-related sampling airflow measured at the given point in time and reported at standard conditions | Registered  1Hz | Z |
|  |  |  |  |  |  |  |
| SPN10 Concentration Normalised - PCRF Corrected | SPN10# | #/*N*cm3 | [1] | SPN10 normalised concentration at standard conditions measured by the PNC and corrected for the PCRF at the given point in time | Registered  10Hz | AB |

### **PM Measurement File**

The testing facility shall generate a CSV or MS Excel™ PM-Mass Measurement file for the entire test. The file shall include information about weighing the filters as specified in paragraph 12.1.5 as well as for weighing the brake parts as specified in paragraph 12.3. PM mass weighing data shall be reported in one tab as specified in Table 13.3. Information about the reference filters shall be reported in a different tab as specified in Table 13.4. Finally, information regarding mass loss of the brake parts shall be reported in a separate tab as specified in Table 13.5.

#### PM Data

The testing facility shall register and calculate the parameters related to the PM mass measurement listed in Table 13.3. Details regarding the applied units and the number of decimals of each parameter are provided in Table 13.3. Additionally, a short description of each parameter is given. PM mass weighing data shall be reported in the tab titled “Test ID – PMMF – PM Mass” of the PM-Mass Measurement file.

Table 13.3.   
**Necessary parameters related to the PM mass measurement procedure for registration and reporting at the PM Measurement file of a brake emissions test**

| *Measurand* | *Unit* | *Decimals* | *Description* | *Column in the File* |
| --- | --- | --- | --- | --- |
| Test ID | # | [N/A] | A unique code that allows the testing facility to identify the tested brake. Shall be the same as in “Test ID” in Table 13.6 | A |
| Filter Material | # | [N/A] | Specifies the type of filter used for PM sampling as per paragraph 12.1.3.2 | B |
| PM2.5 | # | [N/A] | Specifies whether the input data refer to PM2.5 sampling and measurement | C |
| PM10 | # | [N/A] | Specifies whether the input data refer to PM10 sampling and measurement | D |
| Weighing Date | yyyy-mm-dd | [N/A] | Date on which weighing of the unloaded filter takes place | E |
| Weighing Time | hh:mm | [N/A] | Time at which weighing of the unloaded filter takes place | F |
| Stabilization time before weighing | hh:mm | [N/A] | Stabilization time of the unloaded filter before being weighed and used for sampling as per paragraph 12.1.3.3 | G |
| Elapsed time from weighing to test start | hh:mm | [N/A] | Elapsed time from weighing the unloaded filter to the beginning of the emissions test as per paragraph 12.1.3.3 | H |
| Measurement 1 | mg | [3] | Weight of the unloaded filter measured at the first weighing as per paragraph 12.1.3.3 | I |
| Measurement 2 | mg | [3] | Weight of the unloaded filter measured at the second weighing as per paragraph 12.1.3.3 | J |
| Measurement 3 | mg | [3] | Weight of the unloaded filter measured at the third weighing as per paragraph 12.1.3.3 – This measurement is necessary only if the deviation between the first two measurements is higher than 30 μg | K |
| Mean Value | mg | [3] | The average weight of the unloaded filter as specified in paragraph 12.1.3.3 (PMUncorrected) | L |
| Mean Value – Corrected | mg | [3] | The corrected average weight of the unloaded filter after applying the buoyancy correction per paragraph 12.1.3.3 (PMCorrected) | M |
| Ambient Air Temperature | °C | [1] | Weighing room temperature – Report the average temperature of the room during the last hour before the weighing procedure | N |
| Ambient Air Relative Humidity | % | [1] | Weighing room relative humidity – Report the average relative humidity of the room during the last hour before the weighing procedure | O |
| Weighing Date | yyyy-mm-dd | [N/A] | Date on which weighing of the loaded filter takes place | P |
| Weighing Time | hh:mm | [N/A] | Time at which weighing of the loaded filter takes place | Q |
| Stabilization time before weighing | hh:mm | [N/A] | Stabilization time of the loaded filter after sampling and before being weighed as per paragraph 12.1.3.3 | R |
| Elapsed time from weighing to test start | hh:mm | [N/A] | Elapsed time from the end of the emissions tests to weighing the loaded filter as per paragraph 12.1.3.3 | S |
| Measurement 1 | mg | [3] | Weight of the loaded filter measured at the first weighing as per paragraph 12.1.3.3 | T |
| Measurement 2 | mg | [3] | Weight of the loaded filter measured at the second weighing as per paragraph 12.1.3.3 | U |
| Measurement 3 | mg | [3] | Weight of the loaded filter measured at the third weighing as per paragraph 12.1.3.3 – This measurement is necessary only if the deviation between the first two measurements is higher than 30 μg | V |
| Mean Value | mg | [3] | The average weight of the loaded filter as specified in paragraph 12.1.3.3 (PMUncorrected) | W |
| Mean Value – Corrected | mg | [3] | The corrected average weight of the loaded filter after applying the buoyancy correction per paragraph 12.1.3.3 (PMCorrected) | X |
| Ambient Air Temperature | °C | [1] | Weighing room temperature – Report the average temperature of the room during the last hour before the weighing procedure | Y |
| Ambient Air Relative Humidity | % | [1] | Weighing room relative humidity – Report the average temperature of the room during the last hour before the weighing procedure | Z |
| Loaded Mass | mg | [3] | PM2.5-Mass and PM10-Mass: The difference between the mean corrected value of the loaded and unloaded filter – Subtract the value in column M by the value in column X | AA |

#### Reference Filters Data

The testing facility shall register the parameters related to the reference filters used for the PM mass measurement of a given brake. Details regarding the parameters, the applied units, and the number of decimals of each parameter are provided in Table 13.4. The reference filter data shall be reported in the tab titled “Test ID – PMMF – Reference” of the PM-Mass Measurement file.

Table 13.4.   
**Necessary parameters related to the reference filters used at the PM mass measurement procedure for registration and reporting at the PM-Mass Measurement file of a brake emissions test**

| *Measurand* | *Unit* | *Decimals* | *Description* | *Column in the File* |
| --- | --- | --- | --- | --- |
| Test ID | # | [N/A] |  | A |
| Filter Material | # | [N/A] | Type of filter used as reference per paragraph 12.1.3.3 – Shall be the same as the filter used in the emissions test | B |
| Weighing Date Beginning | yyyy-mm-dd | [N/A] | Date on which the initial weighing of the reference filter takes place | C |
| Weighing Time Beginning | hh:mm | [N/A] | Time at which initial weighing of the reference filter takes place | D |
| Measurement Beginning | mg | [3] | Weight of the reference filter measured at the beginning as defined in paragraph 12.1.3.3 | E |
| Ambient Air Temperature | °C | [1] | Weighing room temperature – Average temperature of the room during the last hour before the weighing procedure | F |
| Ambient Air Relative Humidity | % | [1] | Weighing room relative humidity – Average RH of the room during the last hour before the weighing procedure | G |
| Weighing Date End | yyyy-mm-dd | [N/A] | Date on which the final weighing of the reference filter takes place | H |
| Weighing Time End | hh:mm | [N/A] | Time at which final weighing of the reference filter takes place | I |
| Measurement  End | mg | [3] | Weight of the reference filter measured at the end as defined in paragraph 12.1.3.3 | J |
| Ambient Air Temperature | °C | [1] | Weighing room temperature – Average temperature of the room during the last hour before the weighing procedure | K |
| Ambient Air Relative Humidity | % | [1] | Weighing room relative humidity – Average RH of the room during the last hour before the weighing procedure | L |
| Mass Difference | mg | [3] | Difference between the weighed value of the reference filter at the beginning and the end of the testing campaign – Subtract the value in column E by the value in column L | M |

#### Mass Loss Measurement Data

The testing facility shall register the parameters related to the total mass loss of the tested brake in a separate tab as specified in paragraph 12.3. Details regarding the parameters, the applied units, and the number of decimals of each parameter are provided in Table 13.5. The mass loss measurement data shall be reported in the tab titled “Test ID – PMMF –Mass Loss” of the PM-Mass Measurement file.

Table 13.5.   
**Necessary parameters related to the total mass loss of the brake for registration and reporting at the PM- Measurement file of a brake emissions test**

| *Measurand* | *Unit* | *Decimals* | *Description* | *Column in the File* |
| --- | --- | --- | --- | --- |
| Test ID | # | [N/A] | A unique code that allows the testing facility to identify the tested brake – Shall be the same as in “Test ID” in Table 13.6 | A |
| Disc Brake | # | [N/A] | Specifies whether the testing brake couple consists of a disc and a pair of pads | B |
| Drum Brake | # | [N/A] | Specifies whether the testing brake couple consists of a drum and a pair of shoes | C |
| Initial Weightings Inner pad / Leading shoe | mg | [3] | Weight of the inner pad or the leading shoe before the beginning of the overall brake emissions test - Leading shoe is the first shoe after the wheel cylinder in the direction of the wheel rotation | D |
| Initial Weightings Outer pad / Trailing shoe | mg | [3] | Weight of the outer pad or the trailing shoe before the beginning of the overall testing procedure - Trailing shoe is the shoe behind the wheel cylinder in the direction of the wheel rotation | E |
| Initial Weightings Disc / Drum | mg | [3] | Weight of the disc or drum before the beginning of the overall testing procedure | F |
| Final Weightings Inner pad / Leading shoe | mg | [3] | Weight of the inner pad or the leading shoe after the end of the overall testing procedure | G |
| Final Weightings Outer pad / Trailing shoe | mg | [3] | Weight of the outer pad or the trailing shoe after the end of the overall testing procedure | H |
| Final Weightings Disc / Drum | mg | [3] | Weight of the disc or drum after the end of the overall testing procedure | I |
| Mass Loss Inner pad / Leading shoe | mg | [3] | Difference between the weighed value of the inner pad or the leading shoe at the beginning and the end of the overall testing procedure – Subtract the value in column D from the value in column G | J |
| Mass Loss Outer pad / Trailing shoe | mg | [3] | Difference between the weighed value of the outer pad or the trailing shoe at the beginning and the end of the overall testing procedure – Subtract the value in column E from the value in column H | K |
| Mass Loss Disc / Drum | mg | [3] | Difference between the weighed value of the disc or the drum at the beginning and the end of the overall testing procedure – Subtract the value in column F from the value in column I | L |
| Mass Loss Total | mg | [3] | Total mass loss of the brake system during the overall testing procedure – Add the values in columns J, K, and L | M |
| Total Distance | km | [1] | Total distance covered during the entire brake emissions test including all sections | N |
| Mass Loss Rate Averaged | mg/km | [1] | Averaged mass loss rate of the brake system during the overall testing procedure – Divide the values in columns M/N | O |

### **Test Report File**

The testing facility shall create a unique, complete, correctly timed, and traceable dataset as an input file for the generation of the test report for the specific brake under testing. Table 13.6 contains all the necessary information to include in the report.. All information in the report shall be correlated to the specific brake. The test facility shall submit the report in a \*.pdf or equivalent format.

Table 13.6.   
**Overall testing parameters to report after a brake particle emissions test**

| *Serial No.* | *Paragraph* | *Parameters and Inputs* | *Short description* | *Unit* |
| --- | --- | --- | --- | --- |
|  | 8.1.1 | Test ID | A unique code attributed by the testing facility to the brake emissions test for the brake under testing – this value is used in all reporting files | - |
|  | 8.1.1 | Vehicle make and model | Report vehicle make and model where the brake under testing is mounted | - |
|  | 8.1.1 | Axle (front or rear) | Report the axle position on the vehicle for the brake under testing | - |
|  | 8.1.1 | Brake orientation (mounting position in the vehicle) | Report the location of the brake under testing on the vehicle, right-hand corner or left-hand corner | - |
|  | 8.1.1 | Vehicle test mass | Report the vehicle mass simulated on the inertia brake dynamometer during all sections of the brake emissions test (Mveh) | kg |
|  | 8.1.1 | Brake force distribution | Report the distribution of brake force between front and rear axle | % |
|  | 8.4.1 | Fixture style | Report the style of the support fixture of the brake assembly (L0-U or L0-P) | - |
|  | 8.4.1 | Part number for the disc or drum | Report the code labelled by the brake manufacturer on the disc/drum | # |
|  | 8.4.1 | Part number for the friction material | Report the code labelled by the friction manufacturer on the pads/shoes | # |
|  | 8.1.1 | Nominal wheel load | Calculate and report the nominal wheel load of the brake under testing (WLn) following Equation 8.1 | kg |
|  | 8.1.1 | Test (or applied) wheel load | Calculate and report the test wheel load applied on the brake dynamometer (WLt) following Equation 8.2 | kg |
|  | 8.1.1 | Tyre dynamic rolling radius | Report the tyre dynamic rolling radius related to the brake under testing | mm |
|  | 8.1.1 | Brake effective radius | Report the effective radius of the brake under testing | mm |
|  | 8.1.1 | Brake nominal inertia | Calculate and report the nominal moment of inertia for the brake under testing (In) following Equation 8.3 | kg·m2 |
|  | 8.1.1 | Brake Test (or applied) inertia | Calculate and report the moment of inertia applied on the brake dynamometer during testing (It) following Equation 8.4 | kg·m2 |
|  | 7.4.3 | Disc/Drum outer diameter | Report the outer diameter of the brake under testing | mm |
|  | 10.1.1, 10.1.2 | Disc mass | Report the actual mass of the unused disc to allocate the brake to a nominal wheel load to a disc mass group | kg |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  | 8.1.1 | Brake calliper or brake drum efficiency (if applicable) | Report the efficiency to account for friction losses, piston travel, etc. if specified by the brake manufacturer | % |
|  | 8.1.1 | Threshold pressure | Report the minimum pressure to overcome internal resistance before the onset of brake torque | kPa |
|  | 8.1.1 | Lateral run out limit | Report the maximum lateral movement allowed for the brake under testing along its rotating axis when installed on the brake fixture | µm |
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|  | 7.2.1.1 | Instantaneous cooling air temperature – overall compliance | Verify that all parts of the test fulfil the specifications defined in this GTR for the instantaneous cooling air temperature | Y/N |
|  |  |  |  |  |
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|  |  |  |  |  |
|  | 7.2.1.2 | Average cooling air relative humidity – overall compliance | Verify that all parts of the test fulfil the specifications defined in this GTR for the average cooling air relative humidity | Y/N |
|  |  |  |  |  |
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|  | 7.2.1.2 | Instantaneous cooling air relative humidity – overall compliance | Verify that all parts of the test fulfil the specifications defined in this GTR for the instantaneous cooling air relative humidity | Y/N |
|  | 7.2.2.1 | Cooling air cleaning – overall compliance | Verify that the cooling air entering the system complies with the filtering specifications defined in this GTR | Y/N |
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|  | 7.2.2.2.3 | System background verification | Verify that the TPN10 and SPN10 background concentrations measured at different airflows are below the maximum allowed limit defined in point (c) of paragraph 7.2.2.2.3 of this GTR | Y/N |
|  | 7.2.2.2.2 | Pre-test background verification | Calculate and report the TPN10 background concentration measured during the pre-test check (TPN10b#) | #/*N*cm3 |
|  | 7.2.2.2.2 | Pre-test background verification | Calculate and report the SPN10 background concentration measured during the pre-test check (SPN10b#) | #/*N*cm3 |
|  | 7.2.2.2.2 | Post-test background verification | Calculate and report the TPN10 background concentration measured during the post-test check (TPN10b#) | #/*N*cm3 |
|  | 7.2.2.2.2 | Post-test background verification | Calculate and report the SPN10 background concentration measured during the post-test check (SPN10b#) | #/*N*cm3 |
|  |  |  |  |  |
|  |  |  |  |  |
|  | 7.2.2.2.3 | Test background verification | Verify that the TPN10 and SPN10 background concentrations measured at the airflow defined for the brake under testing are below the maximum allowed limit defined in point (c) of paragraph 7.2.2.2.3 of this GTR | Y/N |
|  | 7.2.2.2.3 | Pre-test background verification per distance | Calculate and report the TPN10 background measured during the pre-test check in # per km following Equation 7.1 | #/km |
|  | 7.2.2.2.3 | Pre-test background verification per distance | Calculate and report the SPN10 background measured during the pre-test check in # per km following Equation 7.2 | #/km |
|  | 7.2.2.2.3 | Post-test background verification per distance | Calculate and report the TPN10 background measured during the post-test check in # per km following Equation 7.1 | #/km |
|  | 7.2.2.2.3 | Post-test background verification per distance | Calculate and report the SPN10 background measured during the post-test check in # per km following Equation 7.2 | #/km |
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|  | 7.2.3 | Nominal (or set) cooling airflow | Report the nominal (or set) cooling airflow for the brake under testing (Qset) | m3/h |
|  |  |  |  |  |
|  |  |  |  | m3/h |
|  |  |  |  | % |
|  |  |  |  | *N*m3/h |
|  |  |  |  | km/h |
|  |  |  |  | m3/h |
|  |  |  |  | % |
|  |  |  |  | *N*m3/h |
|  |  |  |  | km/h |
|  |  |  |  | m3/h |
|  |  |  |  | % |
|  |  |  |  | *N*m3/h |
|  |  |  |  | km/h |
|  |  |  |  | Y/N |
|  |  |  |  | # |
|  |  |  |  | # |
|  |  |  |  | Y/N |
|  | 7.2.3 | Instantaneous cooling airflow | Verify that the instantaneous cooling airflow readings (1Hz) do not exceed a 10 per cent difference compared to the nominal cooling airflow value at any point of the cooling adjustment and emissions measurement sections | Y/N |
|  |  |  |  |  |
|  | 7.2.3 | System leak check | Verify that the average measured airflow during the leak check meets the requirements set out in this GTR | Y/N |
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|  | 8.3 | Brake temperature measurement – overall compliance | Verify the compliance of the embedded thermocouple with all the requirements defined in 8.3 of this GTR | Y/N |
|  | 8.3 | Brake temperature measurement | Verify the positioning of the embedded thermocouple meets the specifications defined in this GTR | Y/N |
|  | 8.3 | Brake temperature measurement | Report whether brake pads or shoes temperature was also measured | Y/N |
|  | 8.4.1 |  |  | Y/N |
|  |  |  |  |  |
|  | 8.4.1 | Fixture type | Specify the type of support fixture used for mounting the brake system on the inertia dynamometer | - |
|  | 8.4.1 | Fixture type – overall compliance | Verify that the type of support fixture used for the brake assembly meets the requirements specified in paragraph 8.4.1 of this GTR | Y/N |
|  | 8.4.1 | Brake rotation | Report the rotation direction of the brake disc or drum (CW or CCW) with respect to the direction of evacuation | - |
|  | 8.4.1 | Brake rotation | Verify that the tested brake disc or drum rotates in the direction of the evacuation | Y/N |
|  |  |  |  |  |
|  | 8.4.2 | Calliper orientation | Verify that the calliper orientation of the brake under testing meets the requirements specified in paragraph 8.4.2 of this GTR | Y/N |
|  |  |  |  |  |
|  | 9.2.1 | Initial temperature – cooling adjustment section | Verify that the initial brake temperature in Trip #10 of the cooling adjustment section complies with the criteria defined in paragraph 9.2.1 of this GTR | Y/N |
|  |  |  |  |  |
|  | 9.2.2 | Initial temperature – bedding section | Verify that the initial brake temperature in all five repetitions of the WLTP-Brake cycle of the bedding section complies with the criteria defined in paragraph 9.2.2 of this GTR | Y/N |
|  | 9.2.3 | Initial temperature – emissions measurement section | Report the initial brake temperature in all ten trips of the WLTP-Brake cycle during the emissions measurement section as defined in paragraph 9.2.3. Use the corresponding values of the parameter “Brake Temperature” in the Time-Based File | °C |
|  | 9.2.3 | Initial temperature – emissions measurement section | Verify that the initial brake temperature in all ten trips of the WLTP-Brake cycle of the emissions measurement section complies with the criteria defined in paragraph 9.2.3 of this GTR | Y/N |
|  | 9.3.1, 9.3.2, 9.3.3 | WLTP-Brake cycle interruptions | Verify that all sections of the brake emissions test were completed without any interruption | Y/N |
|  | 9.3.1, 9.3.2, 9.3.3 | WLTP-Brake cycle interruptions | When one or more interruptions occurred, verify that all necessary steps were taken to resume testing following the specifications defined in paragraphs 9.3.1, 9.3.2, and 9.3.3 of this GTR | Y/N |
|  | 9.3.1, 9.3.2, 9.3.3 | WLTP-Brake cycle interruptions | Verify that the brake under testing was not disassembled at any point of the overall brake emissions test | Y/N |
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|  | 9.4.1 | Speed violations – emissions measurement section | Calculate and report the percentage of the speed violations during the emissions measurement section. Use the 1Hz data of the parameters “Linear Speed Actual” and “Linear Speed Nominal” in the Time-Based File. Compare the 1Hz data of the two parameters to calculate the overall percentage of speed violations | % |
|  | 9.4.1 | Speed violations | Verify that all sections of the brake emissions test comply with the speed violations criteria defined in paragraph 9.4.1 of this GTR | Y/N |
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|  | 9.4.2 | Number of brake events limit – emissions measurement section | Verify that the number of brake events equals 303 as specified in paragraph 9.4.2 of this GTR | Y/N |
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|  | 9.4.3 | Kinetic energy dissipation – overall compliance | Verify that all sections of the brake emissions test comply with the kinetic energy dissipation criteria specified in paragraph 9.4.3 of this GTR | Y/N |
|  | 10.1.1 | Nominal wheel load/disc or drum mass ratio | Calculate and report the nominal wheel load to disc mass (or drum mass in case of front drum brakes) ratio (WLn/DM) for the brake under testing | - |
|  | 10.1.1 | Brake group for Nominal Wheel Load / Disc or Drum Mass ratio | Report the group number where the brake under testing belongs according to its nominal wheel load to disc (or drum) mass ratio | - |
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|  | 12.1.1.1 |  |  |  |
|  | 12.1.1.1 | PM sampling plane – probes positioning | Verify that the PM2.5 and PM10 sampling probes are placed at the same horizontal plane to the lower part of the tunnel as specified in Figure 7.7 of this GTR | Y/N |
|  | 12.1.1.1 |  |  | Y/N |
|  | 12.1.1.1 |  |  | Y/N |
|  | 12.1.1.2 | PM sampling probes – dimensions | Report the PM2.5 sampling probe inner diameter (dp) used for the brake under testing | mm |
|  | 12.1.1.2 | PM sampling probes – dimensions | Report the PM10 sampling probe inner diameter (dp) used for the brake under testing | mm |
|  | 12.1.1.2 | PM sampling probes – dimensions | Report the PM2.5 sampling probe overall length from the sampling nozzle tip to the inlet of the PM separation device | mm |
|  | 12.1.1.2 | PM sampling probes – dimensions | Report the PM10 sampling probe overall length from the sampling nozzle tip to the inlet of the PM separation device | mm |
|  | 12.1.1.2 | PM sampling probes – application of a bend | Report if a bend is applied to the PM2.5 and/or PM10 sampling probes used for the brake under testing | Y/N |
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|  |  |  |  |  |
|  | 12.1.1.2 | PM sampling probes – overall compliance | Verify that the PM2.5 and PM10 sampling probes used for the brake under testing meet all the design requirements specified in paragraph 12.1.1.2 of this GTR | Y/N |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Report the PM2.5 sampling nozzle inner diameter (dn) used for the brake under testing | mm |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Verify that the PM2.5 sampling nozzle inner diameter (dn) is appropriate for fulfilling the isokinetic requirements specified in paragraph 12.1.2.3 for the brake under testing | Y/N |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Report the PM10 sampling nozzle inner diameter (dn) used for the brake under testing | mm |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Verify that the PM10 sampling nozzle inner diameter (dn) is appropriate for fulfilling the isokinetic requirements specified in paragraph 12.1.2.3 for the brake under testing | Y/N |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Report the PM2.5 sampling nozzle outer to inner diameter ratio at the nozzle tip used for the brake under testing | - |
|  | 12.1.1.3 | PM sampling nozzles – dimensions | Report the PM10 sampling nozzle outer to inner diameter ratio at the nozzle tip used for the brake under testing | - |
|  | 12.1.1.3 |  |  | ° |
|  | 12.1.1.3 |  |  | ° |
|  | 12.1.1.3 | PM sampling nozzles – overall compliance | Verify that the PM2.5 and PM10 sampling nozzles used for the brake under testing meet all the design requirements specified in paragraph 12.1.1.3 of this GTR | Y/N |
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|  | 12.1.2.1 | PM separation device – overall compliance | Verify that the PM2.5 and PM10 cyclonic separators used for the brake under testing meet all the requirements specified in paragraph 12.1.2.1 of this GTR | Y/N |
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|  | 12.1.2.2 | PM sampling line – application of a bend | Report if a bend is applied to the PM2.5 and/or PM10 sampling lines used for the brake under testing | Y/N |
|  |  |  |  |  |
|  |  |  |  |  |
|  | 12.1.2.2 | PM sampling line – overall compliance | Verify that the PM2.5 and PM10 sampling lines used for the brake under testing meet all the design requirements specified in paragraph 12.1.2.2 of this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow – accuracy requirements | Verify the compliance of the PM sampling flow measurement elements with the measurement accuracy requirements defined in this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow | Verify the compliance of the temperature and pressure sensors of the PM sampling flow measurement elements with the requirements defined in this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow – nominal flow | Report the set (nominal) flow value for PM2.5 sampling for the brake under testing (QPM2.5-set) | l/min |
|  | 12.1.2.3 | PM sampling flow – nominal flow | Report the set (nominal) flow value for PM10 sampling for the brake under testing (QPM10-set) | l/min |
|  | 12.1.2.3 | PM sampling flow – nominal flow | Verify that the set (nominal) flow values for PM2.5 and PM10 sampling are constant throughout the brake emissions test | Y/N |
|  | 12.1.2.3 | PM sampling flow – measured flow | Calculate and report the average measured flow value for PM2.5 sampling for the brake under testing. Use the 1Hz data of the parameter “PM2.5 Sampling Airflow Actual” in the Time-Based File to calculate the average measured flow | l/min |
|  | 12.1.2.3 | PM sampling flow – measured flow | Calculate and report the average measured flow value for PM10 sampling for the brake under testing. Use the 1Hz data of the parameter “PM10 Sampling Airflow Actual” in the Time-Based File to calculate the average measured flow | l/min |
|  | 12.1.2.3 | PM sampling flow – measured flow | Verify that the average measured flow value for PM2.5 sampling for the brake under testing is within ±2 per cent of the nominal flow value | Y/N |
|  | 12.1.2.3 | PM sampling flow – measured flow | Verify that the average measured flow value for PM10 sampling for the brake under testing is within ±2 per cent of the nominal flow value | Y/N |
|  | 12.1.2.3 | PM sampling flow – measured flow | Report the average normalized measured flow value for PM2.5 sampling for the brake under testing (*N*QPM2.5). Use the 1Hz data of the parameter “PM2.5 Sampling Airflow Actual Normalized” in the Time-Based File to calculate the average measured flow | *N*l/min |
|  | 12.1.2.3 | PM sampling flow – measured flow | Report the average normalized measured flow value for PM10 sampling for the brake under testing (*N*QPM10). Use the 1Hz data of the parameter “PM10 Sampling Airflow Actual Normalized” in the Time-Based File to calculate the average measured flow | *N*l/min |
|  | 12.1.2.3 | PM sampling flow – isokinetic ratio | Calculate and report the average isokinetic ratio for PM2.5 sampling for the brake under testing following equation 12.4. Use the PM2.5 nozzle diameter and the 1Hz data of the parameters “Cooling Airflow Actual Normalized” and “PM2.5 Sampling Airflow Actual Normalized” in the Time-Based File. | - |
|  | 12.1.2.3 | PM sampling flow – isokinetic ratio | Verify that the average isokinetic ratio for PM2.5 sampling for the brake under testing meets the requirements defined in this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow – isokinetic ratio | Calculate and report the average isokinetic ratio for PM10 sampling for the brake under testing following equation 12.4. Use the PM10 nozzle diameter and the 1Hz data of the parameters “Cooling Airflow Actual Normalized” and “PM10 Sampling Airflow Actual Normalized” in the Time-Based File | - |
|  | 12.1.2.3 | PM sampling flow – isokinetic ratio | Verify that the average isokinetic ratio for PM10 sampling for the brake under testing meets the requirements defined in this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow – leak check | Verify that a leak check has been carried out according to the requirements defined in paragraph 12.1.2.3 of this GTR | Y/N |
|  | 12.1.2.3 | PM sampling flow – overall compliance | Verify that the PM2.5 and PM10 sampling flow specifications defined in paragraph 12.1.2.3 of this GTR for the brake under testing are met | Y/N |
|  | 12.1.3.1 | PM filter holder – overall compliance | Verify that the PM2.5 filter holder meets all the requirements set out in paragraph 12.1.3.1 of this GTR | Y/N |
|  | 12.1.3.1 | PM filter holder – overall compliance | Verify that the PM10 filter holder meets all the requirements set out in paragraph 12.1.3.1 of this GTR | Y/N |
|  | 12.1.3.2 | PM sampling filters – filter type | Specify the type of filter (filter material) used for PM2.5 sampling for the brake under testing | - |
|  | 12.1.3.2 | PM sampling filters – overall compliance | Verify that the filter used for PM2.5 sampling for the brake under testing meets all the requirements set out in paragraph 12.1.3.2 of this GTR | Y/N |
|  | 12.1.3.2 | PM sampling filters – filter type | Specify the type of filter (filter material) used for PM10 sampling for the brake under testing | - |
|  | 12.1.3.2 | PM sampling filters – overall compliance | Verify that the filter used for PM10 sampling for the brake under testing meets all the requirements set out in paragraph 12.1.3.2 of this GTR | Y/N |
|  | 12.1.4 | Weighing procedure – balance | Verify that the weighing balance has been stored in an appropriate room fulfilling all the requirements described in paragraph 12.1.4 of this GTR | Y/N |
|  |  |  |  |  |
|  | 12.1.4 | Weighing procedure | Verify that all necessary measures to nullify the effects of static electricity as described in point (c) of paragraph 12.1.4 of this GTR have been taken | Y/N |
|  | 12.1.4 | Weighing procedure – Pre-testing | Report the pre-test weighing date and time of the PM2.5 and PM10 filters used for the brake under testing | - |
|  | 12.1.4 |  |  |  |
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|  | 12.1.4 |  |  |  |
|  | 12.1.4 | Weighing procedure – Pre-testing | Report the pre-test weighing room’s average temperature during the measurement of the PM10 and PM2.5 filter weights | °C |
|  | 12.1.4 | Weighing procedure – Pre-testing | Report the pre-test weighing room’s average relative humidity during the measurement of the PM10 and PM2.5 filter weights | % |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 | Weighing procedure – Pre-testing | Verify that pre-sampling conditioning and weighing of the PM2.5 and PM10 filters used for the brake under testing were carried out according to the specifications defined in paragraph 12.1.4 of this GTR | Y/N |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
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|  | 12.1.4 | Weighing procedure – Post-testing | Report the post-test weighing room’s average temperature during the measurement of the PM10 and PM2.5 filter weights | °C |
|  | 12.1.4 | Weighing procedure – Post-testing | Report the post-test weighing room’s average relative humidity during the measurement of the PM10 and PM2.5 filter weights | % |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 | Weighing procedure – Post-testing | Verify that post-sampling conditioning and weighing of the PM2.5 and PM10 filters used for the brake under testing were carried out according to the specifications defined in paragraph 12.1.4 of this GTR | Y/N |
|  | 12.1.4 |  |  |  |
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|  | 12.1.4 | Weighing procedure – reference filters | Verify that the weighing of PM2.5 and PM10 reference filters was carried out according to the specifications defined in paragraph 12.1.4 of this GTR | Y/N |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 |  |  |  |
|  | 12.1.4 | Weighing procedure – overall compliance | Verify that all requirements set out in this GTR for weighing PM2.5 and PM10 filters used for the brake under testing have been followed | Y/N |
|  | 12.1.5 | PM emission factor calculation | Report the PM2.5 emission factor in particle mass per distance driven for the brake under testing as specified in 12.1.5 of this GTR (PM2.5 EF). Use the PM2.5 filter mass loading for the brake under testing (PM2.5-Mass) also calculated in the PM-Mass Measurement File and the data of the parameters “Cooling Airflow Actual Normalized”, “PM2.5 Sampling Airflow Actual Normalized”, and “Driven Distance” in the Time-Based File | mg/km |
|  | 12.1.5 | PM emission factor calculation | Report the PM10 emission factor in particle mass per distance driven for the brake under testing as specified in 12.1.5 of this GTR (PM10 EF). Use the PM10 filter mass loading for the brake under testing (PM10-Mass) also calculated in the PM-Mass Measurement File and the data of the parameters “Cooling Airflow Actual Normalized”, “PM10 Sampling Airflow Actual Normalized”, and “Driven Distance” in the Time-Based File | mg/km |
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|  | 12.2.1.3 | PN sampling nozzles – overall compliance | Verify that the TPN10 and SPN10 sampling nozzles used for the brake under testing meet all the design requirements specified in paragraph 12.2.1.3 of this GTR | Y/N |
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|  | 12.2.1.4 | PN transfer tube – overall compliance | Verify that the TPN10 and SPN10 transfer tubes used for the brake under testing meet all the design requirements specified in paragraph 12.2.1.4 of this GTR | Y/N |
|  |  |  |  | μm |
|  |  |  |  | μm |
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|  | 12.2.3.2 | PN sampling flow – isokinetic ratio | Verify that the average isokinetic ratio for TPN10 sampling for the brake under testing meets the requirements defined in paragraph 12.2.3.2 of this GTR | Y/N |
|  | 12.2.3.2 | PN sampling flow – isokinetic ratio | Verify that the average isokinetic ratio for SPN10 sampling for the brake under testing meets the requirements defined in paragraph 12.2.3.2 of this GTR | Y/N |
|  | 12.2.3.2 | PN sampling flow – overall compliance | Verify that the TPN10 and SPN10 sampling flow specifications defined in paragraph 12.2.3.2 of this GTR for the brake under testing are met | Y/N |
|  | 12.2.4 | PN emission factor calculation | Report the TPN10 emission factor in a number of particles per distance driven for the brake under testing as specified in paragraph 12.2.3.3 of this GTR | #/km |
|  | 12.2.4 |  |  |  |
|  | 12.2.4 | PN emission factor calculation | Report the SPN10 emission factor in a number of particles per distance driven for the brake under testing as specified in paragraph 12.2.3.3 of this GTR | #/km |
|  |  |  |  |  |
|  | 12.2.5 | PN system verification procedures | Verify that the PN system verification procedures defined in paragraph 12.2.5 of this GTR have been applied successfully for the brake under testing | Y/N |
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|  | 14.2 | Calibration requirements – inertia dynamometer | Verify that the calibration requirements defined in this protocol for the brake dynamometer are met | Y/N |
|  | 14.2 | Calibration requirements – inertia dynamometer | Verify that a valid calibration certificate for the brake dynamometer is available at the time of the brake emissions test | Y/N |
|  | 14.3 | Calibration requirements – airflow measurement device | Verify that the calibration requirements defined in this protocol for the cooling airflow measurement device are met | Y/N |
|  | 14.3 | Calibration requirements – airflow measurement device | Verify that a valid calibration certificate for the cooling airflow measurement device is available at the time of the brake emissions test | Y/N |
|  | 14.1 | Calibration requirements – cyclonic separators | Verify that the calibration requirements defined in this protocol for the PM and PN cyclonic separators are met | Y/N |
|  | 14.1 | Calibration requirements – cyclonic separators | Verify that valid calibration certificates for the PM and PN cyclonic separators are available at the time of the brake emissions test | Y/N |
|  | 14.4 | Calibration requirements – weighing balance | Verify that the calibration requirements defined in this protocol for the microgram balance are met | Y/N |
|  | 14.4 | Calibration requirements – weighing balance | Verify that a valid calibration certificate for the microgram balance is available at the time of the brake emissions test | Y/N |
|  | 14.1 | Calibration requirements – PM sampling flow measurement device | Verify that the calibration requirements defined in this protocol for the PM sampling flow measurement device are met | Y/N |
|  | 14.1 | Calibration requirements – PM sampling flow measurement device | Verify that a valid calibration certificate for the PM sampling flow measurement device is available at the time of the brake emissions test | Y/N |
|  | 14.1 | Calibration requirements – PN sampling flow measurement device | Verify that the calibration requirements defined in this protocol for the PN sampling flow measurement device are met | Y/N |
|  | 14.1 | Calibration requirements – PN sampling flow measurement device | Verify that a valid calibration certificate for the PN sampling flow measurement device is available at the time of the brake emissions test | Y/N |
|  | 14.5 | Calibration requirements – treatment and conditioning devices | Verify that the calibration requirements defined in this protocol for the TPN10 dilution system and the SPN10 volatile particle remover are met | Y/N |
|  | 14.5 | Calibration requirements – treatment and conditioning devices | Verify that valid calibration certificates for the TPN10 dilution system and the SPN10 volatile particle remover are available at the time of the brake emissions test | Y/N |
|  | 14.6 | Calibration requirements – particle number counter | Verify that the calibration requirements defined in this protocol for the particle number counter are met | Y/N |
|  | 14.6 | Calibration requirements – particle number counter | Verify that a valid calibration certificate for the particle number counter is available at the time of the brake emissions test | Y/N |

## Calibration Requirements and Ongoing Quality Controls

### **General Calibration Requirements**

This paragraph summarises the minimum calibration requirements for the equipment used for brake emissions testing. Table 14.1 summarises the calibration criteria and the intervals for the main equipment defined in this GTR.

Table 14.1  
**Calibration requirements for main equipment for emissions measurements**

|  |  |  |  |
| --- | --- | --- | --- |
| *Instrument* | *Interval* | *Criterion* | *Paragraph* |
| Brake dynamometer | Upon initial installation, yearly, and at major setup maintenance | Table 14.3 | Paragraph 14.2 |
| Torque measurement device | Upon initial installation, yearly, and at major setup maintenance | Table 14.4 | Paragraph 14.2 |
| Cooling airflow measurement device | Upon initial installation, yearly, and at major setup maintenance | Table 14.5 | Paragraph 14.3 |
| Cooling airflow temperature sensor | Yearly | ±1°C | Paragraph 14.3 |
| Cooling airflow atmospheric pressure sensor | Yearly | ±0.4 kPa | Paragraph 14.3 |
| Cooling air temperature sensor | Yearly | ±1°C | Paragraph 7.2.1 |
| Cooling air relative humidity sensor | Yearly | ±5 per cent of nominal | Paragraph 7.2.1 |
| PM10 Cyclonic separator | Upon initial installation | Table 12.1 | Paragraph 12.1 |
| PM2.5 Cyclonic separator | Upon initial installation | Table 12.2 | Paragraph 12.1 |
| Microgram balance | Upon initial installation, yearly, and at major setup maintenance | Table 14.6 | Paragraph 14.4 |
| PM sampling flow measurement device | Upon initial installation, yearly, and at major setup maintenance | ±2.5 per cent of reading or ±1.5 per cent of full scale  (whichever is the least) | Paragraph 12.1 |
| PM sampling flow temperature sensor | Yearly | ±1°C | Paragraph 12.1 |
| PM sampling flow pressure sensor | Yearly | ±1 kPa | Paragraph 12.1 |
| PN Cyclonic separator | Upon initial installation | Penetration efficiency of ≥80 per cent for a particle electrical mobility diameter of 1.5 µm | Paragraph 12.2 |
| PN sampling flow measurement device | 13 months | ±5 per cent of reading under all operating conditions | Paragraph 12.2 |
| PN sampling flow temperature sensor | Yearly | ±1°C | Paragraph 12.2 |
| PN sampling flow pressure sensor | Yearly | ±1 kPa | Paragraph 12.2 |
| Dilution system for TPN10 | 6 months or 13 months depending on the setup | As per paragraph 14.5.1 | Paragraph 14.5 |
| Volatile Particle Remover for SPN10 | 6 months or 13 months depending on the setup | As per paragraph 14.5.2 | Paragraph 14.5 |
| Particle Number Counter | 13 months and at major maintenance | As per paragraph 14.6 | Paragraph 14.6 |

Any other sensor or auxiliary equipment used to determine e.g. temperature, atmospheric pressure, and ambient humidity of the facilities room or the balance room shall fulfil the requirements prescribed in Table 14.2.

Table 14.2  
**Calibration requirements for auxiliary equipment**

|  |  |  |
| --- | --- | --- |
| *Instrument* | *Interval* | *Criterion* |
| Temperature sensor | Yearly | ±1°C |
| Atmospheric pressure sensor | Yearly | ±1 kPa |
| Relative humidity sensor | Yearly | ±5 per cent of nominal |
| Absolute humidity sensor | Yearly | ±10 per cent of reading or 1 gH2O/kg dry air (whichever is larger) |

### **Brake Dynamometer**

Table 14.3 summarises the calibration criteria and the intervals for the brake dynamometer defined in this GTR. The rotational speed, brake torque, and brake pressure measurement devices shall comply with the linearity requirements of Table 14.4.

Table 14.3  
**Calibration requirements for the brake dynamometer**

|  |  |  |
| --- | --- | --- |
| *Instrument* | *Interval* | *Criterion* |
| Rotational speed device | Upon initial installation, yearly, and at major setup maintenance | Table 14.4 |
| Brake torque sensor | Upon initial installation, yearly, and at major setup maintenance | Table 14.4 |
| Brake pressure sensor | Upon initial installation, yearly, and at major setup maintenance | Table 14.4 |
| Brake fluid displacement (if applicable) | Upon initial installation, yearly, and at major setup maintenance | ±0.5 per cent maximum |
| Temperature data acquisition | Upon initial installation, yearly, and at major setup maintenance | ±0.25 per cent maximum |

Table 14.4  
**Linearity requirements of rotational speed, brake torque, and brake pressure measurement devices**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Measurement system* | *Intercept a0* | *Slope a1* | *Standard error of estimate (SEE)* | *Coefficient of determination r²* |
| Brake Rotational Speed | ≤ 0.05 per cent maximum | 0.98 – 1.02 | ≤ 0.25 per cent maximum | ≥ 0.990 |
| Brake Torque | ≤ 0.05 per cent maximum | 0.98 – 1.02 | ≤ 0.5 per cent maximum | ≥ 0.990 |
| Brake pressure | ≤ 0.05 per cent maximum | 0.98 – 1.02 | ≤ 0.5 per cent maximum | ≥ 0.990 |

Apart from the calibrations of the systems listed in Tables 14.3 and 14.4, the testing facility shall verify the torque zero level and pressure zero level every time before commencing a brake emissions test.

### **Cooling Airflow Measurement Device**

The calibration of the flow measurement device used for the determination of the cooling airflow shall be traceable to national or international standards. The flow measurement device shall comply with the linearity requirements of Table 14.5 with at least four equally spaced reference flows applying a linear regression between the minimum and maximum applicable flowrate of the setup. In addition, each flow measurement point shall be within ±2 per cent of the measured reference flow. The testing facility shall perform the calibration of the airflow measurement device upon the initial installation, annually, and at every major maintenance of the setup.

Table 14.5  
**Linearity requirements of the flow measurement device**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Measurement system* | *Intercept a0* | *Slope a1* | *Standard error of estimate (SEE)* | *Coefficient of determination r²* |
| Flow meter | ≤ 1 per cent maximum | 0.98 – 1.02 | ≤ 2 per cent maximum | ≥ 0.990 |

The testing facility shall use a flow measurement device calibrated to report airflow at both operating and standard conditions (273.15 K and 101.325 kPa). The temperature sensor shall have an accuracy of ±1 °C. The pressure measurements shall have precision and accuracy of ±0.4 kPa. The testing facility shall carry out the calibration of both sensors annually.

### **Microgram Balance**

The calibration of the microgram balance used for particle filter weighing according to paragraph 12.1.4 shall be traceable to national or international standards. The balance shall comply with the linearity requirements of Table 14.6 with at least four equally spaced reference weights applying linear regression. This implies a precision of at least ±2 μg and a resolution of at least 1 μg (1 digit = 1 μg). The testing facility shall use certified calibration weights to verify the stability and the proper function of the microbalance regularly. The testing facility shall perform the calibration of the microgram balance upon the initial installation, annually, and at every major maintenance of the setup.

Table 14.6  
**Verification criteria for microgram balance**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Measurement system* | *Intercept a0* | *Slope a1* | *Standard error of estimate (SEE)* | *Coefficient of determination r²* |
| PM balance | ≤ 1 μg | 0.99 – 1.01 | ≤ 1 per cent maximum | ≥ 0.998 |

### **Sample Treatment and Conditioning Devices**

#### Dilution System for TPN10 Measurement

The calibration of the dilution system’s PCRF across its full range of dilution settings shall be carried out at the instrument’s fixed nominal operating temperatures when the unit is new and following any major maintenance. The periodic validation requirement for the dilution system’s PCRF shall be limited to a check at a single setting typical of that used for emissions testing of any typical brake available in the market. The Technical Service shall ensure the existence of a calibration or validation certificate within a 6-month period before the emissions test. A 13-month validation interval shall be permissible when the dilution system incorporates temperature monitoring alarms.

The dilution system shall be characterised for PCRF with thermally stable particles at the operating conditions of the system of 15 nm, 30 nm, 50 nm, and 100 nm electrical mobility diameters. PCRFs (fr (dx)) for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters shall be no more than 100 per cent, 30 per cent, and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For validation, the mean PCRF shall be within ±10 per cent of the arithmetic mean particle concentration reduction factor (fr) determined during the primary calibration of the dilution system.

The test aerosol for these measurements shall be thermally stable particles at the operating conditions of the system of 15, 30, 50, and 100 nm electrical mobility diameters. The minimum concentration at the dilution system inlet shall be 3000 #/cm-³ for particles of 15 nm electrical mobility diameter and 5000 #/cm-³ for particles of 30, 50, and 100 nm electrical mobility diameters. Particle concentrations shall be measured upstream and downstream of the components. The PCRF at each particle size (fr (dx)) shall be calculated following equation 14.1. Nin (dx) and Nout (dx) shall refer to the same conditions (i.e. standard conditions):

|  |  |
| --- | --- |
|  | (Eq. 14.1) |

Where:

is the upstream PN concentration for particles of electrical mobility diameter dx;

is the downstream PN concentration for particles of electrical mobility diameter dx.

The arithmetic average particle concentration reduction (fr) at a given dilution setting shall be calculated using equation 14.2:

|  |  |
| --- | --- |
|  | (Eq. 14.2) |

Where:

is the PCRF for particles of 30 nm electrical mobility diameter;

is the PCRF for particles of 50 nm electrical mobility diameter;

is the PCRF for particles of 100 nm electrical mobility diameter.

The instrument manufacturer shall prove the particle penetration Pr(dx) by testing one unit for each system model. A system model here covers all systems with the same hardware, i.e. same geometry, conduit materials, flows, and temperature profiles in the aerosol path. The particle penetration Pr(dx) at a particle size, dx, shall be calculated using equation 14.3. DF is the dilution factor between measurement positions of Nin (dx) and Nout (dx) determined either with trace gases or flow measurements.

|  |  |
| --- | --- |
|  | (Eq. 14.3) |

#### Volatile Particle Removal for SPN10 Measurement

The calibration of the VPR’s PCRF across its full range of dilution settings shall be carried out at the instrument’s fixed nominal operating temperatures when the unit is new and following any major maintenance. The periodic validation requirement for the VPR’s PCRF shall be limited to a check at a single setting typical of that used for emissions testing of any typical brake available in the market. The Technical Service shall ensure the existence of a calibration or validation certificate within a 6-month period before the emissions test. A 13-month validation interval shall be permissible when the VPR incorporates temperature monitoring alarms.

The VPR shall be characterised for PCRF with solid particles of 15 nm, 30 nm, 50 nm, and 100 nm electrical mobility diameters. PCRFs for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters shall be no more than 100 per cent, 30 per cent, and 20 per cent higher respectively, and no more than 5 per cent lower than that for particles of 100 nm electrical mobility diameter. For validation, the mean PCRF shall be within ±10 per cent of the arithmetic mean particle concentration reduction factor (fr) determined during the last calibration of the VPR.

The test aerosol for these measurements shall be solid particles of 15 nm, 30 nm, 50 nm, and 100 nm electrical mobility diameters. The minimum concentration at the dilution system inlet shall be 3000 #/cm-³ for particles of 15 nm electrical mobility diameter and 5000 #/cm-³ for particles of 30 nm, 50 nm, and 100 nm electrical mobility diameters. Particle concentrations shall be measured upstream and downstream of the components. The PCRF at each particle size (fr (dx)) shall be calculated following equation 14.1. The arithmetic average particle concentration reduction (fr) at a given dilution setting shall be calculated using equation 14.2

It is recommended that the VPR is calibrated and validated as a complete unit. The volatile particle removal efficiency of a VPR needs to be proven only once for the instrument family measuring SPN10. The instrument manufacturer must provide the maintenance or replacement interval that ensures that the removal efficiency of the VPR does not drop below the technical requirements. If such information is not provided, the volatile removal efficiency has to be checked yearly for each instrument.

The VPR used for SPN10 measurements shall demonstrate greater than 99.9 per cent removal efficiency of Tetracontane (CH3(CH2)38CH3) particles with count median electrical mobility diameter > 50 nm and mass > 1 mg/m3 when operated at its minimum dilution setting and the manufacturers recommended operating temperature.

The instrument manufacturer shall prove the particle penetration Pr(dx) by testing one unit for each system model. A system model here covers all systems with the same hardware, i.e. same geometry, conduit materials, flows, and temperature profiles in the aerosol path. The particle penetration Pr(dx) at a particle size, dx, shall be calculated using equation 14.3.

### **Particle Number Counter**

The responsible authority shall ensure the existence of a calibration certificate for the PNC demonstrating compliance with a traceable standard within a 13-month period before the emissions test. Between calibrations, either the counting efficiency of the PNC shall be monitored for deterioration, or the PNC wick shall be routinely changed every 6 months if recommended by the instrument manufacturer. The PNC shall also be recalibrated and a new calibration certificate issued following any major maintenance.

Calibration shall be traceable to a standard calibration method. The testing facility shall use one of the two following methods for the calibration of the PNC:

1. Comparison of the response of the PNC under calibration with that of a calibrated aerosol electrometer when simultaneously sampling electrostatically classified calibration particles;

Comparison of the response of the PNC under calibration with that of a second PNC that has been directly calibrated by the above method.

The calibration shall be undertaken using at least six standard concentrations across the PNC’s measurement range. Five of these standard concentrations shall be as uniformly spaced as possible between the standard concentration of 3000 #/cm-³ or below and the maximum of the PNC’s range in single-particle count mode. The six standard concentration points shall include a nominal zero concentration point produced by attaching HEPA filters of at least Class H13 of EN 1822:2008 (or equivalent performance) to the inlet of each instrument. The gradient from a linear least-squares regression of the two data sets shall be calculated and recorded. A calibration factor equal to the reciprocal of the gradient shall be applied to the PNC under calibration. Linearity of response is calculated as the square of the Pearson product moment correlation coefficient (r) of the two data sets and shall be equal to or greater than 0.97. In calculating both the gradient and R2, the linear regression shall be forced through the origin (zero concentration on both instruments). The calibration factor shall be between 0.9 and 1.1. Each concentration measured with the PNC under calibration shall be within ±5 per cent of the measured reference concentration multiplied with the gradient, with the exception of the zero point.

The calibration shall also include a check against the requirements on the PNC’s detection efficiency with particles of 10 nm electrical mobility diameter. A check of the counting efficiency with 15 nm particles is not required during periodical calibration.

XXX

1. A separate excel file with i. The 1Hz speed trace for the entire cycle; ii. The 1Hz speed trace for Trip #10; iii. Information about the brake events. [↑](#footnote-ref-2)