United Nations ECE/TRANS/WP.29/2026/36

Economic and Social Council

Distr.: General
29 December 2025

Original: English

Economic Commission for Europe

Inland Transport Committee

World Forum for Harmonization of Vehicle Regulations

198th session
Geneva, 10-13 March 2026
Item 4.13.1. of the provisional agenda
1958 Agreement:
Consideration of proposals for new UN Regulations submitted by the Working Parties subsidiary to the World Forum

Proposal for a new UN Regulation No. [179] on the Laboratory Measurement of Brake Emissions for Light-Duty Vehicles

Submitted by the Working Party on Pollution and Energy*

The text reproduced below was adopted by the Working Party on Pollution and Energy (GRPE) at its ninety-third session (ECE/TRANS/WP.29/GRPE/93, para. 49.). It is based on ECE/TRANS/WP.29/GRPE/2025/18 and GRPE-93-48-Rev.1 as amended by Addendum 8 of the session report. It is submitted to the World Forum for Harmonization of Vehicle Regulations (WP.29) and to the Administrative Committee (AC.1) for consideration at their March 2026 sessions.

* In accordance with the programme of work of the Inland Transport Committee for 2026 as outlined in proposed programme budget for 2026 (A/80/6 (Sect. 20), table 20.7), the World Forum will develop, harmonize and update UN Regulations in order to enhance the performance of vehicles. The present document is submitted in conformity with that mandate.

Contents

		Page
1.	Scope and application	3
2.	Abbreviations and Symbols	3
3.	Definitions	10
4.	Application for approval	22
5.	Approval	22
6.	Markings	23
7.	General Requirements	24
8.	General overview	29
9.	Modification and extension of the type approval	30
10.	Conformity of production (CoP)	31
11.	Penalties for non-conformity of production	33
12.	Production definitively discontinued	33
13.	Names and addresses of the Technical Services responsible for conducting approval tests and of Type Approval Authorities	33
14.	Special provisions	33

Annexes

1.	Information Documentation	34
	Appendix 1.- Brake Corner Emission Family Test Report	43
	Appendix 2 - Individual Friction Braking Share Coefficient (c-factor) Test Report (repeat as applicable for each individual measurement)	53
	Appendix 3 - Vehicle Type Compliance Demonstration Report	59
2.	Communication	65
3.	Arrangements of the approval mark	66
4.	Brake Emissions Test Procedure	67
	Appendix 1.- WLTP-Brake Cycle Events	174
	Appendix 2 - WLTP-Brake Cycle Brake Events	188
5	Method for Measuring and Calculating Vehicle-Specific Braking Share Coefficients	196

1. Scope and application

This Regulation applies to vehicles of category M_1 and N_1 using friction braking, which involves a combination of dry friction materials and a mating brake disc or brake drum or using some form of friction braking in their service.

At the request of the manufacturer, approval may also be granted to vehicles of category N_2 between 3.5 and 5 tonnes maximum mass originating from a type of vehicle of category N_1.

2. Abbreviations and Symbols

2.1. Abbreviations

Table 1 provides a list of the abbreviations, a short description, and the unit of each abbreviation (when applicable) used in this Regulation.

Table 1
Abbreviations

Abbreviation	*Definition*	*Unit*
ABT	Average Brake Temperature during Trip #10	°C
BDD	Brake drum diameter	mm
BRO	Brake runout	µm
DM	Disc mass before testing	kg
DOP	Dioctyl phthalate	-
ECE	Economic Commission for Europe	-
EF	Emission factor	-
EN	"European Norm" - European technical standard	-
FA	Vehicle front axle	-
FAF	Front axle brake force distribution	%
FBT	Final brake temperature at the end of the brake event	°C
FCEV	Fuel-cell electric vehicle	-
FCHV	Fuel-cell hybrid vehicle	-
FCV	Fuel-cell vehicle	-
H13	High-efficiency air filter with a filtering efficiency of at least 99.95 per cent	-
HEPA	High-efficiency particulate filter	-
IBT	Initial brake temperature at the start of the brake event	°C
ICE	Internal combustion engine	-
IPDR	Inertial power difference rating	%
IPDW	Inertial power difference work	J/kg
IR	Isokinetic ratio	-
IWR	Inertial work rating	%

Abbreviation	*Definition*	*Unit*
L0-P	Post-style brake fixture with wheel hub connection	-
L0-U	Universal-style brake fixture without wheel hub connection	-
LHC	Left-hand corner of the vehicle	-
MRO	Mass in running order	kg
MVL	Maximum vehicle load	kg
NOVC-FCHV	Not off-vehicle charging fuel cell hybrid electric vehicle	-
NOVC-HEV	Not off-vehicle charging hybrid electric vehicle	-
NOVC-HEV Cat. 0	Not off-vehicle charging hybrid electric vehicle category 0	-
NOVC-HEV Cat. 1	Not off-vehicle charging hybrid electric vehicle category 1	-
NOVC-HEV Cat. 2	Not off-vehicle charging hybrid electric vehicle category 2	-
OD	Disc/drum outer diameter	mm
ODS	Open document spreadsheet	-
OVC-FCHV	Off-vehicle charging fuel cell hybrid electric vehicle	-
OVC-HEV	Off-vehicle charging hybrid electric vehicle	-
PEV	Pure electric vehicle	-
Plane A	Vertical plane aligned with the enclosure’s inlet	-
Plane A_1	Horizontal level aligned with the axis of the brake rotation and the duct axis	-
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	-
Plane C	Vertical plane tangential to the largest brake for approved M_1, N_1 vehicle category, perpendicular to the duct axis	-
Plane D	Vertical plane aligned with the axis of the brake rotation	-
PND1	Primary particle number diluter	-
PND2	Secondary particle number diluter	-
PAO	poly-alpha-olefin	-
PBT	Peak brake temperature of the brake event	°C
PCRF	Particle concentration reduction factor	-
PM	Particulate matter mass	mg
$PM_{2.5}$	Particulate Matter mass for aerosols with aerodynamic diameter below 2.5 µm	mg
$PM_{2.5}$ EF_{ref}	Reference $PM_{2.5}$ emission factor of the tested brake before applying the friction braking share coefficient	mg/km
$PM_{2.5}$ EF	Final $PM_{2.5}$ emission factor	mg/km

Abbreviation	*Definition*	*Unit*
PM_{10}	Particulate Matter mass for aerosols with aerodynamic diameter below 10 µm	mg
PM_{10} EF_{ref}	Reference PM_{10} emission factor of the tested brake before applying the friction braking share coefficient	mg/km
PM_{10} EF	Final PM_{10} emission factor	mg/km
PN	Particle number	#
PNC	Particle number counter	-
PSA	Pad surface area	cm^2
PTFE	Polytetrafluoroethylene	-
PTT	Particle transfer tube	-
RA	Vehicle rear axle	-
RAF	Rear axle brake force distribution	%
REESS	Rechargeable electric energy storage system	-
RH	Relative humidity	%
RHC	Right-hand corner of the vehicle	-
RMSSE	Root mean square speed error	km/h
SH	Specific humidity	mg H_20/kg dry air
SPN10	Solid particle number concentration of particles larger than 10nm	#/cm^3
SPN10 EF_{ref}	Reference SPN10 emission factor of the tested brake before applying the friction braking share coefficient	#/km
SPN10 EF	Final SPN10 emission factor	#/km
SAE	Society of Automotive Engineers	-
SEE	Standard error of estimate	-
ULPA	Ultra-low particulate air	-
VPR	Volatile particle remover	-
WLTP	Worldwide harmonised light vehicle test procedure	-

2.2. Symbols

Table 2 provides a list of the symbols, a short description, and the units of the symbols as applied in this Regulation.

Table 2
Symbols

Symbol	*Definition*	*Unit*
a	Transition angle of the brake enclosure	°
a_1	The minimum distance between the sampling probes	mm

Symbol	*Definition*	*Unit*
a_2	The minimum distance between the sampling probes and the tunnel walls	mm
α	Deceleration	m/s²
α_{ref}	Setpoint acceleration of the test cycle	m/s²
$A_{1...3}$	Metrics for target temperatures	°C
b	Brake index of the brake (FL: front left, FR: front right, RL: rear left, RR: rear right)	-
$B_{1...3}$	Metrics for measured temperatures	°C
$C_{1...3}$	Metrics for the temperature difference between target and measured values	°C
$C_{e,b}$	Torque to power ratio of each brake b converting measured brake power into braking torque	N·m/W
$C_{p,b}$	Torque to pressure ratio of the considered brake b	N·m/kPa
C*	Average by distance brake effectiveness for drum brakes (internal brake factor)	-
c	(Vehicle-specific) friction braking share coefficient	-
c_{alt}	Vehicle-specific friction braking share coefficient measured through the alternative method	-
$c_{trip\#10}$	Vehicle-specific friction braking share coefficient calculated over Trip #10 of the WLTP-Brake cycle	-
c_{decl}	declared individual friction braking share coefficient	
c_{fix}	fixed friction braking share coefficient of Table 4	
c_{ISC}	friction braking share coefficient measured during In-Service Conformity (ISC)	
d	Total distance driven over Trip #10 of the WLTP-Brake cycle or the WLTP-Brake cycle	km
d_i	Sampling tunnel inner diameter	mm
d_n	Sampling nozzle inner diameter (applies to both PN and PM)	mm
$d_{n-PM2.5}$	The inner diameter of the isokinetic nozzle for sampling $PM_{2.5}$	mm
d_{n-PM10}	The inner diameter of the isokinetic nozzle for sampling PM_{10}	mm
$d_{n-SPN10}$	The isokinetic nozzle's inner diameter for SPN10 sampling	mm
d_{piston}	Calliper piston hydraulic diameter	mm
d_p	Sampling probe inner diameter (applies to both PN and PM)	mm
d_s	The inner diameter of the PM sampling line	mm
d_{tl}	The inner diameter of the PN internal transfer line	mm
d_{tt}	The inner diameter of the PN transfer tube	mm
d_x	Electrical mobility diameter	µm
H	Brake calliper or drum efficiency	%

Symbol	*Definition*	*Unit*
f	Brake rotational speed	rev/min
$f_{r\ (dx)}$	PCRF for each particle of electrical mobility diameter d_x	-
$f_{r-SPN10}$	Arithmetic averaged PCRF for the SPN10 measuring device	-
h_B	Length of Plane B (enclosure)	mm
h_D	Length of Plane D (enclosure)	mm
H_e	The point that defines the end of the mandatory horizontal part in the layout	-
H_s	The point that defines the start of the mandatory horizontal part in the layout	-
I_n	Brake nominal inertia	kg·m²
I_t	Brake test inertia	kg·m²
l_{A1}	Length of plane A_1 (enclosure)	mm
l_i	Length of inlet or outlet transition of brake enclosure	mm
l_1	Height of the enclosure at Plane C	mm
l_2	Depth of the enclosure at Plane C	mm
L_0	Length of the straight duct downstream of the outlet of the enclosure	mm
L_1	Minimum length of the straight duct upstream of the inlet of the brake enclosure	mm
L_2	Minimum length of the straight duct from the last disturbance upstream of the sampling plane to the sampling plane	mm
L_3	Minimum length of the straight duct from the sampling plane to the next disturbance downstream of the sampling plane	mm
L_4	Minimum length of the straight duct from the last disturbance upstream of the airflow measurement element to the airflow measurement element	mm
L_5	Minimum length of the straight duct from the airflow measurement element to the next disturbance	mm
μ	Average by distance brake effectiveness for disc brakes (Apparent Friction Coefficient)	-
M_{Mix}	The molar mass of air in the balance room	g/mol
M_{Veh}	Vehicle test mass to simulate on the dynamometer	kg
υ	Kinematic viscosity of air	m^2/s
$N_{in}(d_x)$	Upstream PN concentration for particles of electrical mobility d_x	$\#/cm^3$
$N_{out}(d_x)$	Downstream PN concentration for particles of electrical mobility d_x	$\#/cm^3$
NQ	Average normalised cooling airflow	*N*m³/h
$NQ_{PM2.5}$	Average normalised $PM_{2.5}$ sampling flow	*N*l/min
NQ_{PM10}	Average normalised PM_{10} sampling flow	*N*l/min

Symbol	*Definition*	*Unit*
NQ_{SPN10}	Average normalised SPN10 sampling flow	*N*l/min
NQ_s	Average normalised airflow in the sampling nozzle	*N*m³/h
$\mathrm{N_t}$	Number of time samples t_i captured during the used cycle ($t_i \in [t_{start}, t_{end}]$)	-
$\mathrm{P_b}$	Atmospheric pressure in the balance room	kPa
$\mathrm{p_{brake}}$	Brake pressure	kPa
$\mathrm{P_{brake,b}}$	Friction brake power of brake b	W
$\mathrm{p_{brake,b}}$	Effective brake pressure at brake b, which causes a brake torque	kPa
$\mathrm{p_{meas,b}}$	Measured brake pressure at brake b	kPa
$\mathrm{P_r}$	Particle penetration	%
$p_{threshold}$	Threshold pressure required to develop braking torque	kPa
$p_{threshold,b}$	Threshold pressure of brake b required to develop braking torque	kPa
$P_{e(2.5)}$	$PM_{2.5}$ filter load corrected for buoyancy	mg
$P_{e(10)}$	PM_{10} filter load corrected for buoyancy	mg
$P_{e(Corrected)}$	Buoyancy-corrected filter mass	mg
$P_{e(Uncorrected)}$	Filter mass without buoyancy correction	mg
Q	Average measured (actual) cooling airflow	m^3/h
$\mathrm{Q_{set}}$	Nominal (or set) cooling airflow	m^3/h
$\mathrm{Q_{PM2.5}}$	$PM_{2.5}$ sampling flow (actual)	l/min
$\mathrm{Q_{PM2.5-set}}$	Nominal (or set) $PM_{2.5}$ sampling flow	l/min
$\mathrm{Q_{PM10}}$	PM_{10} sampling flow (actual)	l/min
$\mathrm{Q_{PM10-set}}$	Nominal (or set) PM_{10} sampling flow	l/min
$\mathrm{Q_{SPN10\text{-}set}}$	Nominal (or set) SPN10 sampling flow	
r_b	Bending radius of the cooling air duct	mm
$r_{D,b}$	Dyno roller radius on which the tyre at brake b is rotating	mm
r_{eff}	Brake effective radius	mm
r_P	Bending radius of the sampling probe or sampling line	mm
r_R	Tyre dynamic rolling radius	mm
$r_{R,b}$	Tyre dynamic rolling radius at brake b	mm
$\mathrm{\rho_a}$	Density of air	kg/m^3
$\mathrm{\rho_f}$	The density of PM filter material	kg/m^3
$\mathrm{\rho_w}$	The density of the PM microbalance calibration object	kg/m^3
$\mathrm{SPN_{10\#}}$	Average normalised and PCRF-corrected SPN10 concentration	#/*N*cm^3
$\mathrm{SPN10_{back}}$	Average normalised SPN10 concentration during the background check	#/*N*cm^3

Symbol	*Definition*	*Unit*
$SPN10_b$ EF	Average SPN10 count per unit distance driven during the background check	#/km
S_p	Output signal for cooling air pressure	kPa
S_Q	Output signal for cooling airflow	m^3/h
S_{RH}	Output signal for cooling air relative humidity	%
S_t	Output signal for cooling air temperature	°C
$t_{brake,n}$	Actual total duration of the deceleration event (actual stop duration) of the n^{th} brake event of the analysed cycle	s
$t_{end,nom,n}$	Nominal end time of the n^{th} brake event of the analysed cycle	s
$t_{end,n}$	Actual end time of the n^{th} brake event of the analysed cycle	s
t_i	Time stamp of the i^{th} sample of the measured signals	s
$t_{start,n}$	Actual start time of the n^{th} brake event of the analysed cycle	s
$t_{start,nom,n}$	Nominal start time of the n^{th} brake event of the analysed cycle	s
t_{90}	Response time of particle number counter	s
$\tau_{alt,b}$	Friction brake torque at brake b calculated through the alternative method	N·m
τ_{brake}	Friction brake torque	N·m
$\tau_{brake-avg}$	Time-averaged friction brake torque	N·m
$\tau_{brake,b}$	Friction brake torque at brake b	N·m
τ_{drag}	Brake drag torque	N·m
$\tau_{meas,b}$	Measured friction brake torque at brake b	N·m
T	Cooling air temperature	°C
T_a	Air temperature in the balance room	°C
T_{brake}	Brake (disc/drum) temperature	°C
U	Average cooling airspeed	km/h
$U_{brake,b}$	Voltage applied to the brake b	V
U_s	Average airspeed of air entering the sampling nozzle	km/h
V	Average actual linear speed of the WLTP-Brake cycle	km/h
V_{set}	The average nominal linear speed of the WLTP-Brake cycle	km/h
W_{brake}	Sum of the friction work dissipated in all friction brake systems of the vehicle during all braking events over the tested cycle	J
$W_{brake,b}$	Friction brake work of brake b during all braking events over the tested cycle	J
$w_{f,n}$	Actual specific friction work (mass specific kinetic energy) of the n_{th} brake event of the analysed cycle	J/kg
WL_n	Nominal wheel load without accounting for vehicle road loads or any other type of losses	kg

Symbol	*Definition*	*Unit*
WL_{n-f}	Nominal front wheel load without accounting for vehicle road loads or any other type of losses	kg
WL_{n-r}	Nominal rear wheel load without accounting for vehicle road loads or any other type of losses	kg
WL_{t}	Test wheel load after accounting for vehicle road loads or any other type of losses	kg
WL_{t-f}	Test front wheel load after accounting for vehicle road loads or any other type of losses	kg
WL_{t-r}	Test rear wheel load after accounting for vehicle road loads or any other type of losses	kg
W_{ref}	Normalization reference for the cycle during which the friction work was measured	J
$w_{total,bc}$	Sum of the mass specific kinetic energy variation of the vehicle during all braking events of WLTP-Brake cycle	J/kg
$w_{total,trip10}$	Sum of the mass specific kinetic energy variation of the vehicle during all braking events of Trip #10 of the WLTP-Brake cycle	J/kg
ω_{b}	Measured rotational wheel velocity at brake b	rad/s
$\omega_{D,b}$	Measured rotational velocity of the dyno roller at brake b	rad/s

3. Definitions

For the purposes of this Regulation, the following definitions apply:

3.0. "Vehicle type with regard to brake emissions" means a group of vehicles which do not differ with respect to the criteria as defined in paragraph 7.1.1.

3.0.1. "Approval of a vehicle" means the approval of a vehicle type with regard to the scope of this Regulation.

3.1. Vehicle and Brake Dynamometer Settings

3.1.1. *"Category M_1 vehicle*" means a vehicle used for the carriage of passengers and comprising not more than eight seats in addition to the driver's seat.

3.1.2. "*Category N_1 vehicle*" means a vehicle used for the carriage of goods and having a maximum mass not exceeding 3,500 kg.

3.1.2.1. "*Category N_1 Class III vehicle*" means a vehicle of category N1 whose reference mass, according to paragraph 3.2.37. of UN Regulation n° 154, is greater than 1,760 kg.

3.1.3. "*Category N_2 vehicle*" means a vehicle used for the carriage of goods and having a maximum mass exceeding 3.5 tonnes but not exceeding 12 tonnes.

3.1.4. "*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.

3.1.5. "*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.

3.1.6. "*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.

3.1.7. "*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.

3.1.8. "*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.

3.1.9. "*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:

(a) 37.5 kg, which corresponds to an additional mass of 0.5 passengers for M_1 category vehicles);

(b) 25 kg plus 28 per cent of the Maximum Vehicle Load (MVL) for N_1 and N_2 category vehicles).

3.1.10. "*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 the frictional losses of the drivetrain. In this Regulation, 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 braking emissions testing.

3.1.11. "*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).

3.1.12. "*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.

3.1.13. "*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.

3.1.14. "*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"*.

3.1.15. "*Brake nominal inertia*" means the inertia of the nominal 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.

3.1.16. "*Brake test inertia*" means the inertia of the test 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"*.

3.1.17. "*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, the apparent friction coefficient, and the effective brake radius of the brake corner.

3.1.18. "*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 effectiveness, brake calliper or brake drum efficiency, threshold pressure and the effective brake radius, induces the actual brake torque output.

3.1.19. "*Threshold pressure*" means the minimum hydraulic pressure to overcome the internal friction and seal forces, move the brake calliper's piston or drum's wheel cylinder to contact the brake disc or drum, and initiate brake torque output. A fixed value of 100 kPa shall be used for disc brake and 350 kPa for drum brake applications.

3.1.20. "*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"*.

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

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

3.1.23. "*Brake effectiveness*" means the ratio between the total tangential force and the actuation force between the brake pads and the disc or between the brake shoes and the drum. The brake effectiveness value from the brake under testing is a function of braking torque, hydraulic pressure, effective brake radius, and the piston area. The brake effectiveness is a calculated (mathematical) value and is not directly measurable. Also referred to as "*apparent coefficient of friction*" for disc brakes and as “internal brake factor” for drum brakes.

3.1.24. "*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 to develop the actuation force.

3.1.25. "*Average by time*" means the averaging method applied to a given measurand over a specified brake event. The resultant value yields the same result as the integration between two instances (threshold and end of level reached) divided by the duration between the corresponding points.

3.1.26. "*Average by distance*" means the averaging method for a given measurand during a brake deceleration event where the sampling frequency is a unit of calculated vehicle distance travelled between sampling points. The resultant value yields the same result as the integration between two instances (start and end thresholds) divided by the distance travelled (or driven) during the corresponding elapsed time. During dynamometer testing, the integration of distance is calculated using the difference in brake speed and the elapsed time.

3.1.27. "*Sampling rate*" means the frequency at which the automation system samples various parameters. It represents the number of events that are measured within 1 second for each parameter.

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

3.1.29. "*Slow sampling rate*" means the sampling rate for the data collection system that is less than or equal to 10Hz.

3.1.30. "*Chassis dynamometer*" means a technical system that imposes and controls a drive schedule on a complete vehicle complying with the requirements of UN Regulation No. 154.

3.2. Test setup

3.2.1. "*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.

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

3.2.3. "*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.

3.2.4. "*Pressure sensor*" in the context of Annex 5 of this Regulation means an electromechanical device that is connected to the brake fluid path close to the brake system and provides a signal that is equivalent to the brake pressure at the corresponding brake corner.

3.2.5. "*Torque to Pressure ratio*" is a constant value that converts the brake pressure into braking torque of a friction brake.

3.2.6. "*Torque to Electric Power ratio*" is a transfer function that converts measured electric power into braking torque of an electromechanical friction brake.

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

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

3.2.9. "*Cooling air temperature*" means the temperature of the cooling air stream measured upstream of the brake enclosure.

3.2.10. "*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 upstream of the brake enclosure.

3.2.11. "*Cooling air specific humidity*" represents the amount of water in grams present in one kilogram of dry air. It is measured upstream of the brake enclosure.

3.2.12. "*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.

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

3.2.14. "*Maximum operational flow*" means the maximum cooling airflow that the system can achieve while fulfilling all relevant cooling air conditioning and measurement requirements defined in this Regulation.

3.2.15. "*Minimum operational flow*" means the minimum cooling airflow that the system can achieve while fulfilling all relevant cooling air conditioning and measurement requirements defined in this Regulation.

3.2.16. "*Brake enclosure*" means an aerodynamically designed chamber through which the cooling air enters from one end and exits from the other end. It is an air-tight chamber that prevents untreated air from entering and mixing with the cooling air flowing around the brake assembly. The brake enclosure shrouds the brake assembly.

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

3.3. Brake hardware

3.3.1. "*Brake under testing*" means the friction brake assembly and its associated vehicle parameters used by the testing facility to measure brake particle emissions according to this Regulation. Vehicle parameters include those from the vehicle body, powertrain, and other systems that are required to calculate the share of friction braking.

3.3.2. "*Brake assembly*" in the case of disc brakes means the set of matching brake discs, brake pads, brake calliper, and associated hardware (to mount, secure, and connect the brake assembly onto the brake fixture and the dynamometer) for a given vehicle and axle application. In the case of drum brakes, the hardware set comprises the brake drum, brake shoes, backplate assembly, and associated hardware used (to mount, secure, and connect the brake assembly to the brake fixture and the dynamometer) for a given vehicle and axle application. The brake assembly mounts on a brake fixture to adapt and connect to the brake dynamometer.

3.3.3. "*Service brake*" means the (friction or non-friction) 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).

3.3.4. "*Full-friction brake*" means a service brake mounted on a vehicle that uses only the friction between a brake disc or drum and the mating friction materials.

3.3.5. "*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.

3.3.6. "*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.

3.3.7. "*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.

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

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

3.3.10. "*Cast-iron disc*" means a brake disc manufactured of grey cast iron and having a carbon content between 2.8 per cent and 4.0 per cent.

3.3.11. "*Cast-iron coated disc*" means a brake disc manufactured of a grey cast iron base body and whose friction ring is coated with an abrasion-resistant material.

3.3.12. "*Carbon-ceramic disc*" means a brake disc manufactured of a carbon fibre reinforced ceramic matrix material with or without a ceramic friction layer.

3.3.13. "*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.

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

3.3.15. "*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. Also referred to as "*Drum brake lining*"

3.3.16. "*Friction material identification code*" means the unique code which, at a minimum, includes the pad/shoe manufacturer's trade name or trade mark, and an identification number that relates uniquely to the friction material formulation.

3.3.17. "*Disc or drum identification code*" means the unique code labelled by the manufacturer to identify the specific disc or drum.

3.3.18. "*Original brake parts*" means either an original brake pad, an original brake pad assembly, an original drum brake lining, an original brake drum or an original brake disc.

3.3.18.1. "*Original brake pad*" means a brake pad type referenced in the vehicle type approval documentation according to UN Regulation No. 13, UN Regulation No.13-H, or UN Regulation No. 78.

3.3.18.2. "*Original drum brake lining*" means a drum brake lining conforming to the data attached to a vehicle type approval documentation.

3.3.18.3. "*Original brake disc*" means a brake disc covered by the vehicle braking system type approval according to UN Regulation No. 13, UN Regulation No.13-H, or UN Regulation No. 78.

3.3.18.4. "*Original brake drum*" means a brake drum covered by the vehicle braking system type approval according to UN Regulation No. 13, UN Regulation No.13-H, or UN Regulation No. 78.

3.3.19. Reserved

3.3.20. "*Replacement brake parts*" means either a replacement brake pad assembly type, a replacement drum brake lining type, a replacement brake drum, or a replacement brake disc.

3.3.20.1. "*Original replacement brake pad*" means an original brake pad intended for servicing the vehicle and carrying an identification code affixed in such a way as to be indelible and clearly legible.

3.3.20.2. Reserved

3.3.20.3. "*Original replacement drum brake lining*" means an original brake drum lining intended for servicing the vehicle and carrying an identification code affixed in such a way as to be indelible and clearly legible.

3.3.20.4. Reserved

3.3.20.5. "*Original replacement brake disc*" means an original brake disc intended for servicing the vehicle and carrying an identification code affixed in such a way as to be indelible and clearly legible.

3.3.20.6. Reserved

3.3.20.7. "*Original replacement brake drum*" means an original brake drum intended for servicing the vehicle and carrying an identification code affixed in such a way as to be indelible and clearly legible.

3.3.20.8. Reserved

3.3.20.9. "*Identification code*" identifies the brake discs or brake drums covered by the braking system approval according to UN Regulation No. 13 and UN

Regulation No. 13-H. It contains at least the manufacturer's trade name or trademark and an identification number.

3.3.21. "*Passive brake filter systems*" means the parts which are mounted additionally to the foundation brake system to collect the brake dust particles generated by the friction between the brake disc and the brake pads. No additional energy is required during the usage of the brake filter system.

3.3.22. "*Active brake filter systems*" means components which are connected to the foundation brake system to collect the brake dust particles generated by the friction between the brake disc and the brake pads. Additional energy is required during the usage of the brake filter system within the vehicle and on the brake dynamometer.

3.3.23. "*Brake runout*" means the total lateral displacement of a spot located either 10 mm radially outwards from the centreline of the outboard braking surface of the brake disc or the total radial displacement of a spot located on the centreline of the inner rubbing surface of the brake drum during one complete revolution.

3.3.24. "*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.

3.3.25. "*Brake drag torque*" means the residual torque or rotational resistance that remains in a brake system after the brake has been released or disengaged.

3.3.26. "*Measured brake drag torque*" means the average-by-time brake drag torque determined by applying the measurement method defined in this Regulation.

3.3.27. "*Material formulation of a disc or drum"* means the product of chemical composition, microstructure and mechanical properties.

3.3.28. "*Material formulation of a brake lining or pad"* means the product of a specified mixture of materials and processes which together determine the characteristics of a brake lining.

3.4. WLTP-Brake Cycle

3.4.1. "*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.

3.4.2. "*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.

3.4.3. "*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.

3.4.4. "*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 the "*Cooling adjustment section*".

3.4.5. "*Brake bedding*" means the section with a sequence of brake events to develop a brake 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*".

3.4.6. "*Brake emissions measurement*" means the section of the brake emissions test where PM and PN emissions are sampled and measured. Also referred to as the "*Emissions measurement section*".

3.4.7. "*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.

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

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

3.4.10. "*Nominal brake deceleration event*" means a measurable period during which the nominal linear speed decreases at a known rate to a predetermined release speed during the cycle. The nominal deceleration event is identified using the fast nominal linear speed signal as per paragraph 9.4.3 (h) of Annex 4.

3.4.11. "*Actual 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. The actual brake deceleration event is identified using the fast actual torque signal as per paragraph 13.1. of Annex 4.

3.4.12. "*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 non-friction torque from the electric machine.

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

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

3.4.15. "*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.

3.4.16. "*Actual initial speed*" means the speed of the vehicle at the actual start of a brake deceleration event. It is determined during data evaluation by averaging the fast actual linear speed value from 1.0 s to 0.5 s before the actual brake deceleration event starts.

3.4.17. "*Actual release speed*" means the speed of the vehicle at the actual end of a brake deceleration event. It is determined during data evaluation by averaging the fast actual linear speed value from 0.5 s to 1.0 s after the actual brake deceleration event has ended.

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

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

3.4.20. "*Set vehicle speed*" corresponds to the setpoint of the vehicle speed at a certain time of the test.

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

3.4.22. "*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. It is determined during data evaluation by averaging the actual brake temperature from 1.0 s to 0.5 s before the actual brake deceleration event starts.

3.4.23. "*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. It is determined during data evaluation by averaging the actual brake temperature from 0.5 s to 1.0 s after the actual brake deceleration event has ended.

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

3.4.25. "*Peak brake temperature*" means the highest brake disc or drum temperature measured during a given brake event. It is determined during data evaluation as the maximum of the actual brake temperature during a given actual brake deceleration event.

3.5. PM and PN Measurement

3.5.1. 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.

3.5.2. "*Particle number emissions*" means the number of particles emitted from the brake under testing and quantified according to the dilution, sampling, and measurement methods specified in this Regulation.

3.5.3. Reserved.

3.5.4. Reserved.

3.5.5. "*Solid particle number emissions*" means the number of solid particles emitted from the brake under testing.

3.5.6. "*SPN10*" means the number of solid particles at a nominal particle size of approximately 10 nm electrical mobility diameter and larger emitted from the brake under testing and quantified according to the dilution, sampling, and measurement methods specified in this Regulation.

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

3.5.8. "$PM_{2.5}$ *emissions*" means the PM with an aerodynamic diameter of approximately 2.5 µm or less.

3.5.9. "PM_{10} *emissions*" means the PM with an aerodynamic diameter of approximately 10 µm or less.

3.5.10. "*Sampling plane*" means the fixed plane (perpendicular to the sampling tunnel axis) where the entries of the sampling nozzles are located.

3.5.11. "*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 measurement system.

3.5.12. "*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.

3.5.13. "*Sampling nozzle tip*" means the upstream cross-section of the sampling nozzle where the aerosol enters the sampling nozzle.

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

3.5.15. "*PM separation device*" means a device that separates the relevant portion of PM from the aerosol according to the specifications of this Regulation.

3.5.16. "*Separation efficiency*" means the ratio of particles removed by the separation device to the overall particles entering the separation device at a given aerodynamic diameter.

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

3.5.18. "*Filter holder*" means a device that enables the collection of PM on filters in accordance with the specifications outlined in this Regulation.

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

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

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

3.5.22. "*Sample conditioning system*" means the parts of the PN measurement systems that dilute and condition the aerosol to be provided to the particle number counter to determine SPN10.

3.5.23. "*Particle number counter*" means a device to determine particle number concentration according to the specifications of this Regulation.

3.5.24. "*Standard conditions*" means pressure equal to 101.325 kPa and temperature corresponding to 273.15 K.

3.5.25. "*Isokinetic ratio*" means the ratio of the airspeed in the PM or PN sampling nozzle to the airspeed in the sampling tunnel.

3.5.26. "*Background emissions*" means the measurement of particle number concentrations 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.

3.6. Test system

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

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

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

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

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

3.6.6. "*Response time*" means the difference in time between the change of the component to be measured at the reference point and a measurement system's response of 90 per cent of the final reading (t_{90}) with the sampling nozzle inlet 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 response time consists of the delay time to the system and the rise time of the system.

3.6.7. "*Fall time*" means the difference in time between t_{90} and t_{10}, where the change of the measured component is at the reference point falls from 90 per cent of the initial reading to 10 per cent of the initial reading, if the change of the set signal takes place in less than 0.1 seconds.

3.6.8. "*Drift*" means the change of the measured signal over a defined time period for a specific setpoint due to influences such as temperature, pressure, voltage, current, etc.

3.6.9. "*Accuracy*" means the difference between a measured value and a reference value, traceable to a national standard and describes the correctness of a result.

3.6.10. "*Precision*" means the degree to which repeated measurements under unchanged conditions show the same results. In this Regulation, precision always refers to one standard deviation.

3.7. Non-friction braking

3.7.1. "*Friction braking*" in the context of this Regulation means the deceleration of the vehicle by using the friction braking system where the brake forces are generated by friction between two parts of the vehicle moving relative to one another.

3.7.2. "*Non-friction braking*" in the context of this Regulation means the deceleration of the vehicle also by different technical means without using solely the friction braking system, e.g. such as regenerative braking. It applies to pure electric vehicles and hybrid electric vehicles with a traction REESS nominal voltage greater than 12V.

3.7.3. "*Full-friction braking*" in the context of this Regulation means the deceleration of the vehicle by using only a full-friction brake system.

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

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

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

3.7.7. "*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.

3.7.8. "*Not off-vehicle charging hybrid electric vehicle*" (NOVC-HEV) means a hybrid electric vehicle that cannot be charged from an external source. In this Regulation, NOVC-HEV are categorised to “NOVC-HEV Category 0”, “NOVC-HEV Category 1”, and “NOVC-HEV Category 2” based on their traction REESS nominal voltage.

3.7.8.1. "*Not off-vehicle charging hybrid electric vehicle – Category 0*" (NOVC-HEV Cat. 0) means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 12V and lower than or equal to 20V that cannot be charged from an external source.

3.7.8.2. "*Not off-vehicle charging hybrid electric vehicle – Category 1*" (NOVC-HEV Cat. 1) means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 20V and lower than or equal to 60V that cannot be charged from an external source.

3.7.8.3. "*Not off-vehicle charging hybrid electric vehicle – Category 2*" (NOVC-HEV Cat. 2) means a hybrid electric vehicle that features a traction REESS with a nominal voltage higher than 60V that cannot be charged from an external source.

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

3.7.10. "*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.

3.7.11. "*Fuel-cell*" means an energy converter transforming chemical energy (input) into electrical energy (output) or vice versa.

3.7.11.1. "*Fuel-cell vehicle*" (FCV) means a vehicle equipped with a powertrain containing exclusively fuel cell(s) and electric machine(s) as propulsion energy converter(s).

3.7.11.2. "*Fuel-cell hybrid vehicle*" (FCHV) means a fuel cell vehicle equipped with a powertrain containing at least one fuel storage system and at least one rechargeable electric energy storage system as propulsion energy storage systems.

3.7.11.3. "*Not off-vehicle charging fuel-cell hybrid electric vehicle*" (NOVC-FCHV) means a fuel cell hybrid electric vehicle that cannot be charged from an external source.

3.7.11.4. "*Off-vehicle charging fuel-cell hybrid electric vehicle*" (OVC-FCHV) means a fuel cell hybrid electric vehicle that can be charged from an external source.

3.7.11.5. "*Fuel-cell electric vehicle*" (FCEV) means a vehicle that uses a propulsion system similar to that of electric vehicles where energy stored as hydrogen is converted to electricity by the fuel cell.

3.7.12. "*Pure internal combustion engine vehicle*" (ICE) means a vehicle where all propulsion energy converters are internal combustion engines.

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

3.7.14. "*Brake Corner Emissions Family Parent*" is the configuration with the highest product of WLn* c over all vehicles using a specific brake corner emission family (front or rear axle) as defined in chapter 7.2. of this Regulation.

3.7.15. "*Friction braking share coefficient*" is the ratio of total energy absorbed by the full friction brake system during a drive cycle, to the total kinetic energy variation of the vehicle during braking events (excluding road loads) over the same drive cycle.

3.7.16. "*Vehicle electrification type*" in the context of this Regulation defines the separation of light-duty vehicles based on their electrification concept and architecture.

3.7.17. "*Vehicle model*" in the context of this Regulation means the vehicle’s commercial name(s).

3.7.18. "*Driver-selectable mode*" in the context of this Regulation refers to a distinct driver-selectable condition that can affect the non-friction braking capability of a vehicle.

3.7.19. "Emission-increase *braking function*" in the context of this Regulation means a function with an increasing impact on the level of brake emissions that becomes active for a specific purpose and in response to a specific set of ambient or operating conditions and only remains operational as long as those conditions exist and are not substantially included within type approval testing.

3.7.20. “Interpolation family” in the context of this Regulation has the same meaning of interpolation family as defined in UN Regulation n° 154.

4. Application for approval

4.1. The application for approval of a vehicle type regarding the requirements of this Regulation shall be submitted by the vehicle manufacturer or by their authorized representative, who is any natural or legal person who is duly appointed by the manufacturer to represent them before the approval authority and to act on their behalf in matters covered by this Regulation.

4.1.1. The application referred to in paragraph 4.1. shall be drawn up in accordance with the model of the information document set out in Annex 1 to this Regulation.

4.2. An appropriate number of sets of brake components representative of the vehicle type to be approved shall be submitted to the Technical Service responsible for the approval tests.

4.3. Changes to the make of a system, component or separate technical unit that occur after a type approval shall not automatically invalidate a type approval, unless its original characteristics or technical parameters are changed in such a way that the vehicle brake emissions are adversely affected.

4.4. Documentation Requirements of Braking Functions

The manufacturer shall, at minimum, provide the type approval authority an overview of all the emission-increase braking functions that:

(a) influence the individual recuperation behavior with impact on brake emission; and/or

(b) require active application of the friction partners; and/or

(c) influence the level of brake emissions through an emission control device (e.g. brake emission filter).

The manufacturer may also include a description of braking functions other than those specified above (e.g. functions decreasing brake emissions).

The type approval authority may request the manufacturer to provide further information on specific braking functions included in the documentation.

The manufacturer and the type approval authority shall agree on a format how to provide the information specified in this paragraph.

The documentation provided by the manufacturer shall be approved by the type approval authority as a prerequisite for granting the type approval according to this regulation.

5. Approval

5.1. If the vehicle type submitted for approval meets all the relevant requirements of this Regulation as defined in paragraph 7, in Annex 4 and in Annex 5 if applicable, approval of that vehicle type shall be granted.

5.2. An approval number shall be assigned to each type approved.

5.2.1. The type approval number shall consist of four sections. Each section shall be separated by the '*' character.

Section 1: The capital letter 'E' followed by the distinguishing number of the Contracting Party which has granted the type approval.

Section 2: The number of this UN Regulation, followed by the letter 'R', successively followed by:

(a) Two digits (with leading zeros as applicable) indicating the series of amendments incorporating the technical provisions of the UN

Regulation applied to the approval (00 for the UN Regulation in its original form);

(b) A slash (/) and two digits (with leading zeros as applicable) indicating the number of supplements to the series of amendments applied to the approval (00 for the series of amendments in its original form);

Section 3: A four-digit sequential number (with leading zeros as applicable). The sequence shall start from 0001.

Section 4: A two-digit sequential number (with leading zeros if applicable) to denote the extension. The sequence shall start from 00.

All digits shall be Arabic digits.

5.2.2. Example of an Approval Number to this Regulation:

E1*[179]R01/00*0123*01

The first extension of the Approval numbered 0123, issued by Germany to Series of Amendments 01.

5.2.3. The same Contracting Party shall not assign the same number to another vehicle type.

5.3. Notice of approval or of extension or refusal of approval of a vehicle type pursuant to this Regulation shall be communicated to the Contracting Parties to the 1958 Agreement which apply this Regulation by means of a form conforming to the model in Annex 2 to this Regulation.

6. Markings

6.1. There shall be affixed, conspicuously and in a readily accessible place specified on the approval form, to every vehicle conforming to a vehicle type approved under this Regulation, an international approval mark consisting of:

6.1.1. A circle surrounding the letter "E" followed by the distinguishing number of the country that has granted approval[1].

6.1.2. The number of this Regulation, followed by the letter "R", a dash and the approval number to the right of the circle described in paragraph 6.1.1.

6.2. If the vehicle conforms to a vehicle type approved, under one or more other Regulations annexed to the 1958 Agreement, in the country which has granted approval under this Regulation, the symbol prescribed in paragraphs 6.1.1. and 6.4.1. need not be repeated; in such a case, the Regulation, approval numbers and the additional symbols of all the Regulations under which approval has been granted in the country which has granted approval under this Regulation shall be placed in vertical columns to the right of the symbol prescribed in paragraph 6.1.1.

6.3. The approval mark shall be clearly legible and be indelible.

6.4. The approval mark shall be placed close to or on the vehicle data plate.

6.4.1. Annex 3 to this Regulation gives examples of arrangements of the approval mark.

[8] The distinguishing numbers of the Contracting Parties to the 1958 Agreement are reproduced in Annex 3 to the Consolidated Resolution on the Construction of Vehicles (R.E.3), document ECE/TRANS/WP.29/78/Rev.6 – Annex 3, https://unece.org/transport/standards/transport/vehicle-regulations-wp29/resolutions.

7. General Requirements

Each of the families specified below shall be attributed a unique identifier of the following format:

FT-nnnnnnnnnnnnnnn-WMI

Where:

FT is an identifier of the family type:

(a) FA = front axle brake corner emission family as defined in paragraph 7.2.

(b) RA = rear axle brake corner emission family as defined in paragraph 7.2.

nnnnnnnnnnnnnnn is a string with a maximum of fifteen characters, restricted to using the characters 0-9, A-Z and the underscore character '_'.

WMI (world manufacturer identifier) is a code that identifies the manufacturer in a unique manner defined in ISO 3780:2009.

It is the responsibility of the owner of the WMI to ensure that the combination of the string nnnnnnnnnnnnnnn and the WMI is unique to the family and that the string nnnnnnnnnnnnnnn is unique within that WMI to the approval tests performed to obtain the approval.

7.1. Compliance Requirements

The compliance of a vehicle type shall be evaluated against the emission limits in Table 3.

The compliance shall be demonstrated by using tests of the brake corner emissions family parents of the front and rear axle according to paragraph 8. and paragraphs 7 to 14 of Annex 4.

7.1.1. Vehicle type criteria

Only vehicles having the same combination of brake corner emission families on front and rear axle may be part of the same vehicle type. The exact assignment to the vehicle axles shall be differentiated, e.g. vehicles with front brake A & rear brake B and vehicles with front brake B & rear brake A shall be part of different vehicle types .

Measurement results of individual brake corner emission families may be used for several front and rear corner combinations, e.g. a test result of front brake A may be used in conbination with rear brake B and rear brake C for vehicle types AB and AC, respectively.

Vehicles of different vehicle electrification types among those listed in Table 4 may be part of the same vehicle type, independent of whether they are assigned a fixed factor from Table 4 or a measured factor according to Annex 5.

For vehicles of the same type as defined in paragraph 3.0 , the brake emissions shall be calculated according to eq. 7.1.

7.1.2 A vehicle type is deemed to comply with this regulation if, for every vehicle electrification type and interpolation family, the emissions calculated according to paragraph 7.1.3. for the vehicle with the highest test mass fulfill the limits of Table 3 as represented in Figure 1a.

Figure 1a

Schematic representation of the vehicle configuration selection for the demonstration of the vehicle type compliance

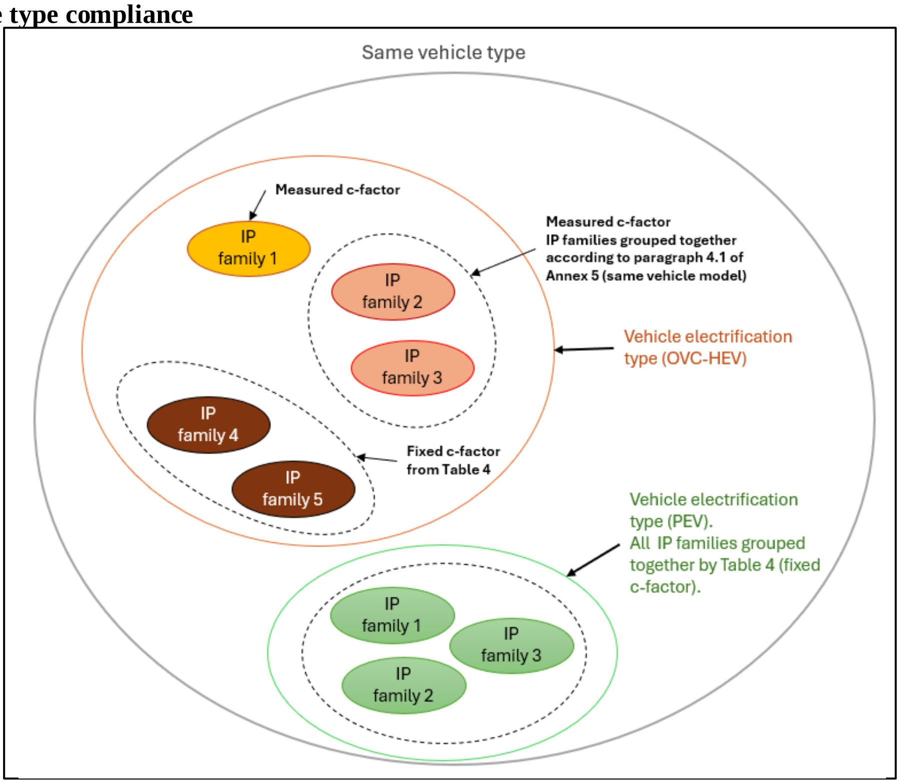


Table 3

Brake particle emission limits in standard driving cycle, by vehicle category and powertrain technology

Emission limits per vehicle	*Vehicles of categories M_1 and N_1, excluding N_1 Class III*				
Powertrain technology	*PEV*	*OVC-HEV*	*NOVC-HEV*	*FCV/FCHV*	*ICEV*
Brake particle emissions (PM_{10}) [mg/km]	3	7	7	7	7
Brake particle emissions (SPN_{10}) [#/km]	Not yet specified				

Emission limits per vehicle	*Vehicles of categories N_1 Class III and N_2*				
Powertrain technology	*PEV*	*OVC-HEV*	*NOVC-HEV*	*FCV/FCHV*	*ICEV*
Brake particle emissions (PM_{10}) [mg/km]	5	11	11	11	11
Brake particle emissions (SPN_{10}) [#/km]	Not yet specified				

7.1.3. Whole vehicle brake emissions

The whole vehicle brake emissions of an individual vehicle shall be calculated according to equation 7.1. where the PM_{10}, $PM_{2.5}$ and SPN10 emissions of the respective axles and brake corners is considered as the product of the reference Emission EF_{ref} by the friction brake coefficient c as defined in Equations 12.9, 12.10 and 12.14 of Annex 4.

$$Emission_{veh} = 2 \cdot EF_{FA} + 2 \cdot EF_{RA} \qquad \text{(Eq. 7.1)}$$

where:

$Emission_{veh}$ is the whole vehicle brake emissions value of the individual vehicle resulting from the emission factors of front and rear axle corners, mg/km or #/km;

$$EF_{FA} = EF_{FA,ref} \cdot \frac{c_{veh} \cdot WL_{veh,FA}}{WL_{FA,ref}} \qquad \text{(Eq. 7.2)}$$

$$EF_{RA} = EF_{RA,ref} \cdot \frac{c_{veh} \cdot WL_{veh,RA}}{WL_{RA,ref}} \qquad \text{(Eq. 7.3)}$$

where:

EF_{FA} is the front axle emission factor of the individual vehicle front axle, mg/km or #/km;

EF_{RA} is the rear axle emission factor of the individual vehicle rear axle, mg/km or #/km;

$EF_{FA,ref}$ is the reference front axle emission factor of front axle Brake Corner Emission Family Parent, mg/km or #/km;

$EF_{RA,ref}$ is the reference rear axle emission factor of real axle Brake Corner Emission Family Parent, mg/km or #/km;

c_{veh} is the friction braking share coefficient of the individual vehicle;

$WL_{veh,FA}$ is the wheel load of front axle of the individual vehicle, kg;

$WL_{FA,ref}$ is the wheel load of front axle Brake Corner Emission Family Parent, kg;

$WL_{veh,RA}$ is the wheel load of rear axle of the individual vehicle, kg;

$WL_{RA,ref}$ is the wheel load of rear axle Brake Corner Emission Family Parent, kg;

To consider the correct vehicle electrification type, either the fixed friction braking share coefficient c_{fix} of Table 4 or the declared individual friction braking share coefficient c_{decl}, based on measurements, according to Annex 5 paragraph 7.1. of this Regulation shall be used for c_{veh}.

7.2. Brake Corner Emissions Family

A brake corner emissions family is defined by a brake assembly considering the calliper, disc or drum-backplate assembly, pad or shoe, and certain other vehicle parameters.

7.2.1. Characteristics of Brake Corner Emissions Families for “Original” and “Original Replacement” Brake Parts and Systems

All vehicle electrification types, independent of their electrification grade, may be part of one brake corner emissions family. Only vehicles that feature an identical brake assembly with respect to the characteristics listed in (a)-(d) may be part of the same brake corner emissions family. This categorization applies to “Original” and “Original Replacement” brakes as defined in paragraphs 3.3.18. and 3.3.20. of this Regulation, respectively.

(a) Type of calliper (floating or fixed calliper, number and size of pistons, type of retraction elements);

(b) Type of brake: disc (friction surface, coating, single, dual, ventilated, solid, dimensions, mass, material formulation) or drum-backplate assembly (friction surface, simplex, duplex, dimensions, mass, material formulation);

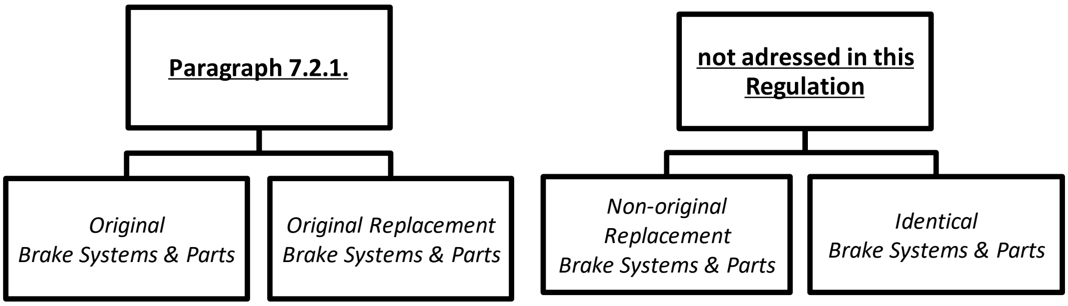
(c) Type of friction material: pad (friction surface size and shape, friction material formulation , backing plate) or shoe (friction surface size and design, friction material formulation, backing plate);

(d) Any other characteristic that has a non-negligible influence on brake emissions (e.g. innovative brake emission reduction systems).

Figure 1b provides a schematic representation of the brake corner emissions family allocation for the different types of brakes as defined in this paragraph.

Figure 1b

Schematic representation of the brake corner emissions family allocation for the different types of brakes



7.2.2. Brake Corner Emissions Family Parent

For all vehicles with an identical brake assembly as described in paragraph 7.2.1., the vehicle with the highest product of friction braking share coefficient (*c-factor* fixed as of Table 4 or vehicle specific as of Annex 5) and test wheel load as defined in paragraph 3.1.14. (WL_t*c) shall be selected as the parent of the brake corner emissions family.

The product of the friction braking share coefficient and test wheel load shall be used only to identify the brake corner emissions family parent and not as input parameter when testing the brake assembly for its emissions.

The friction braking share coefficient for each vehicle electrification type in the scope of this Regulation is given in Table 4. If the product of the test wheel load and the friction braking share coefficient is the same for two or more vehicles of the same brake corner emissions family, the manufacturer shall select the vehicle with the smallest tyre dynamic rolling radius as the brake corner emissions family parent.

At the request of the manufacturer the wheel load of the dedicated brake corner emission family parent may be increased to cover wheel load increases or wheel load uncertainties of future vehicles of the same type or friction braking share coefficient variances. The brake corner shall then be tested on the brake component test stand with this increased wheel load. The test wheel load multiplied by the friction braking share coefficient of any member of the brake corner emissions family shall not be more than 10 % of the original parent product value. This increased value will become the new determining parent product value.

Table 4
Friction braking share coefficients for all vehicle electrification types

Brake type	*Vehicle Electrification Type*	*Friction Braking Share Coefficient (c_{fix})*
Full-friction braking	ICE and other vehicle electrification types not covered in the non-friction braking categories in this Table	1.0
Non-friction braking*	NOVC-HEV Cat. 0 **	0.90
	NOVC-HEV Cat. 1	0.72
	NOVC-HEV Cat. 2	0.52
	OVC-HEV	0.34
	PEV	0.17

**Note*: Testing facilities may use vehicle-specific friction braking share coefficients measured and calculated according to Annex 5 of this Regulation, except for NOVC-HEV Cat. 0.
***Note*: NOVC-FCHV and OVC-FCHV vehicle electrification types shall be considered as NOVC-HEV Cat. 0 for the purpose of this table.

7.2.3. Brake Corner Emissions Family Testing

The brake assembly of original and original replacement brake systems shall be tested on the test stand using the test wheel load, as described in paragraph 8.1. of Annex 4, corresponding to the brake corner emissions family parent.

Original and original replacement brake parts (discs, pads, drums, shoes) shall be tested on the test stand coupled with the corresponding original brake part (e.g. an original brake pad shall be used to test an original replacement brake disc). The test wheel load, as described in paragraph 8.1. of Annex 4, that corresponds to the brake corner emissions family parent shall be applied.

The final brake PM and PN emission factors for the brake corner emissions family parent are calculated after multiplying the reference PM and PN emissions of the tested brake with the friction braking share coefficient of the brake corner emissions family parent vehicle as described in paragraphs 12.1.5. and 12.2.4. of Annex 4, respectively.

7.3. Rounding Requirements

All data must be processed using at least six significant digits. If fewer significant digits are available, data must be processed using all available significant digits. Rounding of intermediate results is not permitted. The final values for a given parameter may be rounded to the number of significant digits necessary to match the number of decimal places defined for the parameter in paragraph 13. of Annex 4. The rounding criteria consider the following:

(a) The resolution of the value cannot exceed its measurement uncertainty;

(b) If there is a set value (e.g., vehicle speed, deceleration rate, event duration), report the actual value with one decimal more than the set value;

(c) If the measurement system is used to evaluate results with a bilateral specification (e.g., ± 1°C, ± 1 kPa), the resolution shall be 1/20 of the specification interval by default or better. In a one-sided specification (e.g., ≤ 3 % speed violations), the resolution shall be less than 1/10 of the specification interval or better;

(d) Report values derived from a calculation (e.g., particle background, emission factors, averages) with one additional decimal place to the values from items (a) and (b) from this paragraph.

7.4. Signal filtering Requirements

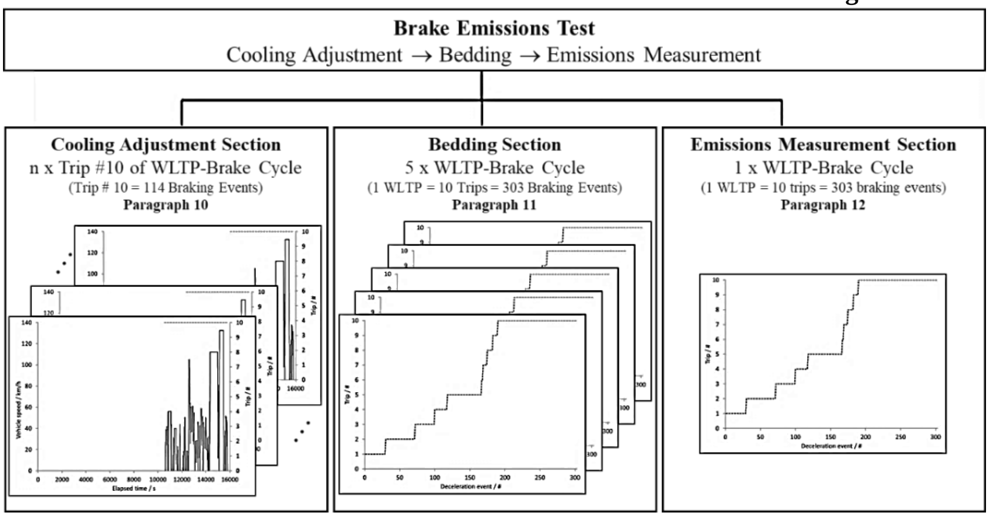
Data acquisition, data recording and every evaluation step performing down sampling to a lower acquisition/recording frequency require signal filtering to fulfil Nyquist-Shannon sampling theorem. A second order filter with a cut-off frequency between 25% and 50% of the lower sampling/recording frequency is considered to fulfil this criterion and avoids unintended smoothing of the signal.

8. General Overview

8.1. Test sections

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 2 provides a schematic overview of a brake emissions test.

Figure 2
Structure of the brake emissions tests for vehicles with full-friction braking



The three sections of the brake emissions test are:

(a) Brake cooling adjustment. This section uses Trip #10 of the WLTP-Brake cycle. The cooling adjustment section is described in detail in paragraph 10. of Annex 4;

(b) Brake bedding. This section includes the execution of five repetitions of the WLTP-Brake cycle. It is carried out with new brake parts. The bedding section is described in detail in paragraph 11. of Annex 4;

(c) Brake emissions measurement. This section includes the execution of one WLTP-Brake cycle. The emissions measurement section is described in detail in paragraph 12. of Annex 4.

8.2. Test execution steps

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

(a) Ensure the test system meets the requirements defined in paragraph 7. of Annex 4 regarding the system layout, cooling airflow, temperature and humidity control, brake dynamometer capabilities, brake enclosure design, sampling tunnel design, and sampling plane design;

(b) Meet all requirements defined in paragraph 8. of Annex 4 for test preparation involving the calculation and application of the correct input parameters, test setup, measurement of brake temperature, and brake positioning in the enclosure;

(c) Be capable of executing the WLTP-Brake cycle per paragraph 9. of Annex 4 and demonstrate compliance with the quality checks;

(d) Perform the brake cooling adjustment section as defined in paragraph 10. of Annex 4;

(e) Perform the brake bedding section as defined in paragraph 11. of Annex 4;

(f) Execute all items from paragraph 12. of Annex 4 for the brake emissions measurement, including particulate matter mass, particle number, and mass loss of the wearable brake hardware;

(g) Report the results of the test following paragraph 13. of Annex 4;

(h) Comply with paragraph 14. of Annex 4 for minimum calibration requirements and periodic evaluations of the used instrumentation and setup.

9. Modification and extension of the type approval

9.1. Every modification of the vehicle type with regard to brake emissions and any inclusion of a new vehicle electrification type or interpolation family to an existing approval shall be notified to the Type Approval Authority that approved the vehicle type. The Type Approval Authority may then either:

9.1.1. Consider that the modifications made are contained within the brake corner emission families covered by the approval or are unlikely to have an appreciable adverse effect on the Type Approval values and that, in this case, the original approval will be valid for the modified vehicle type; or

9.1.2. Require a further test report from the Technical Service responsible for conducting the tests.

9.1.3. In the case of inclusion of a new vehicle electrification type or interpolation family, a demonstration of compliance according to paragraph. 7.1.2. shall be provided and reported according to Appendix 3 of Annex 1.

9.2. Confirmation or refusal of approval, specifying the alterations, shall be communicated by the procedure specified in paragraph 5.3. to the Contracting Parties to the Agreement which apply this Regulation.

9.3. The Type Approval Authority issuing the extension of approval shall assign a series number to the extension and inform thereof the other Contracting Parties to the 1958 Agreement applying this Regulation by means of a communication form conforming to the model in Annex 2 to this Regulation.

9.4. Extension of an approval

An existing type approval may be extended e.g. by adding new vehicle models to it. The added vehicles must also fulfil the requirements of paragraph 9.1. This may require further verification by the Type Approval Authority (e.g. when different friction braking share coefficients apply).

10. Conformity of production (CoP)

The conformity of production procedures shall comply with those set out in the 1958 Agreement, Schedule 1 (E/ECE/324-E/ECE/TRANS/505/Rev.3), with the following requirements:

For the purposes of the manufacturer's conformity of production check on brake systems, brake corner emission family samples shall be taken from the production series according to paragraph 10.1 and tested according to paragraph 10.2. The conformity of the vehicle type shall then be evaluated according to paragraph 10.3.

10.1. CoP test frequency of brake emission testing on component testbed

Once every 12 months one CoP verification check shall be performed according to the following steps and the statistical procedure described in paragraph 10.4:

(a) once every 12 months at least one and not more than four samples of each brake corner emission family (front and rear) shall be randomly chosen and tested with the family parent setting as during type approval over the WLTP-Brake cycle on a component test bench;

(b) once every 12 months at least one and not more than four CoP assessments shall be made according to paragraph 10.3 and considering the brake corner emissions from point a) for the combination of front and rear axles.

For the purpose of paragraph 10.3., the emissions results of front and rear brake components sampled and tested according to point a) may be used for 12 months in different combinations for several vehicle types.

10.2. Measurement of brake emissions on component testbed

CoP tests of the brake corner emission family parents (defined during type approval) shall be executed on a component test bench under full friction braking conditions, measuring PM_{10} and SPN10 emissions. CoP tests shall be carried out according to the following steps of the type approval test procedure, but adding two more repetitions of the emission measurements after bedding to reduce measurement uncertainties and laboratory to laboratory variabilities:

(a) Cooling adjustment section according to type approval data of brake corner emission family parent, during CoP no change of brake components between “Cooling adjustment section” and “Bedding section”;

(b) Bedding section (5 x WLTP-Brake Cycle);

(c) Emissions Measurements section (3 x WLTP-Brake Cycle).

After the completion of all three emission tests, the PM_{10} results of each brake corner emission family parent shall be arithmetically averaged, and these results shall be used for the COP assessment described in paragraph 10.3.

SPN10 results of the three emission tests shall be measured for reporting purposes only until a limit is introduced.

10.3. CoP assessment

The production shall be deemed to conform if the verification procedure described in paragraph 7.1.2. is successfully completed considering the reference emission factors of the brake corner emission family parents of front and rear axle measured in paragraph 10.2.

If the above mentioned verification fails, , another sample of both brake corner emission families in question shall be randomly chosen and tested in the same condition as indicated in paragraph 10.1 a) and a new verification procedure as described above will be completed considering this new sample, whose result will be incorporated in the statistical procedure described in paragraph10.4.

10.4. Statistical evaluation of CoP samples

The decision depends on the cumulative sample size 'n', the passed and failed result counts 'p' and 'f', respectively. The samples shall be from different batches. For the decision on a pass/fail of a verification sample the decision chart in Table 5a shall be used. The chart indicates the decision to be taken for a given cumulative sample size 'n' and failed count result 'f'.

Two decisions are possible for a statistical procedure for the vehicle type and its whole vehicle brake emissions value (for both brake families Front and Rear):

(a) ‘Sample pass’ outcome shall be reached when the decision chart from Table 5a gives a "PASS" outcome for the current cumulative sample size 'n' and the count of failed results 'f';

(b) ‘Sample fail’ decision shall be reached when, for a given cumulative sample size 'n', when the applicable decision chart from Table 5a gives a "FAIL" decision for the current cumulative sample size 'n' and the count of failed results 'f'.

If no decision is reached ('UND' = undecided), the statistical procedure shall remain open and further results shall be incorporated into it, until a decision is reached.

For phase I, until 31 December 2029, only PM10 shall be evaluated according to Table 5a. Where CoP tests are performed by the Approval Authority, in case of n=2 and f=2, the approval authority shall test the next samples in a different testing facility. On request of the manufacturer and in agreement with the Approval Authority, in case of n=2 and f=2, the remaining tests shall be carried out in the same facility as used for the type approval under supervision of the technical service or type approval authority.

Table 5a
Decision chart for pass/fail verification

Failed result count f	3			FAIL	FAIL
	2		UND	UND	PASS
	1	UND	PASS	PASS	PASS
	0	PASS	PASS	PASS	PASS
		1	2	3	4
			n		

n = cumulative sample Size (combination of front and rear brake components = “whole vehicle brake emission”)

From 1st January 2030, PM_{10} and SPN10 shall be evaluated according to Table 5b. During Phase II, in case the PM_{10} emissions of a sample n exceeds the regulatory limit by more than 2.0 mg/km, the CoP assessment shall fail without the need for a further sampling and testing.

Table 5b
Decision chart for pass/fail verification

[Reserved]

11. Penalties for non-conformity of production

11.1. The approval granted in respect of a vehicle type pursuant to this Regulation, may be withdrawn if the requirements described in paragraph 10. of this Regulation are not complied with.

11.2. If a Contracting Party to the 1958 Agreement which applies this Regulation withdraws an approval it has previously granted, it shall forthwith so notify the other Contracting Parties applying this Regulation, by means of a communication form conforming to the model in Annex 2 to this Regulation.

12. Production definitively discontinued

12.1. If the holder of the approval completely ceases to manufacture a type of vehicle approved in accordance with this Regulation, they shall so inform the Type-Approval Authority which granted the approval. Upon receiving the relevant communication, that Authority shall inform thereof the other Contracting Parties to the 1958 Agreement applying this Regulation by means of copies of the communication form conforming to the model in Annex 2 to this Regulation.

13. Names and addresses of the Technical Services responsible for conducting approval tests and of Type Approval Authorities

13.1. The Contracting Parties to the 1958 Agreement which apply this Regulation shall communicate to the United Nations Secretariat the names and addresses of the Technical Services responsible for conducting approval tests and of the Type Approval Authorities which grant approval and to which forms certifying approval or extension or refusal or withdrawal of approval, issued in other countries, are to be sent.

14. Special provisions

14.1. Provisions for special purpose vehicles

14.1.1. Provisions for armoured vehicles

The type approval authority may grant type-approvals including exemption(s) to requirements of this regulation to armoured vehicles in accordance with paragraph 2.5.2. of the Consolidated Resolution on the Construction of Vehicles (R.E.3), if the manufacturer demonstrates that the vehicle cannot meet the requirements due to its special purpose.

14.2 The type of special purpose vehicle and the exemptions granted are to be described in the type-approval certificate in accordance with Annex 2 to this regulation.

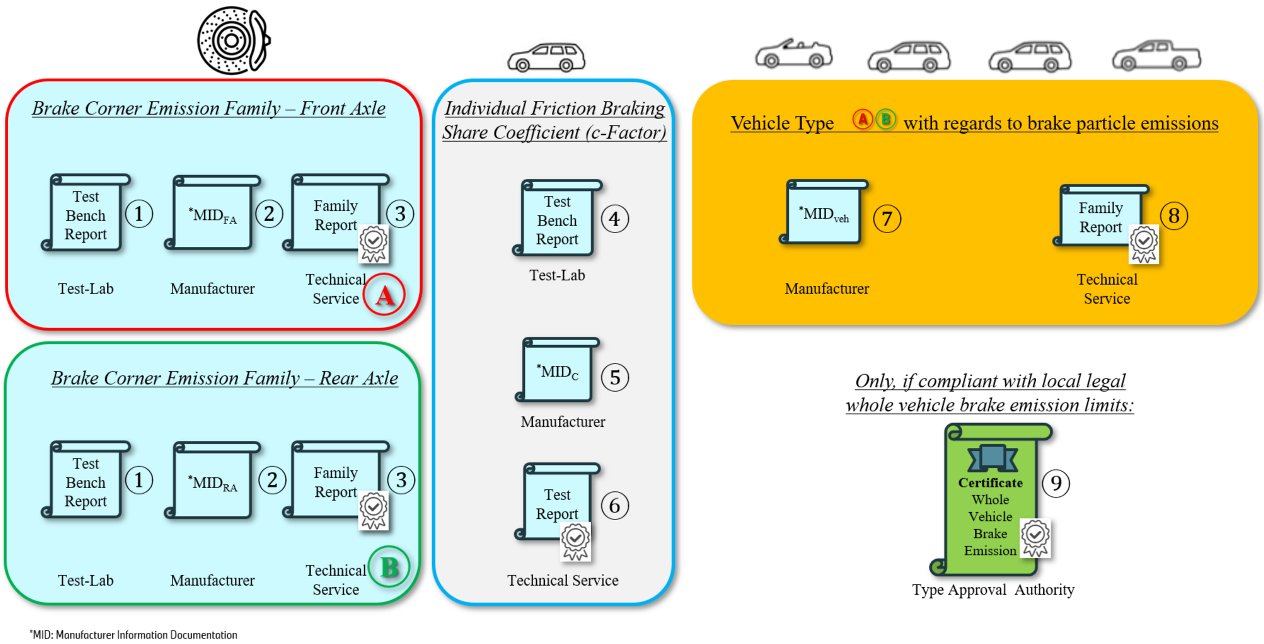
Annex 1

Information Documentation

Figure A1/1

Overview of the different reports during brake emission approval

for reference and orientation only



Input Parameters

The parameters in the information document must be specified using the appropriate units and number of decimal places in accordance with Table 1.

Table 1

Information Document parameters

Paragraph	*Parameters*	*Unit*	*Decim.*
8.13.4.1.1.1.	Brake force distribution	%	1
8.13.4.2.2.	Brake particle emissions	mg/km	3
8.13.4.2.1.	friction braking share coefficient	-	2
8.13.2.4.2.	Diameter of disc	mm	0
8.13.3.5.	Diameter of Drum	mm	0
8.13.2.6.5.	Diameter of piston	mm	2
8.13.2.4.1.	Mass of disc	g	0
8.13.3.4.	Mass of drum	g	0
8.13.4.1.1.2	Nominal wheel load	kg	3
8.13.2.6.4.	Number of pistons - calliper	-	0

8.13.2.7.3.	Size of brake pad	cm²	1
8.13.3.7.4.	Size of brake shoe	cm²	1
8.13.2.4.3.	Thickness of disc	mm	0

Information Documentation

Report ⑦ in Figure A1/1 of this Regulation.

MODEL INFORMATION DOCUMENT No …

0 GENERAL

0.1. Make (trade name of manufacturer): …

0.2. Type: …

0.2.1. Commercial name(s) (if available): …

0.2.3. Family identifiers:

0.2.3.14. Vehicle Type with Regard to Brake Emissions: …

0.2.3.15. Brake Corner Emission Family(s) front axle: …

0.2.3.16. Brake Corner Emission Family(s) rear axle: …

0.2.3.17. Friction braking share coefficient (s) (fixed or report ID)…

0.4. Category of vehicle (c): …

0.4.1. Vehicle electrification type(s) (ICE, NOVC-FCHV, OVC-FCHV, PEV, FCEV):...

0.5 Name and address of the manufacturer

0.8. Name(s) and address(es) of assembly plant(s): …

0.9. Name and address of the manufacturer's representative (if any): …

1 GENERAL CONSTRUCTION CHARACTERISTICS

1.1. Photographs and/or drawings of a representative vehicle/ component/separate technical unit (1): …

1.3. Number of wheels: …

1.3.3. Powered axles (number, position, interconnection): …

2 MASSES AND DIMENSIONS (f) (g) (7)

(in kg and mm) (Refer to drawing where applicable)

2.6. Mass in running order (h)

(a) maximum and minimum for each variant: …

2.6.1. Distribution of this mass among the axles (max. and min. for each variant): …

2.6.3. Rotational mass: 3 % of the sum of mass in running order and 25 kg or value, per axle (kg): …

2.8. Technically permissible maximum laden mass stated by the manufacturer (i) (3): …

3 PROPULSION ENERGY CONVERTER (k) (repeat as applicable for each electrification type)

3.1. Manufacturer of the propulsion energy converter(s): …

3.1.1. Manufacturer's code (as marked on the propulsion energy converter or other means of identification): …

3.2. Internal combustion engine

3.2.1.1. Working principle: positive ignition/compression ignition/ dual fuel (1)

Cycle: four stroke/two stroke/rotary (1)

3.2.1.2. Number and arrangement of cylinders: …

3.2.1.3. Engine capacity (m): … cm3

3.2.1.4. Volumetric compression ratio (2): …

3.2.1.8. Rated engine power (n): … kW at … min–1 (manufacturer's declared value)

3.2.1.10. Maximum net torque (n): … Nm at … min–1 (manufacturer's declared value)

3.2.2. Fuel

3.2.2.1. Diesel/Petrol/LPG/NG or Biomethane/Ethanol (E 85)/ Biodiesel/Hydrogen (1), (6)

3.2.4.3.4.1. Make and type of the control unit (ECU): …

3.2.4.3.4.1.1. Software version of the ECU: …

3.3. Electric powertrain (for PEV only)

3.3.1. General description of electric power train

3.3.1.1. Make: …

3.3.1.2. Type: …

3.3.1.3. Use (1): Monomotor/multimotors (number): …

3.3.1.4. Transmission arrangement: parallel/transaxial/others, to precise: …

3.3.1.5. Test voltage: … V

3.3.1.6. Motor nominal speed: … min–1

3.3.1.9. Maximum power: … kW

3.3.2. Traction REESS

3.3.2.1. Trade name and mark of the REESS: …

3.3.2.2. Kind of electro-chemical couple: …

3.3.2.3. Nominal voltage: … V

3.3.2.5.1. REESS energy: … kWh

3.3.2.5.2. REESS capacity: … Ah in 2 h

3.3.2.5.3. End of discharge voltage value: … V

3.3.2.8. Number of cells:……

3.3.2.11. Battery management system control unit

3.3.2.11.1. Make: ………..

3.3.2.11.2. Type: …….

3.3.2.11.3. Identification number: …..

3.3.3. Electric Motor

3.3.3.1. Working principle:

3.3.3.1.1. direct current/alternating current (1) /number of phases: ……………………..

3.3.3.1.2. separate excitation/series/compound (1)

3.3.3.1.3. synchronous/asynchronous (1)

3.3.3.1.4. coiled rotor/with permanent magnets/with housing (1)

3.3.3.1.5. number of poles of the motor: ……………………..

3.3.3.2. Inertia mass: ……………………..

3.3.4. Power controller

3.3.4.1. Make: ……………………..

3.3.4.2. Type: ……………………..

3.3.4.2.1. Identification number: …..

3.3.4.3. Control principle: vectorial/open loop/closed/other (to be specified): (1)

……………………..

3.4. Combinations of propulsion energy converters

3.4.1. Hybrid electric vehicle: yes/no (1)

3.4.2. Category of hybrid electric vehicle: Off-Vehicle Charging OVC) /Not Off-Vehicle Charging (NOVC): (1)

3.4.3. Operating mode switch: with/without (1)

3.4.3.1. Selectable modes

3.4.3.1.1. Pure electric: yes/no (1)

3.4.3.1.2. Pure fuel consuming: yes/no (1)

3.4.3.1.3. Hybrid modes: yes/no (1)

(if yes, short description): …

3.4.4. Description of the energy storage device: (REESS, capacitor, flywheel/generator)

3.4.4.1. Make(s): …

3.4.4.2. Type(s): …

3.4.4.3. Identification number: …

3.4.4.4. Kind of electrochemical couple: …

3.4.4.5. Energy: … (for REESS: voltage and capacity Ah in 2 h, for capacitor: J, …)

3.4.4.6. Charger: on board/external/without (1)

3.4.4.8. Battery management system control unit

3.4.4.8.1. Make: ………..

3.4.4.8.2. Type: …….

3.4.4.8.3. Identification number: …..

3.4.5. Electric machine (describe each type of electric machine separately)

3.4.5.1. Make: …

3.4.5.2. Type: …

3.4.5.3. Primary use: traction motor/generator (1)

3.4.5.3.1. When used as traction motor: single-/multimotors (number) (1): …

3.4.5.4. Maximum power: … kW

3.4.5.5. Working principle

3.4.5.5.5.1 Direct current/alternating current/number of phases: …

3.4.5.5.2. Separate excitation/series/compound (1)

3.4.5.5.3. Synchronous/asynchronous (1)

3.4.6. Control unit

3.4.6.1. Make(s): …

3.4.6.2. Type(s): …

3.4.6.3. Identification number: …

3.4.7. Power controller

3.4.7.1. Make: …

3.4.7.2. Type: …

3.4.7.3. Identification number: …

3.4.10. FCHV: yes/no (1)

3.4.10.1. Type of Fuel Cell

3.4.10.1.2. Make: …

3.4.10.1.3. Type: …

3.4.10.1.4. Nominal Voltage (V): …

3.4.10.2. System description (working principle of the fuel cell, drawing, etc.): …

3.4.11. Electric energy converters

3.4.11.1. Electric energy converter between the electric machine and traction REESS

3.4.11.1.1. Make: ……………………..

3.4.11.1.2. Type: ……………………..

3.4.11.1.3. Declared nominal power: W

3.4.11.2. Electric energy converter between the traction REESS and low voltage power supply

3.4.11.2.1. Make: ……………………..

3.4.11.2.2. Type: ……………………..

3.4.11.2.3. Declared nominal power: W

3.4.11.3. Electric energy converter between the recharge-plug-in and traction REESS

3.4.11.3.1. Make: ……………………..

3.4.11.3.2. Type: ……………………..

3.4.11.3.3. Declared nominal power: W

4 TRANSMISSION (p)

4.4. Clutch(es)

4.4.1. Type: …

4.5. Gearbox

4.5.1. Type (manual/automatic/CVT (continuously variable trans- mission)) (1)

4.5.1.5. Number of clutches: …

4.6. Gear ratios

Gear Internal gearbox ratios (ratios of engine to gearbox output shaft revolutions)

Final drive ratio(s) (ratio of gearbox output shaft to driven wheel revolutions)

Total gear ratios

Maximum for CVT 1

2

3

…

Minimum for CVT

4.6.1 Gearshift (not applicable in case of automatic transmission)

4.6.1.1. Gear 1 excluded: yes/no (1)

4.6.1.2. n_95_high for each gear: … min–1

4.6.1.3. nmin_drive

4.6.1.3.1. 1st gear: … min–1

4.6.1.3.2. 1st gear to 2nd: … min–1

4.6.1.3.3. 2nd gear to standstill: … min–1

4.6.1.3.4. 2nd gear: … min–1

4.6.1.3.5. 3rd gear and beyond: … min–1

4.6.1.4. n_min_drive_set for acceleration/constant speed phases (n_min_drive_up): … min–1

4.6.1.5. n_min_drive_set for deceleration phases (nmin_drive_down):

4.6.1.6. initial period of time

4.6.1.6.1. t_start_phase: … s

4.6.1.6.2. n_min_drive_start: … min–1

4.6.1.6.3. n_min_drive_up_start: … min–1

4.6.1.7. use of ASM: yes/no (1)

4.6.1.7.1. ASM values: … at … min–1

4.7. Maximum vehicle design speed (in km/h) (q): …

6 SUSPENSION

6.6. Tyres and wheels

6.6.1. Tyre/wheel combination(s)

6.6.1.1. Axles

6.6.1.1.1. Axle 1: …

6.6.1.1.1.1. Tyre size designation

6.6.1.1.2. Axle 2: …

6.6.1.1.2.1. Tyre size designation etc.

6.6.2. Upper and lower limits of rolling radii

6.6.2.1. Axle 1: …

6.6.2.2. Axle 2: …

6.6.3. Tyre pressure(s) as recommended by the vehicle manufacturer: … kPa

8.13. FRICTION BRAKE

8.13.1. Brake system assembly

8.13.1.1. Type of brake system assembly (Brake Corner Emission Family(s) front axle and rear axle in combination with friction braking share coefficient) …

8.13.1.2. Front axle disc/ drum

8.13.1.3. Rear axle disc/drum

8.13.2. Disc(s)

8.13.2.1. Type of disc(s) (identification) …

8.13.2.2.	Construction of disc(s) (solid, ventilated \ single, dual) …
8.13.2.3	Make of disc(s) …
8.13.2.4.	Mass and dimension of disc(s)
8.13.2.4.1.	Mass of disc(s) [g]…
8.13.2.4.2.	Diameter of disc(s) [mm]…
8.13.2.4.3.	Thickness of disc(s) [mm]…
8.13.2.5.	Friction surface of disc(s)
8.13.2.5.1.	Material formulation of friction surface(s) (e.g. material code) …
8.13.2.5.2.	Coating (yes/no)…
8.13.2.5.2.1.	Type of coating…
8.13.2.6.	Calliper(s)
8.13.2.6.1.	Type of calliper(s) (identification)…
8.13.2.6.2.	Construction of calliper(s) (floating or fixed)…
8.13.2.6.3.	Make of calliper(s)…
8.13.2.6.4.	Number of pistons…
8.13.2.6.5.	Diameter of pistons…
8.13.2.6.6.	Type of retraction elements…
8.13.2.7.	Brake pad(s)
8.13.2.7.1.	Type of brake pad(s) (identification) …
8.13.2.7.2.	Make of brake pad(s) …
8.13.2.7.3.	Size of brake pad(s) [cm^2] …
8.13.2.7.4.	Shape of brake pad(s) (e.g. drawing) …
8.13.2.7.5.	Friction surface of brake pad(s)
8.13.2.7.6.	Material formulation of brake pad(s) (e.g. material code) …
8.13.2.7.7.	Backing plate ...
8.13.3.	Brake Drum(s)
8.13.3.1.	Type of drum(s) (identification)…
8.13.3.2.	Construction of drum(s) (simplex or duplex)…
8.13.3.3.	Make of drum(s) …
8.13.3.4.	Mass of drum(s) [g] …
8.13.3.5.	Diameter of Drum [mm] …
8.13.3.6.	Friction surface of drum(s)
8.13.3.6.1.	Material formulation of drum(s) (e.g. material code) …
8.13.3.7.	Brake shoe(s)
8.13.3.7.1.	Type of brake shoe(s) (identification) …
8.13.3.7.2.	Construction of brake shoe(s) …
8.13.3.7.3.	Make of brake shoe(s) …
8.13.3.7.4.	Size of brake shoe(s) [cm^2] …
8.13.3.7.5.	Design of brake shoe(s) (e.g. drawing)…
8.13.3.7.6.	Friction surface of brake shoe(s)
8.13.3.7.7.	Material formulation of brake shoe(s) (e.g. material code) …

8.13.3.7.8. Backing plate …

8.13.4. Manufacturer declared values

8.13.4.1. Test parameters

8.13.4.1.1. Test parameter brake particle emission test (for each Brake Corner Emission Family)

8.13.4.1.1.1. Brake force distribution…

8.13.4.1.1.2. Nominal wheel load…

8.13.4.1.2. Test vehicle parameters for the friction braking share coefficient measurement (if applicable).

Vehicle	*Test Vehicle*	*V representative (only for road load matrix family (*)*	*Default values*
Vehicle bodywork type			
Road load method used (measurement or calculation by road load family)		—	
Tyres make and type, if measurement			
Tyre dimensions (front/rear), if measurement			
Tyre rolling resistance (front/rear) (kg/ t)			
Tyre pressure (front/rear) (kPa), if measurement			
Vehicle test mass (kg)			
Mass in running order (kg)		—	—
Technically permissible maximum laden mass (kg)		—	—
f_0 (N)			
f_1 (N/(km/h))			
f_2 (N/(km/h)^2)			
Frontal area m^2 (0.000 m^2)	—		
Cycle Energy Demand (J)			

8.13.4.2. Manufacturer declared value(s)

8.13.4.2.1 Manufacturer declared value for friction braking share coefficient (if applicable) …

8.13.4.2.2 Manufacturer declared value for brake particle emissions …

12. MISCELLANEOUS

12.10. Devices or systems with driver selectable modes which influence CO2 emissions, fuel consumption, electric energy consumption and/or criteria emissions and do not have a predominant mode: yes/no (1)

12.10.4. c-factor test (if applicable) (state for each device or system)

12.10.4.1. Worst case mode: ………(reference to document for specific braking functions with impact on friction braking share coefficient)

Annex 1 - Appendix 1

Brake Corner Emission Family Test Report (repeat for the front and rear axle)

Report ③in Figure A1/1 of this Regulation.

Family identifier(s) :
Manufacturer :

Brake Corner Emission Family Test Report

UN Regulation No [179]

As last amended by:

Applicant	:	
Manufacturer	:	
Subject	:	
Brake Corner Emission Family identifier(s)	:	
Test ID	:	

Family identifier(s) :
Manufacturer :

General		
Vehicle test mass [kg]	:	
Friction braking share coefficient	:	
Axle	:	
Brake orientation	:	
Brake force distribution [%]	:	
Fixture style	:	
Disc or drum identification code	:	
Friction material identification code	:	
Nominal wheel load [kg]	:	
Test (or applied) wheel load [kg]	:	
Tyre dynamic rolling radius [mm]	:	
Brake effective radius [mm]	:	
Brake nominal inertia [kgm²]	:	
Brake Test (or applied) inertia [kgm²]	:	
Disc/Drum outer diameter [mm]	:	
Disc mass [kg]	:	
WL_{n-f} / DM ratio [--]	:	
Number of pistons per side	:	
Piston mean (or hydraulic) diameter [mm]	:	
Calliper mounting position	:	
Calliper to fixture bolt tightening torque [Nm]	:	
Disc or drum to hub bolt tightening torque [Nm]	:	
Brake calliper or brake drum efficiency [%]	:	

Family identifier(s) :
Manufacturer :

Threshold pressure [kPa]	:	
Brake runout actual value [µm]	:	
System leak check		
Average airflow fulfils requirements set out in this Regulation	:	

Brake dynamometer and automation system		
Measurement equipment fulfils the requirements of paragraph 7 of Annex 4 of this Regulation	:	

Brake enclosure design		
Reynolds number at the entrance of the enclosure [--]	:	
The airspeed at each position of the plane C used for the speed uniformity verification does not vary by more than ±35 per cent of the arithmetic mean of all measurements for the setup's minimum operational airflow	:	
The airspeed at each position of the plane C used for the speed uniformity verification does not vary by more than ±20 per cent of the arithmetic mean of all measurements for the setup's maximum operational airflow	:	
The brake enclosure design fulfils the specifications of paragraph 7.4.2. (a) - (i) of Annex 4 to this Regulation	:	

Brake assembly		
Test conditions acc. paragraph 8. of Annex 4 to this Regulation are fulfilled	:	
Brake rotation	:	
The tested brake disc or drum rotates in the direction of the evacuation	:	

Family identifier(s) :
Manufacturer :

Initial temperature		
Requirements for testing are fulfilled	:	

WLTP-Brake cycle interruptions		
Occurrence	:	
All necessary steps were taken in accordance with the specifications defined in paragraphs 9.3.1. - 9.3.3. of Annex 4 of this Regulation	:	

Average Cooling Air				
		Section		
		Cooling adjustment	Bedding	Emissions measurement
Cycle	[--]	1	1...5	1
Average cooling air temperature1)	[°C]			
Instantaneous violations1)	[%]			
Average cooling air relative humidity1)	[%]			
Instantaneous violations1)	[%]			
Average cooling air specific humidity1)	[mg H20/g] (dry air)			

1) Evidence of fulfilment of all specifications according to this Regulation is verified

Family identifier(s) :
Manufacturer :

Cooling Airflow				
		Section		
		Cooling adjustment	Bedding	Emissions measurement
Cycle	[--]	1	1...5	1
Nominal (or set) airflow1)	[m³/h]			
Average airflow1)	[m³/h]			
Difference with the nominal airflow1)	[%]			
Average normalized airflow1)	[*N*m³/h]			
Instantaneous airflow violations1)	[%]		--	

1) Evidence of fulfilment of all specifications according to this Regulation is verified

Speed violations				
		Section		
		Cooling adjustment	Bedding	Emissions measurement
Cycle	[--]	1	1...5	1
Speed violations1)	[%]			

1) Evidence of fulfilment of all specifications according to this Regulation is verified

Family identifier(s) :
Manufacturer :

Number of decelerations		
Count using the “Stop Duration”	:	
Count using the “Deceleration Rate”	:	

Kinetic energy dissipation				
		Section		
		Cooling adjustment	Bedding	Emissions measurement
Cycle	[--]	1	1...5	1
wf 1)	[J/kg]			
Deviation from the nominal value1)	[%]			

1) Evidence of fulfilment of all specifications according to this Regulation is verified

Family identifier(s) :
Manufacturer :

Nominal front wheel load/disc or drum mass ratio [--]	:	

Cooling Airflow Adjustment		
Brake temperatures over Trip #10		
ABT – Measured value [°C]	:	
ABT - Difference to the target value [°C]	:	
IBT – Measured value [°C]	:	
IBT - Difference to the target value [°C]	:	
FBT – Measured value [°C]	:	
FBT - Difference to the target value [°C]	:	

Definition of the nominal (set) cooling airflow for the specific brake		
FBT - Difference to the target value [°C]	:	

Bedding section		
Requirements acc. paragraph 11. of Annex 4 of this Regulation are fulfilled	:	

PM sampling flow			
		PM2.5	PM10
Nominal flow [l/min]	:		
Normalized measured flow [*N*l/min]	:		
Isokinetic ratio [--]	:		
The PM sampling flow for the isokinetic ratio fulfil the specifications of paragraph 12.1.2.3. (a) - (i) of Annex 4 of this Regulation	:		

Family identifier(s) :
Manufacturer :

PN sampling flow			
			SPN10
Normalized Measured flow [*N*l/min]	:		
Isokinetic ratio [--]	:		
The sampling flow for the isokinetic ratio fulfil the specifications of paragraph 12.2.3.2. (a) - (h) of Annex 4 of this Regulation	:		

PM / PN sampling		
Requirements acc. paragraph 12. of Annex 4 of this Regulation are fulfilled	:	
Sampling layout	:	

Weighting procedure			
1st Emission measurement		PM2.5	PM10
Pre-sampling filter weight corrected [µg]	:		
Post-sampling filter weight corrected [µg]	:		

2nd Emission measurement		PM2.5	PM10
Pre-sampling filter weight corrected [µg]	:		
Post-sampling filter weight corrected [µg]	:		

3rd Emission measurement		PM2.5	PM10
Pre-sampling filter weight corrected [µg]	:		
Post-sampling filter weight corrected [µg]	:		

Family identifier(s) :
Manufacturer :

Average of 1st to 3rd Emission measurement		PM2.5	PM10
Pre-sampling filter weight corrected [µg]	:		
Post-sampling filter weight corrected [µg]	:		
Final filter load [µg]	:		

PM emission factor calculation			
1st Emission measurement		PM2.5	PM10
Reference Emission Factor [mg/km]	:		
2nd Emission measurement		PM2.5	PM10
Reference Emission Factor [mg/km]	:		
3rd Emission measurement		PM2.5	PM10
Reference Emission Factor [mg/km]	:		
Final Emission Factor [mg/km]	:		

PN emission factor			
1st Emission measurement			SPN10
Reference Emission Factor [#/km]	:		
2nd Emission measurement			SPN10
Reference Emission Factor [#/km]	:		

Family identifier(s) :
Manufacturer :

3rd Emission measurement			SPN10
Reference Emission Factor [#/km]	:		
Final EF_{ref} [#/km]	:		
The emissions in [#/Ncm^3] are within the specified measurement range of the PNC device	:		

Mass loss measurement		
Pre-test mass of disc/drum [mg]	:	
Pre-test mass of friction material [mg]	:	
Post-test mass of disc/drum [mg]	:	
Post-test mass of friction material [mg]	:	
Total mass loss [mg]	:	
Total distance driven [km]	:	
Weight loss emission factor [mg/km]	:	

Calibration requirements		
Calibration requirements acc. paragraph 14. of Annex 4 of this Regulation are fulfilled	:	

Conclusion

Order No.
E-Mail
Phone
Fax

End of Test Report

Annex 1 - Appendix 2

Individual Friction Braking Share Coefficient (c-factor) Test Report (repeat as applicable for each individual measurement)

Report ⑥ in Figure A1/1 of this Regulation.

Test Report No.:

Friction braking share coefficient report identifier :
Manufacturer :

Individual Friction Braking Share Coefficient (c-factor) Test Report

UN Regulation No [179]

As last amended by:

Applicant	:	
Manufacturer	:	
Subject	:	Determination of c-factors acc. to UN-R Annex 5
Friction braking share coefficient report identifier	:	

Object submitted to tests		
Vehicle make	:	
IP-Family Identifier	:	

Information Document		
No.	:	
Date of issue	:	
Date of last change	:	

General

Prototype number	:	
VIN	:	
Category	:	
Bodywork	:	
Drive wheels	:	

Friction Brake
(For each axle the points below shall be repeated)

Type of brake system assembly (front/rear)	:	
Disc or drum (front/rear)	:	
Make of disc(s)/drum(s) (front/rear)	:	
Type of disc(s)/drum(s) (front/rear)	:	
Type of calliper(s) (front/rear)	:	
Construction of calliper(s) (front/rear)	:	
Make of calliper(s) (front/rear)	:	
Type of retraction elements (front/rear)	:	
Type of brake pad(s) or brake shoe(s) (front/rear)	:	
Make of brake pad(s) or brake shoe(s) (front/rear)	:	

Powertrain architecture

Vehicle electrification type	:	

Internal combustion Engine (if applicable)

Make	:				
Type	:				
Working principle	:				
Cylinders number and arrangement	:				
Engine capacity [cm3]	:				
Rated engine power	:		[kW] at		[rpm]
Maximum net torque	:		[Nm] at		[rpm]

Control unit

Part reference (same as information document)	:	
Software tested (read via scantool, for example)	:	
Software (data status)	:	

Transmission

Gearbox	:	
Mode with lowest recuperation (normal / drive / eco / … / …)	:	
Part reference (same as information document)	:	
Software tested (read via scantool, for example)	:	
Software (data status)	:	

Tyres

Make	:	
Type	:	

Dimension front / rear	:	
Dynamic circumference of front tyre [m]	:	
Tyre pressure front / rear [kPa]	:	

Electric Machine (if applicable)		
Make	:	
Type	:	
Peak Power [kW]	:	

Traction REESS (if applicable)		
Make	:	
Type	:	
Capacity [Ah]	:	
Nominal Voltage [V]	:	

Fuel Cell (if applicable)		
Make	:	
Type	:	
Maximum Power [kW]	:	
Nominal Voltage [V]	:	

Power Electronics (if applicable)		
Propulsion Converter Make / Type	:	
Power [kW]	:	
Low Voltage System Make / Type	:	
Power [kW]	:	

Battery management system (if applicable)		
Make	:	
Type	:	
Part reference (same as information document)	:	
Software tested (read via scantool, for example)	:	
Software (data status)	:	
Vehicle Description		
Test mass [kg]	:	
MRO [kg]	:	
f0 [N]	:	
f1 [N/(km/h)]	:	
f2 [N/(km/h)²]	:	
Test Description		
Cycle	:	
Method of chassis dyno setting	:	
Dynamometer in 4WD operation	:	
Dynamometer operation mode	:	
Coastdown mode	:	
Method for Friction Brake Torque determination	:	
$P_{threshold}$ front / rear [kPa] (if applicable)	:	
$C_{p,b}$ front / rear [Nm/kPa] (if applicable)	:	
SOC start and end of Traction REESS [%]	:	

Date of tests (dd.mm.yyyy)	:	
Place of tests (chassis dyno, location, country)	:	
Height of the lower edge above ground of cooling fan [cm]	:	
Lateral position of fan centre (if modified as request by the manufacturer)	:	
Distance from the front of the vehicle [cm]	:	
IWR: Inertial Work Rating [%]	:	
RMSSE: Root Mean Squared Speed Error [km/h]	:	
IPDW: Inertial Power Difference Work [J/kg]	:	
IPDR: Inertial Power Difference Rating [%]	:	

Test results					
Test number					
Brakes b	FL	FR	RL	RR	Combined
Wbrake, b [J]					
Wref [J]	--				
Friction braking share coefficient	--				
Declared friction braking share coefficient	--				

Test Report No.
Order No.
E-Mail
Phone
Fax

End of Test Report

Annex 1 - Appendix 3

Vehicle Type Compliance Demonstration Report

Report ⑧ in Figure A1/1 of this Regulation.

Vehicle Type:	-	Revision / Correction	: **00**
Manufacturer:	-		

Vehicle Type Compliance Demonstration Report

Agreement concerning the adoption of uniform technical prescriptions for the wheeled vehicles, equipment and parts which can be fitted and/or be used on wheeled vehicles and the conditions for reciprocal recognition of approvals granted on the basis of these prescriptions

Report	:	
Applicant	:	
Manufacturer	:	
Subject	:	Determination of friction braking share coefficient and brake emissions
Brake corner emission family identifier(s)	:	
C-Factor test report identifier(s)	:	

Object submitted to tests

Make	:	
IP identifier	:	
Emission class	:	

- \- Family Report
- X Granting type approval no.
- \- Extension to type approval no. :
- _ Correction to type approval no. :
- _ Revision to type approval no. :

Conclusion The object submitted to tests complies with the requirements mentioned in the subject.

Vehicle Type:	-	Revision / Correction	: **00**
Manufacturer:	-		

List of revisions

Rev.no.	*Date of revision*	*Amended by*	*Reason of revision / correction*
00	DD.MM.YYYY	First Name Surname	First release

0	**General**	
0.1	Make (trade name of manufacturer)	: -
0.2	Type	: -
0.3	Commercial name(s)	: -
0.4	Manufacturer's name and address	: -
0.4.1	Name and address of representative	: -
0.4.2	Name and address of assembly plants	: -
0.5	Information document	
	No.	: -
	Date of issue	: -
	Date of last change	: -
0.6	Additional data	:

Vehicle Type: *Manufacturer:*	Revision / Correction	: **00**

1. Description of tested object(s)

1.1. Brake combination

1.1.1. Front axle brake

Brake corner emission family :

Brake corner emission test report :

1.1.2. Rear axle brake

Brake corner emission family :

Brake corner emission test report :

1.2. Friction braking share coefficient (for each test the points below shall be repeated)

Tested vehicles (example on how to fill the table is included below. Replace with real data before submitting)

IP-family	*C-Factor test report identifier*	*C-Factor*
IP 1	Test report identifier 1	
IP 3, IP4, IP5	Test report identifier 2	

Vehicle Type: Revision / Correction : **00**
Manufacturer:

2. Test results

2.2. Friction braking share coefficient (example on how to fill the table is included below. Replace with real data before submitting)

IP-family	*Fixed/Declared*	*C-Factor*
IP 1	Declared	
IP 2	Fixed	
IP 3, IP4, IP5	Declared	

2.2. Brake assembly

2.2.1. General information

Axle	*Test ID*	*Test Bench*	*Date*

IP-family	*Wheel load - front [kg]*	*c * Wheel load - front [kg]*

IP-family	*Wheel load - rear [kg]*	*c * Wheel load - rear [kg]*

Vehicle Type: Revision / Correction : **00**
Manufacturer:

2.2.2. Final results - Front

IP-family	*PM_{10} Brake [mg/km]*	*PM_{10} Axle [mg/km]*	*$c*PM_{Axle}$ [mg/km]*

2.2.3. Final results - Rear

IP-family	*PM_{10} Brake [mg/km]*	*PM_{10} Axle [mg/km]*	*$c*PM_{Axle}$ [mg/km]*

2.2.4. Final results - Whole vehicle

IP-family	*PM_{10} Total [mg/km]*

2.3. Remarks

Vehicle Type:	-	Revision / Correction	: **00**
Manufacturer:	-		

3. Statement of conformity

This Test Report is only valid for the described test sample. The test sample representative for this type – complies – with the requirements of the above-mentioned test specification with regard to the documented test method.

This report includes pages 1 to X and is approved by the signer.
Duplication and publishing in extracts of the Test Report is allowed only by written permission of the Test Laboratory.

The XXXX Automobil Test Center is a testing laboratory accredited by the YYYY according to DIN EN ISO/IEC 17025. The accreditation is only valid for the scope of accreditation listed in the documented annex XXXX-01-00.

Place, Date

Title First Name Surname
Specialist
Tel.: XXXXXXXXXXXX – Fax: XXXXXXXXXXXXX – e-mail: firstname.surname@XXXXX.com

---------------------------- *End of test report* -------------------------------

Annex 2 Communication

(Maximum format: A4 (210 x 297 mm)

issued by: (Name of administration)

....

....

....

[1]

concerning[2]: Approval granted
Approval extended
Approval refused
Approval withdrawn
Production definitively discontinued

of determination of brake emissions.

Approval No.: .... Extension No.: ....

1. Manufacturer's name or trade mark(s):………………………………………………

2. Type designation by the manufacturer

3. Manufacturer's name and address..

4. If applicable, name and address of manufacturer's representative ....

5. Summarised description: ....

[1] Distinguishing number of the country which has granted/extended/refused/withdrawn approval (see approval provisions in the regulation).

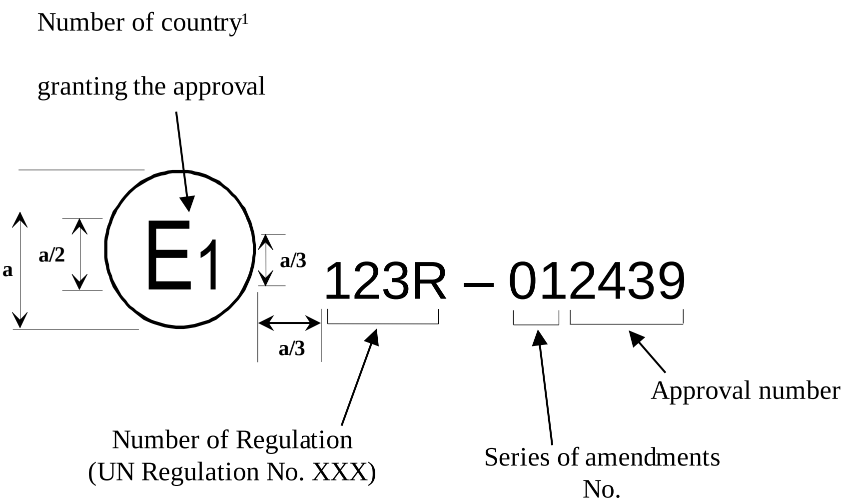
[2] Strike out what does not apply

Annex 3 Arrangement of the approval mark

In the approval mark issued and affixed to a vehicle in conformity with paragraph 7. of this Regulation, the type approval number shall be accompanied by an alphanumeric character reflecting the level that the approval is limited to.

This annex outlines the appearance of this mark and gives an example how it shall be composed.

The following schematic graphic presents the general lay-out, proportions and contents of the marking. The meaning of numbers and alphabetical character are identified, and sources to determine the corresponding alternatives for each approval case are also referred.



a = 8 mm (minimum)

The following graphic is a practical example of how the marking should be composed.

[1] Distinguishing number of the country which has granted/extended/refused/withdrawn approval (see approval provisions in the regulation)

Annex 4

Brake Emissions Test Procedure

1. Introduction

This Annex sets out the procedure for undertaking brake emissions testing as set out in paragraphs 7. and 8. of this Regulation.

All cross-references within this annex to other paragraphs shall be considered as to being to paragraphs within this Annex, unless specified otherwise, for example, ‘paragraph x. of this Regulation’, or ‘paragraph x of Annex x/Appendix x’.

2. - 6. Reserved

7. Test System Requirements

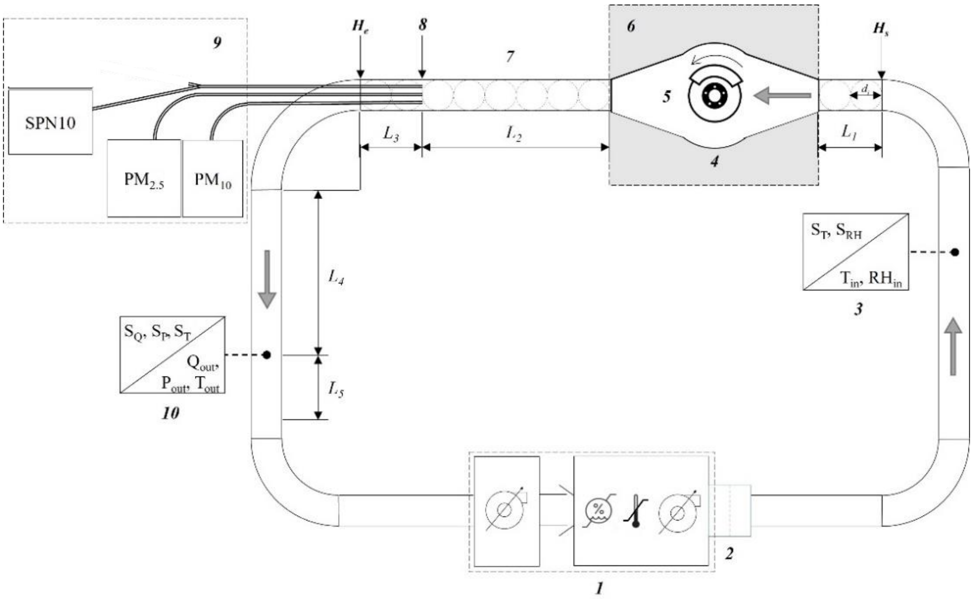
7.1. Overall Test System Layout

This Regulation defines a standard dynamometer test method aiming for repeatable and reproducible measurements of particle emissions from brakes. 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 systems, and data collection, altogether meet the requirements specified in this Regulation.

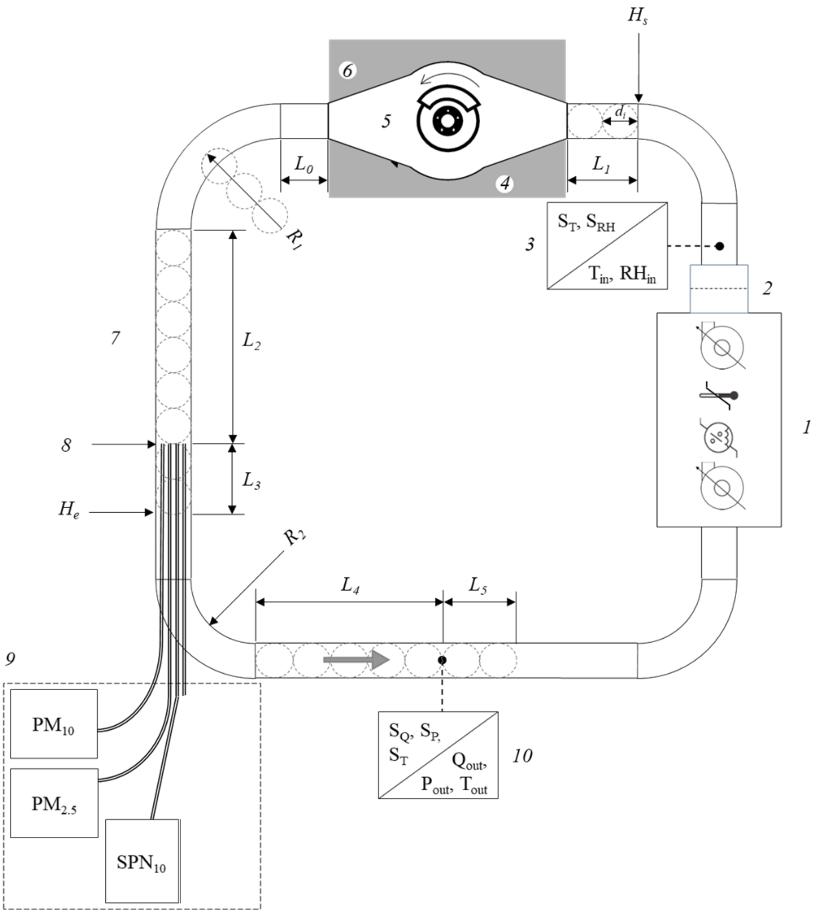
Figure A4/1 provides two indicative layouts that include the minimum required subsystems to carry out a brake emissions test using a brake dynamometer. The illustrated layouts feature a climatic conditioning unit with variable flow fan(s) that supplies the setup with conditioned air. The conditioned 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 three or four sampling probes are mounted. The sampling probes are used to extract the 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 A4/1 is not required.

Figure A4/1

Indicative layout for performing brake emissions test in the laboratory (a) Without a bend downstream of the the enclosure and (b) with one 90°-bend downstream of the enclosure



Note: (a) The layout has the sampling tunnel connected directly to the brake enclosure and assumes four sampling probes. The brake dynamometer is not depicted but only denoted (grey area) – a graphical representation of the brake dynamometer is given in Figure A4/2



Note: (b) The layout has a bend downstream of the enclosure and upstream of the sampling plane and assumes four sampling probes. The brake dynamometer is not depicted but only denoted (grey area) – a graphical representation of the brake dynamometer is given in Figure A4/2

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 least the subsystems and characteristics laid down in Table A4/1 Details regarding the different elements of the setup are given in the corresponding paragraphs of this Regulation as indicated in Table A4/1.

Table A4/1
Subsystems and characteristics required for the brake emissions testing setup as depicted in Figure A4/1

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 grey) 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
SPN10	Systems to control, measure, and output the signal of SPN10 per paragraph 12.2.
$PM_{2.5}$, PM_{10}	Systems to control sampling flow, sample brake particulate matter 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
L_0	Length of the straight duct downstream of the outlet of the enclosure. L_0=L_2 when there is no bend downstream of the enclosure and upstream of the sampling plane
L_1	Minimum length of the straight duct upstream of the inlet of the brake enclosure per paragraph 7.4.2.
L_2	Minimum length of the straight duct from the last disturbance upstream of the sampling plane to the sampling plane per paragraph 7.5.
L_3	Minimum length of the straight duct from the sampling plane to the next disturbance downstream of the sampling plane per paragraph 7.5.
L_4	Minimum length of the straight duct from the last disturbance upstream of the airflow measurement element to the airflow measurement element per paragraph 7.2.3.

Element	*Subsystem*
$\mathbf{L_5}$	Minimum length of the straight duct from the airflow measurement element to the next disturbance downstream of the airflow measurement element per paragraph 7.2.3.
$\mathbf{S_Q}$, $\mathbf{S_P}$, $\mathbf{S_T}$, $\mathbf{S_{RH}}$	Output electronic signals for cooling airflow, pressure, temperature, and humidity per paragraphs 7.2.1. and 7.2.3.
$\mathbf{d_i}$	Reference duct's inner diameter. This is the same as the sampling tunnel's inner diameter
$\mathbf{H_s}$, $\mathbf{H_e}$	Points that define the beginning (H_s) and the end (H_e) of the mandatory horizontal part in the layout (in the direction of the flow) per paragraph 7.4.2.

7.2. 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 in accordance with 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 testing conditions in accordance with 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 may include 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 shall be defined by its minimum and maximum operational flows. The following specifications apply for the minimum and maximum operational flows:

(a) The minimum operational flow shall be defined in the range between 100-300 m^3/h;

(b) The maximum operational flow shall be at least 5 times the minimum operational flow;

(c) The maximum operational flow shall be at least 1000 m^3/h greater than the minimum operational flow.

The system may also combine two-variable flow blowers (one to push and one to pull) to provide a slight negative pressure inside the sampling tunnel. The climatic conditioning unit control shall be capable of providing the necessary interfaces to the operator and the dynamometer.

7.2.1. 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 upstream of the brake enclosure. Positioning the sensors upstream of the brake enclosure avoids influencing the feedback signals with the thermal load from the brake events. Figure A4/1 provides an indicative position for the temperature and air humidity sensors (element 3).

The temperature sensor shall have an accuracy of ±1 °C. The sensor applied for measuring the specific and relative humidity shall have an accuracy of ±5 per cent of the nominal value (i.e. 50 per cent). The testing facility shall use the signals from these sensors to assess the stability of the cooling air's temperature and humidity. Table A4/2 summarises the requirements for the cooling air's temperature, humidity, and flow.

Table A4/2
Summary of cooling air temperature, relative humidity, and flow requirements

Parameter	*Cooling air temperature*	*Cooling air relative humidity*	*Cooling airflow*
Nominal value	23 ºC	50 %	Set value (Q_{set}) per paragraph 10.
Average value: Maximum permissible tolerance	±2 ºC (21 ºC ≤ T ≤ 25 ºC)	±5 % (45 % ≤ RH ≤ 55 %)	±5 % of Q_{set}
Instantaneous values (1Hz): Maximum permissible tolerance	±5 ºC (18 ºC ≤ T ≤ 28 ºC)	±30 % (20 % ≤ RH ≤ 80 %)	±5 % of Q_{set}
Instantaneous values (1Hz): Permissible deviation beyond the maximum permissible tolerance	Not defined	Not defined	±10 % of Q_{set}
Instantaneous values (1Hz): Maximum time exceeding the maximum permissible tolerance	10 % of each test section's duration	10 % of each test section's duration	5 % of each test section's duration

7.2.1.1. Cooling Air Temperature

Cooling air temperature at the measurement point shall be constant as defined below. The testing facility shall carry out the following steps:

(a) Set the cooling air temperature to 23 °C. The average cooling air temperature shall not deviate more than ±2 °C of the set (nominal) value (i.e. 21 ºC ≤ T ≤ 25 ºC). Testing facilities shall aim to keep the temperature as close as possible to the nominal value of 23 °C;

(b) The average cooling air temperature requirements defined in point (a) of this paragraph apply to all sections of the brake emissions test, including cooling air adjustment, bedding procedure, and emissions measurement (soaking sections not included);

(c) Calculate and report the average cooling air temperature in all sections as defined in Table A4/14;

(d) The instantaneous cooling air temperature shall not deviate more than ±5 °C of the nominal value (i.e. 18 ºC ≤ T ≤ 28 ºC). If the instantaneous cooling air temperature deviates more than ±5 °C from the nominal value, the testing facility shall ensure that the provisions described in point (e) of this paragraph are met;

(e) The instantaneous cooling air temperature may deviate more than ±5 °C of the nominal value (T < 18 °C or T > 28 °C) for no longer than the 10 per cent duration of the test (soaking sections not included), provided that the average temperature meets the requirements defined in point (a) of this paragraph:

(i) The total number of instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than

28 °C shall be less than 527 during the cooling adjustment section;

(ii) The total number of instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than 28 °C shall be less than 1,583 for each WLTP-Brake cycle of the bedding section;

(iii) The total number of instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than 28 °C shall be less than 1,583 for the WLTP-Brake cycle of the emissions measurement section (soaking sections not included).

(f) If the average or the instantaneous cooling air temperature falls out of the limits specified in this paragraph, the test shall be invalid.

7.2.1.2. Cooling Air Humidity

Cooling air relative humidity shall be constant as defined below. The testing facility shall carry out the following steps:

(a) 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 (i.e. 45 per cent ≤ RH ≤ 55 per cent). Testing facilities shall aim to keep the relative humidity as close as possible to the target value of 50 per cent;

(b) The average cooling air relative humidity requirements defined in point (a) of this paragraph apply to all sections of the brake emissions test including cooling air adjustment, bedding procedure, and emissions measurement (soaking sections not included);

(c) Calculate and report the average relative humidity of the cooling air in all sections as defined in Table A4/14;

(d) The instantaneous cooling air relative humidity shall not deviate more than ±30 per cent of the nominal value (i.e. 20 per cent ≤ RH ≤ 80 per cent). If the instantaneous cooling air relative humidity deviates more than ±30 per cent from the nominal value, the testing facility shall ensure that the provisions described in point (e) of this paragraph are met;

(e) The instantaneous cooling air relative humidity may deviate more than ±30 per cent of the nominal value (RH < 20 % or RH > 80 %) for no longer than 10 per cent of the duration of the test (soaking sections not included), provided that the average relative humidity meets the requirements defined in point (a) of this paragraph:

(i) The total number of instantaneous cooling air relative humidity readings (1Hz) with a value lower than 20 per cent RH or higher than 80 per cent RH shall be less than 527 during the cooling adjustment section;

(ii) The total number of instantaneous cooling air relative humidity readings (1Hz) with a value lower than 20 per cent RH or higher than 80 per cent RH shall be less than 1,583 for each WLTP-Brake cycle of the bedding section;

(iii) The total number of instantaneous cooling air relative humidity readings (1Hz) with a value lower than 20 per cent RH or higher than 80 per cent RH shall be less than 1,583 for the WLTP-Brake cycle of the emissions measurement section (soaking sections not included).

(f) If the average or the instantaneous relative humidity falls out of the predefined limits specified in this paragraph, the test shall be invalid.

(g) In addition to the specifications defined for the relative humidity, the testing facility shall ensure that the average specific humidity of the cooling air is kept between 6 gH2O/kg and 11 gH2O/kg dry air throughout the entire brake emissions test (soaking sections during emissions measurement are not included).

If the average specific humidity is outside of the limits specified in this paragraph, the test shall be invalid.

7.2.2. Cooling Air Cleaning

7.2.2.1. 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. Figure A4/1 provides an indicative position for the air filtering device (element 2).

7.2.2.2. Particle Background Verification

The particle background in the overall layout shall be defined on 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 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 verification upon the installation of the testbed 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:

(a) Perform the background verification with neither the brake fixture nor any brake components installed inside the brake enclosure;

(b) Perform the background verification with the SPN10 measurement system operating at the minimum calibrated PCRF setting;

(c) Commence the background verification at least five minutes after stabilising the cooling airflow to the average values per paragraph 7.2.3. for cooling airflow stability and to the average values per paragraph 7.2.1. for cooling air temperature and humidity;

(d) Perform the background verification at two different cooling airflow settings. Apply the minimum and maximum operational flow of the system. The testing facility shall sample SPN10 during the system background verification. The testing facility may use a single nozzle size for sampling SPN10 during the system background verification when applying different airflow settings;

(e) The background verification procedure shall run for as long as it takes to allow the background concentration to stabilise. The background concentration is considered stable when the averaged PCRF-corrected PN value, calculated as a 5-minute moving average, stays below the maximum permissible level as per paragraph 7.2.2.2.3. The 5-minute moving average shall be derived from 1-second (1Hz) samples.

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:

(a) 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 not be disturbed. Do not apply braking during the background verification procedure (zero brake pressure);

(b) Perform the pre-test verification with the cooling airflow setting defined for the given brake emissions test. The SPN10 measurement system shall operate at the PCRF setting selected for the brake emissions test of the brake under testing;

(c) Commence the background pre-test verification at least five minutes after stabilising the cooling airflow to the average values per paragraph 7.2.3. for cooling airflow stability and to the average values per paragraph 7.2.1. for cooling air temperature and humidity;

(d) Perform the background pre-test verification for as long as it takes for the background concentration to stabilise. The background concentration is considered stable when the PCRF-corrected PN value, calculated as a 5-minute moving average, stays below the maximum permissible level as per paragraph 7.2.2.2.3. The 5-minute moving average shall be derived from 1-second (1Hz) samples. Do not switch off the PN system after the end of the pre-test verification and before completing the post-test verification.

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

(e) Perform the regular background post-test before purging the PN system 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 verification procedure (zero brake pressure);

(f) Perform the post-test verification with the cooling airflow setting used for the given brake emissions test. The SPN10 measurement system shall operate at the PCRF setting selected for the brake emissions test;

(g) Commence the background post-test verification right after the emissions test and with the cooling airflow stabilised to the average values per paragraph 7.2.3. for cooling airflow stability and to the average values per paragraph 7.2.1. for cooling air temperature and humidity. Do not switch off the PN system after the end of the emissions section and before completing the post-test verification;

(h) Perform the background post-test for as long as it takes for the background concentration to stabilise. The background concentration is considered stable when the PCRF-corrected PN value, calculated as a 5-minute moving average, remains below the maximum permissible level as per paragraph 7.2.2.2.3. The 5-minute moving average shall be derived from 1-second (1Hz) samples.

7.2.2.2.3. Calculation and Reporting of the Particle Background Concentration

The background shall be measured and reported at a SPN10 concentration basis at standard conditions. The testing facility shall apply the following procedure:

(a) Perform a zero verification of the particle number counter (PNC). Apply a filter of appropriate performance at the inlet of the PNC per the equipment manufacturer's specification and record the PN concentration. The reading shall not exceed 0.2 #/cm³ at the inlet of the PNC. Upon removal of the filter, the PNC 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;

(b) Measure the average value of SPN10 ($SPN10_{b\#}$) 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 normalised particle number concentration (#/*N*cm³) as specified in Table A4/14;

(c) The 5-minute average background concentration in the tunnel shall not exceed the maximum limit of 20 #/*N*cm³ for 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.;

(d) Failure to comply with the zero verification of the PNC described in point (a) and with the particle background limits defined in point (c) of this paragraph shall result in an invalid test;

(e) The testing facility shall not subtract the background concentration value when reporting the SPN10 concentration value of the brake emissions measurement section per paragraph 12.2.4.

7.2.2.2.4. Calculation and Reporting of the Particle Background per Distance Driven

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 per distance driven is determined by Equation[s] 7.1 and 7.2:

$$\text{reserved} \qquad \text{(Eq. 7.1)}$$

$$SPN10_{b}EF = 10^{6} \times SPN10_{b\#} \times NQ \div V_{Set} \qquad \text{(Eq. 7.2)}$$

Where:

$SPN10_{b}EF$ is the SPN10 background in the sampling tunnel in #/km;

$SPN10_{b\#}$ is the average normalised and PCRF-corrected SPN10 background concentration in the sampling tunnel in #/*N*cm³;

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

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

(a) The PN background concentration ($SPN10_{b\#}$) corresponds to the average normalised and PCRF- SPN10 value calculated throughout the background verification from the parameters as specified in Table A4/14;

(b) Calculate the normalised average cooling airflow (*N*Q) during the background verification procedure from the parameters as specified in Table A4/14;

(c) The average nominal linear speed of the WLTP-Brake cycle equals to 43.7 km/h (V_{set} = 43.7 km/h);

(d) 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 A4/14.

7.2.3. 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:

(a) The method of measuring cooling airflow shall be such that measurement is accurate to ±2 per cent of the set value under all operating conditions;

(b) Measure the cooling airflow downstream of the sampling plane. Figure A4/1 provides an indicative position for the flow measurement device (element 10);

(c) 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. The flow measurement area may have a different inner diameter from the sampling tunnel. In such a case, duct diameter refers to the inner diameter of the duct where the flow element is located. The installation of the flowmeter shall not introduce significant pressure changes (i.e. the pressure at the flow measurement element shall be within ±1 kPa of ambient pressure). The duct's inner diameter shall be at least 35 per cent of the sampling tunnel's inner diameter;

(d) 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 elements are located. The specifications for the installation of the flowmeter defined in point (c) of this paragraph shall apply when the duct's inner diameter is different from the sampling tunnel's inner diameter;

(e) Use a flow measurement device calibrated to report airflow at standard conditions. To ensure an appropriate conversion to operating conditions, the temperature sensor shall have an accuracy of ±1 °C and the pressure measurements shall have a precision and accuracy of ±0.4 kPa;

(f) When the airflow measurement device is not calibrated to report values at standard conditions, ensure it includes a temperature sensor installed immediately before the measuring device. The temperature sensor shall fulfil the accuracy requirements described in point (e) of this paragraph. Use this measurement to normalise the airflow values;

(g) When the airflow measurement device is not calibrated to report values at standard conditions, ensure it includes the measurement of the absolute pressure or the pressure difference from atmospheric pressure taken upstream from the measuring device. The pressure measurements shall fulfil the precision and accuracy requirements described in point (e) of this paragraph. Use this measurement to normalise the airflow values;

(h) 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. Continuously monitor the pressure drop and, when necessary, correct the measured airflow accordingly. Follow the recommendations regarding the type and specifications of the protective filter provided by the manufacturer of the flow measurement device.

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

(i) The set (nominal) value for the cooling airflow (Q_{set}) shall be the same and constant during all sections of a brake emissions test. The same set value shall apply to cooling adjustment, bedding, and emissions measurement (including soaking) sections. This does not apply to the non-successful iterations of the cooling adjustment section, which may have a different cooling airflow set value;

(j) 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;

(k) 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;

(l) 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;

(m) Calculate and report the time-averaged measured cooling airflow in all sections as defined in Table A4/14;

(n) In case the average nominal or measured cooling airflow does not meet the requirements defined in this paragraph, the test shall be invalid;

(o) 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 emissions measurement sections:

   (i) 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;

   (ii) 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).

(p) In addition to the compliance with the average and instantaneous limits defined in this paragraph, the cooling airflow in combination with the sampling 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;

(q) A system leak check covering the ductwork and the enclosure shall be carried out before testing. Set the cooling airflow at the cooling setting defined for testing the given brake and measure for at least 2 min after the flow is stabilised. If the average measured flow 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. Alternative methods that follow the system manufacturer’s specifications may be applied for determining the leakage rate of the system; however, the testing facility shall always report the actual level of flow fluctuation from the set value;

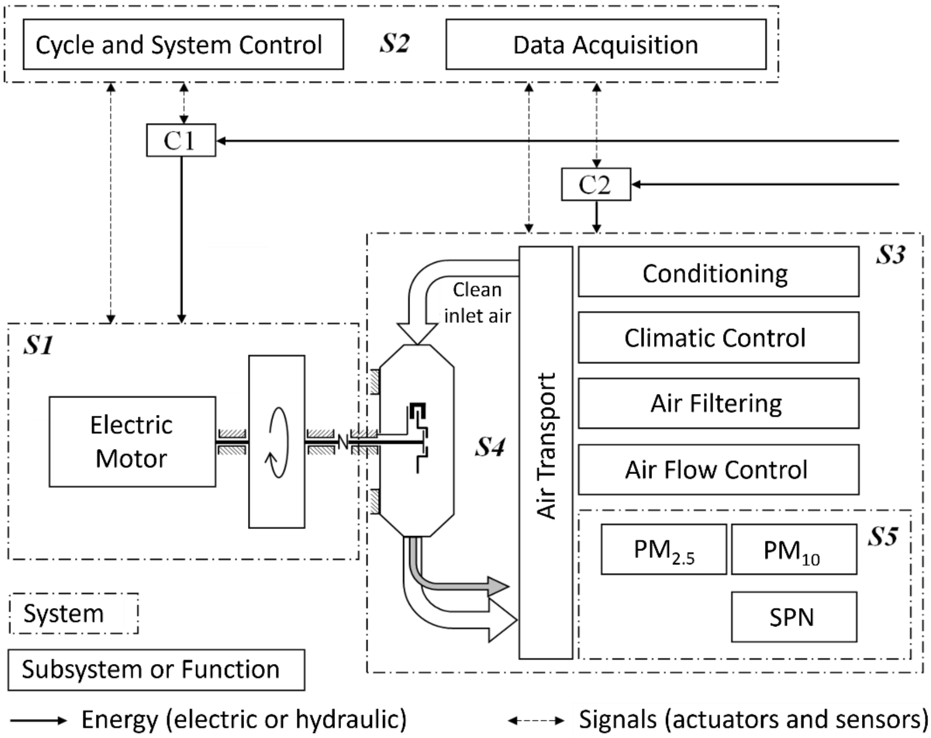
(r) The testing facility shall report the cooling airflow in the Time-Based file of the brake emissions test. Additionally, the testing facility shall report both actual and normalised airflow as defined in Table A4/14

7.3. 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 A4/2 – S1). Figure A4/2 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 Regulation.

Figure A4/2

Brake dynamometer and automation systems in the overall test layout



Note: S1: Brake dynamometer, S2: Automation, control, and data acquisition system, S3: Climatic conditioning unit, 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 aerosol sample from the brake under testing

The brake dynamometer shall consist of at least the following elements:

(a) A variable-speed electric motor to accelerate or keep the rotational speed constant and modulate the test inertia according to the testing needs;

(b) A servo controller (hydraulic or electric) to actuate the brake under testing;

(c) A mechanical assembly to mount the brake under testing, allow free rotation of the disc or drum, and absorb the reaction forces from braking;

(d) A rigid structure to mount all the mandatory subsystems. The structure shall be capable of absorbing the forces and torque generated by the brake under testing;

(e) Sensors and devices to collect data and monitor the operation of the test system;

Integral to the test system is the automation, controls, and data acquisition system (Figure A4/2 – S2). It continuously controls the rotational speed of the motor as well as the operation and the interactions between the different systems (Figure A4/2 – S3, S4, S5). Subsystems S3, S4, and S5 are described in detail in paragraphs 7.2., 7.4.-7.5., and 12.1.-12.2., respectively. The different elements and subsystems in Figure A4/2 are indicative; therefore, exact conformance with the figure is not mandatory.

The automation, control, and data acquisition system performs 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. Additionally, the automation, control, and data acquisition system provides 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:

(f) Execute the driving cycle automatically by operating all the closed-loop processes (mainly for brake controls, cooling air handling, and emissions measurement instruments);

(g) Continuously sample and record data from all relevant sensors to generate the outputs defined in paragraph 13. of this annex;

(h) Monitor signals, messages, alarms, or emergency stops from the operator and the different systems connected to the test system.

7.4. Brake Enclosure Design

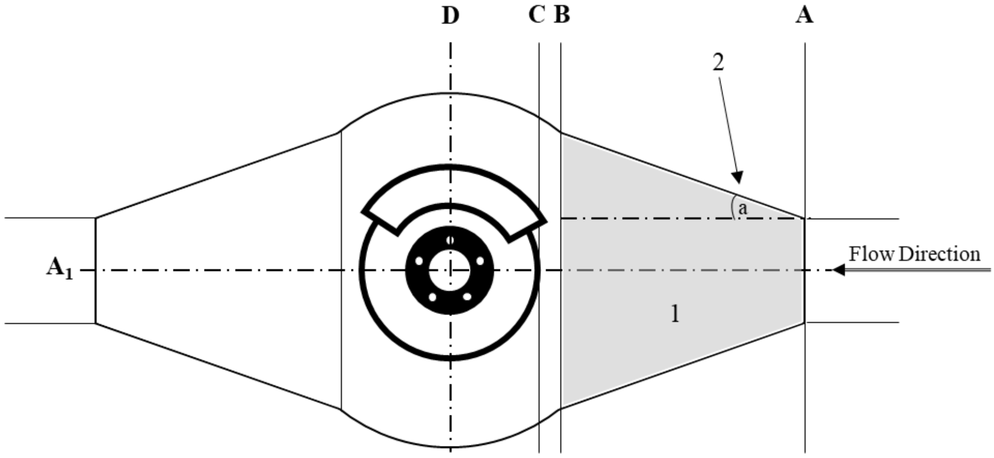
The brake enclosure is the test chamber where the brake assembly is installed during brake emissions testing. It is a sealed chamber that prevents untreated air from entering and contaminating the air flowing around the brake assembly. The brake enclosure directs uniform conditioned air to cool the brake and transport aerosol into the sampling tunnel. Design requirements for the enclosure aim to provide general guidelines to ensure systems' comparability related to brake cooling and particle transport efficiency. Figure A4/1 provides an indicative position for the brake enclosure (element 4).

7.4.1. General Elements

An indicative shape of the enclosure is illustrated in Figure A4/3 The enclosure is defined by one horizontal and four vertical planes. Plane A_1 represents the horizontal level aligned with the axis of the brake rotation and the axis of the inlet and outlet ducts. Plane A represents the vertical plane aligned with the enclosure's inlet. Plane 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 assembly applied on the vehicles that fall under the scope of this Regulation or any brake with similar dimensions (i.e. diameter of 450 mm). Plane D represents the vertical plane aligned with the axis of the brake rotation.

Figure A4/3

Indicative schematic representation of the brake enclosure



The inlet transition volume (Figure A4/3 – 1) is defined as the section of the enclosure between Planes A and B and is illustrated with a grey colour. The transition angle "a" (Figure A4/3 – 2) defines how smoothly the transition area develops in the enclosure. In Figure A4/3, the cooling air flows from right to left.

7.4.2. 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:

(a) The brake enclosure shall have two conical or trapezoidal sections intersecting with a cylinder at the centre concentric to the axis of the brake rotation;

(b) 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 A_1 along the enclosure's cross section (intersecting cylinder);

(c) The inlet and outlet cross-sections shall be designed to ensure smooth transition angles ($15° \leq a \leq 30°$) to avoid sudden changes in cross-section shape or size;

(d) 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;

(e) If fasteners are applied at the transition points, they shall not protrude into the enclosure area;

(f) 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 A_1 shall align with the airflow direction). The tunnel shall be horizontal and straight for at least two duct diameters ($2 \cdot d_i$) upstream of the enclosure's inlet. The tunnel ducting shall also be horizontal after the enclosure at least until two duct diameters ($2 \cdot d_i$) downstream of the sampling plane as specified in paragraph 7.5.;

(g) The surfaces of the brake enclosure that come into contact with the aerosol shall have a seamless construction. Stainless steel with an electropolished finish (or equivalent) shall be used to attain an ultra-clean and ultra-fine surface and to enhance corrosion resistance;

(h) 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;

(i) 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 R_e for a given brake emissions test using Equation 7.3;

$$R_e = (U \times d_i)/(\upsilon \times 3.6 \times 1000) \quad \text{(Eq. 7.3)}$$

Where:

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

U is the average cooling airspeed at the sampling tunnel in km/h;

d_i is the sampling tunnel diameter in mm per Table A4/1;

υ is the kinematic viscosity of air (use a default value of 1.48×10^{-5} m^2/s).

The average cooling airspeed at the sampling tunnel can be calculated using the measured airflow and the sampling tunnel's inner diameter based on Equation 7.4;

$$U = (4 \times 10^3 \times Q)/(\pi \times d_i^2) \quad \text{(Eq. 7.4)}$$

Where:

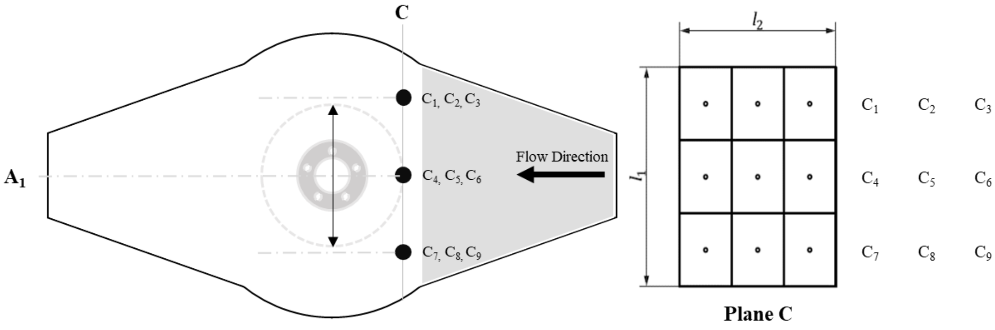
Q is the measured cooling airflow in m^3/h per Table A4/10;

d_i is the sampling tunnel's diameter in mm per Table A4/1

(j) Plane C is tangential to an arbitrary disc of a diameter of 450 mm. Design the cross-section area at the enclosure 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 upstream of Plane B to ensure the highest possible level of uniform flow at Plane C;

(k) Calculate the airspeed values at nine positions in Plane C as defined in Figure A4/4 Divide Plane C into nine equal areas by lines parallel to the sides of the plane (*l_1* represents plane C's height – *l_2* represents plane C's axial depth). Point C5 shall be the centre of Plane C. The remaining 8 points shall be equally distributed around point C5 and placed in the middle of the imaginary lines between point C5 and the enclosure's walls at Plane C as demonstrated in Figure A4/4;

Figure A4/4
Reference positions for airspeed verification



Note: 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 measurement positions on Plane C (view in the direction of flow)

(l) Measure the airspeed values at the nine positions of Plane C without a brake assembly or a brake fixture installed. All the cooling air ducting utilised for the brake emissions test shall remain connected to the enclosure during these measurements. Measure at the minimum and maximum operational flows of the test system. Let the flow stabilise for at least 2 minutes before conducting each measurement. The airflow is considered stabilized when the average measured flow in the sampling tunnel is within ±5 per cent of the set value. Perform the airspeed measurement for at least 2 minutes after the stabilisation. The measurement time shall be of sufficient duration to detect any instability in the airspeed pattern that may affect the airspeed values. Airspeed at each position shall not vary by more than ±35 per cent of the arithmetic mean of all measurements for a given flow.

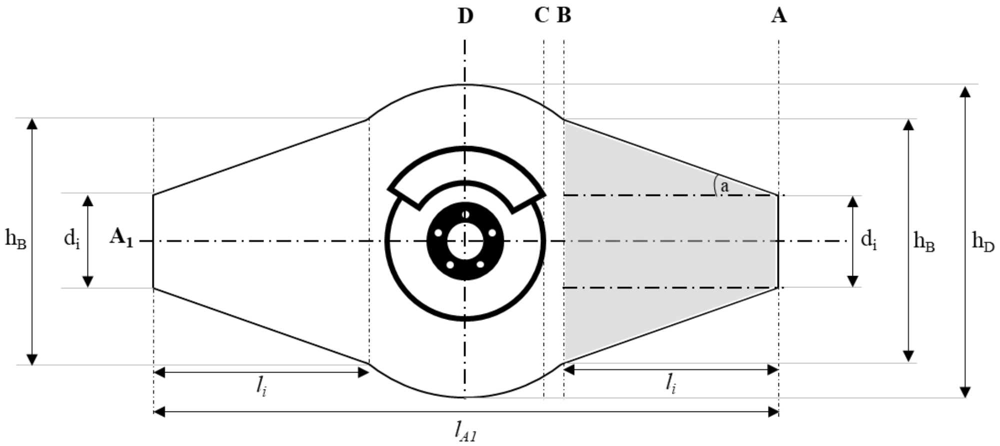
Cleaning and maintenance of the brake enclosure shall follow the specifications provided by the manufacturer regarding the frequency and means. The testing facility shall ensure that the enclosure is clean before commencing a brake emissions test.

7.4.3. Dimensions

The testing facility shall exercise due diligence to select the brake enclosure such that it fits the largest brake assembly applied to vehicles that fall within the scope of this Regulation. This includes possible additional parts designed to reduce particle emissions (e.g. brake filtering devices) provided their dimensions fit the corresponding wheel dimensions on which the brake is mounted. In addition, the testing facility shall verify that the selection is within the capabilities for speed, brake test inertia, and brake torque expected during the test. Oversized brake enclosures may lead to low-pressure regions, low airspeeds to achieve the target brake temperatures, and longer particle transport times. An indicative layout with the principal dimensions of the enclosure is illustrated in Figure A4/5

Figure A4/5

Indicative schematic representation of the brake enclosure and its 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 paragraph 7.4.2.

(a) Design the brake enclosure symmetrically to Plane A_1. The length of Plane A_1 (l_{A1}) represents the most extended length of the enclosure along the flow direction. Plane A_1's length shall be between 1200 mm and 1400 mm (1200 mm ≤ l_{A1} ≤ 1400 mm);

(b) Design the brake enclosure symmetrically to Plane D. The length of Plane D (h_D) 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 ≤ h_D ≤ 750 mm);

(c) 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 Regulation. Plane C's position in Figure A4/5 is given for illustration purposes and does not correspond to any actual dimension specification;

(d) Design the height at Plane B (h_B) such that the h_B/h_D ratio is always greater than 60 per cent (h_B/h_D > 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;

(e) Design the outlet's transition length (l_i) and height (h_B) such that they equate to the inlet's transition length (l_i) and height (h_B);

(f) The inlet and outlet diameters (d_i) shall equal the diameter of the duct in the sampling tunnel as specified in paragraph 7.5.;

(g) 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.

7.4.4. Brake filtering systems

The installation of brake filtering systems or other brake dust collection devices shall not adversely impact the facility performance. Positioning, length and bends of the system hoses shall be representative of real world applications. Parts of the systems may be installed outside the enclosure as long as they do not impact the brake filter system particle collection efficiency. Any extracted flow from the enclosure shall be returned at the inlet of the tunnel, approximately in the center of the cross-section. If an active system is designed to use one or several filter(s) and one blower for more than one brake(s) for vehicle applications, the additional volume flow needed to compensate the volume flow of the other brake(s) shall be extracted by the tunnel upstream of the enclosure (and downstream of the volume flow measurement). If applicable, a new filter shall be used for for bedding and emissions measurement accoring to Figure 2.

All requirements of this GTR shall be fulfilled. For example, cooling air flow adjustments shall be done with the system installed and operating as during emission measurements.

7.5. 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 A4/1 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 (Figure A4/1 (a)) and a layout with one bend (Figure A4/1 (b)). The testing facility shall ensure the design of the sampling tunnel meets the following requirements:

(a) The cooling air shall flow through round ducts with no variations in the cross-section between the enclosure exit and the sampling plane;

(b) Stainless steel with an electropolished finish (or equivalent) shall be used for the surfaces of the tunnel that come into contact with the aerosol;

(c) Any transition between adjacent sectors shall not have imperfections or features that may accumulate brake particulate matter. Whenever this is not feasible, ensure the transitions are engineered to minimise the accumulation of brake particulate matter;

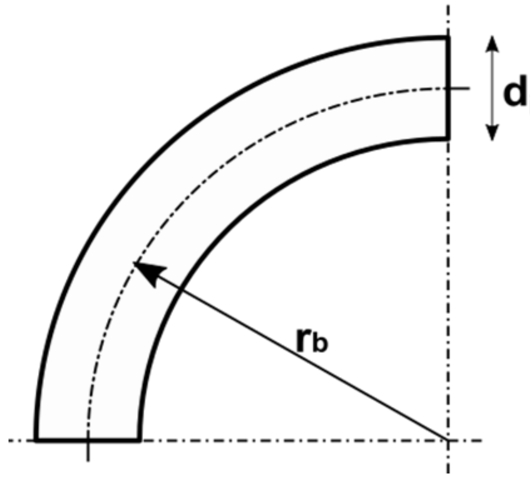
(d) Ducts shall have a constant inner diameter d_i of at least 190 mm and a maximum of 225 mm (190 mm $\leq d_i \leq$ 225 mm). The duct inner diameter d_i is defined as shown in Figure A4/6;

(e) 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;

(f) If a bend is applied in the sampling tunnel, the bending radius r_b shall be at least two times the duct inner diameter ($2 \cdot d_i$). The bending radius is defined as shown in Figure A4/6;

Figure A4/6

Definition of duct diameter (d_i) and bending radius (r_b)



(g) If a bend is applied in the sampling tunnel, a straight duct with a length of at least six times the duct diameter ($6 \cdot d_i$) shall follow the bend before locating the sampling plane. Additionally, a straight duct with a length of at least two times the duct diameter ($2 \cdot d_i$) shall follow the sampling plane before placing any flow disturbance (e.g. a second bend in the setup);

(h) If there is no bend in the sampling tunnel, a straight duct with a length of at least six times the duct diameter ($6 \cdot d_i$) 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 ($2 \cdot d_i$) 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);

(i) 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 times the duct inner diameter ($2 \cdot d_i$) upstream of the enclosure’s inlet to two times the duct inner diameter ($2 \cdot d_i$) downstream of the sampling plane.

7.6. Sampling Plane

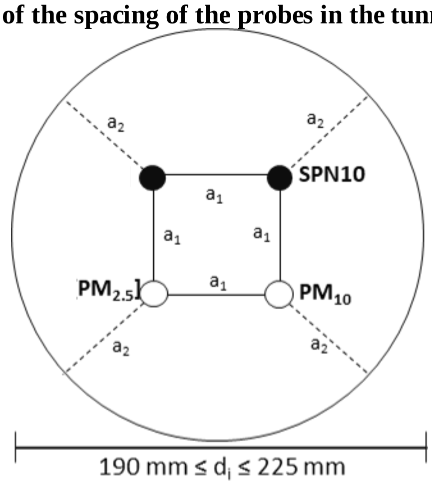
The sampling plane is the vertical plane in the sampling tunnel where the inlet of the sampling probes is placed. Figure A4/1 provides an indicative position for the sampling plane in the overall layout (element 8). The following provisions apply to the sampling plane:

(a) 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;

(b) Use a four-probe configuration fulfilling the requirements of this paragraph. Figure A4/7 illustrates the proper positioning of the PM and PN sampling probes. Alternative positioning of the measurement devices in the four-probe layout may be possible when a flow-splitter device for PN is used per paragraph 12.2.1.1.;

Figure A4/7

Graphic representation of the spacing of the probes in the tunnel



Note: View of the vertical part in the direction of the flow in the sampling tunnel that defines the sampling plane. White dots represent the PM sampling probes ($PM_{2.5}$/PM_{10}). Black dots represent the PN sampling probes (SPN10)

(c) Place the sampling probes equally spaced around the central longitudinal axis of the sampling tunnel based on the centre of the probe inlet;

(d) Place the sampling probes ensuring a minimum distance between them of 47.5 mm (Figure A4/7 – $a_1 \geq 47.5$ mm). Measure the distance between the sampling probes using their outer diameter;

(e) Place the sampling probes ensuring a minimum radial distance from the tunnel wall (probe-to-duct distance) of 47.5 mm (Figure A4/7 – $a_2 \geq$ 47.5 mm). Measure the probe-to-duct distance using the outer diameter of the sampling probes;

8. Test Preparation Requirements

8.1. Input Parameters

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 following this Regulation.

Table A4/3
Required test parameters

No.	*Parameters and Inputs*	*Short description*	*Symbol*	*Unit*	*Decim.*
1	Vehicle make and model	The vehicle make and model where the brake under testing is mounted		-	N/A
2	Vehicle electrification type	The brake corner emissions family parent vehicle electrification type (PEV, OVC-HEV, NOVC-HEV Cat. 0, NOVC-HEV Cat. 1, NOVC-HEV Cat. 2, ICE) where the brake under testing is mounted		-	N/A
3	Vehicle-specific braking share coefficient	The brake corner emissions family parent vehicle-specific braking share coefficient	c	-	2
4	Vehicle axle	The axle on the vehicle, front or rear, where the brake under testing is mounted	FA or RA	-	N/A
5	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	-	N/A
6	Vehicle test mass	The vehicle mass to be simulated on the brake dynamometer as defined in point (a) in this paragraph	M_{veh}	kg	0
7	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	FAF or RAF	%	0
8	Fixture style	The support fixture of the brake assembly per paragraph 8.4.1.	L0-U or L0-P	-	N/A
9	Disc or drum identification code	The code labelled by the brake manufacturer on the disc/drum		-	N/A
10	Friction material identification code	The code labelled by the friction manufacturer on the pads/shoes		-	N/A
11	Nominal Wheel Load	The load at the brake corner under testing (front or rear) before accounting for vehicle road loads or any other type of losses as defined in point (c) in this paragraph	WL_{n-f} or WL_{n-r}	kg	1
12	Test (or applied) Wheel Load	Load at the brake corner under testing (front or rear) after accounting for vehicle road loads or any other type of losses as defined in point (d) in this paragraph	WL_{t-f} or WL_{t-r}	kg	1
13	Tyre dynamic rolling radius	Tyre radius that equates to the revolutions per distance driven as	r_R	mm	0

No.	Parameters and Inputs	Short description	Symbol	Unit	Decim.
		published by the tyre manufacturer for the specific tyre size			
14	Brake Effective radius	The distance defined in point (e) in this paragraph	r_{eff}	mm	1
15	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	I_n	$kg \cdot m^2$	1
16	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	I_t	$kg \cdot m^2$	1
17	Disc/Drum maximum outer diameter	The largest diameter of the disc or drum under testing	OD	mm	1
18	Disc Mass	Mass of the disc before testing – It is used for the allocation of the brake under testing to a nominal front wheel load to disc mass group as described in paragraph 10	DM	kg	4
19	Number of pistons per side	Number of pistons (or “pots”) on one side of the brake calliper		-	N/A
20	Piston Mean (or hydraulic) Diameter	The diameter of the piston of the brake under testing as defined in point (h) in this paragraph		mm	2
21	Calliper to fixture bolt tightening torque	Calliper bolt tightening suggested torque if specified by the brake manufacturer		N·m	1
22	Disc or drum to hub bolt tightening torque	Disc/drum bolt tightening suggested torque if specified by the brake manufacturer		N·m	1
23	Brake calliper or brake drum efficiency	Efficiency to account for internal friction losses between sliding interfaces or piston travel if specified by the brake manufacturer. If not specified, use 100 per cent	H	%	0
24	Threshold pressure	Minimum pressure to overcome internal resistance before the onset of brake torque as defined in paragraph 3.1.19. of this Regulation	$p_{threshold}$	kPa	1
25	Brake runout limit	The maximum runout allowed for the disc/drum when installed on the brake fixture	BRO	µm	0

The following considerations shall be taken into account when calculating some of the required testing parameters provided in Table A4/3:

(a) Vehicle Test Mass (M_{veh}) is the mass in running order (MRO) plus the mass of the optional fitted equipment of the vehicle (kg) on which the tested brake is mounted plus:

(i) 37.5 kg that corresponds to an additional mass of 0.5 passengers, for category 1-1 vehicles;

(ii) 25 kg plus 28 per cent of the Maximum Vehicle Load (MVL), for category 2 vehicles with a fully laden mass below 3500 kg.

(b) Brake Force Distribution (FAF or RAF) represents the ratio between the braking force of each axle and the total braking force on the vehicle, respectively. FAF represents the share of the braking force applied to the front axle. RAF represents the braking force share applied to the rear axle. The brake force distribution is expressed as a percentage. The brake force distribution for each vehicle (FAF or RAF) is provided by the vehicle manufacturer. The brake force distribution per the default method on UN Regulation No. 90 shall be applied only whenever the vehicle manufacturer's specific value is not available. This corresponds to:

(i) 77 per cent for the front axle and 32 per cent for the rear axle for Category M1 vehicles;

(ii) 66 per cent for the front axle and 39 per cent for the rear axle for category 2 vehicles with a fully laden mass below 3,500 kg.

(c) Nominal Wheel Load (WL_n) represents the load on the brake under testing (front or rear) 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 Equations 8.1a and 8.1b. The nominal wheel load is used to calculate the test wheel load. Additionally, it is used to classify the brake under testing into a nominal front wheel load to disc mass group according to its (WL_{n-f}/DM) ratio when adjusting the cooling settings as specified in paragraph 10.

$$WL_{n-f} = 0.5 \times M_{veh} \times FAF \qquad \text{(Eq. 8.1a)}$$

$$WL_{n-r} = 0.5 \times M_{veh} \times RAF \qquad \text{(Eq. 8.1b)}$$

Where:

WL_{n-f} is the nominal front wheel load in kg per Table A4/3;

WL_{n-r} is the nominal rear wheel load in kg per Table A4/3;

M_{veh} is the vehicle test mass in kg per Table A4/3;

FAF is the front brake force distribution per Table A4/3;

RAF is the rear brake force distribution per Table A4/3

(d) Test (or applied) Wheel Load (WL_t) represents the load on the brake under testing (front or rear) 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 Equations 8.2a and 8.2b. The WL_t is reduced by 13 per cent compared to the WL_n to account for the road loads of the vehicle during real-world operation. The WL_t is applied during the entire brake emissions test including cooling adjustment, bedding, and emissions measurement sections.

$$WL_{t-f} = 0.87 \times WL_{n-f} \qquad \text{(Eq. 8.2a)}$$

$$WL_{t-r} = 0.87 \times WL_{n-r} \qquad \text{(Eq. 8.2b)}$$

(e) Brake Effective Radius (r_{eff}) is , for disc brakes, the distance between the centre of rotation and the centreline of the calliper piston(s) when assembled on the fixture. For a drum brake, the effective radius is half of the drum's inner diameter.

(f) Brake Nominal Inertia (I_n) represents the wheel load with a radius of gyration equal to the tyre dynamic rolling radius which imposes the same kinetic energy on the service brake 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:

$$I_n = WL_n \times {r_R}^2 \qquad \text{(Eq. 8.3)}$$

Where:

I_n is the brake nominal inertia in kg·m^2 per Table A4/3;

WL_n is the nominal wheel load in kg per Table A4/3;

${r_R}^2$ is the tyre dynamic rolling radius in m per Table A4/3

(g) Brake Test (or applied) Inertia (I_t) 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 inertia and is calculated following Equation 8.4. 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 operation. The brake test inertia applies to the entire brake emissions test including cooling adjustment, bedding, and emissions measurement sections.

$$I_t = 0.87 \times I_n \qquad \text{(Eq. 8.4)}$$

(h) Piston Mean (or hydraulic) Diameter (d_{piston}) for drum brakes is the wheel cylinder piston diameter. The d_{piston} for the disc brakes represents the equivalent piston diameter of the brake under testing. If the calliper contains several (n) pistons, the testing facility shall determine the piston hydraulic diameter using the equivalent individual piston diameters acting on one side of the calliper with Equation 8.5:

$$d_{piston} = \sqrt{d_1^2 + d_2^2 + \cdots + d_n^2} \qquad \text{(Eq. 8.5)}$$

8.2. Test Setup Preparation

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

(a) Verify the availability of all the test documentation, brake information, control program, dynamometer capabilities, and test conditions;

(b) Update or upload the corresponding control program, test parameters and conditions, and brake information onto the brake dynamometer control system;

(c) Install the brake disc/drum onto the test fixture and the dynamometer tailstock in accordance with the specifications described in paragraph 8.4.1. Connect with the adaptors to the main dynamometer shaft;

(d) Measure the brake runout (BRO) by placing the dial gauge tip 10 mm away from the outer edge (OD) on the outboard or inboard surface (disc brakes). For drum brakes, measure the brake runout by placing the dial gauge radially outwards and 10 mm away from the centreline of the inner surface of the drum. Brake pads or shoes shall not be mounted during this measurement. Verify that the BRO is less than 50 µm while manually rotating the disc or drum installed on the dynamometer.Complete drum assembly after the BRO measurement. If brake parts must be detached to complete the brake assembly, verification measurement shall be done to demonstrate correct runout at final assembly. If the BRO is above 50 µm, adjustments to brake fixturing and/or inspection of the brake parts shall be made to reduce BRO to a value below 50 µm. In case the BRO before the start of the test remains above the limit defined in this paragraph, the test shall be invalid. Report the measured (actual) brake runout in Table A4/14;

(e) Verify the torque and pressure zero levels before commencing a brake emissions test. The verification shall be carried out with the brake calliper piston(s) and brake pads fully retracted. The brake parts shall not touch the disc and the dynamometer hydraulic apply system shall be in a released state. In this position, the torque and pressure sensors shall each be adjusted per the equipment manufacturers's specifications to read zero or as close as possible within the tolerances defined in Table A4/18 The reading shall be observed for at least 30 seconds with the brake stationary to confirm stabilisation. In the case of a drum brake, perform the adjustment with the backing plate assembly (with brake shoes) installed but without the rotating part (drum) installed.

(f) 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;

(g) Perform a visual inspection of the brake under testing, brake fixture, thermocouple wires, and hydraulic brake lines to ensure proper routing and connections;

(h) Ensure all the instruments are available per the standard operating procedure defined by the instrument manufacturers on usage and cleaning. Ensure all filter media are available per the standard operating procedure defined by the filter manufacturer on filter conditioning, handling, and storage;

(i) Brake bleeding is important to ensure there are no air bubbles left inside the brake hose. Perform static brake applications at brake pressures in the range of 300-3000 kPa to verify the fluid displacement curve for bleed check and to visually inspect for any fluid leaks inside the enclosure. A brake fluid displacement sensor or alternative evaluation methods may be used for this operation.

Retract the brake calliper and pads to ensure no contact between the pads and the disc (in the case of a drum brake, ensure that the shoe to drum clearance is set to the nominal value recommended by the manufacturer).

(j) Close the brake enclosure, turn on the environmental conditioning system, and verify the operation of the cooling air system in accordance with the specifications defined in paragraph 7.2.;

(k) Apply 2000 kPa of pressure three times (hold pressure for 2 seconds each apply) to re-set the brake (drum brakes may omit this step). Perform measurements at three different linear speeds (5 km/h, 50 km/h, and 135 km/h) by accelerating to the target speed, holding for 120 seconds (at zero brake pressure) to stabilize, and then measuring the torque signal for 30 more seconds. The drag measurement is the time-based average of this torque signal for the 30 second period. An acceleration level of 1 m/s^2 for 5 km/h and 2 m/s^2 for the other two target speeds shall be applied. Verify that, during the final 30 seconds of each cruise event, the measured brake drag torque (as defined in paragraph 3.3.26. of this Regulation) does not exceed 10 N·m (excluding the torque absorbed by the dynamometer bearings, if applicable, which may be measured separately with the brake not installed). If the drag torque measurement exceeds this value, repeat the procedure after re-checking BRO, clearance between moving and stationary components (including thermocouples wiring), brake bleed and fixture alignment. In case the measured drag torque for the brake assembly on test exceeds 10 N·m, the test shall be invalid;

(l) Repeat the first brake event of the WLTP-Brake cycle ten times to verify data collection, test parameters, brake test inertia, and overall system operation;

(m) 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 10.1.4. Verify that the selected cooling airflow meets the specifications defined in paragraph 10. If not, adjust its value following the instructions in paragraph 10.1.4. until the nominal value is defined;

(n) 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;

(o) Verify all instruments and devices for brake emissions measurements are enabled and running without any errors or warnings;

(p) If no issues arise, continue with the bedding and emissions measurement sections following the procedures defined in paragraphs 11. and 12., respectively.

When the cooling airflow for the axle and brake type under test is known, the testing facility shall carry out bedding and emissions measurement with new brake parts and not the ones used for cooling adjustment. In that case, all steps in this paragraph except for point (m) shall apply to the bedding and emissions measurement section.

When the cooling airflow for the axle and brake type under test is not known, the testing facility shall carry out the cooling adjustment section, applying all steps in this paragraph except for points (h), (n), (o), and (p). Once the cooling airflow is adjusted, the testing facility shall carry out bedding and emissions measurement with new brake parts, applying all steps in this paragraph except for point (m).

8.3. Brake Temperature Measurement

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

(a) Use commercially available temperature sensors containing Nickel-chromium (Chromel) and Nickel-aluminum (Alumel) conductors (Type K thermocouples);

(b) Use embedded thermocouples with a measurement temperature range between 0 °C and a minimum of 800 °C and a maximum permissible error (tolerance) of ±2.2 °C or ±0.75 per cent of the measured value;

(c) Use embedded thermocouples with a solid tip readily installed to embed them onto the brake components;

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

(d) 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 A4/8 illustrates the proper installation of embedded thermocouples on brake discs. The symbol 'X' denotes the surface contact radius of the disc and the pads;

(e) 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 A4/9 illustrates the proper installation of embedded thermocouples on brake drums;

(f) 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 Regulation is strongly discouraged.

Figure A4/8
Schematic installation of embedded thermocouples for brake discs

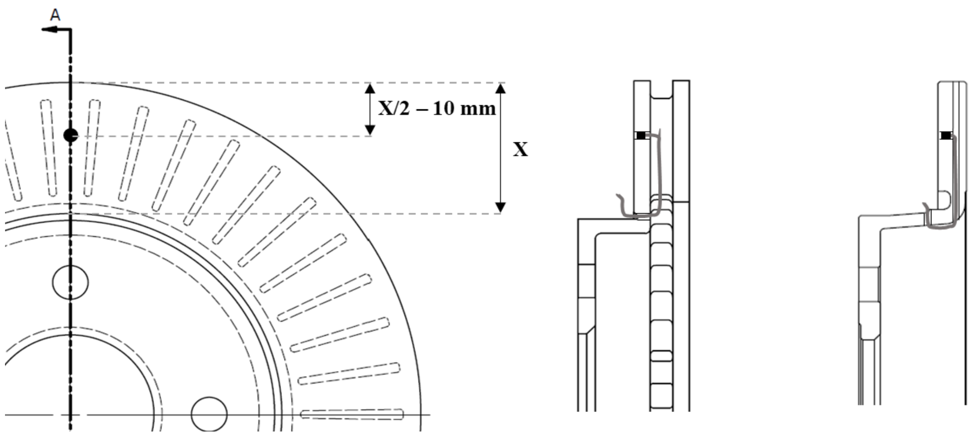
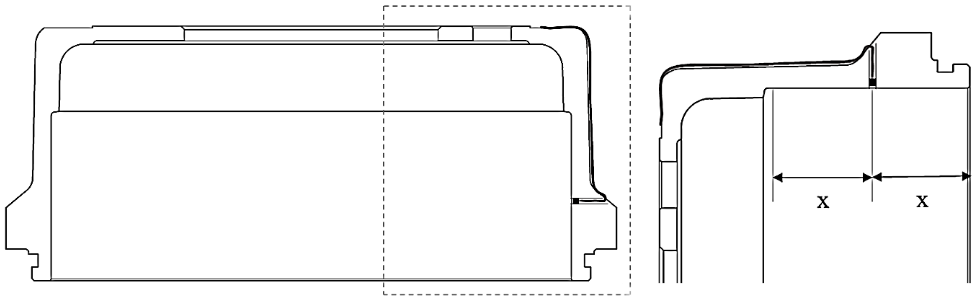


Figure A4/9
Schematic installation of embedded thermocouples for brake drums



Brake temperature shall be reported in the Time-Based file as described in Table A4/14 The testing facility shall use these thermocouple readings for reporting brake temperature during all testing sections. For example, the testing facility shall use the temperature readings from the embedded thermocouples in the Time-Based file (T_{brake}) to verify the correct application of the initial temperature at the individual trip of the WLTP-Brake cycle, in accordance with the specifications described in paragraph 9.2.

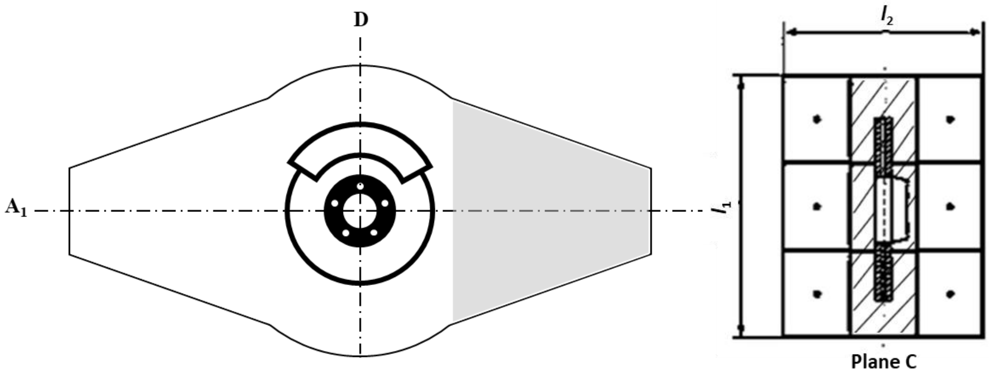
8.4. Brake Positioning

8.4.1. Brake Assembly

The installing position of the brake assembly defines the axis of rotation of the brake assembly and at the same time the location of Planes A_1 and D of the enclosure. The proper installation position is illustrated in Figure A4/10 (a) with A_1 and D perpendicularly intersecting as much as possible the axis of rotation. At the same time, the brake assembly shall be installed using good engineering judgement and ensuring as much as possible that the disc thickness remains within the central section of Plane C (hatched) as shown in Figure A4/10 (b). For drum brakes, the drum friction ring shall be positioned as much as possible within this central section of Plane C.

Figure A4/10

Installation position of the brake assembly and the calliper (a) with respect to planes A_1 and D, (b) with respect to Plane C



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:

(a) Mounting components to attach the brake test fixture to the (non-rotating) tailstock;

(b) Structural components to transfer the braking torque and forces to the tailstock;

(c) Mounting components to take the brake calliper or the backing plate assembly for drum brakes;

(d) Rotating parts to mount the brake disc or brake drum onto;

(e) 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 A4/11 and A4/12 illustrate some examples of the fixture style schematics for disc and drum brakes, respectively.

Figure A4/11

Example of allowed fixture styles schematics for disc brakes

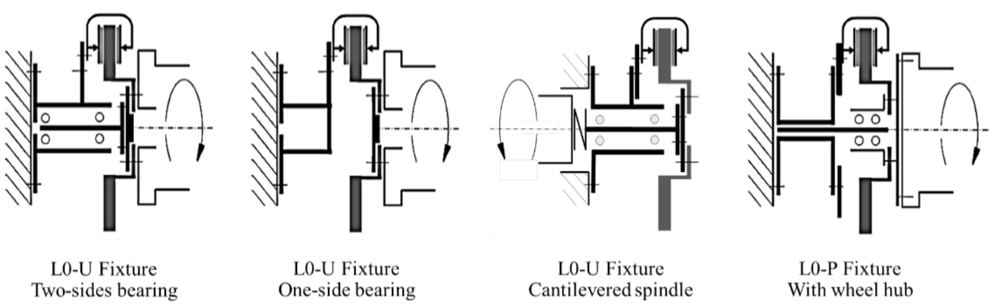
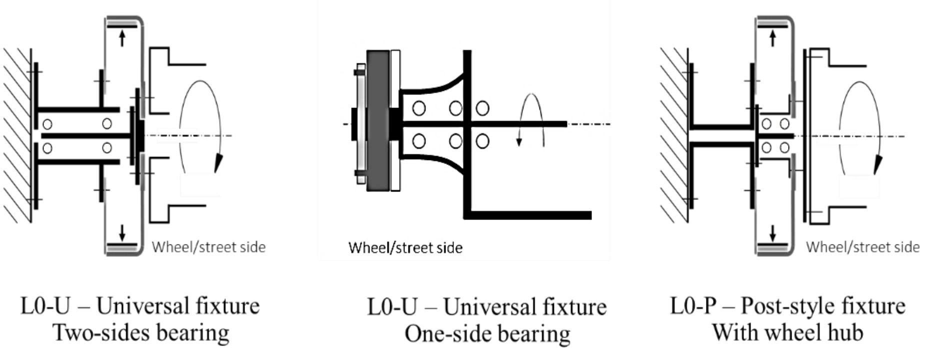


Figure A4/12

Example of allowed fixture styles schematics for drum brakes



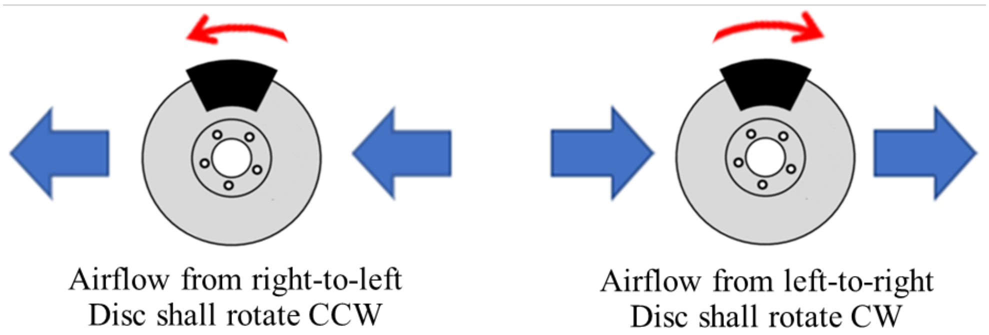
Any variant of these fixtures (one side bearing right or left or both sides bearing) may be applied provided they use an L0 style fixture as a reference (i.e. cylindrical and symmetrical base without additional extensions or protrusions different from those needed to mount the calliper assembly). For example, Figure A4/11 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.

The testing facility shall install the brake configuration (brake disc and calliper or drum assembly) such that it always rotates in the evacuation direction when driving forward as shown in Figure A4/13

Figure A4/13

Schematic representation of disc rotation viewed from the wheel side (road side)



When the cooling air flows in a direction from right to left (Figure A4/13 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 A4/13 right-hand side), the disc shall rotate in a clockwise direction (CW). Alternative rotation directions are not allowed and will invalidate the test.

8.4.2. 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 centre of the calliper in a 12-o'clock position as illustrated in Figure A4/13 irrespective of the mounting position on the vehicle. Other calliper orientations (e.g. vehicle's mounting position) or configurations are not allowed and shall invalidate the test. The parking brake shall not be dismounted for carrying out a brake emissions test. The motor-gear unit shall not be dismounted from the electric parking brake calliper or the e-drum brake to perform a brake emissions test.

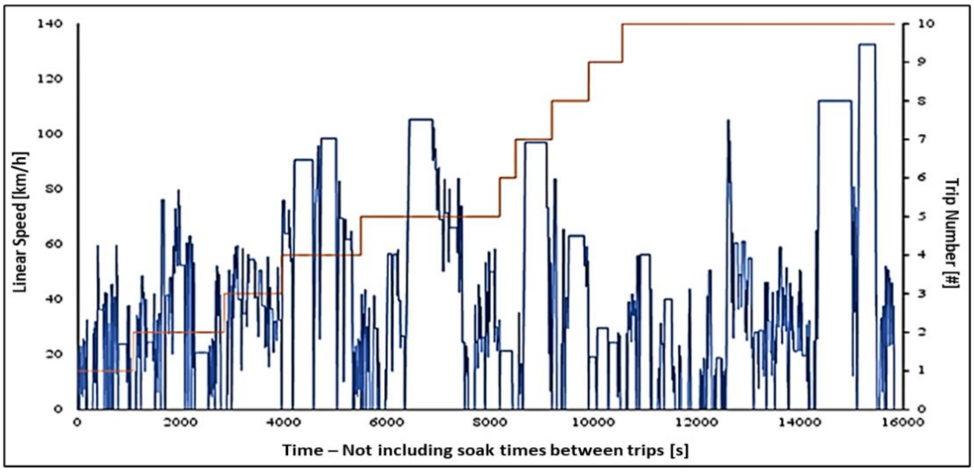
9. WLTP-Brake Cycle

9.1. General Information

The testing cycle for all types of brakes 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 A4/14 illustrates the time-resolved speed trace of the WLTP-Brake cycle.

Figure A4/14

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



In summary, the WLTP-Brake cycle includes:

(a) 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 A4/14;

(b) 15,826 seconds of active speed control, without including the cooling sections between the individual trips of the cycle. The speed trace of the WLTP-Brake cycle is given in Appendix 1;

(c) 303 brake deceleration events. The main properties of each individual brake deceleration event are described in Appendix 2;

(d) 192 km of total distance driven with an average speed of 43.7 km/h and a maximum speed of 132.5 km/h;

(e) An average brake deceleration rate of 0.97 m/s². A maximum brake deceleration rate of 2.18 m/s²;

(f) An average brake deceleration duration of 5.7 s. A maximum brake deceleration duration of 15 s.

9.2. WLTP-Brake Cycle Application

9.2.1. 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 Annex. 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:

(a) Set the cooling airflow to the nominal value determined in paragraph 10;

(b) Warm the brake to (40±1) °C following a sequence of brake events #1 to #7 of Trip #10 (brake events #190 to #196 when the entire WLTP-Brake cycle is considered) with a subsequent cooling phase down to (40±1) °C;

(c) In case the target temperature cannot be reached with the application of the sequence described in (b), select one of the brake events #1 to #7 of Trip #10 and repeat it several times until the brake temperature reaches (40±1) °C;

(d) Commence Trip #10 of the WLTP-Brake cycle at a brake temperature of (40±1) °C;

(e) Run Trip #10 of the WLTP-Brake cycle without any interruption. Paragraph 9.3.1. describes the necessary actions in the case of interruptions.

Failure to comply with the described brake temperature provisions shall result in an invalid cooling adjustment. In such a case, the testing facility shall repeat the cooling adjustment section by applying a different airflow. The same brake parts are allowed to be used for repeating the cooling adjustment.

9.2.2. Bedding Section

Bedding and subsequent emissions measurement sections shall be carried out with new parts. The bedding procedure consists of five consecutive runs of the WLTP-Brake cycle as described in paragraph 11. of this Annex. 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:

(a) Set the cooling airflow to the nominal value for the brake under testing, following the procedure described in paragraph 10.;

(b) Commence the first run of the WLTP-Brake cycle at a brake temperature of (25 ± 5) °C;

(c) Do not apply soaking sections between the individual trips of the WLTP-Brake cycle during the bedding procedure.

(d) Apply soaking sections between the five repetitions of the WLTP-Brake cycle. Commence each of the subsequent four WLTP-Brake cycles when the brake temperature decreases to 40 °C;

(e) If the brake temperature at the end of the previous WLTP-Brake cycle is between 30 °C and 40 °C, commence the subsequent WLTP-Brake cycle immediately without any intervention to warm the brake;

(f) 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;

(g) Run the five individual WLTP-Brake cycles consecutively without any interruption. Paragraph 9.3.2. describes the necessary actions in the case of interruptions.

The minimum threshold temperature of 30 °C specified in this paragraph applies to all tested brakes. 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 the case of repeating the bedding procedure.

9.2.3. 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:

(a) Set the cooling airflow to the nominal value for the brake under testing following the procedure described in paragraph 10.;

(b) Commence Trip #1 of the WLTP-Brake cycle at a brake temperature of (25 ± 5) °C, without conducting any warm-up stops or snubs;

(c) Apply soaking sections between the ten trips of the WLTP-Brake cycle. Commence each of Trips #2-10 as soon as the–brake temperature decreases to 40 °C;

(d) For Trips #2-10, if the brake temperature at the end of the previous trip is between 30 °C and 40 °C, commence the subsequent trip immediately without any intervention to warm the brake disc. For rear brakes the value of 30 °C is lowered to 20 °C;

(e) For Trips #2-10, if the brake temperature at the end of the previous trip is below 30 °C (20 °C for rear brakes), 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;

(f) Run the WLTP-Brake cycle without any interruption. Paragraph 9.3.3. describes the necessary actions in the case of interruptions;

(g) In case of active brake filtering devices, the testing facility shall use the “Brake Pressure” and “Linear Speed” signals to activate the filtering function at the brake event start time as defined in paragraph 13.1. In such a case, the active filtering function may be deactivated up to maximum 5 seconds after the brake event end time as defined in paragraph 13.1.

The minimum threshold temperature of 30 °C specified in this paragraph applies to all brakes. Failure to comply with the described brake temperature provisions shall result in an invalid emissions test.

9.3. WLTP-Brake Cycle Interruptions

9.3.1. 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 such a case, after performing a data review and a visual inspection without disturbing the brake assembly, the testing facility may use the same brake assembly to proceed with the next iteration of Trip #10 and finalise the cooling adjustment section. 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 in accordance with the specifications described in paragraph 8.2.

9.3.2. 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. The testing facility shall not conduct any warm-up stops or snubs to reach 30 °C if the actual brake temperature is lower. The testing facility shall not disassemble the parts. If the brake parts are disassembled after the beginning of the bedding section, they are no longer suitable for completing bedding and the subsequent emissions measurement. In such a case, the testing

facility shall replace them with new brake parts and repeat the bedding procedure from the beginning.

In the case that the bedding section is interrupted for a second time, the testing facility shall declare the test invalid, discard the used parts, and use new ones to carry out a new test including bedding and emissions sections.

9.3.3. Emissions Measurement Section

If the test is interrupted during the emissions measurement section (including soaking), the testing facility shall discontinue the emissions measurement section, declare the test invalid, discard the used parts, and use new ones to carry out a new test including bedding and emissions sections.

9.4. 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.

9.4.1. 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 is outside the speed trace tolerances defined by the prescribed (nominal) speed.

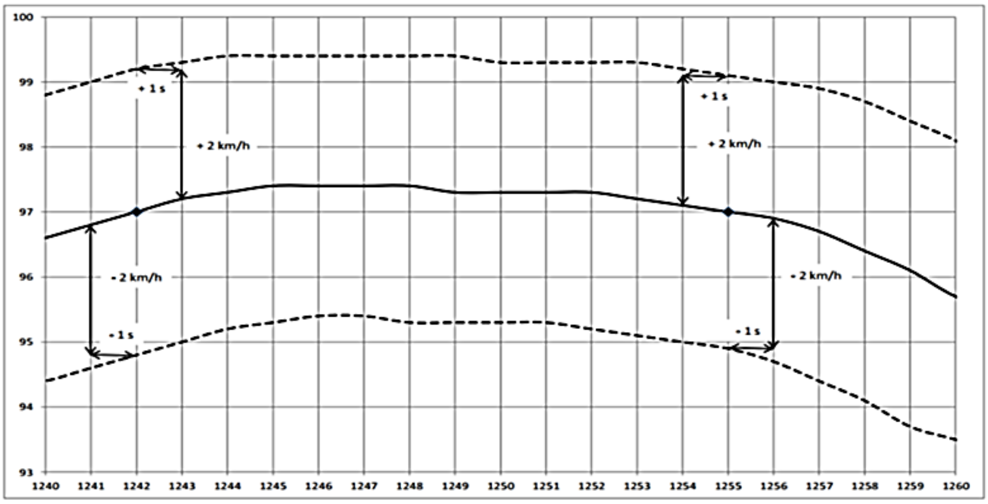
(a) Upper-speed tolerance: 2.0 km/h higher than the nominal linear speed trace within ±1.0 second of the given point in time;

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

Figure A4/15 depicts the upper and lower speed tolerance limits as applied in the WLTP-Brake cycle.

Figure A4/15

Tolerance limits for speed violations during the WLTP-Brake cycle



(c) 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;

(d) 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;

(e) 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;

(f) Calculate and report the number of speed violations in all sections as defined in Table A4/14 The computation of speed violations shall include all types of events (dwell, acceleration, cruising, and deceleration) but not soaking sections;

(g) Failure to run Trip #10 of the WLTP-Brake cycle during the cooling adjustment section or the entire WLTP-Brake cycle during the bedding and emissions measurement sections within the speed tolerances defined in this paragraph shall result in an invalid brake emissions test.

9.4.2. 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 A4/14 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 brake events of the WLTP-Brake cycle during the emissions measurement section as defined in this paragraph shall result in an invalid test.

9.4.3. Kinetic Energy Dissipation

The kinetic energy dissipation quality check is necessary to ensure the application of the correct amount of specific friction work (w_f) 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. This quality check applies to all brakes equipped on vehicles within the scope of this Regulation. The parameters of the brake corner emissions family parent vehicle shall be used for the calculations when testing non-friction braking.

A violation of the kinetic energy dissipation quality check occurs whenever the sum of the calculated specific 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) is outside the defined tolerances:

(a) Trip #10 upper specific friction work tolerance: 278 J/kg higher than the nominal specific friction work value of 5557 J/kg. Thus, the upper specific friction work tolerance is 5835 J/kg;

(b) Trip #10 lower specific friction work tolerance: 278 J/kg lower than the nominal specific friction work value of 5557 J/kg. Thus, the lower specific friction work tolerance is 5279 J/kg;

(c) WLTP-Brake cycle upper specific friction work tolerance: 799 J/kg higher than the nominal specific friction work value of 15986 J/kg. Thus, the upper specific friction work tolerance is 16785 J/kg;

(d) WLTP-Brake cycle lower specific friction work tolerance: 799 J/kg lower than the nominal specific friction work value of 15986 J/kg. Thus, the lower specific friction work tolerance is 15187 J/kg;

(e) During the cooling adjustment section, the calculated specific friction work over Trip #10 shall be between 5279 J/kg and 5835 J/kg. This corresponds to ±5 per cent of the nominal value;

(f) During the bedding section, the calculated specific friction work over the WLTP-Brake cycle shall be between 15187 J/kg and 16785 J/kg. This corresponds to ±5 per cent of the nominal value and applies to all five repetitions of the WLTP-Brake cycle;

(g) During the emissions measurement section, the calculated specific friction work over the WLTP-Brake cycle shall be between 15187 J/kg and 16785 J/kg. This corresponds to ±5 per cent of the nominal value. Soaking sections shall not be included in the calculation;

(h) The testing facility shall calculate the specific friction work for each brake event using the fast actual torque signal and the fast rotational speed signal of the test system. The integration shall start 1.0 s before the brake deceleration event starts until 1.0 s after the brake deceleration event ends according to Equation 9.1:

$$\mathrm{w}_{\mathrm{f,n}} = \frac{2 \times \pi}{60} \cdot \frac{1}{WL_t} \cdot \int_{t=t_{start,nom,n}-1.0s}^{t_{end,nom,n}+1.0s} f(t) \cdot \tau(t) \cdot dt \qquad \text{(Eq. 9.1)}$$

Where:

$w_{f,n}$ is the specific friction work of the n[th] brake deceleration event in J/kg;

WL_t	is the test (or applied) wheel load in kg per Table A4/3;
$t_{start,nom,n}$	is the start time of the n^{th} nominal brake deceleration event in s;
$t_{end,nom,n}$	is the end time of the n^{th} nominal brake deceleration event in s;
f(t)	is the fast rotational speed signal in 1/min;
τ_{brake}	is the fast brake torque signal in N·m;

Both, brake deceleration event start time and brake deceleration end time for each event is identified based on fast nominal linear speed. The acceleration is calculated based on the fast nominal speed. A specific brake event starts at the first time this acceleration value exceeds 0.25 m/s^2 and ends at the first time this acceleration value falls below 0.25 m/s^2.

(i) Equation 9.1 provides the specific 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 specific friction work by summing the calculated specific friction work from the individual brake events. The total specific friction work shall be compared to the prescribed (nominal) specific friction work value as described in points (a)-(c) of this paragraph;

(j) Failure to complete any of the sections of the brake emissions test with a total specific friction work within the tolerances defined in this paragraph shall result in an invalid test.

10. Cooling Airflow Adjustment

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

10.1. Method Description

10.1.1. Definition of Brake Assembly Groups and Verification Parameters

To determine the appropriate cooling airflow for the brake under testing, the testing facility shall first classify the brake into a nominal front wheel load (WL_{n-f}) to disc or drum (in case a drum is used as a front brake) mass (DM) group according to its (WL_{n-f}/DM) ratio.

The WL_{n-f}/DM ratio is calculated by dividing the WL_{n-f} (kg) by the pre-test disc or drum (in case a drum is used as a front brake) mass (kg). The testing facility shall determine the WL_{n-f} following the specifications described in paragraph 8.1. (c).

Four different groups are defined based on the WL_{n-f}/DM ratio: Group 1 with $WL_{n-f}/DM \leq 45$; Group 2 with $45 < WL_{n-f}/DM \leq 65$; Group 3 with $65 < WL_{n-f}/DM \leq 85$; Group 4 with $WL_{n-f}/DM > 85$.

The testing facility shall apply the test wheel load (WL_t) described in paragraph 8.1. (d) – and not the nominal wheel load (WL_n) – 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 WL_{n-f}/DM group. The testing facility shall use the following parameters as a reference against which the cooling adjustment test results shall be compared:

(a) Average brake temperature over Trip #10 of the WLTP-Brake cycle (ABT);

(b) Average initial brake temperature of six selected brake events from Trip #10 of the WLTP-Brake cycle (IBT);

(c) Average final brake temperature of six selected brake events from Trip #10 of the WLTP-Brake cycle (FBT).

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 A4/4 When the entire WLTP-Brake cycle is considered, the brake events' corresponding sequence numbers are #235, #290, #291, #292, #293, and #295.

Table A4/4

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

10.1.2. Verification of Parameters and Tolerances for Brake Temperature

The target values and the corresponding tolerances for the three check parameters are given in Table A4/5

Table A4/5

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

Group	*ABT [A_1]*	*IBT [A_2] ± Tolerance*	*FBT [A_3] ± Tolerance*
$WL_{n-f}/DM \leq 45$	≥ 50 °C	65 ± 25 °C	95 ± 35 °C
$45 < WL_{n-f}/DM \leq 65$	≥ 55 °C	75 ± 25 °C	115 ± 35 °C
$65 < WL_{n-f}/DM \leq 85$	≥ 60 °C	85 ± 25 °C	130 ± 35 °C
$WL_{n-f}/DM > 85$	≥ 65 °C	95 ± 25 °C	150 ± 35 °C

(a) The target values and the corresponding tolerances for the three check parameters apply to all types of front brakes mounted in all types of vehicles within the scope of this Regulation, except for carbon-ceramic disc brakes. For carbon-ceramic disc brakes, the default temperature metrics apply; however, the ABT [A_1] temperature metrics are lowered by 15 °C and the tolerances to the low end of the temperature regime are extended to -40 °C for the IBT [A_2] and to -50 °C for the FBT [A_3];

(b) 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 WL_{n-f}/DM category described in paragraph 10.1.1. shall be carried out using the front brake data;

(c) 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 WL_{n-f}/DM category described in paragraph 10.1.1. shall be carried out using the front brake data.

10.1.3. Computation of Verification Parameters and Acceptance Criteria

Once the brake is classified to its WL_{n-f}/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 A4/6 The testing facility shall apply the WL_{t-f} as defined in paragraph 8.1. (d) to conduct the cooling air adjustment according to paragraph 10.1.4. The measured values for the check parameters shall be calculated using the produced test report files as follows:

(a) Average brake temperature over Trip #10 of the WLTP-Brake cycle (ABT):

(i) The target value (A_1) depends on the WL_{n-f}/DM Group and is defined in Table A4/5;

(ii) The measured value (B_1) is calculated from the Time-Based file of the brake emissions test as defined in Table A4/14;

(iii) B_1 equals the average of all brake temperature entries corresponding to the entire duration of Trip #10 (5272 s).

(b) Average initial brake temperature of selected brake events from Trip #10 of the WLTP-Brake cycle (IBT):

(i) The target value (A_2) and tolerances depend on the WL_{n-f}/DM Group and are defined in Table A4/5;

(ii) The measured value (B_2) is calculated from the Event-Based file of the brake emissions test as defined in Table A4/14;

(iii) B2 equals the average temperature value of the individual IBT values recorded for each of the six selected brake events described in Table A4/4 The testing facility shall calculate B2 following Equation 10.1.

$$B_2 = (Y_1 + Y_2 + Y_3 + Y_4 + Y_5 + Y_6)/6 \qquad \text{(Eq. 10.1)}$$

Where:

B_2 is the average IBT of selected brake events from Trip #10 of the WLTP-Brake cycle in °C;

Y_1 is the IBT of brake event #46 from Trip #10 of the WLTP-Brake cycle in °C;

Y_2 is the IBT of brake event #101 from Trip #10 of the WLTP-Brake cycle in °C;

Y_3 is the IBT of brake event #102 from Trip #10 of the WLTP-Brake cycle in °C;

Y_4 is the IBT of brake event #103 from Trip #10 of the WLTP-Brake cycle in °C;

Y_5 is the IBT of brake event #104 from Trip #10 of the WLTP-Brake cycle in °C;

Y_6 is the IBT of brake event #106 from Trip #10 of the WLTP-Brake cycle in °C.

(c) Average final brake temperature of selected brake events from Trip #10 of the WLTP-Brake cycle (FBT):

(i) The target value (A_3) and tolerances depend on the WL_{n-f}/DM Group and are defined in Table A4/5;

(ii) The measured value (B_3) is calculated from the Event-Based file of the brake emissions test as defined in Table A4/14;

(iii) B_3 equals the average temperature value of the individual FBT values recorded for each of the six selected brake events described in Table A4/4 The testing facility shall calculate B_3 following Equation 10.2.

$$B_3 = (Z_1 + Z_2 + Z_3 + Z_4 + Z_5 + Z_6)/6 \qquad \text{(Eq. 10.2)}$$

Where:

B_3 is the average FBT of selected brake events from Trip #10 of the WLTP-Brake cycle in °C;

Z_1 is the FBT of brake event #46 from Trip #10 of the WLTP-Brake cycle in °C;

Z_2 is the FBT of brake event #101 from Trip #10 of the WLTP-Brake cycle in °C;

Z_3 is the FBT of brake event #102 from Trip #10 of the WLTP-Brake cycle in °C;

Z_4 is the FBT of brake event #103 from Trip #10 of the WLTP-Brake cycle in °C;

Z_5 is the FBT of brake event #104 from Trip #10 of the WLTP-Brake cycle in °C;

Z_6 is the FBT of brake event #106 from Trip #10 of the WLTP-Brake cycle in °C.

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 A4/5 The difference between the target and test results for the check temperature parameters shall be calculated following Equations 10.3, 10.4, and 10.5:

$$C_1 = B_1 - A_1 \qquad \text{(Eq. 10.3)}$$

Where:

C_1 is the difference in average brake temperatures over Trip #10 of the WLTP-Brake cycle in °C;

B_1 is the measured ABT over Trip #10 of the WLTP-Brake cycle in °C;

A_1 is the target ABT over Trip #10 of the WLTP-Brake cycle in °C per Table A4/5

$$C_2 = |B_2 - A_2| \qquad \text{(Eq. 10.4)}$$

Where:

C_2 is the absolute difference in average IBT of the selected events in °C;

B_2 is the average IBT of selected brake events from Trip #10 of the WLTP-Brake cycle in °C;

A_2 is the target IBT of the selected Trip #10 brake events in °C per Table A4/5

$$C_3 = |B_3 - A_3| \qquad \text{(Eq. 10.5)}$$

Where:

C_3 is the absolute difference in average FBT of the selected events in °C;

B_3 is the average FBT of selected brake events from Trip #10 of the WLTP-Brake cycle in °C;

A_3 is the target FBT of the selected Trip #10 brake events in °C per Table A4/5

The testing facility shall compare the obtained results with the acceptance criteria as shown in Table A4/6

Table A4/6
Calculation of brake temperature metrics and acceptance criteria during Trip #10

Trip #10 Event	*Metric*	*Target Temperature*	*Cooling Adjustment Test Temperature*	*Difference*	*Acceptance Criteria*
–	*ABT*	A_1	B_1	C_1 *per Equation 10.3*	$C_1 \geq 0$ °C
–	*Average IBT*	A_2	B_2 *per Equation 10.1*	C_2 *per Equation 10.4*	$C_2 \leq 25$ °C
#46			Y_1	N/A	N/A
#101			Y_2		
#102			Y_3		
#103			Y_4		
#104			Y_5		
#106			Y_6		
–	*Average FBT*	A_3	B_3 *per Equation 10.2*	C_3 *per Equation 10.5*	$C_3 \leq 35$ °C
#46			Z_1	N/A	N/A
#101			Z_2		
#102			Z_3		
#103			Z_4		
#104			Z_5		
#106			Z_6		

(d) All three criteria shall be fulfilled for the successful completion of the cooling airflow adjustment section. In case the cooling adjustment test does not meet all metrics from Table A4/5, the testing facility shall repeat the procedure adjusting the cooling airflow accordingly. If multiple cooling airflows meet the requirements for all metrics in Table A4/5, the testing facility shall select the cooling airflow that is closer to 950 $N\text{m}^3$/h and meets all requirements defined for isokinetic sampling in paragraph 12.;

(e) If there is no suitable cooling airflow meeting all three metrics specified in Table A4/5, the testing facility shall select a suitable cooling airflow that fulfils the acceptable criteria for at least two parameters, one of which shall always be the average Trip #10 temperature (ABT). In such a case, if the measured brake temperature for the failing metric (IBT or FBT) is below the lower threshold value specified in Table A4/5, the testing facility shall demonstrate that a test with the minimum operational flow of the system was performed. If the measured brake temperature for the failing metric (IBT or FBT) is higher than the upper threshold value specified in Table A4/5, the testing facility shall demonstrate that a test with the maximum operational flow of the system was performed. The corresponding Event-Based and Time-Based files for the non-successful cooling adjustment tests shall be included in the test output;

(f) If the maximum operational flow is applied and both the IBT and FBT are higher than the upper threshold values specified in Table A4/5, the testing facility shall perform the bedding and emissions measurement section applying the maximum operational flow of the system. In such a case, the reporting data shall include the ABT, IBT, and FBT values derived from the cooling adjustment section with the application of the maximum operational flow. The corresponding Event-Based and Time-Based files shall be included in the test output. If the minimum operational flow is applied and both the IBT and FBT are below the lower threshold values specified in Table A4/5, the testing facility shall perform the bedding and emissions measurement section applying the minimum operational flow of the system. In such a case, the reporting data shall include the ABT, IBT, and FBT values derived from the cooling adjustment section with the application of the minimum operational flow. The corresponding Event-Based and Time-Based files shall be included in the test output;

(g) If the minimum operational flow is applied and all three temperature metrics are below the lower threshold values specified in Table A4/5, the cooling air adjustment shall be considered invalid.

10.1.4. Brake Dynamometer Testing to Adjust the Cooling Airflow

The test facility shall use the front axle to determine the cooling airflow for both axles—irrespective of the type or size of the brake mounted on the rear axle. The testing facility shall carry out the following steps to adjust the cooling airflow when testing a brake for the first time on a given dynamometer for a given vehicle:

(a) Follow the test setup preparation specifications described in paragraph 8.2.;

(b) Adjust the cooling airflow to a known value used for similar brakes. In the absence of a useful reference, use 950 *N*m³/h to start the test;

(c) Perform 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.;

(d) Perform the calculations using paragraph 10.1.3. and assess the results and deviations for the target parameters;

(e) If the test run meets all the metrics from Table A4/5, finish the process and prepare the test report in accordance with the specifications described in paragraph 13. In this case, the cooling airflow used in (b) is defined as the nominal airflow for the given brake (Q_{set});

(f) In the case of front brakes, 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 testing facility shall use a new set of brake parts to perform bedding and emissions testingThe testing facility may use the same calliper as during the cooling air adjustment section for both bedding and emissions testing sections;

(g) In the case of rear brakes, proceed with the subsequent sections of the brake emissions test ensuring the application of the appropriate dynamometer settings for the rear axle. The required cooling airflow shall be the same as the value determined for the front axle brake of the corresponding vehicle. If different front axle brake cooling airflows meet the requirements for all metrics in Table A4/5, the testing facility shall select the cooling airflow that is closer to 950 *N*m³/h provided that it meets the requirements defined for isokinetic sampling in paragraph 12.;

(h) If the test run does not meet all the metrics from Table A4/5, use sound engineering judgement to determine a new cooling airflow level and repeat the process from step (a). The same set of brakes may be used for repeating the cooling airflow adjustment section; however, it shall always be replaced by new parts for bedding and emissions measurement sections.

11. Bedding Section

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

11.1. 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 Regulation in accordance with the specifications described below:

(a) Set the cooling airflow according to the adjustment of the cooling settings for the brake under testing as specified in paragraph 10.1.;

(b) 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;

(c) Apply five repetitions of the WLTP-Brake cycle for complete bedding of the front brake under testing;

(d) 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.;

(e) 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 Trip #10 of a given WLTP-Brake cycle and Trip #1 of the following WLTP-Brake cycle);

(f) Commence the first WLTP-Brake cycle of the bedding section at a brake temperature of (23 ± 5) °C. Commence the subsequent four repetitions of the WLTP-Brake cycle in accordance with the temperature provisions described in paragraph 9.2.2.;

(g) 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 such a case, the testing facility shall replace them 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 such a 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.

11.2. 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 Regulation in accordance with the specifications described below:

(a) Use the cooling airflow according to the adjustment of the cooling settings for the corresponding front brake as specified in paragraph 10.1. In case of multiple compliant airflows, select the airflow that is closer to 950 $N\text{m}^3$/h per paragraph 10.1.4. (g);

(b) Define all relevant testing parameters and dynamometer settings (testing wheel load, brake test inertia, etc.) for the rear axle and use the same in the emissions measurement section;

(c) Apply five repetitions of the WLTP-Brake cycle for complete bedding of the rear brake under testing;

(d) 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.;

(e) 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 Trip #10 of a given WLTP-Brake cycle and Trip #1 of the following WLTP-Brake cycle);

(f) Commence the first WLTP-Brake cycle of the bedding section at a brake temperature of (23 ± 5) °C. Commence the subsequent four repetitions of the WLTP-Brake cycle following the temperature provisions described in paragraph 9.2.2.;

(g) 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 such a case, the testing facility shall replace them 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 such a 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.

12. Emissions Measurements Section

12.1. Measurement of Particulate Matter Mass

This paragraph describes the specifications for the particulate matter (PM) emissions measurement during a brake emissions test. The PM sampling system enables the quantification of the PM mass generated by the brake 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 PM_{10} and $PM_{2.5}$ emissions gravimetrically using a separate sampling systems for each cut-off diameter (2.5 μm and 10 μm)].Each PM sampling system shall consist of the following elements:

(a) One PM sampling probe located in the tunnel. The specifications for the design of the PM sampling probe are described in paragraph 12.1.1.2.;

(b) An appropriate sampling nozzle installed at the tip of the PM sampling probe. The specifications for the design of the nozzle are described in paragraph 12.1.1.3.;

(c) A cyclone applied as a PM separation device. The specifications for the cyclone are described in paragraph 12.1.2.1.;

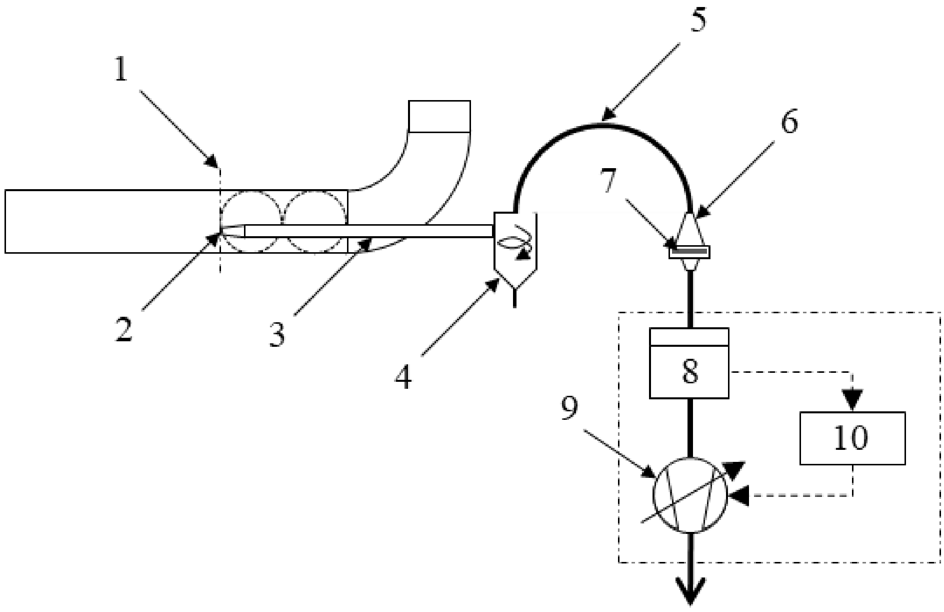
(d) A particle sampling line to transfer the aerosol from the PM separation device to the filter holder. The specifications for the design of the sampling line are described in paragraph 12.1.2.2.;

(e) A filter placed inside the filter holder to collect the particulate matter. The specifications for the filter holder are described in paragraph 12.1.3.1.;

(f) 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.

In general, the setup (separate parts and connections) must be of electrically conductive materials that do not react with the brake particles and electrically grounded to avoid electrical/electrostatic effects. Figure A4/16 illustrates an indicative setup of the PM sampling unit. The positioning and dimensions of the different elements are provided for illustrative purposes; therefore, exact conformance with the figure is not required.

Figure A4/16
Indicative setup of the PM sampling system



1 – Sampling plane. 2 – Sampling nozzle. 3 – PM sampling probe. 4 – PM cyclonic separator. 5 – PM sampling line. 6 – PM (multi) filter holder. 7 – PM sampling filter. 8 – Mass or volumetric flow measurement. 9 – Pump. 10 – Flow controller

12.1.1. Particulate Matter Extraction

12.1.1.1. Sampling Plane

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

(a) Apply two sampling probes with the corresponding sampling nozzles for the PM measurements, one for $PM_{2.5}$ and one for PM_{10}. White dots in Figure A4/7 indicate the PM sampling probes;

(b) Place the two PM sampling probes ($PM_{2.5}$ and PM_{10}) at the same horizontal plane to the lower part of the tunnel as shown in Figure A4/7;

(c) Do not use flow splitters for PM measurements anywhere in the sampling and measurement system.

12.1.1.2. PM Sampling Probes

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

(a) Probes shall be appropriately designed to minimise particle losses from the nozzle tip to the separation device;

(b) Probes shall be made of electrically conductive materials that do not react with brake particles. The probes shall be electrically grounded to avoid electrical/electrostatic effects. Probes shall be made of stainless steel with an electropolished finish (or equivalent) to the inside to attain an ultra-clean and ultra-fine surface;

(c) Probes shall have a constant inner diameter (d_p) of at least 10 mm and a maximum inner diameter of 18 mm ensuring a laminar flow (10 mm $\leq d_p \leq$ 18 mm);

(d) The sampling probes shall be designed to aim for the shortest possible length to minimise losses and possible tubing contamination. The overall length of the probes from the sampling nozzle tip to the inlet of the PM separation device shall not exceed 1 m;

(e) 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;

(f) If a bend is applied to the probes, the bending radius r_b shall be at least four times the inner diameter ($4 \cdot d_p$) of the probes.

Inspect and clean the inner walls of the sampling probes frequently following the specifications of their manufacturer regarding method and frequency. If no such specifications are provided clean the probes at least once every two months of active use.

12.1.1.3. PM Sampling Nozzles

Appropriate nozzles to ensure isokinetic sampling for PM_{10} and $PM_{2.5}$ shall be used. The sampling nozzles shall meet the following requirements:

(a) Nozzles shall be compatible with the PM sampling probes used by the testing facility for brake emissions testing;

(b) Nozzles shall be made of stainless steel with an electropolished finish (or equivalent) to the inside to attain an ultra-clean and ultra-fine surface;

(c) Appropriate nozzles shall be used to achieve an isokinetic ratio (*IR*) of 1.0 in accordance with 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 ($0.90 \leq IR \leq 1.15$);

(d) The nozzle size shall be selected depending on the applied sampling flow. Nozzles shall have an inner diameter (d_n) of at least 4 mm;

(e) The nozzles shall have a constant inner diameter along a length equal to at least one inner diameter or at least 10 mm from the nozzle tip, whichever is greater;

(f) Nozzles shall have 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;

(g) Any variation in the bore diameter of the nozzles shall be tapered with a conical angle of less than 30°;

(h) Nozzles shall be placed with their axis parallel to that of the sampling tunnel making sure that the aspiration angle remains lower or equal to 15°.

The testing facility shall clean the nozzles frequently following the specifications of their manufacturer regarding method and frequency. If no such specifications are provided clean the probes before every brake emissions test following the specifications defined by their manufacturer regarding the cleaning means.

12.1.2. PM sampling

12.1.2.1. PM Separation Device

Single cyclonic separators followed by gravimetrical filter holders shall be used for the collection of the PM_{10} and $PM_{2.5}$ samples. The testing facility shall select cyclonic separators following the provisions described below:

(a) Commercially available cyclonic separators with cut-off sizes of 10 µm and 2.5 µm for the collection of the PM_{10} and $PM_{2.5}$ samples, respectively shall be used;

(b) The PM_{10} and $PM_{2.5}$ cyclones shall fulfil the specifications for the separation efficiency described in Tables A4/7 and A4/8, respectively;

(c) The cyclone shall be made of electrically conductive materials that do not react with brake particles. It shall be electrically grounded to avoid electrical/electrostatic effects;

(d) Place the cyclonic separators 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.

The testing facility shall inspect and clean the inner walls of the cyclones frequently following the specifications of the instrument manufacturer regarding the method and frequency.

Table A4/7
Separation efficiency specifications of PM_{10} cyclonic separator

PM_{10}	*4 µm*	*8 µm*	*12.5 µm*	*20 µm*
Separation Efficiency	< 20 %	< 50 %	> 60 %	> 90 %

Table A4/8
Separation efficiency specifications of $PM_{2.5}$ cyclonic separator

$PM_{2.5}$	*1.5 µm*	*2 µm*	*3 µm*	*4 µm*

$PM_{2.5}$	*1.5 µm*	*2 µm*	*3 µm*	*4 µm*
Separation Efficiency	< 20 %	< 50 %	> 60 %	> 90 %

12.1.2.2. 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:

(a) The sampling line shall be appropriately designed to minimise particle transport losses between the outlet of the cyclonic separator and the inlet of the filter holder;

(b) The sampling line shall be made of conductive stainless steel with the appropriate fittings. Alternatively, flexible antistatic polytetrafluoroethylene (PTFE) sampling lines may be used;

(c) The sampling line shall have a constant inner diameter (d_s) of at least 10 mm and a maximum of 20 mm (10 mm $\leq d_s \leq$ 20 mm);

(d) The overall length of the sampling line from the outlet of the cyclonic separator to the tip of the filter holder shall not exceed 1 m in total;

(e) The PM sampling system's part outside the tunnel (the part of the PM sampling system that includes the cyclonic separator and the PM sampling line) shall be designed in a way that no condensation of water can occur. The temperature inside the sample train shall always remain above 15 °C;

(f) A bend may be applied to the sampling line provided that the bending radius r_b is at least twenty-five times the inner diameter ($25 \cdot d_s$) of the sampling line.

12.1.2.3. PM Sampling Flow

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

(a) The method of measuring the flow of the sampling system ($Q_{PM2.5}$ and Q_{PM10}) 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;

(b) A flow measurement device calibrated to report flow at standard conditions shall be used. When the flow measurement device is not calibrated to report values at standard conditions, it shall include a temperature sensor installed before the measuring device. To ensure an appropriate conversion, the temperature sensor shall have an accuracy of ±1.0 °C and the pressure measurement shall have an accuracy of ±1.0 kPa; this measurement shall be used to convert flow values;

(c) The set (nominal) values for the sampling volumetric flows ($Q_{PM2.5\text{-}set}$ and $Q_{PM10\text{-}set}$) shall be constant during the emissions measurement section of the brake under testing;

(d) The average sampling volumetric flow shall be within ±2 per cent of the set value for the given brake emissions test. A device with a flow control feature (e.g. critical orifice, pressure regulator, feedback controller, or other) shall be used to ensure a stable flow through the filter medium;

(e) Calculate and report the deviation of the average measured sampling volumetric flow from the set value for both PM_{10} and $PM_{2.5}$ using the data of the given parameters in the Time-Based file as defined in Table A4/14;

(f) The sampling flow shall be set 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 shall be between 0.90-1.15 (paragraph 12.1.2.4.). Calculate and report the average isokinetic ratio for both $PM_{2.5}$ and PM_{10} following the procedure described in paragraph 12.1.2.4.;

(g) Checks for possible leaks by sealing the nozzle and starting the suction device shall be undertaken. 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 following the manufacturer's specifications;

(h) In case the sampling volumetric flow and/or the isokinetic requirements set out in this paragraph are not met, the test shall be invalid;

(i) The PM sampling device shall operate continuously during the brake emissions measurement section. This also includes 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. The PM sampling device shall operate for at least 10 s more after the end of the brake emissions measurement section.

12.1.2.4. Isokinetic Ratio

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

$$U = (4 \times 1000 \times Q)/(\pi \times d_i^2) \qquad \text{(Eq. 12.1)}$$

$$U_S = (4 \times 1000 \times Q_S)/(\pi \times d_n^2) \qquad \text{(Eq. 12.2)}$$

Where:

U is the average airspeed in the tunnel in km/h;

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

Q is the average airflow in the tunnel in m³/h per Table A4/10;

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

d_n is the inner diameter at the nozzle tip in mm;

d_i is the sampling tunnel's inner diameter in mm per Table A4/1

The isokinetic ratio is defined as the ratio of the airspeed in the sampling nozzle to the airspeed in the sampling 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:

$$IR = (NQ_S/d_n^2)/(NQ/d_i^2) \qquad \text{(Eq. 12.3)}$$

Where:

IR is the isokinetic ratio;

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

NQ is the average normalised airflow in the sampling tunnel in *N*m³/h per Table A4/10;

d_n is the inner diameter at the nozzle tip in mm;

d_i is the sampling tunnel's inner diameter in mm per Table A4/1

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.

$$IR = 0.06 \times (NQ_S/d_n^2)/(NQ/d_i^2) \qquad \text{(Eq. 12.4)}$$

Where:

IR is the isokinetic ratio;

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

NQ is the average normalised airflow in the sampling tunnel in *N*m³/h per Table A4/10;

d_n is the inner diameter at the nozzle tip in mm;

d_i is the sampling tunnel's inner diameter in mm per Table A4/1

The testing facility shall calculate the average isokinetic ratio during the emissions measurement section of a brake emissions test for both $PM_{2.5}$ and PM_{10}, separately, using Equation 12.4:

(a) Use the corresponding values for the isokinetic nozzle inner diameters for $PM_{2.5}$ ($d_{n-PM2.5}$) and PM_{10} (d_{n-PM10}) sampling;

(b) Use the data of the average normalised tunnel flow (*N*Q) and the average normalised sample flows ($NQ_{PM2.5}$ and NQ_{PM10}) in the Time-Based file;

(c) Report the calculated values as specified in Table A4/14

12.1.3. Sampling Media

12.1.3.1. 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:

(a) Select a filter holder made of inert and non-corroding material such as stainless steel or anodised aluminium. All parts of the filter holder in contact with the aerosol and filters shall be electrically conductive and grounded;

(b) Use a filter holder suitable for the insertion of circular filters. The diameter of the exposed area through which the sampled air passes (i.e. filter stain area) shall be between 34 mm and 44 mm;

(c) Use a filter holder that provides an even flow distribution across the filter stain area;

(d) 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 paragraph 12.1.2.2. and shall remain above 15 °C during the entire brake emissions test.

Multi-filter holders may be used for the PM samples collection. Multi filter-holders shall fulfil the following requirements in addition to those defined in points (a)-(d) of this paragraph:

(e) All filters shall be placed in the same multi-filter holder device under the same conditions within a closed housing to avoid contamination;

(f) Use only one filter at a time for the PM sampling during each section of a given brake emissions test;

(g) The use of a multi-filter holder device shall not introduce any change in the flow direction prior to or within the multi-filter holder device.

A multi-filter holder that introduces changes in the flow direction is permitted if it proves its equivalency to a filter holder (multi or single) with no flow direction change. Existing design criteria of this Regulation for sampling assembly regarding electropolished surfaces (if applicable), smooth transitions and sampling line bend limits shall be fulfilled. The equivalency shall be proved by performing at least three repetitions with at least two tunnel flowrates with the two filter holders measuring simultaneously. The test shall include repetitions of swapping the sampling position of the two filter holders. The average of the difference between the two filter holders shall be within ±2% and one standard deviation of the differences shall be within ±3%. The criteria shall be fulfilled by both PM2.5 and PM10. It is recommended to assess the multi-filter holders at mass filter loading in the range of 0.3-1.0 mg.

12.1.3.2. Sampling Filters

Fluorocarbon-coated glass fibre filters or fluorocarbon membrane filters shall be used for the PM_{10} and $PM_{2.5}$ 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:

(a) U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 102.8: DOP-Smoke Penetration of Aerosol-Filter Element;

(b) U.S.A. Department of Defense Test Method Standard, MIL-STD-282 method 502.1.1: DOP-Smoke Penetration of Gas-Mask Canisters;

(c) 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.

12.1.4. Weighing Procedure

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

(a) 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;

(b) Weighing balance – Use the same microbalance for both pre-sampling and post-sampling weighing for 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 – in accordance with 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. The microbalance shall fulfil the calibration requirements described in paragraph 14.4.;

(c) Static electricity effects – Nullify the effects of static electricity by grounding the balance through placement upon an antistatic mat and neutralising the particle sampling filters before weighing using a polonium neutralizer or a device of similar effect. Alternatively, nullify static effects through equalisation of static charge;

(d) 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 weighing. Weigh the filter at the end of the stabilisation 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. Place the filter in the filter holder within 1h of its removal from the weighing chamber (or room). Use the closed petri dish (or equivalent) or sealed filter holder to transfer the filter to the test rig. Alternatively, mount the filter in the filter holder already in the weighing chamber;

(e) Post-sampling conditioning and weighing – Take the filters to the conditioning room within 8 hours after testing is completed. The filters may remain in the testing room (i.e. the room where the filter holder is located) for a longer period of time provided that they remain sealed within the filter holder and that the temperature in the testing room remains within (15-30) °C. Use a closed petri dish (or equivalent) or sealed filter holder to transfer the filter to the conditioning room. Alternatively, transfer the filter without removing it from the filter holder, ensuring that filter holders are not tilted during transfer. Condition/stabilise the filters at (22 ± 2) °C and (45 ± 8) per cent RH for a minimum of 2 hours. Weigh the filter at the end of the stabilisation 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;

(f) Reference filter weighing – Use reference filters to validate PM weighing following the procedure shown in Figure A4/17 and described below:

(i) At least two unused fluorocarbon coated glass fibre or fluorocarbon membrane reference filters that match each sampled filter media shall be weighed within 12 hours of the sample filter weighing;

(ii) If the reference filters are not weighed on a regular (at least daily) basis, they shall be weighed at the beginning and the end of a sample weighing session (before pre-sampling and after post-sampling weighing);

(iii) Compare the reference filter specific weights obtained in step (i) or (ii) to the rolling average of that reference filter's specific weights. The rolling average shall be calculated from the specific weights collected in the period since the reference filters were placed in the weighing room, including the weights measured in step (i) or (ii);

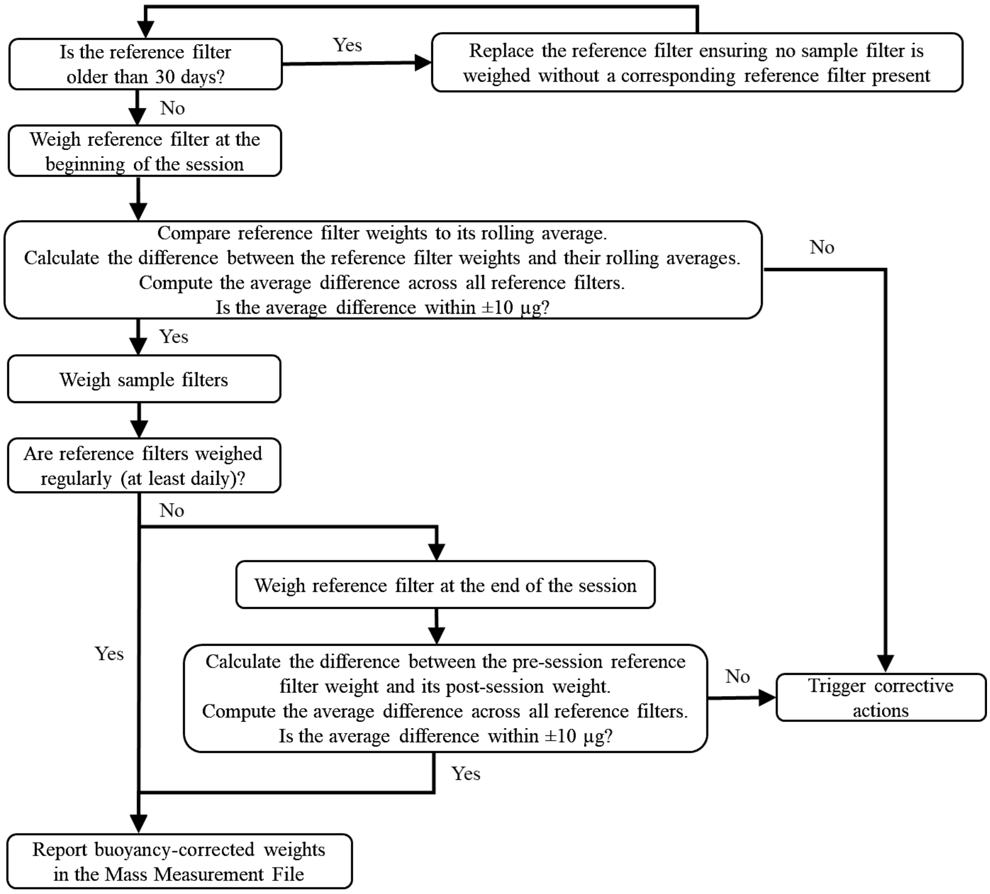
(iv) The average of the absolute values of the difference between the reference filter weights and their rolling average shall be less than 10 µg. Additionally, in the case of reference filters not weighed regularly, the average difference between the initial and final measurement for the reference filter shall be less than 10 µg;

(v) 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 two days;

(vi) Report only the buoyancy-corrected weights in the Mass Measurement File per paragraph 13.3.2.

Figure A4/17

Flowchart describing reference filter weighing procedure



(g) Sample filter weighing – Follow the procedure described below to perform both pre- and post-sampling filter weighing:

(i) Weigh the filter twice and report the buoyancy-corrected weights in the Mass Measurement File;

(ii) If the difference between the first and second measurements is 10 µg or less, use the arithmetic mean to calculate the $Pe_{(Uncorrected)}$ and $Pe_{(Corrected)}$ weights in accordance with point (h) of this paragraph;

(iii) If the difference between the first and second measurements is greater than 10 µg, perform two additional weighings and report the buoyancy-corrected weights in the Mass Measurement File;

(iv) When the difference between the minimum and maximum weights of the four measurements is 13 µg or less, use the arithmetic mean of the four weights to calculate the $Pe_{(Uncorrected)}$ and $Pe_{(Corrected)}$ weights in accordance with point (h) of this paragraph;

(v) When the difference between the minimum and maximum weights of the four measurements is greater than 13 µg and less than or equal to 15 µg, use the median of the four values to calculate the $Pe_{(Uncorrected)}$ and $Pe_{(Corrected)}$ weights in accordance with point (h) of this paragraph. The median value is the arithmetic mean of the second-lowest and the third-lowest values among the four weights taken;

(vi) When the difference between the minimum and maximum weights of the four measurements is greater than 15 µg invalidate the weighing session and quarantine the filter in the conditioning room. The testing facility may decide to void the filter and replace it with a new filter for a pre-sampling weighing session, or discard the filter and repeat the brake emissions test for a post-sampling weighing session;

(vii) After a minimum of 24h take the filter out of quarantine and weigh it twice in accordance with points (i) and (ii) in this paragraph;

(viii) If the difference between the first and second new measurements is greater than 10 µg, void the filter and reject the weighing session. Use a new filter for a pre-sampling weighing session, or discard the filter and repeat the brake emissions test for a post-sampling weighing session.

(h) 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. It does not account for the buoyancy of the particulate matter itself.

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

Use a density (p_w) 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 $PM_{2.5}$ and PM_{10} filters (pre- and post-sampling) following Equation 12.5. Report the corrected measurements in the Mass Measurement File:

$$\mathrm{Pe}_{(\mathrm{Corrected})} = \mathrm{Pe}_{(\mathrm{Uncorrected})} \times [1 - (\mathrm{p_a}/\mathrm{p_w})]/[1 - (\mathrm{p_a}/\mathrm{p_f})] \quad \text{(Eq. 12.5)}$$

Where:

$\mathrm{Pe}_{(\mathrm{Corrected})}$	is the corrected mass for each filter in mg;
$\mathrm{Pe}_{(\mathrm{Uncorrected})}$	is the uncorrected mass for each filter in mg;
$\mathrm{p_a}$	is the density of air in the balance room per Equation 12.6 in kg/m³;
$\mathrm{p_w}$	is the density of the calibration balance weight per paragraph (e);
$\mathrm{p_f}$	is the density of the (unused) 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.

$$\mathrm{p_a} = (\mathrm{p_b} \times \mathrm{M_{mix}})/(\mathrm{R} \times \mathrm{T_a}) \quad \text{(Eq. 12.6)}$$

Where:

p_a	is the density of air in the balance room in kg/m³;
p_b	is the atmospheric pressure in the balance room in kPa;
M_{mix}	is the molar mass of air in the balance room, 28.836 g mol^{-1};
R	is the molar mass constant, 8.3144 J mol^{-1} K^{-1};
T_a	is the air temperature in the balance room in K.

(i) 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 report both $PM_{2.5}$ ($Pe_{(2.5)}$) and PM_{10} ($Pe_{(10)}$) filter loads in the Mass Measurement File. Report the $PM_{2.5}$ and PM_{10} filter loads as specified in Table A4/14;

(j) 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.

12.1.5. PM Emission Factor Calculation

The testing facility shall report the PM emissions in mass per distance driven. Calculate the reference (or initial) $PM_{2.5}$ and PM_{10} emission factors of the tested brake (EF_{ref}) following Equations 12.7 and 12.8, respectively.

$$\mathrm{PM_{2.5}\ EF}_{ref} = \left[\mathrm{Pe}_{(2.5)} \times 1000 \times (NQ/60)/N\mathrm{Q}_{\mathrm{PM2.5}}\right]/\mathrm{d} \qquad \text{(Eq. 12.7)}$$

$$\mathrm{PM_{10}\ EF}_{ref} = \left[\mathrm{Pe}_{(10)} \times 1000 \times (NQ/60)/N\mathrm{Q}_{\mathrm{PM10}}\right]/\mathrm{d} \qquad \text{(Eq. 12.8)}$$

Where:

$\mathrm{PM_{2.5}\ EF}_{ref}$	is the reference $PM_{2.5}$ emission factor for the tested brake in mass per distance driven in mg/km;
$\mathrm{PM_{10}\ EF}_{ref}$	is the reference PM_{10} emission factor for the tested brake in mass per distance driven in mg/km;
$\mathrm{Pe}_{(2.5)}$	is the $PM_{2.5}$ filter mass load in mg per Table A4/11;
$\mathrm{Pe}_{(10)}$	is the PM_{10} filter mass load in mg per Table A4/11;
$N\mathrm{Q}$	is the average normalised airflow in the sampling tunnel in *N*m³/h per Table A4/10;
$N\mathrm{Q}_{\mathrm{PM2.5}}$	is the average normalised airflow in the $PM_{2.5}$ sampling nozzle in *N*l/min per Table A4/10;
$N\mathrm{Q}_{\mathrm{PM10}}$	is the average normalised airflow in the PM_{10} sampling nozzle in *N*l/min per Table A4/10;
d	is the total distance driven during the WLTP-Brake cycle in km per Table A4/10

(a) Calculate the PM masses ($Pe_{(10)}$ and $Pe_{(2.5)}$) as specified in paragraph 12.1.4. (i) after correcting the values for buoyancy as specified in paragraph 12.1.4. (h);

(b) Calculate the average normalised tunnel flow (*N*Q), the average normalised sampling flows ($NQ_{PM2.5}$ and NQ_{PM10}), and the total distance of the WLTP-Brake cycle (d) over the emissions measurement section from the given parameters in the Time-Based file;

(c) Calculate the $PM_{2.5}$ and PM_{10} EF_{ref} of the tested brake following Equations 12.7 and 12.8, respectively. Then, use the friction braking share coefficient either in Table 4 or measured according to Annex 5 of this Regulation to calculate the final $PM_{2.5}$ and PM_{10} EF of the tested brake. In case the friction braking share coefficient is taken from Table 4, apply the friction braking share coefficient that corresponds to the vehicle electrification type of which the parameters were used for testing the brake. Use Equations 12.9 and 12.10 for the calculation of the final $PM_{2.5}$ and PM_{10}, respectively:

$$\mathrm{PM}_{2.5}\ \mathrm{EF} = \mathrm{PM}_{2.5}\ \mathrm{EF}_{ref} * \mathrm{c} \qquad \text{(Eq. 12.9)}$$

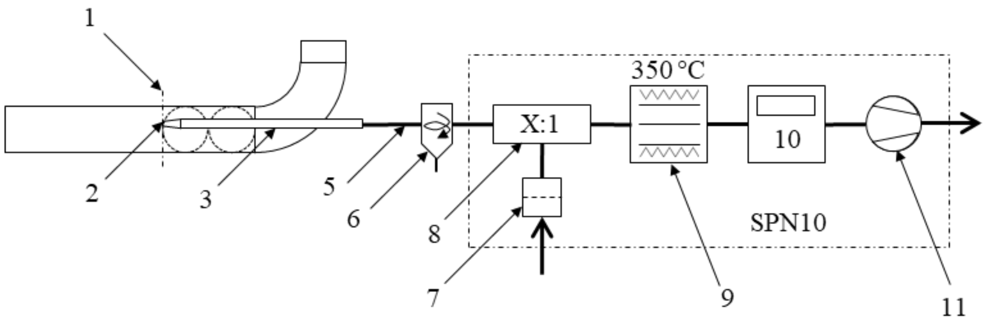
$$\mathrm{PM}_{10}\ \mathrm{EF} = \mathrm{PM}_{10}\ \mathrm{EF}_{ref} * \mathrm{c} \qquad \text{(Eq. 12.10)}$$

(d) Report the final $PM_{2.5}$ and PM_{10} EF as specified in Table A4/14.

12.2. 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 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.

Figure A4/18
Indicative setup of the PN sampling and measurement system



1 – Sampling plane. 2 – Sampling nozzle. 3 – PN sampling probe. 4 – Reserved. 5 – PN particle transfer tube. 6 – PN cyclonic separator. 7 – HEPA-filtered inlet for dilution air. 8 – Dilution stage. 9 – Volatile Particle Remover. 10 – Particle Number Counter with internal flow controller and mass or volumetric flow measurement. 11 – Pump

In general, the setup (separate parts and connections) must be of electrically conductive materials that do not react with the brake particles and electrically grounded to avoid electrical/electrostatic effects. Figure A4/18 illustrates an indicative PN sampling and measurement setup. The test system shall be capable of measuring Solid-PN (SPN10) at a nominal particle size of approximately 10 nm electrical mobility diameter and larger. The positioning and dimensions of the different elements are provided for illustration purposes; therefore, exact conformance with the figure is not required.

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

(h) A PN sampling probe that extracts a sample from the sampling tunnel. The specifications for the design of the PN sampling probe are described in paragraph 12.2.1.2.;

(i) An appropriate PN sampling nozzle that 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.;

(j) A suitable PTT that transfers aerosol from the outlet of the sampling probe to the inlet of the PN pre-classifier. When the PN 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 PN 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.;

(k) A PN pre-classifier that is applied to remove bigger particles. The specifications for the PN pre-classifier are described in paragraph 12.2.2.1.;

(l) A Volatile Particle Remover (VPR) that dilutes the sample and removes volatile particles prior to measuring PN. The specifications for the design of the VPR are described in paragraph 12.2.2.2.;

(m) An internal transfer line that transfers the aerosol from the outlet of the VPR to the inlet of the PNC. The specifications for the design of the transfer line are described in paragraph 12.2.2.3.;

(n) A PNC that measures the SPN10 concentration. The specifications for the PNC are described in paragraph 12.2.3.1.

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).

12.2.1. Sample Extraction

12.2.1.1. Sampling Plane

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

(a) Apply one sampling probe for the SPN10 emissions measurement. Black dots in Figure A4/7 indicate the PN sampling probes;

12.2.1.2. PN Sampling Probes

An appropriate PN sampling probe shall be used to extract the sample from the tunnel to the inlet of the particle transfer tube or the PN pre-classifier. The PN sampling probe shall meet the following design requirements:

(a) Use probe(s) appropriately designed to minimise particle losses from the nozzle tip to the inlet of the particle transfer tube;

(b) Use probe(s) made of electrically conductive materials that do not react with brake particles. The probes shall be electrically grounded to avoid electrical/electrostatic effects. Use probe(s) made of stainless steel with an electropolished finish (or equivalent) to attain an ultra-clean and ultra-fine surface;

(c) Select probe(s) with a constant inner diameter (d_p) of at least 10 mm and a maximum of 18 mm ensuring a laminar flow (10 mm $\leq d_p \leq$ 18 mm) under all operating conditions;

(d) The overall length of the probe(s) from the sampling nozzle tip to the inlet of the particle transfer tube or the PN pre-classifier shall not exceed 1 m;

(e) The residence time from the inlet of the nozzle tip to the inlet of the particle transfer tube or the PN pre-classifier shall be below 3s;

(f) A maximum of one bend of 90° may be applied to the probes provided that the bending radius r_b is at least four times the inner diameter ($4 \cdot d_p$) of the PN sampling probe(s).

12.2.1.3. 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 PN sampling nozzles for SPN10 sampling that meet the following requirements:

(a) Use nozzles made of stainless steel with an electropolished finish (or equivalent) to the inside to attain an ultra-clean and ultra-fine surface;

(b) Use the appropriate nozzles to achieve an isokinetic ratio in the range of 0.6 to 1.5;

(c) 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;

(d) 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;

(e) 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;

(f) Any variation in the bore diameter of the nozzles shall be tapered with a conical angle of less than 30°;

(g) Place the nozzles with their axis parallel to that of the sampling tunnel, making sure that the aspiration angle remains lower than or equal to 15°.

The testing facility shall clean the nozzles frequently following the specifications of their manufacturer regarding method and frequency. If no such specifications are provided clean the nozzels before every brake emissions test following the specifications defined by their manufacturer regarding the cleaning means.

12.2.1.4. Particle Transfer Tube

When the PN 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 PN pre-classifier's inlet. When the PN pre-classifier is directly connected to the probe's outlet, the PTT shall be used to transfer aerosol from the PN pre-classifier's outlet to the sample conditioning system's inlet. In any case, only a single PTT may be used, and its design shall meet the following requirements for SPN_{10} sampling:

(a) Use transfer tubes appropriately designed to minimise particle transport losses between the probe's outlet and the PN pre-classifier's inlet or the PN pre-classifier's outlet and the sample conditioning system's inlet;

(b) When there is a change in diameter between the probe's outlet and the PN pre-classifier's inlet or the PN pre-classifier's outlet and the sample conditioning system's inlet, use transfer tubes with gradual diameter changes;

(c) Use transfer tubes made of electrically conductive materials that do not react with brake aerosol components;

(d) Select transfer tubes with an inner diameter (d_{tt}) of at least 4 mm ensuring a laminar flow under all operating conditions;

(e) The length of the transfer tubes to sample flow ratio shall be below 60000 s/m²;

(f) The particles' residence time inside the transfer tubes shall be below 1 s;

(g) A bend may be applied to the transfer tubes provided that the bending radius r_b shall be at least twenty-five times the tube diameter ($25 \cdot d_{tt}$).

12.2.2. Sample Treatment and Conditioning

12.2.2.1. PN Pre-classifier

The testing facility shall use a cyclonic separator to protect the dilution system and the VPR from possible contamination. The testing facility shall ensure that the PN pre-classifier for SPN10 sampling and measurement meets the following requirements:

(a) Reserved;

(b) Reserved;

(c) Place the cyclonic separator either at the outlet of the sampling probe or at the inlet of the sample conditioning system;

(d) 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;

(e) The cyclone shall achieve a minimum penetration efficiency of 80 per cent for a particle diameter of 1.5 µm;.

(f) The cyclone shall be made of electrically conductive materials that do not react with brake particles. It shall be electrically grounded to avoid electrical/electrostatic effects.

The testing facility shall inspect and clean the inner walls of the cyclones frequently, following the specifications of the instrument manufacturer regarding the cleaning frequency and means.

12.2.2.2. 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:

(a) to (j) Reserved

SPN10

The volatile particle remover (VPR) shall comprise at least one initial 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 the aerosol when measuring SPN10:

(k) 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;

(l) 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;

(m) It shall be capable of maintaining the gas temperature below the maximum allowed inlet temperature specified by the PNC manufacturer;

(n) 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;

(o) 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;

(p) 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;

(q) It shall achieve a PCRF for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters per the method and requirements described in paragraph 14.5.2.;

(r) It shall monitor the dilution factor variation in real-time to report the arithmetic average PCRF ($f_{r\text{-}SPN10}$) at a frequency of 1Hz. The calculation of the arithmetic average PCRF shall follow the method described in paragraph 14.5.2.;

(s) It shall report PCRF-corrected SPN10 concentrations at standard conditions at a reporting frequency equal to or greater than 0.5Hz;

(t) It shall achieve more than 99.9 per cent vaporisation of tetracontane ($CH_3(CH2)_{38}CH_3$) 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;

(u) It shall achieve a solid particle penetration efficiency of at least 70 per cent for particles of 100 nm electrical mobility diameter;

(v) It shall be capable of operating at sample pressures in the 85 to 105 kPa range and relative pressure differences from ambient in the ±5 kPa range.

12.2.2.3. PN Internal Transfer Line

Lines that transfer the aerosol from the VPR to the inlet of the PNC shall meet the specifications described below:

(a) Use internal transfer lines appropriately designed to minimise particle transport losses between the VPR and the inlet of the PNC;

(b) Use internal transfer lines made of electrically conductive materials that do not react with brake aerosol components;

(c) Select internal transfer lines with a constant inner diameter (d_{tl}) of at least 4 mm ensuring a laminar flow under all operating conditions;

(d) The overall length of the internal transfer lines from the exit of the VPR to the inlet of the PNC shall not exceed 1 m;

(e) The particles' residence time inside the internal transfer lines shall be below 1 s;

(f) A bend may be applied to the PN internal transfer lines provided that the bending radius r_b is at least ten times the inner diameter ($10 \cdot d_{tl}$) of the internal transfer line.

12.2.3. Particle Measurement

12.2.3.1. Particle Number Counter

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

(a) Operate under full flow operating conditions;

(b) 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;

(c) Have readability of at least 0.1 #/cm³ at concentrations below 100 #/cm³;

(d) Have a linear response to particle concentrations over the full measurement range in single-particle count mode;

(e) Have a t_{90} response time over the measured concentration range of less than 5 s;

(f) 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;

(g) 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;

(h) 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;

(i) If the PNC makes use of a working liquid, it shall be replaced at the frequency specified by the instrument manufacturer.

12.2.3.2. 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):

(a) 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;

(b) A flow measurement device calibrated to report flow at standard conditions shall be used. When the flow measurement device is not calibrated to report values at standard conditions, it shall include a temperature sensor installed before the measuring device. To ensure an appropriate conversion, the temperature sensor shall have an accuracy of ±1.0 °C and the pressure measurement shall have an accuracy of ±1.0 kPa; this measurement shall be used to convert flow values;

(c) The actual normalised sampling flow (NQ_{SPN10}) 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;

(d) 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.;

(e) Ensure the average isokinetic ratio during the emissions measurement section of a specific brake is between 0.60 and 1.50;

(f) Use Equation 12.4 to calculate the average isokinetic ratio for SPN10. Use the corresponding values for the isokinetic nozzle inner diameters for SPN10 sampling. Use the data of the average normalised tunnel flow (*N*Q) and the average normalised sample flows NQ_{SPN10}) in the Time-Based file. Report the calculated values as specified in Table A4/14;

(g) If the sampling flow or the isokinetic requirements set out in this paragraph are not met, the test shall be invalid;

(h) 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. The PN sampling devices shall operate until the post-test background verification is completed.

12.2.4. PN Emissions Calculation

The testing facility shall report PN emissions in the number of particles per distance driven. The calculation of the reference (or initial) SPN10 emission factor for the tested brake (EF_{ref}) follows Equation 12.12.

Reserved (Eq. 12.11)

$$\mathrm{SPN10\ EF}_{ref} = 10^6 \times (\mathrm{SPN}_{10\,\#} \times N\mathrm{Q})/\mathrm{V} \qquad \text{(Eq. 12.12)}$$

Where:

$\mathrm{SPN10\ EF}_{\mathrm{ref}}$ is the number of SPN10 per distance driven for the tested brake in #/km;

$\mathrm{SPN}_{10\,\#}$ is the average normalised and PCRF-corrected SPN10 emissions in #/*N*cm³ per Table A4/10;

$N\mathrm{Q}$ is the average normalised airflow in the sampling tunnel in *N*m³/h per Table A4/10;

V is the average actual velocity of the WLTP-Brake cycle in km/h per Table A4/10

(a) Calculate the average normalised and PCRF-corrected SPN10 emissions from the given parameters in the Time-Based file;

(b) 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;

(c) Calculate the SPN10 EF_{ref} of the tested brake following Equation12.12. Then, use the friction braking share coefficient either in Table 4 or measured according to Annex 5 of this Regulation to calculate the final SPN10 EF of the tested brake. In case the friction braking share coefficient is taken from Table 4, apply the friction braking share coefficient that corresponds to the vehicle electrification type of which the parameters were used for testing the brake. Use Equation12.14 for the calculation of the final SPN10:

Reserved (Eq. 12.13)

$$\text{SPN10 EF} = \text{SPN10 EF}_{ref} * \text{c} \qquad \text{(Eq. 12.14)}$$

(d) SPN10 EF as specified in Table A4/14;

(e) In case the measured SPN10 emissions are out of the specified measurement range of the PNC device, the test shall be invalid.

12.2.5. PN System Verification Procedures

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

(a) 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;

(b) 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;

(c) The PNC shall report a measured concentration of less than 0.5 #/cm³ (without applying any PCRF correction) 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;

(d) 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.

12.3. Mass Loss Measurement

The mass loss of the brake under testing provides helpful information regarding the robustness and correctness of the overall test procedure. It can serve as an indicator of potential issues during the brake emissions test execution.

The testing facility shall measure the initial and final mass of the brake assembly before and after testing. Make sure not to disrupt the brake assembly during the brake emissions test. Since new parts shall be used after cooling air adjustment, the initial mass corresponds to the mass measured before commencing the bedding section and the final mass corresponds to the mass measured after the emissions measurement section. All measurements shall be carried out according to the following procedure:

(a) Vacuum-clean the parts before conducting the measurements to remove any possible contamination;

(b) Inspect all brake parts for burrs, cracks, voids, or detachments and record accordingly. If there are not such problems proceed with the initial measurements;

(c) Weigh each part separately with the thermocouple installed and the thermocouple connector removed (in the case of discs and drums). Report the initial mass in the Mass Measurement File;

(d) Weigh the brake friction material including the anti-noise shims, pad-shim springs, and other elements when part of the product assembly. Remove the adhesive tape from the brake pads, the grease if present on the friction material abutments, connectors, and other relevant removable components before weighing. The mass of removable components must be reflected in the same way (included or excluded) during both pre-testing and post-testing mass measurement. Report the initial masses in the Mass Measurement File;

(e) Use a weighing scale of a resolution of at least 0.1 g or better for parts below 20 kg of total weight. Use certified calibration weights to verify the stability and the proper function of the balance, regularly (Table A4/15). The microbalance shall fulfil the calibration requirements described in paragraph 14.4. It is recommended to install the weighing scale in a room with controlled air and humidity conditions of (22 ± 2) °C and (45 ± 8) per cent RH;

(f) After the end of the brake emissions test, ensure the brake parts are cool down to a temperature of 30 °C or below by storing them for a maximum of 24h in a room with controlled air and humidity conditions;

(g) After the brake parts cool down, clean the parts to remove any grease or contamination before performing the final mass measurements;

(h) Weigh the brake disc or drum and the brake pads or shoes separately. Report the final masses in the Mass Measurement File;

(i) 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 in the Mass Measurement File following the instructions defined in Table A4/13;

(j) Calculate the overall mass loss of the brake under testing 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 A4/13;

(k) 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 bedding and emission sections (i.e. 6 WLTP-Brake cycles). Report the averaged weight loss emission factor following the instructions defined in Table A4/13.

13. Test Output

This section describes the four main outputs of a brake emissions test. These include the Test Report file – which is the core report of the emissions test – and its supporting files (i.e. Event-Based, Time-Based, and Mass Measurement files). The outputs are summarised below:

(a) Event-Based file. A detailed description of the file and the required parameters is provided in paragraph 13.1.;

(b) Time-Based file. A detailed description of the file and the required parameters is provided in paragraph 13.2.;

(c) Mass-Measurement file. A detailed description of the file and the required parameters is provided in paragraph 13.3.;

(d) Test Report file. A detailed description of the file and the required parameters is provided in paragraph 13.4.

The labs shall keep records of the original measurements, including the relevant information from the soaking between the test events, in order to prove consistency and to be able to recalculate the test results upon request of the responsible authority.

13.1. Event-Based File

The testing facility shall generate an ODS Event-Based file for the brake emissions test. The file shall be named "Test ID_EBF" and 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. Each section of the brake emissions test shall be reported in a separate tab as follows:

(a) Tab 1 titled "Cooling" shall include the data for the parameters specified in this paragraph over the cooling adjustment section. Only data from the successful iteration of Trip #10 shall be reported in this tab when there are multiple iterations of Trip #10. Tab 1 shall include 114 rows with data representing the 114 brake events of Trip #10 of the cooling adjustment section. In the case of rear brakes, the data of the corresponding front brake cooling adjustment shall be reported;

(b) Tabs 2-6 titled "Bedding 1-5" shall include the data for the parameters specified in this paragraph over the bedding section. Each tab shall correspond to one repetition of the WLTP-Brake cycle. Each tab shall include 303 rows with data representing the 303 brake events of the WLTP-Brake cycle for each repetition of the bedding section. Tabs 2-6 shall not include data from the soaking sections applied between the 5 WLTP-Brake cycles;

(c) Tab 7 titled "Emissions" shall include the data for the parameters specified in this paragraph over the brake emissions measurement section. Tab 7 shall not include data from the soaking sections applied between the individual trips of the WLTP-Brake cycle. Tab 7 shall include 303 rows with data representing the 303 brake events of the WLTP-Brake cycle of the emissions measurement section.

The testing facility shall continuously and automatically sample and/or calculate the parameters listed in Table A4/9 All data in the Event-Based File shall be calculated using the raw sampled data. Details regarding the applied units, the number of decimals, and the sampling rate of each parameter are given in Table A4/9 Sampling rate in the context of this Regulation is the frequency with which the automation system samples and registers the various parameters. Failure to submit the Event-Based file as described above results in an invalid test.

Regardless of the sampling rate, in the Event-Based File the parameters shall be reported for each individual brake deceleration event. All evaluations for use in EBF file - except the calculation of friction work values (see paragraph 9.4.3 (h)) - shall be based on the actual brake deceleration event.

Both the actual start time and the actual end time of the deceleration event are identified based on fast actual brake torque. The actual brake event starts at the first time the actual brake torque exceeds 15 % of the nominal brake torque of the brake event. The actual brake event ends at the first time the actual brake torque value falls below 15 % of the nominal brake torque.

The nominal brake torque can be calculated according to Eq 13.1.

$$\tau_{brake,nom,n} = WL_t \cdot \frac{r_{R,b}}{1000} \cdot \frac{\mathrm{V_{set,start,n}} - \mathrm{V_{set,end,n}}}{3.6 \cdot (t_{end,nom,n} - t_{start,nom,n})} \quad \text{Eq. 13.1}$$

Where

$\tau_{brake,nom,n}$	is the nominal brake torque of brake event n in Nm
WL_t	is the test (or applied) wheel load in kg
$r_{R,b}$	is the tyre dynamic rolling radius at brake b in mm
$\mathrm{V_{set,start,n}}$	is the nominal linear speed at the beginning of n^{th} brake event of the WLTP-Brake cycle in km/h

$V_{set,end,n}$	is the nominal linear speed at the end of n[th] brake event of the WLTP-Brake cycle in km/h
$t_{start,nom,n}$	is the nominal start time of the n[th] brake event of the analysed cycle in s
$t_{end,nom,n}$	is the nominal end time of the n[th] brake event of the analysed cycle in s

The value of $\tau_{brake,nom,n}$ shall be reported in the event-based file, as indicated in Table 13.1, on the corresponding line.

Some of the parameters reported in the Event-Based file are defined by the actual brake event start and end time as they represent their instantaneous values at these timestamps (i.e. Time of Stop, Stop Duration, Initial Brake Temperature, Final Brake Temperature). The rest of the parameters shall be averaged (distance- or time-based) over the brake event to report a unique value for each parameter. The averaging of these parameters shall be performed using the 250Hz data sampled between the actual start and end point of the brake event.

Table A4/9

Necessary parameters for sampling and reporting at the Event-Based File of a brake emissions test

Measurand	*Symbol*	*Unit*	*Decimals*	*Description*	*Sampling Rate*	*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). It is not sampled but shall be automatically reported at the individual brake event level	N/A	A
Trip Stop Number	-	-	N/A	The serial number of the deceleration event within the individual trip (it can take values between 1 and 114). It is not sampled but shall be automatically reported at the individual brake event level	N/A	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). It is not sampled but shall be automatically reported at the individual brake event level	N/A	C
Stop Duration	t_{brake}	s	1	The total duration of the deceleration event. It is defined by the time at the beginning and by the time at the end of the deceleration event	250Hz	D
Time of Stop	-	hh:mm:ss	N/A	Time at the beginning of the deceleration event registered by the brake dynamometer	250Hz	E

Measurand	*Symbol*	*Unit*	*Decimals*	*Description*	*Sampling Rate*	*Column in the File*
Date of Stop	-	yyyy-mm-dd	N/A	Date at the beginning of the deceleration event registered by the brake dynamometer. It shall be automatically reported at the individual brake event level	N/A	F
Initial Brake Speed Setpoint	-	km/h	1	The nominal linear speed at the beginning of the deceleration event as defined in the WLTP-Brake cycle. It is not sampled but shall be automatically reported at the individual brake event level	N/A	G
Actual Initial Speed	-	km/h	2	The measured linear speed at the beginning of the actual brake deceleration event as defined in paragraph 3.4.16. of this Regulation	250Hz	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. It is not sampled but shall be automatically reported at the individual brake event level	N/A	I
Actual Release Speed	-	km/h	2	The measured linear speed at the end (release) of the actual brake deceleration event as defined in paragraph 3.4.16. of this Regulation	250Hz	J
Rotational Speed	f	rpm	2	Time-averaged rotational brake speed registered by the brake dynamometer. The rotational speed sampled during the brake event at 250Hz shall be reported at the individual brake event level as time averaged. Averaging shall be performed between the actual start and end time of the deceleration event	250Hz	K
Deceleration Rate Setpoint	-	m/s^2	3	Nominal deceleration rate of the event as defined in the WLTP-Brake cycle. It is not sampled but shall be automatically reported at the individual brake event level	N/A	L
Deceleration Rate Calculated	-	m/s^2	4	Deceleration rate of the given brake event as calculated from parameters in columns D, H, and J	N/A	M

Measurand	*Symbol*	*Unit*	*Decimals*	*Description*	*Sampling Rate*	*Column in the File*
Brake Torque – Distance Averaged	-	Nm	2	Distance averaged brake torque registered by the brake dynamometer. The brake torque sampled during the brake event at 250Hz shall be reported at the individual brake event level as distance averaged. Averaging shall be performed between the actual start and end time of the deceleration event	250Hz	N
Brake Pressure – Distance Averaged	-	kPa	2	Distance averaged brake pressure registered by the brake dynamometer. The brake pressure sampled during the brake event at 250Hz shall be reported at the individual brake event level as distance averaged. Averaging shall be performed between the actual start and end time of the deceleration event	250Hz	O
Brake effectiveness	μ or C*	-	3	Distance averaged friction coefficient as a function of braking torque, effective brake radius, and the piston area. The friction coefficient calculated from these parameters shall be reported at the individual brake event level as distance averaged. Averaging shall be performed between the actual start and end time of the deceleration event	N/A	P
Initial Brake Temperature	IBT	°C	2	Brake temperature at the beginning of the deceleration event measured as defined in paragraph 3.4.22. of this Regulation	250Hz	Q
Final Brake Temperature	FBT	°C	2	Brake temperature at the end of the deceleration event measured as defined in paragraph 3.4.23. of this Regulation	250Hz	R
Peak Brake Temperature	PBT	°C	2	Peak brake temperature of the deceleration event measured as defined in paragraph 8.3.	250Hz	S
Specific Friction Work	$w_{f,n}$	J/kg	1	Specific friction work of the brake deceleration event calculated as defined in paragraph 9.4.3. (h)	N/A	T
Nominal Brake Torque	$\tau_{brake,nom,n}$	Nm	2	Nominal Brake Torqe of the brake deceleration event calculated as defined in equation 13.1	1Hz	U
Deceleration Rate - Distance Averaged	-	m/s²	4	Distance averaged deceleration rate calculated at the individual brake event level.	N/A	V

13.2. Time-Based File

The testing facility shall generate an ODS Time-Based file for the brake emissions test. The file shall be named “Test ID_TBF” and shall include information about specific testing parameters sampled throughout the entire brake emissions test. Each section of the brake emissions test shall be reported in a separate tab as follows:

(a) Tab 1 titled “Pre-test BG” shall include the reported data for the parameters specified in this paragraph over the pre-test background verification procedure. Although the template is the same as for other sections of the brake emissions test, the testing facility may report only the relevant parameters necessary for the calculation of the background emissions as specified in paragraph 7.2.2.;

(b) Tab 2 titled “Cooling” shall include the reported data for the parameters specified in this paragraph over the cooling adjustment section. Only data from the successful iteration of Trip #10 shall be reported in this tab when there are multiple iterations of Trip #10. Tab 2 shall include 5272 rows with data representing the 5272 seconds of the Trip #10 of the cooling adjustment section. In the case of rear brakes, the data of the corresponding front brake cooling adjustment shall be reported;

(c) Tabs 3-7 titled “Bedding 1-5” shall include the reported data for the parameters specified in this paragraph over 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 individual trips of the WLTP-Brake cycle. Each tab shall include 15826 rows with data representing the 15826 seconds of the WLTP- . Tabs 3-7 shall not include data from the soaking sections applied between the 5 WLTP-Brake cycles;

(d) Tab 8 titled “Emissions” shall include the reported data for the parameters specified in this paragraph over 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. Tab 8 shall include 15826 rows with data representing the 15826 seconds of the WLTP-Brake cycle of the emissions measurement section;

(e) Tab 9 titled “Post-test BG” shall include the reported data for the parameters specified in this paragraph over the post-test background verification procedure. Although the template is the same as for other sections of the brake emissions test, the testing facility is requested to 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 sample and/or calculate the parameters listed in Table A4/10 All data in the Time-Based File shall be calculated using the raw sampled data. Details regarding the applied units, the number of decimals, and the sampling rate of each parameter are given in Table A4/10 Sampling rate in the context of this Regulation is the frequency with which the automation system samples and registers the various parameters. Failure to submit the Time-Based file as described above results in an invalid test.

Regardless of the sampling rate, in the Time-Based File the parameters shall be reported at 1Hz. Therefore, the sampled values are averaged to calculate the 1Hz reported values. Table A4/10 also provides a short description of each parameter and the symbol used throughout the text.

Table A4/10
Necessary parameters for sampling and reporting at the Time-Based File of a brake emissions test

Measurand	*Symbol*	*Unit*	*Decimals*	*Description*	*Sampling Rate*	*Column in the File*
Timestamp	-	sec	0	Timestamp in the brake emissions test	10Hz	A
Linear Speed Nominal	V_{set}	km/h	1	Nominal linear speed at the given point in time as defined in the WLTP-Brake cycle. It is not sampled but shall be reported at 1Hz	N/A	B
Linear Speed Actual	V	km/h	2	Actual linear speed registered by the brake dynamometer at the given point in time	10Hz	C
Driven Distance	d	km	3	Total distance driven in the cycle until the given point in time	10Hz	D
Deceleration Rate	α	m/s^2	3	Deceleration rate registered by the brake dynamometer at the given point in time	10Hz	E
Brake Torque	τ_{brake}	N·m	1	Brake torque registered by the brake dynamometer at the given point in time	10Hz	F
Brake Pressure	p_{brake}	kPa	1	Brake pressure registered by the brake dynamometer at the given point in time	10Hz	G
Brake effectiveness	µ or C*	-	3	Instantaneous friction coefficient calculated at the given point in time	10Hz	H
Brake Temperature	T_{brake}	°C	1	Brake temperature at the given point in time	10Hz	I
Cooling Airflow Set	Q_{set}	m^3/h	0	Set (nominal) cooling airflow for the given brake emissions test. It is not sampled but shall be reported at 1Hz	N/A	J
Cooling Airflow Actual	Q	m^3/h	2	Measured cooling airflow at the given point in time	10Hz	K
Cooling Airflow Actual Normalised	NQ	Nm^3/h	2	Normalised cooling airflow at standard conditions at the given point in time	10Hz	L
Cooling Air Temperature	T	°C	1	Temperature of the cooling air at the given point in time	10Hz	M
Cooling Air Relative Humidity	RH	%	1	Relative humidity of the cooling air at the given point in time	10Hz	N
Cooling Air Specific Humidity	SH	mg/g	1	Specific humidity of the cooling air at the given point in time	10Hz	O
Cooling Air Pressure	P	kPa	1	Pressure of the cooling air at the given point in time	10Hz	P

Measurand	*Symbol*	*Unit*	*Decimals*	*Description*	*Sampling Rate*	*Column in the File*
$PM_{2.5}$ Sampling Flow Set	$Q_{PM2.5\text{-set}}$	l/min	1	Set (nominal) $PM_{2.5}$ sampling flow for the given brake emissions test. It is not sampled but shall be reported at 1Hz	N/A	Q
$PM_{2.5}$ Sampling Flow Actual	$Q_{PM2.5}$	l/min	2	$PM_{2.5}$ sampling flow measured at the given point in time	10Hz	R
$PM_{2.5}$ Sampling Flow Actual Normalised	$NQ_{PM2.5}$	*N*l/min	2	Normalised $PM_{2.5}$ sampling flow at standard conditions at the given point in time	10Hz	S
PM_{10} Sampling Flow Set	$Q_{PM10\text{-set}}$	l/min	1	Set (nominal) PM_{10} sampling flow for the given brake emissions test. It is not sampled but shall be reported at 1Hz	N/A	T
PM_{10} Sampling Flow Actual	Q_{PM10}	l/min	2	PM_{10} sampling flow measured at the given point in time	10Hz	U
PM_{10} Sampling Flow Actual Normalised	NQ_{PM10}	*N*l/min	2	Normalised PM_{10} sampling flow at standard conditions at the given point in time	10Hz	V
Reserved						W
Reserved						X
Reserved						Y
Reserved						Z
SPN10 Sampling Flow Set	$Q_{SPN10\text{-set}}$	l/min	1	Set (nominal) SPN10 sampling flow for the given brake emissions test. It is not sampled but shall be reported at 1Hz	N/A	AA
SPN10 Sampling Flow Actual Normalised	NQ_{SPN10}	*N*l/min	2	SPN10-related sampling flow measured at the given point in time and reported at standard conditions. The testing facility shall specify if the sampling rate is different than the nominal	10Hz	AB
SPN10 - Average PCRF	$f_{r\text{-SPN10}}$	-	1	Arithmetic average particle concentration reduction factor for the SPN10 measurement	10Hz	AC
SPN10 Concentration Normalised - PCRF Corrected	$SPN_{10\#}$	$\#/Ncm^3$	1	SPN10 normalised concentration at standard conditions measured by the PNC and corrected for the PCRF at the given point in time	10Hz	AD

13.3. Mass Measurement File

The testing facility shall generate an ODS Mass Measurement file for the entire test. The file shall be named "Test ID_MMF" and shall include information about weighing the filters as specified in paragraph 12.1. as well as for weighing the brake parts as specified in paragraph 12.3. PM mass data shall be reported in one tab as specified in Table A4/11 Information about the reference filters shall be reported in a different tab as specified in Table A4/12 Finally, information regarding mass loss of the brake parts shall be reported in a separate tab as specified in Table A4/13

13.3.1. PM Measurement Data

The testing facility shall report and calculate the parameters related to the PM mass measurement listed in Table A4/11 Details regarding the applied units and the number of decimals of each parameter are provided in Table A4/11 Additionally, a short description of each parameter is given. PM weighing data shall be reported in the tab titled "PM Mass" of the Mass Measurement file.

Table A4/11

Necessary parameters related to the PM mass measurement procedure for reporting at the Mass 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 A4/14	A
Filter Material	-	N/A	Specifies the type of filter used for PM sampling per paragraph 12.1.3.2.	B
$PM_{2.5}$	-	N/A	Specifies whether the input data refer to $PM_{2.5}$ sampling and measurement	C
PM_{10}	-	N/A	Specifies whether the input data refer to PM_{10} 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
Stabilisation time before weighing	hh:mm	N/A	Stabilisation time of the unloaded filter before being weighed and used for sampling per paragraph 12.1.4.	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 per paragraph 12.1.4.	H
Unloaded Measurement 1	mg	4	Weight of the unloaded filter measured at the first weighing per paragraph 12.1.4.	I
Unloaded Measurement 2	mg	4	Weight of the unloaded filter measured at the second weighing per paragraph 12.1.4.	J
Unloaded Measurement 3 (if necessary)	mg	4	Weight of the unloaded filter measured at the third weighing per paragraph 12.1.4. (only if the deviation between the first two measurements is higher than 10 μg)	K

Measurand	*Unit*	*Decimals*	*Description*	*Column in the File*
Unloaded Measurement 4 (if necessary)	mg	4	Weight of the unloaded filter measured at the fourth weighing per paragraph 12.1.4.(only if the deviation between the first two measurements is higher than 10 µg)	L
Unloaded Mean Value – Corrected	mg	4	The corrected average weight of the unloaded filter after applying the buoyancy correction per paragraph 12.1.4. ($Pe_{(Corrected)}$)	M
Ambient Air Temperature	°C	2	Weighing room temperature – Report the average temperature of the room during the last hour before the weighing procedure	N
Ambient Air Relative Humidity	%	2	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
Stabilisation time before weighing	hh:mm	N/A	Stabilisation time of the loaded filter after sampling and before being weighed per paragraph 12.1.4.	R
Elapsed time from end test to weighing	hh:mm	N/A	Elapsed time from the end of the emissions tests to weighing the loaded filter per paragraph 12.1.4.	S
Loaded Measurement 1	mg	4	Weight of the loaded filter measured at the first weighing per paragraph 12.1.4.	T
Loaded Measurement 2	mg	4	Weight of the loaded filter measured at the second weighing per paragraph 12.1.4.	U
Loaded Measurement 3 (if necessary)	mg	4	Weight of the loaded filter measured at the third weighing per paragraph 12.1.4. (only if the deviation between the first two measurements is higher than 10 µg)	V
Loaded Measurement 4 (if necessary)	mg	4	Weight of the loaded filter measured at the fourth weighing per paragraph 12.1.4. (only if the deviation between the first two measurements is higher than 10 µg)	W
Loaded Mean Value – Corrected	mg	4	The corrected average weight of the loaded filter after applying the buoyancy correction per paragraph 12.1.4. ($Pe_{(Corrected)}$)	X
Ambient Air Temperature	°C	2	Weighing room temperature – Report the average temperature of the room during the last hour before the weighing procedure	Y
Ambient Air Relative Humidity	%	2	Weighing room relative humidity – Report the average temperature of the room during the last hour before the weighing procedure	Z

Measurand	*Unit*	*Decimals*	*Description*	*Column in the File*
Loaded Mass	mg	4	$Pe_{(2.5)}$ and $Pe_{(10)}$: The difference between the mean corrected value of the loaded and unloaded filter – Subtract the value in column M from the value in column X	AA

13.3.2. Reference Filters Data

The testing facility shall report 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 A4/12 The reference filter data shall be reported in the tab titled "Reference Filters" of the Mass Measurement file.

Table A4/12

Necessary parameters related to the reference filters used at the PM mass measurement procedure for reporting at the Mass 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 A4/14	A
Filter Material	-	N/A	Type of filter used as reference per paragraph 12.1.4. – Shall be the same as the filter used in the emissions test	B
Weighing Date	yyyy-mm-dd	N/A	Date on which the weighing of the reference filters takes place. In case of reference filters not weighed on a regular basis, report the date on which the initial weighing of the filter takes place	C
Weighing Time	hh:mm	N/A	Time at which weighing of the reference filter takes place. In case of reference filters not weighed on a regular basis, report the time on which the initial weighing of the filter takes place	D
First Reference Filter Weight	mg	4	Corrected weight of the 1st reference filter measured within 12-h of sample weighing or at the beginning of the session as defined in paragraph 12.1.4.	E
First Reference Filter Rolling Average	mg	4	Rolling average of the 1st reference filter specific weights since its placement in the weighing room per paragraph 12.1.4.	F
Second Reference Filter Weight	mg	4	Corrected weight of the 2nd reference filter measured within 12-h of sample weighing or at the beginning of the session as defined in paragraph 12.1.4.	G
Second Reference Filter Rolling Average	mg	4	Rolling average of the 2nd reference filter specific weights since its placement in the weighing room per paragraph 12.1.4.	H

Measurand	*Unit*	*Decimals*	*Description*	*Column in the File*
Average Difference With Rolling Average	mg	4	Average difference between the reference filter weights and their rolling average. Use weights reported in Columns E, F, G, and H to calculate the average difference. In case of reference filters not weighed on a regular basis, this measurement reflects the difference between the pre-test weighing and its rolling average per paragraph 12.1.4. (iii)	I
Ambient Air Temperature Before Session	°C	2	Weighing room temperature – Average temperature of the room during the last hour before the weighing procedure	J
Ambient Air Relative Humidity Before Session	%	2	Weighing room relative humidity – Average RH of the room during the last hour before the weighing procedure	K
Weighing Date End Session	yyyy-mm-dd	N/A	Date on which the final weighing of the reference filter takes place in the case of reference filters not weighed on a regular basis. Report N/A in case reference filters are weighed on a regular basis	L
Weighing Time End Session	hh:mm	N/A	Time at which the final weighing of the reference filter takes place in the case of reference filters not weighed on a regular basis. Report N/A in case reference filters are weighed on a regular basis	M
First Reference Filter Weight End Session	mg	4	Corrected weight of the first reference filter measured at the end of the session as defined in paragraph 12.1.4. Report N/A in case reference filters are weighed on a regular basis	N
Second Reference Filter Weight End Session	mg	4	Corrected weight of the second reference filter measured at the end of the session as defined in paragraph 12.1.4. Report N/A in case reference filters are weighed on a regular basis	O
Average Difference With Rolling Average End Session	mg	4	Average difference between the reference filter weights and their rolling average at the end of the session in case of reference filters not weighed on a regular basis. Use weights reported in Columns O, F, P, and H to calculate the average difference. This measurement reflects the difference between the post-test weighing and its rolling average per paragraph 12.1.4. (iii). Report N/A in case reference filters are weighed on a regular basis	P

Measurand	*Unit*	*Decimals*	*Description*	*Column in the File*
Average Difference Initial And Final Measurement	mg	4	Average difference between the initial and final weighings of the reference filters in case of reference filters not weighed on a regular basis. Use weights reported in Columns E, N, G, and O to calculate the average difference. This measurement reflects the difference between the pre- and the post-test weighing per paragraph 12.1.4. (iv). Report N/A in case reference filters are weighed on a regular basis	Q
Ambient Air Temperature End Session	°C	2	Weighing room temperature – Average temperature of the room during the last hour before the weighing procedure. Report N/A in case reference filters are weighed on a regular basis	R
Ambient Air Relative Humidity End Session	%	2	Weighing room relative humidity – Average RH of the room during the last hour before the weighing procedure. Report N/A in case reference filters are weighed on a regular basis	S

13.3.3. Mass Loss Measurement Data

The testing facility shall report 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 A4/13 The mass loss measurement data shall be reported in the tab titled “Mass Loss” of the Mass Measurement file.

Table A4/13

Necessary parameters related to the total mass loss of the brake for reporting at the Mass 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 A4/14	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
Ambient Air Temperature Before Session	°C	2	Weighing room temperature – Average temperature of the room during the last hour before the weighing procedure	D
Ambient Air Relative Humidity Before Session	%	2	Weighing room relative humidity – Average RH of the room during the last hour before the weighing procedure	E
Initial Weighings Inner pad / Leading shoe	g	1	Weight of the inner pad or the leading shoe before the beginning of the bedding section - Leading shoe is the first shoe after the wheel cylinder in the direction of the wheel rotation	F

Measurand	*Unit*	*Decimals*	*Description*	*Column in the File*
Initial Weighings Outer pad / Trailing shoe	g	1	Weight of the outer pad or the trailing shoe before the beginning of the bedding section - Trailing shoe is the shoe behind the wheel cylinder in the direction of the wheel rotation	G
Initial Weighings Disc / Drum	g	1	Weight of the disc or drum before the beginning of the bedding section	H
Final Weighings Inner pad / Leading shoe	g	1	Weight of the inner pad or the leading shoe after the end of the emissions section	I
Final Weighings Outer pad / Trailing shoe	g	1	Weight of the outer pad or the trailing shoe after the end of the emissions section	J
Final Weighings Disc / Drum	g	1	Weight of the disc or drum after the end of the emissions section	K
Mass Loss Inner pad / Leading shoe	g	1	Difference between the weighted value of the inner pad or the leading shoe– Subtract the value in column F from the value in column I	L
Mass Loss Outer pad / Trailing shoe	g	1	Difference between the weighted value of the outer pad or the trailing shoe– Subtract the value in column G from the value in column J	M
Mass Loss Disc / Drum	g	1	Difference between the weighted value of the disc or the drum– Subtract the value in column H from the value in column K	N
Mass Loss Total	g	1	Total mass loss of the brake assembly– Add the values in columns L, M, and N	O
Total Distance	km	3	Total distance covered during bedding and emission sections	P
Mass Loss Rate Averaged	mg/km	2	Averaged mass loss rate of the brake assembly– Divide the values in columns O/Q	Q

13.4. Test Report File

The testing facility shall create a unique, complete, and traceable dataset as an input file for the generation of the test report for the specific brake under testing. Table A4/14 contains all the necessary information to include in the report. All data in the Test Report File shall be calculated directly using the raw sampled data. Numerical data shall be reported as such and not as inequalities. All information in the report shall be correlated to the specific brake. The testing facility shall submit the report in a *.pdf or equivalent format. Each index (1, 2, 3, …) listed in the first column (No.) of Table A4/14 corresponds to a line in the report, letters (a, b, c, …) correspond to separate columns in the corresponding line.

Table A4/14

Testing parameters to report after a brake particle emissions test

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
1	8.1.	Brake emissions 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 output files	-	N/A
2	8.1.	Vehicle make and model	Report vehicle make and model where the brake under testing is mounted	-	N/A
3	3.7.	Vehicle electrification type	Report vehicle electrification type where the brake under testing is mounted	-	N/A
4	5.2.	Friction braking share coefficient	Report the vehicle friction braking share coefficient where the brake under testing is mounted	-	3
5	8.1.	Axle (front or rear)	Report the axle position on the vehicle for the brake under testing (FA or RA)	-	N/A
6	8.1.	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 (RHC or LHC)	-	N/A
7	8.1.	Vehicle test mass	Report the vehicle mass simulated on the brake dynamometer during all sections of the brake emissions test (M_{veh}). In the case of non-friction braking, report the M_{veh} of the brake corner emissions family parent as applied during the brake emissions test	kg	0
8	8.1.	Brake force distribution	Report the ratio of the braking force on the brake's under testing axle and the total braking force on the vehicle (FAF or RAF). In the case of non-friction braking, report the FAF or RAF of the brake corner emissions family parent as applied during the brake emissions test	%	0
9	8.4.1.	Fixture style	Report the style of the support fixture of the brake assembly (L0-U or L0-P)	-	N/A
10	8.1.	Disc or drum identification code	Report the code labelled by the brake manufacturer on the disc/drum	-	N/A
11	8.1.	Friction material identification code	Report the code labelled by the friction material manufacturer on the pads/shoes	-	N/A
12	8.1.	Nominal wheel load	Calculate and report the nominal wheel load of the brake under testing (WL_{n-f} or WL_{n-r}) following	kg	1

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
			Equation 8.1. In the case of non-friction braking, use the parameters of the brake corner emissions family parent to calculate and report the nominal wheel load		
13	8.1.	Test (or applied) wheel load	Calculate and report the test wheel load applied on the brake dynamometer (WL_{t-f} or WL_{t-r}) following Equation 8.2. In the case of non-friction braking, use the parameters of the brake corner emissions family parent to calculate and report the test wheel load	kg	1
14	8.1.	Tyre dynamic rolling radius	Report the tyre dynamic rolling radius related to the brake under testing (r_R)	mm	0
15	8.1.	Brake effective radius	Report the effective radius of the brake under testing (r_{eff})	mm	1
16	8.1.	Brake nominal inertia	Calculate and report the nominal moment of inertia for the brake under testing (I_n) following Equation 8.3. In the case of non-friction braking, use the parameters of the brake corner emissions family parent to calculate and report the nominal moment of inertia	$kg \cdot m^2$	1
17	8.1.	Brake Test (or applied) inertia	Calculate and report the moment of inertia applied on the brake dynamometer during testing (I_t) following Equation 8.4. In the case of non-friction braking, use the parameters of the brake corner emissions family parent to calculate and report the moment of inertia applied on the brake dynamometer during testing	$kg \cdot m^2$	1
18	8.1.	Disc/Drum outer diameter	Report the outer diameter of the brake under testing	mm	1
19	8.1.	Disc mass	Report the actual mass of the unused disc to allocate the brake to a nominal front wheel load to a disc mass group	kg	4
20	8.1.	Number of pistons per side	Report the number of pistons on one side of the brake calliper	-	0
21	8.1.	Piston Mean (or hydraulic) Diameter	Report the diameter of the piston of the brake under testing following Equation 8.5	mm	2
22	8.1.	Calliper to fixture bolt tightening torque	Calliper bolt tightening torque as specified by the brake manufacturer	N·m	1
23	8.1.	Disc or drum to hub bolt tightening torque	Disc/drum bolt tightening torque as specified by the brake manufacturer	N·m	1
24	8.1.	Brake calliper or brake drum efficiency	Report the efficiency to account for friction losses, piston travel, etc.	%	0
25	8.1.	Threshold pressure	Report the minimum pressure to overcome internal resistance before the onset of brake torque as defined in paragraph 3.1.19. of this Regulation	kPa	1
26	8.1.	Brake runout actual value	Report the measured brake runout per paragraph 8.2. (g)	µm	0

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
27	7.2.	Minimum operational flow of the system	Report the minimum cooling airflow that the testing facility layout can achieve while fulfilling all relevant cooling air conditioning and measurement requirements defined in this Regulation	m^3/h	0
28	7.2.	Maximum operational flow of the system	Report the maximum cooling airflow that the testing facility layout can achieve while fulfilling all relevant cooling air conditioning and measurement requirements defined in this Regulation	m^3/h	0
29	7.2.1.1.	Average cooling air temperature – Cooling adjustment section	Calculate and report the average cooling air temperature measured during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-Based File to calculate the average over Trip #10	°C	2
30	7.2.1.1.	Average cooling air temperature – Bedding section	Calculate and report the average cooling air temperature measured during the bedding section. Report the average cooling air temperature for all five WLTP-Brake cycles separately. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-Based File to calculate the averages over the 5 WLTP-Brake cycles	°C	2
a	7.2.1.1.	Average cooling air temperature	Bedding cycle 1	°C	2
b	7.2.1.1.	Average cooling air temperature	Bedding cycle 2	°C	2
c	7.2.1.1.	Average cooling air temperature	Bedding cycle 3	°C	2
d	7.2.1.1.	Average cooling air temperature	Bedding cycle 4	°C	2
e	7.2.1.1.	Average cooling air temperature	Bedding cycle 5	°C	2
31	7.2.1.1.	Average cooling air temperature – Emissions measurement section	Calculate and report the average cooling air temperature measured during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-Based File to calculate the average over the WLTP-Brake cycle	°C	2
32	7.2.1.1.	Average cooling air temperature – Overall compliance	Verify that all parts of the test fulfil the specifications for the average cooling air temperature defined in this Regulation	Y/N	N/A
33	7.2.1.1.	Instantaneous air temperature violations – Cooling adjustment section	Calculate and report the percentage of the instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than 28 °C during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-	%	1

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
			Based File to calculate the number of such occurrences and their percentage over Trip #10		
34	7.2.1.1.	Instantaneous air temperature violations – Bedding section	Calculate and report the percentage of the instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than 28 °C during the bedding section. Report the percentage for all five WLTP-Brake cycles separately. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-Based File to calculate the number of such occurrences and their percentage over the 5 WLTP-Brake cycles	%	1
a	7.2.1.1.	Instantaneous air temperature violations	Bedding cycle 1	%	1
b	7.2.1.1.	Instantaneous air temperature violations	Bedding cycle 2	%	1
c	7.2.1.1.	Instantaneous air temperature violations	Bedding cycle 3	%	1
d	7.2.1.1.	Instantaneous air temperature violations	Bedding cycle 4	%	1
e	7.2.1.1.	Instantaneous air temperature violations	Bedding cycle 5	%	1
35	7.2.1.1.	Instantaneous air temperature violations – Emissions measurement section	Calculate and report the percentage of the instantaneous cooling air temperature readings (1Hz) with a value lower than 18 °C or higher than 28 °C during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Air Temperature” in the Time-Based File to calculate the number of such occurrences and their percentage over the WLTP-Brake cycle	%	1
36	7.2.1.1.	Instantaneous cooling air temperature – Overall compliance	Verify that all parts of the test fulfil the specifications for the instantaneous cooling air temperature defined in this Regulation	Y/N	N/A
37	7.2.1.2.	Average cooling air relative humidity – Cooling adjustment section	Calculate and report the average cooling air relative humidity measured during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the average over Trip #10	%	2
38	7.2.1.2.	Average cooling air relative humidity – Bedding section	Calculate and report the average cooling air relative humidity measured during the bedding section. Report the average cooling air relative humidity for all five WLTP-Brake cycles separately. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the averages over the 5 WLTP-Brake cycles	%	2
a	7.2.1.2.	Average cooling air relative humidity	Bedding cycle 1	%	2

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
b	7.2.1.2.	Average cooling air relative humidity	Bedding cycle 2	%	2
c	7.2.1.2.	Average cooling air relative humidity	Bedding cycle 3	%	2
d	7.2.1.2.	Average cooling air relative humidity	Bedding cycle 4	%	2
e	7.2.1.2.	Average cooling air relative humidity	Bedding cycle 5	%	2
39	7.2.1.2.	Average cooling air relative humidity – Emissions measurement section	Calculate and report the average cooling air relative humidity measured during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the average over the WLTP-Brake cycle	%	2
40	7.2.1.2.	Average cooling air relative humidity – Overall compliance	Verify that all parts of the test fulfil the specifications for the average cooling air relative humidity defined in this Regulation	Y/N	N/A
41	7.2.1.2.	Instantaneous air relative humidity violations – Cooling adjustment section	Calculate and report the percentage of the instantaneous cooling air relative humidity readings (1Hz) with a value lower than 20 per cent or higher than 80 per cent during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the number of such occurrences and their percentage over Trip #10	%	1
42	7.2.1.2.	Instantaneous air relative humidity violations – Bedding section	Calculate and report the percentage of the instantaneous cooling air relative humidity readings (1Hz) with a value lower than 20 per cent or higher than 80 per cent during the bedding section. Report the percentage for all five WLTP-Brake cycles separately. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the number of such occurrences and their percentage over the 5 WLTP-Brake cycles	%	1
a	7.2.1.2.	Instantaneous air relative humidity violations	Bedding cycle 1	%	1
b	7.2.1.2.	Instantaneous air relative humidity violations	Bedding cycle 2	%	1
c	7.2.1.2.	Instantaneous air relative humidity violations	Bedding cycle 3	%	1
d	7.2.1.2.	Instantaneous air relative humidity violations	Bedding cycle 4	%	1
e	7.2.1.2.	Instantaneous air relative humidity violations	Bedding cycle 5	%	1
43	7.2.1.2.	Instantaneous air relative humidity violations –	Calculate and report the percentage of the instantaneous cooling air relative humidity	%	1

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
		Emissions measurement section	readings (1Hz) with a value lower than 20 per cent or higher than 80 per cent during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Air Relative Humidity” in the Time-Based File to calculate the average over the WLTP-Brake cycle		
44	7.2.1.2.	Instantaneous cooling air relative humidity – Overall compliance	Verify that all parts of the test fulfil the specifications for the instantaneous cooling air relative humidity defined in this Regulation	Y/N	N/A
45	7.2.1.2.	Average cooling air specific humidity – Cooling adjustment section	Calculate and report the average cooling air specific humidity measured during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Air Specific Humidity” in the Time-Based File to calculate the average over Trip #10	mg H_20/g dry air	2
46	7.2.1.2.	Average cooling air specific humidity – Bedding section	Calculate and report the average cooling air specific humidity measured during the bedding section. Report the average cooling air relative humidity for all five WLTP-Brake cycles separately. Use the 1Hz data of the parameter “Cooling Air Specific Humidity” in the Time-Based File to calculate the averages over the 5 WLTP-Brake cycles	mg H_20/g dry air	2
a	7.2.1.2.	Average cooling air specific humidity	Bedding cycle 1	mg H_20/g dry air	2
b	7.2.1.2.	Average cooling air specific humidity	Bedding cycle 2	mg H_20/g dry air	2
c	7.2.1.2.	Average cooling air specific humidity	Bedding cycle 3	mg H_20/g dry air	2
d	7.2.1.2.	Average cooling air specific humidity	Bedding cycle 4	mg H_20/g dry air	2
e	7.2.1.2.	Average cooling air specific humidity	Bedding cycle 5	mg H_20/g dry air	2
47	7.2.1.2.	Average cooling air specific humidity – Emissions measurement section	Calculate and report the average cooling air specific humidity measured during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Air Specific Humidity” in the Time-Based File to calculate the average over the WLTP-Brake cycle	mg H_20/g dry air	2
48	7.2.1.2.	Average cooling air specific humidity – Overall compliance	Verify that all parts of the test fulfil the specifications for the average cooling air specific humidity defined in this Regulation	Y/N	N/A

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
49	7.2.2.1.	Cooling air filtering – Overall compliance	Verify that the cooling air entering the system complies with the filtering specifications defined in this Regulation	Y/N	N/A
50		Reserved			
51	7.2.2.2.1.	System background verification – SPN10 at minimum operational airflow	Report the SPN10 background concentration of the setup measured at the minimum operational airflow	#/*N*cm³	1
52		Reserved			
53	7.2.2.2.1.	System background verification – SPN10 at maximum operational airflow	Report the SPN10 background concentration of the setup measured at the maximum operational airflow	#/*N*cm³	1
54	7.2.2.2.3.	System background verification – Overall compliance	Verify that the SPN10 background concentration measured at different airflows are below the maximum allowed limit defined in point (c) of paragraph 7.2.2.2.3.	Y/N	N/A
55		Reserved			
56	7.2.2.2.2.	Test level background verification – SPN10 PCRF setting	Report the certified value of the PCRF-setting applied during the pre- and post-test background verification for SPN10	-	1
57		Reserved			
58	7.2.2.2.2.	Pre-test background – SPN10 concentration	Calculate and report the SPN10 background concentration measured during the pre-test background verification ($SPN10_{b\#}$). Use the 1Hz data of the parameter “SPN10 Concentration Normalized - PCRF Corrected” in the Time-Based File (Pre-test Background) to calculate the 5-minutes average as described in 7.2.2.2.2. (d)	#/*N*cm³	1
59		Reserved			
60	7.2.2.2.2.	Post-test background – SPN10 concentration	Calculate and report the SPN10 background concentration measured during the post-test background verification ($SPN10_{b\#}$). Use the 1Hz data of the parameter “SPN10 Concentration Normalized - PCRF Corrected” in the Time-Based File (Post-test Background) to calculate the 5-minutes average as described in 7.2.2.2.2. (h)	#/*N*cm³	1
61	7.2.2.2.3.	Test level background verification – Overall compliance	Verify that the SPN10 background concentration measured at the airflow setting defined for the brake under testing are below the maximum permissible limit defined in point (c) of paragraph 7.2.2.2.3.	Y/N	N/A
62		Reserved			
63	7.2.2.2.4.	Pre-test background – SPN10 number per distance	Calculate and report the SPN10 background measured during the pre-test background verification in # per distance travelled following Equation 7.2	#/km	1

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
64		Reserved			
65	7.2.2.2.4.	Post-test background – SPN10 number per distance	Calculate and report the SPN10 background measured during the post-test background verification in # per distance travelled following Equation 7.2	#/km	1
66	7.2.3.	Airflow measurement device – Overall compliance	Verify the compliance of the airflow measurement element with all the requirements defined in 7.2.3. (a)-(h)	Y/N	N/A
67	7.2.3.	Cooling airflow – Nominal (or set) value	Report the nominal (or set) cooling airflow for the brake under testing (Q_{set})	m^3/h	0
68	7.2.3.	Cooling airflow – Nominal (or set) value	Verify that the same nominal cooling airflow has been applied during all brake emissions test sections	Y/N	N/A
69	7.2.3.	Cooling airflow – Average value (cooling adjustment section)	Calculate and report the average measured cooling airflow during the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Airflow Actual” in the Time-Based File to calculate the average over Trip #10. In the case of multiple iterations of the cooling adjustment section, report only the one that resulted in the definition of the Q_{set}	m^3/h	2
70	7.2.3.	Cooling airflow – Difference with the nominal flow (cooling adjustment section)	Calculate and report the per cent difference between the average measured cooling airflow and the nominal cooling airflow during the cooling adjustment section	%	1
71	7.2.3.	Cooling airflow – Average normalized value (cooling adjustment section)	Calculate and report the average normalized measured cooling airflow during the cooling adjustment section. Use the 1Hz data of the parameter “Cooling Airflow Actual Normalized” in the Time-Based File to calculate the average over Trip #10. In the case of multiple iterations of the cooling adjustment section, report only the one that resulted in the definition of the Q_{set}	Nm^3/h	2
72	7.2.3.	Cooling airflow – Average value (bedding section)	Calculate and report the average measured cooling airflow during the bedding section. Report the average measured cooling airflow for all five WLTP-Brake cycles seperately. Use the 1Hz data of the parameter “Cooling Airflow Actual” in the Time-Based File to calculate the averages over the 5 WLTP-Brake cycles.	m^3/h	2
a	7.2.3.	Cooling airflow – Average value	Bedding cycle 1	m^3/h	2
b	7.2.3.	Cooling airflow – Average value	Bedding cycle 2	m^3/h	2
c	7.2.3.	Cooling airflow – Average value	Bedding cycle 3	m^3/h	2

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
d	7.2.3.	Cooling airflow – Average value	Bedding cycle 4	m^3/h	2
e	7.2.3.	Cooling airflow – Average value	Bedding cycle 5	m^3/h	2
73	7.2.3.	Cooling airflow – Difference with the nominal flow (bedding section)	Calculate and report the per cent difference with the nominal cooling airflow during the bedding section. Report the per cent difference for all five WLTP-Brake cycles seperately	%	1
a	7.2.3.	Cooling airflow – Difference with the nominal flow	Bedding cycle 1	%	1
b	7.2.3.	Cooling airflow – Difference with the nominal flow	Bedding cycle 2	%	1
c	7.2.3.	Cooling airflow – Difference with the nominal flow	Bedding cycle 3	%	1
d	7.2.3.	Cooling airflow – Difference with the nominal flow	Bedding cycle 4	%	1
e	7.2.3.	Cooling airflow – Difference with the nominal flow	Bedding cycle 5	%	1
74	7.2.3.	Cooling airflow – Average normalized value (bedding section)	Calculate and report the average normalized measured cooling airflow during the bedding section. Report the average normalized measured cooling airflow for all five WLTP-Brake cycles seperately. Use the 1Hz data of the parameter “Cooling Airflow Actual Normalized” in the Time-Based File to calculate the averages over the 5 WLTP-Brake cycles	Nm^3/h	2
a	7.2.3.	Cooling airflow – Average normalized value	Bedding cycle 1	Nm^3/h	2
b	7.2.3.	Cooling airflow – Average normalized value	Bedding cycle 2	Nm^3/h	2
c	7.2.3.	Cooling airflow – Average normalized value	Bedding cycle 3	Nm^3/h	2
d	7.2.3.	Cooling airflow – Average normalized value	Bedding cycle 4	Nm^3/h	2
e	7.2.3.	Cooling airflow – Average normalized value	Bedding cycle 5	Nm^3/h	2
75	7.2.3.	Cooling airflow – Average value (emissions measurement section)	Calculate and report the average measured cooling airflow during the emissions measurement section. Use the 1Hz data of the parameter “Cooling Airflow Actual” in the Time-Based File to calculate the average over the WLTP-Brake cycle (soaking sections not included)	m^3/h	2

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
76	7.2.3.	Cooling airflow – Difference with the nominal flow (emissions measurement section)	Calculate and report the per cent difference with the nominal cooling airflow during the emissions measurement section	%	1
77	7.2.3.	Cooling airflow – Average normalized value (emissions measurement section)	Calculate and report the average normalized measured cooling airflow during the emissions measurement section. Use the 1Hz data of the parameter "Cooling Airflow Actual Normalized" in the Time-Based File to calculate the average over the WLTP-Brake cycle (soaking sections not included)	$N\text{m}^3/\text{h}$	2
78	7.2.3.	Average cooling airflow – Overall compliance	Verify that all parts of the test comply with the requirements set out in this Regulation regarding the difference between the nominal cooling airflow and the average measured cooling airflow	Y/N	N/A
79	7.2.3.	Instantaneous airflow violations – Cooling adjustment section	Calculate and report the number of the cooling airflow readings (1Hz) with a difference between 5 per cent and 10 per cent compared to the nominal value during the successful iteration of the cooling adjustment section. Use the 1Hz data of the parameter "Cooling Airflow Actual" in the Time-Based File to calculate the number of such occurrences over Trip #10	-	0
80	7.2.3.	Instantaneous airflow violations – Emissions measurement section	Calculate and report the number of the cooling airflow readings (1Hz) with a difference between 5 per cent and 10 per cent compared to the nominal value during the emissions measurement section. Use the 1Hz data of the parameter "Cooling Airflow Actual" in the Time-Based File to calculate the number of such occurrences over the WLTP-Brake cycle (soaking sections not included)	-	0
81	7.2.3.	Instantaneous cooling airflow – Overall compliance	Verify that the cooling adjustment and emissions measurement sections comply with the maximum allowed number of the instantaneous cooling airflow readings (1Hz) with a difference between 5 per cent and 10 per cent compared to the nominal value defined in this Regulation	Y/N	N/A
82	7.2.3.	Instantaneous cooling airflow – Overall compliance	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	N/A
83	7.2.3.	System leak check – Average measured airflow	Calculate and report the average measured airflow during the leak check	m^3/h	2
84	7.2.3.	System leak check – Overall compliance	Verify that the average measured airflow during the leak check meets the requirements set out in this Regulation	Y/N	N/A
85	7.3.	Brake dynamometer and automation system – Overall compliance	Verify that the mandatory specifications for the brake dynamometer set out in paragraph 7.3. (a)-(e) are met	Y/N	N/A

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
86	7.3.	Brake dynamometer and automation system – Overall compliance	Verify that the mandatory specifications for the automation, control, and data acquisition system set out in paragraph 7.3. (f)-(h) are met	Y/N	N/A
87	7.4.2.	Brake enclosure design – Reynolds number at the entrance of the enclosure	Calculate and report the Reynolds number of the airflow at the entrance of the enclosure for the brake under testing. Calculate the Reynolds number only during the emissions measurement section following Equation 7.3.	-	
88	7.4.2.	Brake enclosure design – Speed uniformity verification at the minimum operational airflow	Verify that the airspeed at each position of the plane C used for the speed uniformity verification does not vary by more than ±35 per cent of the arithmetic mean of all measurements for the setup's minimum operational airflow	Y/N	N/A
89	7.4.2.	Brake enclosure design – Speed uniformity verification at the maximum operational airflow	Verify that the airspeed at each position of the plane C used for the speed uniformity verification does not vary by more than ±35 per cent of the arithmetic mean of all measurements for the setup's maximum operational airflow	Y/N	N/A
90	7.4.2.	Brake enclosure design – Overall compliance	Verify the compliance of the brake enclosure with all the specifications defined in paragraph 7.4.2. (a)-(l)	Y/N	N/A
91	7.4.3.	Brake enclosure dimensions – Length	Report the length of plane A1 (I_{A1} – enclosure's length) as defined in paragraph 7.4.3.	mm	1
92	7.4.3.	Brake enclosure dimensions – Height	Report the length of plane D (h_D – enclosure's height) as defined in paragraph 7.4.3.	mm	1
93	7.4.3.	Brake enclosure dimensions – Depth	Report the maximum axial depth of the enclosure at plane D as defined in paragraph 7.4.3.	mm	1
94	7.4.3.	Brake enclosure dimensions – Inlet and outlet diameter	Report the inlet and outlet diameter (d_i) of the enclosure	mm	1
95	7.4.3.	Brake enclosure dimensions – Inlet and outlet transition length	Report the inlet and outlet transition length (l_i)	mm	1
96	7.4.3.	Brake enclosure dimensions – Inlet and outlet transition height	Report the inlet and outlet transition height (h_B)	mm	1
97	7.4.3.	Brake enclosure dimensions – Inlet's height to enclosure's height ratio	Report the inlet's height (h_B) to the enclosure's height (h_D) ratio	%	1
98	7.4.3.	Brake enclosure dimensions – Overall compliance	Verify the compliance of the brake enclosure dimensions with all the specifications defined in paragraph 7.4.3. (a)-(g)	Y/N	N/A
99	7.5.	Design of the sampling tunnel – Duct inner diameter	Report the inner diameter (d_i) of the duct in the sampling tunnel	mm	1
100	7.5.	Design of the sampling tunnel –Presence of a bend	Report if a bend is applied in the sampling tunnel (downstream of the brake enclosure's outlet and upstream of the sampling plane)	Y/N	N/A

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
101	7.5.	Design of the sampling tunnel –Bend's specifications (angle)	When a bend is applied in the sampling tunnel, report the bend's angle. If there is no bend report "NA"	°	0
102	7.5.	Design of the sampling tunnel –Bend's specifications (bending radius)	When a bend is applied in the sampling tunnel, report the bending radius as defined in Figure A4/6 If there is no bend report "NA"	$\# \cdot d_i$	1
103	7.5.	Design of the sampling tunnel – Overall compliance	Verify the compliance of the sampling tunnel with all the specifications defined in paragraph 7.5. (a)-(i)	Y/N	N/A
104	7.6.	Design of the sampling plane – Number of probes	Report the number of sampling probes used for the brake emissions test	-	0
105	7.6.	Design of the sampling plane – Distance between the probes	Report the minimum distance between the probes (a_1) as specified in Figure A4/7	mm	1
106	7.6.	Design of the sampling plane – Distance between probes and walls	Report the minimum distance between the probes and the tunnel wall (a_2) as specified in Figure A4/7	mm	1
107	7.6.	Design of the sampling plane – Overall compliance	Verify the compliance of the sampling plane with all distance and placement specifications defined in paragraph 7.6. (a)-(g)	Y/N	N/A
108	8.3.	Brake temperature measurement – Thermocouples overall compliance	Verify the compliance of the used thermocouples with all the requirements defined in paragraph 8.3. (a)-(f)	Y/N	N/A
109	8.3.	Brake temperature measurement – Friction material temperature measurement	Report whether brake pads or shoes temperature was also measured in addition to the brake disc or drum temperature	Y/N	N/A
110	8.4.1.	Brake assembly – Overall compliance	Verify that the installation position and the type of support fixture used for the brake assembly meet the requirements specified in paragraph 8.4.1.	Y/N	N/A
111	8.4.1.	Brake assembly – Brake rotation	Report the rotation direction of the brake disc or drum (CW or CCW) with respect to the direction of evacuation	CW or CCW	N/A
112	8.4.1.	Brake assembly – Brake rotation	Verify that the tested brake disc or drum rotates in the direction of the evacuation	Y/N	N/A
113	8.4.2.	Calliper orientation – Overall compliance	Verify that the calliper orientation of the brake under testing meets the requirements specified in paragraph 8.4.2.	Y/N	N/A
114	9.2.1.	Initial temperature – Cooling adjustment section	Report the initial brake temperature of the successful cooling adjustment iteration. Use the corresponding value of the parameter "Brake Temperature" in the Time-Based File (i.e. use the entry for brake temperature at the beginning of Trip #10)	°C	2

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
115	9.2.2.	Initial temperature – Bedding section	Report the initial brake temperature during the bedding section. Report the initial brake temperature for all five WLTP-Brake cycles separately. Use the corresponding values of the parameter “Brake Temperature” in the Time-Based File (i.e. use the entries for brake temperature at the beginning of each one of the five WLTP-Brake cycles)	°C	2
a	9.2.2.	Initial temperature	Bedding cycle 1	°C	2
b	9.2.2.	Initial temperature	Bedding cycle 2	°C	2
c	9.2.2.	Initial temperature	Bedding cycle 3	°C	2
d	9.2.2.	Initial temperature	Bedding cycle 4	°C	2
e	9.2.2.	Initial temperature	Bedding cycle 5	°C	2
116	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 (i.e. use the entries for brake temperature at the beginning of Trips #1 to #10 of the WLTP-Brake cycle)	°C	2
a	9.2.3.	Initial temperature	Trip #1 of WLTP-Brake Cycle	°C	2
b	9.2.3.	Initial temperature	Trip #2 of WLTP-Brake Cycle	°C	2
c	9.2.3.	Initial temperature	Trip #3 of WLTP-Brake Cycle	°C	2
d	9.2.3.	Initial temperature	Trip #4 of WLTP-Brake Cycle	°C	2
e	9.2.3.	Initial temperature	Trip #5 of WLTP-Brake Cycle	°C	2
f	9.2.3.	Initial temperature	Trip #6 of WLTP-Brake Cycle	°C	2
g	9.2.3.	Initial temperature	Trip #7 of WLTP-Brake Cycle	°C	2
h	9.2.3.	Initial temperature	Trip #8 of WLTP-Brake Cycle	°C	2
I	9.2.3.	Initial temperature	Trip #9 of WLTP-Brake Cycle	°C	2
j	9.2.3.	Initial temperature	Trip #10 of WLTP-Brake Cycle	°C	2
117	9.2.1., 9.2.2., 9.2.3.	Initial temperature – Overall compliance	Verify that the initial brake temperature in all testing sections complies with the criteria defined in paragraphs 9.2.1., 9.2.2., and 9.2.3.	Y/N	N/A
118	9.3.1., 9.3.2., 9.3.3.	WLTP-Brake cycle interruptions – Occurrence	Report whether any interruption occurred during any part of the brake emissions test	Y/N	N/A
119	9.3.1., 9.3.2., 9.3.3.	WLTP-Brake cycle interruptions – Overall compliance	When an interruption occurred, verify that all necessary steps were taken to resume testing in accordance with the specifications defined in paragraphs 9.3.1. and 9.3.2.	Y/N	N/A

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
120	9.3.1., 9.3.2., 9.3.3.	WLTP-Brake cycle interruptions – Overall compliance	Verify that the brake under testing was not disassembled at any point of the overall brake emissions test	Y/N	N/A
121	9.4.1.	Speed violations – Cooling adjustment section	Calculate and report the percentage of speed violations during the successful iteration of the cooling adjustment 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 number and the overall percentage of speed violations over Trip #10	%	1
122	9.4.1.	Speed violations – Bedding section	Calculate and report the percentage of speed violations during the bedding section. Perform the calculation for all five WLTP-Brake cycles separately. 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 number and the overall percentage of speed violations over the 5 WLTP-Brake cycles	%	1
a	9.4.1.	Speed violations	Bedding cycle 1	%	1
b	9.4.1.	Speed violations	Bedding cycle 2	%	1
c	9.4.1.	Speed violations	Bedding cycle 3	%	1
d	9.4.1.	Speed violations	Bedding cycle 4	%	1
e	9.4.1.	Speed violations	Bedding cycle 5	%	1
123	9.4.1.	Speed violations – Emissions measurement section	Calculate and report the percentage of 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 number and the overall percentage of speed violations over the WLTP-Brake cycle	%	1
124	9.4.1.	Speed violations – Overall compliance	Verify that all sections of the brake emissions test comply with the speed violations criteria defined in paragraph 9.4.1. (a)-(g)	Y/N	N/A
125	9.4.2.	Number of deceleration events – Count using the “Stop duration”	Report the number of numerical and non-zero values of the parameter “Stop Duration” in the Event-Based File over the emissions measurement section	-	0
126	9.4.2.	Number of deceleration events – Count using the “Deceleration rate”	Report the number of numerical and non-zero values of the parameter “Deceleration Rate - Distance Averaged” in the Event-Based File over the emissions measurement section	-	0
127	9.4.3.	Kinetic energy dissipation – w_f during the cooling adjustment section	Calculate and report the kinetic energy dissipation (w_f) during the successful iteration of the cooling adjustment section following Equation 9.1. Sum the actual specific friction work from the individual brake events to report the total specific friction	J/kg	1

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
			work over Trip #10 of the cooling adjustment section		
128	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value (cooling adjustment section)	Calculate and report the per cent difference from the nominal friction work value during the successful iteration of the cooling adjustment section	%	1
129	9.4.3.	Kinetic energy dissipation – w_f during the bedding section	Calculate and report the kinetic energy dissipation (w_f) during the bedding section following Equation 9.1. Report the kinetic energy dissipation for all five WLTP-Brake cycles separately. Sum the actual specific friction work from the individual brake events to report the total specific friction work over each WLTP-Brake cycle of the bedding section	J/kg	1
a	9.4.3.	Kinetic energy dissipation – w_f	Bedding cycle 1	J/kg	1
b	9.4.3.	Kinetic energy dissipation – w_f	Bedding cycle 2	J/kg	1
c	9.4.3.	Kinetic energy dissipation – w_f	Bedding cycle 3	J/kg	1
d	9.4.3.	Kinetic energy dissipation – w_f	Bedding cycle 4	J/kg	1
e	9.4.3.	Kinetic energy dissipation – w_f	Bedding cycle 5	J/kg	1
130	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value (bedding section)	Calculate and report the per cent difference from the nominal friction work value during the bedding section. Report the deviation from the nominal value for all five WLTP-Brake cycles of the bedding section separately	%	1
a	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value	Bedding cycle 1	%	1
b	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value	Bedding cycle 2	%	1
c	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value	Bedding cycle 3	%	1
d	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value	Bedding cycle 4	%	1
e	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value	Bedding cycle 5	%	1
131	9.4.3.	Kinetic energy dissipation – w_f during the emissions measurement section	Calculate and report the kinetic energy dissipation (w_f) during the emissions measurement section following Equation 9.1. Sum the actual specific friction work from the individual brake events to	J/kg	1

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
			report the total specific friction work over the WLTP-Brake cycle of the emissions measurement section		
132	9.4.3.	Kinetic energy dissipation – Deviation from the nominal value (emissions measurement section)	Calculate and report the per cent difference from the nominal friction work value during the emissions measurement section	%	1
133	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. (a)-(j)	Y/N	N/A
134	9.4.4.	Brake torque application – Number of violations	Report the number of brake events during emissions testing that failed to fulfil the requirement for the brake torque application specified in paragraph 9.4.4.	-	0
135	9.4.4.	Brake torque application – Overall compliance	Verify that the emissions section of the brake emissions test comply with the brake torque application criteria specified in paragraph 9.4.4.	Y/N	N/A
136	10.1.1.	Nominal front wheel load/disc or drum mass ratio (WL_{n-f}/DM)	Calculate and report the nominal front wheel load to disc mass (or drum mass in the case of front drum brakes) ratio (WL_{n-f}/DM) for the brake under testing. In the case of non-friction braking, use the parameters of the brake corner emissions family parent to calculate and report the nominal front wheel load to disc mass	-	1
137	10.1.3.	ABT over Trip #10 of the WLTP-Brake cycle – Measured value (cooling adjustment section)	Calculate and report the average brake temperature during the successful iteration of the cooling adjustment section for the brake under testing (B_1). Use the 1Hz data of the parameter “Brake Temperature” in the Time-Based File to calculate the average brake temperature over Trip #10	°C	2
138	10.1.3.	ABT over Trip #10 of the WLTP-Brake cycle – Difference to the target value (cooling adjustment section)	Calculate and report the difference between the average brake temperature during the successful iteration of the cooling adjustment section to the target average brake temperature for the brake under testing (C_1) following Equation 10.3	°C	2
139	10.1.3.	Average IBT of selected brake events from Trip #10 of the WLTP-Brake cycle – Measured value (cooling adjustment section)	Calculate and report the average IBT of the selected brake events during the successful iteration of the cooling adjustment section of the brake under testing (B_2). Use the corresponding data of the parameter “Initial Brake Temperature” for the target events in the Event-Based File to calculate the average IBT according to 10.1.3. (b)	°C	2
140	10.1.3.	Average IBT of selected brake events from Trip #10 of the WLTP-Brake cycle – Difference to the target value (cooling adjustment section)	Calculate and report the difference between the average IBT of the selected brake events during the successful iteration of the cooling adjustment section to the target average IBT for the brake under testing (C_2) following Equation 10.4	°C	2
141	10.1.3.	Average FBT of selected brake events from Trip #10	Calculate and report the average FBT of the selected brake events during the successful	°C	2

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
		of the WLTP-Brake cycle – Measured value (cooling adjustment section)	iteration of the cooling adjustment section of the brake under testing (B_3). Use the corresponding data of the parameter “Final Brake Temperature” for the target events in the Event-Based File to calculate the average FBT according to 10.1.3. (c)		
142	10.1.3.	Average FBT of selected brake events from Trip #10 of the WLTP-Brake cycle – Difference to the target value (cooling adjustment section)	Calculate and report the difference between the average FBT of the selected brake events during the successful iteration of the cooling adjustment section to the target average FBT for the brake under testing (C_3) following Equation 10.5	°C	2
143	10.1.2., 10.1.3.	Definition of the nominal (set) cooling airflow for the specific brake – Overall compliance	Verify that the temperatures of the target parameters measured during the cooling adjustment section for the brake under testing are compliant with the target values defined in Table A4/5	Y/N	N/A
144	11.1., 11.2.	Bedding section – Number of complete WLTP-Brake cycles	Report the number of complete WLTP-Brake cycles carried out during the bedding section	-	0
145	11.1., 11.2.	Bedding section – Overall compliance	Verify that the bedding section was carried out and completed fulfilling all the specifications described in paragraphs 11.1. (a)-(g) or 11.2. (a)-(g)	Y/N	N/A
146	12.1.1.1.	PM sampling plane – Overall compliance	Verify that the design of the sampling plane and the placement of the [$PM_{2.5}$ and]PM_{10} sampling probe[s] fulfil the specifications described in paragraph 12.1.1.1. (a)-(c)	Y/N	N/A
147	12.1.1.2.	PM sampling probes – $PM_{2.5}$ probe dimensions (inner diameter)	Report the $PM_{2.5}$ sampling probe inner diameter (d_p) used for the brake under testing	mm	2
148	12.1.1.2.	PM sampling probes – PM_{10} probe dimensions (inner diameter)	Report the PM_{10} sampling probe inner diameter (d_p) used for the brake under testing	mm	2
149	12.1.1.2.	PM sampling probes – $PM_{2.5}$ probe dimensions (length)	Report the $PM_{2.5}$ sampling probe’s overall length from the sampling nozzle tip to the inlet of the PM separation device	mm	2
150	12.1.1.2.	PM sampling probes – PM_{10} probe dimensions (length)	Report the PM_{10} sampling probe’s overall length from the sampling nozzle tip to the inlet of the PM separation device	mm	2
151	12.1.1.2.	PM sampling probes – Application of a bend	Report if a bend is applied to the [$PM_{2.5}$ and/or]PM_{10} sampling probes used for the brake under testing	Y/N	N/A
152	12.1.1.2.	PM sampling probes – $PM_{2.5}$ probe application of a bend (bending radius)	When a bend is applied to the $PM_{2.5}$ sampling probe report its bending radius in probe diameters. If there is no bend report “0”	$\#\cdot d_p$	1
153	12.1.1.2.	PM sampling probes – PM_{10} probe application of a bend (bending radius)	When a bend is applied to the PM_{10} sampling probe report its bending radius in probe diameters. If there is no bend report “0”	$\#\cdot d_p$	1
154	12.1.1.2.	PM sampling probes – Overall compliance	Verify that the [$PM_{2.5}$ and]PM_{10} sampling probe[s] used for the brake under testing meet all the	Y/N	N/A

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
			requirements specified in paragraph 12.1.1.2. (a)-(f)		
155	12.1.1.3.	PM sampling nozzles – $PM_{2.5}$ nozzle dimensions (inner diameter)	Report the $PM_{2.5}$ sampling nozzle inner diameter (d_n) used for the brake under testing	mm	2
156	12.1.1.3.	PM sampling nozzles – PM_{10} nozzle dimensions (inner diameter)	Report the PM_{10} sampling nozzle inner diameter (d_n) used for the brake under testing	mm	2
157	12.1.1.3.	PM sampling nozzles – $PM_{2.5}$ nozzle aspiration angle	Report the $PM_{2.5}$ sampling nozzle aspiration angle applied for the brake under testing	°	1
158	12.1.1.3.	PM sampling nozzles – PM_{10} nozzle aspiration angle	Report the PM_{10} sampling nozzle aspiration angle applied for the brake under testing	°	1
159	12.1.1.3.	PM sampling nozzles – Overall compliance	Verify that the [$PM_{2.5}$ and]PM_{10} sampling nozzle[s] used for the brake under testing meet all the requirements specified in paragraph 12.1.1.3. (a)-(h)	Y/N	N/A
160	12.1.2.1.	PM separation device – $PM_{2.5}$ cyclone cut-off size	Report the $PM_{2.5}$ cyclonic separator cut-off size used for the brake under testing	µm	1
161	12.1.2.1.	PM separation device – PM_{10} cyclone cut-off size	Report the PM_{10} cyclonic separator cut-off size used for the brake under testing	µm	1
162	12.1.2.1.	PM separation device – Overall compliance	Verify that the [$PM_{2.5}$ and]PM_{10} cyclonic separators used for the brake under testing meet all the requirements specified in paragraph 12.1.2.1. (a)-(d)	Y/N	N/A
163	12.1.2.2.	PM sampling line – $PM_{2.5}$ line dimensions (inner diameter)	Report the $PM_{2.5}$ sampling line inner diameter (d_s) used for the brake under testing	mm	2
164	12.1.2.2.	PM sampling line – PM_{10} line dimensions (inner diameter)	Report the PM_{10} sampling line inner diameter (d_s) used for the brake under testing	mm	2
165	12.1.2.2.	PM sampling line – $PM_{2.5}$ line dimensions (length)	Report the $PM_{2.5}$ sampling line overall length from the cyclone to the tip of the filter holder used for the brake under testing	mm	1
166	12.1.2.2.	PM sampling line – PM_{10} line dimensions (length)	Report the PM_{10} sampling line overall length from the cyclone to the tip of the filter holder used for the brake under testing	mm	1
167	12.1.2.2.	PM sampling line – Application of a bend	Report if a bend is applied to the [$PM_{2.5}$ and/or]PM_{10} sampling line[s] used for the brake under testing	Y/N	N/A
168	12.1.2.2.	PM sampling line – $PM_{2.5}$ line bending radius	When a bend is applied to the $PM_{2.5}$ sampling line report its bending radius in sampling line diameters. If there is no bend report “NA”	$\#\cdot d_s$	1
169	12.1.2.2.	PM sampling line – PM_{10} line bending radius	When a bend is applied to the PM_{10} sampling line report its bending radius in sampling line diameters. If there is no bend report “NA”	$\#\cdot d_s$	1

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
170	12.1.2.2.	PM sampling line – Overall compliance	Verify that the[$PM_{2.5}$ and]PM_{10} sampling line[s] used for the brake under testing meet all the requirements specified in paragraph 12.1.2.2. (a)-(f)	Y/N	N/A
171	12.1.2.3.	PM sampling flow – $PM_{2.5}$ nominal flow	Report the set (nominal) flow value for $PM_{2.5}$ sampling for the brake under testing ($Q_{PM2.5\text{-}set}$)	l/min	1
172	12.1.2.3.	PM sampling flow – PM_{10} nominal flow	Report the set (nominal) flow value for PM_{10} sampling for the brake under testing ($Q_{PM10\text{-}set}$)	l/min	1
173	12.1.2.3.	PM sampling flow – $PM_{2.5}$ normalized measured flow	Report the average normalized measured $PM_{2.5}$ sampling flow over the emissions measurement section for the brake under testing ($NQ_{PM2.5}$). Use the 1Hz data of the parameter "$PM_{2.5}$ Sampling Flow Actual Normalized" in the Time-Based File to calculate the average measured flow over the WLTP-Brake cycle (cooling sections not included)	*N*l/min	2
174	12.1.2.3.	PM sampling flow – PM_{10} normalized measured flow	Report the average normalized measured PM_{10} sampling flow over the emissions measurement section for the brake under testing (NQ_{PM10}). Use the 1Hz data of the parameter "PM_{10} Sampling Flow Actual Normalized" in the Time-Based File to calculate the average measured flow over the WLTP-Brake cycle (cooling sections not included)	*N*l/min	2
175	12.1.2.3. , 12.1.2.4.	PM sampling flow – $PM_{2.5}$ isokinetic ratio	Calculate and report the average isokinetic ratio for $PM_{2.5}$ sampling over the emissions measurement section for the brake under testing. Apply Equation 12.4 and use the $PM_{2.5}$ nozzle diameter and the 1Hz data of the parameters "Cooling Airflow Actual Normalized" and "$PM_{2.5}$ Sampling Flow Actual Normalized" in the Time-Based File to calculate the average isokinetic ratio over the WLTP-Brake cycle (cooling sections not included)	-	3
176	12.1.2.3. , 12.1.2.4.	PM sampling flow – PM_{10} isokinetic ratio	Calculate and report the average isokinetic ratio for PM_{10} sampling over the emissions measurement section for the brake under testing. Apply Equation 12.4 and use the PM_{10} nozzle diameter and the 1Hz data of the parameters "Cooling Airflow Actual Normalized" and "PM_{10} Sampling Flow Actual Normalized" in the Time-Based File to calculate the average isokinetic ratio over the WLTP-Brake cycle (cooling sections not included)	-	3
177	12.1.2.3.	PM sampling flow – Overall compliance	Verify that all the specifications for the $PM_{2.5}$ and PM_{10} sampling flow as well as for the $PM_{2.5}$ and PM_{10} isokinetic ratio defined in paragraph 12.1.2.3. (a)-(i) for the brake under testing are fulfilled	Y/N	N/A
178	12.1.3.1.	PM filter holder – $PM_{2.5}$ filter holder overall compliance	Verify that the $PM_{2.5}$ filter holder meets all the requirements defined in paragraph 12.1.3.1. (a)-(g)	Y/N	N/A
179	12.1.3.1.	PM filter holder – PM_{10} filter holder overall compliance	Verify that the PM_{10} filter holder meets all the requirements defined in paragraph 12.1.3.1. (a)-(g)	Y/N	N/A

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
180	12.1.3.2.	PM sampling filters – Type of filter for $PM_{2.5}$ sampling	Specify the type of filter (filter material) used for $PM_{2.5}$ sampling for the brake under testing	-	N/A
181	12.1.3.2.	PM sampling filters – Type of filter for PM_{10} sampling	Specify the type of filter (filter material) used for PM_{10} sampling for the brake under testing	-	N/A
182	12.1.3.2.	PM sampling filters – Overall compliance	Verify that the filters used for $PM_{2.5}$ and PM_{10} sampling for the brake under testing meets all the requirements defined in paragraph 12.1.3.2.	Y/N	N/A
183	12.1.4.	Weighing procedure – Climatic room	Verify that the weighing balance has been stored in an appropriate room fulfilling all the requirements described in paragraph 12.1.4.	Y/N	N/A
184	12.1.4.	Weighing procedure – Balance resolution	Report the resolution of the weighing balance used for weighing the PM_{10} and $PM_{2.5}$ filters	µg	1
185	12.1.4.	Weighing procedure – Pre-sampling date and time	Report the pre-sampling weighing date and time of the $PM_{2.5}$ and PM_{10} filters used for the brake under testing	-	N/A
186	12.1.4.	Weighing procedure – Pre-sampling room's temperature	Report the pre-sampling weighing room's average temperature during the measurement of the PM_{10} and $PM_{2.5}$ filter weights	°C	2
187	12.1.4.	Weighing procedure – Pre-sampling room's RH	Report the pre-sampling weighing room's average relative humidity during the measurement of the PM_{10} and $PM_{2.5}$ filter weights	%	2
188	12.1.4.	Weighing procedure – Pre-sampling $PM_{2.5}$ filter weight corrected	Report the corrected pre-sampling $PM_{2.5}$ filter weight for the brake under testing ($Pe_{(Corrected)}$). Use Equation 12.5 to calculate the corrected mass measurement	mg	4
189	12.1.4.	Weighing procedure – Pre-sampling PM_{10} filter weight corrected	Report the corrected pre-samplingPM_{10} filter weight for the brake under testing ($Pe_{(Corrected)}$). Use Equation 12.5 to calculate the corrected mass measurement	mg	4
190	12.1.4.	Weighing procedure – Post-sampling date and time	Report the post-sampling weighing date and time of the $PM_{2.5}$ and PM_{10} filters used for the brake under testing	-	N/A
191	12.1.4.	Weighing procedure – Post-sampling room's temperature	Report the post-sampling weighing room's average temperature during the measurement of the PM_{10} and $PM_{2.5}$ filter weights	°C	2
192	12.1.4.	Weighing procedure – Post-sampling room's RH	Report the post-sampling weighing room's average relative humidity during the measurement of the PM_{10} and $PM_{2.5}$ filter weights	%	2
193	12.1.4.	Weighing procedure – Post-sampling $PM_{2.5}$ filter weight corrected	Report the corrected post-sampling$PM_{2.5}$ filter weight for the brake under testing ($Pe_{(Corrected)}$). Use Equation 12.5 to calculate the corrected mass measurement	mg	4
194	12.1.4.	Weighing procedure – Post-sampling PM_{10} filter weight corrected	Report the corrected post-samplingPM_{10} filter weight for the brake under testing ($Pe_{(Corrected)}$). Use Equation 12.5 to calculate the corrected mass measurement	mg	4

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
195	12.1.4.	Weighing procedure – $PM_{2.5}$ final filter load	Report the $PM_{2.5}$ filter mass loading for the brake under testing ($Pe_{(2.5)}$). Use the corrected pre-testing and post-testing $PM_{2.5}$ filter measurements for the calculation as specified in point 12.1.4. (g)	mg	4
196	12.1.4.	Weighing procedure – PM_{10} final filter load	Report the PM_{10} filter mass loading for the brake under testing ($Pe_{(10)}$). Use the corrected pre-testing and post-testing PM_{10} filter measurements for the calculation as specified in point 12.1.4. (g)	mg	4
197	12.1.4.	Weighing procedure – Overall compliance	Verify that all requirements defined in paragraph 12.1.4. for conditioning, handling, and weighing of the [$PM_{2.5}$ and]PM_{10} filters used for the brake under testing have been fulfilled	Y/N	N/A
198	12.1.4.	Weighing procedure – PM reference filters – Difference with rolling average	Report the average difference between the reference filter weights and their rolling average. Use column I of the Mass Measurement File. In case of reference filters not weighed on a regular basis, this measurement reflects the difference between the pre-test weighing and its rolling average per paragraph 12.1.4. (iii)	mg	4
199	12.1.4.	Weighing procedure – PM reference filters – Difference with rolling average (end of session)	Report the average difference between the reference filter weights and their rolling average at the end of the session. Use column P of the Mass Measurement File. Report N/A in case reference filters are weighed on a regular basis	mg	4
200	12.1.4.	Weighing procedure – PM reference filters – Difference between initial and final weighing	Report the average difference between the initial and final weighings of the reference filters in case of reference filters not weighed on a regular basis. Use column Q of the Mass Measurement File. Report N/A in case reference filters are weighed on a regular basis	mg	4
201	12.1.4.	Weighing procedure – Overall compliance of reference filters weighing procedure	Verify that the weighing of PM reference filters was carried out according to the specifications defined in paragraph 12.1.4. (f)	Y/N	N/A
202	12.1.5.	PM emission factor calculation – Reference $PM_{2.5}$ Emission Factor	Report the $PM_{2.5}$ emission factor in mass per distance driven for the brake under testing as specified in paragraph 12.1.5. ($PM_{2.5}$ EF_{ref}). Use the $PM_{2.5}$ filter mass loading for the brake under testing ($Pe_{(2.5)}$) calculated in the Mass Measurement File. Use the data of the parameters “Cooling Airflow Actual Normalized”, “$PM_{2.5}$ Sampling Flow Actual Normalized”, and “Driven Distance” in the Time-Based File over the WLTP-Brake cycle of the emissions measurement section	mg/km	3
203	12.1.5.	PM emission factor calculation – Final $PM_{2.5}$ Emission Factor	Report the final $PM_{2.5}$ emission factor in mass per distance driven for the vehicle on which the brake under testing is mounted ($PM_{2.5}$ EF). Perform the calculation in accordance with Equation 12.9 as specified in paragraph 12.1.5.	mg/km	3

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
204	12.1.5.	PM emission factor calculation – Reference PM_{10} Emission Factor	Report the PM_{10} emission factor in mass per distance driven for the brake under testing as specified in paragraph 12.1.5. (PM_{10} EF_{ref}). Use the PM_{10} filter mass loading for the brake under testing ($Pe_{(10)}$) calculated in the Mass Measurement File. Use the data of the parameters “Cooling Airflow Actual Normalized”, “PM_{10} Sampling Flow Actual Normalized”, and “Driven Distance” in the Time-Based File over the WLTP-Brake cycle of the emissions measurement section	mg/km	3
205	12.1.5.	PM emission factor calculation – Final PM_{10} Emission Factor	Report the final PM_{10} emission factor in mass per distance driven for the vehicle on which the brake under testing is mounted (PM_{10} EF). Perform the calculation in accordance with Equation 12.10 as specified in paragraph 12.1.5.	mg/km	3
206		Reserved			
207	12.2.1.1.	PN sampling plane – PN sampling probes positioning	Verify that the design of the sampling plane and the placement of the SPN10 sampling probe fulfil the specifications described in paragraph 12.2.1.1. (a)	Y/N	N/A
208		Reserved			
209		Reserved			
210		Reserved			
211	12.2.1.2.	PN sampling probes – SPN10 probe dimensions (inner diameter)	Report the SPN10 sampling probe’s inner diameter (d_p) used for the brake under testing	mm	2
212	12.2.1.2.	Reserved			
213	12.2.1.2.	PN sampling probes – SPN10 probe dimensions (length)	Report the SPN10 sampling probe’s overall length from the sampling nozzle tip to the inlet of the particle transfer tube used for the brake under testing	mm	1
214	12.2.1.2.	PN sampling probes – Application of a bend	Report if a bend is applied to SPN10 sampling probe used for the brake under testing	Y/N	N/A
215		Reserved			
216	12.2.1.2.	PN sampling probes – SPN10 bending radius	When a bend is applied to the SPN10 sampling probe report its bending radius in probe diameters. If there is no bend report “NA”	$\#\cdot d_p$	1
217	12.2.1.2.	PN sampling probes – Overall compliance	Verify that the SPN10 sampling probe used for the brake under testing meet all the requirements specified in paragraph 12.2.1.2. (a)-(f)	Y/N	N/A
218	12.2.1.3.	Reserved			
219	12.2.1.3.	PN sampling nozzles – SPN10 nozzle dimensions (inner diameter)	Report the SPN10 sampling nozzle inner diameter (d_n) used for the brake under testing	mm	2
220		Reserved			

No.	Paragraph	Parameters and Inputs	Short description	Unit	Decimals
221	12.2.1.3.	PN sampling nozzles – SPN10 aspiration angle	Report the SPN10 sampling nozzle aspiration angle applied for the brake under testing	°	1
222	12.2.1.3.	PN sampling nozzles – Overall compliance	Verify that the SPN10 sampling nozzle used for the brake under testing meet all the requirements specified in paragraph 12.2.1.3. (a)-(g)	Y/N	N/A
223		Reserved			
224	12.2.1.4.	PN transfer tube – SPN10 PTT dimensions (inner diameter)	Report the SPN10 particle transfer tube inner diameter (d_{tt}) used for the brake under testing	mm	2
225	12.2.1.4.	PN transfer tube – Application of a bend	Report if a bend is applied to the SPN10 particle transfer tube used for the brake under testing	Y/N	N/A
226		Reserved			
227	12.2.1.4.	PN transfer tube – SPN10 bending radius	When a bend is applied to the SPN10 particle transfer tube report its bending radius in sampling transfer tube diameters	$\#\cdot d_{tt}$	1
228	12.2.1.4.	PN transfer tube – Overall compliance	Verify that the SPN10 particle transfer tube used for the brake under testing meet all the requirements specified in paragraph 12.2.1.4. (a)-(g)	Y/N	N/A
229		Reserved			
230	12.2.2.1.	PN separation device – SPN10 cut-off size	Report the SPN10 cyclonic separator cut-off size used for the brake under testing	µm	1
231	12.2.2.1.	PN separation device – Overall compliance	Verify that the PN cyclonic separator(s) used for the brake under testing meets all the requirements specified in paragraph 12.2.2.1. (a)-(f)	Y/N	N/A
232		Reserved			
233	12.2.2.2.	PN sample conditioning – SPN10 average PCRF	Report the arithmetic average PCRF applied for the SPN10 sampling and measurement for the brake under testing. Use the 1Hz data of the parameter “SPN10 - Average PCRF” in the Time-Based File to calculate the arithmetic average PCRF over the WLTP-Brake cycle of the emissions measurement section	-	1
234		Reserved			
235	12.2.2.2.	PN sample conditioning – SPN10 overall compliance	Verify that the volatile particle removal system applied for the SPN10 sampling and measurement for the brake under testing meets all the requirements defined in paragraph 12.2.2.2. (k)-(v)	Y/N	N/A
236		Reserved			
237	12.2.2.3.	PN internal transfer line – SPN10 line dimensions (inner diameter)	Report the SPN10 internal transfer line inner diameter (d_{tl}) used for the brake under testing	mm	2
238		Reserved			

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
239	12.2.2.3.	PN internal transfer line – SPN10 line dimensions (length)	Report the SPN10 internal transfer line length from the exit of the VPR to the inlet of the PNC for the brake under testing	mm	1
240	12.2.2.3.	PN internal transfer line – Application of a bend	Report if a bend is applied to the SPN10 internal transfer line used for the brake under testing. If there is no bend report “NA”	Y/N	N/A
241		Reserved			
242	12.2.2.3.	PN internal transfer line – SPN10 bending radius	When a bend is applied to the SPN10 internal transfer line report its bending radius in transfer line diameters. If there is no bend report “NA”	$\#\cdot d_{tl}$	1
243	12.2.2.3.	PN internal transfer line – Overall compliance	Verify that the SPN10 internal transfer line used for the brake under testing meet all the design requirements specified in paragraph 12.2.2.3.	Y/N	N/A
244		Reserved			
245	12.2.3.1.	Particle number counter – SPN10 PNC overall compliance	Verify that the particle number counter used for the measurement of SPN10 for the brake under testing meets all the requirements specified in paragraph 12.2.3.1. (a)-(i)	Y/N	N/A
246		Reserved			
247	12.2.3.2.	PN sampling flow – SPN10 measured flow	Report the average normalized PN sampling flow value for SPN10 for the brake under testing. Use the 1Hz data of the parameter “SPN10 Sampling Flow Actual Normalized” in the Time-Based File to calculate the average sampling flow over the WLTP-Brake cycle of the emissions measurement section	*N*l/min	3
248		Reserved			
249	12.2.3.2.	PN sampling flow – SPN10 isokinetic ratio	Report the average isokinetic ratio for SPN10 sampling for the brake under testing. Use the SPN10 nozzle diameter and the 1Hz data of the parameters “Cooling Airflow Actual Normalized” and “SPN10 Sampling Flow Actual Normalized” in the Time-Based File (over the WLTP-Brake cycle of the emissions measurement section) for the calculation following Equation 12.4	-	3
250	12.2.3.2.	PN sampling flow – Overall compliance	Verify that all the specifications for the SPN10 sampling flow as well as for the SPN10 isokinetic ratio defined in paragraph 12.2.3.2. (a)-(h) for the brake under testing are fulfilled	Y/N	N/A
251		Reserved			
252	12.2.4.	Reserved			
253		Reserved			
254	12.2.4.	PN emission factor calculation – Reference SPN10 EF_{ref}	Report the SPN10 emission factor (SPN10 EF_{ref}) in the number of particles per distance driven for the brake under testing as specified in paragraph 12.2.4.	#/km	1

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
255	12.2.4.	PN emission factor calculation – Final SPN10 EF	Report the final SPN10 emission factor in number of particles per distance driven for the vehicle on which the brake under testing is mounted. Perform the calculation in accordance with Equation 12.14 as specified in paragraph 12.2.4.	#/km	1
256	12.2.4.	PN emission factor calculation – SPN10 measurement range verification	Verify that the SPN10 emissions in #/*N*cm^3 are within the specified measurement range of the PNC device. Use the 1Hz data of the parameter "SPN10 Concentration Normalized - PCRF Corrected" in the Time-Based File for performing the verification over the WLTP-Brake cycle of the emissions measurement section	Y/N	N/A
257	12.2.5.	PN system verification procedures – Overall compliance	Verify that the PN system verification procedures defined in paragraph 12.2.5. (a)-(d) have been applied successfully for the brake under testing	Y/N	N/A
258	12.3.	Mass loss measurement – Disc or drum pre-test mass	Report the pre-test mass of the disc or drum with the thermocouple installed and the thermocouple connector removed	g	1
259	12.3.	Mass loss measurement – Friction material pre-test mass	Report the total pre-test mass of the brake friction material including the anti-noise shims, pad-shim springs, and other elements when part of the product assembly. Use the data from the Mass Measurement File to report the sum of the pre-test masses for the brake friction material	g	1
260	12.3.	Mass loss measurement – Disc or drum post-test mass	Report the post-test mass of the disc or drum with the thermocouple installed and the thermocouple connector removed	g	1
261	12.3.	Mass loss measurement – Friction material post-test mass	Report the total post-test mass of the brake friction material including the anti-noise shims, pad-shim springs, and other elements when part of the product assembly. Use the data from the Mass Measurement File to report the sum of the post-test masses for the brake friction material	g	1
262	12.3.	Mass loss measurement – Total mass loss	Report the total mass loss of the brake under testing following the procedure defined in Table A4/13 and paragraph 12.3. (j)	g	1
263	12.3.	Mass loss measurement – Total distance driven	Calculate and report the total distance driven during bedding and the emissions measurement section (soaking sections not included)	km	3
264	12.3.	Mass loss measurement – Weight loss emission factor	Report the averaged weight loss emission factor of the brake under testing following the procedure defined in Table A4/13 and paragraph 12.3. (k)	mg/km	2
265	12.3.	Mass loss measurement – Overall compliance	Verify that the mass loss measurement of the brake under testing has been conducted following all the specifications described in paragraph 12.3. (a)-(k)	Y/N	N/A
266	14.2.	Calibration requirements – Inertia dynamometer	Verify that the calibration requirements defined for the brake dynamometer in Table A4/15 and paragraph 14.2. are met and that a valid calibration	Y/N	N/A

No.	*Paragraph*	*Parameters and Inputs*	*Short description*	*Unit*	*Decimals*
			certificate is available at the time of the brake emissions test		
267	14.3.	Calibration requirements – Airflow measurement device	Verify that the calibration requirements defined for the cooling airflow measurement device in Table A4/15 and paragraph 14.3. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A
268	14.1.	Calibration requirements – Cyclonic separators	Verify that the calibration requirements defined for the PM and PN cyclonic separators in Table A4/15 and paragraphs 12.1. and 12.2. are met	Y/N	N/A
269	14.4.	Calibration requirements – Weighing balance	Verify that the calibration requirements defined for the microgram balance in Table A4/15 and paragraph 14.4. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A
270	14.1.	Calibration requirements – PM sampling flow measurement device	Verify that the calibration requirements defined for the PM sampling flow measurement device in Table A4/15 and paragraph 12.1. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A
271	14.1.	Calibration requirements – PN sampling flow measurement device	Verify that the calibration requirements defined for the PN sampling flow measurement device in Table A4/15 and paragraph 12.2. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A
272	14.5.	Calibration requirements – Sample treatment and conditioning devices	Verify that the calibration requirements defined for the SPN10 volatile particle remover in Table A4/15 and paragraph 14.5. are met and that valid calibration certificates are available at the time of the brake emissions test	Y/N	N/A
273	14.6.	Calibration requirements – Particle number counter	Verify that the calibration requirements defined for the particle number counter in Table A4/15 and paragraph 14.6. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A
274	14.4.	Calibration requirements – Brake parts balance	Verify that the calibration requirements defined for the brake parts balance in Table A4/15 and paragraph 14.4. are met and that a valid calibration certificate is available at the time of the brake emissions test	Y/N	N/A

14. Calibration Requirements and Ongoing Quality Controls

14.1. General Calibration Requirements

This paragraph summarises the minimum calibration requirements for the equipment used for brake emissions testing. Table A4/15 summarises the calibration criteria and the intervals for the main equipment defined in this Regulation.

Table A4/15

Calibration requirements for main equipment for emissions measurements

Instrument	*Interval*	*Criterion*	*Paragraph*
Brake dynamometer	Upon initial installation, yearly, and at major maintenance	Table A4/17	Paragraph 14.2.
Torque measurement device	Upon initial installation, yearly, and at major maintenance	Table A4/18	Paragraph 14.2.
Cooling airflow measurement device	Upon initial installation, yearly, and at major maintenance	Table A4/19	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.
PM_{10} Cyclonic separator	Certificate of compliance supplied by cyclone manufacturer upon initial installation	Table A4/7	Paragraph 12.1.
$PM_{2.5}$ Cyclonic separator	Certificate of compliance supplied by cyclone manufacturer upon initial installation	Table A4/8	Paragraph 12.1.
Microgram balance for PM_{10} and $PM_{2.5}$	Upon initial installation, yearly, and at major maintenance	Table A4/20	Paragraph 14.4.
PM sampling flow measurement device	Upon initial installation, yearly, and at major 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	Certificate of compliance supplied by cyclone manufacturer upon initial installation	Penetration efficiency of ≥80 per cent for a particle electrical mobility diameter of 1.5 µm	Paragraph 12.2.

Instrument	*Interval*	*Criterion*	*Paragraph*
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.
Volatile Particle Remover for SPN10	6 months or 13 months depending on the specific instrument	Per paragraph 14.5.2.	Paragraph 14.5.
Particle Number Counter	13 months and at major maintenance	Per paragraph 14.6.	Paragraph 14.6.
Brake parts balance	Upon initial installation, yearly, and at major maintenance	Table A4/20	Paragraph 14.4.

Any other sensor or auxiliary equipment used to determine temperature, atmospheric pressure, and ambient humidity in the facilities room or the balance room shall fulfil the requirements prescribed in Table A4/16

Table A4/16
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
Specific humidity sensor	Yearly	±10 per cent of reading or 1 gH_2O/kg dry air (whichever is greater)

14.2. **Brake Dynamometer**

Table A4/17 summarises the calibration criteria and the intervals for the brake dynamometer defined in this Regulation. The rotational speed, brake torque, and brake pressure measurement devices shall comply with the linearity requirements of Table A4/18

Table A4/17
Calibration requirements for the brake dynamometer

Instrument	*Interval*	*Criterion*
Rotational speed device	Upon initial installation, yearly, and at major setup maintenance	Table A4/18
Brake torque sensor	Upon initial installation, yearly, and at major setup maintenance	Table A4/18
Brake pressure sensor	Upon initial installation, yearly, and at major setup maintenance	Table A4/18

Instrument	*Interval*	*Criterion*
Brake fluid displacement sensor (optional)	Upon initial installation, yearly, and at major setup maintenance	According to the manufacturer's specifications.
Temperature data acquisition	Upon initial installation, yearly, and at major setup maintenance	±0.25 per cent maximum

Table A4/18

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 A4/17 and A4/18, the testing facility shall verify the torque zero level and pressure zero level every time before commencing a brake emissions test. The verification shall be carried out following the methodology described in paragraph 8.2.

14.3. 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 A4/19 with at least four equally spaced reference flows applying a linear regression between the minimum and maximum operational flow rate 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, yearly, and at every major maintenance of the setup.

Table A4/19

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 standard conditions. To ensure an appropriate conversion to operating conditions, the temperature sensor shall have an accuracy of ±1 °C and the pressure measurements shall have a precision and accuracy of ±0.4 kPa. The testing facility shall carry out the calibration of both sensors yearly.

14.4. PM and Mass Loss Scales

14.4.1. Microbalance for PM Filter Weighting

The calibration of the microgram balance used for PM mass 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 A4/20 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 (Table A4/15). The testing facility shall perform the calibration of the microgram balance upon the initial installation, yearly, and at every major maintenance of the setup.

14.4.2. Balance for Brake Parts Weighting

The calibration of the balance used for the brake parts weighing according to paragraph 12.3. shall be traceable to national or international standards. The balance shall comply with the linearity requirements of Table A4/20 with at least four equally spaced reference weights applying linear regression. This implies a precision of at least ±1 g and a resolution of at least 0.1 g. The testing facility shall use certified calibration weights to verify the stability and the proper function of the balance, regularly (Table A4/15). The testing facility shall perform the calibration of the balance upon the initial installation, yearly, and at every major maintenance of the setup.

Table A4/20

Verification criteria for microgram and brake parts balance

Measurement system	*Intercept a0*	*Slope a1*	*Standard error of estimate (SEE)*	*Coefficient of determination r^2*
PM balance	≤ 1 µg	0.99 – 1.01	≤ 1 per cent maximum	≥ 0.998
Brake parts balance	≤ 0.3 g	0.99 – 1.01	≤ 1 per cent maximum	≥ 0.998

14.5. Sample Treatment and Conditioning Devices

Table A4/21

PCRF (f_r (d_x)) requirements for particles of 15 nm, 30 nm, and 50 nm electrical mobility diameters

PCRF Fraction	*Minimum allowed value*	*Maximum allowed value*
(fr (15nm))/(fr (100nm))	0.95	2.00
(fr (30nm))/(fr (100nm))	0.95	1.30
(fr (50nm))/(fr (100nm))	0.95	1.20

14.5.1. Reserved

14.5.2. 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 (Table A4/21). For validation, the mean PCRF shall be within ±10 per cent of the arithmetic mean particle concentration reduction factor (f_r) 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 #/cm³ for particles of 15 nm electrical mobility diameter and 5000 #/cm³ 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 monodisperse particle size ($f_r (d_x)$) shall be calculated following Equation 14.1. The arithmetic average particle concentration reduction (f_r) 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 ($CH_3(CH_2)_{38}CH_3$) particles with count median electrical mobility diameter > 50 nm and mass > 1 mg/m^3 when operated at its minimum dilution setting and the manufacturers recommended operating temperature.

The instrument manufacturer shall prove the particle penetration $P_r(d_x)$ 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 $P_r(d_x)$ at a particle size, d_x, shall be calculated using Equation 14.3.

14.6. Particle Number Counter

The type approval 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:

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

(b) 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. The 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 R^2, 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 by the gradient, with the exception of the zero point.

The calibration shall also include a check against the requirements for 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.

Annex 4 – Appendix 1

WLTP-Brake Cycle Events

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
0	4	1	Idle	0.0	0.0
4	10	1	Accel.	0.0	20.7
10	18	1	Cruise	20.7	20.7
18	24	1	Decel.	20.7	0.0
24	27	1	Idle	0.0	0.0
27	46	1	Accel.	0.0	23.1
46	58	1	Cruise	23.1	23.1
58	65	1	Decel.	23.1	5.6
65	68	1	Cruise	5.6	5.6
68	77	1	Accel.	5.6	15.4
77	85	1	Cruise	15.4	15.4
85	89	1	Decel.	15.4	4.4
89	92	1	Cruise	4.4	4.4
92	100	1	Accel.	4.4	25.7
100	103	1	Cruise	25.7	25.7
103	109	1	Decel.	25.7	7.2
109	112	1	Cruise	7.2	7.2
112	122	1	Accel.	7.2	24.8
122	129	1	Cruise	24.8	24.8
129	132	1	Decel.	24.8	16.7
132	135	1	Cruise	16.7	16.7
135	137	1	Accel.	16.7	18.7
137	140	1	Cruise	18.7	18.7
140	149	1	Decel.	18.7	0.0
149	153	1	Idle	0.0	0.0
153	174	1	Accel.	0.0	32.5
174	177	1	Cruise	32.5	32.5
177	183	1	Decel.	32.5	0.0
183	281	1	Idle	0.0	0.0
281	295	1	Accel.	0.0	27.5
295	298	1	Cruise	27.5	27.5
298	303	1	Decel.	27.5	11.8
303	306	1	Cruise	11.8	11.8
306	311	1	Accel.	11.8	29.4
311	314	1	Cruise	29.4	29.4
314	320	1	Decel.	29.4	9.7
320	323	1	Cruise	9.7	9.7
323	333	1	Accel.	9.7	31.9
333	341	1	Cruise	31.9	31.9

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
341	347	1	Decel.	31.9	9.5
347	351	1	Cruise	9.5	9.5
351	358	1	Accel.	9.5	14.7
358	361	1	Cruise	14.7	14.7
361	366	1	Decel.	14.7	0.0
366	372	1	Idle	0.0	0.0
372	381	1	Accel.	0.0	59.5
381	384	1	Cruise	59.5	59.5
384	388	1	Decel.	59.5	47.6
388	402	1	Cruise	47.6	47.6
402	406	1	Decel.	47.6	36.2
406	478	1	Cruise	36.2	36.2
478	480	1	Accel.	36.2	38.2
480	486	1	Cruise	38.2	38.2
486	490	1	Decel.	38.2	25.5
490	493	1	Cruise	25.5	25.5
493	496	1	Decel.	25.5	18.4
496	499	1	Cruise	18.4	18.4
499	505	1	Decel.	18.4	0.0
505	508	1	Idle	0.0	0.0
508	516	1	Accel.	0.0	42.3
516	543	1	Cruise	42.3	42.3
543	552	1	Decel.	42.3	0.0
552	555	1	Idle	0.0	0.0
555	564	1	Accel.	0.0	42.1
564	566	1	Cruise	42.1	42.1
566	576	1	Decel.	42.1	0.0
576	579	1	Idle	0.0	0.0
579	587	1	Accel.	0.0	31.3
587	592	1	Cruise	31.3	31.3
592	595	1	Decel.	31.3	12.5
595	600	1	Cruise	12.5	12.5
600	605	1	Decel.	12.5	0.0
605	622	1	Idle	0.0	0.0
622	642	1	Accel.	0.0	45.3
642	647	1	Cruise	45.3	45.3
647	657	1	Decel.	45.3	0.0
657	660	1	Idle	0.0	0.0
660	669	1	Accel.	0.0	45.5

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
669	673	1	Cruise	45.5	45.5
673	683	1	Decel.	45.5	0.0
683	685	1	Idle	0.0	0.0
685	704	1	Accel.	0.0	40.7
704	726	1	Cruise	40.7	40.7
726	733	1	Decel.	40.7	12.8
733	736	1	Cruise	12.8	12.8
736	744	1	Accel.	12.8	59.6
744	747	1	Cruise	59.6	59.6
747	751	1	Decel.	59.6	46.7
751	758	1	Cruise	46.7	46.7
758	759	1	Accel.	46.7	48.6
759	768	1	Cruise	48.6	48.6
768	777	1	Decel.	48.6	0.0
777	778	1	Idle	0.0	0.0
778	786	1	Accel.	0.0	23.7
786	941	1	Cruise	23.7	23.7
941	945	1	Decel.	23.7	9.8
945	948	1	Cruise	9.8	9.8
948	956	1	Accel.	9.8	37.5
956	974	1	Cruise	37.5	37.5
974	983	1	Decel.	37.5	0.0
983	986	1	Idle	0.0	0.0
986	993	1	Accel.	0.0	37.7
993	996	1	Cruise	37.7	37.7
996	1005	1	Decel.	37.7	0.0
1005	1008	1	Idle	0.0	0.0
1008	1013	1	Accel.	0.0	18.6
1013	1016	1	Cruise	18.6	18.6
1016	1021	1	Decel.	18.6	0.0
1021	1070	1	Idle	0.0	0.0
1070	1115	2	Idle	0.0	0.0
1115	1119	2	Accel.	0.0	13.8
1119	1122	2	Cruise	13.8	13.8
1122	1126	2	Decel.	13.8	0.0
1126	1129	2	Idle	0.0	0.0
1129	1144	2	Accel.	0.0	34.2
1144	1147	2	Cruise	34.2	34.2
1147	1151	2	Decel.	34.2	18.9
1151	1154	2	Cruise	18.9	18.9
1154	1162	2	Accel.	18.9	32.9
1162	1174	2	Cruise	32.9	32.9
1174	1178	2	Decel.	32.9	23.3

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
1178	1182	2	Cruise	23.3	23.3
1182	1186	2	Accel.	23.3	25.6
1186	1188	2	Cruise	25.6	25.6
1188	1191	2	Decel.	25.6	18.5
1191	1194	2	Cruise	18.5	18.5
1194	1206	2	Accel.	18.5	38.7
1206	1209	2	Cruise	38.7	38.7
1209	1217	2	Decel.	38.7	0.0
1217	1220	2	Idle	0.0	0.0
1220	1236	2	Accel.	0.0	48.4
1236	1253	2	Cruise	48.4	48.4
1253	1256	2	Decel.	48.4	40.6
1256	1259	2	Cruise	40.6	40.6
1259	1262	2	Accel.	40.6	42.4
1262	1282	2	Cruise	42.4	42.4
1282	1286	2	Decel.	42.4	30.3
1286	1290	2	Cruise	30.3	30.3
1290	1295	2	Decel.	30.3	13.7
1295	1298	2	Cruise	13.7	13.7
1298	1315	2	Accel.	13.7	40.0
1315	1319	2	Cruise	40.0	40.0
1319	1325	2	Decel.	40.0	20.0
1325	1328	2	Cruise	20.0	20.0
1328	1331	2	Accel.	20.0	29.7
1331	1334	2	Cruise	29.7	29.7
1334	1338	2	Decel.	29.7	18.9
1338	1341	2	Cruise	18.9	18.9
1341	1344	2	Accel.	18.9	24.5
1344	1448	2	Cruise	24.5	24.5
1448	1451	2	Decel.	24.5	17.5
1451	1454	2	Cruise	17.5	17.5
1454	1476	2	Accel.	17.5	42.0
1476	1482	2	Cruise	42.0	42.0
1482	1491	2	Decel.	42.0	0.0
1491	1502	2	Idle	0.0	0.0
1502	1512	2	Accel.	0.0	22.0
1512	1515	2	Cruise	22.0	22.0
1515	1519	2	Decel.	22.0	11.8
1519	1522	2	Cruise	11.8	11.8
1522	1528	2	Accel.	11.8	32.4
1528	1539	2	Cruise	32.4	32.4
1539	1547	2	Decel.	32.4	6.1
1547	1550	2	Cruise	6.1	6.1

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
1550	1559	2	Accel.	6.1	34.8
1559	1597	2	Cruise	34.8	34.8
1597	1605	2	Decel.	34.8	0.0
1605	1608	2	Idle	0.0	0.0
1608	1624	2	Accel.	0.0	76.1
1624	1662	2	Cruise	76.1	76.1
1662	1675	2	Decel.	76.1	0.0
1675	1678	2	Idle	0.0	0.0
1678	1686	2	Accel.	0.0	22.8
1686	1689	2	Cruise	22.8	22.8
1689	1694	2	Decel.	22.8	0.0
1694	1697	2	Idle	0.0	0.0
1697	1707	2	Accel.	0.0	41.6
1707	1753	2	Cruise	41.6	41.6
1753	1757	2	Decel.	41.6	27.2
1757	1763	2	Cruise	27.2	27.2
1763	1773	2	Accel.	27.2	47.9
1773	1804	2	Cruise	47.9	47.9
1804	1807	2	Decel.	47.9	35.2
1807	1823	2	Cruise	35.2	35.2
1823	1828	2	Decel.	35.2	20.1
1828	1831	2	Cruise	20.1	20.1
1831	1843	2	Accel.	20.1	59.2
1843	1870	2	Cruise	59.2	59.2
1870	1873	2	Decel.	59.2	49.5
1873	1876	2	Cruise	49.5	49.5
1876	1885	2	Accel.	49.5	72.9
1885	1895	2	Cruise	72.9	72.9
1895	1898	2	Decel.	72.9	62.0
1898	1901	2	Cruise	62.0	62.0
1901	1904	2	Accel.	62.0	66.4
1904	1907	2	Cruise	66.4	66.4
1907	1910	2	Decel.	66.4	57.4
1910	1913	2	Cruise	57.4	57.4
1913	1915	2	Accel.	57.4	60.0
1915	1918	2	Cruise	60.0	60.0
1918	1921	2	Decel.	60.0	52.1
1921	1937	2	Cruise	52.1	52.1
1937	1947	2	Accel.	52.1	79.7
1947	1951	2	Cruise	79.7	79.7
1951	1954	2	Decel.	79.7	72.1
1954	1959	2	Cruise	72.1	72.1
1959	1960	2	Accel.	72.1	74.0
1960	1972	2	Cruise	74.0	74.0
1972	1978	2	Decel.	74.0	52.4
1978	2062	2	Cruise	52.4	52.4
2062	2074	2	Decel.	52.4	0.0
2074	2077	2	Idle	0.0	0.0
2077	2093	2	Accel.	0.0	60.3
2093	2123	2	Cruise	60.3	60.3
2123	2133	2	Decel.	60.3	0.0
2133	2137	2	Idle	0.0	0.0
2137	2152	2	Accel.	0.0	62.9
2152	2187	2	Cruise	62.9	62.9
2187	2195	2	Decel.	62.9	0.0
2195	2199	2	Idle	0.0	0.0
2199	2212	2	Accel.	0.0	60.1
2212	2218	2	Cruise	60.1	60.1
2218	2229	2	Decel.	60.1	15.2
2229	2233	2	Cruise	15.2	15.2
2233	2244	2	Accel.	15.2	53.3
2244	2250	2	Cruise	53.3	53.3
2250	2261	2	Decel.	53.3	0.0
2261	2266	2	Idle	0.0	0.0
2266	2272	2	Accel.	0.0	20.7
2272	2520	2	Cruise	20.7	20.7
2520	2526	2	Decel.	20.7	0.0
2526	2529	2	Idle	0.0	0.0
2529	2548	2	Accel.	0.0	23.1
2548	2560	2	Cruise	23.1	23.1
2560	2567	2	Decel.	23.1	5.6
2567	2570	2	Cruise	5.6	5.6
2570	2579	2	Accel.	5.6	15.4
2579	2587	2	Cruise	15.4	15.4
2587	2591	2	Decel.	15.4	4.4
2591	2594	2	Cruise	4.4	4.4
2594	2602	2	Accel.	4.4	25.7
2602	2605	2	Cruise	25.7	25.7
2605	2611	2	Decel.	25.7	7.2
2611	2614	2	Cruise	7.2	7.2
2614	2624	2	Accel.	7.2	24.8
2624	2631	2	Cruise	24.8	24.8
2631	2634	2	Decel.	24.8	16.7
2634	2637	2	Cruise	16.7	16.7
2637	2639	2	Accel.	16.7	18.7
2639	2642	2	Cruise	18.7	18.7

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
2642	2650	2	Decel.	18.7	0.0
2650	2655	2	Idle	0.0	0.0
2655	2669	2	Accel.	0.0	46.6
2669	2672	2	Cruise	46.6	46.6
2672	2677	2	Decel.	46.6	9.4
2677	2680	2	Cruise	9.4	9.4
2680	2690	2	Accel.	9.4	52.0
2690	2698	2	Cruise	52.0	52.0
2698	2701	2	Decel.	52.0	41.5
2701	2704	2	Cruise	41.5	41.5
2704	2708	2	Accel.	41.5	49.9
2708	2714	2	Cruise	49.9	49.9
2714	2719	2	Decel.	49.9	34.0
2719	2722	2	Cruise	34.0	34.0
2722	2728	2	Accel.	34.0	49.0
2728	2738	2	Cruise	49.0	49.0
2738	2745	2	Decel.	49.0	23.8
2745	2748	2	Cruise	23.8	23.8
2748	2754	2	Accel.	23.8	41.6
2754	2759	2	Cruise	41.6	41.6
2759	2767	2	Decel.	41.6	0.0
2767	2835	2	Idle	0.0	0.0
2835	2883	3	Idle	0.0	0.0
2883	2892	3	Accel.	0.0	32.1
2892	2897	3	Cruise	32.1	32.1
2897	2903	3	Decel.	32.1	5.5
2903	2906	3	Cruise	5.5	5.5
2906	2924	3	Accel.	5.5	50.5
2924	2946	3	Cruise	50.5	50.5
2946	2949	3	Decel.	50.5	42.8
2949	2952	3	Cruise	42.8	42.8
2952	2955	3	Accel.	42.8	45.0
2955	2958	3	Cruise	45.0	45.0
2958	2963	3	Decel.	45.0	29.8
2963	2966	3	Cruise	29.8	29.8
2966	2971	3	Decel.	29.8	0.0
2971	2976	3	Idle	0.0	0.0
2976	3001	3	Accel.	0.0	49.2
3001	3006	3	Cruise	49.2	49.2
3006	3011	3	Decel.	49.2	33.1
3011	3014	3	Cruise	33.1	33.1
3014	3025	3	Accel.	33.1	56.2
3025	3032	3	Cruise	56.2	56.2

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
3032	3036	3	Decel.	56.2	44.0
3036	3039	3	Cruise	44.0	44.0
3039	3049	3	Accel.	44.0	59.0
3049	3053	3	Cruise	59.0	59.0
3053	3056	3	Decel.	59.0	51.2
3056	3059	3	Cruise	51.2	51.2
3059	3062	3	Accel.	51.2	55.0
3062	3078	3	Cruise	55.0	55.0
3078	3081	3	Decel.	55.0	47.5
3081	3084	3	Cruise	47.5	47.5
3084	3093	3	Accel.	47.5	59.5
3093	3096	3	Cruise	59.5	59.5
3096	3101	3	Decel.	59.5	39.9
3101	3159	3	Cruise	39.9	39.9
3159	3165	3	Decel.	39.9	14.2
3165	3168	3	Cruise	14.2	14.2
3168	3192	3	Accel.	14.2	58.3
3192	3195	3	Cruise	58.3	58.3
3195	3201	3	Decel.	58.3	34.8
3201	3257	3	Cruise	34.8	34.8
3257	3261	3	Accel.	34.8	39.5
3261	3268	3	Cruise	39.5	39.5
3268	3271	3	Decel.	39.5	30.0
3271	3274	3	Cruise	30.0	30.0
3274	3292	3	Accel.	30.0	56.2
3292	3308	3	Cruise	56.2	56.2
3308	3311	3	Decel.	56.2	46.0
3311	3314	3	Cruise	46.0	46.0
3314	3318	3	Accel.	46.0	54.4
3318	3418	3	Cruise	54.4	54.4
3418	3422	3	Decel.	54.4	40.4
3422	3432	3	Cruise	40.4	40.4
3432	3438	3	Accel.	40.4	53.5
3438	3441	3	Cruise	53.5	53.5
3441	3445	3	Decel.	53.5	40.8
3445	3480	3	Cruise	40.8	40.8
3480	3483	3	Decel.	40.8	32.0
3483	3486	3	Cruise	32.0	32.0
3486	3489	3	Accel.	32.0	34.7
3489	3492	3	Cruise	34.7	34.7
3492	3495	3	Decel.	34.7	26.4
3495	3498	3	Cruise	26.4	26.4
3498	3514	3	Accel.	26.4	50.6

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
3514	3557	3	Cruise	50.6	50.6
3557	3561	3	Decel.	50.6	37.6
3561	3621	3	Cruise	37.6	37.6
3621	3626	3	Decel.	37.6	22.4
3626	3629	3	Cruise	22.4	22.4
3629	3640	3	Accel.	22.4	36.8
3640	3647	3	Cruise	36.8	36.8
3647	3651	3	Decel.	36.8	22.9
3651	3654	3	Cruise	22.9	22.9
3654	3675	3	Accel.	22.9	55.3
3675	3684	3	Cruise	55.3	55.3
3684	3688	3	Decel.	55.3	39.5
3688	3692	3	Cruise	39.5	39.5
3692	3698	3	Decel.	39.5	15.5
3698	3701	3	Cruise	15.5	15.5
3701	3717	3	Accel.	15.5	44.3
3717	3729	3	Cruise	44.3	44.3
3729	3732	3	Decel.	44.3	36.6
3732	3773	3	Cruise	36.6	36.6
3773	3778	3	Decel.	36.6	20.8
3778	3796	3	Cruise	20.8	20.8
3796	3802	3	Accel.	20.8	32.0
3802	3849	3	Cruise	32.0	32.0
3849	3852	3	Decel.	32.0	24.8
3852	3855	3	Cruise	24.8	24.8
3855	3875	3	Accel.	24.8	51.6
3875	3879	3	Cruise	51.6	51.6
3879	3883	3	Decel.	51.6	39.3
3883	3895	3	Cruise	39.3	39.3
3895	3898	3	Decel.	39.3	32.4
3898	3939	3	Cruise	32.4	32.4
3939	3946	3	Decel.	32.4	0.0
3946	3947	3	Idle	0.0	0.0
3947	3949	4	Idle	0.0	0.0
3949	3966	4	Accel.	0.0	75.8
3966	4001	4	Cruise	75.8	75.8
4001	4005	4	Decel.	75.8	63.9
4005	4081	4	Cruise	63.9	63.9
4081	4086	4	Accel.	63.9	72.4
4086	4089	4	Cruise	72.4	72.4
4089	4093	4	Decel.	72.4	58.7
4093	4096	4	Cruise	58.7	58.7
4096	4104	4	Accel.	58.7	65.9
4104	4118	4	Cruise	65.9	65.9
4118	4122	4	Decel.	65.9	53.7
4122	4136	4	Cruise	53.7	53.7
4136	4137	4	Accel.	53.7	54.9
4137	4147	4	Cruise	54.9	54.9
4147	4157	4	Decel.	54.9	0.0
4157	4164	4	Idle	0.0	0.0
4164	4196	4	Accel.	0.0	90.6
4196	4551	4	Cruise	90.6	90.6
4551	4566	4	Decel.	90.6	0.0
4566	4570	4	Idle	0.0	0.0
4570	4578	4	Accel.	0.0	33.0
4578	4586	4	Cruise	33.0	33.0
4586	4601	4	Accel.	33.0	75.0
4601	4612	4	Cruise	75.0	75.0
4612	4619	4	Accel.	75.0	80.3
4619	4635	4	Cruise	80.3	80.3
4635	4653	4	Accel.	80.3	95.6
4653	4668	4	Cruise	95.6	95.6
4668	4683	4	Decel.	95.6	25.5
4683	4688	4	Cruise	25.5	25.5
4688	4714	4	Accel.	25.5	98.4
4714	5004	4	Cruise	98.4	98.4
5004	5019	4	Decel.	98.4	0.0
5019	5022	4	Idle	0.0	0.0
5022	5060	4	Accel.	0.0	82.8
5060	5071	4	Cruise	82.8	82.8
5071	5076	4	Decel.	82.8	69.4
5076	5135	4	Cruise	69.4	69.4
5135	5149	4	Decel.	69.4	10.1
5149	5152	4	Cruise	10.1	10.1
5152	5170	4	Accel.	10.1	69.0
5170	5190	4	Cruise	69.0	69.0
5190	5193	4	Decel.	69.0	61.7
5193	5290	4	Cruise	61.7	61.7
5290	5293	4	Accel.	61.7	64.7
5293	5297	4	Cruise	64.7	64.7
5297	5300	4	Decel.	64.7	57.8
5300	5314	4	Cruise	57.8	57.8
5314	5326	4	Decel.	57.8	0.0
5326	5336	4	Idle	0.0	0.0
5336	5342	4	Accel.	0.0	20.7
5342	5350	4	Cruise	20.7	20.7

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
5350	5356	4	Decel.	20.7	0.0
5356	5359	4	Idle	0.0	0.0
5359	5378	4	Accel.	0.0	23.1
5378	5390	4	Cruise	23.1	23.1
5390	5397	4	Decel.	23.1	5.6
5397	5400	4	Cruise	5.6	5.6
5400	5409	4	Accel.	5.6	15.4
5409	5417	4	Cruise	15.4	15.4
5417	5421	4	Decel.	15.4	4.4
5421	5424	4	Cruise	4.4	4.4
5424	5432	4	Accel.	4.4	25.7
5432	5435	4	Cruise	25.7	25.7
5435	5441	4	Decel.	25.7	7.2
5441	5444	4	Cruise	7.2	7.2
5444	5454	4	Accel.	7.2	24.8
5454	5461	4	Cruise	24.8	24.8
5461	5464	4	Decel.	24.8	16.7
5464	5467	4	Cruise	16.7	16.7
5467	5469	4	Accel.	16.7	18.7
5469	5472	4	Cruise	18.7	18.7
5472	5480	4	Decel.	18.7	0.0
5480	5484	4	Idle	0.0	0.0
5484	5488	5	Idle	0.0	0.0
5488	5496	5	Accel.	0.0	41.8
5496	5514	5	Cruise	41.8	41.8
5514	5524	5	Decel.	41.8	0.0
5524	5527	5	Idle	0.0	0.0
5527	5542	5	Accel.	0.0	34.6
5542	5554	5	Cruise	34.6	34.6
5554	5557	5	Decel.	34.6	27.3
5557	5560	5	Cruise	27.3	27.3
5560	5568	5	Accel.	27.3	43.5
5568	5571	5	Cruise	43.5	43.5
5571	5581	5	Decel.	43.5	0.0
5581	5587	5	Idle	0.0	0.0
5587	5601	5	Accel.	0.0	30.0
5601	5624	5	Cruise	30.0	30.0
5624	5629	5	Decel.	30.0	13.6
5629	5632	5	Cruise	13.6	13.6
5632	5639	5	Accel.	13.6	37.0
5639	5647	5	Cruise	37.0	37.0
5647	5656	5	Decel.	37.0	0.0
5656	5713	5	Idle	0.0	0.0
5713	5734	5	Accel.	0.0	41.2
5734	5749	5	Cruise	41.2	41.2
5749	5753	5	Decel.	41.2	29.5
5753	5789	5	Cruise	29.5	29.5
5789	5792	5	Decel.	29.5	18.0
5792	5795	5	Cruise	18.0	18.0
5795	5800	5	Decel.	18.0	0.0
5800	5803	5	Idle	0.0	0.0
5803	5811	5	Accel.	0.0	29.5
5811	5814	5	Cruise	29.5	29.5
5814	5817	5	Decel.	29.5	22.1
5817	5820	5	Cruise	22.1	22.1
5820	5824	5	Decel.	22.1	8.1
5824	5827	5	Cruise	8.1	8.1
5827	5832	5	Accel.	8.1	16.9
5832	5844	5	Cruise	16.9	16.9
5844	5849	5	Decel.	16.9	0.0
5849	5952	5	Idle	0.0	0.0
5952	5958	5	Accel.	0.0	14.4
5958	5965	5	Cruise	14.4	14.4
5965	5968	5	Decel.	14.4	3.5
5968	5971	5	Cruise	3.5	3.5
5971	6010	5	Accel.	3.5	56.4
6010	6074	5	Cruise	56.4	56.4
6074	6078	5	Decel.	56.4	41.2
6078	6081	5	Cruise	41.2	41.2
6081	6088	5	Decel.	41.2	13.9
6088	6091	5	Cruise	13.9	13.9
6091	6111	5	Accel.	13.9	56.4
6111	6175	5	Cruise	56.4	56.4
6175	6180	5	Decel.	56.4	41.3
6180	6183	5	Cruise	41.3	41.3
6183	6200	5	Accel.	41.3	58.0
6200	6208	5	Cruise	58.0	58.0
6208	6213	5	Decel.	58.0	39.6
6213	6248	5	Cruise	39.6	39.6
6248	6252	5	Decel.	39.6	22.3
6252	6255	5	Cruise	22.3	22.3
6255	6258	5	Accel.	22.3	26.7
6258	6320	5	Cruise	26.7	26.7
6320	6330	5	Decel.	26.7	0.0
6330	6339	5	Idle	0.0	0.0
6339	6425	5	Accel.	0.0	105.2

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
6425	6872	5	Cruise	105.2	105.2
6872	6876	5	Decel.	105.2	90.4
6876	6884	5	Cruise	90.4	90.4
6884	6893	5	Accel.	90.4	102.2
6893	6898	5	Cruise	102.2	102.2
6898	6901	5	Decel.	102.2	91.6
6901	6923	5	Cruise	91.6	91.6
6923	6926	5	Accel.	91.6	94.6
6926	6930	5	Cruise	94.6	94.6
6930	6932	5	Decel.	94.6	87.2
6932	6953	5	Cruise	87.2	87.2
6953	6957	5	Decel.	87.2	72.3
6957	6960	5	Cruise	72.3	72.3
6960	6973	5	Accel.	72.3	84.8
6973	6977	5	Cruise	84.8	84.8
6977	6981	5	Decel.	84.8	73.8
6981	6985	5	Cruise	73.8	73.8
6985	6995	5	Accel.	73.8	87.8
6995	6999	5	Cruise	87.8	87.8
6999	7005	5	Decel.	87.8	69.0
7005	7069	5	Cruise	69.0	69.0
7069	7074	5	Decel.	69.0	50.2
7074	7090	5	Cruise	50.2	50.2
7090	7104	5	Accel.	50.2	83.5
7104	7114	5	Cruise	83.5	83.5
7114	7117	5	Decel.	83.5	71.3
7117	7177	5	Cruise	71.3	71.3
7177	7182	5	Decel.	71.3	53.5
7182	7185	5	Cruise	53.5	53.5
7185	7198	5	Accel.	53.5	80.0
7198	7201	5	Cruise	80.0	80.0
7201	7205	5	Decel.	80.0	66.0
7205	7346	5	Cruise	66.0	66.0
7346	7349	5	Decel.	66.0	56.7
7349	7354	5	Cruise	56.7	56.7
7354	7368	5	Accel.	56.7	83.9
7368	7381	5	Cruise	83.9	83.9
7381	7388	5	Decel.	83.9	42.5
7388	7400	5	Cruise	42.5	42.5
7400	7414	5	Accel.	42.5	73.8
7414	7442	5	Cruise	73.8	73.8
7442	7455	5	Decel.	73.8	24.4
7455	7490	5	Cruise	24.4	24.4
7490	7496	5	Decel.	24.4	0.0
7496	7503	5	Idle	0.0	0.0
7503	7509	5	Accel.	0.0	22.9
7509	7518	5	Cruise	22.9	22.9
7518	7522	5	Decel.	22.9	13.5
7522	7525	5	Cruise	13.5	13.5
7525	7531	5	Accel.	13.5	23.0
7531	7534	5	Cruise	23.0	23.0
7534	7537	5	Decel.	23.0	15.4
7537	7540	5	Cruise	15.4	15.4
7540	7545	5	Accel.	15.4	19.0
7545	7548	5	Cruise	19.0	19.0
7548	7551	5	Decel.	19.0	12.2
7551	7554	5	Cruise	12.2	12.2
7554	7558	5	Accel.	12.2	18.8
7558	7561	5	Cruise	18.8	18.8
7561	7567	5	Decel.	18.8	0.0
7567	7688	5	Idle	0.0	0.0
7688	7699	5	Accel.	0.0	37.9
7699	7704	5	Cruise	37.9	37.9
7704	7709	5	Decel.	37.9	24.4
7709	7748	5	Cruise	24.4	24.4
7748	7752	5	Decel.	24.4	14.9
7752	7755	5	Cruise	14.9	14.9
7755	7764	5	Accel.	14.9	45.3
7764	7769	5	Cruise	45.3	45.3
7769	7774	5	Decel.	45.3	25.9
7774	7777	5	Cruise	25.9	25.9
7777	7787	5	Accel.	25.9	40.6
7787	7795	5	Cruise	40.6	40.6
7795	7800	5	Decel.	40.6	25.4
7800	7803	5	Cruise	25.4	25.4
7803	7814	5	Accel.	25.4	37.2
7814	7817	5	Cruise	37.2	37.2
7817	7822	5	Decel.	37.2	20.8
7822	7825	5	Cruise	20.8	20.8
7825	7829	5	Accel.	20.8	26.3
7829	7883	5	Cruise	26.3	26.3
7883	7889	5	Decel.	26.3	0.0
7889	7892	5	Idle	0.0	0.0
7892	7904	5	Accel.	0.0	53.4
7904	7907	5	Cruise	53.4	53.4
7907	7913	5	Decel.	53.4	28.2

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
7913	7916	5	Cruise	28.2	28.2
7916	7926	5	Accel.	28.2	42.6
7926	7941	5	Cruise	42.6	42.6
7941	7947	5	Decel.	42.6	19.0
7947	7950	5	Cruise	19.0	19.0
7950	7962	5	Accel.	19.0	57.1
7962	7973	5	Cruise	57.1	57.1
7973	7979	5	Decel.	57.1	31.8
7979	7982	5	Cruise	31.8	31.8
7982	7988	5	Accel.	31.8	50.0
7988	8064	5	Cruise	50.0	50.0
8064	8069	5	Decel.	50.0	24.4
8069	8072	5	Cruise	24.4	24.4
8072	8078	5	Accel.	24.4	58.2
8078	8081	5	Cruise	58.2	58.2
8081	8088	5	Decel.	58.2	29.9
8088	8120	5	Cruise	29.9	29.9
8120	8123	5	Decel.	29.9	21.2
8123	8126	5	Cruise	21.2	21.2
8126	8129	5	Accel.	21.2	25.0
8129	8162	5	Cruise	25.0	25.0
8162	8165	5	Accel.	25.0	32.6
8165	8168	5	Cruise	32.6	32.6
8168	8174	5	Decel.	32.6	0.0
8174	8175	5	Idle	0.0	0.0
8175	8177	6	Idle	0.0	0.0
8177	8189	6	Accel.	0.0	21.2
8189	8413	6	Cruise	21.2	21.2
8413	8418	6	Decel.	21.2	9.5
8418	8421	6	Cruise	9.5	9.5
8421	8425	6	Decel.	9.5	0.0
8425	8483	6	Idle	0.0	0.0
8483	8540	7	Idle	0.0	0.0
8540	8547	7	Accel.	0.0	35.1
8547	8552	7	Cruise	35.1	35.1
8552	8560	7	Decel.	35.1	5.5
8560	8563	7	Cruise	5.5	5.5
8563	8577	7	Accel.	5.5	16.5
8577	8609	7	Cruise	16.5	16.5
8609	8614	7	Decel.	16.5	0.0
8614	8625	7	Idle	0.0	0.0
8625	8670	7	Accel.	0.0	96.9
8670	9081	7	Cruise	96.9	96.9

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
9081	9089	7	Decel.	96.9	73.3
9089	9117	7	Cruise	73.3	73.3
9117	9127	7	Decel.	73.3	20.1
9127	9130	7	Cruise	20.1	20.1
9130	9143	7	Accel.	20.1	62.2
9143	9146	7	Cruise	62.2	62.2
9146	9155	7	Decel.	62.2	6.6
9155	9158	7	Cruise	6.6	6.6
9158	9171	7	Accel.	6.6	53.2
9171	9174	7	Cruise	53.2	53.2
9174	9187	7	Decel.	53.2	0.0
9187	9188	7	Idle	0.0	0.0
9188	9190	8	Idle	0.0	0.0
9190	9238	8	Accel.	0.0	83.6
9238	9264	8	Cruise	83.6	83.6
9264	9279	8	Decel.	83.6	0.0
9279	9366	8	Idle	0.0	0.0
9366	9372	8	Accel.	0.0	23.9
9372	9375	8	Cruise	23.9	23.9
9375	9382	8	Decel.	23.9	0.0
9382	9386	8	Idle	0.0	0.0
9386	9402	8	Accel.	0.0	65.3
9402	9427	8	Cruise	65.3	65.3
9427	9439	8	Decel.	65.3	0.0
9439	9443	8	Idle	0.0	0.0
9443	9453	8	Accel.	0.0	40.5
9453	9489	8	Cruise	40.5	40.5
9489	9493	8	Decel.	40.5	29.3
9493	9496	8	Cruise	29.3	29.3
9496	9516	8	Accel.	29.3	63.0
9516	9812	8	Cruise	63.0	63.0
9812	9815	8	Decel.	63.0	52.2
9815	9845	8	Cruise	52.2	52.2
9845	9848	8	Decel.	52.2	44.6
9848	9851	8	Cruise	44.6	44.6
9851	9859	8	Accel.	44.6	59.2
9859	9864	8	Cruise	59.2	59.2
9864	9869	8	Decel.	59.2	45.2
9869	9872	8	Cruise	45.2	45.2
9872	9876	8	Accel.	45.2	53.9
9876	9888	8	Cruise	53.9	53.9
9888	9898	8	Decel.	53.9	0.0
9898	9899	8	Idle	0.0	0.0

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
9899	9901	9	Idle	0.0	0.0
9901	9909	9	Accel.	0.0	19.1
9909	10036	9	Cruise	19.1	19.1
10036	10041	9	Decel.	19.1	6.4
10041	10044	9	Cruise	6.4	6.4
10044	10046	9	Accel.	6.4	10.5
10046	10049	9	Cruise	10.5	10.5
10049	10054	9	Decel.	10.5	0.0
10054	10056	9	Idle	0.0	0.0
10056	10066	9	Accel.	0.0	29.6
10066	10273	9	Cruise	29.6	29.6
10273	10280	9	Decel.	29.6	0.0
10280	10284	9	Idle	0.0	0.0
10284	10294	9	Accel.	0.0	24.3
10294	10453	9	Cruise	24.3	24.3
10453	10458	9	Decel.	24.3	4.5
10458	10461	9	Cruise	4.5	4.5
10461	10469	9	Accel.	4.5	27.8
10469	10475	9	Cruise	27.8	27.8
10475	10479	9	Decel.	27.8	17.3
10479	10482	9	Cruise	17.3	17.3
10482	10486	9	Decel.	17.3	6.5
10486	10489	9	Cruise	6.5	6.5
10489	10496	9	Accel.	6.5	26.8
10496	10507	9	Cruise	26.8	26.8
10507	10514	9	Decel.	26.8	0.0
10514	10554	9	Idle	0.0	0.0
10554	10626	10	Idle	0.0	0.0
10626	10632	10	Accel.	0.0	27.5
10632	10638	10	Cruise	27.5	27.5
10638	10647	10	Decel.	27.5	0.0
10647	10650	10	Idle	0.0	0.0
10650	10663	10	Accel.	0.0	39.0
10663	10696	10	Cruise	39.0	39.0
10696	10700	10	Decel.	39.0	29.0
10700	10707	10	Cruise	29.0	29.0
10707	10712	10	Accel.	29.0	35.1
10712	10721	10	Cruise	35.1	35.1
10721	10725	10	Decel.	35.1	24.5
10725	10728	10	Cruise	24.5	24.5
10728	10737	10	Accel.	24.5	41.9
10737	10758	10	Cruise	41.9	41.9
10758	10761	10	Decel.	41.9	34.1

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
10761	10764	10	Cruise	34.1	34.1
10764	10768	10	Accel.	34.1	39.4
10768	10792	10	Cruise	39.4	39.4
10792	10797	10	Decel.	39.4	24.9
10797	10800	10	Cruise	24.9	24.9
10800	10808	10	Accel.	24.9	36.4
10808	10811	10	Cruise	36.4	36.4
10811	10822	10	Decel.	36.4	0.0
10822	10825	10	Idle	0.0	0.0
10825	10838	10	Accel.	0.0	55.7
10838	10868	10	Cruise	55.7	55.7
10868	10879	10	Decel.	55.7	0.0
10879	10888	10	Idle	0.0	0.0
10888	10901	10	Accel.	0.0	56.2
10901	11088	10	Cruise	56.2	56.2
11088	11101	10	Decel.	56.2	0.0
11101	11104	10	Idle	0.0	0.0
11104	11114	10	Accel.	0.0	43.6
11114	11117	10	Cruise	43.6	43.6
11117	11126	10	Decel.	43.6	0.0
11126	11238	10	Idle	0.0	0.0
11238	11242	10	Accel.	0.0	11.2
11242	11245	10	Cruise	11.2	11.2
11245	11249	10	Decel.	11.2	4.1
11249	11252	10	Cruise	4.1	4.1
11252	11258	10	Accel.	4.1	15.0
11258	11261	10	Cruise	15.0	15.0
11261	11265	10	Decel.	15.0	6.2
11265	11268	10	Cruise	6.2	6.2
11268	11273	10	Accel.	6.2	10.1
11273	11276	10	Cruise	10.1	10.1
11276	11281	10	Decel.	10.1	0.0
11281	11284	10	Idle	0.0	0.0
11284	11293	10	Accel.	0.0	31.3
11293	11313	10	Cruise	31.3	31.3
11313	11316	10	Decel.	31.3	23.8
11316	11348	10	Cruise	23.8	23.8
11348	11351	10	Decel.	23.8	16.9
11351	11354	10	Cruise	16.9	16.9
11354	11361	10	Decel.	16.9	0.0
11361	11364	10	Idle	0.0	0.0
11364	11373	10	Accel.	0.0	40.0
11373	11512	10	Cruise	40.0	40.0

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
11512	11519	10	Decel.	40.0	10.6
11519	11522	10	Cruise	10.6	10.6
11522	11528	10	Accel.	10.6	15.6
11528	11541	10	Cruise	15.6	15.6
11541	11545	10	Decel.	15.6	6.3
11545	11548	10	Cruise	6.3	6.3
11548	11552	10	Accel.	6.3	15.6
11552	11557	10	Cruise	15.6	15.6
11557	11560	10	Decel.	15.6	8.8
11560	11563	10	Cruise	8.8	8.8
11563	11567	10	Accel.	8.8	13.1
11567	11574	10	Cruise	13.1	13.1
11574	11579	10	Decel.	13.1	0.0
11579	11646	10	Idle	0.0	0.0
11646	11652	10	Accel.	0.0	23.1
11652	11659	10	Cruise	23.1	23.1
11659	11662	10	Decel.	23.1	15.0
11662	11665	10	Cruise	15.0	15.0
11665	11666	10	Accel.	15.0	18.1
11666	11669	10	Cruise	18.1	18.1
11669	11671	10	Decel.	18.1	13.6
11671	11674	10	Cruise	13.6	13.6
11674	11680	10	Accel.	13.6	19.4
11680	11684	10	Cruise	19.4	19.4
11684	11687	10	Decel.	19.4	11.5
11687	11690	10	Cruise	11.5	11.5
11690	11694	10	Decel.	11.5	0.0
11694	11830	10	Idle	0.0	0.0
11830	11842	10	Accel.	0.0	34.9
11842	11845	10	Cruise	34.9	34.9
11845	11848	10	Decel.	34.9	27.9
11848	11851	10	Cruise	27.9	27.9
11851	11858	10	Accel.	27.9	43.7
11858	11861	10	Cruise	43.7	43.7
11861	11865	10	Decel.	43.7	32.1
11865	11868	10	Cruise	32.1	32.1
11868	11873	10	Decel.	32.1	12.4
11873	11880	10	Cruise	12.4	12.4
11880	11884	10	Decel.	12.4	0.0
11884	12054	10	Idle	0.0	0.0
12054	12064	10	Accel.	0.0	14.7
12064	12067	10	Cruise	14.7	14.7
12067	12072	10	Decel.	14.7	0.0

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
12072	12075	10	Idle	0.0	0.0
12075	12079	10	Accel.	0.0	13.8
12079	12082	10	Cruise	13.8	13.8
12082	12086	10	Decel.	13.8	0.0
12086	12096	10	Idle	0.0	0.0
12096	12100	10	Accel.	0.0	12.4
12100	12103	10	Cruise	12.4	12.4
12103	12106	10	Decel.	12.4	0.0
12106	12124	10	Idle	0.0	0.0
12124	12129	10	Accel.	0.0	18.7
12129	12132	10	Cruise	18.7	18.7
12132	12140	10	Decel.	18.7	0.0
12140	12173	10	Idle	0.0	0.0
12173	12178	10	Accel.	0.0	18.4
12178	12181	10	Cruise	18.4	18.4
12181	12187	10	Decel.	18.4	0.0
12187	12188	10	Idle	0.0	0.0
12188	12197	10	Accel.	0.0	41.2
12197	12198	10	Cruise	41.2	41.2
12198	12202	10	Decel.	41.2	30.4
12202	12208	10	Cruise	30.4	30.4
12208	12213	10	Decel.	30.4	14.8
12213	12216	10	Cruise	14.8	14.8
12216	12231	10	Accel.	14.8	50.5
12231	12267	10	Cruise	50.5	50.5
12267	12272	10	Decel.	50.5	30.8
12272	12276	10	Cruise	30.8	30.8
12276	12284	10	Decel.	30.8	0.0
12284	12328	10	Idle	0.0	0.0
12328	12333	10	Accel.	0.0	12.4
12333	12336	10	Cruise	12.4	12.4
12336	12340	10	Decel.	12.4	0.0
12340	12356	10	Idle	0.0	0.0
12356	12361	10	Accel.	0.0	14.7
12361	12364	10	Cruise	14.7	14.7
12364	12368	10	Decel.	14.7	0.0
12368	12371	10	Idle	0.0	0.0
12371	12376	10	Accel.	0.0	18.7
12376	12461	10	Cruise	18.7	18.7
12461	12469	10	Decel.	18.7	0.0
12469	12478	10	Idle	0.0	0.0
12478	12484	10	Accel.	0.0	18.4
12484	12487	10	Cruise	18.4	18.4

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
12487	12493	10	Decel.	18.4	0.0
12493	12503	10	Idle	0.0	0.0
12503	12507	10	Accel.	0.0	13.8
12507	12510	10	Cruise	13.8	13.8
12510	12514	10	Decel.	13.8	0.0
12514	12517	10	Idle	0.0	0.0
12517	12521	10	Accel.	0.0	12.4
12521	12524	10	Cruise	12.4	12.4
12524	12528	10	Decel.	12.4	0.0
12528	12544	10	Idle	0.0	0.0
12544	12549	10	Accel.	0.0	14.7
12549	12552	10	Cruise	14.7	14.7
12552	12556	10	Decel.	14.7	0.0
12556	12559	10	Idle	0.0	0.0
12559	12602	10	Accel.	0.0	105.0
12602	12614	10	Cruise	105.0	105.0
12614	12617	10	Decel.	105.0	95.4
12617	12622	10	Cruise	95.4	95.4
12622	12626	10	Decel.	95.4	82.4
12626	12629	10	Cruise	82.4	82.4
12629	12639	10	Accel.	82.4	97.4
12639	12642	10	Cruise	97.4	97.4
12642	12646	10	Decel.	97.4	82.7
12646	12651	10	Cruise	82.7	82.7
12651	12654	10	Decel.	82.7	74.5
12654	12658	10	Cruise	74.5	74.5
12658	12668	10	Decel.	74.5	38.7
12668	12671	10	Cruise	38.7	38.7
12671	12679	10	Accel.	38.7	64.0
12679	12695	10	Cruise	64.0	64.0
12695	12702	10	Decel.	64.0	25.9
12702	12705	10	Cruise	25.9	25.9
12705	12711	10	Accel.	25.9	47.8
12711	12714	10	Cruise	47.8	47.8
12714	12718	10	Decel.	47.8	36.0
12718	12721	10	Cruise	36.0	36.0
12721	12728	10	Accel.	36.0	60.3
12728	12790	10	Cruise	60.3	60.3
12790	12796	10	Decel.	60.3	36.4
12796	12799	10	Cruise	36.4	36.4
12799	12806	10	Accel.	36.4	49.0
12806	12854	10	Cruise	49.0	49.0
12854	12858	10	Decel.	49.0	37.0

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
12858	12861	10	Cruise	37.0	37.0
12861	12877	10	Accel.	37.0	61.0
12877	12926	10	Cruise	61.0	61.0
12926	12932	10	Decel.	61.0	28.0
12932	12938	10	Cruise	28.0	28.0
12938	12944	10	Accel.	28.0	43.2
12944	12959	10	Cruise	43.2	43.2
12959	12965	10	Decel.	43.2	25.0
12965	12968	10	Cruise	25.0	25.0
12968	12974	10	Accel.	25.0	46.7
12974	12977	10	Cruise	46.7	46.7
12977	12980	10	Decel.	46.7	37.9
12980	12983	10	Cruise	37.9	37.9
12983	12997	10	Accel.	37.9	54.9
12997	13053	10	Cruise	54.9	54.9
13053	13060	10	Decel.	54.9	22.4
13060	13063	10	Cruise	22.4	22.4
13063	13067	10	Accel.	22.4	26.2
13067	13072	10	Cruise	26.2	26.2
13072	13075	10	Decel.	26.2	18.6
13075	13078	10	Cruise	18.6	18.6
13078	13080	10	Accel.	18.6	20.1
13080	13084	10	Cruise	20.1	20.1
13084	13090	10	Decel.	20.1	7.0
13090	13093	10	Cruise	7.0	7.0
13093	13097	10	Decel.	7.0	0.0
13097	13100	10	Idle	0.0	0.0
13100	13112	10	Accel.	0.0	28.0
13112	13175	10	Cruise	28.0	28.0
13175	13179	10	Decel.	28.0	16.3
13179	13182	10	Cruise	16.3	16.3
13182	13185	10	Accel.	16.3	18.6
13185	13188	10	Cruise	18.6	18.6
13188	13192	10	Decel.	18.6	7.6
13192	13195	10	Cruise	7.6	7.6
13195	13207	10	Accel.	7.6	28.7
13207	13273	10	Cruise	28.7	28.7
13273	13278	10	Decel.	28.7	14.6
13278	13281	10	Cruise	14.6	14.6
13281	13286	10	Accel.	14.6	22.9
13286	13290	10	Cruise	22.9	22.9
13290	13294	10	Decel.	22.9	12.0
13294	13297	10	Cruise	12.0	12.0

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
13297	13314	10	Accel.	12.0	46.0
13314	13334	10	Cruise	46.0	46.0
13334	13344	10	Decel.	46.0	0.0
13344	13347	10	Idle	0.0	0.0
13347	13364	10	Accel.	0.0	46.2
13364	13379	10	Cruise	46.2	46.2
13379	13384	10	Decel.	46.2	32.1
13384	13408	10	Cruise	32.1	32.1
13408	13412	10	Decel.	32.1	20.8
13412	13442	10	Cruise	20.8	20.8
13442	13445	10	Decel.	20.8	12.4
13445	13448	10	Cruise	12.4	12.4
13448	13460	10	Accel.	12.4	42.5
13460	13482	10	Cruise	42.5	42.5
13482	13488	10	Decel.	42.5	17.8
13488	13491	10	Cruise	17.8	17.8
13491	13495	10	Accel.	17.8	22.7
13495	13498	10	Cruise	22.7	22.7
13498	13506	10	Decel.	22.7	0.0
13506	13509	10	Idle	0.0	0.0
13509	13518	10	Accel.	0.0	25.0
13518	13521	10	Cruise	25.0	25.0
13521	13524	10	Decel.	25.0	17.2
13524	13527	10	Cruise	17.2	17.2
13527	13532	10	Accel.	17.2	30.9
13532	13535	10	Cruise	30.9	30.9
13535	13539	10	Decel.	30.9	16.7
13539	13542	10	Cruise	16.7	16.7
13542	13548	10	Accel.	16.7	43.0
13548	13578	10	Cruise	43.0	43.0
13578	13583	10	Decel.	43.0	29.8
13583	13586	10	Cruise	29.8	29.8
13586	13598	10	Accel.	29.8	58.8
13598	13633	10	Cruise	58.8	58.8
13633	13636	10	Decel.	58.8	48.7
13636	13639	10	Cruise	48.7	48.7
13639	13645	10	Decel.	48.7	23.8
13645	13648	10	Cruise	23.8	23.8
13648	13654	10	Accel.	23.8	44.3
13654	13676	10	Cruise	44.3	44.3
13676	13681	10	Decel.	44.3	30.3
13681	13684	10	Cruise	30.3	30.3
13684	13689	10	Accel.	30.3	41.4
13689	13716	10	Cruise	41.4	41.4
13716	13720	10	Decel.	41.4	28.4
13720	13723	10	Cruise	28.4	28.4
13723	13730	10	Accel.	28.4	51.4
13730	13739	10	Cruise	51.4	51.4
13739	13745	10	Decel.	51.4	32.0
13745	13748	10	Cruise	32.0	32.0
13748	13754	10	Decel.	32.0	10.0
13754	13760	10	Cruise	10.0	10.0
13760	13765	10	Decel.	10.0	0.0
13765	13768	10	Idle	0.0	0.0
13768	13772	10	Accel.	0.0	16.3
13772	13775	10	Cruise	16.3	16.3
13775	13780	10	Decel.	16.3	0.0
13780	13783	10	Idle	0.0	0.0
13783	13796	10	Accel.	0.0	45.8
13796	13817	10	Cruise	45.8	45.8
13817	13822	10	Decel.	45.8	28.6
13822	13825	10	Cruise	28.6	28.6
13825	13833	10	Accel.	28.6	40.9
13833	13836	10	Cruise	40.9	40.9
13836	13841	10	Decel.	40.9	25.4
13841	13844	10	Cruise	25.4	25.4
13844	13850	10	Accel.	25.4	41.1
13850	13853	10	Cruise	41.1	41.1
13853	13856	10	Decel.	41.1	30.7
13856	13862	10	Cruise	30.7	30.7
13862	13865	10	Decel.	30.7	22.1
13865	13868	10	Cruise	22.1	22.1
13868	13873	10	Accel.	22.1	28.2
13873	13878	10	Cruise	28.2	28.2
13878	13881	10	Decel.	28.2	21.2
13881	13947	10	Cruise	21.2	21.2
13947	13953	10	Accel.	21.2	37.6
13953	13956	10	Cruise	37.6	37.6
13956	13959	10	Decel.	37.6	29.8
13959	13962	10	Cruise	29.8	29.8
13962	13972	10	Accel.	29.8	42.8
13972	13975	10	Cruise	42.8	42.8
13975	13978	10	Decel.	42.8	34.5
13978	13981	10	Cruise	34.5	34.5
13981	13988	10	Accel.	34.5	50.6
13988	13994	10	Cruise	50.6	50.6

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
13994	14001	10	Decel.	50.6	21.2
14001	14004	10	Cruise	21.2	21.2
14004	14016	10	Accel.	21.2	49.9
14016	14019	10	Cruise	49.9	49.9
14019	14025	10	Decel.	49.9	25.2
14025	14028	10	Cruise	25.2	25.2
14028	14031	10	Accel.	25.2	38.8
14031	14034	10	Cruise	38.8	38.8
14034	14040	10	Decel.	38.8	19.6
14040	14113	10	Cruise	19.6	19.6
14113	14118	10	Accel.	19.6	30.8
14118	14121	10	Cruise	30.8	30.8
14121	14127	10	Decel.	30.8	10.2
14127	14130	10	Cruise	10.2	10.2
14130	14135	10	Accel.	10.2	26.3
14135	14138	10	Cruise	26.3	26.3
14138	14142	10	Decel.	26.3	16.5
14142	14145	10	Cruise	16.5	16.5
14145	14147	10	Accel.	16.5	19.0
14147	14150	10	Cruise	19.0	19.0
14150	14154	10	Decel.	19.0	7.6
14154	14157	10	Cruise	7.6	7.6
14157	14161	10	Decel.	7.6	0.0
14161	14164	10	Idle	0.0	0.0
14164	14172	10	Accel.	0.0	32.2
14172	14175	10	Cruise	32.2	32.2
14175	14180	10	Decel.	32.2	13.6
14180	14189	10	Cruise	13.6	13.6
14189	14195	10	Decel.	13.6	0.0
14195	14257	10	Idle	0.0	0.0
14257	14263	10	Accel.	0.0	24.9
14263	14266	10	Cruise	24.9	24.9
14266	14270	10	Decel.	24.9	10.9
14270	14277	10	Cruise	10.9	10.9
14277	14281	10	Decel.	10.9	0.0
14281	14284	10	Idle	0.0	0.0
14284	14287	10	Accel.	0.0	11.0
14287	14290	10	Cruise	11.0	11.0
14290	14294	10	Decel.	11.0	0.0
14294	14296	10	Idle	0.0	0.0
14296	14310	10	Accel.	0.0	64.9
14310	14325	10	Cruise	64.9	64.9
14325	14333	10	Decel.	64.9	25.5

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
14333	14336	10	Cruise	25.5	25.5
14336	14360	10	Accel.	25.5	112.0
14360	14992	10	Cruise	112.0	112.0
14992	15001	10	Decel.	112.0	56.1
15001	15004	10	Cruise	56.1	56.1
15004	15010	10	Accel.	56.1	68.2
15010	15013	10	Cruise	68.2	68.2
15013	15021	10	Decel.	68.2	12.0
15021	15024	10	Cruise	12.0	12.0
15024	15045	10	Accel.	12.0	80.9
15045	15048	10	Cruise	80.9	80.9
15048	15057	10	Decel.	80.9	35.3
15057	15060	10	Cruise	35.3	35.3
15060	15073	10	Accel.	35.3	73.4
15073	15076	10	Cruise	73.4	73.4
15076	15083	10	Decel.	73.4	39.3
15083	15086	10	Cruise	39.3	39.3
15086	15098	10	Decel.	39.3	0.0
15098	15102	10	Idle	0.0	0.0
15102	15148	10	Accel.	0.0	132.5
15148	15457	10	Cruise	132.5	132.5
15457	15472	10	Decel.	132.5	34.0
15472	15475	10	Cruise	34.0	34.0
15475	15479	10	Accel.	34.0	41.6
15479	15482	10	Cruise	41.6	41.6
15482	15491	10	Decel.	41.6	0.0
15491	15542	10	Idle	0.0	0.0
15542	15557	10	Accel.	0.0	33.1
15557	15584	10	Cruise	33.1	33.1
15584	15590	10	Decel.	33.1	6.3
15590	15593	10	Cruise	6.3	6.3
15593	15605	10	Accel.	6.3	37.6
15605	15625	10	Cruise	37.6	37.6
15625	15636	10	Decel.	37.6	0.0
15636	15639	10	Idle	0.0	0.0
15639	15654	10	Accel.	0.0	52.0
15654	15664	10	Cruise	52.0	52.0
15664	15675	10	Decel.	52.0	0.0
15675	15676	10	Idle	0.0	0.0
15676	15690	10	Accel.	0.0	50.6
15690	15717	10	Cruise	50.6	50.6
15717	15724	10	Decel.	50.6	22.9
15724	15727	10	Cruise	22.9	22.9

Event time start [s]	Event time end [s]	Trip [#]	Event Type	Speed at start [km/h]	Speed at end [km/h]
15727	15738	10	Accel.	22.9	47.7
15738	15742	10	Cruise	47.7	47.7
15742	15749	10	Decel.	47.7	23.4
15749	15752	10	Cruise	23.4	23.4
15752	15769	10	Accel.	23.4	45.9
15769	15791	10	Cruise	45.9	45.9
15791	15797	10	Decel.	45.9	23.6
15797	15802	10	Cruise	23.6	23.6
15802	15808	10	Accel.	23.6	37.6
15808	15815	10	Cruise	37.6	37.6
15815	15822	10	Decel.	37.6	0.0
15822	15826	10	Idle	0.0	0.0

Annex 4 – Appendix 2

WLTP-Brake Cycle Brake Events

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]
1	1	18	24	6.0	20.7	0.0	0.958	17.24	16.53
1	2	58	65	7.0	23.1	5.6	0.695	27.88	19.38
1	3	85	89	4.0	15.4	4.4	0.760	11.01	8.40
1	4	103	109	6.0	25.7	7.2	0.857	27.47	23.48
1	5	129	132	3.0	24.8	16.7	0.748	17.28	12.97
1	6	140	149	9.0	18.7	0.0	0.577	23.36	13.49
1	7	177	183	6.0	32.5	0.0	1.506	27.11	40.75
1	8	298	303	5.0	27.5	11.8	0.872	27.31	23.80
1	9	314	320	6.0	29.4	9.7	0.915	32.59	29.72
1	10	341	347	6.0	31.9	9.5	1.037	34.47	35.78
1	11	361	366	5.0	14.7	0.0	0.814	10.18	8.34
1	12	384	388	4.0	59.5	47.6	0.820	59.50	49.17
1	13	402	406	4.0	47.6	36.2	0.793	46.59	36.86
1	14	486	490	4.0	38.2	25.5	0.881	35.42	31.21
1	15	493	496	3.0	25.5	18.4	0.659	18.32	12.03
1	16	499	505	6.0	18.4	0.0	0.853	15.35	13.06
1	17	543	552	9.0	42.3	0.0	1.306	52.88	69.03
1	18	566	576	10.0	42.1	0.0	1.170	58.48	68.38
1	19	592	595	3.0	31.3	12.5	1.746	18.25	31.77
1	20	600	605	5.0	12.5	0.0	0.693	8.66	6.03
1	21	647	657	10.0	45.3	0.0	1.258	62.88	79.17
1	22	673	683	10.0	45.5	0.0	1.265	63.25	79.87
1	23	726	733	7.0	40.7	12.8	1.109	52.03	57.59
1	24	747	751	4.0	59.6	46.7	0.893	59.04	52.90
1	25	768	777	9.0	48.6	0.0	1.500	60.77	91.13
1	26	941	945	4.0	23.7	9.8	0.969	18.60	17.96
1	27	974	983	9.0	37.5	0.0	1.157	46.86	54.25
1	28	996	1005	9.0	37.7	0.0	1.164	47.14	54.83
1	29	1016	1021	5.0	18.6	0.0	1.036	12.95	13.35
2	30	1122	1126	4.0	13.8	0.0	0.960	7.68	7.35
2	31	1147	1151	4.0	34.2	18.9	1.059	29.52	31.34
2	32	1174	1178	4.0	32.9	23.3	0.664	31.19	20.81
2	33	1188	1191	3.0	25.6	18.5	0.653	18.37	12.08
2	34	1209	1217	8.0	38.7	0.0	1.343	42.98	57.78
2	35	1253	1256	3.0	48.4	40.6	0.728	37.09	26.78
2	36	1282	1286	4.0	42.4	30.3	0.840	40.41	33.94
2	37	1290	1295	5.0	30.3	13.7	0.921	30.60	28.18

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]
2	38	1319	1325	6.0	40.0	20.0	0.929	49.98	46.30
2	39	1334	1338	4.0	29.7	18.9	0.747	26.98	20.25
2	40	1448	1451	3.0	24.5	17.5	0.643	17.51	11.34
2	41	1482	1491	9.0	42.0	0.0	1.296	52.49	68.06
2	42	1515	1519	4.0	22.0	11.8	0.704	18.77	13.30
2	43	1539	1547	8.0	32.4	6.1	0.915	42.81	39.06
2	44	1597	1605	8.0	34.8	0.0	1.208	38.66	46.72
2	45	1662	1675	13.0	76.1	0.0	1.626	137.41	223.43
2	46	1689	1694	5.0	22.8	0.0	1.269	15.86	20.06
2	47	1753	1757	4.0	41.6	27.2	0.995	38.23	38.22
2	48	1804	1807	3.0	47.9	35.2	1.177	34.59	40.72
2	49	1823	1828	5.0	35.2	20.1	0.836	38.37	32.22
2	50	1870	1873	3.0	59.2	49.5	0.904	45.29	40.68
2	51	1895	1898	3.0	72.9	62.0	1.010	56.23	56.73
2	52	1907	1910	3.0	66.4	57.4	0.828	51.58	42.99
2	53	1918	1921	3.0	60.0	52.1	0.727	46.71	34.17
2	54	1951	1954	3.0	79.7	72.1	0.697	63.26	44.51
2	55	1972	1978	6.0	74.0	52.4	0.999	105.35	105.33
2	56	2062	2074	12.0	52.4	0.0	1.213	87.37	105.93
2	57	2123	2133	10.0	60.3	0.0	1.676	83.80	140.28
2	58	2187	2195	8.0	62.9	0.0	2.183	69.86	152.64
2	59	2218	2229	11.0	60.1	15.2	1.133	115.11	130.44
2	60	2250	2261	11.0	53.3	0.0	1.345	81.39	109.60
2	61	2520	2526	6.0	20.7	0.0	0.958	17.24	16.53
2	62	2560	2567	7.0	23.1	5.6	0.695	27.88	19.38
2	63	2587	2591	4.0	15.4	4.4	0.760	11.01	8.40
2	64	2605	2611	6.0	25.7	7.2	0.857	27.47	23.48
2	65	2631	2634	3.0	24.8	16.7	0.748	17.28	12.97
2	66	2642	2650	8.0	18.7	0.0	0.649	20.77	13.49
2	67	2672	2677	5.0	46.6	9.4	2.070	38.89	80.37
2	68	2698	2701	3.0	52.0	41.5	0.970	38.99	37.88
2	69	2714	2719	5.0	49.9	34.0	0.884	58.20	51.47
2	70	2738	2745	7.0	49.0	23.8	0.998	70.76	70.78
2	71	2759	2767	8.0	41.6	0.0	1.446	46.26	66.77
3	72	2897	2903	6.0	32.1	5.5	1.232	31.37	38.59
3	73	2946	2949	3.0	50.5	42.8	0.714	38.91	27.72
3	74	2958	2963	5.0	45.0	29.8	0.843	51.91	43.86
3	75	2966	2971	5.0	29.8	0.0	1.655	20.68	34.26
3	76	3006	3011	5.0	49.2	33.1	0.893	57.16	51.12
3	77	3032	3036	4.0	56.2	44.0	0.841	55.66	47.16
3	78	3053	3056	3.0	59.0	51.2	0.722	45.95	33.16
3	79	3078	3081	3.0	55.0	47.5	0.692	42.72	29.66
3	80	3096	3101	5.0	59.5	39.9	1.085	69.02	75.16

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s²]	Event Distance [m]	Specific KE (Decel only) [J/kg]
3	81	3159	3165	6.0	39.9	14.2	1.189	45.14	53.64
3	82	3195	3201	6.0	58.3	34.8	1.086	77.60	84.41
3	83	3268	3271	3.0	39.5	30.0	0.882	28.98	25.47
3	84	3308	3311	3.0	56.2	46.0	0.943	42.56	40.22
3	85	3418	3422	4.0	54.4	40.4	0.974	52.67	51.20
3	86	3441	3445	4.0	53.5	40.8	0.885	52.37	46.20
3	87	3480	3483	3.0	40.8	32.0	0.815	30.30	24.72
3	88	3492	3495	3.0	34.7	26.4	0.776	25.45	19.57
3	89	3557	3561	4.0	50.6	37.6	0.900	48.97	44.24
3	90	3621	3626	5.0	37.6	22.4	0.842	41.68	35.19
3	91	3647	3651	4.0	36.8	22.9	0.964	33.20	32.02
3	92	3684	3688	4.0	55.3	39.5	1.099	52.67	57.79
3	93	3692	3698	6.0	39.5	15.5	1.111	45.82	50.93
3	94	3729	3732	3.0	44.3	36.6	0.710	33.68	24.03
3	95	3773	3778	5.0	36.6	20.8	0.879	39.82	34.99
3	96	3849	3852	3.0	32.0	24.8	0.662	23.67	15.78
3	97	3879	3883	4.0	51.6	39.3	0.858	50.49	43.14
3	98	3895	3898	3.0	39.3	32.4	0.634	29.86	19.09
3	99	3939	3946	7.0	32.4	0.0	1.286	31.51	40.50
4	100	4001	4005	4.0	75.8	63.9	0.832	77.61	64.14
4	101	4089	4093	4.0	72.4	58.7	0.958	72.83	69.29
4	102	4118	4122	4.0	65.9	53.7	0.849	66.48	56.29
4	103	4147	4157	10.0	54.9	0.0	1.524	76.18	116.28
4	104	4551	4566	15.0	90.6	0.0	1.677	188.65	316.68
4	105	4668	4683	15.0	95.6	25.5	1.299	252.30	327.51
4	106	5004	5019	15.0	98.4	0.0	1.822	204.95	373.56
4	107	5071	5076	5.0	82.8	69.4	0.748	105.67	78.68
4	108	5135	5149	14.0	69.4	10.1	1.176	154.45	181.88
4	109	5190	5193	3.0	69.0	61.7	0.673	54.48	36.81
4	110	5297	5300	3.0	64.7	57.8	0.641	51.07	32.61
4	111	5314	5326	12.0	57.8	0.0	1.338	96.37	128.89
4	112	5350	5356	6.0	20.7	0.0	0.958	17.24	16.53
4	113	5390	5397	7.0	23.1	5.6	0.695	27.88	19.38
4	114	5417	5421	4.0	15.4	4.4	0.760	11.01	8.40
4	115	5435	5441	6.0	25.7	7.2	0.857	27.47	23.48
4	116	5461	5464	3.0	24.8	16.7	0.748	17.28	12.97
4	117	5472	5480	8.0	18.7	0.0	0.649	20.77	13.49
5	118	5514	5524	10.0	41.8	0.0	1.160	57.99	67.41
5	119	5554	5557	3.0	34.6	27.3	0.680	25.79	17.43
5	120	5571	5581	10.0	43.5	0.0	1.207	60.36	73.00
5	121	5624	5629	5.0	30.0	13.6	0.913	30.29	27.59
5	122	5647	5656	9.0	37.0	0.0	1.140	46.19	52.82
5	123	5749	5753	4.0	41.2	29.5	0.812	39.29	31.91

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]
5	124	5789	5792	3.0	29.5	18.0	1.066	19.80	21.07
5	125	5795	5800	5.0	18.0	0.0	1.000	12.50	12.50
5	126	5814	5817	3.0	29.5	22.1	0.677	21.50	14.73
5	127	5820	5824	4.0	22.1	8.1	0.974	16.81	16.31
5	128	5844	5849	5.0	16.9	0.0	0.939	11.74	11.02
5	129	5965	5968	3.0	14.4	3.5	1.007	7.44	7.53
5	130	6074	6078	4.0	56.4	41.2	1.061	54.21	57.23
5	131	6081	6088	7.0	41.2	13.9	1.083	53.47	58.03
5	132	6175	6180	5.0	56.4	41.3	0.835	67.83	56.92
5	133	6208	6213	5.0	58.0	39.6	1.020	67.74	69.28
5	134	6248	6252	4.0	39.6	22.3	1.199	34.40	41.31
5	135	6320	6330	10.0	26.7	0.0	0.741	37.06	27.50
5	136	6872	6876	4.0	105.2	90.4	1.028	108.66	111.69
5	137	6898	6901	3.0	102.2	91.6	0.977	80.77	79.25
5	138	6930	6932	2.0	94.6	87.2	1.039	50.50	51.90
5	139	6953	6957	4.0	87.2	72.3	1.031	88.60	91.69
5	140	6977	6981	4.0	84.8	73.8	0.766	88.11	67.31
5	141	6999	7005	6.0	87.8	69.0	0.871	130.61	113.73
5	142	7069	7074	5.0	69.0	50.2	1.039	82.77	86.46
5	143	7114	7117	3.0	83.5	71.3	1.128	64.49	72.86
5	144	7177	7182	5.0	71.3	53.5	0.991	86.64	85.70
5	145	7201	7205	4.0	80.0	66.0	0.974	81.14	78.86
5	146	7346	7349	3.0	66.0	56.7	0.859	51.14	44.02
5	147	7381	7388	7.0	83.9	42.5	1.642	122.89	201.89
5	148	7442	7455	13.0	73.8	24.4	1.056	177.40	187.16
5	149	7490	7496	6.0	24.4	0.0	1.130	20.34	22.97
5	150	7518	7522	4.0	22.9	13.5	0.651	20.19	13.20
5	151	7534	7537	3.0	23.0	15.4	0.702	16.02	11.26
5	152	7548	7551	3.0	19.0	12.2	0.631	12.99	8.19
5	153	7561	7567	6.0	18.8	0.0	0.869	15.65	13.64
5	154	7704	7709	5.0	37.9	24.4	0.750	43.29	32.45
5	155	7748	7752	4.0	24.4	14.9	0.661	21.85	14.40
5	156	7769	7774	5.0	45.3	25.9	1.075	49.44	53.29
5	157	7795	7800	5.0	40.6	25.4	0.849	45.84	38.70
5	158	7817	7822	5.0	37.2	20.8	0.913	40.30	36.70
5	159	7883	7889	6.0	26.3	0.0	1.215	21.88	26.69
5	160	7907	7913	6.0	53.4	28.2	1.167	67.98	79.33
5	161	7941	7947	6.0	42.6	19.0	1.093	51.27	56.09
5	162	7973	7979	6.0	57.1	31.8	1.170	74.11	86.77
5	163	8064	8069	5.0	50.0	24.4	1.422	51.67	73.48
5	164	8081	8088	7.0	58.2	29.9	1.123	85.65	96.19
5	165	8120	8123	3.0	29.9	21.2	0.803	21.31	17.15
5	166	8168	8174	6.0	32.6	0.0	1.507	27.13	41.00

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]
6	167	8413	8418	5.0	21.2	9.5	0.653	21.29	13.86
6	168	8421	8425	4.0	9.5	0.0	0.656	5.25	3.48
7	169	8552	8560	8.0	35.1	5.5	1.028	45.06	46.36
7	170	8609	8614	5.0	16.5	0.0	0.915	11.44	10.50
7	171	9081	9089	8.0	96.9	73.3	0.821	189.13	154.97
7	172	9117	9127	10.0	73.3	20.1	1.477	129.73	191.70
7	173	9146	9155	9.0	62.2	6.6	1.716	86.05	147.58
7	174	9174	9187	13.0	53.2	0.0	1.137	96.11	109.19
8	175	9264	9279	15.0	83.6	0.0	1.549	174.24	269.64
8	176	9375	9382	7.0	23.9	0.0	0.946	23.19	22.04
8	177	9427	9439	12.0	65.3	0.0	1.512	108.86	164.51
8	178	9489	9493	4.0	40.5	29.3	0.783	38.78	30.16
8	179	9812	9815	3.0	63.0	52.2	1.006	48.01	48.00
8	180	9845	9848	3.0	52.2	44.6	0.701	40.33	28.38
8	181	9864	9869	5.0	59.2	45.2	0.777	72.49	56.39
8	182	9888	9898	10.0	53.9	0.0	1.497	74.85	112.08
9	183	10036	10041	5.0	19.1	6.4	0.704	17.66	12.49
9	184	10049	10054	5.0	10.5	0.0	0.582	7.27	4.25
9	185	10273	10280	7.0	29.6	0.0	1.175	28.79	33.80
9	186	10453	10458	5.0	24.3	4.5	1.101	19.98	22.00
9	187	10475	10479	4.0	27.8	17.3	0.734	25.05	18.27
9	188	10482	10486	4.0	17.3	6.5	0.747	13.20	9.92
9	189	10507	10514	7.0	26.8	0.0	1.062	26.02	27.71
10	190	10638	10647	9.0	27.5	0.0	0.849	34.38	29.18
10	191	10696	10700	4.0	39.0	29.0	0.689	37.77	26.23
10	192	10721	10725	4.0	35.1	24.5	0.740	33.12	24.37
10	193	10758	10761	3.0	41.9	34.1	0.720	31.66	22.87
10	194	10792	10797	5.0	39.4	24.9	0.807	44.68	35.97
10	195	10811	10822	11.0	36.4	0.0	0.920	55.67	51.12
10	196	10868	10879	11.0	55.7	0.0	1.407	85.10	119.69
10	197	11088	11101	13.0	56.2	0.0	1.201	101.50	121.85
10	198	11117	11126	9.0	43.6	0.0	1.347	54.55	73.34
10	199	11245	11249	4.0	11.2	4.1	0.494	8.54	4.19
10	200	11261	11265	4.0	15.0	6.2	0.611	11.80	7.20
10	201	11276	11281	5.0	10.1	0.0	0.561	7.01	3.94
10	202	11313	11316	3.0	31.3	23.8	0.694	22.92	15.94
10	203	11348	11351	3.0	23.8	16.9	0.636	16.93	10.83
10	204	11354	11361	7.0	16.9	0.0	0.670	16.41	11.02
10	205	11512	11519	7.0	40.0	10.6	1.166	49.23	57.39
10	206	11541	11545	4.0	15.6	6.3	0.651	12.16	7.86
10	207	11557	11560	3.0	15.6	8.8	0.637	10.16	6.40
10	208	11574	11579	5.0	13.1	0.0	0.729	9.12	6.62
10	209	11659	11662	3.0	23.1	15.0	0.753	15.89	11.91

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s²]	Event Distance [m]	Specific KE (Decel only) [J/kg]
10	210	11669	11671	2.0	18.1	13.6	0.625	8.82	5.50
10	211	11684	11687	3.0	19.4	11.5	0.730	12.87	9.42
10	212	11690	11694	4.0	11.5	0.0	0.799	6.39	5.10
10	213	11845	11848	3.0	34.9	27.9	0.652	26.18	16.96
10	214	11861	11865	4.0	43.7	32.1	0.802	42.12	33.92
10	215	11868	11873	5.0	32.1	12.4	1.097	30.91	33.82
10	216	11880	11884	4.0	12.4	0.0	0.860	6.88	5.93
10	217	12067	12072	5.0	14.7	0.0	0.814	10.18	8.34
10	218	12082	12086	4.0	13.8	0.0	0.960	7.68	7.35
10	219	12103	12106	3.0	12.4	0.0	1.145	5.15	5.93
10	220	12132	12140	8.0	18.7	0.0	0.649	20.77	13.49
10	221	12181	12187	6.0	18.4	0.0	0.853	15.35	13.06
10	222	12198	12202	4.0	41.2	30.4	0.748	39.74	29.83
10	223	12208	12213	5.0	30.4	14.8	0.863	31.40	27.20
10	224	12267	12272	5.0	50.5	30.8	1.092	56.43	61.79
10	225	12276	12284	8.0	30.8	0.0	1.069	34.22	36.60
10	226	12336	12340	4.0	12.4	0.0	0.860	6.88	5.93
10	227	12364	12368	4.0	14.7	0.0	1.018	8.14	8.34
10	228	12461	12469	8.0	18.7	0.0	0.649	20.77	13.49
10	229	12487	12493	6.0	18.4	0.0	0.853	15.35	13.06
10	230	12510	12514	4.0	13.8	0.0	0.960	7.68	7.35
10	231	12524	12528	4.0	12.4	0.0	0.860	6.88	5.93
10	232	12552	12556	4.0	14.7	0.0	1.018	8.14	8.34
10	233	12614	12617	3.0	105.0	95.4	0.888	83.49	74.22
10	234	12622	12626	4.0	95.4	82.4	0.901	98.78	89.17
10	235	12642	12646	4.0	97.4	82.7	1.025	100.07	102.14
10	236	12651	12654	3.0	82.7	74.5	0.756	65.50	49.73
10	237	12658	12668	10.0	74.5	38.7	0.994	157.30	156.35
10	238	12695	12702	7.0	64.0	25.9	1.512	87.35	132.14
10	239	12714	12718	4.0	47.8	36.0	0.822	46.56	38.15
10	240	12790	12796	6.0	60.3	36.4	1.108	80.57	89.16
10	241	12854	12858	4.0	49.0	37.0	0.829	47.77	39.81
10	242	12926	12932	6.0	61.0	28.0	1.529	74.17	113.31
10	243	12959	12965	6.0	43.2	25.0	0.843	56.75	47.89
10	244	12977	12980	3.0	46.7	37.9	0.815	35.24	28.72
10	245	13053	13060	7.0	54.9	22.4	1.289	75.09	96.92
10	246	13072	13075	3.0	26.2	18.6	0.704	18.67	13.14
10	247	13084	13090	6.0	20.1	7.0	0.603	22.57	13.70
10	248	13093	13097	4.0	7.0	0.0	0.488	3.91	1.89
10	249	13175	13179	4.0	28.0	16.3	0.808	24.62	20.00
10	250	13188	13192	4.0	18.6	7.6	0.761	14.55	11.12
10	251	13273	13278	5.0	28.7	14.6	0.783	30.06	23.55
10	252	13290	13294	4.0	22.9	12.0	0.760	19.40	14.68

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s²]	Event Distance [m]	Specific KE (Decel only) [J/kg]
10	253	13334	13344	10.0	46.0	0.0	1.279	63.95	81.64
10	254	13379	13384	5.0	46.2	32.1	0.779	54.38	42.59
10	255	13408	13412	4.0	32.1	20.8	0.791	29.38	23.06
10	256	13442	13445	3.0	20.8	12.4	0.777	13.80	10.76
10	257	13482	13488	6.0	42.5	17.8	1.146	50.21	57.46
10	258	13498	13506	8.0	22.7	0.0	0.787	25.19	19.88
10	259	13521	13524	3.0	25.0	17.2	0.721	17.55	12.70
10	260	13535	13539	4.0	30.9	16.7	0.983	26.43	26.08
10	261	13578	13583	5.0	43.0	29.8	0.734	50.52	37.07
10	262	13633	13636	3.0	58.8	48.7	0.942	44.80	41.89
10	263	13639	13645	6.0	48.7	23.8	1.151	60.40	69.65
10	264	13676	13681	5.0	44.3	30.3	0.775	51.77	40.29
10	265	13716	13720	4.0	41.4	28.4	0.905	38.75	35.01
10	266	13739	13745	6.0	51.4	32.0	0.898	69.57	62.42
10	267	13748	13754	6.0	32.0	10.0	1.020	35.04	35.65
10	268	13760	13765	5.0	10.0	0.0	0.556	6.94	3.86
10	269	13775	13780	5.0	16.3	0.0	0.906	11.33	10.25
10	270	13817	13822	5.0	45.8	28.6	0.955	51.70	49.37
10	271	13836	13841	5.0	40.9	25.4	0.856	46.04	39.65
10	272	13853	13856	3.0	41.1	30.7	0.956	29.91	28.81
10	273	13862	13865	3.0	30.7	22.1	0.800	22.01	17.52
10	274	13878	13881	3.0	28.2	21.2	0.646	20.55	13.34
10	275	13956	13959	3.0	37.6	29.8	0.724	28.08	20.28
10	276	13975	13978	3.0	42.8	34.5	0.761	32.20	24.75
10	277	13994	14001	7.0	50.6	21.2	1.166	69.82	81.44
10	278	14019	14025	6.0	49.9	25.2	1.145	62.60	71.57
10	279	14034	14040	6.0	38.8	19.6	0.888	48.66	43.26
10	280	14121	14127	6.0	30.8	10.2	0.954	34.14	32.58
10	281	14138	14142	4.0	26.3	16.5	0.680	23.75	16.18
10	282	14150	14154	4.0	19.0	7.6	0.794	14.78	11.70
10	283	14157	14161	4.0	7.6	0.0	0.526	4.21	2.23
10	284	14175	14180	5.0	32.2	13.6	1.036	31.83	32.87
10	285	14189	14195	6.0	13.6	0.0	0.630	11.33	7.14
10	286	14266	14270	4.0	24.9	10.9	0.977	19.90	19.34
10	287	14277	14281	4.0	10.9	0.0	0.755	6.04	4.58
10	288	14290	14294	4.0	11.0	0.0	0.766	6.13	4.67
10	289	14325	14333	8.0	64.9	25.5	1.367	100.49	137.41
10	290	14992	15001	9.0	112.0	56.1	1.724	210.12	362.53
10	291	15013	15021	8.0	68.2	12.0	1.949	89.14	173.89
10	292	15048	15057	9.0	80.9	35.3	1.407	145.18	204.43
10	293	15076	15083	7.0	73.4	39.3	1.356	109.57	148.27
10	294	15086	15098	12.0	39.3	0.0	0.909	65.44	59.59
10	295	15457	15472	15.0	132.5	34.0	1.824	346.87	632.73

Trip	Brake Event #	Start time [s]	End time [s]	Event duration [s]	Initial Speed Setpoint [km/h]	Final Speed Setpoint [km/h]	Deceleration Rate [m/s^2]	Event Distance [m]	Specific KE (Decel only) [J/kg]
10	296	15482	15491	9.0	41.6	0.0	1.283	51.98	66.77
10	297	15584	15590	6.0	33.1	6.3	1.239	32.84	40.74
10	298	15625	15636	11.0	37.6	0.0	0.948	57.37	54.54
10	299	15664	15675	11.0	52.0	0.0	1.313	79.42	104.32
10	300	15717	15724	7.0	50.6	22.9	1.102	71.46	78.55
10	301	15742	15749	7.0	47.7	23.4	0.964	69.13	66.66
10	302	15791	15797	6.0	45.9	23.6	1.032	57.87	59.79
10	303	15815	15822	7.0	37.6	0.0	1.491	36.53	54.54

Annex 5

Method for Measuring and Calculating Vehicle-Specific Friction Braking Share Coefficients

1. Purpose

This annex describes the procedure to determine vehicle-specific friction braking share coefficients. The method described in this annex may be used as an alternative to the friction braking share coefficients given in Table 4 of this Regulation.

2. Scope and Application

The method described in this annex may be applied to all vehicle electrification types with non-friction braking capabilities, except for NOVC-HEV Cat. 0. It is meant as an enhancement for Table 4 of this Regulation. and describes the methodology for establishing the vehicle-specific friction braking share coefficients for specific vehicle electrification types (i.e. NOVC-HEV Cat. 1, NOVC-HEV Cat. 2, NOVC-FCHV, OVC-HEV, OVC-FCHV, and PEV).

This annex describes the method setup and procedures for running the WLTP-Brake cycle - or Trip #10 of the WLTP-Brake cycle - on a chassis dynamometer and how to determine the vehicle-specific friction braking share coefficient. Furthermore, it states a procedure and acceptance criteria for the use of alternative methods.

3. Reference Method and Calculation

The vehicle-specific friction braking share coefficient shall be determined applying the WLTP-Brake cycle on a fully UN Regulation No. 154 compliant chassis dynamometer. All brakes shall be equipped with external sensors to determine the brake torque at each of the wheels. Alternatives and acceptance criteria are described in paragraph 5 of this annex.

3.1. Calculation of the Vehicle-Specific Friction Braking Share Coefficient c

The friction braking share coefficient is calculated dividing the “deceleration energy dissipated by the friction brakes” by the “total deceleration energy reduced by 13 per cent to account for the road loads” as shown in Equation 1:

$$c = \frac{W_{brake}}{W_{ref}} \qquad \text{(Eq. 1)}$$

Where:

c is the vehicle-specific friction braking share coefficient;

W_{brake} is the sum of the friction work dissipated in the friction brake systems of the vehicle during all braking events over the used cycle in J;

W_{ref} is the normalization reference for the cycle over which the friction work was measured in J.

Depending on the tested cycle, the value of the normalization reference W_{ref} is given according to Table A5/1.

Table A5/1

Normalization reference values for different tested cycles

Tested Cycle	*Normalization Reference*
WLTP-Brake cycle	$W_{ref} = 0.87 \cdot M_{Veh} \cdot w_{total,bc}$
Trip #10 of the WLTP-Brake cycle	$W_{ref} = 0.87 \cdot M_{Veh} \cdot w_{total,trip\#10}$

Where:

$w_{\text{total,bc}}$ is the sum of the mass specific kinetic energy variation of the vehicle during all braking events of the WLTP-Brake cycle ($15986\ J/kg$).

$w_{\text{total,trip\#10}}$ is the sum of the mass specific kinetic energy variation of the vehicle during all braking events of Trip #10 of the WLTP-Brake cycle ($5557\ J/kg$).

The overall friction work is the sum of the friction work of all brakes installed as shown in Equation 2:

$$W_{brake} = \sum_{b=[FL,FR,RL,RR]} W_{brake,b} \qquad \text{(Eq. 2)}$$

Where:

W_{brake} is the sum of the friction brake work of all brakes installed in the vehicle during all braking events in the used cycle in J;

$W_{brake,b}$ is the friction brake work of brake b during all braking events in the used cycle in J;

b is the index of the brake (FL: front left, FR: front right, RL: rear left, RR: rear right).

3.2. Method to Determine the Friction Work

The method described in this paragraph shall be applied by the testing facility to determine the vehicle-specific friction braking share coefficient. For the determination and validation of the c-factor during type approval, the testing facility shall apply one of the methods described in paragraphs 3.2.2.1., 3.2.2.2., 3.2.2.3., or 3.2.2.4 of this annex. The friction work per brake is computed as the integral of the friction power over the whole duration of the reference cycle following Equation 3:

$$W_{brake,b} = \int_{t_{start}}^{t_{end}} P_{brake,b}(t)\,\mathrm{d}t \qquad \text{(Eq. 3)}$$

Where:

$W_{brake,b}$ is the friction brake work of brake b during all braking events in the used cycle in J;

$P_{brake,b}$ is the friction brake power of brake b in W;

t_{start} is the start time setpoint of the analysed cycle in s;

t_{end} is the end time setpoint of the analysed cycle in s.

The trapezoidal method shall be applied to perform the numerical integration of the sampled signals at time t_i following Equation 4:

$$W_{brake,b} = \sum_{i=1}^{N_t} \frac{t_{i+1} - t_i}{2} \cdot \left(P_{brake,b}(t_i) + P_{brake,b}(t_{i+1})\right) \qquad \text{(Eq. 4)}$$

Where:

$W_{brake,b}$ is the friction brake work of brake b during all braking events in the used cycle in J;

t_i is the time stamp of the i[th] sample of the measured signals in s;

N_t is the number of time samples t_i during the used cycle ($t_i \in [t_{start}, t_{end}]$);

$P_{brake,b}$ is the friction brake power of brake b in W.

As an intermediate step, the friction work increments for each time sample t_i shall be computed following Equation 5:

$$W_{brake,b,i} = \frac{t_{i+1} - t_i}{2} \cdot \left(P_{brake,b}(t_i) + P_{brake,b}(t_{i+1})\right) \qquad \text{(Eq. 5)}$$

3.2.1. Method to Determine the Friction Power

The friction power is computed from the friction brake torque of each brake and the measured rotational wheel velocity at each brake during the deceleration phases of the reference cycle at each brake following Equation 6:

$$P_{brake,b}(t) = \begin{cases} \tau_{brake,b}(t) \cdot \omega_b(t) & \text{for} \quad a_{ref}(t) < 0 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 6)}$$

Where:

$P_{brake,b}$ is the friction brake power of brake b in W;

$\tau_{brake,b}$ is the friction brake torque at brake b in N·m;

ω_b is the measured rotational wheel velocity at brake b in rad/*s;*

a_{ref} is the setpoint acceleration of the test cycle in m/s^2.

The rotational wheel velocity can be computed from the rotational dyno roll velocity at that wheel following Equation 7:

$$\omega_b = \frac{r_{D,b}}{r_{R,b}} \omega_{D,b} \qquad \text{(Eq. 7)}$$

Where:

ω_b is the measured rotational wheel velocity at brake b in rad/*s;*

$\omega_{D,b}$ is the measured rotational velocity of the dyno roller at brake b in rad/s;

$r_{D,b}$ is the dyno roller radius on which the tyre at brake b is rotating in m;

$r_{R,b}$ is the tyre dynamic rolling radius at brake b in m.

3.2.2. Methods to Determine the Friction Brake Torque

3.2.2.1. Torque Based Method

The torque-based method requires the direct measurement of the actual braking-torque ($\tau_{brake,b}$) at the respective brake-systems following Equation 8. A positive sign of the measured torque shall indicate braking activity.

$$\tau_{brake,b}(t) = \begin{cases} \tau_{meas,b}(t) & \text{for} \quad \tau_{meas,b}(t) > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 8)}$$

Where:

$\tau_{brake,b}$ is the friction brake torque at brake b in N·m;

$\tau_{meas,b}$ is the measured brake torque at brake b in N·m.

3.2.2.2. Pressure Based Method

The pressure-based method requires the determination of the pressure in the hydraulic friction brake systems as close to the wheel as possible in terms of safety, handling, and measurement quality. The brake torque at hydraulic friction brakes is calculated from the measured brake pressure ($p_{brake,b}$) multiplied by the torque to pressure ratio ($C_{p,b}$) at the respective brake during the brake applications of the driving cycle according to Equations 9 and 10.

$$\tau_{brake,b}(t) = C_{p,b} \cdot p_{brake,b}(t) \qquad \text{(Eq. 9)}$$

$$p_{brake,b}(t) = \begin{cases} p_{meas,b}(t) & \text{for} \quad p_{meas,b}(t) > p_{threshold,b} \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 10)}$$

Where:

$\tau_{brake,b}$ is the friction brake torque at brake b in N·m;

$C_{p,b}$ is the torque to pressure ratio in of the considered brake b in N·m/kPa;

$p_{brake,b}$ is the effective brake pressure at brake b which causes a brake torque in kPa;

$p_{meas,b}$ is the measured brake pressure at brake b in kPa;

$p_{threshold,b}$ is the threshold pressure of brake b required to develop braking torque in kPa as defined in paragraph 3.1.19. of this Regulation.

3.2.2.3. Electromechanical Brakes

Reserved

3.2.2.4. Alternative Methods

The brake torque and signals provided by electronic buses (e.g. CAN-Bus signals and/or On-Board Diagnostics) of the vehicle that allow the calculation of the brake torque based on the methods from paragraphs 3.2.2.1., 3.2.2.2., or 3.2.2.3. of this annex may be used. The equivalency criterion of the alternative method against the reference method is described in paragraph 5.3 of this annex. The equivalence of the signals with the chosen reference method shall be confirmed by the type approval authority.

3.3. Determination of C_p Values

The $C_{p,b}$ value for the pressure-based method for a specific brake system is determined by running the WLTP-Brake cycle on a brake dynamometer fully compliant to this Regulation. The $C_{p,b}$ of a specific brake system shall be assumed to be representative for all members of the same brake emission family as defined in paragraph 7.2.1. of this Regulation.

3.3.1. Preparation of Brake Dynamometer

The brake dynamometer and all testing equipment shall be setup and operated according to the specifications described in Annex 4.

3.3.2. Operation

The testing facility shall follow the steps described below:

(a) Install the brake system following the procedure described in paragraph 8.2. of Annex 4;

(b) Run the WLTP-Brake cycle following the procedure described in paragraphs 9.2.1., 9.2.2., and 9.2.3. of Annex 4;

(c) Record the brake torque and brake pressure for hydraulic or electro-hydraulic brakes;

(d) Use data from the brake emissions measurement section as defined in paragraph 9.2.3. of Annex 4 for the calculation of the $C_{p,b}$ values.

3.3.3. Calculation of $\boldsymbol{C_p}$

The $C_{p,b}$ value describes the relationship between brake pressure and brake torque and is calculated following Equation 11:

$$C_{p,b}(t) = \frac{\tau_{brake,b}(t)}{p_{brake,b}(t)} \qquad \text{(Eq. 11)}$$

For a given friction material, $C_{p,b}$ may depend on vehicle speed, applied brake pressure, brake rotor, and pad temperature. It may vary among different brake applications during the execution of the test. To reduce the influence of $C_{p,b}$ variability on brake energy calculation in the test cycle, the "energy weighted $C_{p,b}$ value" given in Equation 12 shall be used:

$$C_{p,b} = \frac{\int_{t_{start}}^{t_{end}} \tau_{brake,b} \cdot \omega_b(t)\, \mathrm{d}t}{\int_{t_{start}}^{t_{end}} \cdot p_{brake,b}(t) \cdot \omega_b(t)\, \mathrm{d}t} \qquad \text{(Eq. 12)}$$

Additionally, to avoid the usage of invalid signals the following applies for the correct calculation of the brake pressure and brake torque according to Equation 13 and 14. Value for $p_{threshold,}$ shall be applied according to paragraph 3.1.19. of this Regulation:

$$\tau_{brake,b}(t) = \begin{cases} \tau_{meas,b} & \text{for} \quad p_{meas,b}(t) > p_{threshold,b}\ and\ \tau_{meas,b} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 13)}$$

$$p_{brake,b}(t) = \begin{cases} p_{meas,b} & \text{for} \quad p_{meas,b}(t) > p_{threshold,b}\ and\ \tau_{meas,b} > 0 \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 14)}$$

When the vehicle-specific friction braking share coefficient is calculated on the chassis dynamometer over Trip #10 of the WLTP-Brake cycle, the C_p value shall be evaluated using the data of the corresponding test performed with the same brake system over Trip #10 of the WLTP-Brake cycle on the brake dynamometer.

3.3.4. Calculation of $\boldsymbol{C_e}$

Reserved

4. Testing Setup and Specifications

4.1. Vehicle Selection

Each vehicle shall be attributed a vehicle-specific friction braking share coefficient. When a vehicle features different driver-selectable modes, it shall be tested over the mode that results in the lowest recuperation as this represents the worst-case version in terms of the specific friction braking share coefficient. The measured specific friction braking share coefficient shall be attributed to all driver-selectable modes of this vehicle. Operating strategies applied for optimization of the brake function (e.g. anti-corrosion measures) shall not be de-activated or omitted during testing, as long as the safe operation of the vehicle on the chassis dynamometer is not affected.

On the basis of technical evidence provided by the manufacturer and with the agreement of the type approval authority, the dedicated driver-selectable modes for very special limited purposes (e.g. Sand, Snow/Alpine, Crawler, discharge modes for safety reasons) may be exempted from fulfilling the declared specific friction braking share coefficient.

For the purposes of this Regulation, upon the request of the manufacturer, only one vehicle of each interpolation family may be tested to determine the vehicle-specific friction braking share coefficient of the entire interpolation family. The vehicle with the lowest recuperation capability (i.e. the vehicle with the highest specific friction braking share coefficient) in the interpolation family shall be selected and tested. In this case, all vehicles within the same interpolation family shall be attributed the same vehicle-specific friction braking share coefficient regardless of the variant, version, and option configuration. The manufacturer shall be able to demonstrate compliance with the approved braking share coefficient for every vehicle in the interpolation family.

For the purposes of this Regulation, upon the request of the manufacturer when a specific vehicle model comes in different configurations that belong in more than one interpolation families, the worst-case vehicle in terms of the specific friction braking share coefficient in each vehicle electrification type according to Table 4 of this Regulation may be tested (i.e. the vehicle with the highest specific friction braking share coefficient). In such a case, the measured vehicle-specific friction braking share coefficient shall be attributed to all vehicles in each vehicle electrification type according to Table 4 of this Regulation. In this case, the manufacturer shall be able to demonstrate compliance with the approved braking share coefficient for every configuration within the vehicle model.

4.2. Preparation

4.2.1. Brake Torque Sensors

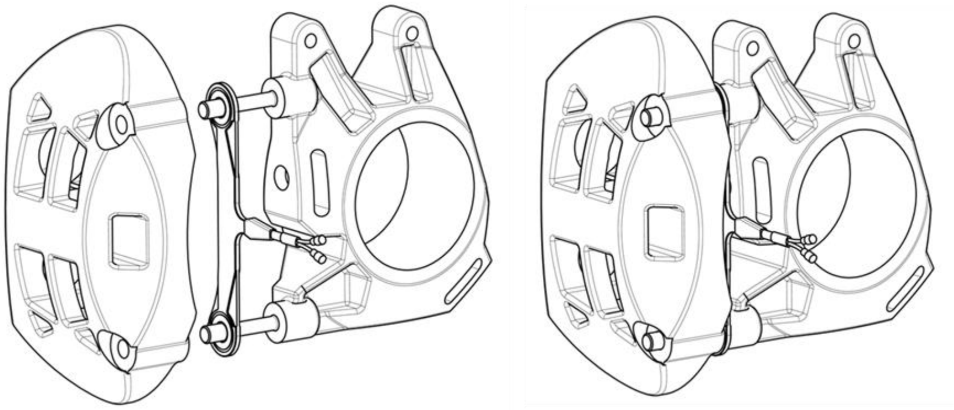
4.2.1.1. Piezoelectric sensors

The brake torque sensor is a sensor capable to measure the true amount of brake torque directly at the position where the torque occurs – between the calliper and the knuckle. Brake torque sensors are typically tailored to fit into the individual brake systems. Typically, depending on the mounting bolt diameter, the thickness is between 3.5 mm to 5.0 mm.

For the purposes of the current methodology, external torque sensor(s) shall be mounted to the calliper for each brake corner of the vehicle. Figure A5/1 provides a schematic example of brake torque sensor mounting. Depending on the technical layout of the brake and the sensor, one sensor per mounting hole or the integration in a single tool is required. The calliper or pad may be re-machined to allow the application of the sensor(s). However, great care shall be taken not to damage the brake and ensure that the calliper is still able to fulfil the intended requirements of the WLTP-Brake cycle without any safety risk or negative impact on the braking behaviour (e.g. due to deformation). This applies to the entire operation range of the sensor as specified by the sensor manufacturer.

The measured torque over time shall be converted to friction brake work according to paragraph 3.2. of this annex. Due to the functional principle of the sensor, it is required to check the zero stability before and after the test and take any drift into account.

Figure C1.
Schematic example of brake torque sensor mounting



An overall resulting range of 0 to 800 N·m is recommended. The maximum range of the measurement chain shall be chosen according to the vehicle mass, geometry of the brakes, and the expected resulting torque conditions during the tests. The testing facility shall refer to the recommendations of the brake-, vehicle-, and sensor system manufacturer to ensure the proper function of the sensor and data collection devices.

Sensor calibrations shall meet the following specifications:

(a) The accuracy of the sensor system shall be within 2 per cent of full-range or ±5 N·m, whichever is greater;

(b) The amplifiers for the torque sensors shall be adjusted to zero before the test with no brake torque applied to the system;

(c) After the test, the torque sensors shall be checked for zero drift. A maximum zero-drift of ±0.5 per cent of full-scale is acceptable.

A reference calibration sensor is required to carry out the calibration procedure. Figure A5/2 provides a schematic representation on how to attach the reference calibration sensor to the wheel hub. After the installation of the brake torque sensor, the reference calibration sensor shall be attached to the wheel and torque shall be applied. Figure A5/3 summarises schematically the calibration procedure.

Figure A5/2
T-handle and reference calibration sensor attached via wheel hub adapter to the wheel hub.

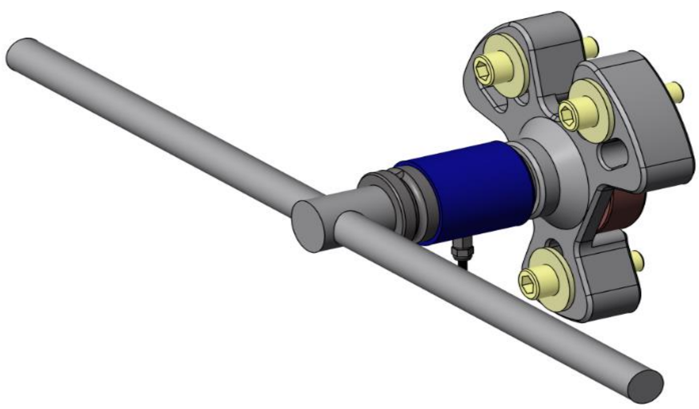
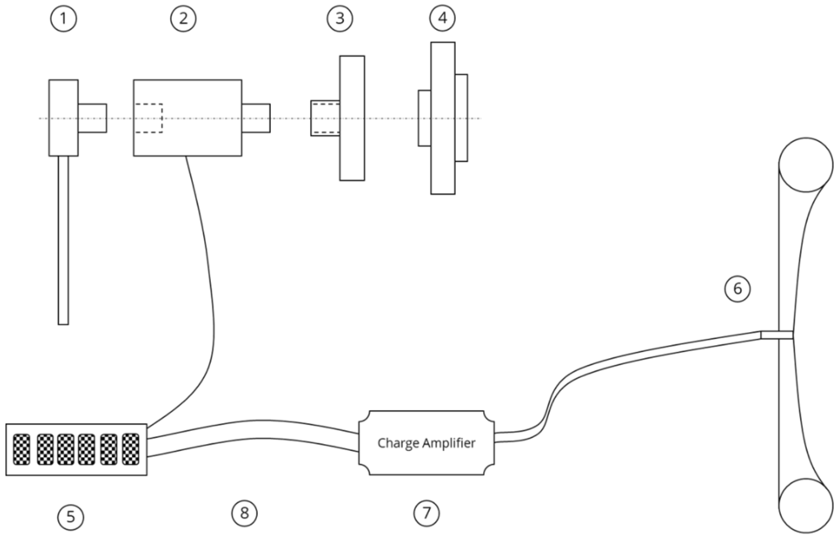


Figure A5/3

Schematic example of calibration.



No.	*Article in Figure A5/3*
1	Standard wrench square drive (which fits in the reference sensor)
2	Reference calibration sensor
3	Wheel hub adapter (to apply torque directly on the axle)
4	Wheel hub
5	Data acquisition system (which is compatible with strain gauge input)
6	Brake Torque Sensor(s) incl. cable
7	Charge amplifier
8	System Cable with Connector to data acquisition system

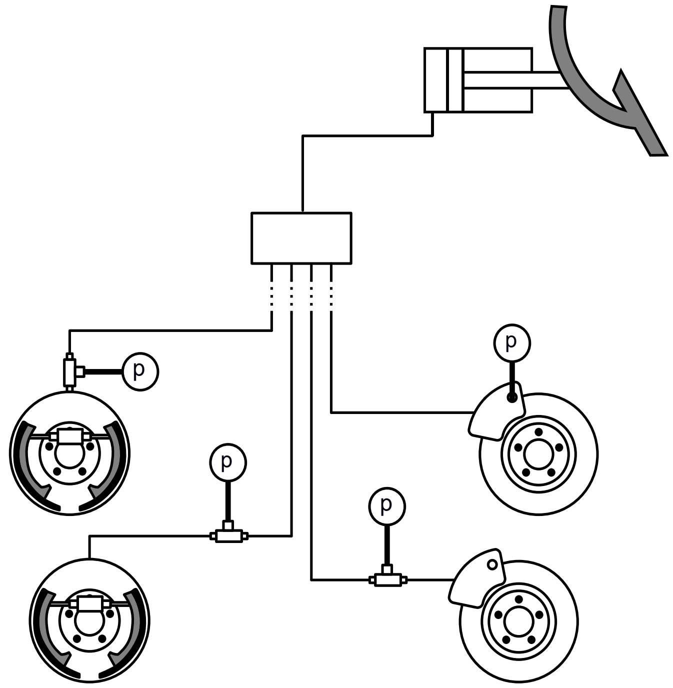
The linearity of the sensor shall be checked according to the recommendation of the measurement system manufacturer. It shall not show residuals larger than 2 per cent of full-scale or ±5 N·m, whichever is greater at any point of the operational range above zero. The measurement system shall be compensated for temperature influence according to the manufacturer specifications. The reference calibration sensor shall be calibrated according to ISO 17025 within the last 12 month of usage.

4.2.2. Pressure Transducers and Sensors

An external pressure sensor shall be mounted to the brake fluid path for each brake corner of the vehicle. Preferably, it shall be mounted to the venting screw of the respective brake corner. If this is not possible due to space limitations or other issues, alternative mounting locations are allowed; however, they shall be located as close as possible to the respective brake corner. Figure A5/4 provides a schematic representation on how to mount brake pressure sensors at the brake pipes of the tested vehicle. The measured pressure over time shall be converted to brake torque according to Equation 9 and to a friction braking share coefficient as described in paragraphs 3.1. and 3.2. of this annex.

Figure A5/4

Examples of mounting of brake pressure sensors (P) at brake pipes of the tested vehicles.



The use of a pressure sensor capable of measuring in the range of 0 – 6000 kPa is recommended, while the maximum range of the sensor shall be chosen according to the expected maximum pressure conditions during the tests. The combined uncertainty of non-linearity, hysteresis, and repeatability for pressure measurement shall be at 0.5 per cent of reading or 0.3 per cent of full scale, whichever is greater (entire uncertainty budget).

4.2.3. Sensors for Force Measurements on Electromechanical Brakes

Reserved

4.3. Data Recording

4.3.1. Chassis Dynamometer Data

Dedicated data recording systems shall be used to log the raw data from the chassis dynamometer as well as from the vehicle and its instrumented components during testing. Data recording is recommended to be carried out following the specifications described in the Annex B5 of UN Regulation No. 154 (Paragraph 2 Chassis Dynamometer).

In addition to the data requested in UN Regulation No. 154, the foundation brake related parameters shall be recorded per Table A4/3 of Annex 4. This includes at least the parameters chosen by the main method and the reference method. The measurement shall be carried out with a frequency of not less than 10Hz. The vehicle mass shall be defined according to paragraph 3.1.9. of this Regulation, regardless of the tested cycle. Moreover, the torque to pressure ratio C_p values shall be documented (if applicable).

The data recording shall be initiated before or at the same time as the actual chassis dynamometer test. The data recording of the chassis dynamometer and the vehicle shall ensure synchronized data meaning that the signals shall refer to the same time trace. It is recommended to record the signals time-aligned on a single file. Alternatively, the vehicle speed signal shall be recorded together with the brake information and be used for time alignment if the data is recorded on different systems. Recorded data shall be provided in a common and open access data format.

4.4. Chassis Dynamometer Settings

The test setup and method shall fulfil the requirements of UN Regulation No. 154 in the currently valid version at the time of testing. No deviations, except the provisions in this document, are allowed.

The tests shall be performed at 23±5 °C with the vehicle, brake systems, and measurement systems soaked for 6-36 h. The road load simulation shall be fully compliant to UN Regulation No. 154 regardless the testing cycle. Soaking, pre-conditioning, and road loads shall be set according to UN Regulation No. 154. This means that the road load coefficients (f0, f1, f2) of the road load equation shall be taken into account for the test execution.

4.5. Test Sequence

The test vehicle shall be run-in in accordance with the requirements defined in paragraphs 2. to 2.3. of Annex B8 to UN Regulation No. 154. In addition to that, the brakes of the test vehicle shall be adequately bedded. Upon the request of the type approval authority technical evidence shall be provided by the manufacturer.

Generally, the test is carried out by applying the sequence of preconditioning, soaking, and (for OVC-HEV, OVC-FCHV and PEV) recharging. This shall be followed by the performance test to derive the friction braking share coefficients (see Figure A5/5). These procedures are set out in Annex B8 of UN Regulation No. 154 unless specified otherwise as below.

Figure A5/5
Principle structure of chassis dyno testing according to this section.

Pre-conditioning WLTC Exhaust Cycle	**Soak and Recharge** 6-36 hours	**Testing Cycle** WLTP-Brake Cycle or Trip #10 of WLTP-Brake Cycle

The vehicle shall be set and tested over the driver-selectable mode that results in the lowest recuperation (i.e. worst-case in terms of specific friction braking share coefficient) as described in paragraph 4.1. of this annex. Dedicated driver-selectable modes for very special limited purposes as defined in paragraph 4.1. of this annex may not be selected.

Notwithstanding the above requirements, the applicable test cycle during the performance test shall be the WLTP-Brake cycle as described in Annex 4, or, in line with the provisions in paragraph 6. of this annex, the Trip #10 of the WLTP-Brake cycle. For all the vehicle electrification types the preconditioning WLTC cycle and the applicable test cycle shall be driven only once.

4.6. Chassis Dynamometer Test Quality Criteria

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

In case the vehicle cannot comply with all the criteria or follow the speed trace of any of the tested cycles, the friction braking share coefficients in Table 4 of this Regulation shall be used by default.

4.6.1. Computation of Signals used for Quality Checks

4.6.1.1. Driven and Target Velocity

Velocity signals shall be used for the computation of the quality check criteria. The measured and reference velocity shall be postprocessed to obtain the target and driven velocity signals, which are utilized to perform the quality checks.

The measured and reference velocity shall be smoothed using a symmetric moving average filter with a length of 0.5 seconds. To apply the discrete moving average filter, the number of samples to consider is obtained as the odd number of samples that fit into the 0.5-second interval. The number of samples to be considered in both directions is given as (Equation 15):

$$m = \left\lfloor \frac{0.25\ \mathrm{s}}{t_s} \right\rfloor \quad \text{(Eq. 15)}$$

Where

t_s is the sampling interval of the velocity signal in sec;

$\lfloor\ \rfloor$ is the operator for rounding down.

For a sampling rate of 10Hz this results in a width of $2m + 1 = 5$ samples.

The moving average of signal x with a length of $2m + 1$ samples is denoted by the operation $\mathrm{mavg}(x)$ and computed according to Equation 16:

$$\mathrm{mavg}(x) = \begin{cases} \dfrac{1}{2m+1} \displaystyle\sum_{j=i-m}^{j=i+m} x_i & \text{for} \quad m < i < N - m \\ 0 & \text{otherwise} \end{cases} \quad \text{(Eq. 16)}$$

Where

N is the number of time samples of the signal for the whole test;

x_i is the i[th] time sample of the signal to be smoothed.

The driven and target velocity for the computation of quality checks are obtained by applying the 0.5 sec moving average filter to the reference velocity and the measured vehicle velocity on the dynamometer two consecutive times (Equations 17 and 18):

$$v_T = \mathrm{mavg}\left(\mathrm{mavg}(v_{ref})\right) \quad \text{(Eq. 17)}$$

$$v_D = \mathrm{mavg}\left(\mathrm{mavg}(v_{dyno})\right) \quad \text{(Eq. 18)}$$

Where

v_{ref} is the set point velocity of the test cycle in m/s;

v_{dyno} is the velocity of the vehicle in m/s;

v_D is the driven velocity used for quality checks in m/s;

v_T is the target velocity used for quality checks in m/s.

4.6.1.2. Driven and Target Acceleration

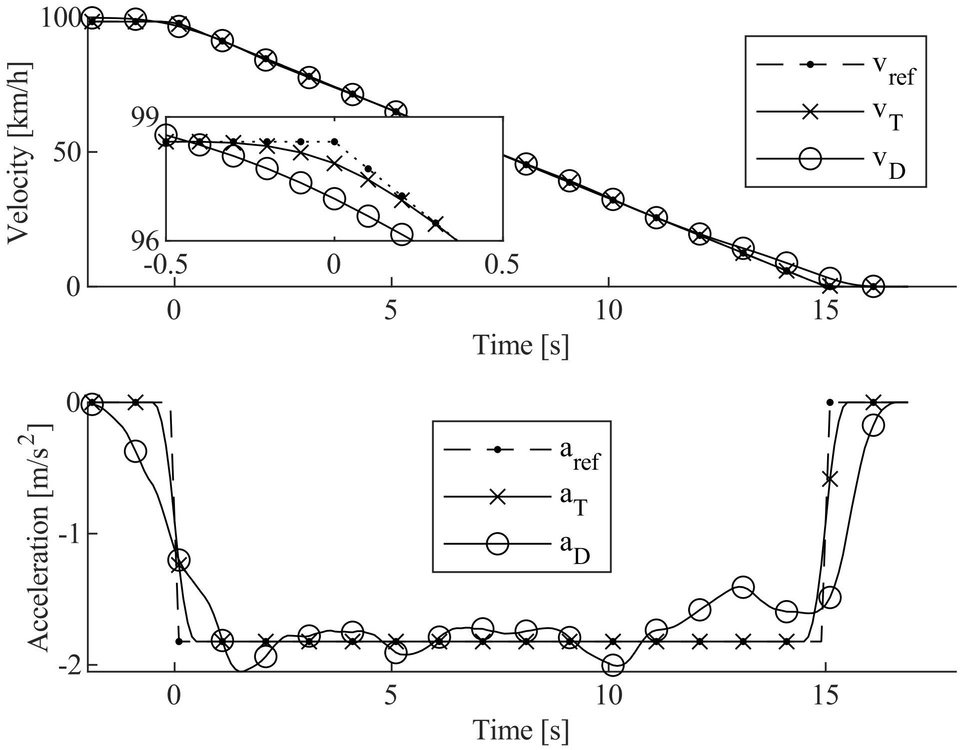
For the computation of quality checks, the acceleration shall be computed from the velocity signals. This is done using the symmetric finite difference according to Equations 19 and 20:

$$a_{T,i} = \begin{cases} \dfrac{v_{T,i+1} - v_{T,i-1}}{2t_s} & \text{for} \quad 1 < i < N - 1 \\ 0 & \text{otherwise} \end{cases} \quad \text{(Eq. 19)}$$

$$a_{D,i} = \begin{cases} \dfrac{v_{D,i+1} - v_{D,i-1}}{2t_s} & \text{for} \quad 1 < i < N-1 \\ \\ 0 & \text{otherwise} \end{cases} \qquad \text{(Eq. 20)}$$

Figure A5/6

Example of the smoothed signals with a_{ref} being the set point acceleration signal.



4.6.1.3. Driven and Target Specific Inertial Power

For the computation of quality checks, the specific inertial power of the inertial force acting during the respective velocities shall be computed according to Equations 21 and 22:

$$\tilde{P}_{T,i} = v_{T,i} \cdot a_{T,i} \qquad \text{(Eq. 21)}$$

$$\tilde{P}_{D,i} = v_{D,i} \cdot a_{D,i} \qquad \text{(Eq. 22)}$$

Where

$\tilde{P}_{T,i}$ is the i[th] sample of the target specific inertial power signal in W/kg;

$\tilde{P}_{D,i}$ is the i[th] sample of the driven specific inertial power signal in W/kg.

4.6.2. Root Mean Squared Speed Error

To check the quality of the test, the root mean squared speed error (RMSSE) in km/h shall be computed according to Equation 23:

$$\text{RMSSE} = \frac{3.6\ \text{km/h}}{1.0\ \text{m/s}} \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(v_{D,i} - v_{T,i}\right)^2} \qquad \text{(Eq. 23)}$$

For a valid test the Equation 24 criterion shall be fulfilled:

$$\mathrm{RMSSE} < 1.3\,\frac{\mathrm{km}}{\mathrm{h}} \qquad \text{(Eq. 24)}$$

4.6.3. Inertial Work Rating for Deceleration

To check the quality of the test, the inertial work rating for deceleration (IWR^-) shall be computed according to Equation 25:

$$\mathrm{IWR}^- = 100\% \cdot \frac{w_D^- - w_T^-}{w_T^-} \qquad \text{(Eq. 25)}$$

Where

w_D^- is the driven specific inertial work during deceleration in J/kg;

w_T^- is the target specific inertial work during deceleration in J/kg.

The specific inertial work during deceleration is computed as the numerical integral of the specific inertial power only during deceleration (Equations 26 and 27):

$$w_T^- = \sum_{i=1}^{N_t-1} \frac{t_{i+1} - t_i}{2} \cdot \left(\tilde{P}_{T,i}^- + \tilde{P}_{T,i+1}^-\right) \qquad \text{(Eq. 26)}$$

$$w_D^- = \sum_{i=1}^{N_t-1} \frac{t_{i+1} - t_i}{2} \cdot \left(\tilde{P}_{D,i}^- + \tilde{P}_{D,i+1}^-\right) \qquad \text{(Eq. 27)}$$

Where

$\tilde{P}_D^-$ is the driven specific inertial power during deceleration in J/kg,

$\tilde{P}_T^-$ is the target specific inertial power during deceleration in J/kg.

The specific inertial power during deceleration is defined as follows (Equations 28 and 29):

$$\tilde{P}_{T,i}^- = \begin{cases} \tilde{P}_{T,i} & \text{for} \quad \tilde{P}_{T,i} < 0 \\ 0 & \quad \text{otherwise} \end{cases} \qquad \text{(Eq. 28)}$$

$$\tilde{P}_{D,i}^- = \begin{cases} \tilde{P}_{D,i} & \text{for} \quad \tilde{P}_{D,i} < 0 \\ 0 & \quad \text{otherwise} \end{cases} \qquad \text{(Eq. 29)}$$

For a valid test the Equation 30 criterion shall be fulfilled:

$$|\mathrm{IWR}^-| < 15\% \qquad \text{(Eq. 30)}$$

4.6.4. Inertial Power Difference Work

The inertial power difference work (IPDW) is the effective work done by the difference of the specific inertial power between the driven and the target specific inertial power signals in J/kg.

In general, the effective specific inertial work of the difference of two specific inertial power signals shall be defined according to Equation 31:

$$w_{\Delta P^2} = \sqrt{\left(t_{end} - t_{start}\right) \cdot \int_{t_{start}}^{t_{end}} \left(\tilde{P}_D - \tilde{P}_T\right)^2 \mathrm{d}t} \qquad \text{(Eq. 31)}$$

To apply it to the WLTP-Brake cycle, the IPDW is computed for each brake deceleration event k , during the interval from 1 sec before the start of the brake deceleration event until 1 sec after the end the brake deceleration event, according to Equations 32 and 33:

$$\mathrm{IPDW_k} = \sqrt{\left(t_{end,k} - t_{start,k} + 2\mathrm{s}\right) \cdot \sum_{i \in \mathrm{I_k}} \frac{t_{i+1} - t_i}{2} \left(\Delta\tilde{P}_i^2 + \Delta\tilde{P}_{i+1}^2\right)} \quad \text{(Eq. 32)}$$

$$\Delta\tilde{P}_i = \tilde{P}_{D,i} - \tilde{P}_{T,i} \quad \text{(Eq. 33)}$$

Where

k is the index for each brake deceleration event;

i is the index of the time sample;

$t_{start,k}$ is the set point start time of the brake deceleration event according to the reference in sec;

$t_{end,k}$ is the set point end time of the brake deceleration event according to the reference in sec;

t_i is the i[th] time sample;

$\Delta\tilde{P}_i$ is the difference of the driven and target specific inertial power signal in W/kg;

$\mathrm{I_k}$ is the set of sample time points inside the brake deceleration event.

The set of sample points from 1 sec before to 1 sec after the k[th] brake deceleration event is defined in Equation 34:

$$\mathrm{I_k} = \left\{ i \in \mathbb{N} \mid t_{start,k} - 1\mathrm{s} \leq t_i < t_{end,k} + 1\mathrm{s} \right\} \quad \text{(Eq. 34)}$$

The IPDW for the whole WLTP Brake is computed as the root-mean-square value of the $\mathrm{IPDW_k}$ of all brake deceleration events (Equation 35):

$$\mathrm{IPDW} = \sqrt{\frac{1}{K} \sum_{k=1}^{K} \mathrm{IPDW}_k^2} \quad \text{(Eq. 35)}$$

Where

K is the number of stops in the cycle, which is 303 for the whole WLTP Brake or 114 for WLTP Brake Trip 10.

For a valid test the Equation 36 criterion shall be fulfilled:

$$\mathrm{IPDW} < 30\,\frac{J}{\mathrm{kg}} \quad \text{(Eq. 36)}$$

4.6.5. Inertial Power Difference Rating

The inertial power difference rating (IPDR) is the ratio between the IPDW of every brake deceleration event compared to the reference inertial work of the according brake deceleration event in percent.

The $\mathrm{IPDR_k}$ of each k-th brake deceleration event is defined in Equation 37:

$$\mathrm{IPDR_k} = \frac{\mathrm{IPDW_k}}{w_{ref,k}} \quad \text{(Eq. 37)}$$

Where

$w_{ref,k}$ is the reference specific inertial work of the brake deceleration event k as indicated in the “Specific KE” column of the table in Appendix 2 to Annex 4.

The IPDR for the whole WLTP Brake is computed as the root-mean-square value of the $\mathrm{IPDR_k}$ of all brake deceleration events (Equation 38):

$$\mathrm{IPDR} = 100\% \cdot \sqrt{\frac{1}{K}\sum_{k=1}^{K} \mathrm{IPDR}_k^2} \quad \text{(Eq. 38)}$$

Where

K is the number of brake deceleration event in the cycle, which is 303 for WLTP Brake or 114 for only Trip 10.

For a valid test the Equation 39 criterion shall be fulfilled:

$$\mathrm{IPDR} < 50\% \quad \text{(Eq. 39)}$$

4.6.6. Speed Violations Check

The speed tolerance criteria of paragraph 9.4.1. of Annex 4 shall apply. The 3% approach as defined in that paragraph shall apply to Trip #10 of the WLTP-Brake cycle when it is chosen as the applicable test cycle.

5. Equivalency of Methods

An alternative method as described in paragraph 3.2.2.4. of this annex may be used for the determination of the individual friction braking share coefficient instead of the reference methods described in paragraphs 3.2.2.1., 3.2.2.2. or 3.2.2.3. of this annex upon request of the manufacturer and provided that the equivalence criteria described in paragraph 5.3. of this annex are fulfilled.

5.1. Selection of Vehicle for Proof of Equivalence

The manufacturer shall demonstrate the equivalency of an alternative method for those vehicle electrification types of paragraph 2 of this annex for which the alternative method is requested to be applied. At least one vehicle for each vehicle electrification type shall be used for such a demonstration.

5.2. Testing of the Alternative Method.

To demonstrate equivalency, the vehicle shall be equipped with brake torque meters, brake pressure transducers, and/or sensors according to paragraph 4.2. of this annex and shall be subjected to the WLTP-Brake cycle according to the test sequence defined in paragraph 4.5. of this annex.

5.3. Equivalency Criterion

The alternative method shall be deemed to be equivalent to the reference method if any of the following conditions is fulfilled (Equations 40 and 41):

$$\left|\frac{c_{alt} - c}{c}\right| \leq 10 \text{ per cent} \quad \text{(Eq. 40)}$$

$$|c_{alt} - c| \leq 0.02 \quad \text{(Eq. 41)}$$

Where:

c_{alt} is the vehicle-specific friction braking share coefficient measured through the alternative method.

6. Equivalency of Test Cycle

As an alternative to derive the vehicle-specific friction braking share coefficient from WLTP-Brake cycle, the manufacturer may choose to calculate it executing Trip #10 of the WLTP-Brake cycle according to the procedure defined in paragraph 4.5. of this annex. In such a case, the vehicle-specific friction braking share coefficient calculated on Trip #10 of the WLTP-Brake cycle shall be deemed equivalent to that of the WLTP-Brake cycle and shall be reported. In case of discrepancy between the measured c-factors, the c-factor determined on the WLTP-Brake cycle shall be decisive.

7. Test Output

The reference measurement method for the determination and validation of the vehicle-specific friction braking share coefficient used for type approval by the vehicle manufacturer shall be noted (see paragraph 3.2. of this annex for details).

7.1. Offset of the Friction Braking Share Coefficient ("Declaration")

7.1.1. The vehicle-specific friction braking share coefficient calculated according to this annex may be increased by the manufacturer by up to 50 per cent of the measured value or 0.05 absolute value, whichever is greater.

7.1.2. At the request of the manufacturer and the approval of the approval authority manufacturers may increase the friction braking share coefficient calculated according to this annex up to the values indicated in Table 4 of this Regulation for the respective vehicle electrification type, or up to the values indicated in paragraph 7.1.1 of this annex, whichever is greater.