



BSI Standards Publication

Road vehicles — Portable Emission Measuring Systems (PEMS) — Performance assessment

National foreword

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Road vehicles - Portable Emission Measuring Systems (PEMS) - Performance assessment

Véhicules routiers - Systèmes portatifs de mesure des
émissions (PEMS) - Vérification de la performance

Straßenfahrzeuge - Mobile Abgasmesssysteme (PEMS)
- Leistungsbewertung

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European foreword

This document (EN 17507:2021) has been prepared by Technical Committee CEN/TC 301 “Road vehicles”, the secretariat of which is held by AFNOR.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2022, and conflicting national standards shall be withdrawn at the latest March 2022.

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Introduction

The intention of this document is to determine the measurement uncertainty of mobile vehicle exhaust emission testing equipment (e.g. Portable Emissions Measurement Systems, PEMS) under consideration of applicable legal requirements (e.g. European Legislation on Light-Duty Real Driving Emission measurement, RDE).

The specific aims include the following:

- To be able to assess PEMS (for gaseous and particle number emissions) under various operating environments with the intention of predicting PEMS performance and uncertainty over the whole range of conditions used. For the time being, it focusses on light-duty-vehicle application and serves as a basis for assessing the uncertainty of heavy-duty emission measurement using PEMS.
- To be able to evaluate the deviation of gaseous PEMS under various light-duty on-road test conditions and heavy-duty PEMS test conditions against known analyser systems under standard laboratory conditions for the specified gas, which is traceable to national or international primary standards.
- To be able to evaluate the deviation of Particle Number (PN) - PEMS under various light-duty on-road test conditions and heavy-duty PEMS test conditions against a known analyser system under standard laboratory conditions for the same sample, which is traceable to national or international primary or secondary standards.
- To define the means for demonstrating that the PEMS equipment is stable and the measurement quality is sufficient between PEMS equipment service intervals.
- To provide input to the development of future specifications and quantified information about instrument and process accuracy to help improve the accuracy and robustness of PEMS systems and on-road measurements.
- To set a framework for determining the measurement uncertainty by analysing available data and providing a method for data evaluation.

In particular, the derivation of the uncertainty according to all parts of the document allows the following:

- The instrument measurement uncertainty can be evaluated.
- The instrument measurement uncertainty on-road can be reported as a part of the measurement result following ISO 10012:2003.
- The results of an investigation based on this document provides information about the suitability of the equipment for the intended use.
- Transparency with respect to the instrument measurement uncertainty of currently available equipment.
- Transparency with respect to the testing processes for the measurement uncertainty.
- Assessment of the statistical significance of the difference of measurement results.

1 Scope

This document defines the procedures for assessing the performance of test equipment that is used for the on-road measurement of tailpipe emissions of light-duty vehicles, on the basis of a common test procedure that simulates the range of conditions experienced during on-road tests.

This document prescribes:

- the tests to be conducted, and
- a procedure to determine, for any type of PEMS equipment, an appropriate uncertainty margin to reflect its performance over those conditions.

The key test variables are as follows (but not limited to the ones mentioned):

- a) temperature, humidity and pressure (including step-wise or gradual changes),
- b) acceleration and deceleration (longitudinal and lateral),
- c) vibration, inclination and shock tests,
- d) instrument positioning on a vehicle,
- e) combinations of (a) to (d),
- f) cross-interferences,
- g) signal-processing, data treatment and time alignment, and
- h) calculation methods (excluding the regulatory post-processing of data).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN ISO 29463 (all parts), *High-efficiency filters and filter media for removing particles in air (ISO 29463 (all parts))*

ISO 27891:2015, *Aerosol particle number concentration - Calibration of condensation particle counters*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1.1**analyser**

component of a Measurement Module(s) for detecting the gaseous or particle emission concentrations

Note 1 to entry: The type is defined by the specific analyser model and the applied analytical principle or the combination of multiple analytical principles.

3.1.2**filtered air**

air filtered with a high efficiency filter according to EN ISO 29463-1, class 35H

3.1.3**inspection decision**

result of an inspection

3.1.4**inspection****inspection process**

conformity evaluation by observation and judgement accompanied as appropriate by measurement, testing or gauging

3.1.5**limit of error****maximum permissible error**

extreme value of measurement error, with respect to a known reference quantity value, permitted by specifications or regulations for a given measurement, measuring instrument, or measuring system

3.1.6**measurement standard**

realization of the definition of a given quantity, with stated quantity value and associated measurement uncertainty, used as a reference

3.1.7**measuring and test equipment**

device used for making measurements, alone or in conjunction with one or more supplementary devices

3.1.8**measuring system**

set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adapted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

3.1.9**measurement uncertainty**

non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

3.1.10**module**

discrete or integrated sub-component within a PEMS, which supports the analyser(s) with the necessary supplementary components to fulfil the necessary requirements for each pollutant being measured

3.1.11

Portable Emission Measurement System PEMS

system that can measure exhaust emissions from a vehicle on the road, allowing real-world testing

Note 1 to entry: For regulatory purposes, a PEMS comprises all the components necessary to monitor, process and report the real-driving emissions of the regulated pollutants in accordance with the relevant regulation. The PEMS used for emissions regulatory purposes typically integrate Measurement Module(s) (for example, for gaseous, particulate and exhaust-mass-flow). Additional accessories to fulfil the regulatory monitoring and processing functions are also included (for example, a weather station, Global Navigation Satellite System (GNSS) and, if required, connection to the vehicle networks).

3.1.12

uncertainty budget

statement of a measurement uncertainty, of the components of that measurement uncertainty, and of their calculation and combination

3.2 Symbols and abbreviations

A	Accuracy
c	concentration
CLD	Chemiluminescence Detector
CPC	Condensation Particle Counter
D	Drift
d	distance or diameter
DMA	Differential Mobility Analyser
E	Specific mass emission
ECU	Engine Control Unit
EFM	Exhaust Flow Meter
FS	Full Scale
GMD	Geometric Mean Mobility Diameter
GRR	Gauge Repeatability Reproducibility
GSD	Geometric Standard Deviation
GUM	Guide to the Expression of Uncertainty in Measurement
i	index
k	k-factor
LSL	Lower Limit of Specification

m	mass
MFC	Mass Flow Controller
MPE	Maximum Permissible Error
NDIR	Non-Dispersive Infra-Red
NDUV	Non-dispersive Ultra Violet
NMC	Non-Methane Cutter
NMHC	Non-Methane Hydrocarbons
p	pressure
P	Precision
PAS	Photoacoustic Spectroscopy
PEMS	Portable Emission Measurement Systems
PMP	Particle Measurement Programme
PN	Particle Number from exhaust emission according to relevant legal definition
PSD	Power Spectral Density
PSU	Power Supply Unit
Q	flow
R&R	Repeatability and Reproducibility
RDE	Real Driving Emissions
RE	Resolution (of measurement system)
RH	Relative Humidity
SOC	State of Charge
T	Temperature
t _e	time at end of test
t	time
TOL	Tolerance
u	uncertainty
u _{AV}	Uncertainty contribution of operator
u _{Bi}	Uncertainty contribution of bias

u_{CAL}	Uncertainty contribution of calibration
u_{EVO}	Uncertainty contribution of repeatability at the object
u_{EVR}	Uncertainty contribution of repeatability on standards
U_{IAI}	Uncertainty contribution of interdependence
u_{MP}	Uncertainty contribution by measurement procedure
U_{MP}	Extended measurement uncertainty contribution by measurement procedure
u_{MS}	Uncertainty contribution by measurement system
U_{MS}	Extended measurement uncertainty contribution by measurement system
u_{RE}	Uncertainty contribution by resolution
USL	Upper Limit of Specification
VDE	Verband der Elektrotechnik, Elektronik und Informationstechnik (Association for Electrical, Electronic & Information Technologies)
VDI	Verein Deutscher Ingenieure (Association of German Engineers)
VIM	Vocabulary of Metrology
VPR	Volatile Particle Remover
Δc	Concentration offset
Δt_e	Test duration
Δt	Time offset
	Sensor or monitoring device for indicated entity (e.g. temperature sensor)
	Controlling device for indicated entity (e.g. pressure controller or release valve)

3.3 List of subscripts

act	actual value (value that would be displayed by a perfect instrument)
amb	ambient, referring to ambient conditions
cur	current value
drift	concerning drift
err	error
gas	gas
i	index
j	index
m	mass (e.g. for flow)
meas	measured value
mono	monodisperse
poly	polydisperse
rd	relative density
ref	reference, referring to values of a reference device (if used)
s	sample
set	set value
span	span
T	Test duration
true	true value
V	Volume
zero	zero

4 Document structure including requirements, responsibilities and results

The whole document is structured according to the following table. This table also includes recommendations, which party should be responsible to conduct the tests and evaluate the uncertainty following the procedures which are described in this document.

Table 1 — Document structure

#	Requirement	Responsible party	Result
5	On-road testing process using PEMS	---	---
6	PEMS requirements and specifications of PEMS	PEMS manufacturers	PEMS technical specifications and test procedures for each type of PEMS component under ideal laboratory conditions
7	PEMS performance testing	PEMS manufacturers	PEMS performance test procedure for the evaluation of each type of PEMS component under simulated boundary conditions of use (in the laboratory)
8	Motivation and methods for uncertainty evaluation	---	---
9	Uncertainty evaluation of on-road testing (Type A – experimentally)	---	---
9.3	Determination of the combined measurement uncertainty I – PEMS validation	Individual PEMS User	Combined measurement uncertainty of the PEMS validation
9.4	Determination of the measurement uncertainty of the measurement II – on-road measurement process	PEMS User Community	Combined measurement uncertainty of the on-road measurement process
10	Uncertainty evaluation of on-road testing (Type B – non experimentally)	Individual PEMS User	Combined measurement uncertainty of the PEMS validation

5 On-road testing process using PEMS

The basis for this document is a common understanding of the on-road inspection process including all influencing parameters. The general description of the test procedure is defined in the relevant regulations. However, the following process chart (Figure 1) summarizes the most important steps.

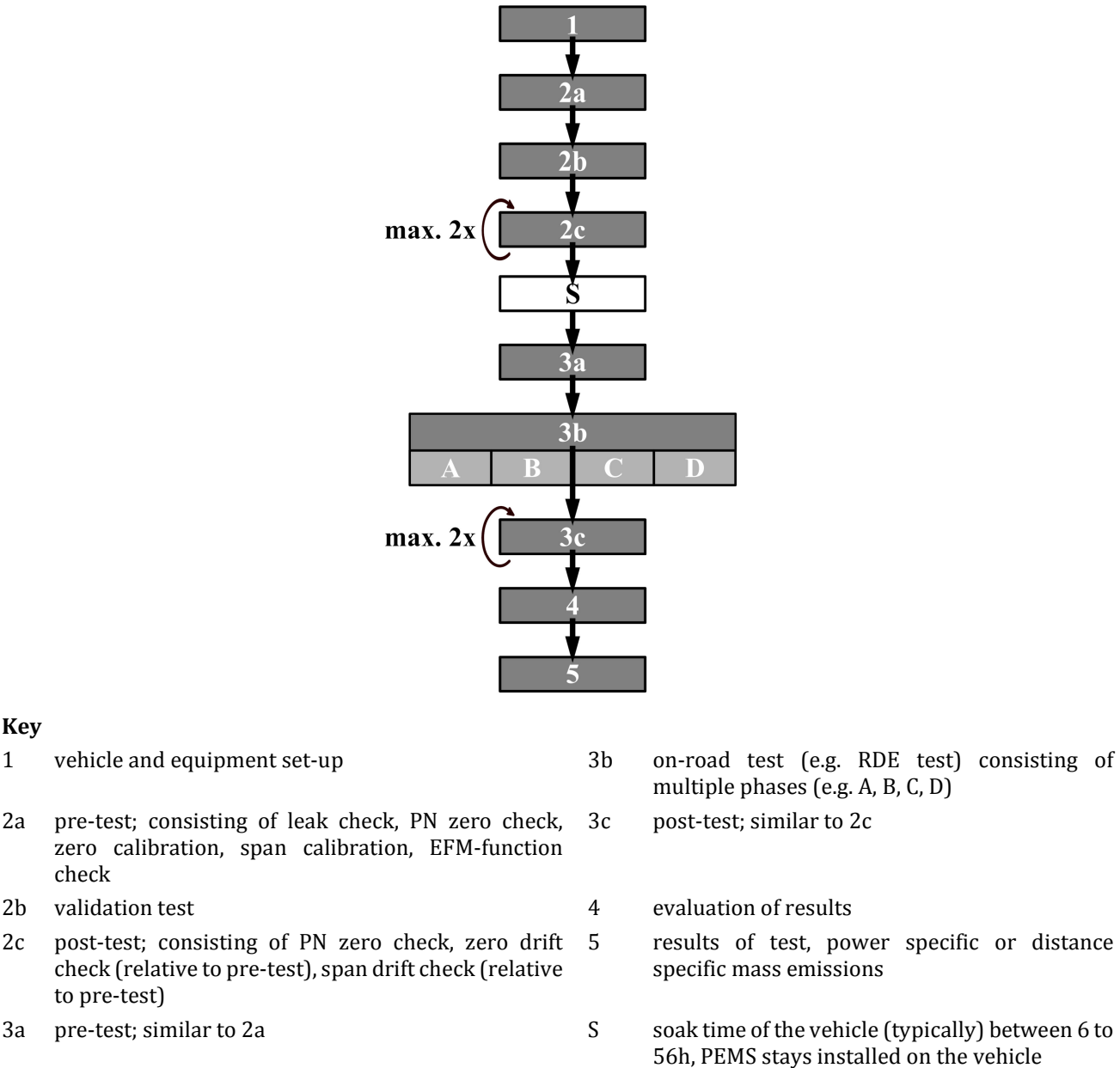


Figure 1 — Example of general on-road measurement process (based on the European Legislation on Light-Duty Real Driving Emission measurement, RDE)

The final result of the exhaust emission measurement is the distance specific mass of an emission component limited by the relevant regulations. These results are given in the unit g/km or mg/km for gaseous species, or in the unit 1/km for particle number for light-duty vehicles. Therefore, the uncertainty has to be derived with respect to these final values.

As the applicable testing scheme may vary due to legally defined procedures, this process is taken as a minimum reference for the description of errors, their dependencies and propagation. If the testing procedure does significantly deviate from this process, the approach of uncertainty assessment shall be reassessed accordingly based on the recommendations of this document.

6 PEMS requirements and specifications

6.1 General requirements

6.1.1 General

The technical requirements in this Clause are based on PEMS capabilities at the time of writing of this document. It is up to the instrument manufacturer to prove the compliance to relevant legal requirements or to prove an even better performance (lower uncertainty) for a specific analyser type, based on appropriate testing and statistical methods.

6.1.2 Boundary conditions

PEMS are used in a wide range of conditions. Table 2 below gives the main parameters that should be taken into account with their possible range according to the on-road procedure and their real range of variation during a real test.

Table 2 — Parameters of the boundary conditions

Boundary conditions	Possible range for on-road testing	Possible variation during single test
Temperature	- 7 °C to 35 °C	± 12 °C during one test up to - 30 °C if soaked in a garage
Altitude	0 m to 1 300 m	+ 1 200 m / 100 km as positive altitude gain
Pressure	850 hPa to 1 050 hPa (sea level)	up to ± 150 hPa variation during the test
Humidity	5 % to 90 % non-condensing relative humidity (RH)	
Vibrations	See 7.2.1	See 7.2.1
Duration of the test	1,5 h to 2 h	1,5 h to 2 h

6.1.3 Temperature

During the test, according to the real life, the vehicle with the installed measurement equipment can be soaked in a garage at 23 °C and go outside with a temperature at - 7 °C, the direct variation can be up to 30 °C.

According to extreme atmospheric conditions and the fact that the vehicle can climb a mountain, the variation of temperature during the test can be negative (decrease of the temperature at the top of the mountain) and positive (increase of the temperature at the bottom of the mountain).

A variation of - 30 °C and + 12 °C shall be considered during a test to check the impact of the measurement accuracy and drift.

6.1.4 Altitude / Pressure

To cover applicable altitudes between sea level and 1 300 m above sea level under various atmospheric conditions the pressure during the test can show negative gradients (climbing during test) or positive gradients (increase of pressure at sea level).

The testing range is therefore defined as starting from 1 013 mbar (± 5 %) and reaching < 850 mbar and at least 150 mbar less than the starting point. Based on a duration of an on-road measurement of 2 h and a closed route, the gradient shall be at least 75 hPa/h.

6.1.5 Humidity

The range of humidity shall be checked for each pollutant taking into account the analyser technology. The impact on its performance (e.g. interference, drift, correction) shall be identified. The main variation in terms of hygrometry is linked to the exhaust gas humidity concentration for the analyser.

During the engine start, condensation may occur in the exhaust pipe line and exhaust gases are of low humidity. Depending on the fuel and the combustion process, the relative humidity of the exhaust gas may also reach up to 35 %. The ambient humidity however, can vary according to Table 1.

6.2 Auxiliary equipment

Auxiliary equipment includes sensors like the ones used for determination of ambient temperature, ambient pressure, ambient humidity and or, if applicable, according values from the vehicles cabin.

Accuracy requirements for measurement parameters

Measurement parameter	MPE value
Temperatures ≤ 600 K	± 2 K absolute
Temperatures > 600 K	$\pm 0,4$ % of reading in Kelvin
Ambient pressure	$\pm 0,2$ kPa absolute
Relative humidity	± 5 % absolute
Absolute humidity	± 10 % of reading or, 1 gH ₂ O/kg dry air, whichever is larger

6.3 Global Navigation Satellite System

Global Navigation Satellite Systems (for example a Global Positioning System) receivers used in the PEMS should meet, or exceed, the specifications as defined in the Global Positioning System Standard Positioning Service Performance Standard (5th edition, Table 3.8.3, April 2020) or any other similar standard. All Global Navigation Satellite Systems receivers used shall be supported with the receiver manufacturer information stating clear and unambiguous compliance to the related standard.

6.4 Exhaust gas parameters

6.4.1 Exhaust flow meter

6.4.1.1 General

The determination of the exhaust mass flow is critical for the calculation of the distance specific emission mass of a vehicle. Therefore, it is required that the signals used for the calculation of the mass flow are of the best available quality. The sensitivity of instruments, sensors and signals to shocks, vibration, aging, variability in temperature, ambient air pressure, electromagnetic interferences and other impacts related to vehicle, installation and instrument operation shall be on a level as to minimize additional errors.

6.4.1.2 Specification

The exhaust mass flow rate shall be determined by a direct measurement method applied in either of the following instruments:

- a) Pitot-based flow devices,
- b) Pressure differential devices like flow nozzle (for details see the appropriate part of ISO 5167),
- c) Ultrasonic flow meter,
- d) Vortex flow meter.

Each individual exhaust mass flow meter shall fulfil the linearity requirements set out in point 6.4.1.2. Furthermore, the instrument manufacturer shall demonstrate the compliance of each type of exhaust mass flow meter with the specifications in points 6.4.1.5 to 6.4.1.11.

6.4.1.3 Linearity

All flow-measuring instruments shall comply with the linearity requirements given in Table A.1 of Annex A.

6.4.1.4 Calibration and verification standards

The measurement performance of exhaust mass flow meters shall be verified with air or exhaust gas against a traceable standard such as, e.g. a calibrated exhaust mass flow meter or a full flow dilution tunnel.

6.4.1.5 Frequency of verification

The compliance of exhaust mass flow meters with points 6.4.1.5 to 6.4.1.11 shall be verified no longer than what is required at the relevant regulations or one year before the actual test.

6.4.1.6 Accuracy

Under steady state conditions in the laboratory, the accuracy of the EFM, defined as the deviation of the EFM reading from the reference flow value, shall not exceed ± 3 % of the reading, 0,5 % of full scale or $\pm 1,0$ % of the maximum flow at which the EFM has been calibrated, whichever is larger.

6.4.1.7 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given nominal flow, approximately in the middle of the calibration range, shall not exceed 1 % of the maximum flow at which the EFM has been calibrated.

6.4.1.8 Noise

The noise shall not exceed 2 % of the maximum calibrated flow value. Each of the 10 measurement periods shall be interspersed with an interval of 30 s in which the EFM is exposed to the maximum calibrated flow.

6.4.1.9 Zero response drift

The zero response drift is defined as the mean response to zero flow during a time interval of at least 30 s. The zero response drift can be verified based on the reported primary signals, e.g. pressure. The drift of the primary signals over a period of 4 h shall be less than ± 2 % of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

6.4.1.10 Span response drift

The span response drift is defined as the mean response to a span flow during a time interval of at least 30 s. The span response drift can be verified based on the reported primary signals, e.g. pressure. The drift of the primary signals over a period of 4 h shall be less than $\pm 2 \%$ of the maximum value of the primary signal recorded at the flow at which the EFM was calibrated.

6.4.1.11 Rise time

The rise time of the exhaust flow instruments and methods should match as far as possible the rise time of the gas analysers but shall not exceed 1 s.

6.4.1.12 Response time check

The response time of exhaust mass flow meters shall be determined by applying similar parameters as those applied for the emissions test (i.e. pressure, flow rates, filter settings and all other response time influences). The response time determination shall be done with gas switching directly at the inlet of the exhaust mass flow meter. The gas flow switching shall be done as fast as possible, but highly recommended in less than 0,1 s. The gas flow rate used for the test shall cause a flow rate change of at least 60 % full scale of the exhaust mass flow meter. The gas flow shall be recorded. The delay time is defined as the time from the gas flow switching (t_0) until the response is 10 % (t_{10}) of the final reading. The rise time is defined as the time between 10 % and 90 % response (t_{90} to t_{10}) of the final reading. The response time (t_{90}) is defined as the sum of the delay time and the rise time. The exhaust mass flow meter response time (t_{90}) shall be ≤ 3 s with a rise time (t_{90} to t_{10}) of ≤ 1 s.

As an alternative to the change of gas flow rate check method above, the speed of EFM response can be validated by a pressure change at the inlet of the EFM Sensor Box which is equivalent to at least 60 % of the EFM tube flow range. The change of pressure should be as fast as possible but highly recommended to be less than 0,1 s.

6.5 General requirements for gas analysers

6.5.1 Permissible types of analysers

6.5.1.1 Standard analysers

The analysers measuring CO and/or CO₂ shall be Non-Dispersive Infrared analyser (NDIR) type.

The analyser measuring NO_x shall be either of the chemi-luminescent (CLD) or of the non-dispersive ultra-violet resonance absorption (NDUV) type, both with NO_x -NO converters. If a NDUV analyser measures both NO and NO₂ or a CLD is combined with a photoacoustic spectroscopy (PAS) analyser, a NO₂/NO converter is not required.

6.5.1.2 Alternative analysers

Any analyser not meeting the design specifications of a standard analyser (e.g. photoacoustic spectroscopy) is permissible provided that it fulfils the requirements of this standard. The manufacturer shall ensure that the alternative analyser achieves an equivalent or better measurement performance compared to a standard analyser over the range of pollutant concentrations and co-existing gases that can be expected from vehicles operated with permissible fuels under moderate and extended conditions of valid on-road testing as specified in the relevant regulations. Upon request, the manufacturer of the analyser shall submit in writing supplemental information, demonstrating that the measurement performance of the alternative analyser is consistently and reliably in line with the measurement performance of standard analysers.

6.5.2 Analyser specifications

6.5.2.1 General

The analyser manufacturer shall demonstrate compliance of analyser types with the specifications of this document. Analysers shall have a measuring range and response time appropriate to measure with adequate accuracy the concentrations of the exhaust gas components at the applicable emissions standard under transient and steady state conditions. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible and at minimum to provide the analyser performance specified in this section.

6.5.2.2 Linearity of analysers

All gas analysers shall comply with the linearity requirements given in Table A.1 of Annex A.

6.5.2.3 Accuracy

The accuracy, defined as the deviation of the analyser reading from the reference value, shall not exceed 2 % of reading or 0,3 % of full scale, whichever is larger.

6.5.2.4 Precision

The precision, defined as 2,5 times the standard deviation of 10 repetitive responses to a given calibration or span gas, shall be no greater than 1 % of the full scale concentration for a measurement range equal or above 155 ppm (or ppmC1) and 2 % of the full scale concentration for a measurement range of below 155 ppm (or ppmC1).

6.5.2.5 Noise

The noise shall not exceed 2 % of full scale. Each of the 10 measurement periods shall be interspersed with an interval of 30 s in which the analyser is exposed to an appropriate span gas. Before each sampling period and before each span period, sufficient time shall be given to purge the analyser and the sampling lines.

6.5.2.6 Zero response drift

The drift of the zero response, defined as the mean response to a zero gas during a time interval of at least 30 s, shall comply with the specifications given in Table 3.

6.5.2.7 Span response drift

The drift of the span response, defined as the mean response to a span gas during a time interval of at least 30 s, shall comply with the specifications given in Table 3.

Table 3 — Permissible zero and span response drift of analysers for measuring gaseous components under laboratory conditions

Pollutant	Absolute Zero response drift	Absolute Span response drift
CO ₂	≤ 1 000 ppm over 4 h	≤ 2 % of reading or ≤ 1 000 ppm over 4 h, whichever is larger
NO _x	≤ 5 ppm over 4 h	≤ 2 % of reading or 5 ppm over 4 h, whichever is larger

6.5.2.8 Rise time

The rise time, defined as the time between the 10 % and 90 % response of the final reading (t_{90} to t_{10} ; see point 6.5.3), shall not exceed 3 s.

6.5.2.9 Gas drying

Exhaust gases may be measured wet or dry. A gas-drying device, if used, shall have a minimal effect on the composition of the measured gases. Chemical dryers are not permitted.

6.5.2.10 Additional requirements

The effects from additional components, instrument design or methods used for the determination of the species concentration shall be determined according to Annex B. For alternative analysers quenching, converter efficiency, and additional response and interference effects etc. if applicable shall be determined.

6.5.3 Response time check of the analytical system

For the response time check, the settings of the analytical system shall be exactly the same as during the emissions test (i.e. pressure, flow rates, filter settings in the analysers and all other parameters influencing the response time). The response time shall be determined with gas switching directly at the inlet of the sample probe. The gas switching shall be done in less than 0,1 s. The gases used for the test shall cause a concentration change of at least 60 % full scale of the analyser.

The concentration trace of each single gas component shall be recorded. The delay time is defined as the time from the gas switching (t_0) until the response is 10 % of the final reading (t_{10}). The rise time is defined as the time between 10 % and 90 % response of the final reading (t_{90} to t_{10}). The system response time (t_{90}) consists of the delay time to the measuring detector and the rise time of the detector.

For time alignment of the analyser and exhaust flow signals, the transformation time is defined as the time from the change (t_0) until the response is 50 % of the final reading (t_{50}).

The system response time shall be ≤ 12 s with a rise time of ≤ 3 s for all components and all ranges used. When using a NMC for the measurement of NMHC, the system response time may exceed 12 s.

6.6 Analysers for measuring (solid) particle emissions (particle number)

6.6.1 General

The PN analyser shall consist of a pre-conditioning unit and a particle detector that counts from approximately 23 nm or 10 nm depending on the relevant regulation. It is permissible that the particle detector also pre-conditions the aerosol. The sensitivity of the analysers to shocks, vibration, aging, variability in temperature and air pressure as well as electromagnetic interferences and other impacts related to vehicle and analyser operation shall be limited as far as possible and shall be clearly stated by the equipment manufacturer in its support material. The PN analyser shall only be permitted to be used within its manufacturer's declared parameters of operation.

6.6.2 Efficiency requirements

The complete PN analyser system including the sampling line shall fulfil the efficiency requirements of Table 4.

Table 4 — 23 nm or 10 nm PN analyser (including the sampling line) system efficiency requirements with monodisperse aerosol

23 nm PN analyser system							
d_p [nm]	23	30	50	70	100	200	
$E(d_p)$ 23 nm PN analyser	0,2 – 0,6	0,3 – 1,2	0,6 – 1,3	0,7 – 1,3	0,7 – 1,3	0,5 – 2,0	
10 nm PN analyser system							
d_p [nm]	10	15	30	50	70	100	200
$E(d_p)$ 10 nm PN analyser	0,1 – 0,5	0,3 – 0,7	0,75 – 1,05	0,85 – 1,15	0,85 – 1,15	0,8 – 1,2	0,8 – 2,0

Efficiency $E(dp)$ is defined as the ratio in the readings of the PN analyser system to a reference Condensation Particle Counter (CPC)'s ($d_{50} = 10$ nm or lower for 23 nm PN analysers or 5 nm or lower for 10 nm PN analysers, checked for linearity and calibrated with an electrometer) or an Electrometer's number concentration measuring in parallel monodisperse aerosol of mobility diameter dp and normalized at the same temperature and pressure conditions.

The material should be thermally stable soot-like (e.g. spark discharged graphite or diffusion flame soot with thermal pre-treatment). If the efficiency curve is measured with a different aerosol (e.g. NaCl), the correlation to the soot-like curve shall be provided as a chart, which compares the efficiencies obtained using both test aerosols. The differences in the counting efficiencies have to be considered by adjusting the measured efficiencies based on the provided chart to give soot-like aerosol efficiencies. The correction for multiply charged particles should be applied and documented but shall not exceed 10 %. These efficiencies refer to the PN analyser systems including the sampling line. The PN analyser system can also be calibrated in parts (i.e. the pre-conditioning unit separately from the particle detector) as long as it is proven that the PN analyser and the sampling line together fulfil the requirements of Table 4. The measured signal from the detector shall be > 2 times the limit of detection (here defined as the zero level plus 3 standard deviations of the measured value).

6.6.3 Linearity requirements

The PN analyser system including the sampling line shall fulfil the linearity requirements described in Table A.1 of Annex A - using monodisperse or polydisperse soot-like particles. The particle size (mobility diameter or count median diameter) should be larger than 45 nm. The reference instrument shall be an Electrometer or a Condensation Particle Counter (CPC) with detection efficiency > 90 % at that size, verified for linearity. Alternatively, a particle number counting system compliant with the relevant regulation can be used.

In addition, the differences of the PN analyser system from the reference instrument at all points checked (except the zero point) shall be within 15 % of their mean value. At least 5 points equally distributed (plus the zero) shall be checked. The maximum checked concentration shall be the maximum allowed concentration of the PN analyser.

If the PN analyser system is calibrated in parts, then the linearity can be checked only for the PN analyser, but the efficiencies of the rest parts and the sampling line have to be considered in the slope calculation.

6.6.4 Volatile removal efficiency

The system shall achieve > 99 % removal of ≥ 30 nm tetracontane ($\text{H}(\text{CH}_2)_{40}\text{H}$) particles with an inlet concentration of $\geq 10\,000$ particles per cubic-centimetre at the minimum dilution.

The system shall also achieve a removal efficiency of tetracontane > 99 % with count median diameter > 50 nm and mass > 1 mg/m³.

The volatile removal efficiency with tetracontane have to be proven only once for the analyser type. The instrument manufacturer though shall provide the maintenance or replacement interval that ensures that the removal efficiency 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.

6.6.5 Zero response drift

The drift of the zero response, defined as the mean response to filtered air at the inlet of the sampling line during a time interval of at least 30 s, shall comply with the specifications given in Table 5.

6.6.6 Span response drift

The drift of the span response, defined as the mean response to a span gas at the inlet of the sampling line during a time interval of at least 30 s, shall comply with the specifications given in Table 5.

Table 5 — Permissible zero and span response drift of PN analyser systems under laboratory conditions

Pollutant	Absolute Zero response drift	Absolute Span response drift
PN	5 000 particles per cubic centimetre over 4 h	According to manufacturer specifications

7 PEMS Performance testing

7.1 Uncertainty assessment for PEMS performance testing according to GUM

This part of the standard describes the requirements, procedures and test set-ups to investigate the performance of mobile exhaust emission measurement instruments under laboratory conditions. It is intended to enable the instrument manufacturers to prove that the PEMS is operating within its MPE values under defined boundary conditions as described in the relevant paragraphs (6.1.1). For each test set-up, the measurement uncertainty shall be evaluated according to GUM (ISO/IEC Guide 98-3:2008). The documentation supplied with each PEMS performance test should include:

- the real time data logged from the PEMS module(s) or analyser(s) during the test,
- the deviation(s) at the 95th percentile observed during the test, in order to exclude spurious outliers,
- the relevant data from the test rig during the test e.g. chamber temperature or pressure,
- the calculation of the uncertainty of the test rig and of any reference device(s), if used.

It is up to the instrument manufacturer to prove the compliance to legal requirements or to prove an even better performance (lower uncertainty) for a specific analyser type.

The PEMS system shall be properly maintained, installed and operated according to the PEMS supplier's specifications.

7.2 General requirements

7.2.1 Vibration and shock tests

Vibration and shock testing of gaseous analysers will be performed in a laboratory using a vibration table that is appropriate for the mass of the complete PEMS. The vibration excitation will be applied at the mounting point of the PEMS, whether that is internal or external to the vehicle. A 30-min random vibration test will be performed according to the conditions of Table 6 at 0,5 G_{rms} (root mean square acceleration) in the Z (vertical) direction while measuring zero gas. This profile is an adaptation of ISO 16750-3:2012 Test IV, which was designed as an accelerated durability test for components on passenger vehicles operating on a variety of road conditions. For the purpose of determining PEMS vibration insensitivity, only the first three break points are used (from 10 Hz to 180 Hz), and the acceleration is lowered to 0,5 G_{rms} . This test may be performed in conjunction with the vibration test of the particulate analyser system.

Table 6 — Values for Power Spectral Density (PSD) and frequency

Frequency (Hz)	PSD (G^2/Hz)
10	6.73E-03
55	2.19E-03
180	8.42E-05

7.2.2 PEMS battery voltage test

7.2.2.1 General

Two methods are proposed to test the PEMS battery voltage.

The aim is to determine the analyser response variation with respect to variation in power supply voltage alone, minimising the potential analyser response variation due to variation in the concentration produced by the particle generator unit or by uncontrollable variations in ambient conditions over the longer time period of the on-road test (typically up to 120 min). Therefore, the maximum duration of these checks shall not exceed 30 min.

7.2.2.2 Method A: Using a Power Supply Unit (PSU) with a Controllable Voltage

Zero drift:

- Ensure stable environmental conditions.
- Connect the PSU to the PEMS and adjust the voltage to the maximum specified by the PEMS Manufacturer.
- Perform a zero adjust with the PSU connected and let zero gas flow through the PEMS.
- Start data logging.
- Reduce the set voltage in at least four steps to the minimum specified by the PEMS manufacturer.
- Adjust the voltage to the maximum specified by the PEMS manufacturer and continue logging for 10 min.

Span drift:

- Ensure stable environmental conditions.
- Connect the PSU to the PEMS and adjust the voltage to the maximum specified by the PEMS manufacturer.
- Perform a span adjust with the PSU connected and let span gas flow through the PEMS.
- Start data logging.
- Reduce the set voltage in at least four steps to the minimum specified by the PEMS manufacturer.
- Adjust the voltage to the maximum specified by the PEMS manufacturer and continue logging for 10 min.

7.2.2.3 Method B: Using a Battery (or Batteries if specified by the PEMS manufacturer)**Zero drift:**

- Ensure stable environmental conditions.
- Connect the charger to the PEMS and fully load the batteries.
- Perform a zero adjust while the charger is connected and let zero gas flow through the PEMS.
- Start data logging.
- Add an electrical load to the battery such that the voltage will reduce to the minimum specified by the PEMS manufacturer in no less than 30 min.
- Disconnect the charger.
- Log data until the PEMS has reached its minimum specified voltage.
- Connect the charger again and continue logging for 10 min.

Span drift:

- Ensure stable environmental conditions.
- Connect the charger to the PEMS and fully load the batteries.
- Perform a span adjust while the charger is connected and let span gas flow through the PEMS.
- Start data logging.
- Add an electrical load to the battery such that the voltage will reduce to the minimum specified by the PEMS manufacturer in no less than 30 min.
- Disconnect the charger.
- Log data until the PEMS has reached its minimum specified voltage.
- Connect the charger again and continue logging for 10 min.

To achieve a maximum test duration of 30 min additional electrical consumers/ load can be connected to the batteries.

For PN analyser systems, the appropriate procedure shall be performed against an appropriate reference PN counting device such as an Electrometer, a CPC (Condensation Particle Counter) or a reference PMP (Particle Measurement Programme) device. Any of the setups of 7.4 may be suitable. This chapter's zero and span for PN refer to Table 8 requirements.

7.3 Gaseous analysers

7.3.1 General requirements and prerequisites on the performance testing of a gaseous PEMS

As CLD is specific to NO, CLD analyser performance verifications should be made using NO/N₂ gases.

For NO_x measurement using CLD for NO without NO₂, the converter is required.

NO₂ testing should be required for all types of analysers (converter function shall be approved under different ambient conditions as well), NO₂ calibration gas shall be specified to maintain stability.

The gaseous PEMS configuration, adjustments and operation for this performance testing shall be identical to the ones defined and specified by the PEMS manufacturer for "real" tests on the road:

- The performance testing shall be performed with all accessories and operating media, if there are any used,
- The operation of the PEMS shall be according to the PEMS manufacturer instructions,
- For vibration testing the originally defined mounting / vibration damping solutions shall be used as during road tests,
- The entire gaseous PEMS shall be exposed to the ambient environmental conditions as defined in Table 2. Especially all components which are typically in contact with the ambient shall be at the same pressure, temperature, and ambient humidity.

The gaseous PEMS shall be maintained, calibrated and the linearities of the analysers shall fulfil the required criteria (see Clause 6). The actual maintenance and valid linearization protocols shall be included in the final test report.

A PEMS manufacturer shall be given the possibility to check the setup in advance to the performance test, as well as the test and observe the test execution.

The span gases, the gas divider (if used) and the gas humidifier shall follow the accuracy and calibration requirements of the relevant regulations.

The used reference gases and gas divider shall have valid calibration protocols, which shall be included in the final test report.

In case of analysers which directly and simultaneously measure the NO and NO₂ (e.g. NDUV analysers or photoacoustic analysers), a dedicated / separate NO₂ gas cylinder shall be used for the span adjust and as sample gas during the test. For CLD analysers a NO_x (NO + NO₂) gas might be used, where the NO₂ concentration of the gas mixture shall be less than 5 % of the NO concentration.

The measurement uncertainty of the entire reference test setup shall be determined according to 7.1 of this document and reported.

Zero and span adjustments and checks, if any, shall be done prior the test execution and shall be reported. During the performance tests continuous data shall be recorded and reported at least with 1 Hz. There shall be no zero- or span adjustment done within the test, unless required by the test procedure.

Negative values or peaks shall be reported and shall not be removed in the result calculation.

For analysers which measure NO and NO₂ directly, the NO_x concentration (NO_x = NO + NO₂) shall be used for the calculation of the result, but all NO, NO₂ and NO_x shall be reported according to the approach for the on-road reports.

7.3.2 Performance test execution, test matrix and test setup

7.3.2.1 Performance test execution

- Warm up the gaseous PEMS according to the PEMS manufacturer's specifications until it is fully stable.
- Ensure that the gaseous PEMS does not display any errors and warnings.
- Allow the pressure / climate chamber, gas divider (if used) and the gas humidifier sufficient time to become stable.
- Perform a leak check to ensure that there is no leakage in the test setup / gaseous PEMS.
 - Do the zero adjust and span adjust with dry calibration gases.
 - For humidification, a humidifier can be used.
 - If the humidifier does control the water content, a sensor for relative humidity (RH) is optional.
- Start data recording.
- Start sampling of the test gas through the sample gas inlet.
- Do the result calculation as described by the PEMS suppliers as part of their PEMS performance test documentation. A relative measurement of concentrations is accepted.

7.3.2.2 Performance test matrix overview

Table 7 presents the tests to be performed for the gaseous analyser.