Programa Clima y Aire limpio en Ciudades de América Latina

TECHNICAL GUIDE ON INSTRUMENTS FOR MEASURING VEHICLE EXHAUST PARTICULATE NUMBER EMISSIONS
Part 1: Metrological and technical requirements

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Technical guide on instruments for measuring vehicle exhaust particulate number emissions

Part 1: Metrological and technical requirements – Version 1.0

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Content

1. Introduction

Particle counting has been shown to be a more appropriate alternative to the conventional free acceleration smoke opacity test to detect the correct operating condition of diesel combustion engines equipped with particulate filters. In the framework of the first Latin American Conference on nanoparticle emissions from internal combustion engines, organized by the Secretariat of Environment of the Mexico City Government (SEDEMA), with the support of the Climate and Clean Air Project in Latin American Cities Plus (CALAC+), the need for all countries in the Region to standardize the particle number measurement in internal combustion engines was recognized as an effective way to replace smoke opacity measurement in both periodic technical inspections and road inspection programs.

In December 2020, the CALAC+ project coordinated the development and publication of the "*Technical guide for the periodic technical inspection (PTI) of DPF-fitted vehicles using particle counters*", which was the result of collaborative work between the CALAC+ countries (Mexico, Chile, Colombia and Peru). The purpose of this guide was to serve as a support for those countries in the Region, and mainly those that are part of the CALAC+ project, as an instrument to harmonize the replacement of the smoke opacity test by the particle counting test in DPF-fitted vehicles during the periodic technical inspection. It provides a detailed description of the basic requirements to be met by particle counters, irrespective of its operating principle, as well as the measurement procedure and defined the threshold of 250,000 $\#/cm^3$ as a passing criterion for the test.

The guide adapted to the requirements of the countries in the Region the proposed standards developed by the Netherlands Organisation for Applied Scientific Research (TNO), the Netherlands Vehicle Authority (RDW), the Netherlands Measurement Institute (NMi) and the Ministry of Infrastructure and Water Management. These organizations have developed a new test procedure for the PTI of DPF-fitted road vehicles using particle counters, which will replace the current smoke opacity standard for PTIs of diesel vehicles in the Netherlands from January 1, 2022.

The purpose of this guide is to set out recommendations for equipment that measures the volumetric particle concentration for PTIs and roadside inspections. The guide is divided into two parts:

Part 1: Metrological and technical requirements, and
Part 2: Metrological controls and performance tests

The basic working documents on which this guide has been developed were those proposed by NMi (The Netherlands): *Proposal Particulate Number Counter. Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements. 2019-10-16, Part 2: Metrological controls and performance tests*.

2. Objective

To make available to CALAC+ member countries and the Latin American region in general, the technical guide to harmonize their respective standards/regulations concerning the description of the emission test procedure for PTIs and roadside inspections (RSI) to assess the metrological and technical requirements of the instruments in order to measure the PN volumetric concentration in the exhaust gas generated by DPF-fitted combustion engines.

3. Scope

This Guide specifies the metrological and technical requirements and tests for digital measuring instruments (hereinafter referred to as "instrument(s)") that serve to determine the amount of particles per volume of the exhaust gases emanating from combustion engines. The conditions with which such instruments shall comply in order to meet the performance requirements are also established.

The Guide is applicable to instruments, intended for the inspection and maintenance of combustion engines. These instruments are used to determine the particle number per volume of defined particle sizes in the raw exhaust gas (without dilution).

This Recommendation does not apply to on-board diagnostic equipment incorporated in combustion engine vehicles.

4. Normative references

The following normative documents contain provisions that, through reference in this text, constitute provisions of this Guide.

Subsequent amendments to, or revisions of dated references do not apply. However, parties to agreements based on this Guide are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

Members of ISO, IEC and the OIML maintain registers of currently valid international standards. The current status of the Standards referred to can also be found on the Internet:

- IEC Publications: http://www.iec.ch
- ISO publications: http://www.iso.org
- OIML Publications: http://www.oiml.org (with free download of PDF files).

- Particulate number counter. Version 2019-10-16. Instruments for measuring vehicle exhaust particulate number emissions. Part 1: Metrological and technical requirements.
- Particulate number counter. Version 2019-10-16. Instruments for measuring vehicle exhaust particulate number emissions. Part 2: Metrological controls and performance tests.

For further references on the background and evolution of particle number counting tests in ITP of vehicles with DPF it is recommended to see CALAC+ Guide No. 1.

4.1 ISO Standards

ISO 3929 (2003), Road vehicles - Measurement methods for exhaust gas emissions during inspection or maintenance.

ISO 7637-1 (2002) and Amendment 1 (2008), Road vehicles - Electrical disturbance from conducting and coupling - Part 1: Definitions and general considerations.

ISO 7637-2 (2011), Road vehicles - Electrical disturbance by conducting and coupling - Part 2: Electrical transient conduction along supply lines only.

ISO 7637-3 (2007) Road vehicles - Electrical disturbance by conducting and coupling - Part 3: Passenger cars and light commercial vehicles with nominal 12 V supply voltage and commercial vehicles with 24 V supply voltage - Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines.

ISO 14912 (2003) with correction 1 (2006), Gas analysis - conversion of gas mixture composition data.

ISO 15900 (2009) Determination of particle size distribution - Differential electrical mobility analysis for aerosol particles.

ISO 16750-2 Ed. 4.0 (2012), Road vehicles - Environmental conditions and testing for electrical and electronic equipment -- Part 2: Electrical loads.

ISO 27891 (2015), Aerosol particle number concentration - Calibration of condensation particle counters.

4.2 IEC Standards

IEC 60068-2-1 Ed. 6.0 (2007-03), Environmental testing - Part 2: Test methods - Section 1: Test A: Cold.

IEC 60068-2-2 Ed. 5.0 (2007-07), Environmental testing - Part 2: Test methods - Section 1: Test B: Dry heat.

IEC 60068-2-30 Ed 3.0 (2005-08), Environmental testing - Part 2: Test methods - Section 30: Test Db: Damp heat, cyclic (12 + 12 hour cycle).

IEC 60068-2-78 Ed. 2.0 (2012-10), Environmental testing - Part 2: Test methods - Section 78: Test Cab: Damp heat, steady state.

IEC 60068-2-31 Ed. 2.0 (2008-05), Environmental testing - Part 2: Test methods - Section 31: Test Ec: Rough handling shocks, primarily for equipment-type specimens.

IEC 60068-2-64 Ed 2.0 (2008-04), Environmental testing - Part 2: Test methods - Section 64: Test Fh: Vibration, broad-band random and guidance.

IEC 60068-3-1 Ed. 2.0 (2011-08), Environmental testing - Part 3: Supporting documentation and guidance - Section 1: Cold and dry heat tests.

IEC 60068-3-4 Ed. 1.0 (2001-08), Environmental testing - Part 3: Supporting documentation and guidance - Section 4: Damp heat tests.

IEC/TR 61000-2-1 Ed. 1.0 (1990-05), Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public power supply systems.

IEC 61000-4-2 Ed. 2.0 (2008-12), Basic EMC Publication - Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 2: Electrostatic discharge immunity test.

IEC 61000-4-3 consolidated Ed. 3.2 (2010-04) Basic EMC Publication - Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 3: Radiated, radio-frequency, electromagnetic field immunity test.

IEC 61000-4-4-4 Ed. 3.0 (2012-04), Basic EMC Publication - Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 4: Electrical fast transient/burst immunity test.

IEC 61000-4-5 (2005), Correction 1 on Ed. 2.0 (2009-10), Basic EMC Publication, Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 5: Surge immunity test.

IEC 61000-4-6 Ed 4.0 (2013-10), Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 6: Immunity to conducted disturbances, induced by radio-frequency fields (EMC).

IEC 61000-4-8 Ed. 2.0 (2009-09). Basic EMC Publication - Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 8: Power frequency magnetic field immunity test.

4.3 OIML Publications

OIML V 1 (2013) International Vocabulary of Terms in Legal Metrology (VIML).

OIML V 2-200 (2012) International Vocabulary of Metrology – Basic and General Concepts and Associated Terms (VIM).

OIML D 11 (2013) General requirements for measuring instruments - Environmental conditions.

4.4 UN ECE Publications

UNECE Regulation 83, Uniform provisions concerning the approval of vehicles with regard to the emission of pollutants according to engine fuel requirements. Annex 4a, Appendix 5.

In 2011, a particle number (PN) measurement was introduced in the European type-approval emission legislation for light-duty diesel vehicles. Vehicles have been tested on a chassis dynamometer with a so-called Constant Volume Sampler (CVS) system. The CVS system which operates with highly diluted exhaust gas is equipped with a particulate counter and a sample conditioning system. The sample conditioning system removes volatile particles. The remaining volumetric solid particle concentration is measured in the particle counter which has a size-dependent counting efficiency and a measuring range of around 0 to 25,000 #/cm^3.

The type-approval emission test consists of a defined driving cycle and the volumetric PN emission of the diluted sample is continuously measured. The final test result is expressed in particles per kilometre (#/km).

Due to the high efficiency of the particulate filters applied in vehicles, the PN concentration of undiluted exhaust gas at idle speed is around or below the PN concentration of ambient air. DPF leakage will lead to an increased PN emission and a DPF removal mostly yields a PN emission at idle speed in the range of 1 to 15 million #/cm^3.

4.5 Other publications

Guide to the expression of uncertainty in measurement (GUM), (1995): Joint publication by the BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, and OIML.

Verordnung des EJPD uber Abgasmessgeräte für Verbrennungsmotoren.

5. Terms and definitions

For the purposes of this Guide, the following terms and definitions apply:

Mobility diameter: Diameter of a particle that exhibits the same electrical mobility as a spherical particle when measured in a mobility analyser according to ISO 15900:2009.

Nanoparticles: These are a sub-classification of ultrafine particles with lengths in two or three dimensions greater than 1 nm and less than 100 nm and which may or may not exhibit size-related intensive (mass function) properties. Their definition is currently the subject of controversy. Their common use in the field of internal combustion engines emphasizes their size rather than their properties. The scale of measurement can be either mobility diameter or aerodynamic diameter [ASTM E2456].

Particle number concentration: Number of solid particles with a mobility diameter between 20 and 300 nm per unit volume of gas, specified per cubic centimetre (#/cm^3). Liquid droplets (condensates) are removed from the gas stream by a dilution system with filtered air and the use of a thermal or catalytic removal system. [SN 277206:2014].

Efficiency (E): Quotient of the particle number concentration displayed on the instrument including the sampling unit and the particle number concentration determined with a reference particle counter.

Total particles: Diesel particles consist mainly of carbonaceous material (soot or solid particles) generated during combustion, on which organic compounds are absorbed/adsorbed from the exhaust gas.

Solid particles: Solid fraction of total particles, considered to be those whose size is greater than or equal to 23 nm.

Volatile particles: Volatile fraction of total particles, usually smaller than 23 nm in size. They are generally formed from the condensation of high molecular weight organic compounds.

Sampling probe: Tube that is inserted into the exhaust tail pipe of a vehicle to take gas samples.

HEPA filter: A device that removes particulates from the air.

Note: HEPA stands for High Efficiency Particulate Air.

Gas handling system: Instrument components, from the sampling probe to the gas sample outlet, through which the exhaust gas sample is conveyed by the pump.

Adjustment (of a measurement system): A set of operations carried out on a measurement system so that it provides prescribed indications corresponding to given values of a quantity to be measured (VIML, 0.15).

Semi-automatic adjustment facility: A facility allowing the user to initiate an adjustment of the instrument without having the possibility of influencing its magnitude, whether or not the adjustment is automatically required.

Note: For those instruments that require the values of the adjustment reference to be entered manually, the facility is considered to be semi-automatic.

Automatic adjustment facility: A facility performing the adjustment of the instrument as programmed without the intervention of the user, to initiate the adjustment or its magnitude.

Zero setting facility: Facility to set the indication of the instrument to zero.

Internal adjustment facility: A facility to adjust the instrument to a designated value without the use of an external adjustment reference.

Warm-up time: Time elapsed between the moment power is applied to an instrument and the moment at which the instrument is capable of complying with the metrological requirements.

(Step) response time: The duration between the instant when an input quantity value of a measuring instrument or measuring system is subjected to an abrupt change between two specified constant quantity values and the instant when a corresponding indication settles within specified limits around its final steady value (VIM, 4.23).

Reference (quantity) value: Quantity value used as a basis for comparison with values of quantities of the same kind *(*VIM, 5.18).

(Measurement) error: Measured quantity value minus a reference quantity value (VIM, 2.16).

Relative error: Error of measurement divided by the reference quantity value of the measurand.

Fault: Difference between the error of indication and the intrinsic error of the instrument (VIML, 5.14).

Significant fault: Fault exceeding the applicable fault limit (VIML, 5.14).

Note: The following faults are considered to be not significant:

a) fault arising from simultaneous and mutually independent causes in the instrument itself or in its checking facilities;

b) faults implying the impossibility to perform any measurement;

c) transitory faults being momentary variations in the indication, which cannot be interpreted, recorded or transmitted as a measurement result; and

d) faults giving rise to variations in the measurement results that are so large as to be noticed by all those interested in the measurement result.

Influence quantity: A quantity that, in a direct measurement, does not affect the quantity actually measured, but affects the relation between the indication and the measurement result (VIM, 2.52).

Tolerance: Since a certain amount of error will inevitably occur between the measured value and the true value, the difference between the maximum and minimum dimensions of the allowable errors is called tolerance.

Rated operating conditions: The operating condition that must be fulfilled during measurement in order that a measuring instrument or system perform as designed (VIM, 4.9).

Disturbance: An influence quantity having a value within the limits specified in this Guide but outside the rated operating conditions of the instrument (VIML, 5.19).

Reference condition: An operating condition prescribed for evaluating the performance of a measuring instrument or system or for comparison of measurement results (VIML, 4.11).

Checking facility: A facility that is incorporated in the instrument and that enables significant faults to be detected and acted upon (VIML, 5.07).

Note: "Acted upon" refers to any adequate response by the instrument (luminous signal, acoustic signal, prevention of the measurement process, etc.).

Automatic checking facility: Checking facility operating without the intervention of the user.

Legally relevant software: Any part of the software, including stored parameters, which has an influence on the calculated, displayed, transmitted or stored measurement result.

Reference PN sample: Aerosol of sufficient stability and homogeneity whose composition is properly established for use in various performance tests.

Types of instruments (*analysers*):

a) *Hand-held instrument*: A type of instrument (analyser) that is designed for hand-held use with its standard accessories by one person.
b) *Transportable instrument (analyser)*: A type of instrument (analyser) that rests on a suitable surface during use, which may be designed for hand-held transportation with its standard accessories by one person.

Motor vehicle: A unit of land transport of cargo or passengers, powered by a built-in engine, that runs on gasoline, liquefied petroleum gas, natural gas, diesel or other alternative fuels; it has been disposed of at least once and is licensed to operate on the road network.

Note: Typically used for applications such as:

- carrying persons and/or goods;
- towing vehicles used for the carriage of persons and/or goods.

5.1 Abbreviations

AC Alternating Current

AM Amplitude Modulation

ASD Acceleration Spectral Density

DC Direct Current

DPF Diesel particulate filter

EMC Electromagnetic compatibility

e.m.f. electromotive force

EUT Equipment under test

IEC International Electrotechnical Commission

ISO International Organisation for Standardisation

MPE Maximum Permissible Error

NMi Netherlands Measurement Institute (Nederlands Meetinstituut)

NPTI New Periodic Technical Inspection

OBD On-board diagnostics

OIML International Organization of Legal Metrology

PN Particle number

PTI Periodic Technical Inspection

PMP Particle Measurement Programme

RDW Dutch Type Approval Authority (Rijksdienst voor Wegverkeer)

RSI Roadside Inspection

SPN Solid Particle Number

TNO Netherlands Organisation for Applied Research

VPR Volatile Particle Remover

WLTC Worldwide Harmonised Light Vehicles Test Procedure)

6. Description of the instrument

Generally, the instrument provides a means for sampling and then measuring the exhaust gases emitted from the tailpipe of a motor vehicle. A pump provides the means for conveying the gas sample through a gas handling system. One or more detection devices, incorporated in the gas handling system, analyse the sample and provide signals related to the number of particles per unit volume. The detector signals are then electrically processed to display and possibly record the results of a particulate number measurement.

- The major instrument components are:
- sampling probe introduced in the tail pipe of an operating motor vehicle to collect the exhaust gas sample;
- pump(s) to convey the gases through the instrument;
- device(s) to prevent water condensation from forming in the sampling line and in the instrument;
- filter(s) to remove particles that could cause contamination of various sensitive parts of the instrument;

- ports to introduce ambient air and reference PN sample when required by the technology used;
- device to remove volatile particles of the sample,
- detection devices for measuring the particulate number of the gas sample;
- a data system to process the signal including an indicating device to display the results of a measurement; and
- a control facility to initiate and check instrument operations and a semi-automatic or automatic adjustment facility to set instrument operating parameters within prescribed limits.

7. Metrological requirements

7.1 Indication of the measurement result

The particle number per volume shall be expressed as number of particles per cm^3 for particles of specified sizes. The inscriptions for this unit shall be assigned unambiguously to the indication, for example, "#/cm^3".

7.2 Measuring range

The minimum range, that may be subdivided, shall be 5 000 to 5 000 000 #/cm^3.
The exceeding of the range is indicated (visibly) by the instrument.

7.3 Resolution of the indication

As indicated in the *Scope* section, this Guide only refers to digital indicating instruments. Digital figures shall be at least 5 mm high. The least significant figure of the display shall provide a minimum resolution of 1000 #/cm^3.

7.4 Durable recording of the measurement results

The measurement results shall be recorded by a durable means, accompanied by information to identify the particular measurement.

7.5 Maximum permissible errors

7.5.1 Maximum permissible error

Type of error	*Maximum permissible error* [#/cm3]*
Absolute	25 000
Relative	± 25% of the actual value
Absolute or relative, whichever is greater	

7.5.2 Fault limit

The fault limit is 25 000 #/cm^3.

7.6 Influence quantities

7.6.1 Reference conditions

(a) ambient temperature	20 °C ± 2 °C;
(b) relative humidity	50 % ± 20 %;
(c) atmospheric pressure	stable ambient;
(d) mains voltage	nominal voltage ± 2 %;
(e) network frequency	nominal frequency ± 1 %;
(f) vibration	none / negligible;
(g) voltage of battery	nominal voltage of the battery

7.6.2 Rated operating conditions

(a) ambient temperature	+ 5 °C to + 40 °C (1);
(b) relative humidity	up to 85 %, non-condensation (closed location); up to 95 % condensation (open location) (2); 860 hPa to 1 060 hPa (3);
(c) atmospheric pressure	750 hPa to 1 060 hPa (3);
(d) mains voltage	- 15 % to + 10 % of the nominal voltage;
(e) mains frequency	± 2 % of the nominal frequency;
(f) voltage of road vehicle battery	12 V battery: 9 V to 16 V; 24 V battery: 16 V to 32 V;
(g) voltage of internal battery	low voltage as specified by the manufacturer, up to the voltage of a new or fully charged battery of the specified type.

(1) Unless otherwise specified by the manufacturer, these are standardized ranges for the ambient temperature. The manufacturer, however, can specify different ranges under the following conditions:

- the lower temperature shall be 5 °C or less;
- the higher temperature shall be either 40 °C or higher.

Outside the temperature range, the instrument shall not indicate the measured value, instead it shall indicate a warning the temperature is outside the range.

(2) Closed location: the instrument is meant for use inside; open location: the instrument is meant for use outside.

(3) Unless otherwise specified by the manufacturer, this is the standardized range for the atmospheric pressure. The manufacturer can specify an extended range for atmospheric pressure that includes the standardized range. Equipment operating outside this range must have a barometric compensator for proper measurement and certification of calibration performed at the specified pressure.

7.6.3 Influence of particle size

The design of the instrument shall be such that the detection efficiency related to the particle size is the following:

Counting efficiency	Particle size [nm]
0,2 – 0,6	23 +/- 5%
0,6 – 1,3	50 +/- 5%
0,7 – 1,3	80 +/- 5%

7.7 Disturbances

Significant faults as defined in section 5 shall either not occur or shall be detected and acted upon by means of checking facilities in case of the following disturbances:

Mechanical shock	Handheld: 1 fall of 1 m on each bottom edge Transportable: 1 fall of 50 mm on each bottom edge
Vibration	10 Hz to 150 Hz, 1.6 ms^{-2}, 0.05 m^2s^{-3}, -3 dB/octave
AC mains voltage dips, short interruptions and reductions	0.5 cycles reduction to 0 %. 1 cycle reduction to 0% 10/12 (*) cycles reduction to 40 %. 25/30 (*) cycles reduction to 70 %. 250/300 (*) reduction to 80% 250/300 (*) reduction to 0% (*) For 50 Hz/ 60 Hz respectively
Bursts (transients) on AC mains	Amplitude 2 kV Repetition rate 5 kHz
Bursts (transients) on signal, data and control lines	Amplitude 1 kV Repetition rate 5 kHz
Surges on AC mains power lines	Line to line 1.0 kV Line to ground 2.0 kV
Surges on signal, data and control lines	Line to line 1.0 kV Line to ground 2.0 kV
Electrostatic discharge	6 kV contact discharge 8 kV air discharge
Radiated, radio-frequency, electromagnetic fields	80 (26) MHz up to 6 GHz, 10 V/m
Conducted radio-frequency fields	0.15 up to 80 MHz, 10 V (e.m.f.)
Power frequency magnetic fields	Continuous 100 A/m Short duration 1000 A/m for 1 s
For instruments powered by the road vehicle battery:	
Electrical transient conduction along supply lines	Pulses 2a, 2b, 3a, 3b, test level IV (ISO 7637-2)
Electrical transient conduction via lines other than supply lines	Pulses a and b, test level IV (ISO 7637-3)
Load dump	Test B (ISO 16750-2)

7.8 Response time

For measuring PN concentration, the instrument including the specified gas handling system, shall indicate 95 % of the final value (as determined with reference PN samples) within 15 s after changing from ambient air. The instrument may be provided with a logging device to check this requirement.

7.9 Warm-up time

After the warm-up time, the instrument shall meet the metrological requirements stated in this Guideline. The instrument shall prevent an indication of measured particle number during the warm-up time.

7.10 Stability with time or drift

When used in accordance with the manufacturer's operating instructions, the measurements made by the instrument, under stable environmental conditions and after adjustment using a reference PN sample or the internal adjustment facility, shall remain within the maximum permissible error for at least 12 h without the need for reference PN sample or internal readjustments by the user. If the instrument is equipped with a means for drift compensation, such as automatic zero or automatic internal adjustment, the action of these adjustments shall not produce an indication that can be confused with a measurement of an external gas.

7.11 Repeatability

For 20 consecutive measurements of the same reference PN sample carried out by the same person with the same instrument within relatively short time intervals, the experimental standard deviation of the 20 results shall not be greater than one third of the modulus of the maximum permissible error for the relevant sample.

8. Technical requirements

8.1 Communication

8.1.1 The PN measurement instrument shall communicate with the software of the technology platform of the centralized technical inspection line, ensuring interconnectivity between the instrument and the technology platform for the management and control of the vehicle technical inspection line.

8.1.2 The instrument shall have a visible and commanded test stabilization protocol to assist the operator in performing the test correctly (in accordance with Guide 1, Section 7).

8.1.3 The PN measuring instrument shall not have a display of the measurement test result on the equipment (except for equipment to be used for on-road inspection).

8.1.4 The instrument shall have correct measurement security protocols so that measurements outside the exhaust can be detected. The communication protocol between the PN equipment and the vehicle inspection line management technology platform shall be encrypted.

Note: The suggested communication protocol is intended to:

8.1.5 Avoid manipulation of the result by the operator at the periodic technical inspection site.

8.1.6 Enable limit values to be monitored and set in a centralized system managed by the relevant authority.

8.2 Construction

8.2.1 All components of the gas handling system shall be made of corrosion-resistant material. The material of the sampling probe shall withstand the exhaust gas temperature. The materials used shall not influence the composition of the gas sample.
8.2.2 The sampling probe shall be so designed that it can be inserted at least 30 cm into the exhaust tail pipe of the vehicle and be held in place by a retaining device, regardless of the depth of insertion.
8.2.3 The instrument shall either contain a device that prevents water condensation from forming in the sampling line and measuring components or a detector that gives an alarm and prevents a measurement result from being indicated.

Note: Examples of devices are heating of sampling line or dilution with ambient air near the sampling probe.

8.2.4 If an adjustment reference is needed due to the measurement technique, simple means to provide such a sample shall be available with the instrument.
8.2.5 The pump conveying the exhaust gas shall be mounted so that its vibrations do not affect the measurements. The user shall be able to switch the pump on and off if a measurement is not possible when the pump is switched off.

Note: It is recommended that the gas handling system be flushed automatically with ambient air before the pump is switched off.

8.2.6 The instrument shall be equipped with a device that indicates when the gas flow rate decreases to a level that would cause the detection to exceed either the response time or half the modulus of the maximum permissible error. And, when that limit is reached, the device shall prevent measurements from being carried out.
8.2.7 The gas handling system shall be airtight to such an extent that the influence of dilution with ambient air on the measurement results shall not exceed half the modulus of the maximum permissible error.

The instrument shall not be able to make a measurement if this value is exceeded.

A clean air test procedure with sufficient accuracy (por example, HEPA filter with 99.97% efficiency) to detect this specific maximum leakage shall be provided in the manufacturer's operating instructions.

The instrument shall be equipped with a device that at first use per 24 h performs an automatic zero-setting procedure. This device may be combined with the clean air test procedure.

8.2.8 The instrument may be equipped with an interface that allows coupling to any peripheral device or other instrument.

An interface shall not allow the metrological functions of the instruments or their measurement data to be influenced by peripheral devices, by other interconnected instruments or by disturbances acting on the interface.

Functions that are performed or initiated via an interface shall meet the relevant requirements and conditions.

If the instrument is connected to a data printer or external data storage device, then the data transmission from the instrument to the printer shall be designed so that the results cannot be falsified.

It shall not be possible to print a document or store the measuring data in an external device for legal purposes if the instrument checking facility(es) detect(s) a significant fault or malfunction.

8.2.9 The instrument has a reporting frequency equal to or greater than a frequency of 1 Hz.

8.2.10 The instrument is designed in accordance with good engineering practice to ensure particle concentration reduction factors (por example, of a dilution system) are stable across a vehicle test.

8.2.11 The instrument achieves a > 95 percent removal efficiency of 30 nm Tetracontane ($C_{40}H_{82}$) particles.

8.3 Security of operation

8.3.1 If the detection of one or more of the disturbances listed in section 7.7 'Disturbances' is achieved by the use of automatic self-checking facilities, then it shall be possible to check the correct functioning of such facilities.

8.3.2 The instrument shall be controlled by an automatic checking facility that shall operate in such a way that, before a measurement can be indicated or printed, all adjustments and all other checking facility parameters shall be confirmed for proper values or status (i.e., within limits).

8.3.3 Instruments equipped with an automatic or semi-automatic adjustment system shall not be able to make a measurement until correct adjustments have been completed.

8.3.4 Instruments equipped with a semi-automatic adjustment facility shall not be able to make a measurement when an adjustment is required.

8.3.5 A means for warning of a required adjustment may be provided for both automatic and semi-automatic adjustment facilities.

8.3.6 Effective sealing devices shall be provided on all parts of the instrument that are not otherwise materially protected against operations liable to affect the accuracy or integrity of the instrument.

This applies in particular to:

- adjustment means;
- software integrity.

8.3.7 The legally relevant software shall be clearly identified. The identification shall be displayed or printed:

- on command or
- during operation or
- at start-up for a measuring instrument that can be turned off and on again.

8.3.8 The software shall be protected in such a way that evidence of any intervention (e.g., software updates, parameter changes) shall be available.

8.3.9 The metrological characteristics of an instrument shall not be influenced in any inadmissible way by the connection to it of another device, by any feature of the connected device itself, or by any remote device that communicates with the measuring instrument.

8.3.10 A battery-operated instrument shall function correctly with new or fully charged batteries of the specified type and either continue to function correctly or not indicate any value whenever the voltage is below the manufacturer´s specified value.

Specific voltage limits for road vehicle batteries are prescribed in section 7.6.2 "Rated operating conditions".

9. Inscriptions and operating instructions

9.1 Inscriptions

The instrument shall have a permanent, non-transferable and easily readable label or labels giving the following information:

(a) Manufacturer's trademark/corporate name;

(b) Year of manufacture;

(c) Serial approval mark and model number;

(d) Serial number of the instrument;

(e) Details of the electrical power:

- in the case of mains power: the nominal mains voltage, frequency and power required;
- in the case of power by a road vehicle battery: the nominal battery voltage and power required;
- in case of internal removable battery: the type and nominal voltage of the battery.

9.2 Operating instructions

The manufacturer shall provide written operating instructions for each instrument in the language(s) of the country in which it will be used.

The operating instructions shall include:

a) The time intervals and the procedures for adjustment and maintenance that shall be followed to comply with the maximum permissible errors (see also 8.2);

b) A description of the clean air test procedure;

c) If applicable, the zero-setting procedure;

d) The maximum and minimum storage temperatures;

e) A statement of the rated operating conditions listed in 7.6.2 and other relevant mechanical and electromagnetic environmental conditions;

f) If applicable, details about compatibility with ancillary equipment;

g) The ambient temperature range shall be included in the operating instructions;

h) Any specific operating condition, for example, a limitation of the length of signal, data or control lines;

i) If applicable, the specifications of the battery (see 8.2);

j) A list of error messages with explanation.

10. Contact information

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