Proposed scope & content for

Guidance on

Particle number (PN) Measurement for the Periodical Technical Inspection (PTI) of vehicles equipped with compression ignition engines

Final draft

Version 01

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European Commission

JRC, MOVE C.2

Disclaimer: This is a draft guidance for PN-PTI measurements and not an official document

This document proposes a set of definitions, identifies components for particle number (PN) measurement instruments as well as content for the labelling of PN measurement instruments for exhaust emissions, appropriate for periodic technical inspections and roadworthiness tests. It suggests elements to be included in the operating instructions of the instrument. The document further elaborates on technical requirements, metrological requirements and their control. It proposes measurement procedures and a pass/fail PN limit for the periodical technical inspection (PTI) tests of certain vehicles.

A first discussion of this proposal took place at the Roadworthiness expert group on 11 February 2022. Member States' feedback was requested both on the proposed content of the document as well as on the specific questions identified in relevant sections until 25 March 2022.

The feedback has been taken into account and incorporated in this version of the document.

1. Scope

This document presents a proposal on the particle number (PN) concentration test during the periodical technical inspection (PTI). PN concentration measurements during the PTI can be applied to all M and N category vehicles equipped with compression ignition engines and diesel particulate filters. This guidance may be applied to light-duty vehicles registered as of 1 January 2013 and to heavy-duty vehicles registered as of 1 January 2014.

2. Terms and Definitions

Sampling probe: Tube that is introduced into the exhaust tail pipe of a vehicle to take gas samples (OIML R 99)

Particle(s): Solid (thermally stable) particles with size between 23 nm and at least 200 nm emitted by the vehicle and measured in the airborne phase according to the methods specified in this guidance

HEPA filter (High-Efficiency Particulate Air Filter)**:** A device that removes particles from the air with efficiency higher than 99,95% (i.e. class H13 or higher according to DIN EN 1822-1:2019-10)

Response time: Duration between the instant when an input quantity value of a measuring instrument or measurement 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)

Warm-up time: Elapsed time between the moment power is applied to an instrument and the moment at which the instrument is capable of complying with the metrological requirements (OIML R 99)

Particle size: Here refers to electrical mobility size, i.e. the diameter of a sphere with the same migration velocity in a constant electric field as the particle of interest

PN-PTI instrument: Instrument for measuring the particle number (PN) concentration in the exhaust gas of internal combustion engines sampled during the PTI in the tailpipe of a vehicle

PN-PTI instrument type: All instruments from the same manufacturer with the same working principle, hardware and software calculation and correction algorithms

Particle detector: Device or instrument that indicates the presence of particles when a threshold value of particle number concentration is exceeded (similar to VIM 3.9)

Condensation Particle Counter (CPC): Particle detector in which the measuring principle is based on condensation on particles in a saturated environment to suitably enlarge the particles for optical detection

Counting efficiency: The ratio of the PN-PTI instrument reading and a traceable reference instrument or device reading, including all internal calibration factors

Measuring range: Set of values of quantities of the same kind that can be measured by a given measuring instrument or measuring system with specified instrumental measurement uncertainty, under defined conditions (VIM 4.7)

Resolution of the displaying device: Smallest difference between displayed indications that can be meaningfully distinguished (VIM 4.15)

Monodisperse particles: Particles with a very narrow distribution around one particle size

Polydisperse particles: Particles with many different particle sizes

Legally relevant software: Any part of the software, including stored parameters, which has an influence on the calculated, displayed, transmitted, or stored measurement result (OIML R 99)

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

Maximum permissible measurement error (MPE): 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 (VIM 4.26)

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

Disturbance: Influence quantity having a value within the limits specified in this guidance but outside the rated operating conditions of the measuring instrument (OIML D 11)

Reference operating condition: Operating condition prescribed for evaluating the performance of a measuring instrument or measuring system or for comparison of measurement results (VIM 4.11)

Zero-setting or zero level facility or procedure: Facility or procedure for the adjustment of a measuring system so that it provides a null indication corresponding to a zero value of a quantity to be measured (VIM 3.12)

Verification: Provision of objective evidence that a given item fulfils specified requirements. NOTE 1: Verification pertains to the examination and marking and/or issuing of a verification certificate for a measuring system or instrument (VIM 2.44)

Maintenance: Precisely defined periodic maintenance and periodic adjustment work in order to keep a measuring instrument in an operational condition

Adjustment: Set of operations carried out on a measuring system so that it provides prescribed indications corresponding to given values of a quantity to be measured (VIM 3.11)

Significant fault: Fault, which has a magnitude greater than the magnitude of the maximum permissible error on initial verification (OIML R 99)

Sample-preconditioning device: A device for diluting and/or removing volatile particles

Vehicle OBD information: The information relating to an on-board diagnostic (OBD) system for any electronic system on the vehicle

Metrological traceability: property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty (VIM 2.41)

Correction: Compensation for an estimated systematic effect (VIM 2.53)

Expanded uncertainty: product of a standard measurement uncertainty (obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model) and a factor larger than the number one (VIM 2.35)

Measurement result: Set of quantity values being attributed to a measurand together with any other available relevant information (VIM 2.9)

Test result: The final measurement result for a vehicle tested with the PN-PTI "Measurement procedure" described herein.

National metrological institute (NMi): The metrological institute responsible for type examination of PN-PTI instruments in a member State

3. Description of the instrument and inscription

The main PN-PTI instrument components are as follows:

- A sampling probe introduced in the tail pipe of an operating vehicle to collect the exhaust gas sample. The sampling probe design should facilitate sampling at the inlet of the sampling probe without touching the wall of the exhaust tail pipe.

Independently of the tailpipe shape, size, and wall thickness the sampling probe should be securely locked at the tailpipe and the user should be able to take samples in a depth of at least 0,05 m;

- A sampling line to transport the sample to the instrument (optional);
- A sample-preconditioning device to dilute high particle concentration by a constant dilution factor and/or to remove volatile particles of the sample (optional);
- Detection device(s) to measure the PN concentration of the gas sample; it is permissible that the particle detector also pre-conditions the gas;
- Device(s) to convey the gases through the instrument. In case the particles pass through such filter(s) before the detection device, the counting efficiency criteria according to this guidance must still be met;
- Device(s) to prevent water condensation from forming in the sampling line and in the instrument; alternatively, this can be also achieved by heating at a higher temperature and/or diluting the sample or oxidizing the (semi)volatile species;
- Filter(s) to remove particles that could cause contamination of various sensitive parts of the PN-PTI instrument or to provide clean air for the zero-setting or zero-check procedure. In case the particles pass through such filter(s) before the detection device, the counting efficiency criteria according to this guidance must still be met;
- Ports for in-field verification to introduce ambient air and reference particle samples when required by the technology used;
- A software to process the signal including an indicating device to display the results of a measurement and a logging device to capture and store data;
- 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.

Inscription

As required by the Directive 2014/32/EU (Annex I), the PN-PTI instrument must have a permanent, non-transferrable, and easily readable label or labels. The label(s) are required to include the following information:

i. Manufacturer's name, registered trade name or registered trade mark;
ii. Year of manufacture;
iii. Number of the type examination certificate;
iv. Identity marking;
v. Details of the electrical power:
    a. In case of mains power: the nominal mains voltage, frequency and power required,
    b. In case of power by a road vehicle battery: the nominal battery voltage and power required,
    c. In case of internal removable battery: the type and nominal voltage of the battery;
vi. The minimum and (if applicable) the nominal flow rate;

vii. Measuring range;
viii. Temperature, pressure, and humidity operation range;

For PN-PTI instruments with software-controlled metrological functions, the identification of the legally relevant software is required to be either included at the label or to be displayable on the indicating device.

If the dimensions of the instrument do not allow including all inscriptions, then they should be included in the manual of the instrument. It is also recommended to include the storage ambient conditions range (temperature, pressure, humidity).

An additional label should indicate the date of the last verification of the PN-PTI instrument.

Operating instructions

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

- Unambiguous instructions for installation, maintenance, repairs and permissible adjustments;
- The time intervals and the procedures for maintenance, adjustment and verification that are followed in order to comply with the maximum permissible errors;
- A description of the clean air and/or leak test procedure;
- If applicable, the “zero level” determination procedure;
- Ambient air or high PN concentration measurement procedure (optionally);
- The maximum and minimum storage temperatures;
- The ambient temperature range;
- A statement of the rated operating conditions (see below) and other relevant mechanical and electromagnetic environmental conditions;
- If applicable, details about compatibility with ancillary equipment;
- Any specific operating conditions, for example a limitation of the length of signal or data;
- If applicable, the specifications of the battery;
- A list of error messages with explanations.

4. Metrological requirements

Indication of the measurement result

The instrument should ensure that: The PN per volume is expressed as number of particles per cm^3. The inscriptions for this unit are assigned unambiguously to the indication; “#/cm^3”, “cm^{-3}”, “particles/cm^3”, “1/cm^3” are allowed. The PN concentration refers to the ambient conditions prevailing during the individual measurement.

Measuring range

The instrument should ensure that: The minimum measuring range, that may be subdivided, is from the PN-PTI limit value divided by 20 (maximum value for lower range) to twice the PN-PTI limit value (minimum value for the upper range). The exceedance of the range is indicated (visibly) by the instrument (e.g. warning message or flashing number). The "Measuring range" is declared by the PN-PTI instrument manufacturer and fulfils the minimum range defined in this paragraph. It is recommended, that the PN-PTI instrument display range is wider than the measuring range and specifically up to at least five times the PN-PTI limit value.

Resolution of the displaying device (for digital indicating instruments only)

The instrument should ensure that: Particle number concentrations as measurement results are legible, clear and unambiguously shown with the unit and are unequivocally as such to the user. Digital figures are at least 5 mm high. The least significant figure of the display provides a minimum resolution of 1 000 1/cm^3. If required by the NMi, during type examination/initial verification/subsequent verification a minimum resolution of 100 1/cm^3 below 50 000 1/cm^3 is available.

Response time

The instrument should ensure that: For measuring PN concentration, the PN-PTI instrument including the sampling line and sample preconditioning device indicates 95% of the final value within 15 s after changing from HEPA filtered or ambient air. Optionally, this test may be performed with two different PN concentrations. The PN-PTI instrument may be provided with a logging device to check this requirement.

Warm-up time

The instrument should ensure that: After the warm-up time, the PN-PTI instrument meets the metrological requirements indicated in this section. The instrument does not indicate the measured PN concentration during the warm-up time.

Maximum permissible measurement error (MPE)

- Reference conditions: 25% or the applicable PN limit divided by 40 (absolute value), whichever is greater.
- Rated operating conditions: 50% or the applicable PN limit divided by 20 (absolute value), whichever is greater.
- Disturbances: 50% or the applicable PN limit divided by 20 (absolute value), whichever is greater.

Efficiency requirements

The counting efficiency is defined as the ratio of the PN-PTI instrument and the reference instrument (or system) readings, both normalized to the same conditions. The whole PN-PTI instrument (i.e. including the sampling probe and sampling line, if any) should fulfil the counting efficiency requirements listed in Table 1. At the request of a manufacturer, the PN-

PTI instrument counting efficiencies may be tested in separate parts at representative conditions inside the instrument. In this case the efficiency of the whole PN-PTI instrument (i.e. multiplication of efficiencies of all parts) fulfils the counting efficiency requirements listed in Table 1. If any internal calibration factor is included, it must remain the same (fixed) for all tests described in this paragraph.

Table 1. PN-PTI instrument efficiency requirements

	Particle size [nm]	Counting efficiency [-]
Required	23 +/- 5 %	0,2-0,6
Optional	30 +/- 5 %	0,3-1,2
Required	50 +/- 5 %	0,6-1,3
Required	70 or 80 +/- 5 %	0,7-1,3
Optional	100 +/- 5 %	0,7-1,3
Optional	200 +/- 10 %	0,5-3,0

Regarding the testing methodology, it should be ensured that: The counting efficiency is determined with monodisperse particles with sizes defined in Table 1 or with polydisperse particles with geometric mean diameter (GMD) defined in Table 1 and geometric standard deviation (GSD) lower or equal to 1,6 determined with a scanning mobility particle sizer (SMPS). Counting efficiency tests are performed under reference conditions (see below). The material is thermally stable and soot-like. If needed, any neutralization and/or drying of the generated particles takes place before the splitter to the reference and test instrument(s). In case of monodisperse particles testing, the correction for multiple charged particles that exit the Differential Mobility Analyzer (DMA) that is used for size selection is not higher than 10% (and is reported). The concentration of the particles used for the counting efficiency determination is in the measuring range. The reference instrument is a traceable faraday cup electrometer or a traceable Condensation Particle Counter (CPC) with cut-off size $d_{50} \leq 10$ nm (combined with a traceable diluter if necessary for polydisperse particles). The expanded uncertainty of the reference system, including the diluter if applicable, is less than 12,5%.

Linearity requirements

Regarding the linearity testing, it should be ensured that: The whole PN-PTI instrument is tested for its linearity with polydisperse particles with GMD 70 +/- 10 nm and GSD lower or equal to 1,6 determined with a SMPS. The material is thermally stable and soot-like. The reference instrument is a traceable CPC with cut-off size d50 ≤ 10 nm. The reference instrument may be accompanied by a traceable diluter in order to measure high concentrations, but the entire reference system (diluter + CPC) expanded uncertainty remains below 12,5%. The linearity tests are done with at least 9 different concentrations within the measuring range and the MPE at reference conditions is respected. Table 2 presents the linearity requirements.

Table 2. Linearity requirements of PN-PTI instruments

Control (Location)	Reference	Minimum number of concentrations	Maximum Permissible Error (MPE)
Type examination (NMi)	Traceable CPC with a traceable diluter	9	Reference conditions

The applicable PN limit (+/- 10%), twice the PN limit (+/- 10%) and the point where the MPE changes from absolute to relative (+/- 10%) is required to be tested during the type examination linearity test. At least one concentration should be between the limit and the maximum concentration as well as at least 4 concentrations distributed equally between the point where the MPE changes from absolute to relative and the PN limit. The PN concentrations for linearity check are presented in Table 3.

Table 3. PN concentrations for linearity check of PN-PTI instruments

	Type examination	Initial verification	Subsequent verification
Limit/10	Required		
Limit/5	Indicative	Required	Required
Limit/2,5	Indicative		
Limit/1,67	Indicative	Indicative	
Limit/1,25	Indicative		
Limit	Required	Required	Required
Limit*1,2	Indicative		
Limit*1,6	Indicative	Indicative	
Limit*2	Required	Required	Required

If the device is tested in parts, then the linearity check may be limited to the particle detector, but the efficiencies of the rest parts should be taken into account.

Zero-level

The zero point is tested with a HEPA filter. “Zero level” is defined as the average signal of the PN-PTI instrument with a HEPA filter at its inlet over a period of 15 s after a stabilization period of at least 15 s. The maximum permissible zero level is 5 000 1/cm^3.

Volatile removal efficiency

Regarding the volatile removal efficiency testing, it should be ensured that: The system achieves > 95 % removal efficiency of tetracontane ($C_{40}H_{82}$) particles with electrical mobility size 30 +/- 5 % and with concentration between 10 000 and 20 000 1/cm^3. Size selection is

done with a DMA and if needed, any neutralization of the tetracontane particles takes place before the splitter to the reference and test instrument(s). The reference system fulfils the same requirements as the reference systems used for type examination counting efficiency tests.

Alternatively, polydisperse tetracontane particles may be used with GMD between 30 and 35 nm and total concentration between 50 000 and 100 000 1/cm^3. The reference system fulfils the same requirements as the reference systems used for type examination linearity tests. The GMD of polydisperse particles should be determined with a SMPS.

Volatile removal efficiency tests with larger tetracontane particle size (monodisperse) or GMD (polydisperse) and/or higher tetracontane concentrations than those described in this paragraph may be accepted only if the PN-PTI instrument passes the test (>95% removal efficiency).

Stability with time or drift

Regarding the stability of the instrument it has to be ensured that: 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, 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 an automatic zero or automatic internal adjustment, the action of these adjustments does not produce an indication that can be confused with a measurement of an external gas. The stability measurements are performed with nominal concentration of at least 100 000 1/cm^3 and the comparison to a reference instrument (same requirements as the reference system used for the type examination linearity test) is done at least every hour. It is also permitted to perform an accelerated test of 3 h with nominal concentration >10 000 000 1/cm^3.

Repeatability

Regarding the repeatability testing, it should be ensured that: 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 is not greater than one third of the MPE (reference conditions) for the relevant sample. Repeatability is tested with a nominal concentration of at least 100 000 1/cm^3. Between each measurement, HEPA filtered air flow or ambient air flow is supplied to the PN-PTI instrument.

Influence quantities

- Reference conditions

Ambient temperature	20 °C ± 2 °C
Relative humidity	50 % ± 20 %
Atmospheric pressure	Stable ambient (±10 hPa)
Mains voltage	Nominal voltage ± 5 %
Mains frequency	Nominal frequency ± 1 %

Vibration	None / negligible
Voltage of battery	Nominal voltage of the battery

- Rated operating conditions (minimum requirements)

Ambient temperature (IEC 60068-2-1, IEC 60068-2-2, IEC 60068-3-1)	From + 5 °C (test level index 2 according to OIML D11) (or less if specified by the manufacturer) to + 40 °C (test level index 1 according to OIML D11) (or more if specified by the manufacturer). When critical internal temperatures of the PN-PTI instrument are out of range then the instrument does not indicate the measured value and it indicates a warning
Relative humidity (IEC 60068-2-78, IEC 60068-3-4, IEC 60068-2-30)	Up to 85 %, no condensation (test level index 1 according to OIML D11) (use inside) Up to 95 % condensing (use outside)
Atmospheric pressure	860 hPa to 1060 hPa
Mains voltage (IEC 61000-2-1, IEC 61000-4-1)	- 15 % to + 10 % of the nominal voltage (test level index 1 according to OIML D11)
Mains frequency (IEC 61000-2-1, IEC 61000-2-2, IEC 61000-4-1)	± 2 % of the nominal frequency (test level index 1 according to OIML D11)
Voltage of the road vehicle battery (ISO 16750-2)	12 V battery: 9 V to 16 V; 24 V battery: 16 V to 32 V
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

<u>Disturbances</u>

The instrument should ensure that: Significant faults as defined in “Rated operating conditions” either do not occur or are detected and acted upon by means of checking facilities in case of the minimum requirements for disturbances described below:

Mechanical shock (IEC 60068-2-31)	Handheld: 1 fall of 1 m on each bottom edge Transportable: 1 fall of 25 mm on each bottom edge (test level index 1 according to OIML D11)
Vibration only for hand-held instruments (IEC 60068-2-47, IEC 60068-2-64, IEC 60068-3-8)	10 Hz to 150 Hz, 1,6 ms^{-2}, 0,05 m^2s^{-3}, -3 dB/octave (test level index 1 according to OIML D11)

AC mains voltage dips, short interruptions and reductions (IEC 61000-4-11, IEC 61000-6-1, IEC 61000-6-2)	0,5 cycles - reduction to 0 % 1 cycle – reduction to 0 % 25/30 (*) cycles – reduction to 70 % 250/300 (*) cycles – reduction to 0 % (*) For 50 Hz/ 60 Hz respectively (test level index 1 according to OIML D11)
Burst (transients) on AC mains (IEC 61000-4-4)	Amplitude 2 kV Repetition rate 5 kHz (test level index 3 according to OIML D11)
Burst (transients) on signal, data, and control lines (IEC 61000-4-4)	Amplitude 1 kV Repetition rate 5 kHz (test level index 3 according to OIML D11)
Surges on AC mains power lines (IEC 61000-4-5)	Line to line 1,0 kV Line to ground 2,0 kV (test level index 3 according to OIML D11)
Surges on signal, data, and control lines (IEC 61000-4-5)	Line to line 1,0 kV Line to ground 2,0 kV (test level index 3 according to OIML D11)
Electrostatic discharge (IEC 61000-4-2)	6 kV contact discharge 8 kV air discharge (test level index 3 according to OIML D11)
Radiated, radio-frequency, electromagnetic fields (IEC 61000-4-3, IEC 61000-4-20)	80 (26*) MHz up to 6 GHz, 10 V/m (test level index 3 according to OIML D11) * For an equipment under test without any cabling to apply the test, the lower frequency limit is 26 MHz.
Conducted radio-frequency fields (IEC 61000-4-6)	0,15 up to 80 MHz, 10 V (e.m.f.) (test level index 3 according to OIML D11)
Power frequency for magnetic fields (IEC 61000-4-8)	Continuous 100 A/m Short duration 1000 A/m for 1 s (test level index 5 according to OIML D11)
For instruments powered by a 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)

5. Technical requirements

Construction

The instrument should fulfil the following specifications:

- All parts from the exhaust pipe up to the particle detector, which are in contact with raw and diluted exhaust gas are made of corrosion-resistant material and do not influence the composition of the gas sample. The material of the sampling probe withstands the exhaust gas temperature;
- The PN-PTI instrument incorporates good particle sampling practises for minimization of particle losses;
- The sampling probe is so designed that it can be inserted at least 0,05 m into the exhaust tail pipe of the vehicle and be held in place by a retaining device regardless of the depth of insertion;
- The instrument either contains a device that prevents water condensation from forming in the sampling and measuring components or a detector that gives an alarm and prevents a measurement result to be indicated. Examples of devices or techniques that can prevent water condensation are: heating of sampling line or dilution with ambient air near the sampling probe;
- If an adjustment reference is needed due to the measurement technique, simple means to provide such a sample (for example a sample/adjustment/verification port) is available with the instrument;
- When a dilution unit is included in the PN-PTI instrument, the dilution factor remains constant during a measurement;
- The device conveying the exhaust gas is mounted so that its vibrations do not affect the measurements. It is allowed to switch the device on and off by the user separately from the other instrument components. However, it is not possible to make a measurement when the device is switched off. The gas handling system should be flushed automatically with ambient air before the device is switched off;
- The instrument is 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 the reference MPE. Additionally, and according to the technology used, the particle detector is equipped with temperature current/voltage or any other relevant sensors that monitor critical parameters for the operation of PN-PTI instrument in the MPE defined in this guidance;
- The sample preconditioning device (when applicable) has to be airtight to such an extent that the influence of dilution air on the measurement results is not more than zero-level or 5 000 1/cm^3;
- The instrument may be equipped with an interface permitting coupling to any peripheral device(s) or other instrument(s), as long as the metrological functions of the instrument(s) or their measurement data are not influenced by the peripheral devices, by other interconnected instruments or by disturbances acting on the interface. Functions that are performed or initiated via an interface meet the relevant requirements and conditions. If the instrument is connected to a data

printer or an external data storage device, then the data transmission from the instrument checking facility(ies) detect(s) a significant fault or a malfunction. The PN-PTI instrument interface respects the requirements of OIML D 11 and OIML D 31;
- The PN-PTI instrument has a reporting frequency equal to or greater than a frequency of 1 Hz;
- The instrument is designed according to good engineering practice to ensure that particle efficiencies are stable across the test;
- The PN-PTI instrument or the device with the relevant software permits the logging time defined by the "Measurement procedure" and reports the measurement and the test result according to the "Measurement procedure";
- The PN-PTI instrument or the device with the relevant software guides the user through the steps described in the "Measurement procedure";
- Optionally the PN-PTI instrument or the device with the relevant software may count the hours of operation in measurement mode.

Requirements for ensuring correct operation

To ensure correct operation, the following requirements should be checked:

- If the detection of one or more of the "Disturbances" is achieved by the use of automatic self-checking facilities, then it should be possible to check the correct functioning of such facilities;
- The instrument is controlled by an automatic checking facility that operates in such a way that, before a measurement can be indicated or printed, all adjustments, and all other checking facility parameters are confirmed for proper values or status (i.e. within limits);
- The following checks are integrated:
    i) The PN-PTI instrument automatically and continuously monitors relevant parameters that have a significant influence on the measuring principle used (e.g. sample volume flow, detector temperature). If intolerable deviations occur, no measured value is displayed. If the PN-PTI requires a working fluid, performing measurements is not possible if its level is not sufficient,
    ii) Memory test with clear verification of the software and function of the most important assemblies (automatically after each switch-on, then at the latest after each change of day),
    iii) A clean air or leakage test procedure to detect the specific maximum leakage (at least with each self-test, recommended before each measurement). If the measured value is larger than the zero-level or 5 000 $1/cm^3$ the instrument does not allow the user to further proceed with the measurement,
    iv) If required by the measuring principle, a zero setting procedure performed with a HEPA filter at the inlet of the PN-PTI instrument (at least with each self-test, recommended before each measurement);
- Optionally, the PN-PTI instrument may integrate an ambient air or high PN concentration measurement procedure check, performed before the clean air or

leakage test procedure, in which the PN-PTI instrument detects more particles than a predefined PN concentration;
- Instruments equipped with an automatic adjustment facility or a semi-automatic adjustment facility allow the user to make a measurement only after correct adjustments have been completed;
- Instruments equipped with a semi-automatic adjustment facility do not allow the user to make a measurement when an adjustment is required;
- A means for warning of a required adjustment may be provided for both automatic and semi-automatic adjustment facilities;
- Effective sealing devices are provided on all parts of the instrument that are not materially protected in another way against operations liable to affect the accuracy or the integrity of the instrument. This applies in particular to: (a) adjustment means; (b) software integrity (see also OIML D 31 requirements and Welmec 7.2 risk class C);
- The legally relevant software is clearly identified. The identification is displayed or printed: (a) on command, or (b) during operation, or (c) at start up for a measuring instrument that can be turned off and on again. All relevant provisions in Welmec 7.2 risk class C apply;
- Software is protected in such a way that evidence of any intervention (e.g. software updates, parameters changes) is available. All relevant provisions in Welmec 7.2 risk class C apply;
- The metrological characteristics of an instrument are not 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 (Directive 2014/32/EU, Annex I);
- A battery-operated instrument functions correctly with new or fully charged batteries of the specified type and either continue to function correctly or not indicate any values whenever the voltage is below the manufacturer's specified value. Specific voltage limits for road vehicle batteries are prescribed in rated operating conditions.

6. Metrological controls

Metrological requirements are tested in three different stages:

- Type examination
- Initial verification
- Subsequent verification

Type examination

Compliance check for "Metrological requirements" and "Technical requirements" applied to at least one PN-PTI instrument, which represents the definitive instrument type. Tests are performed by the NMi of the country of homologation or in a NMi to which national authorities delegated the PN-PTI instruments homologation.

Initial verification

Regarding the initial verification, it should be ensured that:

For each PN-PTI instrument produced, the instrument manufacturer does an “Initial verification”.

The “initial verification” includes a linearity test with polydisperse particles with GMD 70 +/- 10 nm and GSD lower or equal to 1,6 measured with a SMPS. The linearity check is performed with 5 reference PN samples. The MPE at reference conditions applies. The 5 reference PN samples concentration cover from one fifth of the limit to two times the limit (including these two concentrations, +/-10%) and also includes the limit (+/-10%) (see Table 3).

The reference system consists of a traceable particle counter with cut-off size d50 ≤ 23 nm. The particle counter may be accompanied by a traceable diluter. The expanded uncertainty of the entire reference system fulfils the same requirements as for reference systems used for type examination linearity tests.

The material used for initial verification is thermally stable and soot-like. Other materials (e.g. salt particles) may be used.

The entire experimental setup used for initial verification (particle generator and reference system), is tested by the responsible NMi and a correlation to the soot-like particles used during type examination testing is determined and expressed via a “correction factor”. The “correction factor” takes under consideration also the efficiency of the reference system. The “correction factor” of the soot-like and the other material correlation should be constant over the aforementioned concentration range (standard deviation +/- 5%) and it is recommended to be in the range 0,65 to 1,5. When the reference system or the particle generator change, a new approval by the NMI is required.

The linearity requirements during “Initial verification” are:

Control (Location)	Reference	Minimum number of concentrations	Maximum Permissible Error (MPE)
Initial verification (Manufacturer)	Traceable particle counter (optionally with a traceable diluter)	5	Reference conditions

Additional tests during the initial verification include: a visual inspection to determine conformance with the approved PN-PTI instrument type, a check of the power supply voltage and frequency at the location of use to determine compliance with the specifications on the measuring instrument’s label, leak (or zero) check (as described in the operating instructions), a zero level test (if it differs from the leak check) performed with a HEPA filter at the inlet of the PN-PTI instrument over a period of 15 s after a stabilization

period of at least 15 s (the PN-PTI instrument reading is less than the zero-level or 5 000 1/cm^3), high PN concentration test (optionally), low gas flow check by restricting the gas flow supplied to the sampling probe, response time check. Optionally, counting efficiency and repeatability tests may be performed.

Subsequent verification

Regarding the subsequent verification, it should be ensured that:

Whenever required by the instrument manufacturer, but not later than one year from the latest verification, the PN-PTI instrument is subject of a “Subsequent verification” for its accuracy. The “Subsequent verification” is a test performed with polydisperse particles at 3 different concentrations with GMD 70 +/- 10 nm and GSD lower or equal to 1,6. The MPE at rated operating conditions applies. The concentrations used for the test is one fifth of the limit, the limit, and twice the limit (concentrations within 20%) (see Table 3).

The subsequent verification test may be done either (i) in the premises of the manufacturer using the same “approved” setup for the “Initial verification” of linearity or (ii) at the place of use of the PN-PTI instrument using a portable setup.

When the subsequent verification is performed in the premises of the manufacturer using the same “approved” setup for the “initial verification” then the same correction factor.

When the subsequent verification is performed at the place of use of the PN-PTI instrument, the portable setup comprises a portable particle generator and a portable reference system (traceable particle counter and optionally a traceable diluter).

The GMD produced by the portable particle generator (if not checked at the place of use of the PN-PTI instrument and measured with a SMPS), is required to fulfil the GMD and GSD defined in this paragraph for a total of at least 3 h in 3 different days under the same conditions that will be used in the field. This test is required to be repeated at least annually.

The portable reference system fulfils the same requirements as the reference systems used for initial verification linearity tests but its expanded uncertainty may be up to 20% at a range of operating conditions.

The entire portable experimental setup used for subsequent verification (particle generator and reference system), is tested by the responsible NMi and a correlation to the soot-like particles used during type examination testing is determined and expressed via a “correction factor”. The “correction factor” takes under consideration also the efficiency of the reference system. The “correction factor” of the soot-like and the other material correlation should be constant over the aforementioned concentration range (standard deviation +/- 5%) and it is recommended to be in the range 0,65 to 1,5. When the portable reference system or the portable particle generator change, a new approval by the NMi is required.

Optionally, vehicle exhaust may be used for the subsequent verification if: (i) it is proven that the GMD is 70 +/- 10 nm and (ii) the required concentrations for linearity can be achieved.

The “Subsequent verification” test requirements are:

Control (Location)	Reference instrument	Minimum number of concentrations	Maximum Permissible Error (MPE)
Subsequent verification (Manufacturer facilities or field)	Traceable particle counter (optionally with a traceable diluter)	3	Rated operating conditions

Additional tests during the subsequent verification include: A visual inspection to determine the validity of the previous verification and the presence of all required stamps, seals and documents, leak (or zero) check (as described in the operating instructions), a zero level test (if it differs from the leak check) performed with a HEPA filter at the inlet of the PN-PTI instrument over a period of 15 s after a stabilization period of at least 15 s (the PN-PTI instrument reading is less than the zero-level or 5 000 1/cm^3), high PN concentration test (optionally), low gas flow check by restricting the gas flow supplied to the sampling probe, response time check.

7. Measurement procedure

The measurement procedure should include the following points:

- The PN concentration test determines the particles per cubic centimetre in the exhaust gases and is applied to vehicles described in “Scope”;
- The PN concentration test is conducted at low idling engine operation;
- The PN-PTI instrument is powered on for at least the warmup time indicated by the manufacturer while self-checks of the instrument (defined in “Technical requirements”) monitor the proper operation of the instrument during operation and trigger a warning or message in case of malfunction;
- Each test checks that the sampling system is in good condition, including checking the sampling hose and probe for damage;
- The probe is inserted at least 0,05 m into the outlet of the exhaust system. The sampling probe does not touch the walls of the tailpipe;
- If the exhaust system has more than one outlet, the test is done to all of them and the respective PN limit is respected at all tests. In this case, the highest measured PN concentration measured at different exhaust system outlets is considered to be the vehicle’s PN concentration;
- In case the engine of a vehicle is not switched on during idling then the start/stop system is deactivated by the test operator. For plug-in hybrid vehicles, the thermal engine is required to be switched on;

- The vehicle is not tested during regeneration of the DPF. This may be checked by the OBD;
- The software of the particle counter automatically guides the instrument operator through the measurement procedure;
- Before the start of a measurement, the following data is registered:
  a. vehicle registration number,
  b. vehicle identification number,
  c. type-approved emissions level;
- After the probe has been inserted into the tailpipe, the following steps are followed for the PN-PTI test:
  a. Optionally 2-3 accelerations are performed (>2 000 rpm engine speed). It is recommended that the engine coolant temperature is >60 ^{o}C,
  b. A stabilization period of at least 15 seconds with the engine running at idle speed,
  c. After the stabilization period, the PN concentration emissions are measured. The duration of the test is at least 15 s (total measurement duration). If the measured PN concentration is more than two times the limit then the measurement may stop immediately before waiting for 15 s to elapse. The final result is the average PN concentration of the measurement duration. After the measurement and according to the result there are two different options:
     - If the average PN concentration is lower than the limit then the result of the test is the final PN concentration of the vehicle and the measurement procedure stops,
     - If the average PN concentration is higher or equal to the limit then the sampling probe of the PN-PTI instrument is removed from the tailpipe and the vehicle is conditioned for 5 minutes by performing accelerations at low idling (>2 000 rpm engine speed) or by driving for at least 5 minutes. After the conditioning, the sampling probe is placed accordingly to the tailpipe and the test is repeated. The engine coolant temperature is required to be >60 ^{o}C. The average PN concentration measured during the second measurement is the final PN concentration of the vehicle.

After the completion of the test, the PN-PTI instrument reports (and store or print) the average PN concentration of the vehicle and a “PASS” or “FAIL” message:

- if the measurement value is less than the limit, the instrument reports a “PASS” message and the test was passed;
- if the measurement value is greater than the limit, the instrument reports a “FAIL” message and the test failed.

8. PN-PTI limit

Vehicles that are subject to the PN concentration test (described in “1. Scope”) are required to respect the limit of 250 000 (1/cm^3) after being tested with a PN-PTI instrument that fulfils the requirements set out in this guidance and the procedure described under “7. Measurement procedure”. These procedures may be applied for limits up to 1 000 000 (1/cm^3).

9. List of sources

ISO standards

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

ISO 7637-2 (2011) Road vehicles – electrical disturbance from conducting and coupling – Part 2: Electrical transient conduction along supply lines only

ISO 7637-3 (2007) Road vehicles – electrical disturbance from 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

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

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

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

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

IEC 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 61000-4-1 Ed. 3.0 (2006-10), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 4: Testing measurement techniques – Section 1: Overview of IEC 61000-4 series

IEC 61000-2-2 Ed. 1.0 (1990-05), *Electromagnetic compatibility (EMC)* – Part 2: *Environment* – Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

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IEC 60068-2-47 Ed. 3.0 (2005-4), Environmental testing – Part 2: Test methods – Section 47: Mounting of specimens for vibration, impact and similar dynamic tests

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 60068-3-4 Ed. 1.0 (2003-08), Environmental testing – Part 3: Supporting documentation and guidance – Section 8: Selecting amongst vibration tests

IEC 61000-4-11 Ed. 2.0 (2004-03), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 4: Testing measurement techniques – Section 11: Voltage dips, short interruptions and voltage variations immunity tests

IEC 61000-6-1 Ed. 2.0 (2005-3), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 6: Generic standards – Section 1: Immunity for residential, commercial and light-industrial environments

IEC 61000-6-2 Ed. 2.0 (2005-01), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 6: Generic standards – Section 2: Immunity for industrial environments

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

IEC 61000-4-5 Ed. 2.0 (2005-11) Correction 1 on Ed. 2.0 (2009-10), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 4: Testing measurement techniques – Section 5: Surge immunity test

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

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

IEC 61000-4-20 Ed. 2.0 (2010-08), Basic EMC publication - Electromagnetic compatibility (EMC) – Part 4: Testing measurement techniques – Section 20: Emission and immunity testing in transverse electromagnetic (TEM) waveguides

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

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

OIML publications

OIML R 99-1 & 2 (2008) Instruments for measuring vehicle exhaust emissions

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

Other publications

DIN EN 1822-1:2019-10, Particulate air filters (EPA, HEPA and ULPA) – Part 1: Classification, performance testing, marking