

Evaluation of measuring methods for particle emissions from modern diesel vehicles in periodic emissions control

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In the scope of the research work in the second work package (WP2) of the “[ENV02 PartEmission](#)” project within the European Metrology Research Programme (EMRP), four metrological institutions (PTB, Germany, METAS, Switzerland, MIKES, Finland) and the Joint Research Center (JRC-IET) of the European Commission are going to evaluate candidate measurement devices and metrological procedures for the periodic emissions inspection of modern diesel vehicles. The EMRP is jointly funded by EMRP participating countries within EURAMET and the EU.

In a report “[Consistent requirements specified for novel measuring instruments \(prototypes\) and comparison with European legislative requirements](#)”¹, the technical requirements laid down in the European regulation, but also through national regulatory authorities for the calibration of opacimeters, were collated and reviewed in order to establish a frame of reference for the establishment of the minimum requirements for the candidate instrumentation and to provisionally define the required calibration procedures.

The requirements for the opacimeter are not included in the European Measuring Instruments Directive (MID). However, it was found that national requirements are substantially based on Directive 72/306 EEC² and ISO 11614³.

The first Directive for the introduction of exhaust gas emission testing in regular periodic inspection checks came into force in 1992⁴ intending to ensure that the emissions remain at a low level throughout the useful life of the vehicle, and to harmonize the test procedures. Recognizing that the application of the type-approval procedures for testing gaseous emissions and fumes emitted by all types of vehicles presents some difficulty, it was decided to employ simpler, quicker and less expensive procedures for roadworthiness checks. At that point, it was decided that measurement of the opacity of the diesel exhaust fumes was an adequate indicator of the condition of the vehicle’s state of maintenance, with regard to emission. It was stated though that “this Directive will be adapted from time to time to take into account developments in vehicle construction which facilitate in-service testing and in test methods which reflect more closely the actual conditions in which a vehicle is used”.

In recent years the European Commission requested a tightening of the PM emission standards at a level that would necessitate the mandatory installation of the best available technology for Diesel Particulate Filters (DPFs) in all compression ignition passenger cars⁵. Recognizing that the gravimetric procedure would not be sensitive enough to discriminate between the very efficient wall flow DPFs and flow-through particulate filters, a particle number limit was also introduced which became effective at a Euro 5b stage (9/2011) for passenger cars⁶ and at a Euro VI stage for Heavy Duty Engines⁷.

Up to now the periodic inspection and maintenance procedures, however, have not been amended to reflect the recent advances in diesel aftertreatment technology (widespread use of efficient DPFs) and the shift of the

certification procedures to the particle number limit. Current opacimeters are not sensitive enough to quantify the emission performance of DPF-equipped diesels and there are concerns about whether they will be able to identify malfunctions (e.g. cracks) of the DPF. In order to adapt the exhaust emission control to technical progress, the establishment of novel measuring instruments for periodic emission control will become necessary in the near future.

Significant progress has, however already been made in aerosol instrumentation: High-sensitivity soot emission instrumentation which significantly outperforms classical opacimeters has appeared in research applications and on the market. A European project under the acronym “*TEDDIE (TEst (D) DIEsel)*”⁸ investigated the performance of several candidate instruments. The German project “*Emission 2010*”⁹ concluded that the On-board diagnostics (OBD) does not cover all emission aspects, the reference values used during periodic emission control are too high and the new instruments working on scattering light principles are much more sensitive and precise. Furthermore, in 2010 the German Garage Equipment Organisation (ASA) launched - together with PTB - the project “*Partikeldiagnostik*” with the aim to build up know-how on particle diagnostics for periodic inspection with new measuring principles (e.g. scattered light).

Significant progress was also made in Switzerland where an alternative procedure for the inspection of the performance of DPFs installed in construction machineries¹⁰ was introduced, which is based upon particle number counting. During low and high idle constant speed, the number concentration is measured within several minutes with handheld instruments.

The various candidate instruments envisaged in the aforementioned studies operate on different principles (diffusion charging and number counting, light scattering, photoacoustic spectroscopy) and, therefore, measure different aerosol properties. Thus, the implementation of these prototypes in legal metrology requires a well-based metrological validation and comparability.

This project (ENV02WP2) will develop a metrological background for the validation of novel instruments measuring the concentration of combustion particles in exhaust gases from diesel vehicles, which can be used for the regulatory periodic emission control of vehicles. Furthermore, the capability of these instruments shall be investigated with regard to the regulated requirements.

In this project the candidate instrumentation will be assessed via comparative measurements of particle number concentration (PN) and/or the aerosol opacity. Laboratory tests will be performed over a range of particle number concentrations (10^5 to 10^8 cm^{-3}) and light extinction coefficients (0.01 m^{-1} to 3.0 m^{-1}) using a range of well-controlled particle size distributions typical for light duty diesel exhaust. This means polydisperse aerosols with a geometric mean diameter of 50 to 100 nm and a geometric standard deviation of 1.6 to 2.0. The calibration aerosol should include soot from combustion sources like the Combustion Aerosol Standard (CAST) or other.

The performance characteristics to be evaluated include measurement accuracy, sensitivity and dynamic response. All of these investigations need to be assessed for the complete system, including the necessary sampling devices. Special attention will be given to considering the effects of sample pressure or temperature on the instrument response. Furthermore, the possibility of an official verification, as required in some Member States, of the novel instruments will be evaluated.

Some candidate instruments are capable of measuring directly at the exhaust, whereas others require some kind of gas conditioning (e.g. dilution and/or thermal treatment) to remove interferences by volatile components and avoid condensation, or pressure fluctuation reduction. However, such conditioning of the exhaust may affect the accuracy, sensitivity and dynamic response of the measurements. In that respect, the candidate instrumentation to be assessed must include the conditioning devices necessary to sample directly from the vehicle tailpipe.

In order to identify candidate instrumentation to be tested within the framework of the ENV02 project, a call for interest was launched in February 2012.

Field measurements and practical usability tests with suitable instruments under required conditions are planned after the laboratory tests.

The results of this project will facilitate the implementation of novel instruments for regulatory periodic emissions control in legal metrology.

- 1 A. Mamakos, A. Jordan-Gerkens, A. Krasenbrink; Consistent requirements specified for novel measuring instruments (prototypes) and comparison with European legislative requirements, ENV02 PartEmission Report WP2 D1, February 2012; <http://www.ptb.de/emrp/partemission-publications.html>.
- 2 Council Directive 72/306/EEC of 2 August 1972 on the approximation of the laws of the Member States relating to the measures to be taken against the emission of pollutants from diesel engines for use in vehicles (OJ No L 190, 20. 8. 1972, p. 1). Last amended by Commission Directive 89/491/EEC (OJ No L 238, 15. 8. 1989, p. 43).
- 3 ISO 11614:1999. Reciprocating internal combustion compression-ignition engines -- Apparatus for measurement of the opacity and for determination of the light absorption coefficient of exhaust gas.
- 4 Council Directive 92/55/EEC of 22 June 1992 amending Directive 77/143/EEC on the approximation of the laws of the Member States relating to roadworthiness tests for motor vehicles and their trailers (exhaust emissions).
- 5 Preliminary draft proposal for a Regulation of the European Parliament and of the Council relating to emissions of atmospheric pollutants from motor vehicles (Euro 5). Document available for download at: http://ec.europa.eu/enterprise/sectors/automotive/files/pagesbackground/pollutant_emission/stakeholder_consultation/euro_5_draft_reg_en.pdf.
- 6 Commission Regulation (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:199:0001:0136:EN:PDF>
- 7 Agreement Concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be Fitted and/or be Used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals Granted on the Basis of these Prescriptions. Revision 2 Including the Amendments which Entered into Force on 16 October 1995. Addendum 48: Regulation No. 49. Revision 4.
- 8 <http://www.cita-vehicleinspection.org/Home/Publications/Studies/TEDDIE2011/tabid/458/Default.aspx>.
- 9 <http://www.vdtuev.de/presse/tuevnachrichten/sachverstaendige-fordern-verbesserungen-bei-der-diesel-au>.
- 10 Jürg Schlatter; Instruments for on-site control of particle number concentration, 2st VERT-Forum, March 25th 2011, http://www.metas.ch/metasweb/Fachbereiche/Gasanalytik/Annexes/Abgasmessger%C3%A4te_Baumaschinen/2011_VERT-Forum_METAS.pdf.

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16th ETH-Conference on Combustion Generated Nanoparticles

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Motivation:

Since 1992 exhaust gas emission testing in regular periodic inspection checks in the EU [92/55/EEC]

- ensuring low level emissions over the useful life of the vehicle
- harmonizing the test procedures
- opacity of the diesel exhaust fumes as an adequate indicator (simpler, quicker and less expensive procedure)

"This Directive will be adapted from time to time to take into account developments in vehicle construction which facilitate in-service testing and in test methods which reflect more closely the actual conditions in which a vehicle is used".

Tightening of the PM emission standards down to the particle number limit, which became effective at a Euro 5b stage ((EC) No 692/2008) for passenger cars and at a Euro VI stage for Heavy Duty Engines.

Current opacimeters are not sensitive enough to quantify the emission performance of DPF-equipped diesels and there are concerns about whether they will be able to identify malfunctions (e.g. cracks) of the DPF.

In order to adapt the exhaust emission control to technical progress, the establishment of novel measuring instruments for periodic emission control will become necessary in the near future.



Objectives:

- Metrological background for the measurement of particle concentration in exhaust gases of diesel vehicles in periodic emission control
- Validation of novel instruments provides ideas for new developments of instruments
- Support for the adaption of the periodic exhaust emission control to technical progress
- Trusted periodic emission control

Research activities:

Evaluation of measurement devices and metrological procedures for the periodic emissions inspection of modern diesel vehicles.

The various candidate instruments operate on different physical principles, therefore, measure different aerosol properties. Hence, the candidate instrumentation will be assessed via comparative measurements of the particle number concentration (PN) and/or the aerosol opacity.

Your expertise in new devices measuring particle concentration in PTI

If you are developing or have already developed such instrumentation (even as a prototype) and you are interested in participating in the measurement campaign, please get in touch with us.

(Confidentiality of instrument details will be guaranteed and results of the research project will be published as an anonymous intercomparison)

Technical requirements in European regulation

Technical requirements from national regulatory authorities

Report:

Consistent requirements specified for novel measuring instruments (prototypes) and comparison with European legislative requirements

published 03/2012 at the ENV02-website

Candidate Instrumentation Requirements

Planned activities:

Laboratory tests at METAS, MIKES and PTB:



Performance characteristics:

- measurement accuracy
- sensitivity
- dynamic response
- sample pressure or temperature effects on the instrument response will be assessed for the complete system, including necessary sampling and conditioning devices.

Calibration aerosol:

- soot aerosol from CAST or other combustion sources
- number concentrations: 10^5 to 10^8 cm^{-3}
- light extinction coefficients: 0.01 m^{-1} to 3.0 m^{-1}
- polydisperse aerosols with geometric mean diameter of 50 to 100 nm and geometric standard deviation of 1.6 to 2.0



Applicability of novel measuring instruments in field tests:

- Suitable instruments identified in the laboratory have to be tested in field measurements at JRC/IE
- User handling experience with the novel instruments under service conditions at service organisations in cooperation with PTB