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Framework for the assessment of PEMS (Portable Emissions Measurement Systems) uncertainty

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ABSTRACT

European regulation 2016/427 (the first package of the so-called Real-Driving Emissions (RDE) regulation) introduced on-road testing with Portable Emissions Measurement Systems (PEMS) to complement the chassis dynamometer laboratory (Type I) test for the type approval of light-duty vehicles in the European Union since September 2017. The Not-To-Exceed (NTE) limit for a pollutant is the Type I test limit multiplied by a conformity factor that includes a margin for the additional measurement uncertainty of PEMS relative to standard laboratory equipment. The variability of measured results related to RDE trip design, vehicle operating conditions, and data evaluation remain outside of the uncertainty margin. The margins have to be reviewed annually (recital 10 of regulation 2016/646). This paper lays out the framework used for the first review of the NO_x margin, which is also applicable to future margin reviews. Based on experimental data received from the stakeholders of the RDE technical working group in 2017, two NO_x margin scenarios of 0.24–0.43 were calculated, accounting for different assumptions of possible zero drift behaviour of the PEMS during the tests. The reduced uncertainty margin compared to the one foreseen for 2020 (0.5) reflects the technical improvement of PEMS over the past few years.

1. Introduction

Nitrogen oxides (NO_x) (especially nitrogen dioxide, NO_2) are major air pollutants due to their role as precursors of smog (WHO, 2013). They react with water to produce nitric acid, which is irritating to the eyes and respiratory tract. They can cause inflammation, respiratory diseases, decreased lung function, and increased reactions to allergens. Moreover, they contribute to the formation of secondary particulate matter (PM) and ground-level ozone. Exposure to NO_2 in ambient air led to an estimated 78.000 premature deaths across the population of 41 European countries in 2014 (EEA, 2017).

Road traffic contributes significantly to urban air pollution. The annual limit value for NO_2 continues to be exceeded across Europe, with around 10% of all the reporting stations recording concentrations above the standard in 2015 in a total of 22 of the 28 European Union (EU) countries and three other reporting countries. Almost 90% of all concentrations above this limit value were observed at traffic stations (EEA, 2017). A recent study demonstrated that vehicle exhaust has a far greater impact on concentrations of NO_2 than PM (Harrison and Beddows, 2017). Although PM concentrations have been declining the last decade due to the use of diesel particle filters, this is not true for NO_x (Harrison and Beddows, 2017).

NO_x emissions from vehicles in Europe are regulated through the Euro standards, which were first introduced in the 1990s. Since that time, the allowable limits have been progressively tightened. At the same time, the gap between NO_x measurements in laboratory tests and real-driving emissions (RDE) has been increasing for diesel vehicles. For Euro 3 diesel vehicles (limit 500 mg/km), the difference was a factor of 2, for Euro 5 (limit 180 mg/km) it increased to 3–4 (Transport and Environment, 2016; Baldino et al., 2017), whereas the first Euro 6 cars introduced between 2012 and 2015 (limit 80 mg/km) on the market were typically emitting 3–7 (Transport and Environment, 2016; Franco et al., 2014) times more NO_x than allowed. Similarly, a limited number of studies showed that Euro 5 diesel light commercial vehicles, like vans, (limit 280 mg/km) had 5–6 times higher emissions on the road (Kadijk et al., 2016). The main reasons for such discrepancies are: a) the lack of representativeness of the type approval procedure (specifically the NEDC test, a chassis dynamometer driving cycle with an artificial driving profile), and b) the use of defeat devices (i.e., illegitimate

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emission control strategies, such as "cycle detection) or "thermal window", which reduce the effectiveness of the emission control system under driving conditions not covered by the type approval procedure and which were at the centre of the diesel emissions scandal in Europe (Degraeuwe and Weiss, 2017).

The gap between official laboratory results and the actual on-road emissions led to a revision of the type approval requirements in the EU. To that end, a technical working group on RDE was set up in 2011. The work of the RDE group produced several pieces of legislation: Commission Regulation (EU) 2016/427 (first regulatory act of the RDE regulation, RDE1) (RDE1, 2016) introduced on-road testing with Portable Emissions Measurement Systems (PEMS) to complement the laboratory Type I test for the type approval of light-duty vehicles in EU. Subsequently, Commission Regulation (EU) 2016/646 (RDE2, 2016) introduced the Not-To-Exceed (NTE) limits which are the emission limits for the laboratory Type I test multiplied by a so-called conformity factor that takes into account the measurement uncertainty of the PEMS. Both regulations were consolidated in the World Harmonised Light Duty test Procedure (WLTP) Commission Regulation (EU) 2017/1151 (WLTP, 2017) and further developed by Commission Regulation (EU) 2017/1154 (RDE3, 2017), which also introduced a RDE conformity factor for the on-road test of Particle Number (PN) emissions. The fourth part of the RDE regulation introduced on-road emissions testing as part of in-service conformity checks (RDE4, 2018).

The objective of this paper is to outline the framework for the annual systematic reviews and revisions of PEMS measurement uncertainty, which determines the conformity factor. This framework can be useful for researchers conducting tests with PEMS to characterise the uncertainty of their measurements.

2. Background

According to the RDE regulations, a first-step, temporary conformity factor of 2.1 for NO_x tailpipe emissions may apply from September 2017 upon the request of the manufacturer. From January 2020, a second-step conformity factor (currently 1.5) will apply for all new type approvals. This conformity factor allows a measurement margin (currently 0.5 or 50%) solely to account for the additional uncertainty of PEMS relative to standard laboratory equipment (recital 10 of Commission Regulation 2016/646, (RDE2, 2016)). The recitals in the RDE regulations require the Commission to review annually the appropriate level of the final conformity factor in light of technical progress, a task that was undertaken by the European Commission's Joint Research Centre (JRC).

2.1. Rationale for the definition of the NO_x conformity factor

To obtain a quantitative estimate of the measurement uncertainty, JRC conducted an assessment of PEMS and laboratory equipment in 2015 (Weiss et al., 2015) based on the technical performance requirements laid down for PEMS and laboratory equipment in the RDE Commission Regulation 2016/427 (RDE1, 2016) and in UNECE regulation 83 (2015), respectively. This assessment was complemented by a scenario analysis based on emission measurements conducted with 4 vehicles with engine displacements ranging from 1.2 to 3.0 litres. The results that were presented to the RDE working group in October 2015 suggested that PEMS test might be subject to up to 30% higher measurement uncertainty than the laboratory test (i.e., an uncertainty margin of 0.3), broken down as follows: (i) 10% (margin 0.1) additional uncertainty resulting from the performance requirements for PEMS analysers, exhaust flow meter, and the vehicle speed signals. (ii) 20% (margin 0.2) additional uncertainty resulting from possible analyser drift affecting the second-by-second measurement of NO_x concentrations during an on-road test. Analyser drift is virtually negligible in the laboratory, as the NO_x concentration (and that of other pollutants) in the sampling bags is determined once at the end of a test, immediately after a calibration of the analyser, rather than over longer periods (circa 2 h) on a second-by-second basis as it is done with PEMS.

This first assessment of the PEMS uncertainty margin for NO_x was however limited to vehicles with 1.2–3.0 litres engines, and it assumed a gradual (linear) drift over the test. This meant that assuming a worst-case scenario for the drift (maximum allowable drift occurring from the beginning of the test) and taking into account the increased effect of drift (expressed in mg/km) for engines with displacement above 3.0 litres, the uncertainty margins could, in some cases, exceed those quantified initially by the JRC. Taking these observations into account, the currently established NO_x margin of 0.5 can be regarded as a conservative estimate of the additional uncertainty of NO_x emissions measured with PEMS for a very broad range of engine displacements. An annual review clause was introduced in the legislation in order to allow for further improvements and analysis.

2.2. Review activities and amendments implemented in 2016

In 2016, the European Commission organized two stakeholder meetings dedicated on the issue of uncertainty of PEMS measurements. In these meetings, PEMS manufacturers expressed their support to reduce the maximum allowable zero drift for NO_x analysers by 50% through a revision of Table 2 of Appendix 1 of Commission Regulation 2016/427 (RDE1, 2016). This table specified that the zero and span drift over a test had to be within 5 ppm and 2% of the reading, respectively. The provision used to apply individually to NO_2 and NO/NO_x measurements. As NO_x is calculated as the sum of the measured NO_2 and NO concentrations, the effective allowable NO_x zero drift was thus 10 ppm. The revised provisions in Commission Regulation 2017/1154 (RDE3, 2017) clarified that NO_x concentrations are to be determined within a zero drift of 5 ppm. The amendment thereby lowered the permissible drift for NO_x measurements by 50% compared to the original requirements in Commission Regulation 2016/427 (RDE1, 2016) (in line with the recommendations of PEMS manufacturers), which in turn provided the scope for revising the PEMS uncertainty margin for NO_x.

2.3. Review activities in 2017

The RDE regulation requires the European Commission to "keep under annual review the appropriate level of the final conformity factor in light of technical progress". To this end, "appropriate level" should be understood as the level of conformity factor that is justified by the additional measurement uncertainty of PEMS which comply with the performance requirements of the RDE regulation, relative to the laboratory equipment. The term "technical progress" should be understood as improved PEMS measurement performance achieved in real-world use, and/or prescribed by more stringent regulatory RDE requirements with regard to measurement equipment performance criteria.

The review of the PEMS measurement uncertainty therefore focused on quantifiable error sources resulting from the technical performance requirements defined in the RDE regulation (e.g. for NO_x analyser drift, accuracy of analysers and exhaust flow meters). The variability of measured results related to the RDE trip design, vehicle operating conditions, and ex-post data evaluation remained outside of the uncertainty margin and thus outside of the scope of this paper.

The 2017 review focused on the definition of the framework for the assessment of the measurement uncertainty. Experimental data from the laboratory and from on-road measurements identified areas that needed attention and further input (Giechaskiel et al., 2018).