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SELECTED PROBLEMS OF REAL DRIVING EMISSIONS MEASUREMENT

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Abstract

The article compares driving test data using the latest legislative proposals applicable to passenger cars. Real Driving Emissions procedures have been introduced in the Commission Regulation (EU) 2016/427. Currently, quantitative RDE requirements have been established to limit emissions from exhaust systems in all operating conditions in accordance with the road emission limits set out in Regulation (EC) No. 715/2007. Several measurements were performed on the same test route in accordance with the RDE test guidelines, which requires a number of criteria to be met. These criteria include the length of the measuring segments, their overall test time-share, and the dynamic characteristics of the drive. A mobile device for reading the EOBD System information was used to record the engine and vehicle operating parameters during tests. This allowed for the monitoring of parameters such as: load value, engine speed and vehicle velocity. The obtained results were then analysed for their compatibility with the RDE procedure requirements. Despite the same research route, the obtained results were not the same. The analysis also uses the two-dimensional operating time-share characteristics expressed in vehicle velocity and acceleration co-ordinates. As a result, it was possible to compare the dynamic properties, share of operating time and, consequently, to check the validity of conducted drive tests in terms of their practicability and emission values.

Keywords: *exhaust emissions, road test, real driving emissions, environmental protection*

1. Introduction

The need to reduce negative impact on the environment has become a key driving force for the sustainable industry development. This has led legislators to adopt more stringent pollutant emission standards for the automotive sector [7, 8]. The push towards this practice is still growing, as road transport is considered one of the major sources of pollution in the European Union. Currently, efforts are being made to introduce such emission testing procedures, which would extend to include the operating range of the engine used in real driving conditions. This is in contradiction to the previous testing procedures, where the exhaust emission values are measured in laboratory conditions (on chassis dynamometer for passenger cars) in the adopted type approval test [9]. Moreover, due to the global scope of production and sales of motor vehicles, there is a developing trend of type approval testing procedures unification [4, 6].

In order to allow manufacturers gradually to adapt to the RDE testing, the final quantitative RDE requirements should be introduced in two successive stages [1, 2]. In the first stage, which should come into force after 4 years from the mandatory application of the Euro 6 standard, a conformity factor of 2.1 should be used. The second stage should begin 1 year and 4 months after the first stage and should require full compliance with the NOx road emission limit value of 80 mg/km as specified in Regulations (EC) No. 715/2007 and (EC) 692/2008, plus a margin, taking into account additional measurement uncertainties resulting from the use of portable emission measurement systems (PEMS) (Tab. 1).

RDEs should cover all possible road situations, using specific driving styles for the tested vehicles to intentionally alter the results to be more positive or negative in a way that does not result from the technical characteristics of the vehicle, but from a very unusual driving style should be carefully avoided [3, 5]. Therefore, complementary boundary conditions for RDE tests are introduced to prevent such situations. Owing to their nature, driving conditions occurring during individual PEMS drive tests cannot fully correspond to the "normal conditions of vehicle operation". The emission intensity control during such tests may therefore vary.

Tab. 1. RDE testing requirements in Europe [2, 3]

2015	2016	2017	2018	2019	2020	2021	2022
Euro 6b		Euro 6c				Euro 6d	
NEDC		WLTC					
Research and concept phase		Conformity Factor (CF)					
		$CF_{NOx} = 2.1$ $CF_{PN} = 1.5$			$CF_{NOx} = 1.5$ $CF_{PN} = 1.5$		

2. Research methodology

2.1. Exhaust emission measurement

The testing apparatus is presented in Fig. 1a. A portable Semtech DS analyser was used for the measurement of the exhaust emission from vehicles (Fig. 1b). It allowed the measurements of carbon monoxide, carbon dioxide, hydrocarbons and nitrogen oxides exhaust emission. A portable AVL analyser was used to measure the particle mass, while a PMP-compliant AVL condensation particle counter was used to measure the particle number.

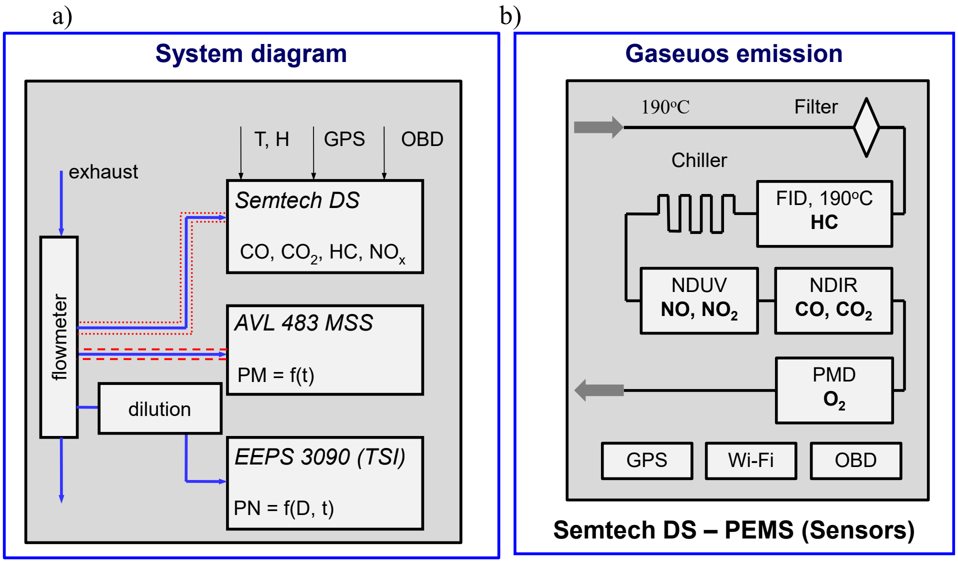

Fig. 1. The measuring systems used for testing under real driving conditions

2.2. Test route characteristics

Measurements were made 8 times conforming to the real driving conditions in urban, non-urban and motorways in the city of Poznan and its surroundings. The average distance travelled was 80.2 km. Fig. 4 shows an example route. The test route has been chosen so that it meets the requirements of the European Commission as described in the Regulation [2, 3], with particular attention paid to its topography. Tab. 3 shows the characteristics of the route in terms of terrain.

The topography analysis of the test route confirms its compliance with the test requirement of the altitude difference between the start and end points of the test to not exceed 100 m. In addition, it was possible to distinguish between urban, non-urban and motorway sections.

3. Vehicle parameter analysis

In spite of traveling on a similar route, the results obtained varied. In Fig. 2 results from all test drives are shown using the V = f(S) relationship. It shows the division of the research route into 3 portions: urban (0 km/h – 60 km/h), rural (60 km/h – 90 km/h) and motorway (90 km/h). In spite of the similar research route, both the velocity results as well as its average values in the individual test portions are not the same. The driving parameters defined by acceleration, constant velocity, braking and stopping are similar. The average values were for acceleration – 24.6%, constant driving velocity – 34.7%, braking – 23.6%, and for stationary – 16.9%.

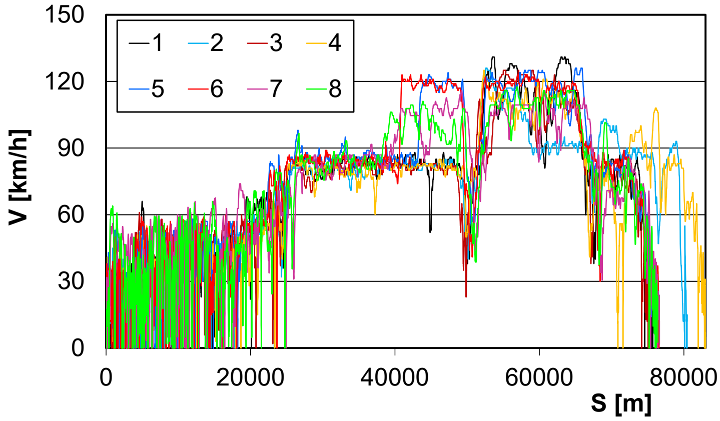

Fig. 2. Vehicle velocity for all RDE test-drives

Detailed requirements of the RDE road test standard are given below, where the verification of individual driving parameters (defined earlier) conformity has been demonstrated, and their values are compared also giving the permitted ranges (if required) and with mean values determined.

The analysis of test drive data in the urban part showed that drive No. 2 was characterized by the longest distance travelled and the drive No. 4 with the shortest. However, the values of the distance covered for all test drives were within the permissible range, i.e. they were more than 16 km long (Fig. 3a).

Analysis of the travelled distance data in the rural portion showed that drive No. 2 was characterized by the longest distance travelled and the drive No. 8 with the shortest distance. The values of the distance covered for all test drives were within the permissible range, i.e. they were more than 16 km long (Fig. 3b). The distance travelled on the motorway was the longest for the drive No. 8 and the shortest for the drive 1. The distance of the drives No. 1 and No. 3 were too small. Other drives were within the acceptable range, i.e. their distance was longer than 16 km and mean was 21.25 km (Fig. 3c).

The percentage time-share of the urban portion in the drive tests was the largest for drive No. 3, and the smallest for drive No. 2. The percentages of urban share of all drives (except for drive No. 2) were within the permissible range of 29% – 44% (Fig. 4a). The percentage time-share of the non-urban portion in the drive tests was the largest for the drive No. 1, and the lowest for the drive No. 8. Only the values obtained from the drives No. 5-8 were within the acceptable range of 23% –43%. The remaining drives did not meet this requirement (Fig. 4b). The analysis of percentage time-share data of the motorway section in the drive tests showed that the highest value was for the drive No. 8, and the smallest – for the drive No. 1. The shares of the motorway portion were within the permissible range of 23% – 43% (Fig. 4c) except for the values of drives No. 1, 3 and 4.

Analysis of the RPA dynamics data in the urban portion showed that the highest value was achieved in drive No. 8 and smallest for drive No. 2. All drives reached a value greater than the permissible value based on the average velocity in the urban part (Fig. 5a).

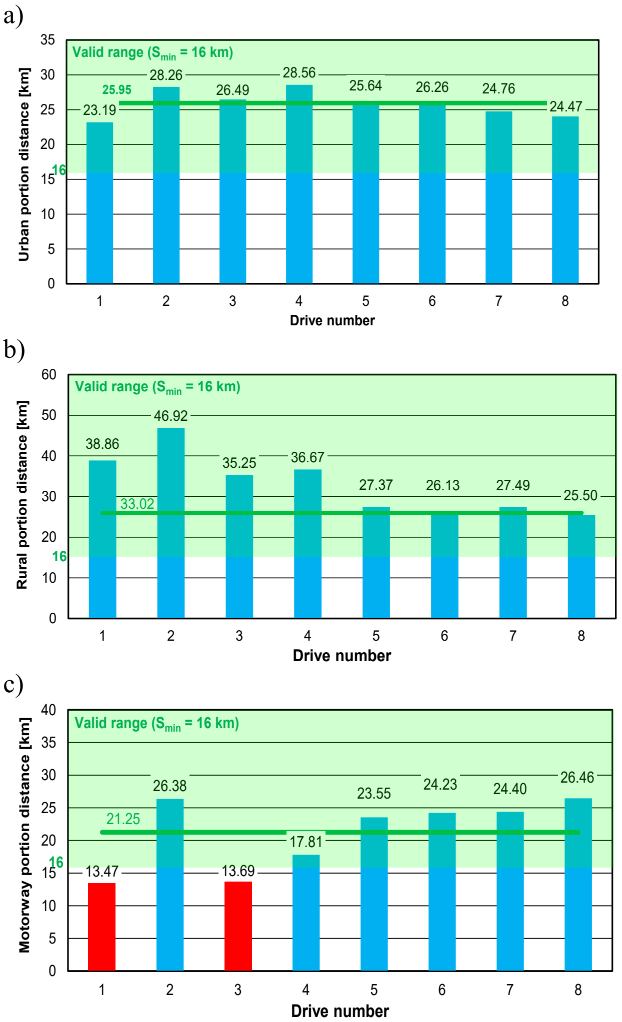

Fig. 3. Travel distance comparison of urban (a), rural (b) and motorway (c) test drives with the minimum distance (required) for all drives and the mean value

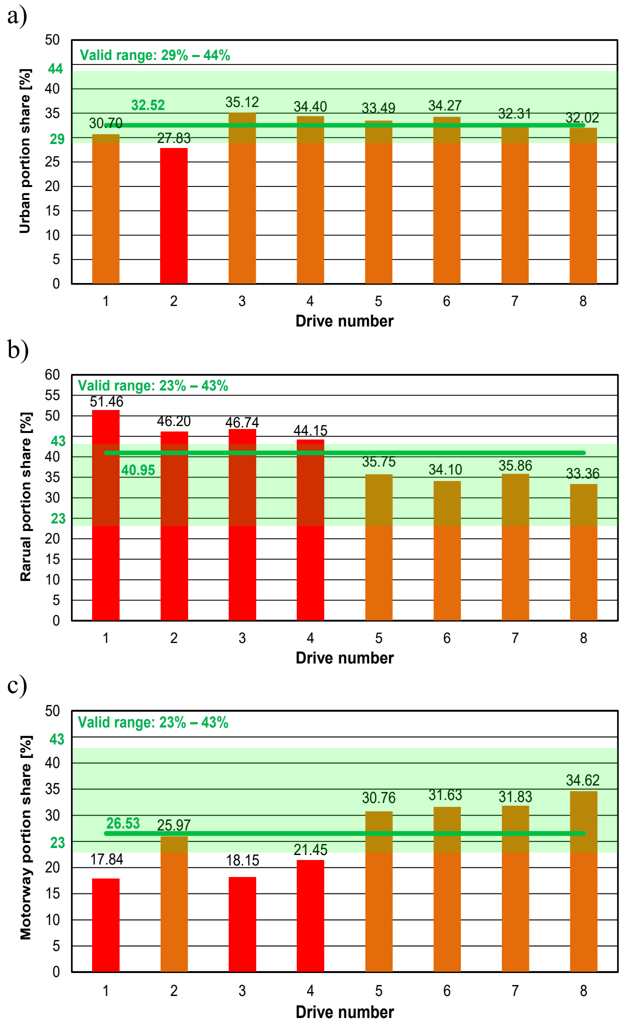

Fig. 4. Test time share comparison of urban (a), rural (b) and motorway (c) test drives with the minimum value (required) for all drives and the mean value

The analysis of the RPA dynamics data in the non-urban portion showed that the highest value was obtained in the drive No. 8 and the smallest for drive No. 3. Drives number 1-3 did not reach the minimum required value, i.e. they were invalid, as opposed to the other drives (Fig. 5b).

Analysis of the RPA dynamics data in the motorway test portion showed that the highest value was achieved in drive No. 1 and smallest in drive No. 6. All the drives reached a value greater than the minimum required value dependent on the average velocity in the motorway section (Fig. 5c).

The analysis of the 95th percentile of the product of velocity and acceleration values for the urban portion of the test showed that the value was highest for the 8th and the smallest for the 2nd drive. The values for all the drives were within the acceptable range, i.e. they were less than the maximum determined based on the average velocity in the urban part (Fig. 6a).

The analysis of the data for the 95th percentile of the product of velocity and acceleration in the non-urban portion of the test showed that the value was the highest for drive No. 6 and the lowest for drive No. 2. The values of all drives were within the acceptable range, based on the average velocity in the non-urban part (Fig. 6b).

The analysis of the data for the 95th percentile of the product of velocity and acceleration in the motorway portion of the test showed that the value was the highest for drive No. 6 and lowest for drive No. 7. The value of all drives was within the acceptable range, i.e. they did not exceed the maximum value, determined by the average velocity in the motorway section (Fig. 6c).

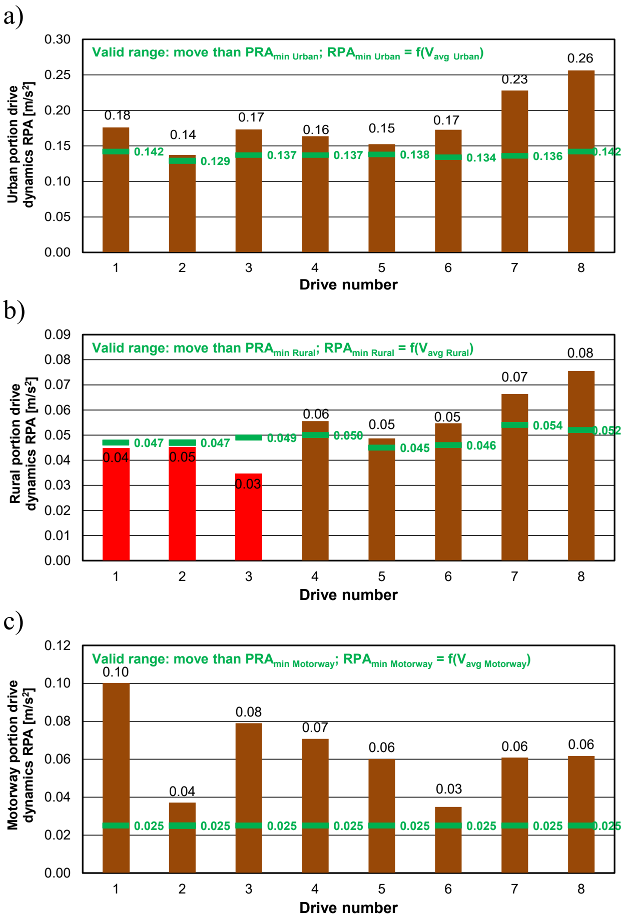

Fig. 5. Relative positive acceleration comparison of urban (a), rural (b) and motorway (c) test drives with the minimum value (required) for all drives and the mean value

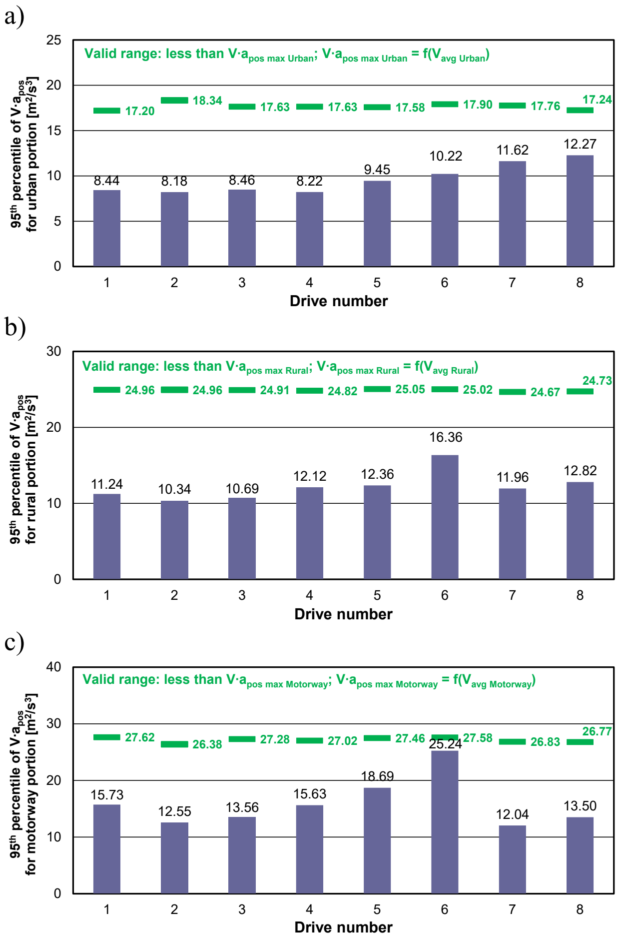

Fig. 6. Vehicle velocity and acceleration product 95th percentile comparison of urban (a), rural (b) and motorway (c) test drives with the maximum limit value (required) for all drives

From the data presented in the Fig. 5-8 it can be seen that the drives 1–4 only slightly differ from the guidelines for which the test should meet all requirements. In these cases, as non-compliant (the drives that fail to meet the criteria are shown on the graph in red) the following parameters can be listed: too short distance travelled on the motorway (drives No. 1 and 3), urban drive share too small (drive No. 2), too large share of the non-urban drive portion (drives No. 1, 2, 3 and 4), too small share of the motorway drive portion (drives No. 1, 3 and 4), too much time spent stationary in the urban portion (drive No. 1), too low drive dynamics in the non-urban portion (drives No. 1, 2 and 3). Test drives, number from 5 to 8, meet all the requirements of the RDE procedure. In the remainder of the article, the practicability study of the tests was performed based on the presented results for all drives, with only selected ones being presented.

4. Exhaust emission results

Previous studies with simultaneous emission measurement were used to determine the distance emission of pollutants. Due to the fact that the study was carried out for a passenger vehicle equipped with a Euro 6b gasoline engine (without a particulate filter – GPF), the emission values of carbon dioxide, carbon monoxide, hydrocarbons, nitrogen oxides and particle number were measured (Fig. 7). The results were presented for all eight test drives, indicating that the first four drives did not meet the formal requirements (marked in red), although this fact was not a disqualifying factor for determining the road emission value. The disqualified drives were marked in red, whereas the range of values found in the acceptable drives (for drives No. 5-8) was marked in green. The road emission limits shown in Fig. 8, labelled Euro 6d-Temp, refer to future emission standards (to be adopted starting from 1.09.2017), where the road emission limit values are set as follows: for nitrogen oxides at 2.1, for particle number at 1.5 relative to the Euro 6b road emission limits. The analysis of the individual emission values of pollutants indicates a similar character of the obtained test data, which is discussed below.

The maximum value of carbon monoxide road emission (Fig. 7a) for the valid drives was 356 mg/km (drive No. 8) and the smallest was 264 mg/km (drive No. 6). Test drive number 6 was characterized by a small RPA value, even relative to other valid drives. The road emission values in all the performed test drives did not exceed the Euro 6b limit values for passenger vehicles equipped with petrol engines (1000 mg/km). The extreme hydrocarbons road emission values (Fig. 7b) were obtained for the same drives as the ones for the road emission of nitrogen oxides. The maximum value was 41.5 mg/km (drive No. 8) and the minimum was 34.6 mg/km (drive No. 6). The quoted values did not exceed the Euro 6b road emission limit of 100 mg/km. The road emission of nitrogen oxides (Fig. 7c) varied between 39.7 mg/km (drive No. 5) and 44.9 mg/km (drive No. 8) for the valid drives. The road emission value did not exceed the road emission limit, i.e. 60 mg/km, for any of the drives. The nature of the particle number was similar to the previous results (Fig. 7d): the highest value was obtained for drive number 8 (4.3×10^{12} 1/km), and the lowest for drive number 6 (2.5×10^{12} 1/km).

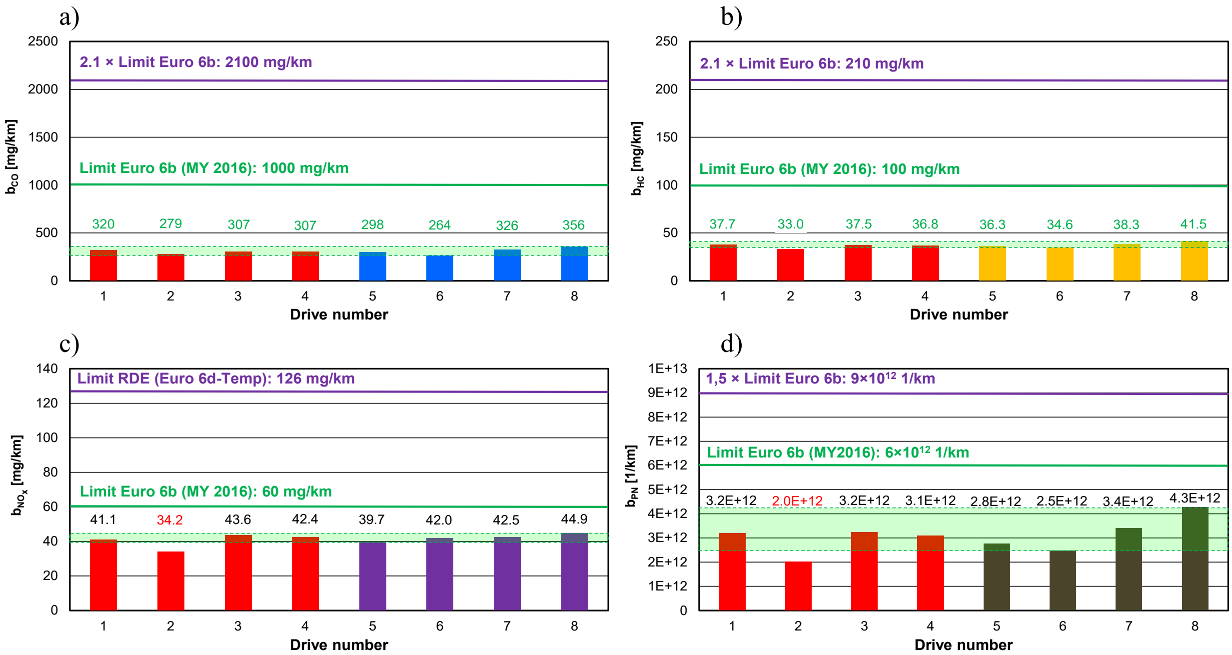

Fig. 7. Distance emission results for: a) CO, b) HC, c) NOx, and d) PN for all drives; the invalid drives are shown in red, while the range of parameter value changes from valid drives (No. 5-8) are shown in green

In order to compare the road emission change ranges for the individual exhaust gas components, a relative error of the calculated emission was determined for each component, in each drive, described by the equation:

$$\Delta b_j = \frac{b_{j,avg(5-8)} - b_j}{b_j}, \qquad (1)$$

where:
$b_{j,avg(5\text{-}8)}$ – average road emission value from the drives numbered 5-8,
b_j – specific road emission value of the given substance.

An analysis of the individual relative error values allows the following observations to be made: The relative error value for carbon monoxide road emission between individual drives does not exceed 15% (Fig. 8a); all drives were within this range (also the non-RDE compliant). In this case, the highest values of relative error (extreme values, of 14.5% and - 15%) were obtained for the valid RDE test drives. The relative error of carbon monoxide road emission for the invalid test drives was lower than that of the valid tests, i.e. the carbon monoxide road emission measured during non-RDE compliant tests were mostly close to each other – as opposed to the values obtained in the tests that were in line with the RDE test procedure requirements. Hydrocarbons road emission relative error values had a similar character as the values obtained for carbon monoxide (Fig. 8b); all drives – except for drive No. 2 again – were in the relative error range of ±10%, regardless of whether they were valid drives or not. The relative error value of the nitrogen oxide distance emission did not exceed 6% between individual drives (Fig. 8c); all drives were within this range – except for drive No. 2 (not meeting the requirements of the RDE test procedure), whose result was about 20% less than the average value of the average drive. At the same time, there is no clear trend in relative error values for the invalid drives. The nature of the relative error of the particle number confirms the previous results; the relative error between each valid drive is the greatest among all measured emissions and exceeds more than 30% (Fig. 8d); all drives were within that range – except for drive No. 2.

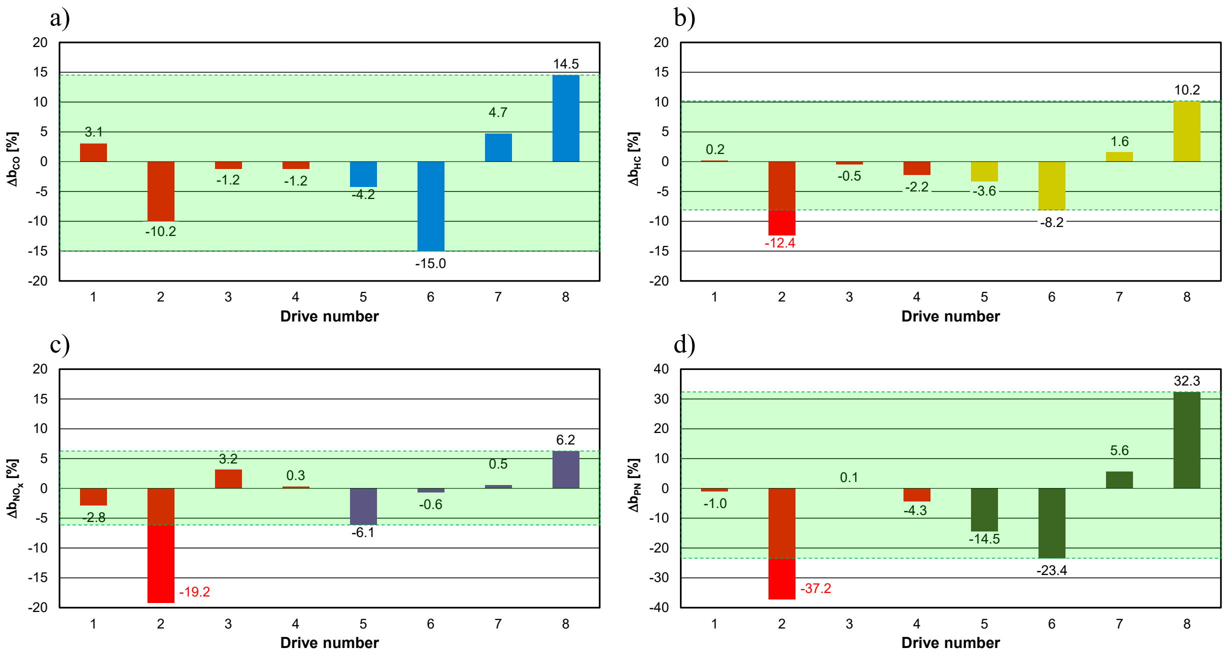

Fig. 8. Relative error for road emission of: a) CO, c) HC, d) NOx, e) PN for all drives; invalid drives are marked in red, while the range of parameter changes from the valid test drives (No. 5-8) is marked in green

5. Summary

The article compares road emission test data using the latest legislative proposals for passenger cars. The tests were carried out in accordance with the RDE guidelines for which a minimum test duration of 90 minutes – 120 minutes is required. The results obtained were analysed in terms of their compliance with the RDE procedure requirements. Despite the similar research route, both the results of the velocity profile as well as the average velocity values in each part of the test were not the same. The driving parameters defined by acceleration, constant velocity, braking and stationary were similar. In road tests, it was shown that using a similar route led to obtaining different results in each drive, although the values were fairly close. With regard to the accuracy of the measurements in real operation, it should be noted that the final result depends on the operating conditions of the vehicle. However, these conditions (such as traffic and congestion, driver's predisposition and driving style, as well as random events occurring during the drive) are unpredictable. Two-dimensional characteristics of the vehicle operating time, compiled in the vehicle velocity-acceleration coordinates, were also used in the analysis. This made it possible to compare dynamic properties, operating time-shares and, consequently, to check the validity of the test drives carried out.

The result of the study is the road pollutant emission results value range for RDE tests carried out in accordance with the European Union procedures with the following required test parameters (for vehicles equipped with gasoline engines with direct injection systems compliant with the Euro 6b norms):

- for carbon monoxide road emission – the emission value range was ±15%,
- for hydrocarbons road emission – the emission value range was ±10%,
- for nitrogen oxides road emission – the emission value range was ±6%,
- for particle number – the value range was ±32%.

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