Aspect of repeatability in Real Driving Emissions tests regarding to velocity profile

J. Matla*, L. J. Sitnik†, Z. J. Sroka†, R. M. Włostowski†

†Wrocław University of Science and Technology
Faculty of Mechanical Engineering
Department of Vehicles Engineering
ul. Wybrzeże Wyspianskiego 27
50-370 Wrocław, POLAND

*jedrzej.matla@pwr.edu.pl

Abstract. Relatively large results discrepancies observed in vehicles emission tests became a reason for change of test procedure. The New European Driving Cycle (NEDC) test was replaced by more dynamic Worldwide Harmonized Light Vehicles Test Procedure (WLTP) on September 2017, however it occurred that emissions obtained in WLTP are still far from real ones. Due to that fact a new Real Driving Emissions (RDE) test was introduced in order to complement WLTP. RDE testing involves emissions measurement while vehicle being driven in real traffic conditions which is the biggest difference from previous tests conducted on chassis dynamometer. Because of that it is suspected that repeatability of RDE tests is significantly lower than in case of WLTP or even does not have to appear. Subject of authors investigation was evaluation of RDE tests repeatability. It included portable emission measuring system (PEMS) installation on vehicle and six test runs along test route designed in accordance with European Commission requirements. Results were then compared regarding to velocity profile of vehicle. Performed analysis involved statistical distribution of velocity profiles and their kurtosis and skewness comparison. It was found that tests repeatability occurs for some velocity ranges, however it is not satisfactory. Conclusions present the concept of further research on this problem.

1. Introduction

Studies on vehicles emissions began over 60 years ago, however normalized test procedures rapid development started along with establishment of first agencies and law regulations in early seventies of twentieth century. Since then many approaches were taken in order to create universal normalized emission test. One of the first tests implemented at large scale were EPA Federal Test Procedure in United States and New European Driving Cycle in Europe. Such state of matter for decades was problematic for manufacturers who had to test their vehicles according to various regulations depending on world region. As a result the Worldwide Harmonized Light Vehicle Test Procedure was created and approved by most of countries with highly developed automotive industry [1].

Over the years NEDC was criticized mainly for its long idling time, very stable velocity changes as well as constant cruising speeds. In comparison, the WLTP incorporated higher maximal and average
speeds, longer duration and travel distance, however the most important difference was change of velocity profile (fig.1) and more accurate measurement conditions. All of those factors resulted in more realistic emissions values nonetheless still being obtained in precisely controlled laboratory conditions.

![Figure 1. NEDC and WLTP velocity profiles [2]](image)

In order to compromise WLTP results a Real Driving Emissions test was introduced. During RDE test vehicle is driven on public roads and over a wide range of constantly changing conditions such as weather, traffic or road inclination. Pollutant emissions are measured in real time by a set of analyzers fitted by a test car called PEMS. Moreover during test it is permitted to use auxiliary devices being a part of car equipment which in combination with individual driving style makes RDE test results significantly different from data obtained in WLTP [3]. Taking into account many variables as well as analyzers margin of error so called conformity factors were introduced by European Commission’s regulatory committee. Conformity factors are defined as not-to-exceed limits and their task is to correlate WLTP and RDE test results.

2. Test setup

Presented experiment being a part of wider research concentrates its interest on a velocity profiles of RDE tests repeated along pre-defined route. Due to that fact test setup consisted of a full set of portable emission measuring system mounted on a vehicle as it is presented in the figure 2. Such configuration allowed for precise record of a car velocity independently on its own instruments. Data used in presented paper came from GARMIN GPS16HVS system mounted on the vehicle’s roof and being capable to communicate with up to 12 satellites at the same time.

Test vehicle was classified as a M1 category according to European Parliament regulation [4] which makes RDE testing of it fall under LDV test procedure described in details by European Commission JRC [5]. Further requirements analysis enabled to classify it as having certain mileage thus being suitable to apply in-service conformity testing procedures. Vehicle technical condition assessment covering computer diagnostic together with its complete service history inquiry allowed to ensure minimal risk of potential failures and their effect on collected data.
3. Test route

Test course developed for the purposes of testing was created with regard to LDV on-road testing requirements of EC JRC presented in table 1. The route consisted of two loops encircling city of Wrocław and its neighbouring districts, having starting point coinciding with its finish. Total length of test course confirmed with GPS data was around 78.4 km while elevation gain being approximately 45 m.

Figure 2. Test vehicle with installed PEMS

Figure 3. Test route [6]
Table 1. General trip requirements for RDE test [7]

| Distance       | Urban        | > 16 km |
|----------------|--------------|---------|
|                | Rural        | >16 km  |
|                | Motorway     | >16 km  |
| Trip composition | Urban        | 29% to 44% of total distance |
|                | Rural        | 23% to 43% of total distance |
|                | Motorway     | 23% to 43% of total distance |
| Average speeds | Urban        | 15 to 40 km/h |
|                | Rural        | 60 to 90 km/h |
|                | Motorway     | >90 km/h (including >100 km/h for 5 min. at least) |
| Total duration | Between 90 and 120 min |

EC JRC regulations defines also additional criteria connected with driving dynamics not mentioned in table 1. According to moving average windows method called EMROAD, parameters such as acceleration points or relative positive acceleration are described by adequate formulas [8]. Due to velocity profile being the subject of presented research, mentioned parameters were not considered in further steps.

4. Software tools

Purposes of presented research required usage of various software in order to acquire and process obtained data. In order to control measuring equipment and record time course of velocity an AVL M.O.V.E. System Control application was used. It allowed for simultaneous acquisition of data from various measuring devices such as GPS and vehicle ECU during whole test, giving the operator live preview of parameters such as engine speed, ambient conditions or actual velocity.

Undoubtedly big advantage of mentioned system control application was its ability of storage data from all devices and sensors in one file. Moreover it featured also user-guided test sequences, which allowed for continuous monitoring of test conformity with RDE requirements. Thanks to that property it was possible to minimize number of invalid test runs. Software was constantly recalculating parameters such as trip duration, composition, average velocities, travelled distance and driving dynamics. Results were presented to the driver in form of table with values changing its color to green every time one of them became compliant with RDE test requirements, as it is presented in the figures 4a and 4b.

Once all test runs were finished, results were further subjected to post-processing with AVL Concerto 5 software provided together with PEMS equipment. Data channels related to time and GPS ground speed were selected and exported to ASCII format files in order to make them suitable for subsequent MS Excel calculations.
Figure 4. RDE test parameters: a) at the beginning and b) at the end of test run

5. Results and analysis

Obtained results consisted of vehicle GPS ground speed sampled every 500ms. Using simple formulas it was possible to calculate instantaneous and cumulative distance so velocity profiles of test runs could be created (see figure 5).
Figure 5. Velocity profile of RDE test no.1

Having all velocity profiles created next step was data preparation to statistical analysis. In order to do so sampling points were grouped into intervals regarding to instantaneous velocity. Each interval covered range of 10km/h excluding the highest value. For example an interval denoted as “10” was mathematically described as <0,10) etc. As a result graph of velocity distribution for each test was created as it is presented in the figure 6.

Figure 6. Velocity distribution graph
At this point it was observed that intervals “100” and “140” exhibited relatively low frequencies for all test runs, while in case of others ex. interval “10” or “50” it was hard to recognize results repeatability. In order to investigate results correlation all test runs were subjected to more detailed statistical analysis, which results were demonstrated in table 2.

**Table 2.** Statistics of RDE test runs

| Parameter                              | Test 1     | Test 2     | Test 3     | Test 4     | Test 5     | Test 6     |
|----------------------------------------|------------|------------|------------|------------|------------|------------|
| Average velocity [km/h]               | 48.830     | 48.116     | 48.305     | 47.635     | 41.396     | 50.371     |
| Standard error of the mean            | 0.320      | 0.330      | 0.341      | 0.326      | 0.300      | 0.319      |
| Median                                 | 45.900     | 45.400     | 45.200     | 43.750     | 39.000     | 47.100     |
| Population standard deviation          | 34.392     | 35.788     | 36.844     | 35.545     | 35.048     | 33.760     |
| Population variance                    | 1182.821   | 1280.810   | 1357.503   | 1263.423   | 1228.382   | 1139.760   |
| Kurtosis                               | -0.494     | -0.353     | -0.571     | -0.533     | -0.296     | -0.497     |
| Skewness                               | 0.405      | 0.520      | 0.484      | 0.481      | 0.671      | 0.333      |
| Range                                  | 132.600    | 139.900    | 136.800    | 133.000    | 131.100    | 131.800    |
| Minimum                                | 0          | 0          | 0          | 0          | 0          | 0          |
| Maximum                                | 132.600    | 139.900    | 136.800    | 133.000    | 131.100    | 131.800    |
| Count                                  | 11565      | 11739      | 11687      | 11852      | 13658      | 11206      |
| Confidence (95.0%)                      | 0.627      | 0.647      | 0.668      | 0.640      | 0.588      | 0.625      |

Further statistical parameters assessment enabled to indicate rather minor differences between tests except for test no.5. At first glance difference in average velocity being lower than other tests was recognized. Later on it was found that other parameters departing significantly from the rest were kurtosis, skewness and confidence level. Worth mentioning is fact that at the same time standard deviation remained at comparable level (see figure 7).

![Figure 7. Selected test runs parameters](image-url)
In the last step it was checked how neglection of test no. 5 will affect overall data repeatability. For this purpose distribution of skewness and kurtosis for all tests was investigated as parameters characterizing statistical distribution. Results were presented in table 3, where dataset 1 stands for all 6 tests and dataset 2 excludes test no. 5.

**Table 3. Influence of test no.5 neglection on data variation**

| Parameter                      | Dataset 1 | Dataset 2 | Dataset 1 | Dataset 2 |
|-------------------------------|-----------|-----------|-----------|-----------|
| Average                       | -0.457    | -0.490    | 0.482     | 0.445     |
| Standard error of the mean    | 0.044     | 0.037     | 0.047     | 0.034     |
| Median                        | -0.495    | -0.497    | 0.483     | 0.481     |
| Population standard deviation | 0.108     | 0.083     | 0.114     | 0.075     |
| Population variance           | 0.012     | 0.007     | 0.013     | 0.006     |
| Kurtosis                      | -1.136    | 2.651     | 1.165     | -0.385    |
| Skewness                      | 0.787     | 1.428     | 0.607     | -0.901    |
| Range                         | 0.275     | 0.218     | 0.338     | 0.186     |
| Minimum                       | -0.571    | -0.571    | 0.333     | 0.333     |
| Maximum                       | -0.296    | -0.353    | 0.671     | 0.520     |
| Count                         | 6         | 5         | 6         | 5         |
| Confidence (95.0%)            | 0.087     | 0.072     | 0.091     | 0.066     |
| Coefficient of variation      | -0.237    | -0.169    | 0.237     | 0.169     |
| Relative standard deviation   | 100.000   | 71.296    | 100.000   | 71.139    |

6. Conclusions

Presented research focusing its interest on velocity profile investigation of RDE tests allowed for improvement in test repeatability by means of simple statistical analysis. While interpreting presented results it is important to remember that test distance and shape were assumed equal at the beginning.

Despite fact that all of six test runs were qualified by AVL System Control application as valid it occurred that it is still possible to observe differences between them. Such state of matter is caused by factors randomly varying during RDE tests however limited to some extent by regulations. Mentioned factors are connected with ambient conditions, traffic and individual driving style.

In this place authors formulated two questions in order to maximize tests repeatability: what limits of statistic parameters variations should be assumed and should the tests with significantly different velocity profiles be excluded from consideration?

Results showed that in both cases velocity profiles should be described with statistical distribution regardless of its form, due to the fact that each distribution may be described by its skewness and kurtosis. Among six conducted tests the one with extreme values of skewness and kurtosis was chosen to be neglected and then two datasets were created. First dataset consisted of all data while second one excluded results of selected test. Statistical analysis of both datasets indicated almost 30% decrease of data variation in case of dataset 2. All of that lead to conclusion that test no.5 is characterized by statistical distribution different from others.

As a result authors presented a method basing on simple preliminary calculations, which may be helpful to assess RDE tests repeatability and decide about test consideration or rejection. In order to verify and develop presented method it is required to collect more data, that is why further research covering wide range of RDE parameters are in progress.
References

[1] Regulation (EC) No 715/2007 of the European Parliament and of the Council of 20 June 2007 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

[2] https://www.fuchs.com/pt/en/company/news/news-entry/2203-differences-between-wltp-and-nedc/ accessed on 12.03.2020

[3] Marotta A, Pavlovic J, Serra S, Anagnostopoulos K, Ciuffo B, Fontaras G, Tsiakmakis S, Zacharof N 2015 A Comparison of Gaseous Emissions from Light-Duty Vehicles under the NEDC and the WLTP test procedures Transportation Research Board 94th Annual Meeting, At Washington DC, United States

[4] Regulation (EU) No 168/2013 of the European Parliament and of the Council of 15 January 2013 on the approval and market surveillance of two- or three-wheel vehicles and quadricycles

[5] Valverde Morales V, Bonnel P 2018 On-road testing with Portable Emissions Measurement Systems (PEMS) - Guidance note for light-duty vehicles, EUR 29029 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-79-77345-7

[6] https://www.google.com/maps, accessed on 6.01.2020

[7] Commission Regulation (EU) 2016/646 of 20 April 2016 amending Regulation (EC) No 692/2008 as regards emissions from light passenger and commercial vehicles (Euro 6)

[8] Commission Regulation (EU) 2018/1832 of 5 November 2018 amending Directive 2007/46/EC of the European Parliament and of the Council, Commission Regulation (EC) No 692/2008 and Commission Regulation (EU) 2017/1151 for the purpose of improving the emission type approval tests and procedures for light passenger and commercial vehicles, including those for in-service conformity and real-driving emissions and introducing devices for monitoring the consumption of fuel and electric energy

Abbreviations

ASCII – American Standard Code for Information Interchange
AVL – Anstalt für Verbrennungskraftmaschinen List
ECU – Engine Control Unit
EPA – Environmental Protection Agency
EU – European Union
GPS – Global Positioning System
ISC – In-Service Conformity
JRC – Joint Research Centre
LDV – Light Duty Vehicle
M.O.V.E. – Mobile Onboard Vehicle Evaluation
NEDC – New European Driving Cycle
PEMS – Portable Emissions Measuring System
RDE – Road Driving Emissions
WLTP – Worldwide harmonised Light-duty vehicles Test Procedure

Acknowledgements

Testing equipment used in presented research was purchased by Wroclaw University of Science and Technology as a part of “Complex GEO-3EM ENERGY ECOLOGY EDUCATION” financed by European Regional Development Fund within the Regional Operational Program of the Lower Silesian Voivodship for the years 2014-2020.
Authors are also deeply indebted to express their gratitude to Mrs Anna and Mr Leszek Leśniak for provision of test vehicle.