SIMULATION OF ROAD TRAFFIC CONDITIONS ON A CHASSIS DYNAMOMETER

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Abstract

The article presents and compares the results of exhaust emission tests in conditions of real vehicle traffic with the results obtained during bench tests on a chassis dynamometer in conditions of road traffic simulation. Laboratory tests were designed according to an algorithm approximating the actual driving sections, and when choosing their order during the test construction, a random factor was introduced. The presented approach reflects the random nature of road traffic while ensuring the representativeness of toxic emissions from the vehicle's exhaust system.
The results of measurements of carbon dioxide emission, carbon monoxide, nitrogen oxides and hydrocarbons registered in road and stationary tests were compared. Substantial agreement was found between the tests.

Keywords: drive test, exhaust emission, road tests, chassis dynamometer

1. Introduction

The conducted research consisted of experimental verification of the emission test method synthesis based on data recorded in real road traffic. Verification of the efficiency of the synthesis method was performed by measuring the emission of harmful exhaust substances using a mobile PEMS type analyzer while simultaneously recording vehicle operation parameters. Then, the tests of the intensity of harmful substances emission from the vehicle in the chassis dynamometer conditions were carried out during a direct simulation of the speed course in accordance with the course recorded in real road traffic. The results of direct simulation measurements were compared with the emission intensity measured in the conditions of the original synthetic tests.

The procedure including the method of mapping road conditions in the laboratory road test can be divided into two basic stages [1, 2, 5]. These are:

- Analysis of the standard course of speed recorded on the road, treated as a model in terms of road information. In particular, it is about separating individual sections of the

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speed course and their approximation with straight lines and using them in the reference test [3, 6, 10].

- Synthesis of the driving test on the basis of isolated approximations of velocity waveforms. In particular, a procedure for drawing lots of subsequent approximations is envisaged, while maintaining the continuity of the synthesized test and probabilistic constraints [7].

In the procedure of drawing lots and building the test, it was necessary to comply with the boundary assumptions. The beginning of the first random test section had to start at point of zero speed, and the starting point of each successively drawn one had to take place at the end point of the previous section in order to maintain the speed continuity [14,16, 17]. To obtain a full continuity of the synthesis of the test, the quantization of the obtained sections was also performed before the synthesis process. Another restriction was that the set of speed fragments from a given pool was each time reduced by the number of drawn sections of a given type, which reduced the likelihood of re-drawing a given type of fragment again. A simplified model showing the sequence of actions performed in the process of synthesizing the exemplary test is shown in Figure 1 [20, 21, 22].

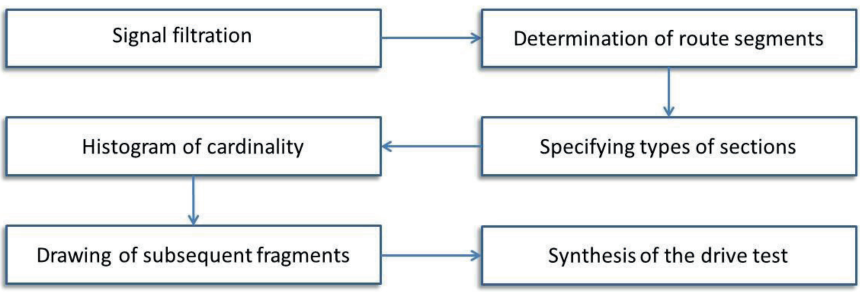

Fig. 1. Model of the driving tests synthesis procedure

2. Measuring techniques

As part of the operational tests, the following measurements were made: vehicle speed with a frequency of 1 Hz recording using a diagnostic signal reader from vehicle controllers (compliant with OBDII / EOBD standards) as well as measurements and registration of harmful gaseous compounds to which the Semtech DS analyzer with the GPS module from Sensors Inc. was used. It was a PEMS type analyzer that allows measuring the mass flow of exhaust gases and the concentration of harmful compounds such as: carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx). The device makes it possible to determine the road emission and unit and mileage fuel consumption.

The tests were aimed at determining the profile of vehicle speed and emissions of toxic substances from the exhaust system during repetitive trips in road traffic. The measurements were carried out in urban traffic conditions in Warsaw, in the afternoon hours, on the sections: "Radosław" roundabout - the Central station and the Central station - the "Radosław" roundabout. Each trip to the above the loop route was a separate registration of traffic and emission parameters. All tests were carried out on a Ford Focus passenger vehicle.

The bench part of the exhaust emission test was carried out on a 2-roller chassis dynamometer manufactured by the Jaroš company, type 2PT220EX with two rolls with a diameter of 372 mm, with electric simulation of motion resistance and mechanical simulation of inertia of the vehicle, placed in the low temperature chamber.

Emission measurements were made using a set of AMA i60 AVL analyzers.

3. Analysis of results

The following charts show the average values of the results obtained, grouped by the type of harmful substance. Each of the graphs contains the average result of the value measured in road traffic, in the direct test carried out on the chassis dynamometer according to the standard road speed, and the average result of measurements in synthetic tests, representing measured road conditions, also carried out on the chassis dynamometer [13, 18, 19].

Figure 2 presents average values and confidence intervals (at the significance level of 0.05) for road emissions of carbon dioxide, respectively on: road tests, laboratory "direct" tests on chassis dynamometer and synthetic tests.

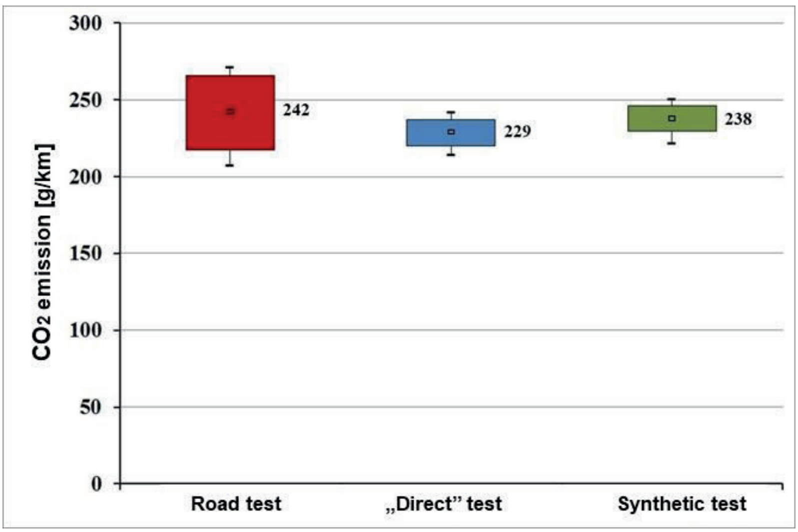

Fig. 2. Statistical comparison of carbon dioxide emissions during road tests (red), "direct" (blue), synthetic (green)

Relative differences between mean values from laboratory tests and road measurements are respectively: 5.4% for "direct" and 1.5% for synthetic tests. These are relatively small values, especially in the case of synthetic tests. This gives grounds to draw the conclusion about the overall compatibility between observations, especially road tests and synthetic tests.

The results of the statistical significance test of differences between averages confirm the above assumption. The Mann-Whitney test showed that at the significance level of 0.05 there are no grounds to reject the hypothesis about the lack of significant differences between the results of road and synthetic tests. This is the key information that authorizes us to accept the hypothesis about the compatibility of road and synthetic tests for the most important exhaust component.

There is also no statistical basis for rejecting the hypothesis that there are no significant differences between road tests and "direct" tests.

Emission of carbon monoxide

Figure 3 presents average values and confidence intervals (at the significance level of 0.05) for road emissions of carbon monoxide, respectively for: road tests, "direct" tests and synthetic tests.

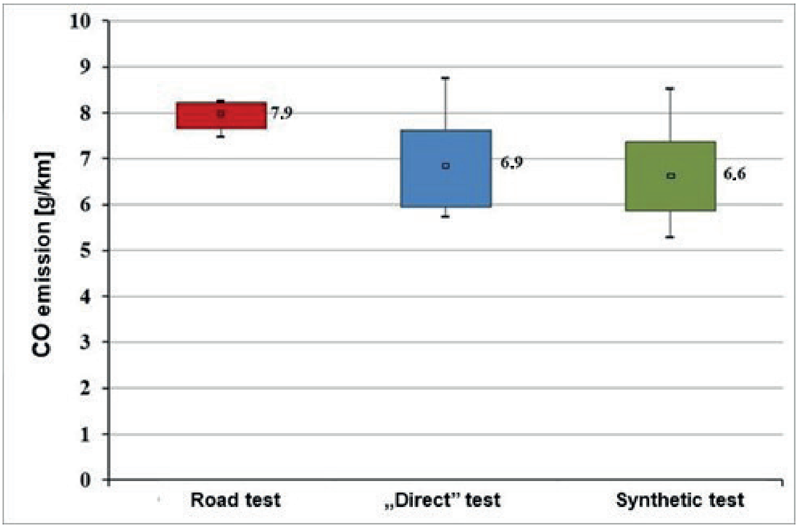

Fig. 3. Statistical comparison of carbon monoxide emissions during road tests (red), "direct" (blue), synthetic (green)

As can be seen in Figure 3 in the case of CO, observations collected during laboratory tests are markedly more diffuse than CO_2 measurements. Confidence intervals in the main part, however, overlap. Comparing the mean values, there is a clear discrepancy between road and laboratory tests and compliance in the field of laboratory tests ("direct" and synthetic).

These conclusions are also supported by the statistical significance test, which indicates the grounds for rejecting the hypothesis about the lack of significant differences between the results of road and synthetic research as well as road and "direct" tests.

Emissions of nitrogen oxides

Figure 4 presents the results of statistical comparison (at the significance level of 0.05) for the emission of nitrogen oxides, for: road tests, "direct" tests and synthetic tests.

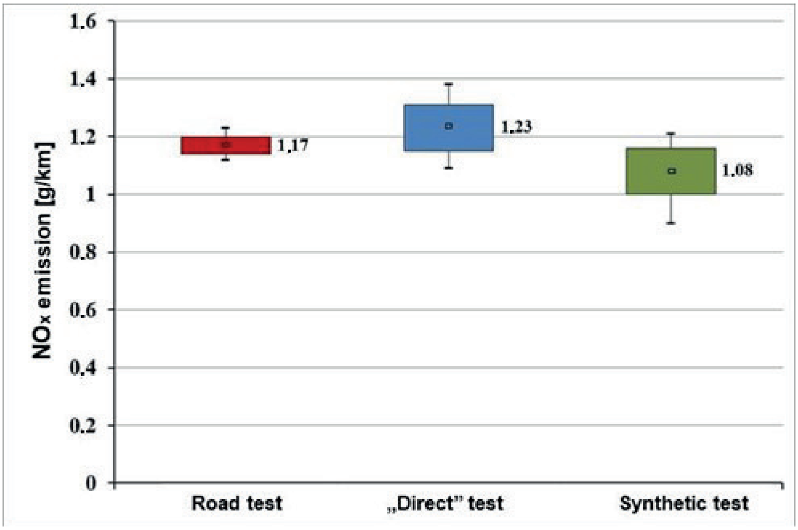

Fig. 4. Statistical comparison of emissions of nitrogen oxides during road tests (red), "direct" (blue), synthetic (green)

Confidence intervals are comparable for all three study groups. However, the comparison of average values is varied. The average emission of nitrogen oxides in the "direct" test was higher than in road tests, while in synthetic tests it was smaller than in the "direct" tests. This makes there is a difference between the mean values of the results of "direct" and synthetic tests.

This is reflected in the statistical significance test. When comparing road tests with "direct" tests and road tests with synthetic tests, the statistics values were close to critical values.

Hydrocarbon emission

Figure 5 presents the results of statistical comparison (at the significance level of 0.05) for hydrocarbon emissions, for: road tests, "direct" tests and synthetic tests, respectively.

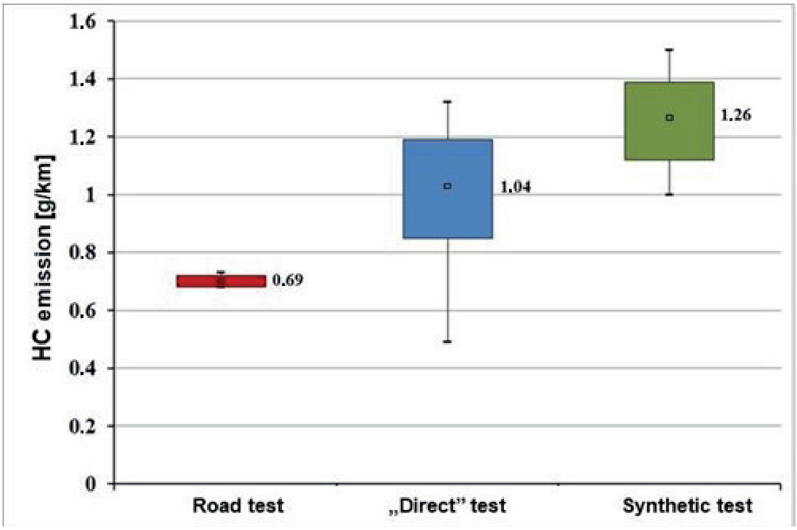

Fig. 5. Statistical comparison of hydrocarbon road emissions during the implementation of individual road tests (red), "direct" (blue), synthetic (green)

Figure 5 shows differences between the results of road and laboratory tests and between "direct" and synthetic laboratory tests. These observations are also confirmed by the Mann-Whitney statistical significance tests. For all sets pairs, the test statistic values overlap with the critical area, so there are grounds for rejecting the hypothesis that there are no significant differences between the considered observation groups. The values of test stats corresponding to the comparison between road and laboratory tests are far from critical values, which means that the error of rejecting an erroneous hypothesis of no significant differences is clearly lower.

For clarification, attention should be paid to the various properties of exhaust gas analyzers used during road tests and laboratory tests. In the case of road tests, a PEMS mobile measuring device equipped with infrared radiation was used, which is relatively inaccurate when measuring the emission of carbon particles. However, in the case of laboratory tests, an FID type analyzer was used, which is highly accurate in the measurement of carbon compounds. As a result, the recorded road values of hydrocarbon emission intensity are proportionally lower than the values recorded in laboratory tests [4, 8, 9].

4. Conclusions

A series of researches were made on the designated route in real traffic, registering the operating parameters of the test vehicle and exhaust emissions using a mobile analyzer. The car was then placed in a laboratory bench and exhaust emissions measured using stationary analyzers. The driving tests were programmed according to the actual course of the car's operating speed (the so-called "direct" tests) and "synthetic tests". Significant agreement was found between road and synthetic studies. In the case of measuring the average emission of carbon dioxide, constituting the most important determinant of the operation parameters of the internal combustion engine in synthetic tests, results were obtained that differ by no more than 2.5% compared to road tests. Therefore, they confirm the high reproduction accuracy. The average road emissions of the measured harmful exhaust components on the chassis dynamometer in synthetic tests were in line with the results of the direct tests.

Based on the results of the statistical analysis, the consistency between synthetic tests and road tests was confirmed. Only in the case of carbon monoxide, small differences in road and stationary emission tests were found. Their cause was the use of other measuring equipment on the road and in the laboratory.

The application of the developed method allowing simulation of road traffic conditions in laboratory, allows to verify the fundamental discrepancies in the value of emissions from vehicles that often exist between manufacturer's declarations and the results of tests on a chassis dynamometer. It also allows to determine the road emission in the conditions of traffic simulation of vehicle in the laboratory [11, 12, 15].

5. Nomenclature

CO	carbon monoxide
CO_2	carbon dioxide
FID	flame ionization detector
HC	hydro carbons
NOX	nitrogen oxides
OBD	on-board diagnostic
PEMS	portable emissions measurement systems

6. References

[1]. Andersson J., May J., Favre C., Bosteels D., Vries S., Heaney M., Keenan M., Mansell J.: On-Road and Chassis Dynamometer Evaluations of Emissions from Two Euro 6 Diesel Vehicles. SAE International Journal of Fuels and Lubricants. 2014, 7, 3, 919-934, DOI: 10.4271/2014-01-2826.

[2]. Badin F., Berr F., Briki H., Dabadie J.-C., Petit M., Magand S., Condemine E.: Evaluation of EVs energy consumption influencing factors, driving conditions, auxiliaries use, driver's aggressiveness. World Electric Vehicle Symposium and Exhibition (EVS27). 6, 112-123, DOI: 10.3390/wevj6010112.

[3]. Bielaczyc P., Merkisz J., Szczotka A.: An Investigation of Cold Start and Warm-up Phases with a SI Engine for Meeting New European Emissions Regulations. PTNM, The Archives of Automotive Engineering. 1999, 1-2.

[4]. Bielaczyc P., Szczotka A., Woodburn J.: Investigations into Exhaust Particulate Emissions from Multiple Vehicle Types Running on Two Chassis Dynamometer Driving Cycles. SAE Technical Paper. 2017, DOI: 10.4271/2017-01-1007.

[5]. Bukrejewski P., Skolniak M., Kowalski Ł.: Comparison of the environmental effect of M1 category vehicles fed with traditional and alternative fuels. The Archives of Automotive Engineering. 2017, 75(1), 5-21, DOI: 10.14669/AM.VOL.75.ART1.

[6]. Chłopek Z., Biedrzycki J., Lasocki J., Wójcik P.: Examination of pollutant emissions and fuel consumption at tests simulating the real conditions of operation of a passenger car. The Archives of Automotive Engineering. 2014, 65(3), 3–18.

[7]. Chłopek Z., Strzałkowska K.: Analysis of the correlation between pollutant emissions and operation states of a compression ignition engine. The Archives of Automotive Engineering. 2014, 63(1), 3–24.

[8]. Chłopek Z., Strzałkowska K.: Research on the impact of automotive sources on the immission of specific size fractions of particulate matter in a street canyon. The Archives of Automotive Engineering. 2018, 2, 80(2), 19–35, DOI: 10.14669/AM.VOL80.ART2.

[9]. Degraeuwe B., Weiss M.: Does the New European Driving Cycle (NEDC) really fail to capture the NOX emissions of diesel cars in Europe. Environmental Pollution. 2017, 222, 234-241, DOI: 10.1016/j.envpol.2016.12.050.

[10]. Demuynck J., Favre C., Bosteels D., Hamje H.: Real-World Emissions Measurements of a Gasoline Direct Injection Vehicle without and with a Gasoline Particulate Filter. SAE Technical Paper. 2017, DOI: 10.4271/2017-01-0985.

[11]. Esteves-Booth A., T. Muneer, H. Kirby, J. Kubie, J. Hunter.: The measurement of vehicular driving cycle within the city of Edinburgh Transportation Research Part D. Transport and Environment. 2001, 6, 3, 209-220, DOI: 10.1016/S1361-9209(00)00024-9.

[12]. Fontaras G., Rexeis M., Dilara P., Hausberger, S.: The Development of a Simulation Tool for Monitoring Heavy-Duty Vehicle CO2 Emissions and Fuel Consumption in Europe. SAE Technical Paper. 2013, DOI: 10.4271/2013-24-0150.

[13]. Galgamuwa U., Perera L., Bandara.: Developing a General Methodology for Driving Cycle Construction: Comparison of Various S. Established Driving Cycles in the World to Propose a General Approach. Journal of Transportation Technologies. 2015, 5, 191-203, DOI: 10.4236/jtts.2015.54018.

[14]. Gietelink O., Ploeg J., Schutter B., Verhaegen M.: Development of advanced driver assistance systems with vehicle hardware-in-the-loop simulations. Vehicle System Dynamics. 2006, 44, 569-590, DOI: 10.1080/00423110600563338.

[15]. Hadler J., Lensch-Franzen C., Gohl M., Guhr C.: Methods for the development of a RDE-capable powertrain. MTZ Worldide - Springer. 2015, 76, 7–8, 32–37, DOI: 10.1007/s38313-015-0025-7.

[16]. Merkisz J., Pielecha J., Bielaczyc P., Woodburn J.: Analysis of Emission Factors in RDE Tests As Well as in NEDC and WLTC Chassis Dynamometer Tests. SAE Technical Paper. 2016, DOI: 10.4271/2016-01-0980.

[17]. Merkisz J., Rymaniak Ł.: Tests of urban bus specific emissions in terms of currently applicable heavy vehicles operating emission regulations. Combustion Engines. 2017, 168(1), 21–26, DOI: 10.19206/CE-2017-103.

[18]. Sileghem L., Bosteels D., May J., Favre C., Verhelst S.: Analysis of vehicle emission measurements on the new WLTC, the NEDC and the CADC, Transportation Research Part D. Transport and Environment. 2014, 32, 70-85, DOI: 10.1016/j.trd.2014.07.008.

[19]. Smit R., Ntziachristos R., Boulter L.: Validation of road vehicle and traffic emission models – A review and meta-analysis. Atmospheric Environment. 2010, 44, 2943-2953. DOI: 10.1016/j.atmosenv.2010.05.022.

[20]. Suchecki A., Nowakowski J.: Badania podczas procesu homologacji na hamowni podwoziowej i silnikowej. TS Technika Transportu Szynowego. 2015, 12, 1459-1463.

[21]. Tong H., Hung W., Cheung C.: Development of a driving cycle for Hong Kong. Atmospheric Environment. 1999, 33, 15, 2323-2335, DOI: 10.1016/S1352-2310(99)00074-6.

[22]. Wiśniowski P., Ślęzak M., Niewczas A., Szczepański T.: Method for synthesizing the laboratory exhaust emission test from car engines based on road tests. IOP Conference Series: Materials Science and Engineering. 2018, DOI: 10.1088/1757-899X/421/4/042080.