Method for synthesizing the laboratory exhaust emission test from car engines based on road tests

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The work concerns the development of emission control methods in car exhausts, in a manner consistent with operating conditions, by improving driving tests. Based on the literature study, it was demonstrated that the improvement in the representativeness (accuracy) of driving tests should be based on the appropriate introduction of a random factor in the programming of the speed of the tested vehicle. The paper presents the original method of synthesis of exhaust emission tests on a chassis dynamometer. The developed method consists in transferring to the laboratory program the driving test linearized vehicle speeds approximating the actual driving sections, the condition of continuity of the speed function is fulfilled. Thanks to meeting the conditions of continuity of synthesized sections, an important feature of the method is the possibility of random selection of the order of their implementation in the test. This corresponds to the random nature of the conditions existing in real traffic while maintaining similarity of pollutant emissions. The effectiveness of the proposed method was verified experimentally. A series of rides on a designated route in real road traffic was carried out, with registration of the operating parameters of the test vehicle and exhaust emissions using a mobile analyzer. Then the car was placed in a laboratory stand and the exhaust emissions were analyzed using stationary analyzers. The driving tests were programmed according to the actual course of the car's operating speed (so-called "direct" tests) and "synthetic tests" programmed according to the author's method. A significant convergence was found between road and laboratory tests.

1. Introduction

In the tests of dynamic operating states of the engine, carried out on a chassis dynamometer, one can distinguish two basic ways of mapping road conditions. The first of these is a faithful copy of the actual course of the momentary parameters of work (usually the speed of the car or engine crankshaft speed and the loading moment measured on the wheels of the car or on the engine crankshaft) [1]. This solution allows for relatively accurate reconstruction of road conditions. The disadvantage of this method is the lack of correlation (or weak correlation) between the particular case of engine operating conditions and the general set of conditions occurring during actual operation. Faithful copying of operational runs reduces the representativeness of the test, limiting it to the area of special cases registered as part of road tests [10].

The second method is to develop an artificially generated course of the above motion parameters [2]. This solution introduces some differences between road and laboratory operation, but allows the parameterization of the test (for example, the reference of programmed travel speeds to the maximum speed of the vehicle). The problem to be solved here is the introduction of a stochastic factor that
makes it possible to increase the representativeness of the characteristics of the drive test in relation to the overall set of road conditions in the traffic conception being considered [3, 8]. As a goal of this work, it was therefore assumed to develop a method for the synthesis of a benchmark emission test in line with actual emissions under road service conditions.

The conducted research consisted in the development and experimental verification of the method of synthesizing the emission test on the basis of data recorded in real road traffic. Verification of the effectiveness of the author's method of synthesis was made by measuring emissions of harmful substances in the flue gas using a mobile PEMS type analyzer while simultaneously recording vehicle traffic parameters. Then, the tests of the emission intensity of harmful substances from the vehicle in the chassis dynamometer conditions were carried out during a faithful simulation of the speed course in accordance with the course recorded in real road traffic. The results of the direct simulation measurements were compared with the emission intensity measured under the conditions of the original synthetic tests.

The procedure comprising the method of mapping road conditions in a laboratory road test can be divided into two basic stages.

- Analysis of the standard course.
  Analysis of the course of speed registered on the road, treated as a model in terms of information on road maintenance. In particular, it is about the separation of individual sections of the speed course and their approximation by means of straight lines and the use of isolated approximations in the reference test.
- Synthesis of the drive test.
  Synthesis of the driving test on the basis of separated approximations of the velocity waveforms. In particular, a procedure is foreseen for random successive approximations, while maintaining the continuity of the synthesized test and probabilistic constraints.

2. Test method
In the presented method of synthesizing the test, the approximated sections of the speed course, recorded during the actual road use, were used. The introduction of short approximations of real waveforms to the drive test makes the synthesized driving test contains the same traffic conditions that occurred on the road [4, 5].

The stochastic factor here is the change in the order of short sections of the mileage separated from the routes recorded on the road. The sequence of episodes in the synthesized test cannot be arbitrary. Two limiting conditions are introduced. The first is to ensure the continuity of the speed function. This means choosing the order of the speed sections so that the starting speed of each segment is equal to the final speed of the previous segment. The second limitation is the necessity to enter into the test so many episodes of the actual speed course, as is the case in road conditions.

An important element in the concept of the presented method is to determine the length of the velocity sections, which will consist of a synthesized driving test. When selecting too long sections, the stochastic features of the test will be limited, so it is advisable to use relatively short sections. As a solution, it is proposed to extract such sections that are suitable for approximation with straight lines. The time of successive segments will then be different and will range from a few to several dozen seconds. Fig. 1 shows a block diagram presenting the original method of running test synthesis.
In order to register the input data needed to develop a new bench test, tests have been carried out to determine the vehicle speed profile 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: Radom Group Zgrupowania AK - the Central Station and the Central Station - the Radom group's Zgrupowania AK. Each trip to the above loop route was a separate registration of traffic and emission parameters. The object of research was the Ford Focus Flexifuel spark-ignition engine shown in Fig. 2, produced in 2008. Technical data of the car can be found in tab. 1.

**Figure 1.** Block diagram of the test construction

**Figure 2.** Research vehicle on a measurement stand
Table 1. Technical data for Ford Focus Flexifuel

| Name                        | Data                                    |
|-----------------------------|-----------------------------------------|
| Mark                        | Ford                                    |
| Type                        | focus                                   |
| Power                       | 92 kW                                   |
| Engine stroke volume        | 1798 cm³                                |
| The layout and number of cylinders | Row, 4                              |
| Emission level              | Euro 4                                  |
| Transmission                | Manual (five forward gears, one reverse gear) |

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) and measurements and registration of harmful exhaust gas compounds to which the Semtech DS analyzer with a Sensors GPS module was used Inc. 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 (CO2), carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOx).
Registered vehicle speeds, which at a later stage were used to develop station cycles, are shown in Fig. 3.
The benchmark emission tests were carried out on a 2-cylinder chassis dynamometer produced by Jaroš company, type 2PT220EX with two rolls with a diameter of 372 mm each, with electric simulation of motion resistance and mechanical simulation of inertia placed in the low temperature chamber.

Figure 3. Running speed: a) ride No. 1, b) ride No. 2, c) ride No. 3, d) ride No. 4, e) ride No. 5
Figure 4. Ford Focus Flexifuel on the bench

The first stage of the bench tests was the reconstruction of the road speed. Fig. 5 shows an example of the course of reconstructed speeds. Coating the line of graphs indicates the correctness of the test. The results of measurements of individual toxic substances on the example of the first test are presented on Figs. 6-9.

Figure 5. The course of the vehicle speed during the first road test (red color) and four tests of the "direct" test (black color)
Figure 6. The course of the carbon dioxide emission intensity during the implementation of the 1st road test (red color) and four tests of the "direct" test (black color).

Figure 7. The course of the emission intensity of carbon monoxide during the implementation of the 1st road test (red color) and four tests of the "direct" test (black color).
The course of synthetic tests is illustrated by the block diagram shown in Fig. 1. It is worth noting that the registered vehicle speed signal contains noise, which can introduce read interference. Therefore, a low-pass filtering operation was performed. An operation involving the weave of a speed signal with a specially prepared time window was applied. The final synthesis of the speed course in the driving test consisted in generating a speed course consisting of line segments in random order. As a result, a stochastic signal was generated, in which stochastic properties result from the accidental order of arranging particular sections. Two types of bonds were imposed on the stochastic apparatus. The first of them required that the synthesized course of speed should be continuous, and the second impose the frequency of occurrence of particular types of velocity sections in the generated test, close to the frequency of their occurrence in the model run describing the road conditions. Ultimately, the draws must be made so that the initial speed of 0 km / h is ensured by drawing a segment from the set of sections with zero initial speed. The drawing of each successive episode was analogous, but another condition was met - the equality of the initial speed of each of the drawn sections with the final speed of the previously drawn episode. It is worth mentioning that every subsequent draw causes a decrease
in the size of a given set of sections in order to reduce the probability of drawing a given segment once again. After completing the test building process, the algorithm calculates the histogram of the occurrence of individual segments and compares it with the expected shape by calculating the relative error. The test synthesis procedure is repeated 100,000 times to generate a test for which the relative error is the smallest.

3. Tests results
Fig. 10 presents the speed courses resulting from the operation of the synthesis algorithm, resulting from successive draws of sections of velocity waveforms (from the same set of segments).

![Image](image_url)

**Figure 10.** Speeds in synthetic tests: a) ride No. 1, b) ride No. 2, c) ride No. 3, d) ride No. 4, e) ride No. 5
Fig. 11 presents a comparison of average values of CO2 road emissions in all completed tests. Traffic emissions in road traffic are marked in red. These are values registered using the Semtech mobile analyzer. The color values of road emission in the "direct" tests representing the real road crossings are marked in blue. Green color refers to the average road emission in the original synthetic tests. Each of the five "direct" and synthetic tests, corresponding to five passes in road conditions, was made on the chassis dynamometer three or four times, in order to ensure repeatability of results.

![Graph](image)

**Figure 11.** Carbon dioxide road emission during road tests (red), 'direct' (blue), synthetic (green) dynamometer

4. Conclusions
The results of carbon dioxide road emissions as the component most credibly reflecting the emission of individual trips are presented. The amount of separated carbon dioxide is directly proportional to the amount of fuel consumed by the car engine [6, 7, 9].

Tests built using the synthetic method were verified against road tests. Statistical significance tests were performed. They showed high convergence of results, meeting the assumed test accuracy criteria. It can therefore be concluded that the developed method of synthesizing laboratory tests based on road traffic tests, including the random factor, meets the criteria of emission representativeness between particular cycles.

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