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THE PARAMETERS OF PASSENGER CARS ENGINE IN TERMS OF REAL DRIVE EMISSION TEST

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Abstract: *This paper presents the preliminary concept research to develop the test used in the measurement of emissions in real traffic conditions for passenger vehicles. Work based on the lack of legal solutions for determining the environmental performance of light vehicles – as opposed to heavy-duty vehicles for which such regulations have specified. The elaboration is to compare the emission test used in clinical approval of passenger cars, while the synthesis of the results obtained under different conditions road tests. The intention is to develop a test for assessing the ecological vehicle in real traffic conditions, where restrictions will only drive type (gasoline engine, diesel engine, hybrid vehicle), which is consistent with the requirements of the certification tests. The result should be the foundation for the development of the test in terms of: the duration, to determine the operating conditions and vehicle and proposals for emission limit values.*

Key words: *exhaust emission, road tests, passenger cars*

1. Introduction

Manufacturers of combustion engines are obliged to the design drive units with best possible ecological characteristics and with supreme performance parameters. In recent years the popularity of measuring parameters of combustion engines in real operating conditions has significantly increased. The latest results of tests carried out in real traffic conditions show that some components of exhaust emissions are emitted in greater amounts compared with the tests carried out on stationary engine test benches. The lack of legal provisions regarding the testing of emissions in real traffic conditions resulted in the need to determine common areas of operating of the engines in order to enable the comparison between the engines [1].
The concept of exhaust gas toxicity tests performed in real traffic conditions for passenger vehicles should be based on the following premises: determination of a consistent area of operation of the engine for all passenger vehicles in a way to the greatest extent corresponding with the most common traffic conditions, determination of the parameters measured during the road tests and the obtained emission indicators [2, 3]. The article presents the results of the measurements concerning determination of working conditions for the engines used to drive the cars. The tests of working conditions were carried out for a group of vehicles driving along the predefined sections of roads in urban traffic and out-of-town traffic. The result of the study was the assessment of the working conditions of passenger vehicles considering determination of road emissions of pollutants.

2. Presentation of the issue

Measurements of emissions in passenger cars are conducted during the type-approval tests on the chassis dynamometer, during the road tests in real traffic conditions and on vehicle inspection stations (there the concentration of compounds is measured and not the emission). The type-approval measurements are performed on the chassis dynamometer according to precisely determined procedures and are used only for new passenger cars. The aim of the NEDC (New European Driving Cycle) and the FTP (Federal Test Procedure) type-approval tests for a fixed speed profile is to control whether a vehicle meets ecological requirements [4, 5]. Road tests of passenger vehicles concerning exhaust emissions are not legally regulated as opposed to heavy goods vehicles, for which the research test NTE (Not to Exceed) has been designed – the test checking whether the vehicle does not exceed the limit values [6, 7]. The test determines the area of engine operation within which the emission cannot exceed certain limits. The NTE test is conducted during actual operation of engine and is dedicated for the evaluation of emission of toxic compounds in exhaust gases from engines intended for heavy-goods vehicles. The characteristic feature of this test is the determined operation area of the engine for heavy goods vehicle. Emissions from beyond the test area are not taken into account [8, 9].

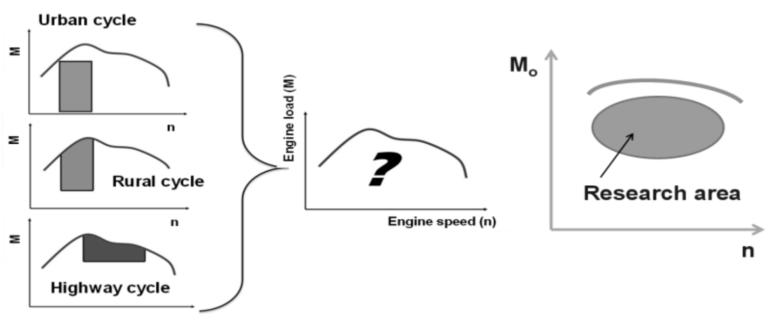
3. The concept of development of a research test for passenger cars

Lack of any defined legal provisions has prompted the authors of the article to explore the concept of creating a test to assess the exhaust emissions from passenger cars in real traffic conditions [10–12]. The concept of developing exhaust gas toxicity test performed in real traffic conditions for passenger vehicles should be based on the following premises:

– determination of one consistent area of operation of engines for all passenger vehicles in a way to the greatest extent corresponding with the most common traffic conditions; if determination of one common area of operation is not possible, there should be introduced a division into different classes of vehicles with different drives based on some common criteria (e.g. spark ignition and diesel engines without division based on the way of powering the engine);
– determination of the parameters measured during the road tests and the derived emission indicators.

In order to meet the presented general requirements for the research test, realisation the following points of the algorithm is proposed:

1. Determination of the engine operation area (engine load in function of engine speed) in research tests (e.g. NEDC test) and comparison of the obtained area with the operation area characteristic for the most common operating conditions of passenger vehicles; with division into different measuring sections of roads: urban areas and out-of-the town areas, motorways (Fig. 1). The operation area of the engine should be characterized by at least two parameters (engine speed and engine load), available e.g. from the data from internal computer network of the vehicles. The difficulty here is to develop the indicator of engine load, as in passenger vehicles the on-board diagnostic system provides only a supportive parameter, which is the engine load at a given engine speed expressed as a percentage [13, 14]. As a result we should obtain a defined engine operation area, which should be subject to the test, i.e. measurements of toxicity of exhaust fumes in road conditions only from this area should be taken into account.



Test, conditions	Heavy-duty vehicle n, M_o	Passenger vehicle n, M_o
Test limits	known (area)	to designate
Emission limits	known (1.25×limit)	to designate

Fig. 1. Determination of the operation area of the engine used during the test

2. Determination of the share of engine (or vehicle) operation time in the type-approval tests (e.g. NEDC or FTP) in relation to e.g. the engine operation area (engine load–engine speed coordinates) or vehicle operation area (vehicle speed–vehicle accelerated coordinates), followed by determination of the main engine (or vehicle) operation areas responsible for the highest values of road emissions of harmful compounds. Based on experiments – tests conducted in real traffic conditions, it is estimated that compliance of the harmful emissions determined in NEDC test and in the real traffic conditions is not satisfactory. The result of this stage should be proposal how to determine the duration of road test. One of the options is also to determine the duration in relative units (for example, in relation to a specified parameter of the engine (or vehicle) operation).
3. Performance of verification testing (with defined engine operation range, according to the results of point 1, and the duration of the test, according to the results of point 2) for different passenger vehicles and their emission classes, confirming the correctness of the assumptions about the test.
4. Modifying the concepts of the research test in case of negative conclusions ensuing from procedure in point 3.
5. Attempt to determine the values defining the maximum emission in road tests for different emitting vehicles. These limits can be defined as indexes of emission of particular harmful compound or as multiplicity of increase in relation to the value of the emission standards.

4. Research methodology

Parametrization of operation ranges of combustion engines was conducted for a representative group of vehicles including 11 passenger vehicles with gasoline engines and 11 passenger vehicles with diesel engines. Vehicle characteristics are shown in Table 1.

In order to determine the most commonly used engine operation ranges were conducted test runs in urban conditions lasting at least 1 hour. During the run, the parameters associated with the vehicle (including vehicle speed, acceleration) were recorded at a frequency of 1 Hz, as well as operation-related parameters (e.g., engine speed, engine load, temperature of the cooling agent). On this basis it was possible to perform the most important tasks of the stage of parametrization of the engine operation conditions while driving in urban conditions.

The registered temporary changes of engine speed $n = f(t)$ and of engine load $M_o = f(t)$ allowed development of two-dimensional characteristics of engine operation during testing. These characteristics were developed for all vehicles, and then was conducted the analysis of possibilities of generalizing the characteristics for all drive units.

In order to get possibly general characteristics for all vehicles, it was assumed that they would be presented as dependence of the share of engine load for a given engine speed (presented as $M_o/M_{o\max}|n$) and the relative engine speed (in relation to engine maximum speed) $n/n_{\max}$, both expressed as percentage (Fig. 2).

Table 1. Data of the vehicles selected for testing

Parameter	Value
Gasoline	
capacity	1.1 – 3.0 dm^3
ecology class	Euro 3 – Euro 5
year of poroduction	2005 – 2011
Diesel	
capacity	1.9 – 3.0 dm^3
ecology class	Euro 2 – Euro 5
year of poroduction	2003 – 2010

The engine operation area in $n/n_{\max}$–$M_o/M_{o\ \max}$ system was divided into rectangular elements with dimensions (Fig. 3):

$$\Delta(n/n_{\max}) = (n/n_{\max})/N \qquad (1)$$

$$\Delta M_o/M_{o\ \max}) = (M_o/M_{o\ \max})/K \quad (2)$$

For elements numbered (i, j) the share of operation time – that is the time density (TD) – is defined as follows:

$$\mathrm{TD}_{(i,\,j)} = t_{(i,\,j)}/t \qquad (3)$$

where $t_{(i,\,j)}$ means the time of the engine operation during which the considered parameters (engine speed and load) belong to the ΔL area designated as i, j. The following relations must be fulfilled:

$$\sum_{i=1}^{N}\sum_{j=1}^{K} t_{(i,j)} = t \qquad (4)$$

$$\sum_{i=1}^{N}\sum_{j=1}^{K} \mathrm{TD}_{(i,j)} = 1 \qquad (5)$$

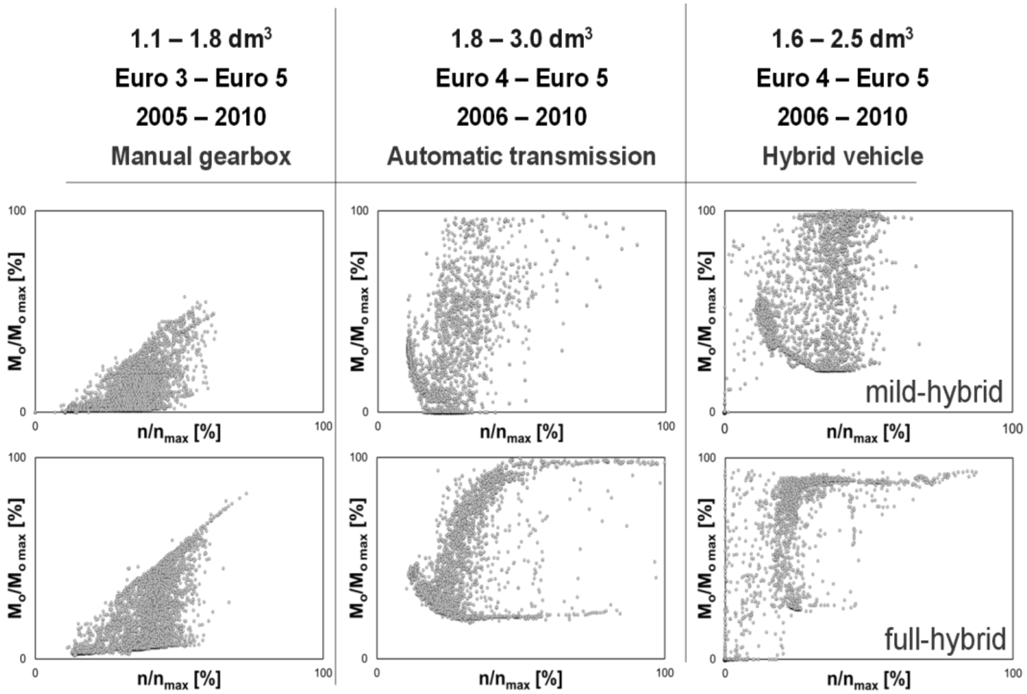


Fig. 2. Exemplary registered characteristics of the engine operation

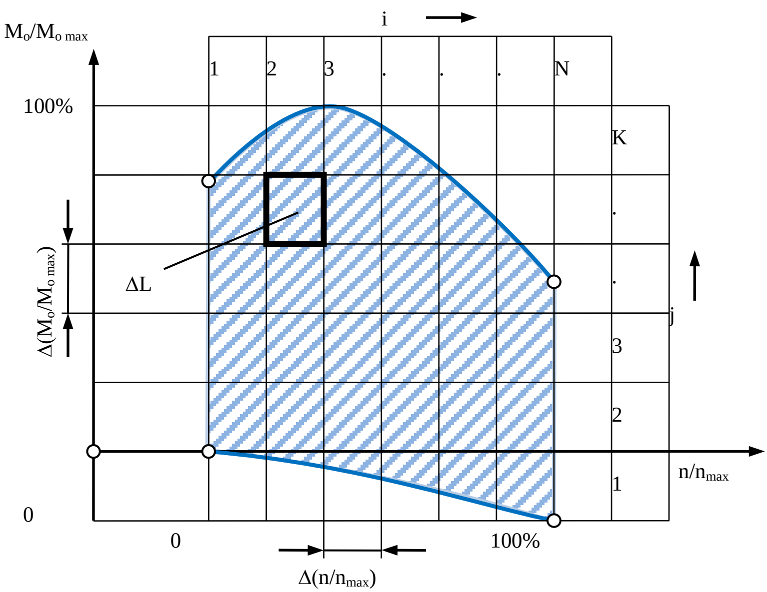


Fig. 3. Division of the engine operation area into elements

The characteristic parameter of a given element of the engine operation area is its centre which, for the purposes of the considered issue, was defined as the arithmetic mean of the beginning and end of range for given range of relative speed or relative engine load.

The presented way of defining the two-dimensional characteristics of engine operation time share, in accordance with the equation (4), requires, first and foremost, determination of the number of ranges of relative engine speed (N) and the number of ranges of relative load (K). Proper definition of those ranges results subsequently in the possibility of generalizations of the obtained results (for all vehicles from given category – e.g. separately for gasoline engines and diesel engines) and, at the same time, is the basis for further research.

The authors of the article suggest establishing the number of ranges on the basis of:

- the minimum average value of the adjacent elements for separate ranges (*i*, *j*), which is the measure of data variability within these ranges – smaller values will be the basis for the adoption of the representativeness of the centre of the range as approximate engine operating conditions;
- equality of the number of ranges *N* and *K*;
- limitation of the total number of ranges to 100.

5. Results

Determination of the division of the engine operation areas common for all engines required the adoption of standard testing time. In assumptions it was time not shorter than one hour (3600 measuring points). The determination of area division started from *N* and *K* values of 5 × 5 (Fig. 4). Adoption of such values for division of operation area allowed to fill almost all elements (*i*, *j*), which is not fully consistent with real conditions. The maximum share of operation time in the element was 37.7% at a maximum value of variability of 19.7%; while the average value of the standard deviation (only for filled areas) amounted to 4.06. The same procedure was repeated for subsequent values of *N* and *K*, incrementing them by one unit up to the value of 10. The results of these operations are shown in Figs. 5–7.

Compiling the obtained mean values of variability for the entire operation area it was possible to establish the dependence, from which it ensues that the most compliant with the requirements is the division of the engine operation area into *K* × *L* elements with values of 10 × 10). The figure shows that the exemplary operation of combustion engine in urban traffic conditions is contained in the area of 0-30% of relative engine speed and area of 20-30% of the relative load.

The subsequent stage of the study was comparison of engine operation areas with dimensions 10 × 10, followed by their generalization for all engines (with separate division for spark ignition engines and diesel engines). Determination of the average values for all the tested vehicles allowed determination of generalized and parametrized areas of combustion engine operation. Comparison of these areas suggests that gasoline engines work within the range of n/n_{max} = 25% and $M_o/M_{o\ max}$ = 15%, and diesel engines within the ranges of n/n_{max} = 15% and $M_o/M_{o\ max}$ = 40%, that is in ranges of smaller engine speeds and higher engine loads (Fig. 8).

a) b)

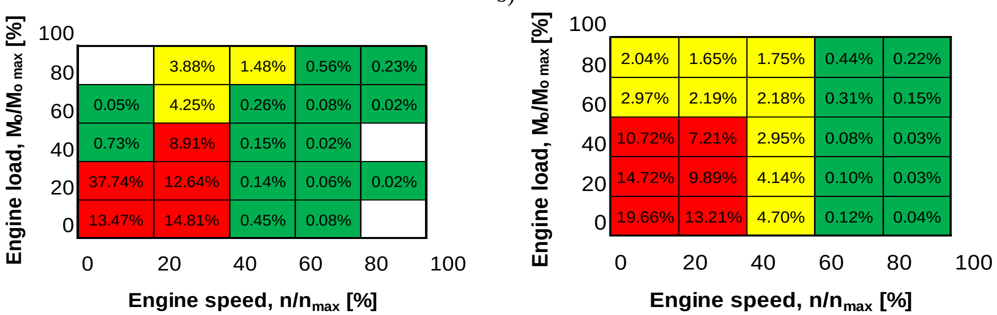


Fig. 4. The results of the analysis for the division number 5 × 5: a) share of the operation time, b) average value for adjacent division number

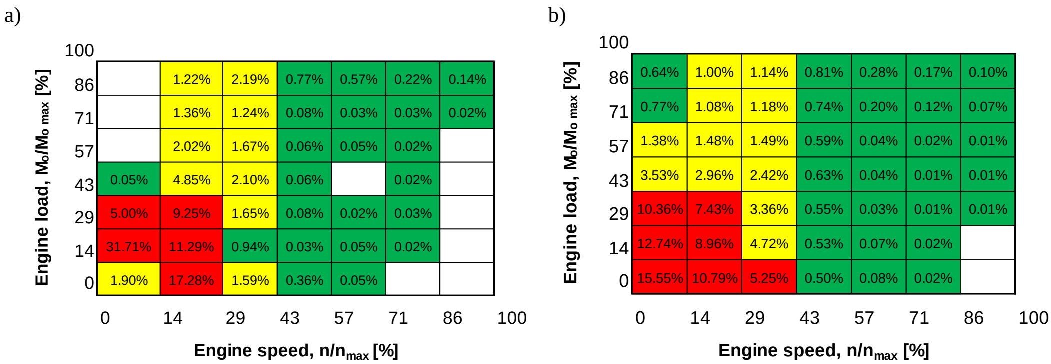


Fig. 5. The results of the analysis for the division number 7 × 7: a) share of the operation time, b) average value for adjacent division number

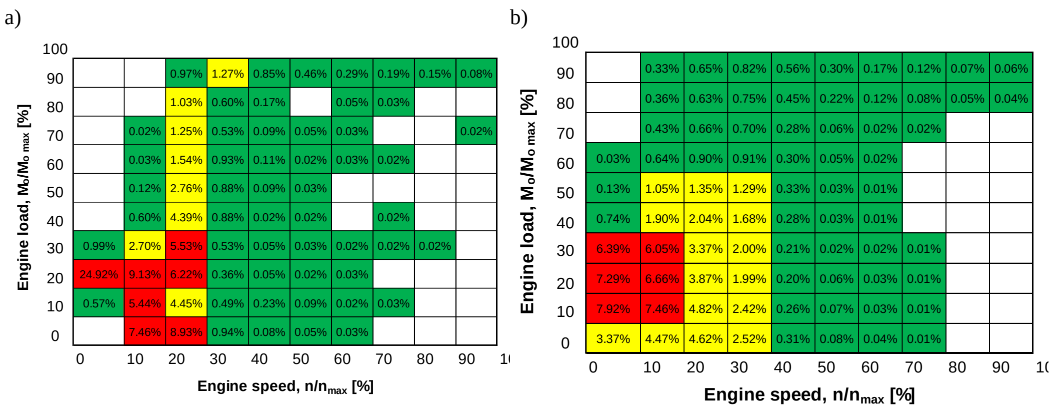


Fig. 6. The results of the analysis for the division number 10 × 10: a) share of the operation time, b) average value for adjacent division number

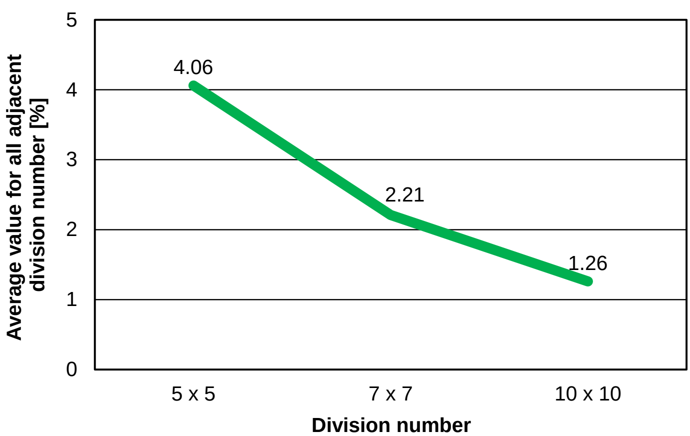


Fig. 7. Average value for all adjacent division number

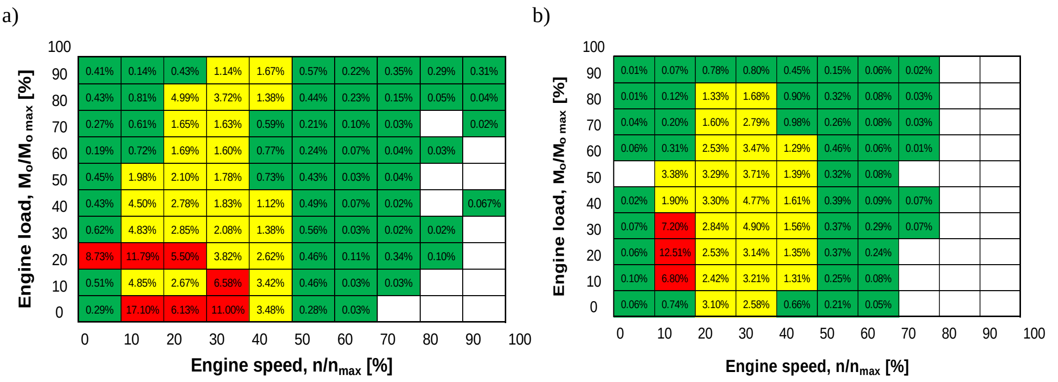


Fig. 8. The results of the analysis for the division number 10 × 10: a) gasoline engines, b) diesel engines

The effect of obtained dependencies was compact engine operation area for considered passenger vehicles. The test should conform to the most common engine work conditions and create opportunity to determine emission indexes (road emissions) measured under road tests (fig. 9).

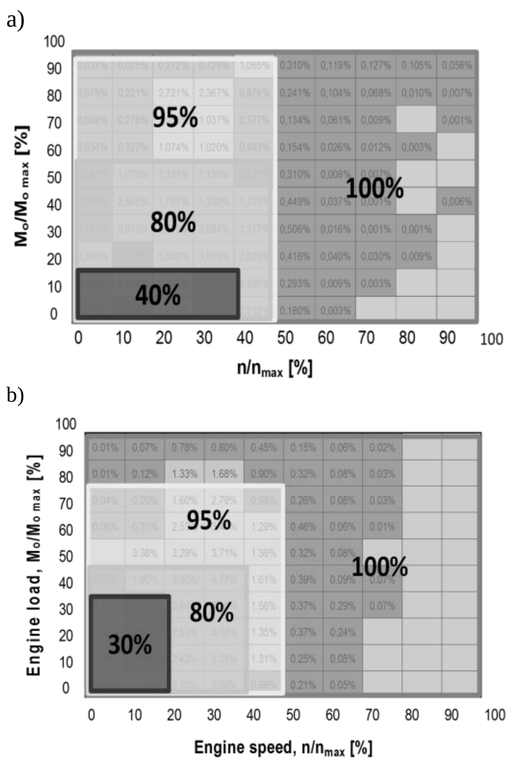


Fig. 9. Engine operation areas designated in terms of road emission tests: a) gasoline engines, b) diesel engines

6. Conclusions

The presented concept of tests of passenger vehicles for their emissions in real traffic conditions has no equivalent in legal provisions. The issue was undertaken as a result of implementation in European regulations of similar tests only for heavy goods vehicles and also as a result of experience acquired in tests in real traffic conditions of different means of transport.

Implementation of the undertaken task might be used for preparation of guidelines for testing toxicity of exhaust fumes stated in legal provisions and, at the same time, can indicate the possibility of ecological assessment of vehicles during their operation. This is another way of assessing the technical condition of the vehicles, with a detailed assessment of the vehicle's emission, which can be performed in parallel to emission procedures at vehicle inspection stations.

Determined and parametrized operating ranges of combustion engines in urban traffic conditions can be a guide to introduction of toxicity testing system in real traffic conditions with the use of mobile gas analysers.

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