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Investigation of pollutant emissions from a motor vehicle engine in tests simulating real vehicle use in road traffic conditions

Abstract: Vehicle driving tests worked out by the authors and simulating the typical road operation of a motor vehicle have been described. The tests have been developed on the grounds of analyses of vehicle speed processes recorded during empirical tests, which were carried out in road traffic conditions. In the vehicle motion models adopted, the conditions of vehicle operation in congestion, urban, extra–urban, and high–speed traffic were separately considered. Pollutant emission test results obtained from the driving test procedures proposed have been presented.

Keywords: *internal combustion engines, pollutant emissions, vehicle driving tests, simulation of motor vehicle motion conditions*

Badania emisji zanieczyszczeń z silnika samochodu w testach symulujących rzeczywiste użytkowanie trakcyjne

Streszczenie: W pracy przedstawiono opracowane przez autorów testy jezdne symulujące typowe użytkowanie trakcyjne samochodu. Opracowano je na podstawie analiz procesów prędkości samochodu uzyskanych w badaniach empirycznych przeprowadzonych w ruchu drogowym. W przyjętych modelach ruchu wyodrębniono warunki użytkowania samochodu w zatorach ulicznych, w miastach, poza miastami i na trasach szybkiego ruchu. Przedstawiono wyniki badań emisji zanieczyszczeń uzyskane z zastosowaniem zaproponowanych testów jezdnych

Słowa kluczowe: *silniki spalinowe, emisja zanieczyszczeń, testy jezdne, symulacja warunków ruchu samochodów*

1. Introduction

In most cases, the pollutant emissions from engines of light motor vehicles, i.e. passenger cars and light–duty trucks, are tested with the use of the test procedures employed at type–approval tests [14]. The type–approval test procedures are to ensure adequate repeatability of vehicle operation conditions so that the test results can be considered as unbiased. The time histories of vehicle test speeds are intended by the designers of the test procedures to correspond to the typical conditions of vehicle use. For practical reasons, however, the test conditions must be significantly simplified in comparison with the reality. In respect of vehicle motion conditions, individual tests used within type–approval test procedures may be categorized as follows:

a) Tests for the simulation of urban driving conditions, such as UDC (Urban Driving Cycle) or, in a part, FTP–75 (Federal Transient Procedure) or Japan 10–15 Mode;
b) Tests for the simulation of extra–urban driving conditions, such as EUDC (Extra–Urban Driving Cycle) or, in a part, FTP–75 or Japan 10–15 Mode;
c) Tests for the simulation of vehicle driving on motorways and fast roads, chiefly HWFET (Highway Federal Extra Test) and, in a part, EUDC.

Apart from the type–approval tests, special tests typical for other vehicle driving conditions are also employed, e.g. the Stop–and–Go test to simulate vehicle driving in the conditions of street congestions or the Autobahn test to simulate vehicle driving on a motorway.

All the above tests, however, exclusively represent special cases of the possible conditions of motor vehicle motion. It is known that the utility characteristics of internal combustion (IC) engines are susceptible to engine operation conditions [5]. This susceptibility is particularly high when the engine operates in dynamic conditions [5]. The states of operation of motor vehicle engines are determined by vehicle motion processes. It is also known that for different realizations of the vehicle motion processes corresponding to typical traffic conditions, the characteristics of IC engines may vary within wide limits, with this variability being particularly high in the case of pollutant emissions [5]. For these reasons, a decision was made that the typical conditions of vehicle motion should be treated at this work as stochastic processes and that the investigations should be carried out for several selected realizations of the vehicle speed processes under consideration.

The driving tests having been developed make it possible to investigate the properties of IC engines in pseudorandom vehicle motion conditions. The driving tests were designed on the grounds of an analysis of results of empirical tests of the motion of a passenger car; the empirical tests were carried out at the Automotive Industry Institute (PIMOT) in Warsaw within a project entitled “Susceptibility of pollutant emissions and fuel consumption to the conditions of operation of a spark –ignition IC engine,” sponsored by the National Science Centre.

2. Empirical tests of the motion of a motor vehicle in road traffic conditions

The test specimen was a Honda Civic car manufactured in 2000, provided with a 4 cylinder in–line spark–ignition engine of 1 400 cm^3 capacity, meeting the requirements of the Euro 3 exhaust emission standard.

The tests were carried out within the area of Mazowieckie and Łódzkie Voivodships. The test program included the real–time measurements and recording of time histories of engine speed, engine controls operation, vehicle speed, and vehicle location, with 10 Hz sampling frequency.

The vehicle motion conditions were modelled to represent the vehicle driving in the following situations:

a) in urban traffic congestions (denoted by “CT”);
b) in urban traffic without congestions (denoted by “UT”);
c) in extra–urban (“rural”) traffic (denoted by “RT”);
d) in high–speed traffic (denoted by “HT”).

For individual traffic categories as listed above, the following vehicle speed samples were taken:

a) 38 samples in urban congestions;
b) 68 samples in urban traffic without congestions;
c) 32 samples in extra–urban traffic;
d) 16 samples in high–speed traffic (on fast roads and motorways).

Based on analyses of results of the empirical tests of vehicle speed, four driving tests were worked out, in compliance with the criterion of faithful simulation in time domain, for each of the above traffic categories; these tests were treated as realizations of the processes representing the vehicle operation in traffic congestions, in urban traffic, in extra–urban traffic, and in high–speed traffic.

The vehicle speed vs. time curves for the driving tests worked out have been presented in Figs. 1 to 4.

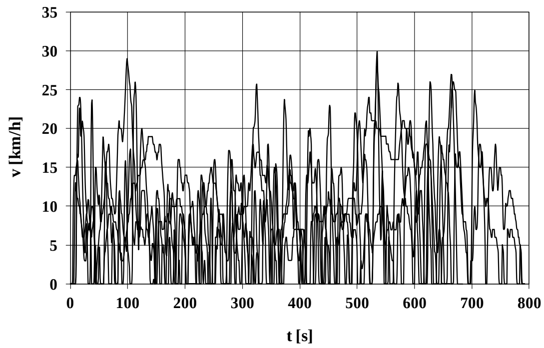

Fig. 1. Vehicle speed vs. time curves for the tests representing the driving in traffic congestions (CT)

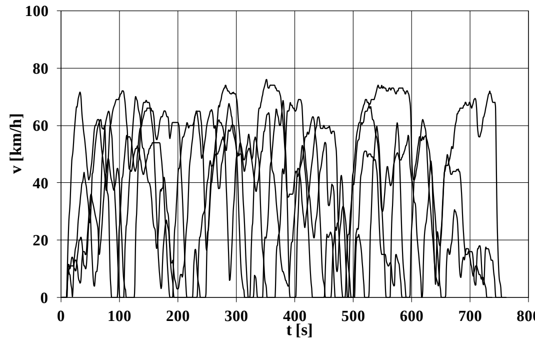

Fig. 2. Vehicle speed vs. time curves for the tests representing the driving in urban traffic (UT)

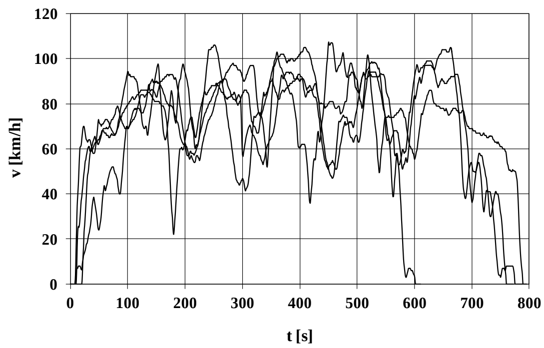

Fig. 3. Vehicle speed vs. time curves for the tests representing the driving in extra–urban traffic (RT)

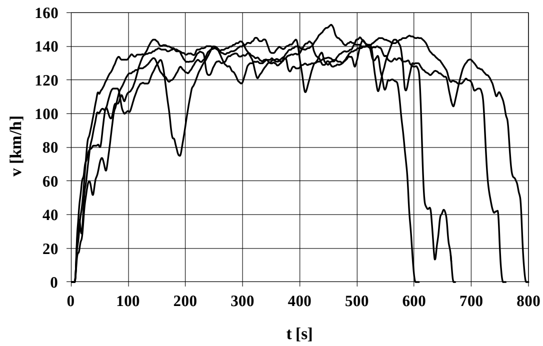

Fig. 4. Vehicle speed vs. time curves for the tests representing the driving in high–speed traffic (HT)

The tests to determine the on–road pollutant emissions and operating fuel consumption were carried out at the Vehicle Engine and Chassis Section of the Automotive Industry Institute (PIMOT). The PIMOT testing laboratory was provided with a Schenck–Komeg vehicle chassis dynamometer EMDY 48 with a single roll of 48" dia., a Horiba exhaust–gas analyser MEXA 7200, and an AVL Opacimeter 4390–G003.

The particulate matter (PM) emission rate was determined from the smoke opacity, with employing a correlational method. According to this method, the PM emission rate is considered as directly proportional to the exhaust gas flow rate and to the increasing values of the light extinction coefficient of the exhaust gases as determined with the use of a smoke meter [2].

The measurements were carried out on the Honda Civic car previously used for the tests of vehicle operation in road traffic conditions. Each test was carried out five times.

The average values of the average on–road pollutant emissions in individual realizations of the CT, UT, RT, and HT driving tests have been presented in Figs. 5 to 9.

It can be clearly seen that the average on–road pollutant emission values differed from each other in individual realizations of the tests. Such a finding was expected because the performance characteristics of motor vehicle engines in dynamic conditions are determined by the history of engine operation states [5].

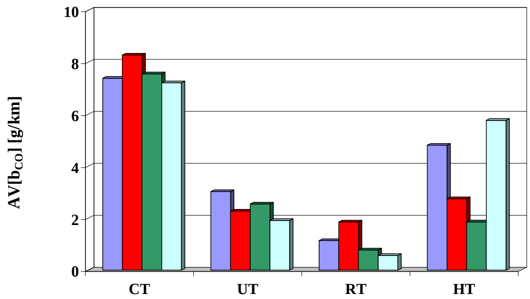

Fig. 5. Average values (AV) of the average on–road emission of carbon monoxide (b_{CO}) in individual realizations of the driving tests

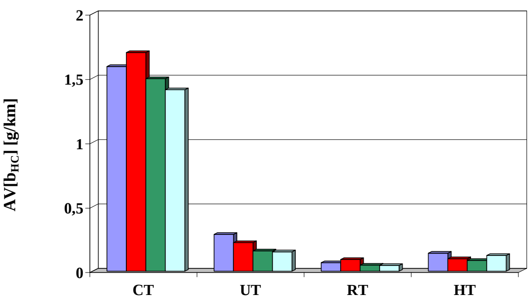

Fig. 6. Average values (AV) of the average on–road emission of hydrocarbons (b_{HO}) in individual realizations of the driving tests

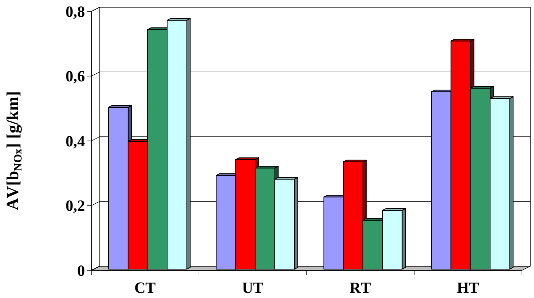

Fig. 7. Average values (AV) of the average on–road emission of nitrogen oxides (b_{NOx}) in individual realizations of the driving tests

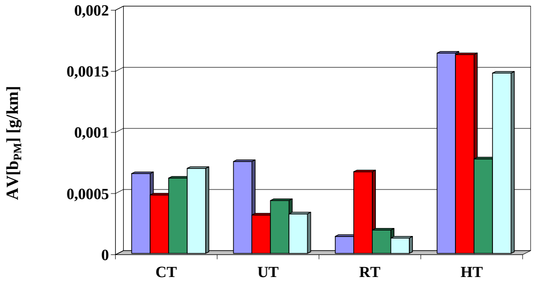

Fig. 8. Average values (AV) of the average on–road emission of particulate matter (b_{PM}) in individual realizations of the driving tests

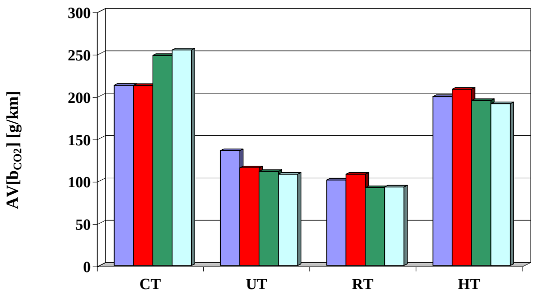

Fig. 9. Average values (AV) of the average on–road emission of carbon dioxide (b_{CO2}) in individual realizations of the driving tests

Significant scatters were also observed in the average on–road pollutant emission values in individual realizations of the tests. The coefficients of variation of the average on–road pollutant emission values in individual realizations of the driving tests have been shown in Fig. 10.

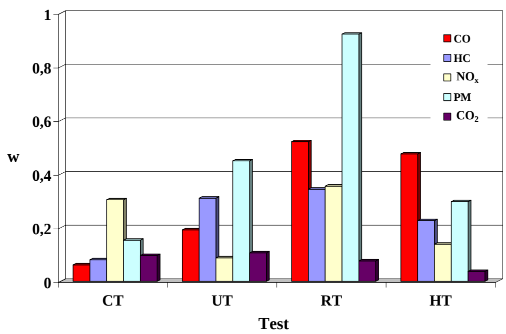

Fig. 10. Coefficient of variation of the average on–road pollutant emission values in individual realizations of the driving tests

In some cases, the test results showed considerable unrepeatability, which was caused by significant susceptibility of pollutant emissions to test conditions. For this reason, the tests had to be repeated and conclusions could only be drawn from the averaged test results.

Based on the averaged test results, pollutant emission characteristics could be determined in the form of a dependence of the average on–road pollutant emissions, averaged in individual realizations of the driving tests, on the average speed, averaged in individual realizations of the driving tests (see Figs. 11 to 15). The sets of measuring points were approximated, depending on the nature of the dependence, by third degree polynomial functions; only for hydrocarbons, a power function was used.

Thanks to the averaging of test results in individual realizations of the tests, clearly visible regularity of the characteristic curves of pollutant emissions was obtained. The dependencies determined are consistent with those that can be found in the literature and that have been based on extensive statistical data [1, 4, 10].

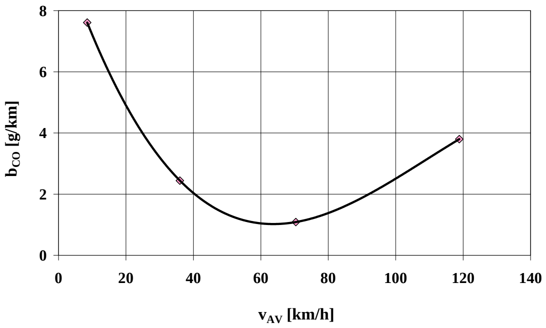

Fig. 11. Dependence of the average on–road emission of carbon monoxide (b_{CO}), averaged in individual realizations of the driving tests, on the average speed (v_{AV}), averaged in individual realizations of the driving tests

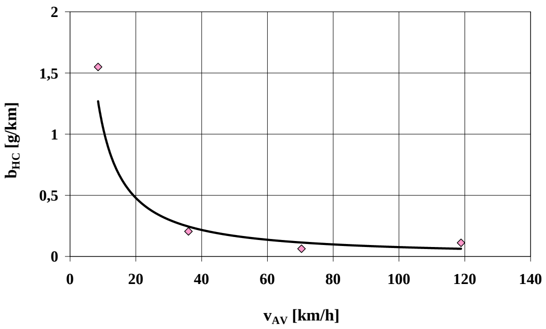

Fig. 12. Dependence of the average on–road emission of hydrocarbons (b_{HC}), averaged in individual realizations of the driving tests, on the average speed (v_{AV}), averaged in individual realizations of the driving tests

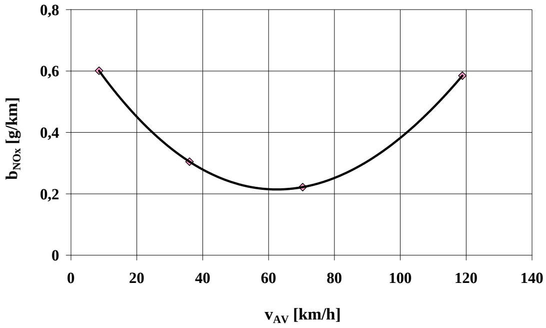

Fig. 13. Dependence of the average on–road emission of nitrogen oxides (b_{NOx}), averaged in individual realizations of the driving tests, on the average speed (v_{AV}), averaged in individual realizations of the driving tests

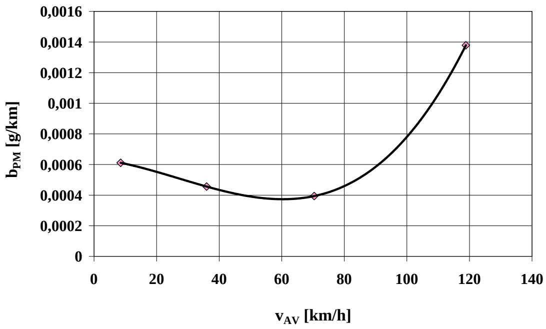

Fig. 14. Dependence of the average on–road emission of particulate matter (b_{PM}), averaged in individual realizations of the driving tests, on the average speed (v_{AV}), averaged in individual realizations of the driving tests

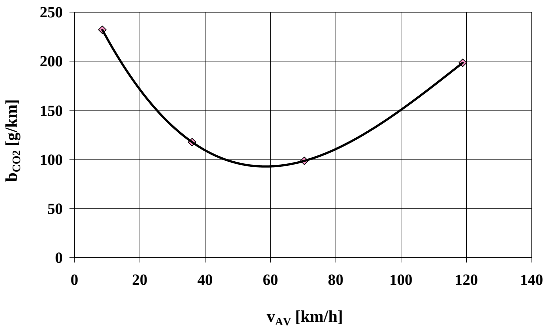

Fig. 15. Dependence of the average on–road emission of carbon dioxide (b_{CO2}), averaged in individual realizations of the driving tests, on the average speed (v_{AV}), averaged in individual realizations of the driving tests

3. Recapitulation

The investigation of utility characteristics of internal combustion (IC) engines in dynamic states, when the characteristics are determined by random conditions of operation of the engines in motor vehicles, provides knowledge significantly exceeding the scope of the knowledge obtainable from standard test procedures. It is possible to broaden this knowledge by processing the test results, e.g. by the application of stochastic methods for the research into properties of systems in pseudorandom operation conditions [3, 5, 7, 8]. As regards pollutant emissions, a particularly interesting testing possibility is offered by the use of mobile systems for exhaust gas analysing, such as the PEMS (Portable Emissions, Measurement Systems) [11, 12, 13].

The treating of the conditions of operation of IC engines of motor vehicles as stochastic processes of vehicle driving speed offers a possibility of evaluating not only the utility characteristics of such engines but also the unrepeatability of the characteristics [6].

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