Comparison of the combustion engine operating parameters and the ecological indicators of an urban bus in dynamic type approval tests and in actual operating conditions

Lukasz Rymaniak^{1,*}

¹Poznan University of Technology, Faculty of Machines and Transport, ul. Piotrowo 3, 60-965 Poznan, Poland

Abstract. The article presents the considerations regarding a city bus combustion engine performance parameters in dynamic type approval tests and in real operating conditions when servicing an urban bus line. A comparison of the designated engine operating time shares with respect to load and crankshaft rotational speed was made. The analysis included the ETC and WHTC tests, which showed significant discrepancies in the work areas of internal combustion engines in these test when compared to actual driving conditions. The details of the type approval tests used and the method of their denormalization for the drive unit were presented. The vehicle used for this research was an eighteen meter city bus equipped with a CI engine with a displacement of 9.2 dm³. The latest PEMS mobile equipment technology was used to conduct the road measurements. This allowed the emission indicators for CO, HC, NO_x and PM to be determined, including specific emissions. The obtained values were then compared with the Euro V limits. The analysis of the test results was supplemented with the calculation of fuel consumption using the carbon balance method.

1 Introduction

Currently urban buses most commonly use conventional powertrains, where the compression ignition (CI) internal combustion engine is connected to the gearbox and the transmission. Such systems will most probably continue to be used for several years to come. Due to the shape of the infrastructure, relatively low purchase costs and easy exploitation/repair of the vehicle, when compared to alternative drives and fuel prices. As a consequence, many modern CI engines are designed and engineered to improve their efficiency and emission performance [1-3]. According to the current trends, engine families of similar design are being developed, differing among others with, for example: charging system or control parameters [4-6]. As a result, vehicle and machinery manufacturers have the option of choosing a specific engine that meets their mechanical operating requirements [7].

For heavy-duty vehicles (HDVs), due to their large size and the power generated by the powertrain, the type approval of the exhaust gas emission is made for the internal combustion engine itself at the engine dynamometer. For this reason, the limit values are given in the regulations in g/(kW·h). Within the European Union, Euro standards are marked with numbers from I (introduced in 1992) to VI (currently in force). An additional EEV standard (enhanced environmentally friendly vehicle) for eco-friendly vehicles was introduced in 1999 [8]. It supplemented the regulations

from Euro III and was incorporated into Euro V. The specific emission values and the methods of their determination are set out in the directives and regulations of the European Union.

Euro VI is currently in force in the European Union, with the new World Harmonized Stationary Cycle (WHSC) and World Harmonized Transient Cycle (WHTC), replacing the European Transit Cycle (ETC), European Stationary Cycle (ESC) and European Load Response (ELR). The Euro V and Euro VI norms provide mileage and operating time shares corresponding to the normal operation of a heavy duty vehicle. Minimal requirements for durability tests are also provided, depending on the category and maximum mass of the tested vehicle. The records are supplemented by data on the deterioration factors (more precise and clear definitions are given in Euro VI) [9].

Substantial changes in regulations have been made in the field of compliance checks – it is now necessary to perform specific emission measurements of exhaust pollutants in real driving conditions using PEMS (portable emission measurement system). Previously, only the internal combustion engines were tested after being removed from the vehicles. However, it should be noted that the type approval of the vehicle group discussed is carried out on engine dynamometers. It should be noted that, research of exhaust emissions in real driving conditions using PEMS are implemented for all vehicles with combustion engines [10-15]. The article presents the comparison of engine operating conditions

* Corresponding author: lukasz.rymaniak@put.poznan.pl

in real road conditions and dynamic type approval tests. The ETC and WHTC tests are intended to reflect the operation of the combustion engine in the actual moving vehicle.

2 City buses dynamic type approval tests – emission of pollutants

For all Euro standards it is necessary to perform tests at fixed internal combustion engine operating points in static tests. The emission limit values for CO, THC, NO_x and PM (Particulate Matter) for CI engines have been reduced with the introduction of further directives and regulations. Due to the development of internal combustion engines and exhaust aftertreatment systems, it became necessary to introduce limit values for the number of particles emitted designated as PN (particle number) and ammonia NH₃ in Euro VI norms [16]. With the introduction of the Euro III standard in 2000, dynamic braking tests began to apply, in which the internal combustion engine was tested in variable operating parameters, taking into account the presence of an external drive. As in static tests, unit emission limits were gradually reduced for further Euro standards.

In accordance with the Euro V and EEV norms it is necessary to perform ETC, ESC and ELR tests, which are performed in laboratory conditions. The first of these cycles aims at mapping the actual operating conditions of the combustion engine by applying variable operating parameters (dynamic conditions, Fig. 1). Its procedure envisages the possibility of carrying out measurements both on the chassis and engine dynamometers – the simulated operating conditions of the vehicle are converted to the operating parameters of the drive unit. However, it should be noted that only the second variant is tested for type approval. In normal engine operating conditions there can occur negative loads, which is related to the transmission of external torque (simulation of driving down a hill). The test drive cycle is divided into three parts – urban, rural, and motorway. The duration of the test is 1800 s, with each stage contributing 600 s, where the theoretical average vehicle speeds are 6.47 m/s, 20 m/s and 24.44 m/s for each part respectively.

Fig. 1. Torque and engine speed during the ETC test [17].

On the ETC test results, normalized torque and engine speed values are expressed as: n_{norm} [%] and T_{norm} [%]. In order to carry out a real test for a particular

internal combustion engine, it is necessary to perform standardization in accordance with the procedure described in Directive 2005/55/EC [17]. Using the full power characteristics the following parameters are determined: n_{idle} , n_{low} , n_{hi} and n_{pref} . The last of these components is the reference speed, at which the torque integral represents 51% of the torque integral in the interval $\langle n_{\text{idle}}; n_{95h} \rangle$. It is then possible to calculate the specific values of the combustion engine operating parameters. When determining the actual crankshaft rotation speed, the consecutive test steps use the following formula:

$$n_{\text{actual}} = 0.01n_{\text{norm}}(0.05n_{\text{lo}} + 0.95n_{\text{hi}} - n_{\text{idle}}) + n_{\text{idle}} \quad (1)$$

where:

n_{actual} – actual engine speed [rpm],

n_{norm} – normalized engine speed in the test [%],

n_{lo} – the smallest rotational speed at which the engine reaches 55% of its maximum power output [rpm],

n_{hi} – the highest rotational speed at which the engine reaches 70% of its maximum power output [rpm],

n_{idle} – engine idle speed [rpm],

n_{95h} – the highest rotational speed at which the engine reaches 95% of its maximum power output [rpm].

Detailed guidelines for determining the engine operating parameters are provided in [17].

Calculations of torque value are made using the formula:

$$T_{\text{actual}} = (T_{\text{norm}} \cdot T_{\text{max}})/100 \quad (2)$$

where:

T_{actual} – actual torque [N·m],

T_{norm} – normalized torque in the test [%],

T_{max} – maximum engine torque [N·m].

In the Euro VI standard, in relation to previous regulations, the overall time share of individual WHTC dynamic test phases has changed. The results of the road tests in selected EU countries, Japan and the USA were taken into account when developing WHTC and static WHSC. This was to bring the measured cycles closer to real driving operating conditions around the world. The tests used previously were designed based only on European conditions. Detailed test requirement data is contained in UNECE Global GHS Regulations 4 [18]. Two equivalent methods can be used in both pollutant emissions tests: continuous sampling and constant volume sample (CVS). As with the dynamic cycle of the Euro V standard, WHTC tests can be carried out on chassis and engine dynamometers, with the second variant being the required one for type approval tests (Fig. 2). There are three parts in the test – urban, non-urban and motorway. The test duration is 1800 s, with successive parts lasting 900 s, 481 s and 419 s, where the theoretical average vehicle speeds are 5.92 m/s, 12.11 m/s and 21.31 m/s for each drive part respectively.

In order to carry out tests on a specific engine, it is necessary to denormalize the engine operating conditions. The actual load is determined in accordance with the formula (2) and the actual crankshaft rotation speed is determined by the formula:

$$n_{\text{actual}} = 0,01n_{\text{norm}} (0,45n_{\text{lo}} + 0,45n_{\text{pref}} + 0,1n_{\text{hi}} - n_{\text{idle}}) \cdot 2,0327 + n_{\text{idle}} \quad (3)$$

where the subsequent variables of the equation are defined just as for the formula (1).

Fig. 2. Torque and engine speed during the WHTC test [18].

3 Research methodology

An eighteen-meter urban bus equipped with a conventional CI engine (Tab. 1) was used. The internal combustion engine had a maximum power of 265 kW at 1900 rpm and a maximum torque of 1450 N·m between 1100 and 1700 rpm. The drive system used a six-speed automatic transmission and a retarder for enhanced braking performance. The vehicle was type approved, complete and technically operational. It had a two-part bodywork and was fitted with four pairs of doors. In order to prepare the test bus, a replacement load was used to reflect the occupants during everyday bus operation. The equipped exhaust gas aftertreatment systems included: diesel oxidation catalyst (DOC), selective catalytic reduction (SCR) and diesel particulate filter (DPF).

Table 1. Tested vehicle technical data.

Parameter	
Engine type/fuel	4-stroke, CI/diesel oil
Displacement [dm ³]	9.2
Cylinder number and setup	6/in-line
Compression ratio	17.5
Maximum power [kW]/[rpm]	265/1900
Maximum torque [N·m]/[rpm]	1450/1100–1700
Exhaust aftertreatment systems	DOC/SCR/DPF
Exhaust emission norm	Euro V and EEV
Vehicle total mass with load [kg]	24,000

SEMTECH DS mobile gas measurement equipment and AVL MSS (Micro Soot Sensor) for solid particle concentration measurement (Fig. 3) were used in the experiments. The portable analyzer SEMTECH DS is coupled with a mass flow meter where a probe is fitted that takes the samples of the exhaust gases. The tested gas volume is transported through a special heated line where the temperature of 191°C is maintained. This solution prevents hydrocarbons condensation before their concentration is measured. Subsequently the sample goes through a filter where particulate matter is

eliminated. Now the prepared exhaust gases are accurately measured in individual analyzers (Tab. 2). In the first place the emission of THC is measured in the FID analyzer (flame ionization detector). Another stage is chilling of the sample to 4 °C and sending it to the NDUV analyzer (non-dispersive ultraviolet detector) responsible for the measurement of NO_x. The next stage is the measurement of the CO_x through an NDIR analyzer (non-dispersive infrared detector) [19]. All the analyzers are calibrated and reset prior to the measurement to ensure that the ambient air pollution is taken into account. This takes a few minutes to complete. The sampling frequency range for each analyzer is different. Hence the measurement of all the exhaust components an assumption has to be made for the frequency that all the analyzers can operate at.

Fig. 3. Picture of the mobile PEMS equipment during bus road tests: a) AVL MSS 483, b) SEMTECH DS.

Table 2. Technical specifications of the portable exhaust emission analyzer SEMTECH DS [19].

Parameter	Measurement method	Accuracy
Component concentration:		
CO	NDIR, 0–10%	±3%
HC	FID, 0–10 000 ppm	±2.5%
NO _x	NDUV, 0–3000 ppm	±3%
CO ₂	NDIR, 0–21%	±3%
O ₂	electrochemical, 0–21%	±1%
Exhaust gas flow	mass flow rate T_{max} to 700°C	±2.5% ±1%
Diagnostic standards	SAE J1850/SAE J1979; SAE J1708/SAE J1587; CAN SAE J1939/J2284	

For the measurement of the PM emission a portable analyzer AVL MSS was used. It allows the continuous concentration measurements of particulate matter in the diluted exhaust gases. The principle of operation is based on the photo-acoustic method and allows measurements of particulates starting from 5 µg/m³. The measurement of the PM (the device measures the main part of the PM) through the photo-acoustic method consists of the

absorption of the modulated laser light by the soot particles [20]. This results in a periodical heating up and cooling down of the medium gas (change of the pressure in the measurement chamber) and the generated sound wave is recorded by microphones. Presented PEMS could be used in research of various groups of vehicles [21-23].

For the purposes of the experiment the urban line operated by the local communications operator was used, classed as one of the more busy in terms of both the distance and the number of passengers (Fig. 4). Its total distance was 11.2 km and included twenty-seven stops along with loops. The route started in the northern part of the city (os. Sobieskiego) and travelled through main roads of varying traffic intensity to the Poznan city center (Plac Bernardynski). During the route selection, the EU guidelines on traffic conditions have been incorporated in accordance with EU Regulation 582/2011 [24]. However, the conditions for the minimum work performed by the internal combustion engine were not fulfilled due to the nature of urban buses operation.

Fig. 4. The route used during the measurements under actual operating conditions (map created using GPS Visualizer).

4 Internal combustion engine operating parameters in type approval test

In order to compare the operating conditions of the internal combustion engine in the type approval tests and test in real driving conditions, the operating time shares of the engine unit were classified into load and crankshaft rotational speed compartments. The analysis quoted the dynamic test cycles ETC and WHTC. These tests have been developed in such a way as to simulate actual engine operating conditions, which is why they have been included in the article's considerations. Based on the performed simulation tests, the total work performed in these tests was determined. It is not only useful to determine the engine performance parameters

Fig. 5. Shares of rotational speed and torque ranges and power characteristic, together with the work sum of the internal combustion engine of the tested vehicle for tests: a) ETC, b) WHTC.

in the WHTC test for the comparative assessment, but it is also necessary in order to determine the pollutant emission factors for compliance, as reflected in EU Regulation 582/2011 [24]. The procedure it describes assumes using the total energy generated by the internal combustion engine in the WHTC test, which is to be used for determining the measuring windows. However, the research vehicles were Euro V compliant buses, so the ETC test was also included. It should be noted that the obtained values do account for the negative power determined by the nature of the test cycles, whereas the curve representing the sum of the work performed only takes into account the positive values (Fig. 5).

The conventional bus internal combustion engine powered with diesel oil in the ETC test worked most often at crankshaft rotational speed of (1600 rpm; 2000 rpm), in the full load range (0 N·m; 1600 N·m), where the total operating time share reached 73% (Fig. 5a). A significant value of the work area 8.7% also occurred in the range of the smallest rotational speed (the most significant was the range where the torque did not exceed 200 N·m). The instantaneous power generated by the internal combustion engine shows that the test vehicle often reached values close to the rated engine power, which resulted in a significant overall work value of 47.4 kW·h. In the Euro VI dynamic test, the engine operating range also includes a significant area, with the largest share of operating time being in the range of small loads (Fig. 5b). The largest share was 61.6% for rotational speed range of (1200 rpm; 1800 rpm) at a load of up to 1200 N·m, whereas in the area of up to 200 N·m the share of operating time was 29.7%. For idle, the operating time share was 17.6% of the WHTC test duration. Power generation characteristic shows that the vehicle achieved a rated power much less often than the assumed in the ETC test. As a result, total work sum was also smaller at 28 kW·h.

5 Engine operating parameters in real operating conditions

To fully understand the impact of the engine operating conditions and the type of propulsion system used on the performance of the internal combustion engine, a bus test drive was conducted on the urban bus line. The average speed of the tested vehicle was 4.6 m/s. The total sum of operating area shares with the constant velocity of ($a = 0 \text{ m/s}^2$) reached 3%, while the vehicle stop duration time share was 22.6% of the whole test drive duration (Fig. 6). In the speed range of (0 m/s; 12 m/s) and the acceleration range (-0.8 m/s^2 ; 0 m/s^2) and (0 m/s²; 0.8 m/s^2) operating time shares were determined to be 23.5% and 36.8% respectively. The characteristic of the entire propulsion system was the most influential on the latter of the mentioned ranges. More dynamic acceleration was difficult to achieve due to the weight of the vehicle and the gear ratios used.

Based on the internal combustion engine operation analysis it can be concluded that the conventional diesel oil powered bus has reached the highest share value of 33% in the idle speed range for torque in the range of

(0 N·m; 200 N·m) (Fig. 7). The most significant share in the basic ranges occurred at engine speeds of (800 rpm; 1200 rpm) and a load of up to 200 N·m considering the entire route. The sum of individual time shares were determined as 12.6% and 9%. For the next torque range in the crankshaft rotation range of (600 rpm; 1200 rpm) the share of engine operating time was equal to 7%, 10.5%, and 17.9%. For the omitted single ranges these shares had values below 4.2%. The maximum crankshaft rotational speed that was recorded in the test cycle was 1687 rpm.

Fig. 6. Share of the urban bus operation time in speed and acceleration intervals during urban road test.

Fig. 7. Percentage share of engine operating time for the tested vehicle in the given speed and torque ranges when measuring driving in urban areas.

Due to the length of the urban bus line and the road conditions in the test drive cycles that occurred during the measurements, the internal combustion engine of the tested vehicle generated a combined work of 27.4 kW·h (Fig. 8). The created acceleration curves indicate the strongest correlation with total work sum value. This is related to the production of a momentary power by the internal combustion engine, characterized by large values. Thus, the acceleration of the vehicle has a strong influence on the total energy increase. For example, a speed variation of 0 to 14.6 m/s occurs in the time period between 1700 s and 1742 s, resulting in an energy requirement of 1 kW·h. When the vehicle is stationary

the energy increase is small – it results from the need to supply the functional and auxiliary systems in the bus by the internal combustion engine (such as the pneumatic system, air conditioning, steering, etc.).

Fig. 8. The instantaneous velocity and acceleration characteristics of the tested vehicle together with the overall work sum of the internal combustion engine in the urban road test.

6 Comparison of combustion engine operating parameters in type approval and road tests

In order to compare the operating conditions of internal combustion engines in the type approval and real driving tests, the difference in the registered operating time shares in the speed and torque ranges was determined (Fig. 9). In both the standardized road tests and the selected test routes the recorded areas of engine operation and their operating time shares are significantly different from those found in the engine dynamometer tests. Dynamic type approval tests were prepared in such a way as to best reflect the actual operation of a heavy-duty vehicle. Therefore, the difference between the two values was taken for the analysis: the operating time share of the examined ranges in the type approval test and the time share of the corresponding compartment in the road tests. A positive value indicates a higher share of operating time in type approval tests compared to road tests. In addition, the operating areas that occurred during the urban test drive are shown on the characteristics, which makes it possible to compare the size of the work area.

Taking into account the ETC test data, the operation area of the internal combustion engine for the bus line test drive was lower within the selected ranges by 43% (Fig. 9a). The average value of absolute differences in engine operating time shares was 2.6%. The largest discrepancies in the presented characteristics were determined in the engine idle range, and also the smallest load range, which was -24.25% . This indicates that in engine dynamometer tests the engine unit operates in these ranges for a too small amount of time, where these conditions are much more often obtained during the actual operation of city buses.

The test vehicle's internal combustion engine gained a larger operating time share in the ETC test than in the

road conditions for engine speeds between (1800 rpm; 2000 rpm) and load in the range of (0 N·m; 600 N·m), where for single parameter ranges the difference in operating time share obtained ranged from 7.17% to 13.32%. In addition for ETC tests on engine dynamometer significantly higher rotational speeds were achieved (over 2400 rpm), which did not occur in road tests, due to the characteristics of the propulsion unit and the selection of gear ratios. Based on the determined relationships, it can be stated that in the ETC test conditions, the proportion of operating time in the minimum load range of up to 200 N·m and engine speed of less than 1200 rpm is significantly too small. Extremely high operating time shares are present in the engine speed range of over 50% of the maximum value, with a torque of up to 50% of the nominal value, as well as for the maximum values of both parameters.

Fig. 9. Difference in engine operating time shares for the tested vehicle in the type approval tests and in the real driving measurements on an urban bus line divided into engine speed and torque compartments: a) ETC test, b) WHTC test.

When comparing the time shares recorded in the WHTC test and in actual operating conditions, minor differences in the individual designated compartments were obtained (Fig. 9b). Based on the size of the work areas obtained, it can be concluded that the Euro VI Dynamic Test conditions include a greater range of engine rotational speeds and loads than is the case in

road conditions. Using the characteristics it can be seen that the largest differences in the considered values occurred for a load of up to 200 N·m in the range from idle speed to 1800 rpm. For the first single interval, the operating time share difference was –15.35%; While in other areas, these values varied from –11.01% to 11.3%.

Estimated mean of the absolute difference values was 2.1%. Using this comparison, the WHTC dynamic type approval test better reflects the conditions for the actual operation of a heavy duty urban bus. However, it is characterized by too wide a range of operating parameters – especially the crankshaft rotational speed. In addition, in the lowest load range at a rotational speed of 1200 rpm for CI engines there is an underestimation of operating time shares, and in the ranges above these values are therefore too high.

7 Analysis of ecological indicators and fuel consumption

From the data collected by the mobile exhaust gas analyzer and the GPS system, the emissions of harmful compounds in urban test drive were determined (Fig. 10). CO road emission was 7.11 g/km, and for HC it was 0.46 g/km. The performance characteristics of the CI engine (large λ values) is favorable in terms of emissions of the toxic compounds. The large amount of air contributes to better mixing of fuel with the air in the cylinder, however, it should be noted that under local conditions (e.g. with improperly shaped injection stream), incomplete combustion may occur. The NO_x road emission value of 7.28 g/km was heavily influenced by the exhaust aftertreatment system. In the selective catalytic reduction system, the rate of conversion depends primarily on the temperature and exhaust gas mass flow rate – with a higher flow rate, the conversion is lower. Thus, the variability of the combustion engine operating parameters is not beneficial in terms of exhaust aftertreatment efficiency. The PM emission was 30.74 g/km. A DPF filter was used in the vehicle, which limited the emission of this compound. However, the conditions of vehicle operation (frequent stopping and starting and acceleration dynamics) favored a greater emission of PM.

Fig. 10. Road emissions of CO, HC, NO_x, CO₂ and PM determined for the test bus route.

CO₂ road emissions depend significantly on fuel consumption and thus the vehicle's energy needs to

travel a specific route. Based on the results of the conducted research, it is possible to determine the fuel consumption of the tested vehicle in road tests. Carbon balance method was used to determine the specific value, taking into account the road emission results of harmful exhaust gases. In this method for diesel vehicles, the formula for the calculation takes the following form:

$$FC = \frac{0,1155}{\rho_{\text{fuel}}} \cdot [(0,866 \cdot \text{HC}) + (0,429 \cdot \text{CO}) + (0,273 \cdot \text{CO}_2)] \quad (4)$$

where:

FC – fuel consumption in [dm³/100 km],

HC, CO, CO₂ – measured exhaust emissions [g/km],

ρ_{fuel} – test fuel density in the temperature of 15°C [g/cm³].

The method used allows for accurately calculating the volume of fuel consumed over a given distance (100 km). It is also possible to use data from the on-board diagnostic system or the method associated with the tank volume, but these solutions are burdened with notable uncertainties. Based on the recorded data, the vehicle fuel consumption was 61.7 dm³/100 km. The result was most affected by the conditions in which the bus was operated. In order to reduce operating expenses by reducing fuel consumption, drivers employed in transport companies often receive a training in eco-driving. Apart from the economic aspect, upgrading and more efficient use of the vehicle fleet contributes to the reduction of environmental impact in urban areas, especially in urban centers of large agglomerations.

The specific emission values for type approval tests are determined using the net engine operating parameters measured at the end of the crankshaft or its equivalent. In actual operating conditions, the internal resistance of the combustion engine is calculated as a percentage – a specified value for the entire engine speed range. It should be noted, however, that this is in a way a simplification that affects the final results of the study. The obtained emission results of a single city bus while traveling on a city bus line are shown in Figure 11. Based on the calculations, the following unit emission results for CO = 2.93 g/(kW·h) and NO_x = 3.04 g/(kW·h). In the PM emission range, a value of 12.68 g/(kW·h) was obtained.

Fig. 11. Specific emissions of CO, HC, NO_x and PM determined from the urban bus route test drive results.

Based on the results of the unit emissions of harmful compounds, their values can be referred to the emission standard supposedly met by the tested vehicle (Euro V and EEV). To this end, the emission factor k_j should be determined, as was done in [25, 26]. The emission factor is defined as:

$$k_j = \frac{e_{\text{real}, j}}{e_{\text{limit}, j}} \quad (5)$$

where:

j – exhaust component, for which the emission factor is determined,

$e_{\text{real}, j}$ – specific emission value obtained from road tests [g/(kW·h)],

$e_{\text{limit}, j}$ – accepted specific emission limit for Euro V or EEV [g/(kW·h)].

The emission limits of the ETC dynamic type approval test were adopted for the analysis, because this test is assumed to reflect actual vehicle operation. The tested vehicle did not exceed the emission limits set for Euro V and EEV for the exhaust emissions of CO, HC and PM (Fig. 12). For these toxic compounds, the emission factor was smaller than one $k < 1$. On the other hand, for NO_x, the emission factor was $k = 1.52$ for both considered limits, which are identical to the standards in question. This means that the emission limits were exceeded by more than 50%. This result was mostly influenced by the exhaust gas aftertreatment system. The SCR system did not reduce NO_x emission continuously, but the conversion rate depended on many factors, including: the exhaust mass flow rate and its temperature. Due to the concerned emission size, the latest vehicle exhaust emission test procedures that already incorporate road emission tests allow for the possibility of exceeding the emission limit. This is also the case for particulate matter emissions.

Fig. 12. Emission factor k determined for the measurement results on the urban bus line.

8 Conclusions

Due to the size of the urban bus population and the power of their propulsion systems, they have a significant impact on the quality of the environment in urban agglomerations where there are large concentrations of people. The operating conditions of the

vehicle group in question are very specific and have a direct bearing on the operating conditions of the drive systems used. Taking into account the operating conditions of the internal combustion engines designated in the type approval tests and under actual operating conditions, it can be concluded that there are significant discrepancies between the obtained results. For the ETC test, valid for the tested vehicle, the biggest differences are in the engine idle speed range. The share of operating time in the compartment greater than 40% of the maximum engine speed in the complete load range is too large. The WHTC test is more similar to the actual operating conditions, but the overall operating area achieved during its implementation is much larger than for real driving, especially for the maximum torque range.

Using the characteristics of the engine operating time share of the tested vehicle and the intensity of pollutant emissions, determined with special assumptions regarding the operation of urban buses, it has been shown that the largest operating time share of these vehicles is for being stationary. The most common acceleration values were in the range of $\langle -0.8 \text{ m/s}^2; 0 \text{ m/s}^2 \rangle$ and $\langle 0 \text{ m/s}^2; 0.8 \text{ m/s}^2 \rangle$ for vehicle driving speed in the range of $\langle 0 \text{ m/s}; 14 \text{ m/s} \rangle$. Small shares of operating time were recorded for uniform speed. It was found that the most significant are the compartments describing the crankshaft rotational speed at idle speed up to 800 rpm and the load not exceeding 200 N·m.

The observed operating conditions of the internal combustion engine had a direct impact on the achieved ecological indicators. Emission factors k were determined referring the measured results of the harmful gas emissions to the emission limits set by the standards met by the tested vehicle. This allowed to discern the relationship between the results of the road test emissions and the legislative guidelines. The analysis shows that CO, HC and PM emissions in road conditions are lower with respect to Euro V and EEV limits for dynamic tests. It has been demonstrated that NO_x unit emissions significant exceed the emission limit, by about 50%. The fuel consumption of the tested vehicle during urban road tests has reached 61.7 dm³/100 km, which was determined using the carbon balance method taking into account the road emission of relevant exhaust gases.

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