Article citation info:
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

Jerzy MERKISZ
Łukasz RYMANIAK

CE-2017-103

Tests of urban bus specific emissions in terms of currently applicable heavy vehicles operating emission regulations

The article presents a study of a city bus in real operating conditions (RDE) from the perspective of the latest regulations for the assessment of specific emissions compliance for heavy-duty vehicles (Euro VI standard). The object of the research was a serial configuration hybrid drive vehicle. Measurements were made in the real driving conditions in Poznan agglomeration. The latest mobile equipment PEMS was used for the measurements. This article presents the details of the EU 582/2011 Procedure in operational conformity assessment, the methodology of the study was discussed, and the obtained results were presented, both in terms of vehicle operating conditions and engine operation, as well as specific emissions evaluation.

Key words: *bus, drive system, hybrid, RDE, specific emissions*

1. Introduction

Buses have a significant impact on the environmental quality in urban areas, where there are large concentrations of people. This is due to the number of the vehicles in the considered group and the power used in their drive systems. The share of urban buses, non-urban buses, and tourist coaches from all the HDVs (Heavy-Duty Vehicle) in the European Union is 11%, while the estimated fuel consumption by these vehicles accounts for 15% of the consumption of all HDVs [12, 13]. The total number of registered heavy vehicles (including special vehicles) in Poland in December of 2014, was over 3.6 million units. Buses accounted for 106 057 units, of which almost 85% (89 996 units) were operated by public transport companies [3]. In 2000–2006, the number of registered vehicles remained at a similar level, reaching about 81 000 units, and in each subsequent year, their population increased by an average of 2.3%. 15 498 regular communication lines were operated in 2014, with a total travel length of 788 612 km, and transported nearly 431.5 million passengers. Due to the age distribution of the buses, vehicles of up to five years old constituted 8.1% of the total, buses in the age range of 6–15 years reached 28%, the remaining 45.7% was in the last age group, of up to 30 years [3].

For the approval of heavy-duty vehicles, in terms of compliance with the emission standards in the European Union, new Euro standards, from I to VI, were gradually introduced, supplemented with the EEV standard (Enhanced Environmentally Friendly Vehicle) for the Euro III–V. These rules expect for tests of only the combustion units themselves to be performed on an engine dynamometer, in defined static and dynamic measurement cycles. With the introduction of Euro VI (type approvals from 31.12.2012, first registration from 31.12.2013) new compulsory tests have been added: WHSC (World Harmonized Stationary Cycle) and WHTC (World Harmonized Transient Cycle), and replaced the previously used ETC (European Transient Cycle), ESC (European Stationary Cycle) and ELR (European Load Response) tests. The recent years of research work have indicated that the measurements quality and quantity of exhaust gases from internal combustion engines performed under laboratory conditions may differ from the actual vehicle emissions of the given category, including HDV [4, 5, 7, 8]. As a result continuous efforts are made to develop detailed and universal methods of emissions assessment in road conditions RDE (Real Driving Emissions). From the moment the Euro VI standard came into effect, it became necessary for manufacturers to perform road measurements to verify the operating conformity of heavy-duty vehicles powered by different types of fuels [1, 2, 9].

2. Legal regulations concerning the control of operational compliance of in-service HDV

The Euro V and Euro VI standards provide mileages and operating periods corresponding to the normal life span of a heavy vehicle. Minimal mileages for durability tests depending on the vehicle category and maximum mass are also compiled. The records are supplemented with data for determining the deterioration factors (more precise and unambiguous definitions are outlines in the Euro VI standard) [6]. Significant changes in the regulations occurred for the operational conformity control – at present it is necessary to perform emission measurements in real driving conditions, using PEMS type equipment. While previously, only combustion engines themselves were tested, after being removed from used vehicles.

The EU Regulation 582/2011 (Annex II) provides detailed description of the requirements for the operating compliance evaluation for engines or vehicles. Among the most important information it should be noted that the measurements need to be carried out on public roads in the EU, using normal driving patterns and loads. This means that the tests are conducted using the standard (the most common) operating conditions. It is also important to ensure that the driver has the appropriate driving skills and training for the given vehicle type, and it is best when the procedure involves a person who usually drives it. In the case when it is impossible to carry out tests under normal operating conditions it is possible to use other alternative routes. If there is insufficient information on a representative vehicle load an additional load is used to obtain 50–60% of the maximum vehicle load.

After the first registration of a complete vehicle is obtained, with a combustion engine which comes from the approved group (family) of engines, the manufacturer must carry out field tests within an 18 month time frame and obtaining a mileage of at least 25 000 km [9]. According to [10], measurements have to be repeated periodically, at least every 24 months during the normal vehicle operation. The testing rejection and acceptance criteria, as a part of the compliance checks, is determined based on the number of tested vehicles, as relative to the total number of vehicles produced [9]. An inspection and testing of the used lubricating oils and fuels samples is included as supplementary procedures. It should be noted that the vehicle used for the measurement cannot be over-exploited, modified or improperly exploited.

The test route must include driving on urban roads (speed range: 0–13.89 m/s), suburban roads (13.89–20.83 m/s) and highways (over 20.83 m/s); the order can be changed should a legitimate case be made for doing so. The share in driving time for different conditions depends on the category of the tested vehicle (Table 1). These shares are determined with an accuracy of ±5% due to the difficulty of predicting the actual traffic conditions. Sampling is carried out continuously, and it begins even before starting the engine. While the data evaluation is carried out from the moment the coolant achieves the temperature of 343 K (70°C) or is stabilized within ±2 K in the span of 300 s. The measurement must be continuous and the data cannot be combined or modified. In addition to measuring the emissions intensity the acquisition of data from on-board diagnostic system must also be carried out in accordance to the guidelines [9]. It is imperative for the test on the realized route to perform work five times higher than during the WHTC test, or to achieve five times the CO_2 reference mass value of the same test.

Table 1. Shares of driving time in different conditions during operational compliance tests for heavy vehicles [9]

Category	Operating time share [%]		
	urban	suburban	highway
M_1, N_1	45	25	30
M_2, M_3 class I, II and A	70	30	0
M_2, M_3 others	45	25	30
N_2	45	25	30
N_3	20	25	55

The conformity factor is determined for the measuring windows which are devised two ways: based on the weight of CO_2, or based on the total work performed by the drive system. When issuing positive/negative decisions in the legislative process only the second variant should be used. The research involves the specific emission of gaseous compounds: CO and THC (for CI), NMHC and CH_4 (for SI) and NO_x (for CI and SI). Currently the weight and number of particles is not taken into account. In addition, it is necessary to measure exhaust gas mass flow, the engine operating parameters, the vehicle speed and its location, fuel flow rate, ambient conditions, etc. The legislation [9] also provides detailed information about the standards and functions, which the measuring equipment must meet, as well as a method of calibration, resetting, and self-diagnostics of instruments.

Pollutants specific emission evaluation is done using the moving averaging window method. Their determination is based on defining the mass flow rate of harmful substances emission for a subset of the complete data set, whose length is determined so as to correspond to the weight of CO_2 from the engine or the work measured on a test bench in transient operating conditions (WHTC test). Moving average is calculated for the time increment Δt, corresponding to the sampling period. The determined mass flow of emissions is expressed in mg/window [9]. For the method based on the work, the averaging windows are determined from the relation (Fig. 1):

$$W(t_{2,i}) - W(t_{1,i}) \geq W_{ref} \quad (1)$$

where: $W(t_{j,i})$ – engine work measured between the engine start and the time $t_{j,i}$ [kW·h], W_{ref} – engine work in the WHTC test [kW·h].

When calculating the value of $t_{2,i}$, the following relations must be met:

$$W(t_{2,i} - \Delta t) - W(t_{1,i}) < W_{ref} \leq W(t_{2,i}) - W(t_{1,i}) \quad (2)$$

where: Δt depends on the sampling frequency (1 s or less).

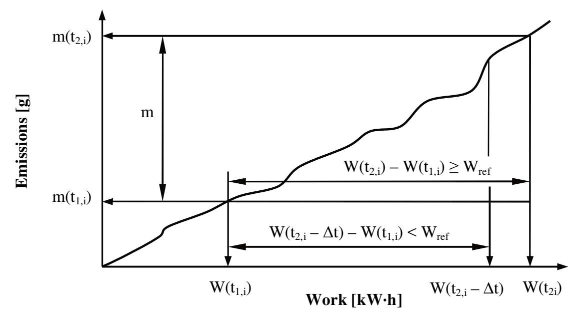

Fig. 1. Determining the measuring windows in the method based on the reference engine work [9]

In order for a measurement window to be considered valid, it needs to achieve an average power of more than 20% N_{emax}. Throughout the test, the percentage of valid measurement windows must be 50% or more. If this is not achieved the data evaluation must be repeated using lower power thresholds. This reduction is done in 1% increments, down to a level of 15% N_{emax}. Smaller values invalidate the test results. Specific emissions of pollutants are calculated for each measurement window using:

$$e_j = \frac{m}{W(t_{2,i}) - W(t_{1,i})} \quad (3)$$

where: e_j – specific emission j in i-th averaging window [mg/(kW·h)], m – mass of the exhaust component in i-th averaging window [mg], $W(t_{2,i}) - W(t_{1,i})$ – engine work in i-th averaging window [kW·h].

The vehicle operational conformity with regard to emissions CF (Conformity Factor) is calculated for all windows and for each considered component of exhaust gases according to the formula (4). To ensure the evaluation in any given averaging period was positive, the coefficients determined cannot be larger than 1.5. The vehicle itself is considered as meeting the legal requirements, provided

90% of the calculated CF values in the test fulfills this criterion.

$$CF = \frac{e_j}{L_j} \quad (4)$$

where: CF – conformity factor in the given averaging window [–], L_j – the permissible pollutant emission j in the WHTC test [mg/(kW·h)].

3. Research methodology in real operating conditions

3.1. Test vehicle

The study involved a city bus equipped with a series hybrid drive (Fig. 2). The drive system of the 18-meter vehicle used an internal combustion CI engine, with a displacement of 6.7 dm^3, a rated power of 209 kW at 2300 rpm, and a maximum torque reaching 1008 N·m at 1200 rpm. The vehicle is equipped with a traction motor with a power of 240 kW, and supercapacitors used to store the recovered braking energy, which is then used for acceleration. In addition, the bus uses electric drive solutions – in air compressor, radiator fan, power steering, door servos, as well as the air conditioning system. As a result, the power for the selected systems originates not directly from the internal combustion engine (mechanical drive), but from the electricity stored in the capacitors. The test vehicle meets the requirements of Euro V–EEV.

Fig. 2. Bus with a length of 18 m with a series hybrid drive system

3.2. Measuring equipment

Mobile device SEMTECH DS dedicated to the research in real traffic conditions was used in the measurements, it is classified in the PEMS group (Portable Emissions Measurement Systems). This device allows for making research measurements of spark and compression ignition engines that meet the Euro III and higher, and the principle of its operation is shown in Figure 3. The exhaust gases of the tested vehicle are directed to the exhaust mass flow probe, where the exhaust gas sample is taken. The taken gas sample is transported to a set of analyzers through heated conduits. The use of the heated conduit is to prevent condensation. The gases then go to the filter, where the particles are separated. Such a prepared sample is fed to the individual analyzers, each studying an individual exhaust gas component. The first FID analyzer (Flame Ionization Detector) is used to measure the hydrocarbons. In the next step the exhaust gas is cooled to a temperature of approx. 4°C and the sample volume is transported to the NDUV analyzer (Non-Dispersive Ultra Violet Detector) for the measurement of nitrogen oxides. Subsequently, the carbon monoxide and dioxide content is determined using NDIR analyzer (Non-Dispersive Infra-Red Detector). The last step is to electrochemically test the oxygen content in the exhaust gas. The analyzer can synchronize with the GPS positioning system, WLAN connection, and can communicate with the vehicle's OBD [11]. Using these road emission results it is possible to determine the vehicle fuel consumption using the carbon balance method.

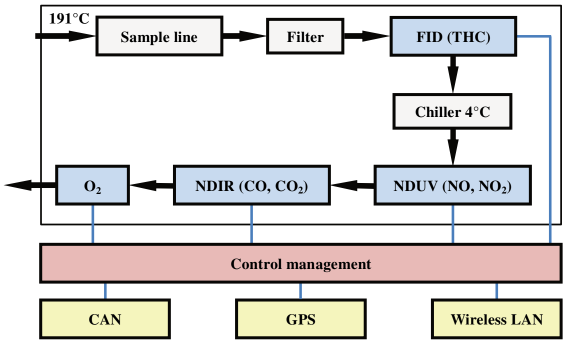

Fig. 3. SEMTECH DS operating schematic [11]

3.3. Test route

Measurements in real operating conditions required for the route selection to be representative of the tested vehicle type. The route is drawn on a map fragment in Figure 4.

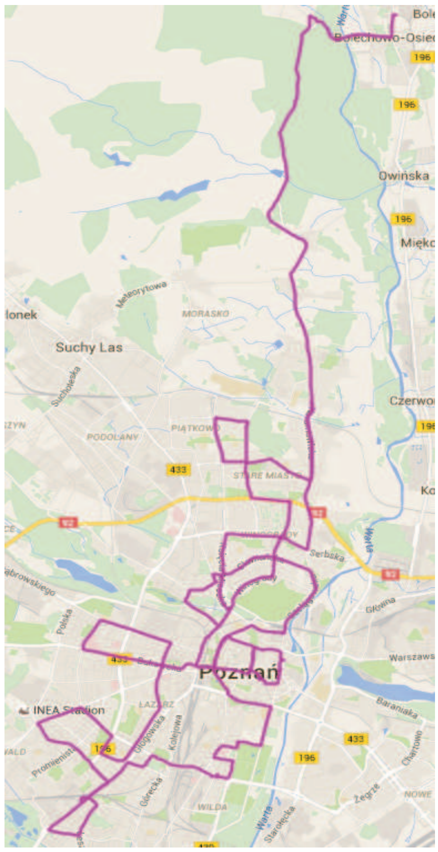

Fig. 4. The path of the test route used in the emissions test during real operating conditions (map created using GPS Visualizer [14])

The developed test route includes the suburban conditions, as well as the agglomeration center of the city, also using roads with speed limits above 50 km/h. The test route starting point was located in Bolechowo, it then led to the Poznan city center and ended in its northern part – the total distance of the route was 72.4 km. This considerable route length was driven by the need to obtain the minimum work value which had to be obtained during the test drive for the measurements to be valid according to [9] (at least five times the value obtained in the dynamic type approval engine test). The maximum relative elevation difference was 54 m, and the maximum slope did not exceed 5.2%. These factors had a direct impact on the values of the instantaneous and average velocity, the acceleration and the downtime of the vehicles tested.

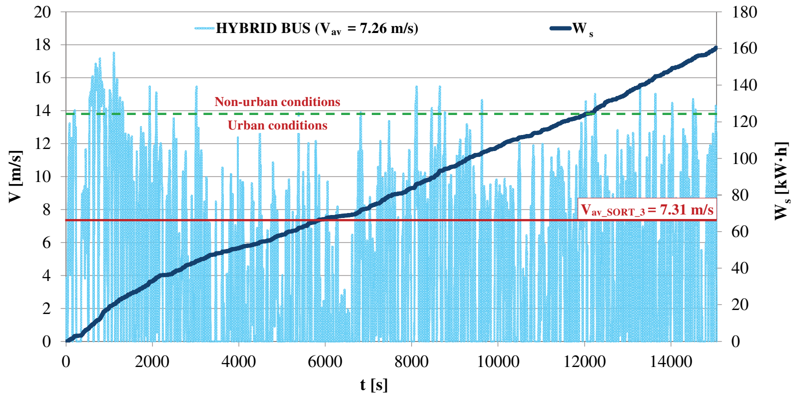

Fig. 5. The change in speed of a city bus on the test route with an added line representing the average speed of the SORT 3 road test

4. Research results

4.1. Analysis of the vehicle and engine operating conditions

For research purposes the specific emission of gaseous exhaust components: CO, THC and NO_x have been determined and compared to the EU Regulation 582/2011 [9], which refers to a group of heavy vehicles with Euro VI emission category. This allows checking whether the results obtained by this method correspond to the results obtained from all the data recorded during the test. It should be noted, however, that the test vehicle did not meet the Euro VI standard, and therefore, it was necessary to adopt some assumptions for the performed test procedure. The analysis was performed according to the previously described methods: using measurement windows defined using reference work measurements. The second method algorithm was not used, because the total weight of CO_2 produced by the combustion engines of the vehicles from laboratory tests was not known. Furthermore, the calculated results were referenced not only to the WHTC test, but also the ETC test. The presented discussion only refers to buses equipped with a hybrid drive, because the operating conditions of the combustion engine in such drives were the most reliable in terms of determining the measuring windows.

During the development of the test route it was assumed that it would consist of roads with an urban and non-urban character, ones with a sufficient possibility of obtaining an adequate vehicle speed (above 50 km/h, i.e. 13.89 m/s). However, the performed road tests have failed to meet the condition described in [9] regarding the shares of time driven in each type of road. To make the measurement compliant with the standard, it was necessary to achieve speed shares for the urban conditions of 70% and non-urban 30% with an accuracy of ±5%, whereas the performed test provided shares of 95.2% and 4.8% respectively. The resulting average speed value of the recorded drive (Fig. 5) was 7.26 m/s, and was most similar in this respect to the standardized non-urban test SORT 3 (7.31 m/s). This was primarily the result of local road conditions and congestion. Analyzing the current structure of roads in the Poznan agglomeration and its surrounding areas, it is difficult to unambiguously determine the route, which would meet the requirements of the existing standard. The use of highway section for the measurements would increase the share of non-urban speed, but this would conflict with the idea of reflecting the city buses operating conditions in everyday use.

Based on the operating parameters recorded by the CAN diagnostic system, it was calculated that the total work in the test cycle performed by the internal combustion engine was 160.4 kW·h. This value meets the requirements of the Regulation 582/2011, because it is close to nine times greater than in the WHTC test (legislation requires it to be at least five times greater). With regard to the dynamic ETC test for Euro V, taken into account for the needs of the research, the obtained results were more than five times greater. Characterization of the combustion engine and the cooperation with hybrid drive elements caused the resulting distribution of operating points had a specific pattern – increased density of measurement points can be seen for specific crankshaft speed values (Fig. 6). Maximum torque (1000 N·m) occurred in a limited speed range of 1600 and 1700 rpm, while for the interval of 2000 and 2100 rpm the highest torque value reached about 950 N·m.

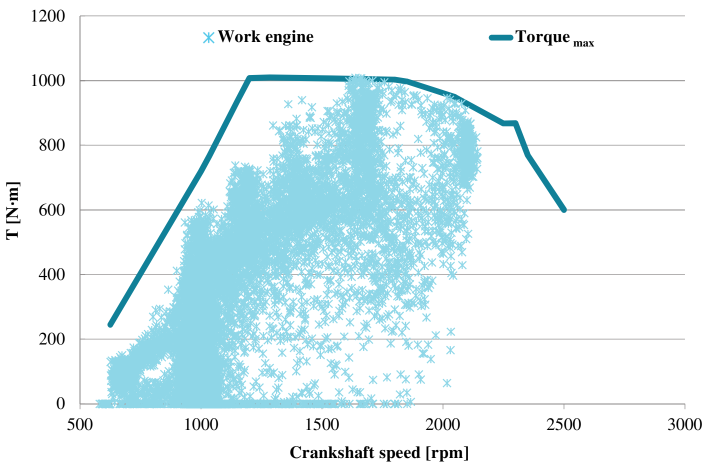

Fig. 6. Operating points of the combustion engine in the tested bus when the road measurements on the test route were made

4.2. Assessment of specific emissions in the measurement windows in the whole test route

Determination of parameters of the measuring windows in relation to the engine work shown in Figure 7. The determined values of specific emissions of gaseous exhaust components show that the values obtained in the context of EU Regulation 582/2011 are lower than during the entire measurement cycle (Fig. 8).

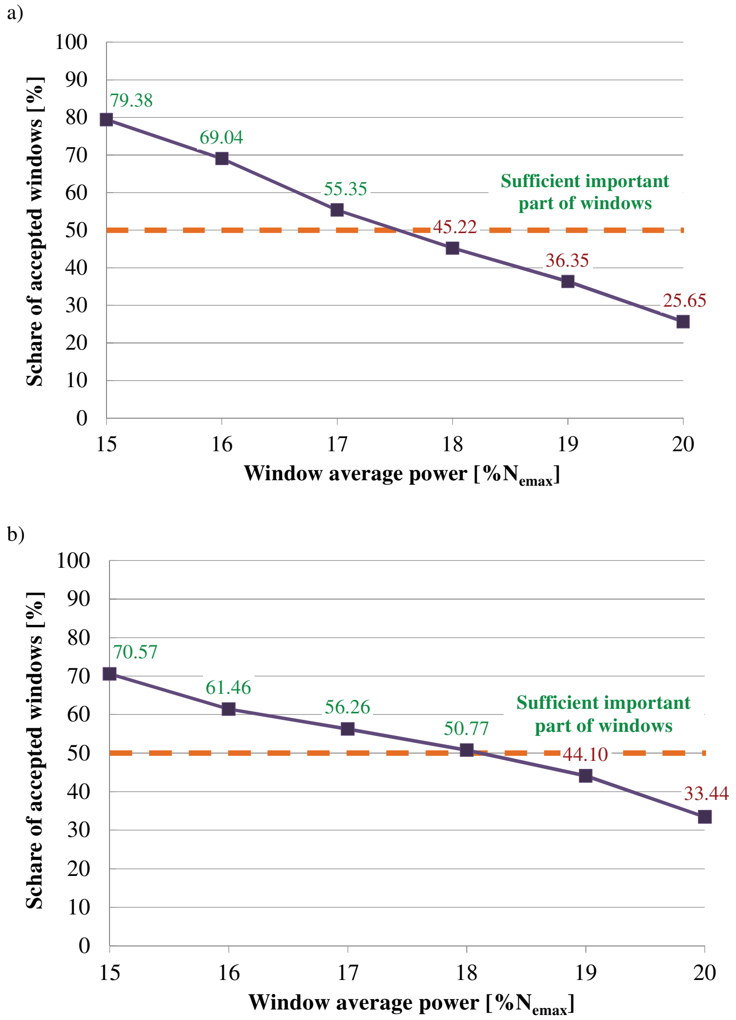

Fig. 7. The share of accepted measurement windows relative to the average power in the window [%N_{emax}] in tests: a) ETC, b) WHTC

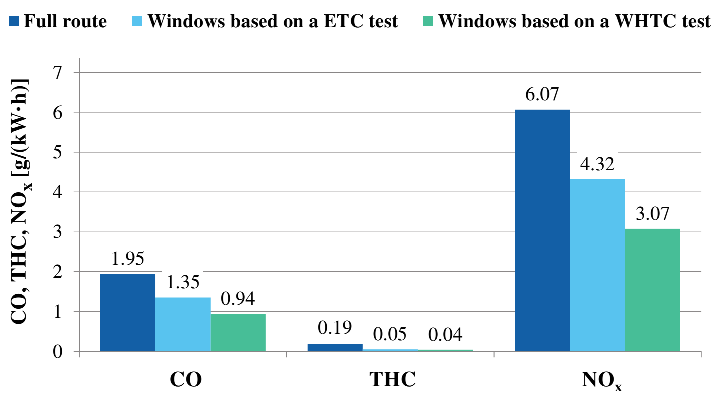

Fig. 8. Specific emission of CO, THC, NO_x and CO_2 obtained from the measurements made on the whole test route as well as in measuring windows (ETC, WHTC tests)

Due to the nature of urban traffic it is difficult to get a 50% share of the valid measurement windows, while maintaining the condition to get 20% of the N_{emax} value (Fig. 7). For this reason, it was necessary to decrease the value by 1% in accordance with the procedure described in [9]. In terms of ETC test the ability to assess the pollution generated for an average power measurement window of 17% N_{emax} (35.5 kW), whereas while referring to the WHTC the accepted windows had to be 18% of N_{emax} (37.6 kW). In the current dynamic type approval test there is less load on the engine and therefore the total work it generates is also smaller, which has a beneficial effect on the ability to determine the measurement intervals. It should also be noted that the engine used in the hybrid bus operated in the idle range to a lesser extent, and therefore the calculation of the average power of measurement windows it provides the best solution. In contrast, for a conventional drive, where the engine parameters are largely dependent on the conditions of vehicle movement it is more difficult, and sometimes impossible, due to the greater share of operating time in the area of smallest load and speed resulting from the characteristics of urban operation and visiting bus stops.

As required by [9] the research measurements were performed continuously and the complete collection of recorded data was used for the analysis. For the purposes of this research, the conformity factor was determined for the bus, while the calculations using the formula (4) were referred to the Euro V–EEV standard, as that was the standard used for the type approval of the tested vehicle. The averaged results for subsequent harmful exhaust gas components were: $CF_{CO} = 0.45$, $CF_{THC} = 0.4$ and $CF_{NOx} = 2.16$. For CO and THC over 90% of the obtained results had values of less than 1.5; while for NO_x only 32.4% of the windows measured met this condition. The internal combustion engine's operating parameters were favorable for use with the measuring windows because the engine was idle for a very limited amount of time. The lowest emission rates were achieved in the windows defined based on a WHTC test, which was the result of their shorter duration.

5. Conclusions

The operating conditions of city buses are specific due to the nature of the realized transport route, the line load and the number of stops on the route, and these parameters have a direct impact on the operating conditions of the drive systems used in the vehicles. Research pilot programs are currently conducted worldwide, and laws are introduced that codify the research of vehicle emissions in real operating conditions. The article presents a study of a hybrid city bus in light of the current legal rules on the operating compatibility – EU Regulation 582/2011. Due to the characteristics of the vehicles used for the research the following assumptions were made when analyzing the research results: the obtained values were compared to emission standards as well as the currently enforced Euro V–EEV tests. The results of this research indicate that the conformity factors CF obtained using the moving measuring windows method are different (the emission of pollutants is smaller) than for the whole test cycle. Moreover, based on the assumptions made for the measurements procedures, it can be stated that the assessment of the operational compatibility is often impossible to carry out for urban buses, due to the time requirements involving non-urban drive share.

Acknowledgements

The research was funded by the National Centre for Research and Development (Narodowe Centrum Badań i Rozwoju) – research project within the Applied Research Programme (contract No. PBS3/A6/25/2015).

Nomenclature

CF	conformity factor
e	emission of harmful exhaust components
EEV	enhanced environmentally friendly vehicle
ELR	European Load Response
ESC	European Stationary Cycle
ETC	European Transient Cycle
FID	flame ionization detector
GPS	global positioning system
HDV	heavy-duty vehicle
LAN	local area network
L_j	permissible emission of pollutants j in WHTC test
m	mass
NDIR	non-dispersive infrared
NDUV	non-dispersive ultraviolet
N_e	combustion engine power output
PEMS	portable emission measurement system
RDE	real driving emissions
SORT	standarised on-road tests
W	combustion engine work
WHSC	World Harmonized Stationary Cycle
WHTC	World Harmonized Transient Cycle

Bibliography

[1] ENGELJEHRINGER, K. Automotive emission testing and certification. past, present and future. *Conference materials: 2nd International Exhaust Emissions Symposium*, Bielsko-Biała 2011.

[2] FULPER, C. New Measurement techniques & procedures for measuring "real world" emissions with PEMS and PAMS. *2013 PEMS Conference & Workshop University of California*, Riverside 2013.

[3] Central Statistical Office of Poland: transport – wyniki działalności w 2014 roku. *Zakład Wydawnictw Statystycznych*, Warszawa 2015.

[4] MERKISZ, J., FUĆ, P., LIJEWSKI, P., ZIÓŁKOWSKI, A., RYMANIAK, Ł. The research of exhaust emissions and fuel consumption from HHD engines under actual traffic conditions. *Combustion Engines*. 2014, **158**(3), 56-63.

[5] MERKISZ, J., PIELECHA, J., NOWAK, M. Exhaust emissions from vehicles in real traffic conditions on the example of Poznan agglomeration. *Postępy Nauki i Techniki*. 2012, **15**.

[6] MERKISZ, J., RADZIMIRSKI, S. Nowe przepisy Unii Europejskiej o emisji zanieczyszczeń z pojazdów samochodowych. *Transport Samochodowy*. 2011, **2**, 41-70.

[7] NYLUND, N.O., ERKKILÄ, K., HARTIKKA, T. Fuel consumption and exhaust emissions of urban buses. *VTT Tiedotteita Research Notes 2373*, Helsinki 2007.

[8] PETROVIĆ, V.S., JANKOVIĆ, S.P., TOMIĆ, M.V., JOVANOVIĆ, Z.S., KNEŽEVIĆ, D.M. The possibilities for measurement and characterization of diesel engine fine particles – a review. *Thermal Science*. 2011, **4**(15), 915-938.

[9] Commission Regulation (EU) No 582/2011 of 25 May 2011 implementing and amending Regulation (EC) No 595/2009 of the European Parliament and of the Council with respect to emissions from heavy duty vehicles (Euro VI) and amending Annexes I and III to Directive 2007/46/EC of the European Parliament and of the Council.

[10] Regulation (EC) No 595/2009 of the European Parliament and of the Council of 18 June 2009 on type-approval of motor vehicles and engines with respect to emissions from heavy duty vehicles (Euro VI) and on access to vehicle repair and maintenance information and amending Regulation (EC) No 715/2007 and Directive 2007/46/EC and repealing Directives 80/1269/EEC, 2005/55/EC and 2005/78/EC.

[11] Sensors Inc. Emissions measurement solutions. SEMTECH® DS On Board In-Use Emissions Analyzer. Erkrath 2010.

[12] SHARPE, B., MUNCRIEF R. Literature review: real-world fuel consumption of heavy-duty vehicles in the United States, China, and the European Union. *International Council on Clean Transportation*, Washington DC 2015.

[13] The International Council on Clean Transportation (ICCT): Global transportation roadmap model (www.theicct.org/global-transportation-roadmap-model, access: 3.08.2015).

[14] http://gpsvisualizer.com (access: 29.10.2016).

Prof. Jerzy Merkisz, DSc., DEng. – Faculty of Machines and Transport at Poznan University of Technology.

e-mail: *Jerzy.Merkisz@put.poznan.pl*

Łukasz Rymaniak, DEng. – Faculty of Machines and Transport at Poznan University of Technology.

e-mail: *Lukasz.Rymaniak@put.poznan.pl*