Exhaust emissions from small engines in handheld devices

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Abstract. The paper presents the results of investigations on the exhaust emissions carried out under real operating conditions of gasoline engines operating in a power generator and a chainsaw. During the operation of these devices the authors measured the following exhaust emissions: CO, HC, NO_x and CO₂. For the measurements the authors used a portable exhaust emission analyzer SEMTECH DS by SENSORS. This analyzer measures the concentrations of the exhaust gas components in an on-line mode while the engine is running under real operating conditions (road, field etc.). The exhaust emissions tests of non-road engine applications are performed on engine test beds in the NRSC (ISO 8178) and NRTC tests. The presented method is a new solution in determining of the exhaust emissions from such engines. The obtained results were compared with the applicable emission requirements. Besides, based on the performed investigations, the authors attempted an evaluation of the possibilities of the use of the measurement method for development works related to the reduction of the emission from small gasoline engines.

1 Introduction

Combustion engines in their various applications still remain the main source of propulsion. Aside from typical applications in on-road vehicles, combustion engines are also fitted in non-road vehicles and machines. A numerous group are small engines used in handheld devices (handheld chainsaws, lawnmowers etc.), small power generators or scooters. The number of these small engines grows rapidly, the example of which are scooters. The global market for motorcycles, scooters, and mopeds is projected to reach 61.2 million by 2020, driven by population growth, urbanization and expanding middle class population countries [1]. Unfortunately, this is followed by an increased global fuel consumption (CO₂ emission) and exhaust emissions. It is noteworthy that small engines are a serious threat to the natural environment. The exhaust emission limits for these vehicles are more liberal compared to other on-road engine applications.

Homologation tests related to exhaust emissions from small spark ignition engines, used to power handheld devices are carried out in stationary tests i.e. for constant engine speeds and loads (NRSC – Non Road Stationary Cycle, Fig. 1) [2]. In recent years, tests performed under engine actual operating conditions are gaining in importance (RDE – Real Driving Emissions). These tests are performed with the PEMS equipment (Portable Emission Measurement System). The fundamental advantage of such tests is the coverage of all actual conditions of operation and aspects of a combustion engine, which is hardly reproducible under laboratory conditions during tests performed on engine test beds. When analyzing the literature, we need to stress the RDE tests are performed for a variety of vehicle categories

(on-road vehicles [3-8], non-road vehicles [9-14] or aircraft [15-17]). In the said works, particular attention was drawn to several aspects such as the research methodology, exhaust emissions level and engine operating parameters. The advancement of RDE tests made them commonplace and resulted in their introduction in the homologation procedures of on-road as well as non-road vehicles (NRMM – Non Road Mobile Machinery). It is to be stressed that the exhaust emissions tests on small engines operating under actual conditions of operation are rarely performed and the results are rarely published. In few relevant publications the authors indicate the potential problems related to the testing of small engines [18, 19]. Exhaust emission important issue for non-road and small engine is vibration in occupational lives [20, 21]

The largest problem is the lack of appropriate testing equipment of compact, light design adapted to the testing of small engines in terms of the measurement range. The adaptation is also the case for such parameters as concentration of the exhaust components or the measurement of the exhaust mass flow [19, 22].

Fig. 1. NRSC (ISO 8178-G3) cycle for handheld rated speed applications.

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Another problem is that the recording of the engine operating parameters is impossible (engine speed and load), which, in the case of on-road vehicles (thanks to the OBD system fitted) is very simple [18]. Hence, it appears fully justified to initiate research in terms of exhaust emissions from small engines. Eventually, the RDE tests performed on small engines should be included in the homologation procedures, as is in the case of engines of regular on-road vehicles. This, however, requires resolving of a variety of issues, developing methodology, and adapting engines and the measurement equipment. This paper is one of the first works devoted to the said problems.

2 Testing methodology and measurement equipment

The exhaust emission tests were performed under actual engine operating conditions. The investigated equipment (handheld chainsaw, power generator) performed typical work not different from that carried out on a daily basis. The technical specifications of the tested engines have been presented in Table 1 and the view of the investigated equipment in Figure 2.

Table 1. Technical specifications of the tested engines.

	Handheld chainsaw	Power generator
Engine type	2-stroke, air cooled, spark ignition	4-stroke, air cooled, spark ignition
Displacement	64 cm ³	170 cm ³
Power output	1.8 kW/12000 rpm	4.25 kW/3000 rpm

Fig. 2. View of the equipment during the tests (handheld chainsaw and power generator).

The engines in the investigated equipment operate mainly at two engine speeds: idle and maximum (or close to maximum). The tests were, thus, performed according to a scenario of a test presented schematically in Figure 3. The entire test for each device lasted approx. 30 min. The measurements of the concentrations of the exhaust components and the exhaust mass flow were performed on a continuous basis and were initiated immediately after the start of the engines. The schematic of this procedure was typical of regular operation of these machines. The measurements carried out in this way allow for the engine cold start and non-stationary

operating conditions – changes in the engine speed (from idle to the operating engine speed) and load.

Fig. 3. Course of the cycle according to which the tests were performed.

One of the main test objectives was the application of the Semtech DS measurement equipment. However, due to the high concentrations of the exhaust components emitted by the power generator that exceeded the measurement range of the Semtech DS analyzer, it was necessary to use the Testo 360 device. Even then, the emission was still out of the measurement range, which is why the results of the tests related to this component were not included in the paper. The typical PEMS analyzer (Semtech DS.) was used only for the testing of the handheld chainsaw. The technical specifications of both analyzers have been presented in Tables 2 and 3.

Table 2. Characteristics of Semtech DS, a portable exhaust emissions analyser.

Parameter name	Measurement method	Accuracy
1. Emissions		
CO	NDIR, range 0–8%	±3%
HC	FID, range 0–10.000 ppm	±2%
NO _x (NO + NO ₂)	NDUV, range 0–2500 ppm	±3%
CO ₂	NDIR, range 0–20%	±3%
O ₂	Electrochemical, range 0–25%	±1%
2. Data storage capacity	Over 10 hours at 1 Hz data acquisition rate	
3. Interface	SAE J1850 (PWM), SAE J1979 (VPW)	

Table 3. Characteristics of the Testo 360 exhaust analyser.

Parameter name	Measurement range
CO ₂	0–25 Vol %
NO	0–3000 ppm (0–6160 mg/m ³)
NO ₂	0–500 ppm (0–1030 mg/m ³)
NO _x (NO + NO ₂)	0–3500 ppm (0–7190 mg/m ³)
CO	0–10000 ppm (0–12560 mg/m ³)
SO ₂	0–5000 ppm (0–14650 mg/m ³)
O ₂	0–21 Vol. %
With integrated absolute pressure measurement	40–1200 hPa
Temperature FT	–40–1200 °C

For the measurement of the exhaust mass flow, Semtech EFM-HS (High Speed Exhaust Flow Meter) was applied. Its technical specifications have been presented in Table 4.

Since the investigated engines were not equipped with on-board diagnostic systems enabling the recording of the engine speed, an AVL DiTEST Speed 2000 device was applied.

Table 4. Characteristics of a High Speed Exhaust Mass Flow Meter – Semtech EFM-HS.

Parameter name	Value
Exhaust temperature range	–5 to 700 °C standard, higher temp capability available upon request
Exhaust temperature accuracy	±1% of reading or ±2°C, whichever is greater
Flow measurement linearity	< 1.0% of full scale (exceeds 1065 Subpart D and ISO 16183 standards)
Flow measurement accuracy	±2% of reading or ±0.5% of full scale, whichever is greater
Warm-up time	< 5 minutes at 20 °C ambient
Data rate	5 Hz standard
High speed option data rate	500 Hz (100 Hz display rate)
Flow tube outer diameter	25 mm
Flow tube length (length including extension)	508 mm
Flow rate at 100 °C	6.9 – 85 kg/h
Flow rate at 400 °C	10.4 – 64 kg/h

3 Results and analysis

Figures 4, 5 and 6 present the hourly exhaust emission of HC, CO and NO_x. These are selected fragments of the entire test cycle. Thanks to these curves we may analyze the influence of a variety of factors (e.g. engine speed and load) on the emission changes. For the engine of the chainsaw, the curves showing the emission of HC, CO and NO_x we can clearly see the influence of particularly the engine speed and load on the exhaust emissions. The changes of the engine load result from the specificity of the chainsaw operation. This load is variable, which results from the chain resistance in contact with timber. In this case, the load changes very dynamically in a wide range.

Fig. 4. HC emission from the chainsaw in the test cycle.

Fig. 5. CO emission from the chainsaw in the test cycle.

Fig. 6. HC emission from the chainsaw in the test cycle.

These changes are most visible in Fig. 7 showing the curve of the mass flow and temperature of the exhaust. The emission of all three exhaust components was close to zero when the engine idled (the fragment from approx. 500 to 550s). Besides, it is noteworthy that in the initial phase of operation (up to approx. 100 s) a relatively high emission of CO and HC occurred while the emission of NO_x was rather low. This was the start of the engine operation and it most likely resulted from the engine thermal state (engine was cold).

Fig. 7. The curves of the exhaust mass flow and temperature of the chainsaw engine during the tests.

In the case of the engine fitted in the power generator, the hourly emission of HC and CO changes proportionally to the engine load (Fig. 8 and 9). The

engine load was determined based on the energy consumption by the electrical receivers. The power generator operated at a steady engine speed of 3000 rpm. Similarly to the chainsaw engine, in the initial phase of operation we may observe an increased emission of HC and CO.

The nature of the emission changes along the changes in the engine load is most visible for HC, for which the change of load immediately results in an increased emission of this exhaust components and the temperature (Fig. 8). The changes in the emission of CO are not as great as it is in the case of HC.

Fig. 8. HC emission from the power generator and temperature changes in the test cycle.

Fig. 9. CO emission from the power generator in the test cycle.

Figure 10 present the results of the measurements of the exhaust emissions and the applicable Stage III emission limits (standard applicable to the investigated equipment). It should be noted that the tests according to the European standards are performed under different conditions – these are laboratory tests carried out on measurement test stands, which is why the comparison is for information purposes only. Additionally, since the engine load of the handheld chainsaw was not measured, it was arbitrarily assumed at 80% of the nominal power output throughout the entire test. In this case, the results are for information purposes as well. From the presented comparisons it results that the emission of CO and $\text{NO}_x + \text{HC}$ under actual operating conditions of the chainsaw is greater than the admissible values similarly to the emission of HC and CO from the power generator

(NO_x not included, because the concentration was out the measurement range).

Fig. 10. Comparison of the exhaust emissions from the handheld chainsaw, the power generator and Stage III limits.

4 Conclusions

The results of the investigations presented in the paper and their analysis confirm that the selected method of testing under actual conditions of operation may be successfully applied in works on the advancement of small engines fitted in handheld devices. It is however, necessary to continue works on the improvement of not only the measurement equipment dedicated for the engine of these devices but also the engines themselves. The measurements carried out on small engines are different from the measurements performed on the engines of on-road vehicles, which results from their specificity, conditions of operation as well as their design. One of the more important issues the needs to be resolved is the measurement of the engine speed and engine load that, contrary to on-road engines, are currently impossible to measure in majority of engines from the small engine category. Another issue is the adaptation of the PEMS measurement equipment. Majority of these devices have the exhaust components and exhaust mass flow measurement ranges out of the range that would correspond to the category of small engines. An additional problem is the need of a compact design of the measurement equipment. The development of the testing methodology for small engines operating under actual conditions, allowing for the specificity of operation of these devices also needs to be addressed.

The conducted research indicates that the engine load and speed have a significant impact on the exhaust emission of the tested engines. The operation of the chainsaw engine is characterized by changes in engine speed and engine load, which is expected to be the cause of the relatively high exhaust emissions. The impact of the engine load on the exhaust emission is clearly visible for the power generator engine, especially for the HC emission. Measured in real operating conditions, both HC and CO emissions are higher than the permissible values, which is likely due to different engine operating conditions. Therefore, changes in research test procedures (type approval) should be sought that aim to better reflect actual operating conditions of the tested units.

While carefully following the current trends in engine exhaust emissions, it appears fully justified to undertake emission research related to small engines working under actual operating conditions. In the future such research should be included in the homologation procedure.

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