The on-road exhaust emissions from vehicles fitted with the start-stop system

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Abstract. The paper describes the influence of the start-stop system on the exhaust emissions and fuel consumption. The tests were performed for two vehicles. The first one was a vehicle designed specifically to operate in city conditions. It was fitted with a gasoline engine of the displacement of 0.9 dm^3 and maximum power output of 63.7 kW. The other vehicle was an SUV (Sports Utility Vehicle) fitted with a diesel engine of the displacement of 3.0 dm^3. The measurements of the exhaust emission were carried out on the same route under actual traffic conditions. For the tests a portable exhaust emissions analyzer from the PEMS group – SEMTECH DS was used (PEMS – Portable Emissions Measurement System).

Introduction

One of the consequences of the advancement of global civilization as has been observed in the last decades is an increased demand for energy resources. This situation is particularly conspicuous in developing countries such as China and India. As recent research shows (carried out by institutions responsible for energy management) excess use of fossil fuels may lead to their early depletion. Hence, a variety of legal acts have been introduced aiming at limiting the use of conventional energy sources. These attempts have already earned a name and are referred to as Global policy of sustainable use of conventional energy resources [7]. In the automotive industry this policy is realized chiefly through the introduction of increasingly stringent exhaust emission limits and attempts to reduce the fuel consumption. In order to reduce the fuel consumption by vehicles the European Union has attempted to extend the homologation regulations related to the exhaust gases, in order to introduce limits of average emission of CO_2 from the whole vehicle fleet of a given vehicle manufacturer. The effect of these actions is the introduction of two regulations– 443/2009 and 510/ 2011 [1-2] that precisely determine both the CO_2 emission limits and the way to achieve this. It was assumed that from 2015 the average CO_2 emission limit from a given fleet would be 140 g/km. The effect of these attempts are new solutions in vehicle powertrains. Among the main trends in the development of powertrains there is constant modernization and technological powertrain advancement or the application of hybrid and electric powertrains. Currently, with a high level of probability we can forecast that a combustion engine will remain a prevailing source of vehicle propulsion for years to come, if not as a standalone unit then certainly in a hybrid configuration [3-4]. The application of typical electric powertrais belongs to a more distant future. One of a group of systems increasingly used in vehicles is a start-stop system. The system deactivates the engine when the vehicle is stationary in traffic jams. The reason for the application of this solution is the reduction of the fuel consumption and exhaust emissions. The tests on the influence of the application of the start-stop system on the exhaust emissions and fuel consumption are the subject of this paper.

Characterisics of the research obejcts

For the evaluation of the start-stop system two vehicles were selected. Vehicle A was fitted with a turbocharged gasoline engine of the displacement of 0.9 dm^3, fitted with a three way catalytic converter (Tab 1). The engine was characterized with a volumetric power output index of 70.8 kW/dm^3. This is an excellent example of a downsized engine. The application of the start-stop system requires an introduction of a variety of modifications of the engine starting system and an application of an advanced engine control system fully compatible with the CAN bus. In the first research object (vehicle A) a specially modified starter motor was used (more powerful and more durable than the standard version Fig. 1). The said starter motor ensures a greater number of successful engine starts due to the application of modified materials used for its manufacturing. The modification of the materials and geometry ensured a reduction of noise in the starting phase and an increased power output, which reduces time needed for the engine start.

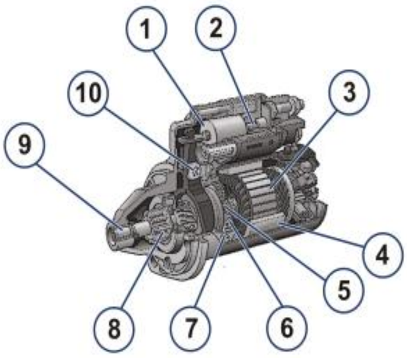

Fig. 1, Schematics of the starter motor used in the tested vehicle A: 1 – activation relay; 2 – springs; 3 – electric motor; 4 – permanent magnets; 5 – transmission; 6 – gears with a roller bearing; 7 – transmission with torsion dampers; 8 – attacking gear; 9 – final sleeve with a roller bearing; 10 – lever [9]

In vehicle A a battery of increased capacity was also used, which ensured the required energy for repeated engine starts when the alternator was not in operation. In the negative terminal of the battery a battery level sensor was installed play a fundamental role in the start-stop control system (Fig. 2). The sensor provides information to the system on the battery voltage, current and internal temperature. This information is used by the control system to activate or deactivate the start-stop system. In order to prevent the vehicle systems from damage due to voltage drop a special voltage stabilizer is used when the start-stop system is engaged.

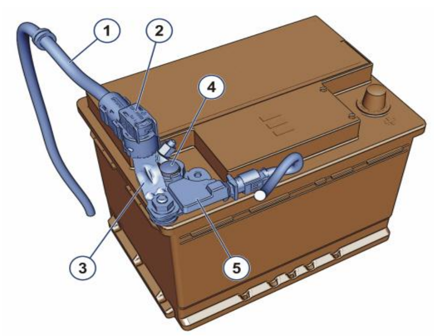

Fig. 2, The battery with the sensor: 1 – ground wire; 2 – quick discharge negative terminal; 3 – connection between the terminal and the sensor; 4 – negative terminal; 5 – the sensor [9]

Vehicle B was fitted with a diesel engine of the displacement of 3.0 dm^3. In this case the volumetric power output index amounted to 58.7 kW/dm^3 and was lower by 17% than the index of vehicle A. The engine of this vehicle was fitted with a diesel oxidation catalyst (DOC) and a diesel particulate filter.

Table 1, Characteristics of the tested objects [9]

	Vehicle A	**Vehicle B**
Type of ignition	Spark ignition	Self ignition
Engine displacement	0.9 dm^3	3.0 dm^3
Cylinder number and arrangement	Straight– 2	V – 6
Maximum torque	145 N·m at 1800 rpm	550 N·m at 2000÷2250 rpm
Volumetric power output index	70.8 kW/dm^3	58.7 kW/dm^3
Injection system	MPI	Common rail
Aspiration	Turbocharger	Turbocharger
Aftertreatment system	TWC	EGR, DPF, DOC
Type of transmission	Automated	Automatic

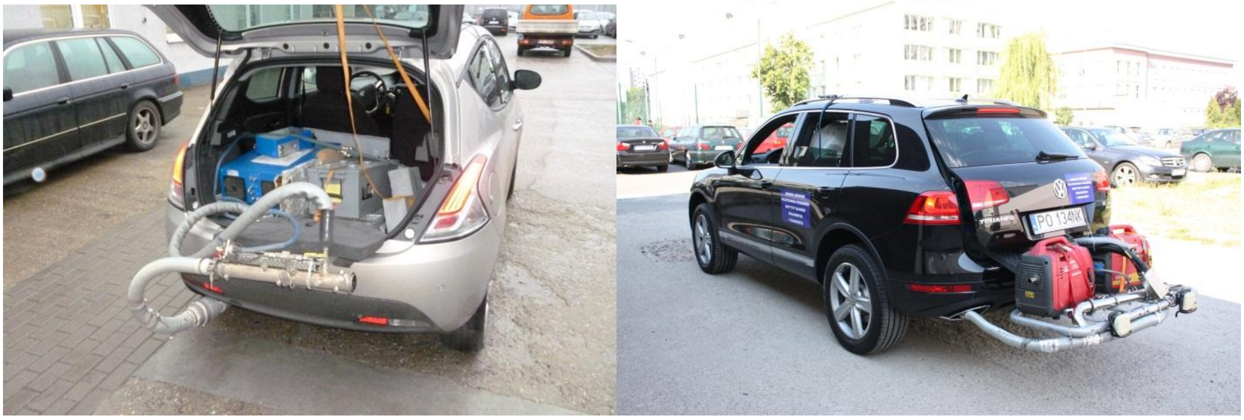

Fig. 3, The tested objects ready for the on-road exhaust emissions tests

Testing methods and experimental equipment

Exhaust emissions tests (CO_2, NO_x, CO, THC) were performed in real operating conditions of the vehicle in traffic in the city of Poznań. The vehicle route during the tests is shown in figure 4 The length of the route was 12.71 km, it was diversified and included a typical urban section and an extra-urban section, where it was possible to drive at highway speed (with maximum speed of 120 km/h). The extra-urban section was 5.5 km long. As shown in figure 4, the length of the vehicle route during the road test was similar to the length of the vehicle route in the NEDC test [5]. The time of drive in road tests, approximately 1200 s, was similar to the time of drive in the NEDC test.

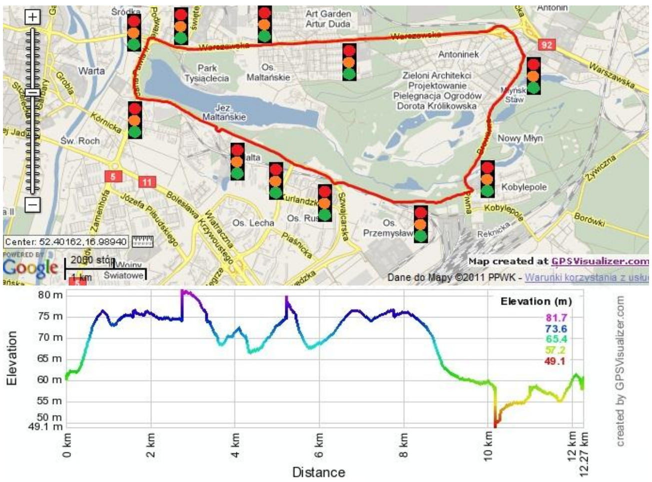

Fig. 4, The marked road used for the testing of exhaust emissions (read line)
[created by GPSVisualizer.com]

For the measurement of the concentration of the exhaust emissions a portable exhaust emissions analyzer (SEMTECH DS by SENSORS) was used. The analyzer measures the concentration of the exhaust components and simultaneously measures the flow rate of the exhaust gases. The exhaust gases are introduced into the analyzer through a probe maintaining the temperature of 191°C. Then the particulate matter is filtered out (compression ignition engine) and the exhaust is directed to the flame-ionizing detector (FID) where HC concentration is measured. The exhaust gases are then chilled to the temperature of 4°C and the measurement of the concentration of NO_x (NDUV analyzer), CO, CO_2 (NDIR analyzer) and O_2 follows in the listed order. It is possible to add data sent directly from the vehicle diagnostic system to the central unit of the analyzer and use the GPS signal. In the tests not only the measurements of the emissions were used but also, for the purpose of comparison, signals from the on-board diagnostic system were recorded, e.g. engine speed, load, vehicle speed, intake air temperature, etc. Some of these signals served to specify time density maps presenting the share of the operating time of the vehicles under actual operating conditions [5-6].

Results

In order to determine the efficiency of the start-stop system the measurements of the exhaust emissions were performed for the enabled and disabled system. Average speed was selected as a criterion decisive of the possibility of comparison of both drives of the vehicles. Its maximum relative difference was assumed on the level of 5%. For vehicle A the relative speed difference was 3,5% and for vehicle B – 5%.

Based on the data recorded from the OBD system of the vehicles the operating time share characteristics of the vehicle engines were made depending on the engine speed and torque (Fig. 5). In the case of vehicle A, thanks to the start-stop system, as much as 10% of the driving time the engine was off and for vehicle B it was this time amounted to 5%.

a) b)

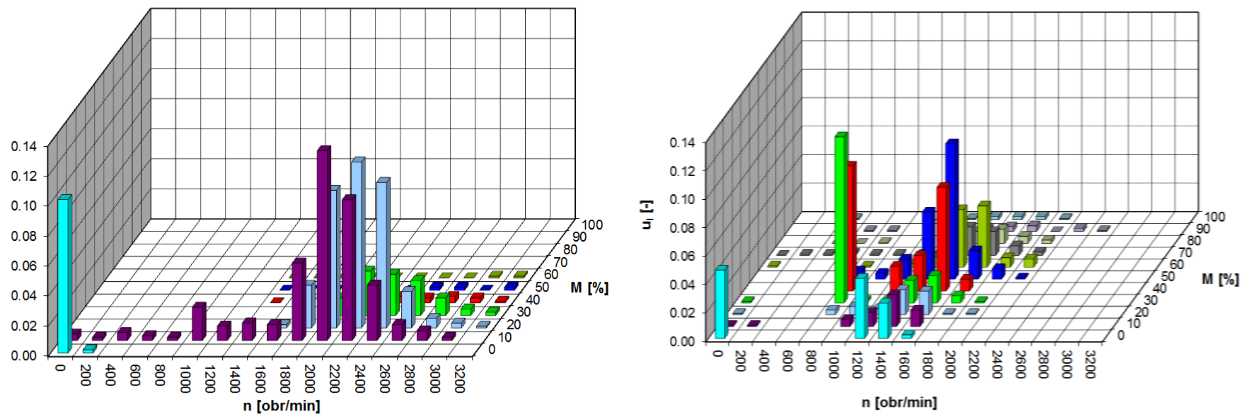

Fig. 5, Characteristics of the operating time share referred to the engine: a) of vehicle A, b) of vehicle B

Figure 6 presents the changes in the exhaust emissions measured with the second-by-second resolution (CO_2, NO_x, CO, THC) and the engine speed on the example of vehicle B during a drive with the start-stop system activated. Having analyzed the obtained courses we observed that the system switched off the engine three times. The effect of this was obviously zero emission of CO_2 at that time. It has also been observed that in the first half of the test (0-600 s) the maximum values of the emission of CO_2 were lower than for the second part of the test. This depended on the characteristics of the test route – the second part of the test was a drive close to the extra urban traffic conditions (a road portion of the entrance to the city). On this road portion greater speed was obtained which resulted in an increased energy demand of the engine, hence a growth in the emission of CO_2. In the case of the exhaust emissions of NO_x and CO a similar situation was observed. The highest level of the emission of THC occurred in the first phase of the test. This most likely resulted from a cold engine start – lower temperature of the catalytic converter. We can deduct that the DOC catalyst in the beginning of the test did not reach the light-off temperature. Figure 7 shows the courses of the emissions of CO_2, NO_x, CO, THC and the engine speed of vehicle A overlain on the vehicle route. In these figures we can see an increased emission during drive-off and acceleration.

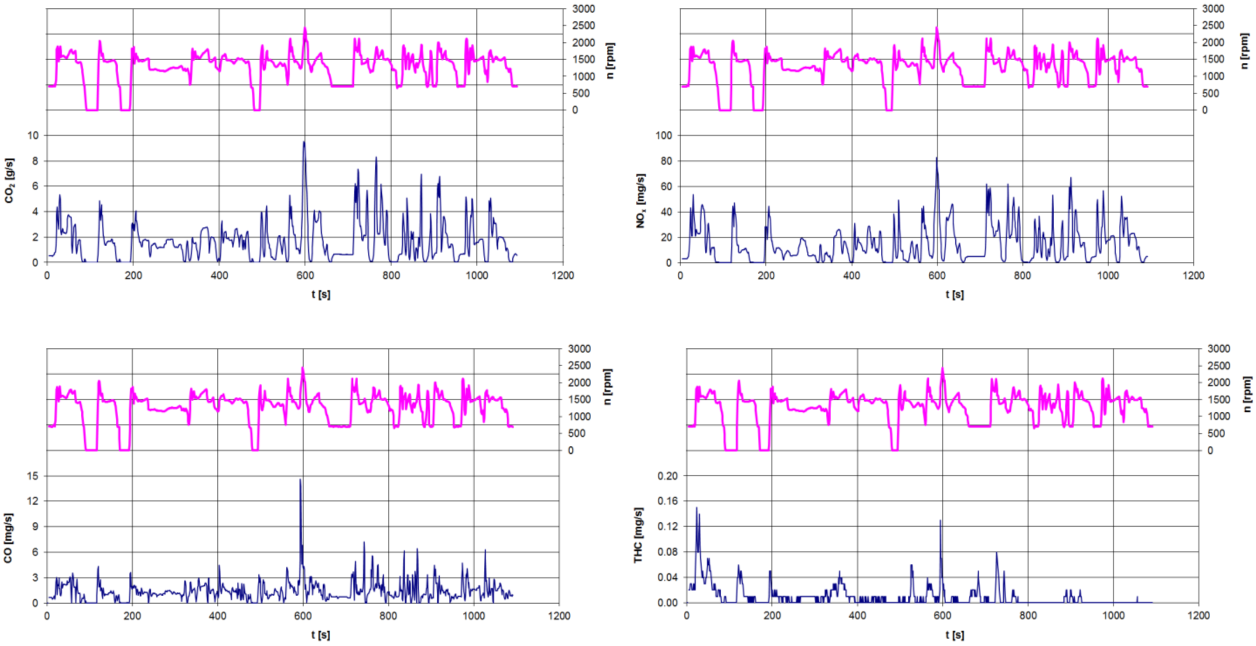

Fig. 6, The courses of the emissions of CO_2, NO_x, CO and THC measured with the second-by-second resolution and engine speed of vehicle B during a drive with the start-stop system enabled

a) b)

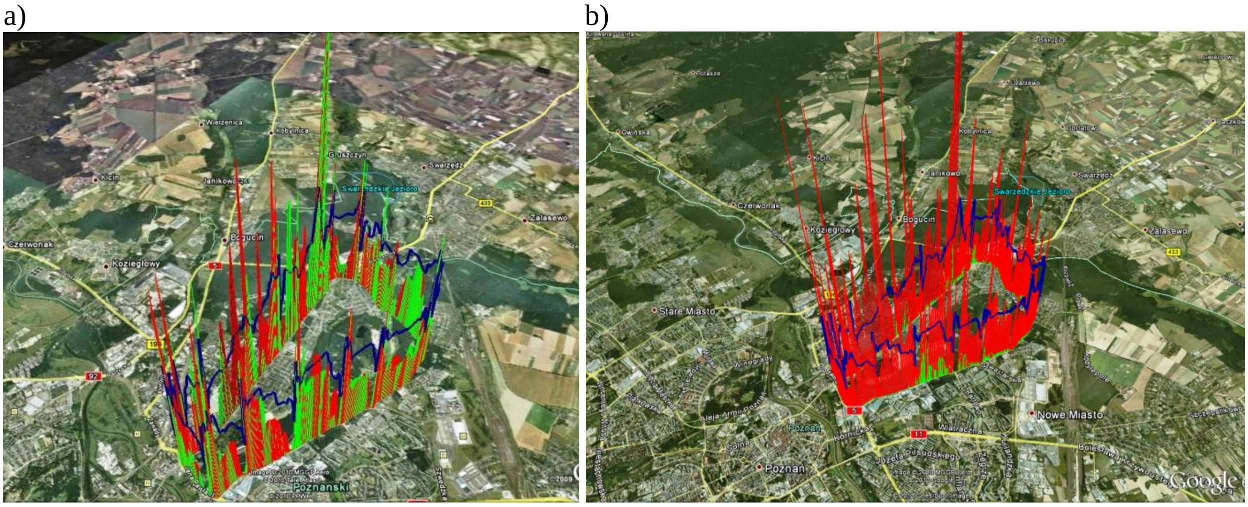

Fig. 7, The engine speed of vehicle A (blue), and the emission (second-by-second resolution) of (a) CO_2 (green), NO_x (red); (b) THC (green), CO (red) overlain on the vehicle route with the start-stop system enabled

Conclusion

Based on the performed measurements the on-road emissions of CO_2, NO_x, CO, THC and a gas mileage were determined. The obtained values were compared to the limits set forth in the Euro 5 standard [8] (Fig. 8). Both vehicles during the tests reached the values of THC and CO emission that fell within the limits. Only in the case of NO_x the limits were exceeded.

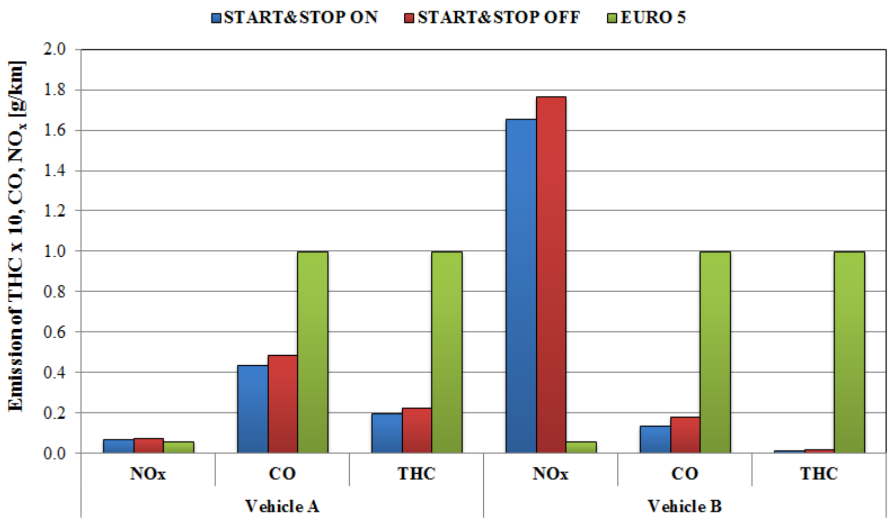

Fig. 8, The obtained on-road emissions of NO_x, CO and THC referred to the limits determined in the Euro 5 standard

The authors also determined the efficiency of the applied start-stop system. For vehicle A the enabling of the system resulted in a reduction of:

- the emission of CO_2 by 7%,
- the emission of NO_x by 8%,
- the emission of CO by 10%,
- the emission of THC by 10%,
- gas mileage by 9%.

For vehicle B a reduction drop has been recorded of:

- the emission of CO_2 by 10%,
- the emission of NO_x by 7%,
- the emission of CO by 8%,
- the emission of THC by 15%,
- gas mileage by 11%.

The obtained results confirm the efficiency of the application of the start-stop system. It is worth emphasizing that the presented results reflect the actual benefits from the application of this system as the tests were performed in actual traffic. Hence, operating factors were taken into account having impact on the exhaust emissions and fuel consumption – factors that are not always considered during laboratory tests.

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