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On-Road Exhaust Emissions from Passenger Cars Fitted with a Start-Stop System

Jerzy Merkisz*
Ireneusz Pielecha*
Jacek Pielecha*
Kamil Brudnicki*

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Abstract

The paper presents the results of on-road (city traffic) exhaust emission and fuel consumption tests related to a vehicle fitted with a start-stop system. The tests of different types of vehicle cruise cycles were performed on road portions of several kilometers under different traffic conditions. For the tests a portable exhaust analyzer SEMTECH DS was used. It measured the concentrations of the exhaust components and the exhaust gas mass flow. As a result the authors determined the usefulness of the engine disengaging systems in vehicles under the conditions of city traffic.

Keywords: start-stop system, exhaust emission, real traffic conditions

1. Introduction

The world's automotive industry is currently undergoing huge changes related to such issues as environment pollution, global warming, generating of waste or society ageing in developed countries. Hence, the aspects related to the protection of environment have gained considerable attention.

Recent years have seen a lot of attention directed at hybrid technology. A hybrid system is defined as a power train that comprises two collaborating different sources of energy or propulsion. Contemporary hybrid electric vehicles (HEV) can

* Poznań University of Technology, Poznań, Poland

be divided into three classes different in terms of their functionality: micro hybrid, mild hybrid and full hybrid [5, 7].

Due to a relatively low power output of the auxiliary (secondary) source of energy the start-stop systems fall into the category of micro hybrid. Their role is to automatically switch off the engine at each vehicle stop. For this to happen a variety of necessary conditions have to be fulfilled at the same time. A restart of the engine takes place when the driver wants to continue the trip. Start-stop systems give considerable fuel economies – on average in an urban cycle 10% and in extremely unfavorable driving conditions such as congested cities up to 20% [1, 2, 4, 6].

To date, this solution has mostly been introduced by passenger vehicle manufacturers, yet some applications in heavy-duty vehicles are known as well. The use of the start-stop systems raised questions related to the exhaust emissions from these vehicles [3, 8]. The inspiration for the tests performed by the authors was to substantiate the idea of start-stop systems application and answer the question whether the exhaust emissions drop along with the reduction of fuel consumption in engines using this system. The bases for the performed measurements were on-road tests under traffic conditions.

2. Research Methodology

The investigations were carried out on a passenger vehicle (Mercedes A 150 Blue Efficiency) fitted with the start-stop option whose basic technical data have been shown in Table 1 and the vehicle view with the fitted testing equipment in Figure 1. The measurements of the on-road exhaust emissions were performed under real road operating conditions in the city of Poznań. For a better reflection of the real road operating conditions two routes were determined: route 1 – around the Lake Malta (faster, having fewer traffic light intersections) and route 2 – a loop through the very center of the city of Poznań (Fig. 2). The tests were carried out in the afternoon hours in moderate city traffic. The conditions were so selected as to avoid their dramatic change in a short time and to compare the exhaust emissions from two cruises. The tests comprised the measurement of the exhaust emissions (CO, CO_2, HC, NO_x) and exhaust mass flow for the drive with the start-stop system on and off subsequently using the data obtained from the OBD (on board diagnosis) system determining the road exhaust emissions.

The tests were performed with the use of a portable exhaust emission analyzer SEMTECH DS by SENSORS. This analyzer measures the concentration of the exhaust emission components and mass flow of the exhaust. The central processing unit of the analyzer received data directly from the vehicle OBD and a GPS system [9].

In the investigations the measurements of the exhaust emissions and the signals from the OBD and GPS were used for comparison [engine speed (n), load (Z), vehicle speed (V)]. Some of these signals were used for the determining of the

Table 1

Technical parameters of the tested vehicle

Quantity	Value
Engine	A 150
Number of cylinders, arrangement	4, in-line
Capacity [cm^3]	1498
Maximum power output: [kW at rpm]	70 at 5200
Maximum torque: [N·m at rpm]	140 at 3500-4000
Maximum speed [km/h]	175
Acceleration [s]: 0–100 km/h	12.6
Fuel consumption [dm^3/100 km] urban cycle/extra urban cycle/mixed	7.4-7.8 / 5.1-5.5 / 5.8-6.2*
Emission of CO_2 [g/km]	139-149*
Starter motor	1 – Regular, high power output; 2 – Starter-generator
Generator	Starter-generator (electric machine)
Battery	Master (regular 70 A·h), Auxiliary (12 A·h)
Transmission	Manual, 5-speed
Emission standard	Euro 5
* Data on the fuel consumption are of comparative nature and were obtained on a test stand as per the 80/1268/EEC standard last updated by 204/3/EEC. The actual values may vary.	

Fig. 1. View of the vehicle during the tests with the fitted SEMTECH DS analyzer

a) b)

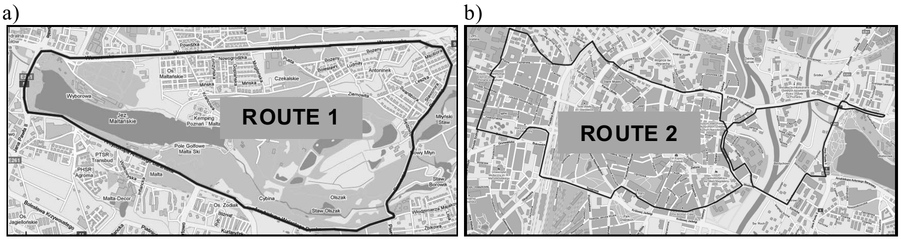

Fig. 2. The routes during the exhaust emission tests:
a) ROUTE 1 – urban area, b) ROUTE 2 – strict city center

time density of the shares of the engine operation (u_i) of a vehicle under real road operating conditions.

3. Test Results of the Exhaust Emissions under Real Traffic Conditions

In order to confirm the repeatability of the performed drives, the shares of the engine operating times were compared as a dependence of speed and acceleration (a) of the vehicle (Fig. 3). For both drives on route 1 the highest share of the engine operation in the tested road conditions fell into the area of low and medium speeds of the vehicle and minimum acceleration. For route 2 (drives through the city center) the share of the engine operating time is more evenly distributed throughout the whole range of speeds for low and medium acceleration.

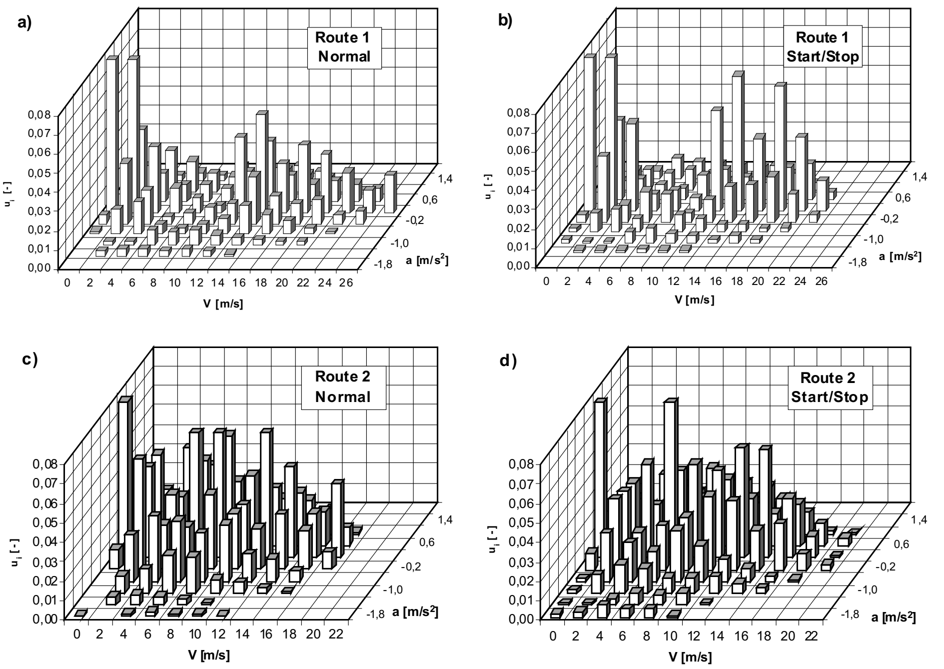

Fig. 3. The operating time shares of the vehicle in the ranges of speed and acceleration: a) route 1– normal, b) route 1 – start-stop, c) route 2 – normal, d) route 2 – start-stop

It is noteworthy that the measurements were conducted under the conditions of real city traffic: hence, strongly variable and uneven. Despite this fact, we could confirm that the drives in the individual routes were characterized by high similarity of the dynamic traffic conditions. Even though the operating time shares of the vehicle were slightly different from one another, the general trend of the characteristics was preserved.

Additionally, a comparison has been performed of the ranges of acceleration, steady vehicle speed, vehicle deceleration, vehicle stop, average speed, average fuel consumption (Q) and route length (S) – (Fig. 4). The differences were minimal and, thus the comparison of the exhaust emission level was possible on these two routes.

The recorded values of the concentrations and the calculated (based on the exhaust volume) exhaust emissions CO_2, CO, HC and NO_x were presented for all the performed drives against their duration (Fig. 5-6). They mainly depend on the characteristics of the drive. The concentration of carbon dioxide is tightly related to the fuel consumption, acceleration and deceleration of the vehicle. The level of carbon dioxide dropping to zero when switched off characterizes the drives with the start-stop system on. An almost steady characteristic on route 1 in the normal mode denotes a cruise under heavy traffic congestion (frequent stops in a traffic jam). The same portion of the route in the start-stop mode is distinguished by frequent engine switch offs. Both drives are characterized by a high variability.

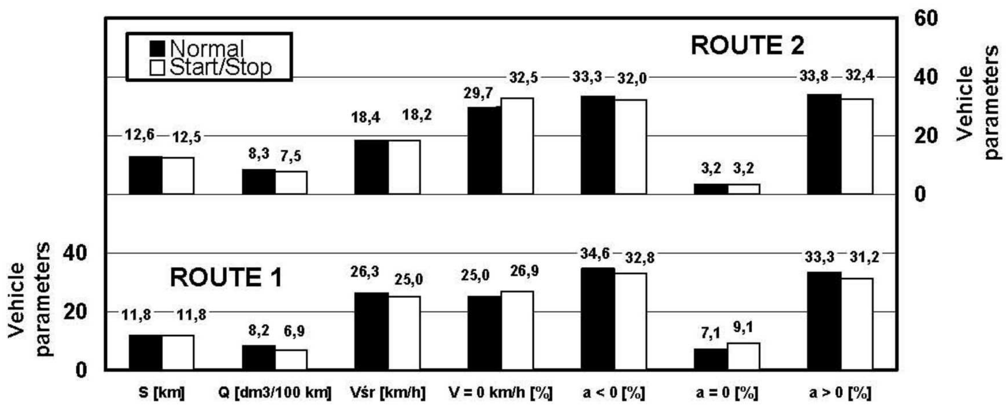

Fig. 4. Comparison of the vehicle driving conditions during the road tests on two routes in the normal and start-stop modes

The concentration of carbon monoxide is significant throughout the whole drive and changes in very limited range. At the same time the period of very high concentration of CO (under heavy engine load for example) is very short, which is influenced by the operation of the catalytic converter. For the drives on route 1 and 2 in the start-stop mode this concentration grows dramatically during engine restart (Fig. 5 and 6). This is also related to the reduction of the temperature of the catalytic converter when stopped in the engine off mode. The concentration of hydrocarbons is analogical to that of CO, but the amount is much lower than concerning CO. The concentrations of nitric oxides are correlated with the vehicle speed and the course of their change is in line with the trends characteristic of the carbon dioxide. Their

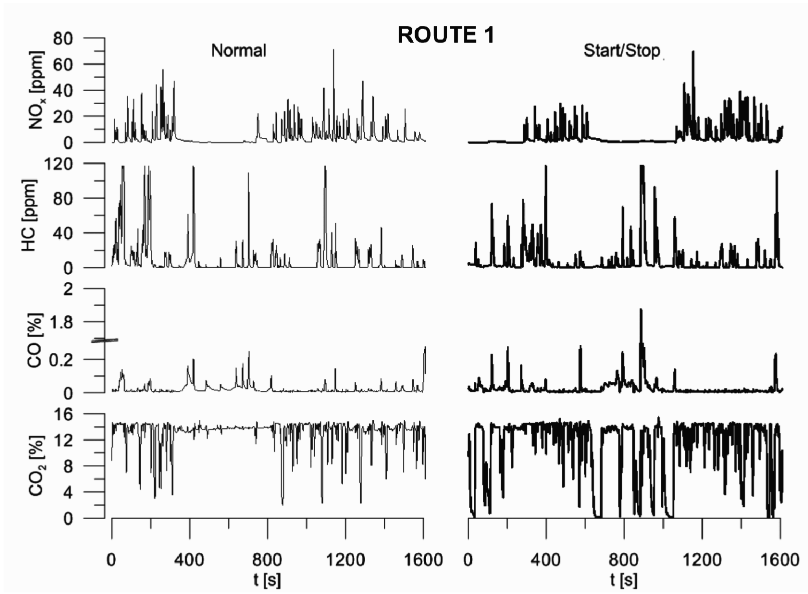

Fig. 5. Concentration of the exhaust emissions on route 1

amount is tightly connected with the thermal state of the engine depending on the traffic phase. When stopped or in the engine off mode the temperature reduces and the concentration of nitric oxides lowers as well.

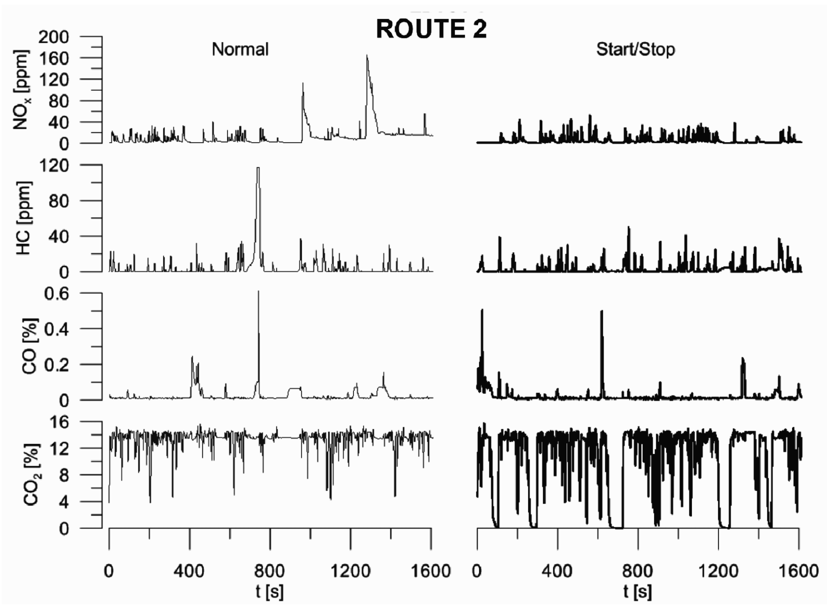

Fig. 6. Concentration of the exhaust emissions on route 2 (strict city center)

From the comparison shown in Fig. 7 it results that the joint mass of the emitted carbon dioxide is higher for the drives through the city center (route 2) irrespective of the drive mode. At the same time from this figure we judge that the drives in the start-stop mode are characterized by a lower joint emission of CO_2 for the individual routes. The joint value of the CO_2 emission for route 1 in the normal mode reaches 2283 g and 1933 g for route 1 in the start-stop mode. For route 2 in the normal mode it equals 3099 g and 2702 g for route 2 in the start-stop mode. The course of the joint value of the CO_2 emission is almost linear for the drives with the start-stop system on. The course for the normal mode is different. We can see abrupt surges of the joint value and they are related to the traffic conditions during the test. Such a surge denotes that the vehicle at this point was not in motion and the engine was running and thus emitting CO_2 – (burning fuel). In such a case the switching off of the engine is a recommended solution.

A lower joint value of the carbon dioxide emission has obviously a significant influence on the fuel consumption during the tests. As has been presented earlier (Fig. 4), for the drives in the start-stop mode higher fuel consumption has been obtained. For route 1 it reduced from 8.2 to 6.9 dm^3/100 km and for route 2 (city center) from 8.3 to 7.5 dm^3/100 km.

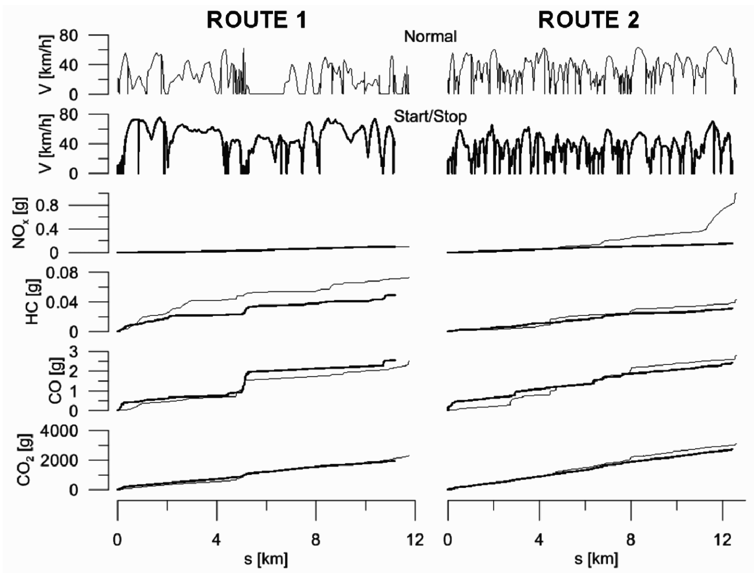

Fig. 7. Exhaust emission in two routes against the speed profiles

The joint mass of carbon monoxide emitted during the tests (Fig. 7) is the only low point of the start-stop system operation. For route 1 in the normal mode it reaches a value of 2508 mg and for the start-stop mode 2553 mg. To a large extent the vehicle emission depends on the engine load, but also the number of engine start-ups and the thermal state of the catalytic converter are decisive. The observed sudden surge of the joint emission for route 1 in the start-stop mode is an effect of the traffic conditions and very frequent engine switch-offs. Even though in this case the value of the joint emission of CO for route 2 in both modes (normal and start-stop) was 2779 mg and 2412 mg respectively, probable is the situation that for a higher number of engine restarts the values of this emission increase for the drives in the start-stop mode.

According to the comparison of the joint mass of hydrocarbons emitted during the test we can see that this emission is higher for route 1 irrespective of the drive mode. This is related to the fact that this route is faster and higher vehicle and engine speeds are reached. These are favorable conditions for higher hydrocarbon emissions. The joint emission of HC for route 1 in the normal mode reaches 72 mg and 49 mg for the start-stop mode and for route 2 in the normal mode 43 mg and 31 mg in the start-stop mode.

From the comparison it results that almost identical value of the joint mass of the nitric oxides was emitted on route 1 for both modes. This value was 98 mg. In this situation the start-stop system does not have a material effect on the emission of NO_x. The results of the drive in the city center are quite contrary (route 2). In the normal mode (route 2) the joint mass of the NO_x emission reaches a dramatic value of 1.003 g and for route 2 in the start-stop mode 0.151 g. In this case the engine start-stop system switch-offs (no combustion process) significantly influenced the reduction of the joint mass of the emitted nitric oxides.

4. Test Results

Using the values of the joint exhaust emissions and the values of the recorded data the on-road emission was obtained for each exhaust component for individual drives. As a result dependencies were obtained indicating that on route 1 only the emission of carbon monoxide was exceeded as opposed to the normal mode, the emission of nitric oxides had the same level and the values of the outstanding road emissions (hydrocarbons and carbon dioxide) were lower. From the comparison it also results that for route 2 (the one in the city center) the values of the road emissions of all the components were lower for the start-stop mode. The active start-stop system efficiently reduced the exhaust emission of the tested vehicle.

Using the values of the road emissions the authors converted it into relative emissions for individual operating modes of the vehicle. The base emission level (100%) was assumed to be the one when the vehicle worked in the normal mode (start-stop system off). This comparison indicates measurable benefits of the start-stop system application. For route 1 the relative emission of CO was 1.4% higher for the start-stop mode and the emission of NO_x stayed on the same level. The other emissions, HC and CO_2 were lower as opposed to the normal mode by 33.3% and 15.8% respectively. For the city center drive (route 2) we obtained the following values of the relative emissions: start-stop mode is characterized by a lower emission of CO (12.7%), lower emission of HC (15%), lower emission of NO_x (85%) and lower emission of CO_2 (11.7%).

The comparison of the exhaust emissions of the drives in the normal and start-stop modes indicates benefits that come from the application of the start-stop system. From the analysis of the test data it results that the values of the emissions in the road tests differ from one another depending on the vehicle operating mode. The table below has been prepared for both the road emission of the individual exhaust components and for the fuel consumption expressed in dm^3/100 km. Table 2 presents the results of the normal and start-stop system comparison.

Table 2

Start-stop system emission test results

Route	Mode	Exhaust emissions [g/km]				Fuel consumption [dm^3/100 km]
		CO_2	CO	HC	NO_x	
Route 1	normal	194	0.213	0.006	0.008	8.17
	start-stop	164	0.216	0.004	0.008	6.88
Difference		30	-0.003	0.002	0.0	1.29
Savings		**15.8%**	**-1.4%**	**33.3%**	**0.0%**	**15.8%**
Route 2	normal	245	0.221	0.004	0.080	8.28
	start-stop	216	0.193	0.003	0.012	7.53
Difference		29	0.028	0.001	0.068	0.75
Savings		**11.7%**	**12.7%**	**15%**	**85%**	**9%**

5. Conclusions

A constantly growing interest in the start-stop systems and their development are dictated by the EU regulations related to the exhaust emissions. These regulations are applicable to all types of vehicles. The regulations regarding the emission of CO_2 in Europe are to be 130 g/km by 2012 and 125 g/km by 2015. This is certainly a good policy and confirms the growing awareness of the society related to the environmental perils that come from human activity.

A growing number of vehicles in the world and pollution of the natural environment causes an increase in the exhaust emission requirements. According to the declarations of the leading vehicle manufacturers the start-stop systems should efficiently reduce both the exhaust emission and the fuel consumption. Analyzing the results of the conducted investigations, we should state that the above assumption puts forward by the vehicle manufacturers is right. A drive on the same route by a vehicle having the start-stop system switched on was characterized by a much lower emission level and lower fuel consumption as compared to the vehicle with the start-stop system switched off. The savings reached the level of 15% on one of the routes (similar data are provided by the manufacturer).

As the vehicle manufacturers assure, the operation of the start-stop system is virtually imperceptible for the driver and, what is more, increases the driving comfort – the vehicle does not generate noise and vibration during the 'engine stopped' mode. Under the test conditions when investigating the system there were no issues related to the reliability of the system either–the engine was switched off each time the situation required such an action. Besides contrary to what the manufacturers claim, the tests were conducted with the air conditioning on, which did not influence the operation of the whole system. The climate control was maintained at the same time reducing the exhaust emissions and fuel consumption.

Comparing the conventional vehicle with the one fitted with the start-stop system we also need to consider the economic factor. Most of the manufacturers gave up additional surcharges for vehicles fitted with this system and treat such vehicle equipment as a standard option. Start-stop systems thus generate economic and ecological benefits right from the beginning of their operation. Under appropriate conditions these benefits can even be more extensive than those confirmed during the investigations.

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