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Analysis of operating parameters of hybrid vehicle under real traffic condition

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Abstract. Nowadays, protecting the environment and reducing harmful emissions is an increasingly discussed topic. One way to reduce vehicle emissions, especially for individual car traffic, is to use a hybrid drive. The advantages of the electric drive and the classic combustion engine are used here. By combining both types of drive, a synergetic effect is achieved, where both drives can be used in optimal operating mode.

The aim of the experiment was to demonstrate the benefit of a hybrid vehicle in real driving. The operating parameters of the Lexus LX400h hybrid vehicle was compared to a conventional low-class vehicle Škoda Fábia 1.2 HTP with a classic SI engine. The experiment took place on a route including typical urban, extra-urban and motorway traffic condition. During experiment, the engine operating parameters and CO, CO_2, HC and NO_X emissions were measured.

The results show that the emission production and fuel consumption of the hybrid vehicle are significantly lower in urban traffic condition than the vehicle with classic internal combustion engine. On the contrary, in motorway conditions, the hybrid vehicle must use both drives, as higher performance is required to overcome higher driving resistances and therefore achieves higher fuel consumption and higher emissions than a conventional vehicle.

Key words: fuel consumption, emission production, urban traffic, energy recuperation.

INTRODUCTION

The reduction of transport-generated energy consumption and consequent emission production are currently a problem of global interest. Hybrid electric vehicles (HEVs) are considered as one promising technological solution for limiting transport-generated energy consumption and emission production. HEVs can be categorised with respect to the level of electric power integration in the powertrain system and the engine-electric motor coupling strategy. HEVs may be classified as either parallel or series in powertrain configuration. Parallel HEVs may be simultaneously powered by the engine and electric motor. In a series HEV, the drive system is solely powered by the electric motor that draws its power from the on-board battery unit which is charged by the vehicle engine (Adly et al., 2006; Fontaras et al., 2008).

There also exist configurations that combine the characteristics of both series and parallel powertrain. What basically characterises all HEVs regardless of their powertrain architecture is reduced engine capacity, compared to the equivalent conventional model, engine shut-off capability and the ability of regenerative braking. Based on the level hybridisation HEVs can be characterised as presented in Table 1 (Fontaras et al., 2008).

Table 1. Type of hybrid electric vehicles

Vehicle operation	Conventional vehicle	Belt/muscle/ micro hybrid	Mild hybrid	Full hybrid	Plug-in hybrid
Engine shut-off	Yes	Yes	Yes	Yes	Yes
Regenerative braking		Yes	Yes	Yes	Yes
Smaller IC engine compared to conventional			Yes	Yes	Yes
Electric drive				Yes	Yes
Electric grid battery recharge					Yes

Currently, the number of HEVs in the market remains limited, but this picture will change in the years to come as HEVs are expected to pave the way for cleaner technologies transport (Fontaras et al., 2008).

Study comparing HEVs and conventional cars was carried out with the aim to prove benefits of HEVs under legislated driving cycle conditions (e.g. New European Driving Cycle, NEDC) or real world conditions (simulation driving cycles ARTEMIS). The Artemis measuring protocol called according to the project Assessment and Reliability of Transport Emission Models and Inventory Systems (ARTEMIS), which was a scientific programme funded by the European Commission aiming at the development of a harmonised emission model. It is important to note that the simulation essentially works in a reverse direction to what happens in the real world – that is, the drive cycle is the input to the vehicle model, and the required changes to the vehicle speed are calculated based on the drive cycle (Manzie et al., 2007).

A driving cycle is composed of a unique profile of stops, starts, constant speed, accelerations and decelerations and is typically characterized by an overall time-weighted average speed (Frey & Unal, 2000). Different driving cycles (e.g. see above) are used to represent driving under different conditions. Dynamometer tests typically suffer from well-known shortcomings associated with non-representativeness of actual driving conditions (Frey & Unal, 2000). For example, many tests under-represent short-term events that causes high emissions even for a properly functioning vehicle, such as high accelerations. Driver behaviour can affect the duration of both cold starts and of events leading to high-emissions enrichment operation, which in turn have substantial effects on emissions regardless of the total number of vehicle miles travelled.

Results of dynamometer measurements conducted on a Prius II and a Honda Civic IMA using both the European legislated driving cycle (New European Driving Cycle, NEDC) and real-world simulation driving cycles (Artemis) indicate that in most cases both vehicles present improved energy efficiency and pollutant emissions compared to conventional cars. The fuel economy benefit of the two HEVs peaked under urban driving conditions where reductions of 60% and 40% were observed, respectively. Over higher speeds the difference in fuel economy was lower, reaching that of conventional diesel at 95 (km h^{-1}). The effect of ambient temperature on fuel consumption was also quantified. It is concluded that urban operation benefits the most of hybrid technology, leading to important fuel savings and urban air quality improvement (Fontaras et al., 2008).

From the above laboratory experiments, it is clear that HEV vehicles have the potential to reduce the production of harmful emissions, especially in urban traffic condition. The aim of this article is to demonstrate the benefit of a hybrid vehicle in real traffic condition and to analyse the production of harmful exhaust gases and fuel consumption of HEV and conventional vehicle (ICEV - internal combustion engine vehicle) in different real traffic conditions. In the experiment as a representantive of HEV vehilce Lexus LX400H was choosen. As a ICEV vehicle has been selected Skoda Fabia 1.2 HTP as a typical representative of one of the most used lower-class cars in the Czech Republic typically designed for operating in urban traffic condition. Despite the obvious technical differences between these two vehicles, there is a presumption that significantly larger and heavier HEV can achieve better operating parameters than small ICEVs in urban traffic condition.

MATERIALS AND METHODS

Measurement of harmful emission production of driven vehicles under ordinary urban and suburban traffic conditions was carried out with the aim to assess an ecological benefit of hybrid vehicles' use. The only condition of driving was that driver's behaviour had to be complying with the instantaneous traffic situation i.e. high non-casual accelerations or braking etc. was forbidden.

The measurement was carried out with the hybrid vehicle LEXUS LX400H (see Table 2) and conventional car equipped with a combustion engine i.e. Skoda Fabia 1.2 HTP, spark ignition (other details are in Table 3). Both cars were equipped with PEMS analyzer, GPS and OBD diagnostic system.

A mobile PEMS on-board emission analyser VMK was used to measure emissions. The analyser uses non-dispersive infrared (NDIR) method to detect CO, CO_2, and HC emissions and electrochemical cell to O_2 and NO_X emissions. Data was recorded with 1 Hz frequency on memory card. The analyser was equipped with GPS system Garmin GPS-18x-5Hz to record vehicle's position and speed. The technical data of analyser are summarized in Table 4.

Table 2. Technical parameters of Lexus LX400H

Engine	Hybrid
Power	200 kW (272 hp)
Voltage	650 V
Combustion engine	
Volume	3,311 ccm
Power	155 kW (211 hp) under 5,600 rpm
Torque	288 Nm under 4,400 rpm
Front electro-engine	
Power	123 kW under 4,500 rpm
Torque	333 Nm under 0–1,500 rpm
The highest revolutions	12,400 rpm
Voltage	650 V
Rear electro-engine	
Power	50 kW under 4,610–5,120 rpm
Torque	130 Nm under 0–610 rpm
The highest revolutions	10,752 rpm
Voltage	650 V
Accumulator	
30 8-cells modules (240 cells with 12V)	
Type	Nikl-metal hydrid
Power	45 kW (61 hp)
Capacity	65 Ah
Gearshift box	
Drive	Elec. driven all wheels
Torque distribution f/r	Front el. + V6 / rear el.
box	E-CVT

Table 3. Technical parameters of measured vehicles

COMBUSTION ENGINE	LEXUS LX400H 	FABIA 1.2 HTP 
Design	spark ignition, atmospheric	spark ignition, atmospheric
Number of cylinders	6, in V, 24 valves	3, row, 6 valves
Volume of cylinders	3,311 ccm	1,198 ccm
Power	155 kW under 5,600 rpm	40 kW under 4,750 rpm
Torque	288 Nm under 4,400 rpm	106 Nm under 3,000 rpm
EU limit	EU4	EU4
Year of manufacture	2005	2003
CAR BODY		
Service weight	2,000 kg	1,055 kg
Total weight	2,505 kg	1,570 kg
DRIVE PERFORMANCE		
Max. speed	200 km h^{-1}	150 km h^{-1}
Acceleration 0-100 km h^{-1}	7.6 s	18.5 s
Fuel consumption	9.1 / 7.6 / 8.1 (liter·100 km^{-1})	7.8 / 4.8 / 5.9 (liter·100 km^{-1})

Table 4. Technical parameters of mobile emission analyser

Measured values	Measurement range	Resolution	Accuracy
CO	0...10% Vol.	0.001% Vol.	0…0.67%: 0.02% absolute, 0.67%…10%: 3% of measured value
CO_2	0...16% Vol.	0.01% Vol.	0…10%: 0.3% absolute, 10…16%: 3% m.v.
HC	0...20,000 ppm	1 ppm	10 ppm or 5% m.v.
NO_X	0...5,000 ppm	1 ppm	0…1,000 ppm: 25 ppm, 1,000…4,000 ppm: 4% m.v.
O_2	0...22% Vol.	0.1% Vol.	0…3%: 0,1% 3…21%: 3%

Vehicle operating data from the engine control unit via the OBD interface were recorded using car diagnostic system VAG–COM. The fuel consumption was evaluated by a flow meter WF007 fitted to the fuel system of the car. The technical parameters of the flowmeter is shown in Table 5.

Routes (or tracks see Fig. 1) of drives were selected with the aim that they should consist of three different sections. The first section was a typical urban drive influenced by ordinary traffic conditions (congestions, signal lights etc.). The second section was oriented out from the city. Its origin was placed on a parking lot next to last underground station and the destination

Table 5. Technical parameters of flow–meter WF007

Parameter	Value
Measuring principle	Oval gear
Sensing principle	Hall Sensor
Flow range	0.005–1.5 L min^{-1}
Pulses output	1,800 pulses L^{-1}
Viscosity	0–2,000 mPas
Accuracy	± 0.5%

in a suburb municipality in app. 15 km distance. This section is taken as semi-urban conditions. The last section was proposed prevailingly on motorways around Prague and this route performs as extra urban conditions. The road test uncertainty has been minimized by repetition of measurement. With respect to time-consuming of experiment, the measurement was repeated five times on each track.

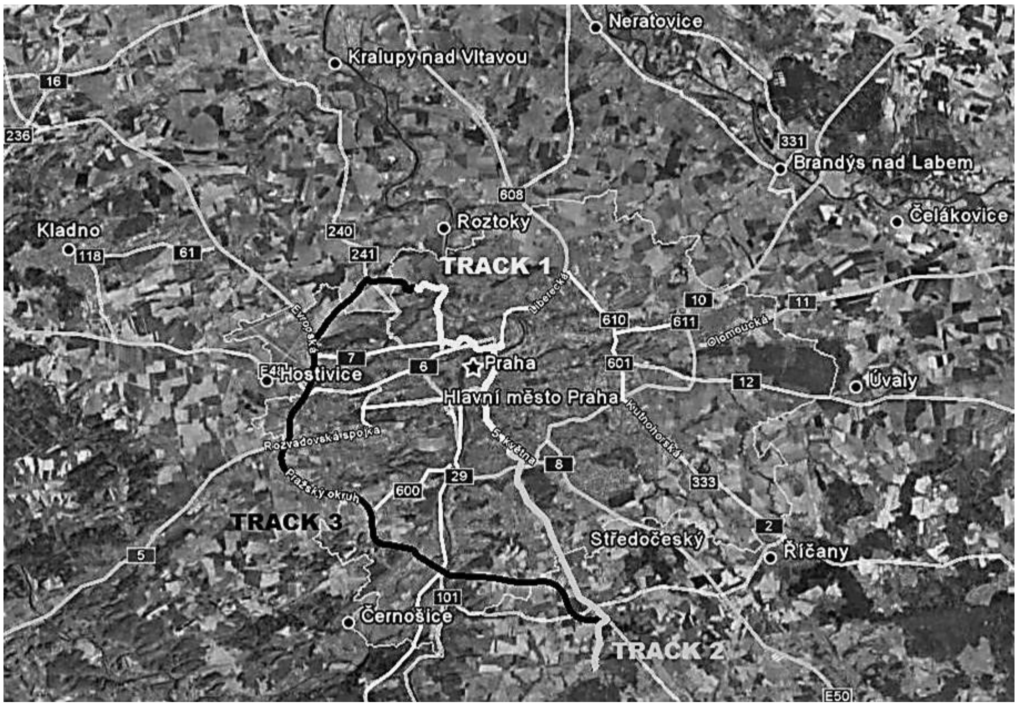

Figure 1. Single routes (Tracks1–3) of measurement (map source Google Earth).

RESULTS AND DISCUSSION

Table 6 summarizes the basic results describing each test car routes in terms of distance, average speed and selected operating parameters of tested cars. As is evident from Table 6, Track 1 represents typical urban traffic conditions with frequent stops and accelerations with low average speed of 30 km h^{-1}. Track 2 represents semi-urban traffic conditions with slightly higher average speed. The last test route Track 3 with average speed of 77 km h^{-1} represents motorway traffic conditions.

Table 6. Results of selected operating parameters on tracks

	TRACK 1	TRACK 2	TRACK 3
Distance (km)	16.4	15.1	41.3
Average speed (km h^{-1})	30 ± 8.6	36 ± 5.6	77 ± 4.2
LEXUS LX400H			
Averag fuel consumption (L 100 km^{-1})	10.9 ± 2.1	8.7 ± 1.6	10.9 ± 1.8
Fraction of engine in operation (%)	37 ± 8.8	41 ± 2.6	80 ± 2.1
CO_2 production (g km^{-1})	256 ± 35	204 ± 15	255 ± 12
SKODA FABIA 1.2 HTP			
Average fuel consumption (L 100 km^{-1})	12.2 ± 2.5	9.1 ± 2	7.1 ± 1.2
CO_2 production (g km^{-1})	284 ± 29	215 ± 18	165 ± 10

Results in Table 6 assess also a total CO_2 emission production and fuel consumption of conventional vehicle and HEV on specified sections of road. Measurement was carried out with HEV Lexus and conventional car equipped with a combustion engine i.e. Skoda Fabia 1.2 HTP, spark ignition (other details are in Table 3). This vehicle has been selected as a typical representative of one of the most used lower-class cars in the Czech Republic typically designed for operating in urban traffic conditions. It necessary to underline that the comparison of these vehicles is radically different in vehicles' parameters. Vehicles have different combustion engines, design, service weights and powertrains. It is necessary to compare results even with single technical parameters of both referred vehicles. Yet, in a certain type of traffic conditions, a significantly larger hybrid vehicle achieves better operating results.

In case of HEV, the percentage part of combustion engine's operational time is very important information. From Table 6 is evident that the Lexus combustion engine is more than half of operational time switched off under city and semi-urban conditions - the lower is vehicle's average speed the more is used its electromotor. Under motorway conditions it possible to see the significant increase of emission production. These higher speeds bring the requirement for higher percentage part of combustion engine power and it is evident when the electromotor is not able to provide the adequate power the combustion engine is more than 80% of time in operation. Similar results were obtained from several studies. The fuel savings (and emission production as well) of hybrid cars are more obvious under urban conditions due to their ability to reduce engine operation time under low efficiency conditions (Huang et al., 2019).

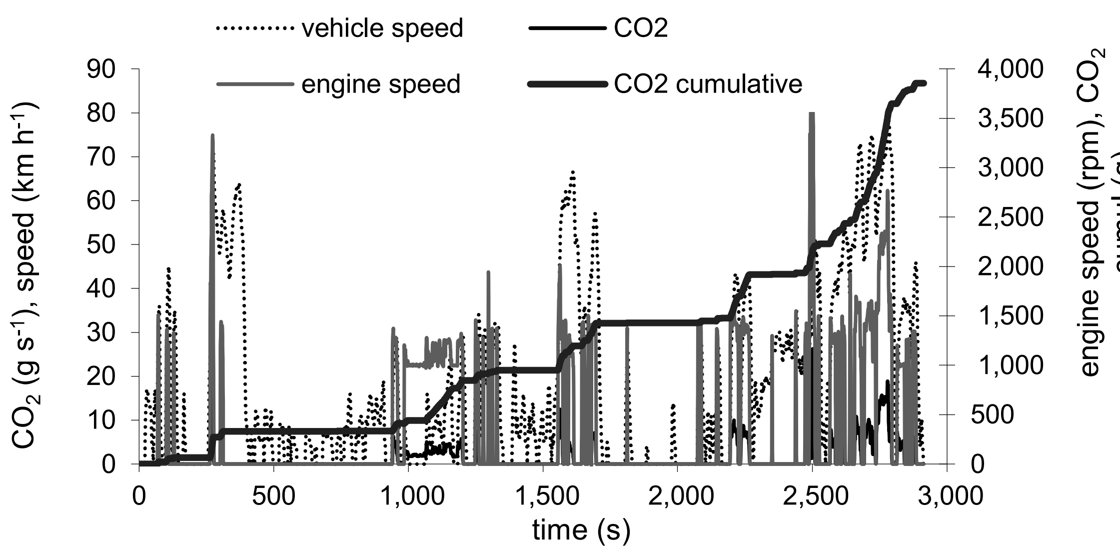

Figure 2. LEXUS LX400H under congestion conditions (Track 1).

Fig. 2 shows obtained and processed quantities of measurement on Track 1 under city congestion conditions. These values prove positive role of hybrid vehicles under urban traffic conditions. The decision making criterion used to decrease harmful emission production is fulfilment of conditions when combustion engine not used during operation. The first assumption of proper hybrid car's function is sufficiently charged accumulators. In case that accumulators are discharged (charge level less than 55%) the combustion engine takes the role as a generator of electric power and charges accumulators as possible to see Fig. 2 in time app t = 1,000 s - i.e. vehicle stands, and combustion engine is in a operation. The second important assumption is the requirement for instantaneous power. This requirement is affected by acceleration quantities under the city conditions (time period to reach the vehicle's required speed). Especially required speed changes (increments) are rather low under these congestion conditions and the required power for these increments is normally covered by an electromotor only. It is evident (see Fig. 2) mainly in time t = 400–900 s when vehicle stopped or during a low speed increase (combustion engine is not in operation i.e. revolutions are equal to zero). In case of higher requirement for the instantaneous power both as a combustion engine as an electromotor are in operation simultaneously. Revolutions of the combustion engine are controlled in a relation to required power quantity. During accumulator charging the combustion engine was used in operation with 1,000 rpm, during drive the most often used range 1,400–2,400 rpm or exceptionally during the full acceleration 4,500 rpm. It possible to suppose that hybrid car's producer adjusted control of these combustion engine's operational revolutions with the aim to minimise a harmful emission production and fuel consumption. In case of a braking the combustion engine is not in operation, the electromotor shifts automatically into generator mode and accumulators are charged immediately.

The car Škoda Fabia 1.2 HTP has absolutely different trend in an emission production. The emission production (see Fig. 3) is significantly higher under city conditions in comparison with the semi-urban and motorway conditions. It is caused that this conventional vehicle with combustion engine is prevailingly operated on idle revolutions, i.e. in ineffective way, especially under congestion conditions (Grote et al., 2016).

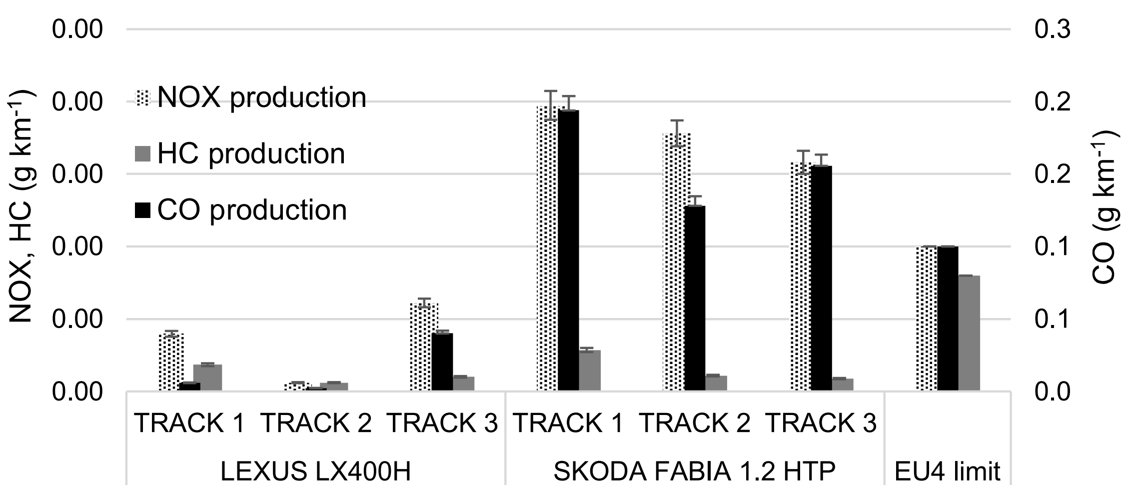

Figure 3. Result of emission on individual routes.

Further disadvantage of the conventional car during frequently repeated accelerating periods is its higher harmful emission production. (Brundell-Freij & Ericsson, 2005). This production is caused by transient modes of engine that prefers the requirement for instantaneous power at the expense of fuel mixture quality control which causes the decrease of catalyser's effectiveness (Fontaras et al., 2017). As can be seen from Fig. 3, Škoda Fabia produced significantly higher emissions than a hybrid vehicle, even exceeding the CO and NO_X emission limits for EURO-IV vehicles. This is a fairly common situation when in real driving condition the limits are exceeded. The NEDC driving cycle test (related to setting the EURO-IV limits) disregards various real-world conditions such as real weight (number of passengers), use of air conditioning, individual gear shifting, cold starts, operation at higher accelerations and congestion, etc. (Fontaras & Dilara, 2012) and examines only a small operating range of the engine (Pelkmans & Debal, 2006). However as is can be seen from Fig. 3., the Lexus vehicle did not exceed the limits set in all emission components. The benefits of HEV are obvious, but they depend on many factors, such as (temperature, air conditioning, ambient temperature, traffic situation, etc.) to be taken into account (Fontaras et al., 2008; Alvarez et al., 2012; Sonchal et al., 2012).

CONCLUSIONS

This study focused the real-driving fuel consumption and pollutant emissions performance of HEVs and conventional vehicle under real traffic condition. From the experiments carried out, the HEV benefits are particularly evident in urban traffic. Hybrid cars can cover inefficient combustion engine modes by means of an electric motor. The experiments carried out show that in urban and semi-urban traffic HEV can reach up to 60% save of combustion engine operating time, which leads to minimize of harmful exhaust gas production. Furthermore, it has been shown that in real operation the same results as in laboratory testing are often not achieved. Škoda Fabia in real-traffic condition exceeded the EURO-4 limits, while HEV fulfilled these limits. Appropriate use of advantageous HEV operating modes is needed to minimize fuel consumption and emission. This is one of the ways to meet the stringent emission limits for newly manufactured vehicles.

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