Boran Pikula, Ivan Filipović, Dževad Bibić, Murad Džeko

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METHOD FOR FAST DETERMINATION OF BASIC IC ENGINE CHARACTERISTICS AT DIFFERENT FUELS USE

Abstract

A permanent race for achieving low pollutants emissions in exhaust gases from the IC engines is characterized by introduction of new technical and technological solutions in fuel injection systems, improvement of combustion process, after treatment of exhaust gases, as well as the use of alternative fuels. An advantage in use of alternative fuels with IC engines for motor vehicle propulsion has fuels which do not require greater modifications of the IC engines. In this scope, bio fuels and LPG are the best fuels, especially LPG where good supply infrastructure exists.

Use of petrol and LPG fuels operated IC engines, simultaneously, represents the best solution for powering of the motor vehicles. Besides ecological aspects, the most important parameter for additional setting of LPG installation is economical, due to price of this fuel which is significantly lower when compared to petrol. Although manufacturers of LPG systems offer a swift change of petrol to LPG use on IC engines and viceversa, a question on how LPG system influences the basic IC engine characteristics could be asked.

Results of research related with the basic IC engine characteristics in case of petrol and LPG use, for pointed vehicle, are presented in the paper. In order to determin mentioned engine characteristics, the measurements of vehicle dynamics characteristics was carried out and afterwords the determination of the IC engine characteristics was done by calculation. The decisive role on these characteristics has the way of introduction of LPG in the combustion chamber and setting of system's parameters.

1. Introduction

In the contemporary world a great attention is paid on the problem of environmental pollution, which is a result of fast technological development and a rapid increase of human population. A lot of gases made by combustion of fossil fuels are significant pollutants both at the local and global levels. At the local level, in densely populated urban areas, emissions of carbon monoxide (CO), unburnt hydrocarbons (C_XH_Y), sulphur and nitric oxides (NO_X) are very considerable pollutants locally and globally.

Densely populated urban regions present very important tendency to due to their portion in smog forming coming from carbonmonoxide (CO), unburned hydrocarbons (C_xH_y), sulphur and nitrogen oxides (NO_x).

At the global level there is a considerable emission of CO_2, methane and certain nitric oxides, which stimulate the greenhouse effect. Since the conventional fuels for motor vehicle propulsion, petrol and diesel, hydrocarbon fuels, during their combustion in real conditions, apart from hydrocarbon (CO_2) and water (H_2O), also emit products of incomplete combustion such as carbon monoxide, nitric oxides, unburnt hydrocarbons, particles, and different kinds of polycyclic aromatic hydrocarbns *(PAH*) and other volatile organic compounds *(VOC)*. The emissions of CO, NO_X, C_XH_Y and particles (so-called *regulated emission*) are regulated by legal norms, while emissions of other components are not legally regulated (so-called *unregulated emission*). Besides, due to increasing global warming effect, there is a considerable emission of gases such as CO_2, CH_4, N_2O contributing to greenhouse effect. The most commonly used methods in reducing emissions of contaminating substances from motor vehicles are:

- use of new technical and technological solutions with IC engines (modern combustion control systems, exhaust gas treatment, etc.)
- regulations and stimulations for reducing emissions as well as emission control technology,
- improving fuel efficiency,
- use of alternative fuels and
- transport requirement management.

Nevertheless, only the use of alternative fuels provides reducing the emissions of contaminating substances from motor vehicles of all the generations. If we consider the fact that the vehicle fleet in the countries of the region is approximately 15 years old, which actually means that almost a half of drive units for motor vehicle propulsion do not include even the most basic regulation system for complying with the initial EURO 1 norm, the use of alternative fuels is an excellent solution for reducing the emissions of contaminating substances. Still, when it comes to using alternative fuels with IC engines for motor vehicle propulsion those fuels which do not require major engine modifications have more advantages, which means that LPG fuel can be recommended since its supply infrastructure is already present.

Today the use of IC engine with petrol and LPG is the most common solution for motor vehicle propulsion. Apart from ecological benefits of using LPG, the price of LPG is the most significant parameter for installation of LPG system since it is considerably cheaper than petrol. Although the manufacturers of LPG systems provide an easy shift from petrol to LPG, we can discuss the influence of LPG systems on IC engine characteristics. The basic objective of this paper is to find the answer in the development of method for fast determination of basic IC engine characteristics.

2. Vehicles with petrol and LPG propulsion

2.1 Use of LPG in motor vehicle in general

As oppose to conventional fuels, LPG at standard atmospheric conditions is in gaseous state, so there are some differences in the distribution and technological requirements set for vehicles with LPG.

In motor vehicles LPG is located in cylindrical containers under pressure of 6 to 8 bars, which requires an additional room in the vehicle. A container for LPG occupies twice as much space and it is 1,5 times heavier than a petrol container for the same energy content. Due to lower energy content per capacity unit [7] when compared to conventional fuels, for the same container capacity, vehicles using LPG show up to 30 % less range. Nevertheless, this is not a big disadvantage for the vehicles mainly used for city driving and with well developed gas station network. When adjusting vehicles to the use of LPG, besides pressure container for fuel storage, a system for supplying fuel to the engine needs to be reconstructed (fuel lines, pressure regulator, air/LPG mixer).

Engines using LPG can be made in the way that they use LPG only (*dedicated LPG*) or in the way that they also have an option of using both conventional fuels and LPG, so called *bi-fuel* engines. With bi-fuel engines a user can choose the fuel by simple activating the switch.

In the case of factory reconstruction of IC engines with LPG, use of its advantages have to be utilized and optimal engine parameters need to be adjusted to it (compression ratio, pre-ignition point, etc.) in order to obtain appropriate energetic characteristics. It needs to be said that IC engines are usually only adjusted to optimal parameters for the use of petrol, so with the use of LPG some deviations in energetic characteristics of IC engines occure, demonstrating somewhat lower vehicle dynamic characteristics. Emission of contaminants in exhaust gases of IC engines mostly depend on adjusted parameters of IC engines which directly influence the combustion process. In the same combustion conditions LPG, as oppose to petrol due to its chemical contents, shows better performances from the point of contaminating substances emission in exhaust gases.

2.2 Basic characteristics of test vehicles

In studying a motor vehicle with petrol and LPG propulsion a light delivery vehicle *Opel Combo* with petrol engine *1.4 Twinport Ecotec* was chosen, which basic characteristics are presented in the Table 1 [9].

A complete system for the use of LPG was additionally installed in the vehicle. Nevertheless, apart from using LPG as the alternative fuel [8] there are no other additional information on IC engine characteristics (power, torque, fuel consumption), as well as on the basic vehicle dynamic characteristics including acceleration period, maximum speed, etc. Considering the complexity of testing on test rig (break or rollers) of IC engine speed characteristics, after the system for the LPG use was installed, a method for fast determination of basic IC engine characteristics was developed based on experimental research of vehicle dynamic characteristics which is shown in the paper.

Table 1: Basic characteristics of the vehicle Opel Combo 1.4 Twinport Ecotec

Vehicle characteristics	**Opel Combo 1.4 l Twinport Ecotec**		
Motor fuel	Petrol	Front surface A, m^2	2,58
Fuel supply system	MPI, Motor management system, GM – Multec	Shape resistance coefficient c_X, -	0,35
Fuel ignition system	Motor management system, GM – Multec	**Transmission ratio of gearbox**	
Engine capacity V, cm^3	1364	1-speed transmission i_1	3,73
Engine power $P_{e,MAX}$, kW	66 at 5600 min^{-1}	2-speed transmission i_2	1,96
Torque $M_{e,MAX}$, Nm	125 at 4000 min^{-1}	3-speed transmission i_3	1,31
Maximum speed v_{MAX}, km/h	164	4-speed transmission i_4	0,95
Acceleration period t 0-100 km/h, s	14,0	5-speed transmission i_5	0,76
Empty vehicle weight m_V, kg	1280	Reverse - i_R	3,31
Useful load m_T, kg	520	**Transmission ratio-main gearbox**	
Maximum allowable weight m_{UK}, kg	1800	i_0	3,94
Fuel consumption 1999/100/EU - city driving - highway driving - average	 8,0-8,3 *l/100 km* 5,3-5,6 *l/100 km* 6,3-6,6 *l/100 km*	Wheels: - rim - pneumatic tyre - radius r_d, m	 5,5Jx14 175/65 R 14 0,31

3. Method for fast determination of basic IC engine characteristics

A device for measuring acceleration or deceleration was used for determining vehicle dynamic characteristics in the acceleration process. This is a universal device which is based on measuring inertia force and which can be a part of different equipment sets (from vehicle field test equipment to specific field test equipment).

Checking of dynamic characteristics of a test vehicle with the use of both fuels were conducted through acceleration measurements at starting the vehicle. Since the tests were done on a light delivery motor vehicle, we especially observed the influence of useful load and in this specific case it was adjusted that the weight of a useful load and a driver reach, with the weight of an empty vehicle, its maximum allowable weight of 1800 kg.

In order to determine the vehicle dynamic characteristics with accelerating the vehicle when starting it, with the use of petrol and LPG, our test driver was fully pressing the accelerator pedal and he tried to change gears at approximately identical engine revolution number. The test was conducted on the same 1 km test run in the urban environment characterized by horizontal surface without any incline or decline. The acceleration results on this test run with the use of petrol and LPG are shown in the Figure 1.

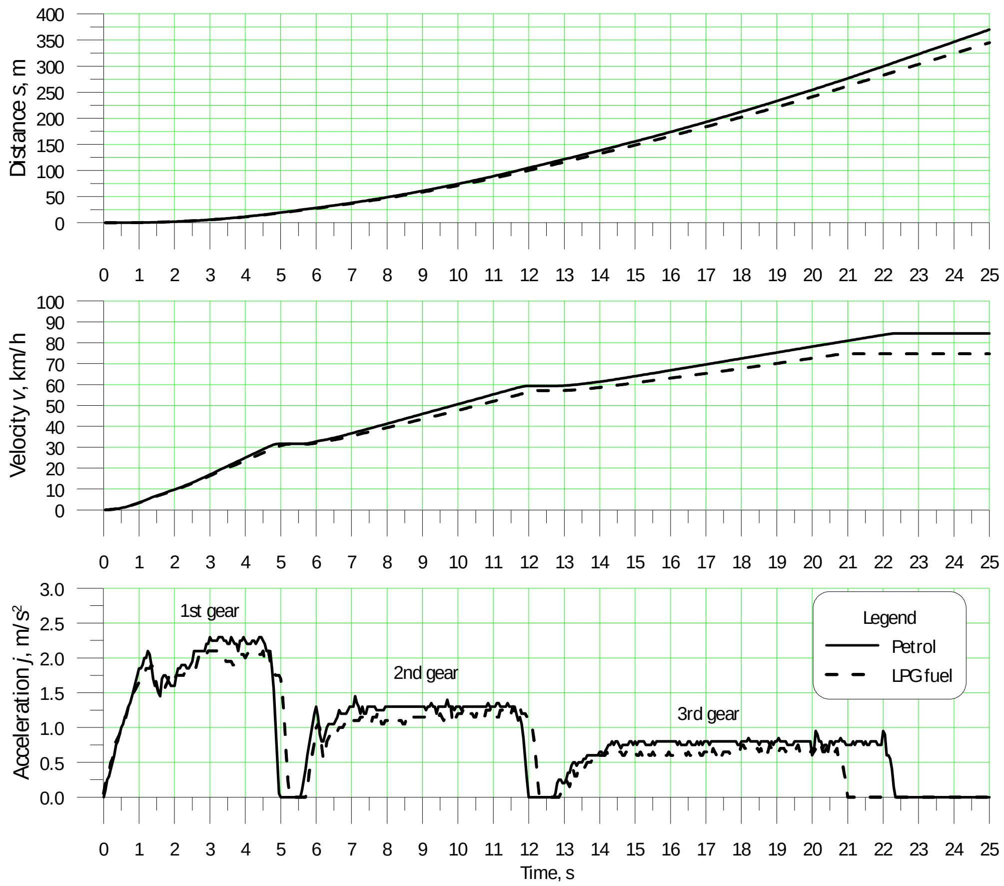

Figure 1: Vehicle dynamic characteristics achieved on the test run

The Figure 1 shows that, with different fuels and with accelerator pedal fully pressed, different vehicle dynamic characteristics were achieved (acceleration, speed and distance covered) which can be explained by different engine characteristics. By using the basic laws of vehicle dynamics [3] and [4], and finding out the obtained (measured) values of vehicle acceleration, basic characteristics of the engine can be determined by a calculation.

Acceleration of the vehicle in a particular gear (*mj*) can be calculated from the following expression:

$$j_{mj} = \frac{g}{\lambda_{mj}} \left(D_{mj} - f \right) \tag{1}$$

with: g – acceleration of g-force, D_{mj} – dynamic factor (characteristic) in a particular gear, f – rolling resistance coefficient, λ_{mj} – rotating masses influence coefficient.
Today the most applicable expression for defining the rolling resistance coefficient [5] is:

$$f = f_0 + f_1 v + f_2 v^4 \quad \text{for } v \text{ expressed in m/s} \tag{2}$$

where, for radial pneumatics and high vehicle speeds, the values of the aforementioned coefficients are:

$$f_0 = 9{,}91 \cdot 10^{-3}, \; f_1 = 1{,}95 \cdot 10^{-5}, \; f_2 = 1{,}76 \cdot 10^{-9}$$

The rotating masses influence coefficient depends on design characteristics of IC engine and vehicle, thus according to [4] is calculated with expression:

$$\lambda_{mj} = 1 + \frac{g}{G} J_m \frac{i_{mj}^2 i_0^2 \eta_{mj} \eta_0}{r_d^2} + \frac{g}{G} \sum J_t \frac{1}{r_d^2} \tag{3}$$

where the characteristical parameters in the expression (3) are: J_m – moment of inertia of rotating masses of the engine, ΣJ_t – moment of inertia of rotating masses of the vehicle, i_{mj} – transmission ratio in a particular gear, i_0 – transmission ratio in the main gearbox, η_{mj} – transmission efficiency coefficient in a particular gear, η_0 – efficiency coefficient of the main gearbox, G – weight of the vehicle and r_d – dynamic radius of a wheel.

Table 2: Transmission efficiency coefficients

Transmission coefficient	**1.**	**2.**	**3.**	**4.**	**5.**
Transmission efficiency coefficients η_{mj}	0,95	0,96	0,96	0,97	0,98
Main gearbox					
Efficiency coefficient η_0	0,97				

If the moments of inertia of rotating masses of the engine and the vehicle are not known, the rotating masses influence coefficients can be approximately determined by empirical expressions give in [4].

Incorporating the transmission ratio in particular gears and in the main gearbox the transmission efficiency coefficients are shown in the Table 2.

Finally, we are able to determine a dynamic factor (characteristic) in a particular gear during the acceleration of a light delivery vehicle on a test run by using the following expression:

$$D_{mj} = \frac{\lambda_{mj}}{g} j_{mj} + f \tag{4}$$

A dynamic factor presents a modification of towing force, and it was introduced for more transparent analysis of vehicle movement dynamics. Starting from the definition of dynamic factor:

$$D_{mj} = \frac{F_{O,mj} - R_v}{G} \tag{5}$$

the values of driving force on a wheel $F_{O,mj}$ in a particular gear can be determined by:

$$F_{O,mj} = D_{mj}G + R_v = D_{mj}G + \frac{1}{2}\rho c_X A v^2 \tag{6}$$

Using the expression (6) the values of driving force on a wheel were obtained which depends on the acceleration on a test run shown in the Figure 2. Having the values of driving force on a wheel and characteristical parameters of power transmission system the values of driving momentum on a wheel (M_O), engine torque (M_e) which is used for vehicle propulsion, as well as motor revolution number during the accelertion process were obtained. The dependence of the values mentioned above can be expressed in the following formula:

$$M_O = F_{O,mj} r_d \quad \rightarrow \quad M_e = \frac{F_{O,mj} r_d}{i_{mj} i_0 \eta_{mj} \eta_0} \tag{7}$$

$$\omega_e = \frac{v}{r_d} i_{mj} i_0 \quad \text{i} \quad n = \frac{\omega_e}{2\pi} \tag{8}$$

The Figure 2 shows a diagram of the vehicle dynamic characteristic and the engine characteristics in the acceleration process on the test run.

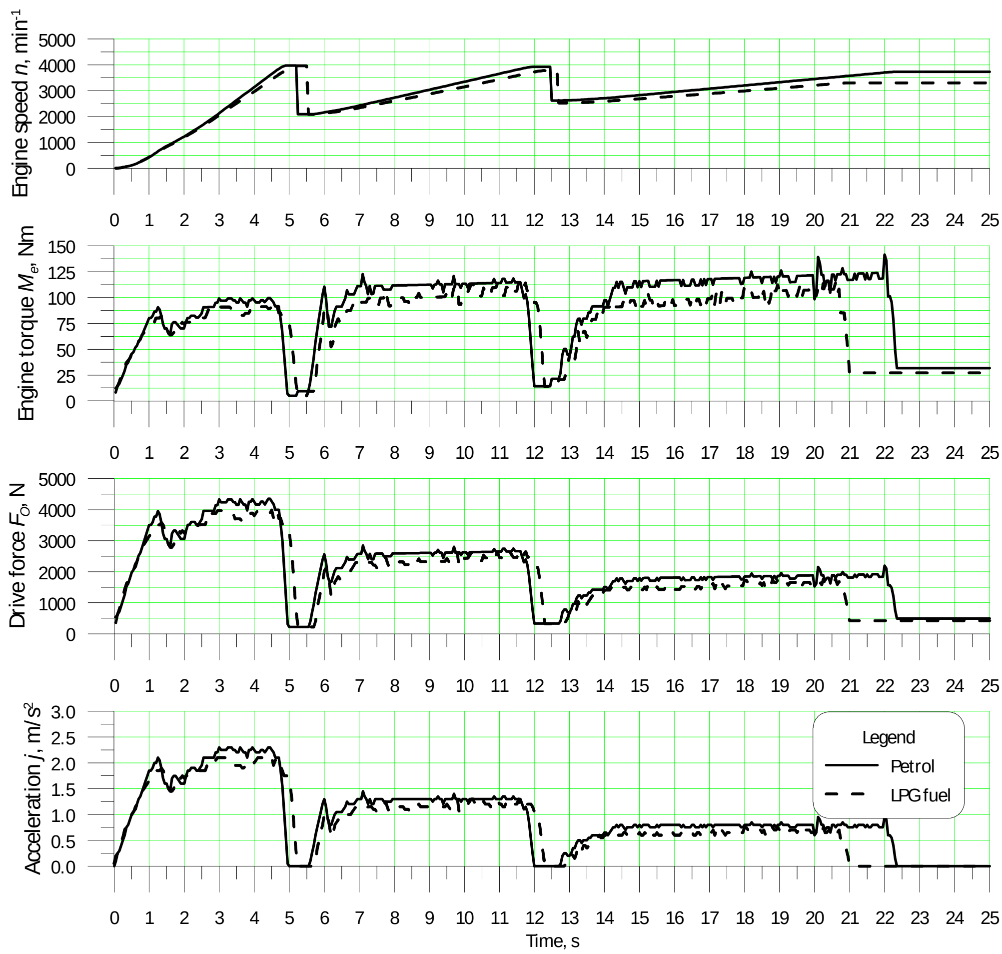

Figure 2: Compared values of the vehicle dynamic characteristic and the engine characteristics

The analysis of the results from the Figure 2 shows that achieving different vehicle accelerations with the use of different fuels can be a result of different driving forces, or different engine torques. It is important to emphasize that the engine torque was based on a transferred torque on a wheel, which at vehicle starting, due to clutch slipping in the period of 0÷1,5 s, does not show the real value of the engine torque.

Also, at vehicle starting, due to possible slipping of driving wheels and, during acceleration in the 1-speed transmission due to major inertia forces and short acceleration period, it is not possible to maintain the accelerator fully pressed which would cause lower engine torque values. Nevertheless, if the transmission is shifted into 2- or 3-gear, a driver will be able to press fully the accelerator in a short period providing maximum torques of the engine for the acceleration process getting close to top speed characteristics declared by the vehicle manufacturer [9], which is best shown in the Figures 3 and 4.

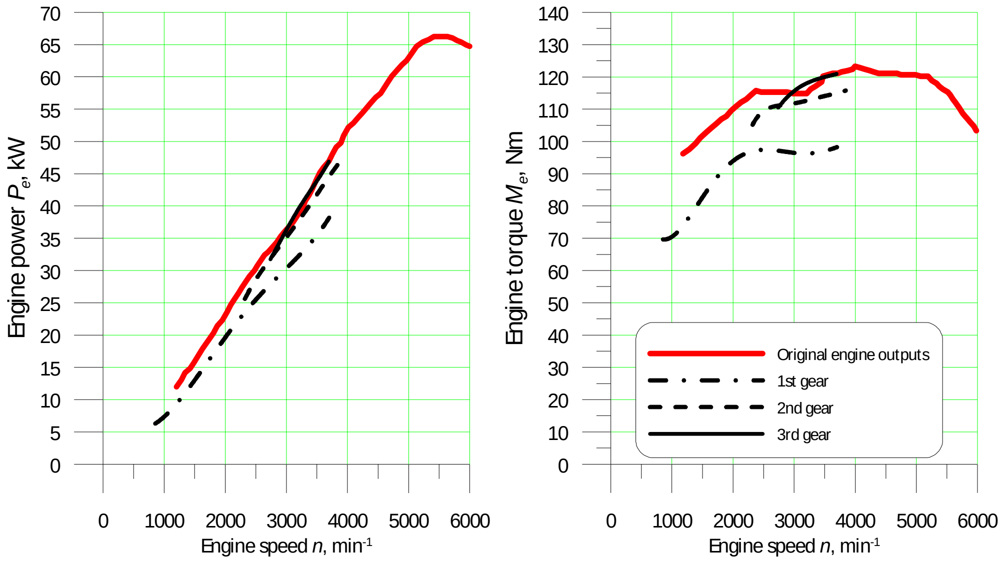

Figure 3: Engine characteristics of power and torque in case of the petrol use

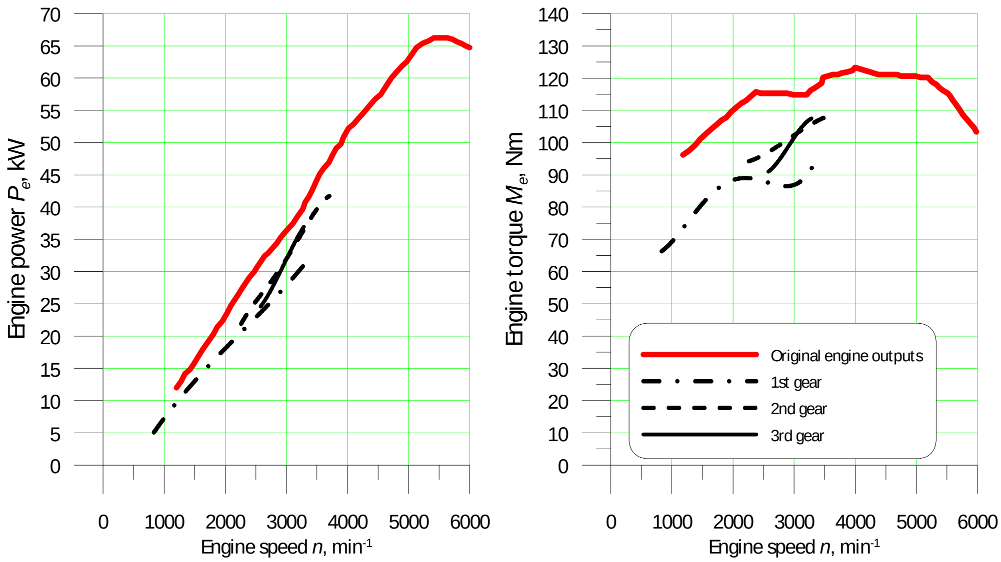

Figure 4: Engine characteristics of power and torque in case of the LPG use

After the analysis of engine speed characteristics obtained in the calculation based on measured vehicle dynamic characteristics during the acceleration process, with the accelerator fully pressed and with the use of different fuels, we can conclude that the developed method presents an efficient way of testing the basic engine characteristics. It is recommended that when using this method we dispose of results of acceleration measurement at all gears and in all the performance areas of motor speed.

Based on the presented results it can be concluded that with the use of LPG, as the alternative fuel of the specific motor vehicle, lower values of engine power and torque are achieved. The explanation for this difference, in the conditions of equal input energies of both fuels, could be found in the combustion process in IC engine. Still, the combustion process of LPG in IC engine can be less efficient due to:

- Different physical characteristics of LPG when compared to petrol.
- Different process of supplying engine with fuel. Petrol is directly injected to intake valves of each cylinder, and LPG is supplied by dosing valves at the beginning of each intake pipe leading to a cylinder. The latter obviously has more hydraulic losses in the process of forming air/LPG mixture in IC engine, as well as slightly increased fuel losses in the process of valve overlapping, etc.
- Use of LPG in IC engine, which characteristical parameters are originally optimized for petrol.

4. Conclusion

Based on the detailed analysis of the use of LPG in petrol engines and the results obtained in the paper it can be concluded:

1. The use of LPG, as an alternative fuel, in motor vehicles with petrol engines is quite popular due to economic effects and decreased emission of contaminating substances in exhaust gases.
2. The LPG fuel is mostly used in the combination with petrol, so called bi-fuel engines with the IC engine characteristics optimized for petrol. When adjusting the same IC engine to LPG only the amount of fuel was adjusted through equal energies in the fuel which did not guarantee that the equal vehicle speed characteristics with LPG, when compared to the use of petrol, were maintained.
3. A method for fast determination of basic engine characteristics at different fuels use was developed and presented. A very simple inertia-type device for measuring acceleration/deceleration and self-developed program for calculating speed characteristics of IC engines was used for this purpose.
4. The presented method can serve as a fast adjustment of alternative fuel supply system (in this case, of LPG) in order to establish adequate speed IC engine characteristics and dynamic characteristics of a vehicle.

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UDK	ključne riječi	key words
621.433/.434	dvogorivni plinski i benzinski motor	dual fuel gas/gasoline engine
665.632	ukapljeni naftni plin UNP	liquefied petroleum gas LPG
665.733.5	motorni benzin	motor gasoline
531.768	mjerenje ubrzanja	acceleration measurement
621.43.018.7	snaga motora	engine power
621.43.03	uređaj za dovod goriva i punjenje motora	fuel supply and motor charging device
621.43-545	regulacija i vođenje klipnih motora	piston engine tuning and control

Authors
Doc. dr. Boran Pikula, dipl. ing.
Red. Prof. dr Ivan Filipović, dipl. ing.
Doc. dr. Dževad Bibić, dipl. ing.
mr. Murad Džeko, dipl.ing.
E-mail: pikula@mef.unsa.ba , filipovic@mef.unsa.ba , bibic@mef.unsa.ba , dzeko@mef.unsa.ba
Facult of Mechanical Engineering Sarajevo, Department for IC Engines and Vehicles, Vilsonovo šetalište 9, 71000 Sarajevo, BiH

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