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Study of the Influence of Road Resistance on the Fuel Consumption of a Passenger Car with an Automatic Transmission

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***Abstract*. One of the directions in the modern automotive industry is related to optimizing processes of the working cycle of internal combustion engines, which is related on another hand to reducing fuel consumption. This article presents calculation results of fuel consumption of a passenger car Honda Accord with automatic gearbox which are based on experimentally obtained power characteristics by using a chassis dynamometer DYNO COSBER. The fuel consumption was determined at different speeds of the car on a road without a slope and with 2%, 4% and 6% slope by using the chassis dynamometer and diagnostic equipment. The results of calculations about the influence of road resistances on fuel consumption were compared and analyzed with those obtained from measurements.**

Keywords: fuel consumption, slope, passenger car chassis dynamometer, road resistances.

I. Introduction

Important operating properties of the car are its fuel economy characteristics. They are evaluated by the fuel consumption when the vehicle is driving in different road conditions [1]. The fuel consumption of the car depends on the fuel economy of the internal combustion engine (ICE).

Internal combustion engines are the main source of energy for vehicle for various purposes [3]. Recently, more attention is devoted to problems related to the ecology and emissions release by ICE of vehicles.

Modern cars are equipped with ICE with relatively higher power. Designers are looking for solutions to reduce weight and fuel consumption and to improve the aerodynamic characteristics by using modern electronic systems for controlling the ICE and the vehicles as a whole. Significant portion of the currently available studies in the area of ICE and vehicle optimization are focused on the impact of the different factors on the fuel consumption. The effect of the change of the transmission efficiency of useful action on the fuel economy was determined analytically in [4], while in [5] the influence of the aerodynamic resistances on the fuel consumption was investigated.

Researches of various parameters of the car can be conducted in laboratory conditions or through road tests. In recent time, chassis dynamometers are increasingly used to conduct various tests [2, 6, 7, 8]. The chassis dynamometers are used to measure the power performances of the car and the engine, but they are also used to realize various loads and simulate road conditions [6, 7]. The researchers in [8] do investigate on the fuel consumption of a conventional car and a hybrid, with road conditions realized via chassis dynamometer.

The purpose of the study is a calculation and experimental measurement of the influence of road resistance of the fuel consumption of a passenger car with an automatic transmission. The experimental measurements were carried out on a COSBER dynamometer and with the application „Car Scanner Pro“ connected via Bluetooth LE (4.0) adapters to the electronic control unit (ECU) of ICE through which current fuel consumption data were obtained.

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II. METHODS OF THE DETERMINATION OF FUEL CONSUMPTION

Fuel consumption can be determined analytically and experimentally.

Resistance forces applied on a moving car are opposite to its direction of motion and they are overcome by the tractive force F. Figure 1 presents when the car with front-wheel drive without trailer steady moving on a slope. Total resistance force in steady motion can be presented by

$$F_{tot} = F_f \pm F_i + F_a \quad , \tag{1}$$

where F_f is rolling resistance force; F_i is gradient resistance force; and F_a is aerodynamic drag force.

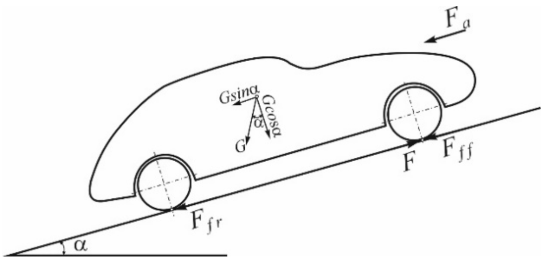

Fig. 1. Resistance forces acting on a moving car on a slope.

Rolling resistance force and gradient resistance force are represented by the sum by force F_ψ, known as road resistance and is determined by [1]

$$F_\psi = F_f \pm F_i = fG\cos\alpha \pm G\sin\alpha = \psi G \quad , \tag{2}$$

where f is rolling resistance coefficient, [-], which depends on many factors, and varies as a value, but in the study of performance properties it is usually assumed to be constant for the relevant road condition; G is the weight of the car; ψ is the road resistance coefficient and is determined by [1]

$$\psi = f + i \quad , \tag{3}$$

where i is a slope of the road, [%].

Aerodynamic drag force is distributed over the entire surface of the car, but is considered as force applied at a single point and it is determined by the formula [1]

$$F_a = \frac{1}{2} c_A \rho_A S \frac{v^2}{13} \quad , \tag{4}$$

where c_A is the aerodynamic drag coefficient, [-]; ρ_A is the mass density of air; S is the frontal area of the car, which is the projected area of the car in the driving direction, [m^2]; v is the car velocity, [km/h].

The fuel consumption in [l/100 km] of traveled distance with a steady speed of the car is calculated according to [1]

$$Q = \frac{g_e P_c}{10 \rho v} \quad , \tag{5}$$

where g_e is specific fuel consumption of ICE, [g/kW.h]; v is the car velocity, [km/h]; ρ is density of the fuel, [kg/l]; P_c is the engine power, necessary for the motion of the car and can be represented by

$$P_c = \frac{F_c v}{3,6 \eta_t} \quad , \tag{6}$$

where η_t is transmission efficiency.

Taking into account the above dependencies for fuel consumption is obtained

$$Q = \frac{g_e (F_\psi + F_в)}{36 \rho v} \quad . \tag{7}$$

In the cases when the fuel economy characteristic of the engine is not available, the specific effective fuel consumption can be determined by an empirical formula [1]

$$g_e = g_p k_p k_\omega , \tag{8}$$

where g_p is the specific fuel consumption at maximum engine power and it is $g_p = (1,05 \div 1,15) g_{e\min}$, [g/kW.h]; k_p is the coefficient which takes into account the effect of the engine load on g_e; k_ω is the coefficient which takes into account the effect of the of the angular velocity of the crankshaft on g_e.

The coefficients k_p and k_ω are determined by empirical dependences from [1].

The object of this study is a passenger car Honda Accord Executive (CL9), with petrol engine (K24A3). The electronic control unit (37820-RBB-E57) of the ICE and automatic transmission has modified Firmware. Table 1 presents parameters of the car [9] and necessary coefficients.

TABLE 1 PARAMETERS OF THE CAR AND COEFFICIENTS.

Parameters	Designation	Unit	Value
Total mass	m	[kg]	1610
Aerodynamic drag coefficient	c_A	[-]	0,26
Frontal area	S	[m^2]	2,11
Acceleration due to gravity	g	[m/s^2]	9,81
Rolling resistance coefficient	f	[-]	0,01
Mass density of air	ρ_A	[kg/m^3]	1,225
Width of the tire	h_{tire}	[m]	0,225
Aspect ratio of the tire	-	%	45
Rim diameter	d	[m]	0,432
Radius of the tire	r_k	[m]	0,310
Air pressure of tire	p_{tire}	[MPa]	0,23

The experimental studies were carried out by using a chassis dynamometer DYNO COSBER 4000 in a laboratory of TU-Sofia, Plovdiv branch (fig. 2). The environmental parameters in which measurements were made are presented in the table 2. The tests were performed when the hydrodynamic torque converter was operating in mode $M_{impeller} = \mathrm{M}_{turbine}$, torque ratio $k = 1$ and clutch is locked-up. In locked-up mode the impeller, turbine and stator of the torque converter rotate as one and there are no losses.

The experimental studies and calculations were made for the car steady moves on a horizontal road and at the three values of the road slope. The slopes of 2%, 4% and 6% are aligned with the regulations in [10].

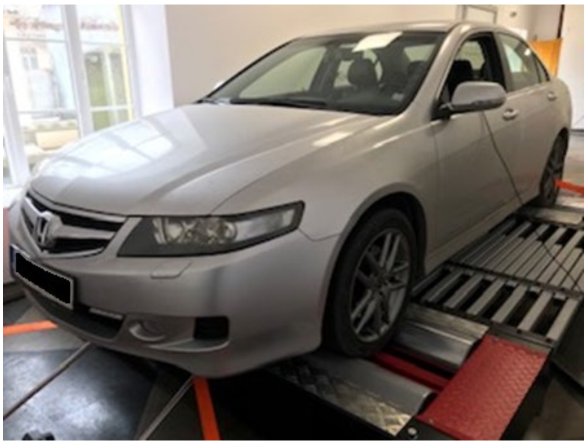

Fig. 2. Experimental study of a passenger car Honda Accord 2.4.

TABLE 2 ENVIRONMENTAL PARAMETERS.

Parameters	Unit	Value
Temperature	^{0}C	19
Pressure	kPa	101
Humidity	%	46

Figure 3 shows the input data to the chassis dynamometer software.

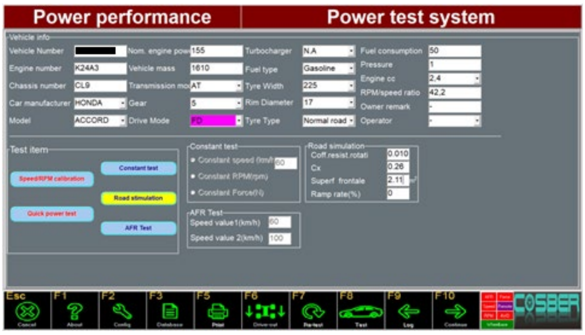

Fig. 3. Work screen with details of the passenger car and road parameters.

Figure 3 shows the „Road simulation“ mode used in the chassis dynamometer measurements. Fuel consumption measurements were made when the passenger car was in operated like a manual transmission for steady speed values when driving the car in third, fourth and fifth gear respectively and at the corresponding values of road resistance without a slope, and slope 2%, 4% and 6%.

Fig. 4. „Road simulation“ mode.

The „Car Scanner Pro“ application enables real-time reading of various engine and car parameters. This data can also be saved to a log file for further processing and analysis. Figure 5 shows some of the data obtained through the experiment.

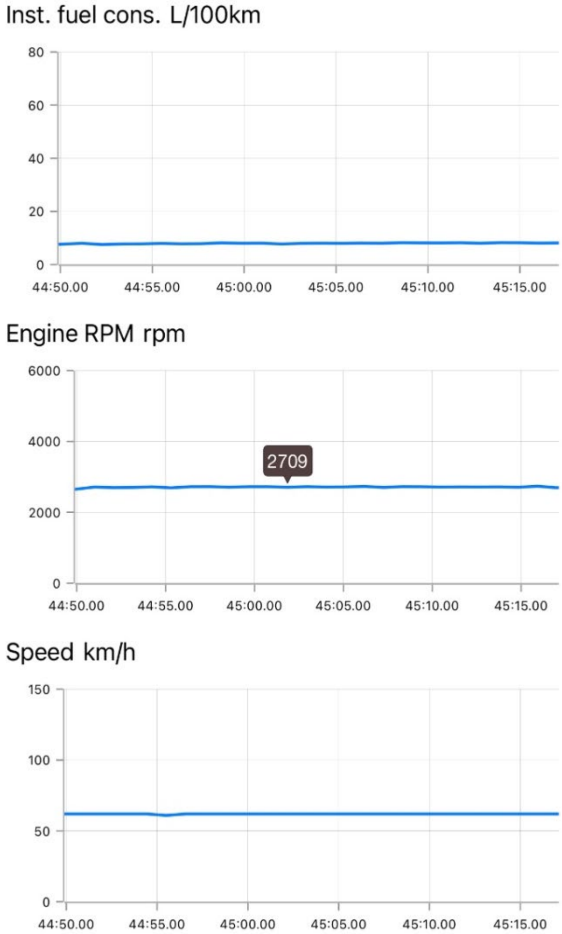

Fig. 5. Work screen of software “Car Scanner Pro“.

III. RESULTS AND DISCUSSION

Figure 6 presents the experimentally obtained power performance of the passenger car and engine performance. The engine performance is derived from the car power performance by taking in consideration the transmission efficiency.

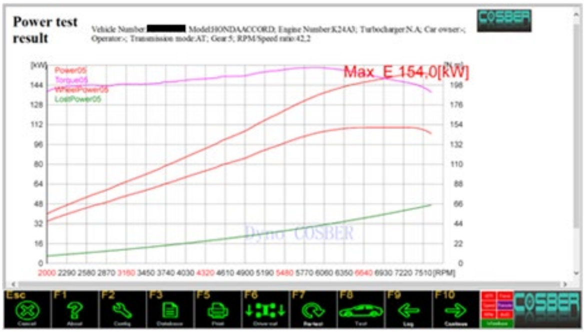

Fig. 6. Power performance of the passenger car and performance of the engine.

The obtained measurement result on the chassis dynamometer for maximum engine power (154 kW) with modified firmware of ECU is higher than the original one (140 kW).

The fuel consumption of the car with the third, fourth and fifth gears engaged was calculated by usage of equations (2), (3), (7) and (8) in combination with the experimentally determined power performance of the car and the engine. For the calculation of the fuel consumption for the gears, the change in the transmission efficiency was taken into account.

Figures 7, 8, 9 and 10 present the results of the fuel consumption in third, fourth and fifth gear at road resistances without a slope and slope of 2%, 4% and 6%, respectively, derived from the calculations and the experimental measurements.

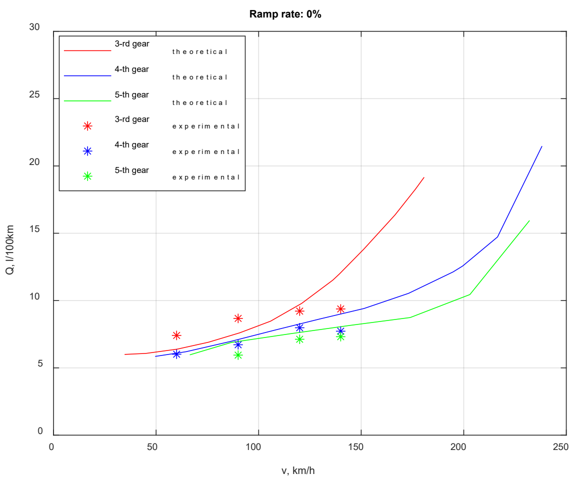

Fig. 7. Fuel consumption in third, fourth and fifth gear without a slope.

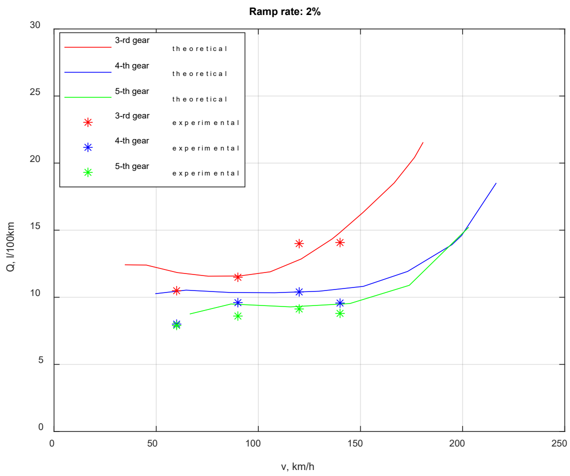

Fig. 8. Fuel consumption in third, fourth and fifth gear at 2% slope.

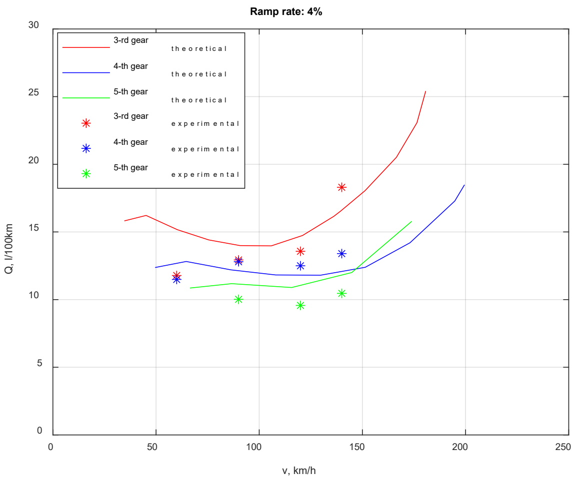

Fig. 9. Fuel consumption in third, fourth and fifth gear at 4% slope.

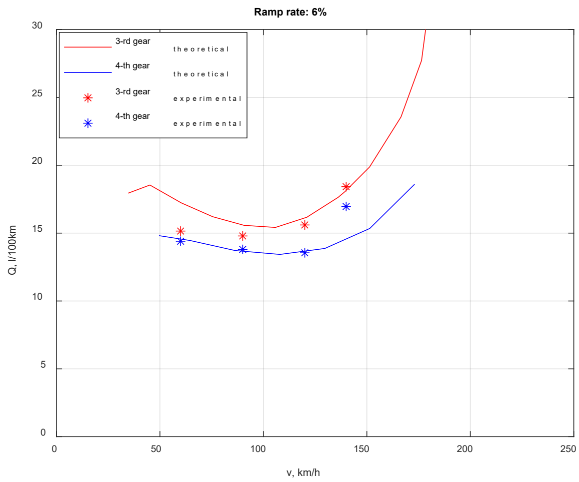

Fig. 10. Fuel consumption in third, fourth and fifth gear at 6% slope.

The fuel consumption of the car increases as the slope of the road increases. From the obtained results, it can be seen that lower fuel consumption is obtained in the fifth gear when the car is moving without a slope, and slope of

2% and 4%. At road of 6% slope the fuel consumption is lowest in fourth gear and at this road gradient the car cannot move in fifth gear.

IV. CONCLUSIONS

An experiment was performed to validate the results of the analytical dependences for determining the fuel consumption of a Honda Accord passenger car. The results obtained from the analytical dependences are close to the experimental results.

The small differences between the calculated and experimental fuel consumption values are due to some specifics of the system which controls the continuously variable camshaft phasing system used on the intake camshaft of DOHC engine (intelligent-VTEC) and some peculiarities in the setting of ECU's firmware of car's engine. The peculiarities of the methodology for analytical determination of fuel consumption also have an influence on this difference.

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