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Influence of operating conditions on vehicle fuel economy

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ABSTRACT: Fuel economy is one of the criteria in order to evaluate the quality of the vehicle. A vehicle model affected by forces in the general case is presented for estimating vehicle fuel economy under operating conditions. The fuel consumption equation is established, and the fuel economy is determined by the fuel consumption for 100km of running distance. The results show that the fuel economy depends not only on the structural parameters, but also on the operating conditions.
KEYWORDS: Fuel consumption, vehicle model, simulation.

I. INTRODUCTION

With the strong development of science and technology and its impact, the criteria for the quality requirement of the vehicle are increasing strictly. One of those criteria is fuel economy. However, this criterion depends on quite a few factors. The fuel supply system is one of the significant systems of the vehicle. Therefore, strategies to optimize injection timing to reduce fuel consumption are widely used in modern vehicles [1].

One of the disadvantages of spark ignition engines is the increased fuel consumption at low loads and an idle speed of the engine. Therefore, the advance of ignition ability by adjusting the ignition timing is one of the effective ways to improve fuel economy, and this was studied by [2]. The results showed that the power increased and also the fuel consumption decreased when improving the ignition system.

Many studies have focused on objective factors, such as high mountainous terrain, small turning radius, and difficult driving conditions to improve fuel economy. Experiment results from the study [3] indicated that the dump trucks working under those conditions increased fuel consumption.

The environment is one of the difficult factors to control. The study [4] reported the effect of the ambient air temperature on the fuel efficiency of the vehicle. They indicated that the fuel consumption of the vehicle increased when operating in a region with low ambient air temperature. Significant differences in fuel consumption and emission rates were observed on different road surfaces [5].

In addition, the fuel of the vehicle is wasted as a result of unreasonable driving behaviours, even in the case of highly experienced drivers [6].

Futhermore, experimental studies on other factors, such as tire condition, weight of passenger cargo and air conditioning unit usage (load), vehicle speed, fuel type, maintenance status, showed that these factors also greatly affected the fuel consumption of the vehicle [7]. Therefore, these factors have to be regularly considered during vehicle use in order to have economical fuel consumption.

The objective of this study is to analyze the effect of the operating process on the fuel economy of the vehicle. A vehicle model affected by forces acting on moving vehicles is constructed to achieve this goal. In addition, fuel consumption equations and also equations for each specific operating condition are established.

II. ESTABLILSHMENT OF VEHICLE MODEL AND MATHEMATIC EQUATION

Vehicle model

The vehicle dynamics model in the case of an uphill vehicle is shown in Figure 1 to estimate the vehicle fuel economy under operating conditions.

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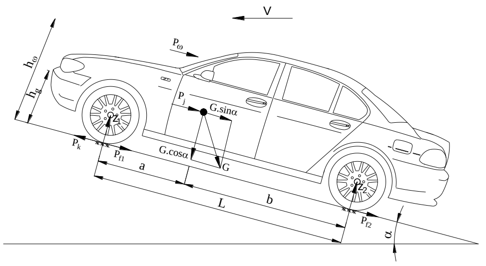

Figure 1. Forces acting on a vehicle moving uphill.

where: G is total weight; L is wheel base length; a, b are the location of the center of gravity of the vehicle behind the front axle and in front of the rear axle, respectively; hg is the height of the center of gravity of the vehicle; hω is the distance from the point where the aerodynamic force is applied to the road surface; α is the slope angle of the road; Grading resistance, Pi, can be express as Pi = G.sinα; Pj the inertial drag when the vehicle is in unstable motion; z1, z2 are the normal loads on the front and rear axles, respectively; Pf is rolling resistance force, Pf = G.f; Pω is aerodynamic drag force, Pω=K.F.v2 , where K is coefficient of air resistance, K = Ckđ.ρ, where ρ is air density; V is the relative velocity; F is vehicle frontal area, F = B.H where B, H are the width and height of the vehicle, respectively.

Equation of fuel consumption

The fuel economy of a vehicle depends on the performance of a vehicle engine and the power consumption to overcome the moving resistance. When testing the engine on the test bench, the fuel consumption over time (kg/h) and the effective power of the engine, Ne (kW), are measured, respectively.

When a vehicle moves, the power generated by the vehicle engine to overcome the moving resistance forces is determined as below equation.

$$N_e = \frac{P_\psi + P_\omega \pm P_j}{1000.\eta_{tl}} \qquad 1$$

where: Ne is the effective power; are the moving resistance forces; ηtl is the power transmission efficiency.

Therefore, the equation for determining the fuel consumption for 100 km is written as:

$$Q_d = \frac{0,36.g_e.(P_\psi + P_\omega \pm P_j)}{\rho_{nl}.\eta_{tl}} \qquad 2$$

where: ρ_{nl} is fuel density; ge is the brake specific fuel consumption, and it can be determine as the following equation:

$$g_e=k_v.k_n.g_N \qquad 3$$

where: g_N is the brake specific fuel consumption at maximum effective power N_{emax}; k_v is the coefficient that takes into account the relationship ge = f(v); k_n is the coefficient that takes into account the relationship g_e = f(n).

III. EVALUATION OF CRITERIA FOR THE VEHICLE FUEL ECONOMY

The vehicle fuel economy (Q_d) is determined by the fuel consumption for 100 km of the running distance or 1 ton per km, and the following equation was used to express Q_d:

$$Q_d = \frac{100.Q}{s_d} \qquad 4$$

where: Q is the amount of fuel consumption; sd is the running distance of the vehicle.

On the other hand, the vehicle fuel economy per unit of cargo transported was also determined as the following equation.

$$Q_d = \frac{Q.\rho_{nl}}{G_t.s_t} \qquad 5$$

where G_t is the volume of cargo transported; s_t is the running distance of the vehicle; ρ_{nl} is fuel density.

IV. RESULTS AND DISCUSSION

To determine the vehicle fuel economy, Matlab/Simulink software was used to calculate the objective functions when the vehicle was operating in different conditions with parameters as shown in Table 1:

Table 1: Vehicle technical parameters

No.	Parameters	Values	Unit
1	Engine: Inline 4-cylinder, dual camshaft with VVT-i, 16 valves		
2	Effective Torque (Me)	17,4/4200	kg.m/rpm
3	Maximum effective power (Ne)	134/6000	Hp/rpm
4	Wheelbase (L)	2600	mm

5	Vehicle Width (B)	1480	mm
6	Vehicle Height (H)	1500	mm
7	Center coordinates	a = 1.56; b = 1.04;hg=800	
8	Ground clearance	167,8	mm
9	Total allowable weight (G)	1460	KG
10	Tire size	195/60R15 88V	
11	Petrol tank capacity	55	L
12	Maximum velocity	195	km/h

Effect of vehicle speed

The calculations are taken into account when the vehicle moves with various gearbox ratios from 1st to 5th gear and vehicle speeds from 5m/s to 50m/s to evaluate the impact of vehicle speed on the fuel economy.

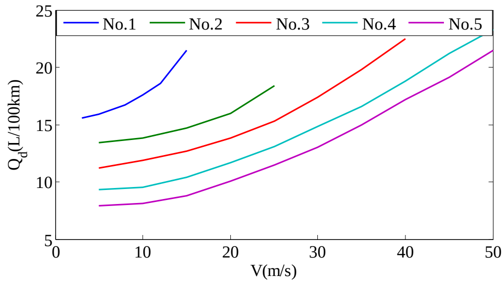

Figure 2. Effect of vehicle speed on fuel consumption

Figure 2 shows the impacts of vehicle speed on fuel consumption. It can be seen that the fuel consumption, Q_d, decreases until reaching the minimum value, Q_{dmin}, at the optimum speed when the vehicle speed increases in the low-velocity regime. Due to the low-speed regime, the total moving resistance forces are not very large and have almost no effect on fuel consumption. When the vehicle speed increases, the fuel consumption increases as well. The variable fuel consumption is because of the change in ge related to the power utilization factor.

Effect of road surface

It is similar to the Section 4.1; To evaluate the impact of road surface on the fuel economy, the calculations are taken into account with moving vehicle with different rolling resistance coefficient f1 = 0.01, f2 = 0.012, f3 = 0.023, f4 = 0.025, f5 = 0.05 and various vehicle speeds from 5 m/s to 50 m/s. The results are shown in Figure 3.

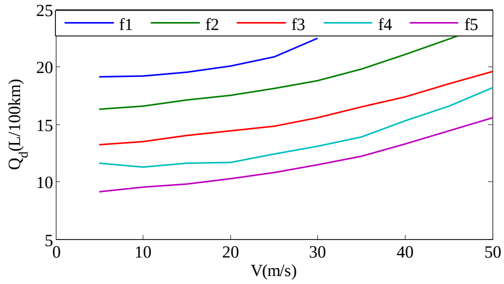

Figure 3. Effect of road surface on fuel consumption

Figure 3 shows that the fuel consumption increases with higher the rolling resistance due to the higher level of engine power usage. Fuel consumption at any given speed increases with a higher rolling resistance coefficient. The distance between the two fuel consumption lines is the increment range when the rolling resistance coefficient increases. This increment range reaches steadily when the distance between the two coefficients is lower.

Effect of load

The vehicle load varies depending on the purpose of the user. To evaluate the fuel economy under this condition, the calculations are considered when the vehicle moves in 3 modes idling, medium and full load, and at various speeds from 5 m/s to 50 m/s.

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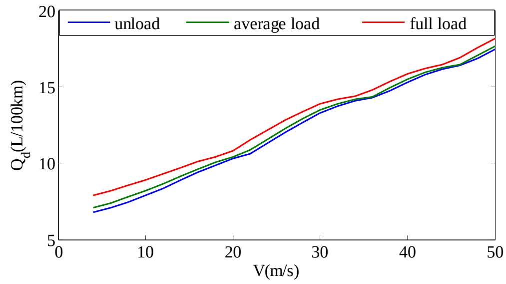

Figure 4. Effect of load on fuel consumption

Figure 4 shows the impact of load on fuel consumption. It can be seen that when the load increases, it makes a change in road surface resistance, and therefore, the fuel consumption increases.

Effect of slope angle

The gear used is the lowest number to evaluate the effect of slope angle on fuel economy. The calculations are made with the condition that the vehicle moves on the road with a slope of 10%, 20% and 30%. The calculation results are shown in figure 5.

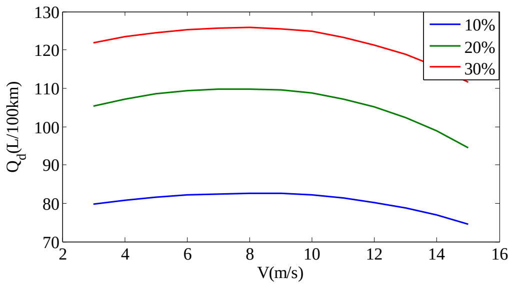

Figure 5. Effect of slope angle on fuel consumption

Figure 5 shows that the steeper the slope, the higher the rolling resistance, and the gears that can be used are low gears leading to more fuel consumption.

V.CONCLUSIONS

A simulation study was conducted to determine the effect of operating conditions on the vehicle fuel economy. The main conclusions of this work can be summarized as follows.

(1) The factors of speed, road surface, and load and slope angle greatly impact the vehicle fuel economy.

(2) When the vehicle moves in mountainous and sloping terrain, the fuel consumption is relatively high.

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