Relationships Between Vehicle Traction Properties and Fuel Consumption for Total Engine Load

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Summary. This paper presents the effect of respective vehicle traction parameters (acceleration capacity, grade ascending ability) on its mileage fuel consumption. These relationships were determined under total engine load conditions for the vehicle speeds being reached at more than one gear ratio.

It has been shown that the maximum values of vehicle dynamic parameters are connected with maximum fuel consumption.

Key words: mileage fuel consumption, passenger car, acceleration capacity, grade ascending ability.

INTRODUCTION

Traction properties as a set of values describing the operation of vehicles allow evaluation of acceleration at respective gears, ability to ascend grades and the maximum speed being reached [13,16]. They show how a car behave under specific driving conditions. The latter are accompanied by energy consumption of vehicle motion which is related to overcoming the resistance to motion [2].

In order to compensate it, energy is being generated in the engine (by burning the air-fuel mixture) which is delivered at the wheels and reduced by the losses occurring in the drive system [18]:

$$E = B_L \cdot W_d - \Delta E_s - \Delta E_p \,, \qquad (1)$$

where:
E – energy delivered to the wheels [J],
B_L – quantity of fuel delivered to the engine [dm³],
W_d – net calorific value of fuel [J/dm³],
DE_S – losses of energy conversion in the engine [J],
D E_p- losses of energy transmission to the driven wheels [J].

The energy being delivered to the driven wheels is used to compensate the energy consumption of vehicle motion [18]:

$$E = E_t + E_p + E_w + E_k \,, \qquad (2)$$

where:
E_t – energy expended to overcome the rolling resistance [J],
E_p – energy expended to overcome the air resistance [J],
E_w – energy expended to overcome the grade resistance [J],
E_k – kinetic energy of a vehicle [J].

Vehicle motion conditions being described by energy consumption of motion affect the value of mileage fuel consumption [9,12].

Developed road infrastructure in good condition and drivers' training in ecological driving (eco-driving) affect the value of this parameter [3, 14].

One of the ways aimed at minimisation of fuel consumption is continuous development in the construction of motor vehicle systems, particularly vehicle drive units.

In the era of increasing emphasis on economics and ecology (reduction of emissions, among other of carbon dioxide being a greenhouse gas monitored by federal agencies [5, 6, 19]), engine design engineers try to increase overall engine efficiency by, for instance, application of turbocharging. Its common use has made the downsizing, consisting in maintaining the maximum power at the unchanged level with reduction of engine capacity, to become one of more important developmental trends in internal combustion engines being also associated with the reduction of fuel consumption [7].

However, the value of this parameter is often higher than that being given by vehicle manufacturer and this discrepancy results from different traffic characteristics being at variance with a stationary conditions of fuel consumption determination according to predetermined driving cycle (e.g. NEDC, ADAC Ecotest, WLTC) [1, 8, 10, 11, 14].

The intended tests did not assume the use of maximum vehicle acceleration or its possibility to ascend the maximum grade.

Although they are the manoeuvres being made occasionally (accelerator pedal fully depressed), achievement of the maximum values of traction parameters by a vehicle and determination of fuel consumption for them become important.

STUDY OBJECTIVE

The aim of this study was to determine and evaluate the relationships between car traction properties and fuel consumption for total engine load.

TEST OBJECT

The object of simulation tests was a FIAT Panda vehicle (Fig. 1) equipped with a MultiJet 1.3 JTD engine. This vehicle was characterised by technical features, such as: maximum gross vehicle weight, height, width, dynamic wheel radius, air resistance coefficient, drive system efficiency and gear ratio, which were adopted based on vehicle manufacturer's instruction [20] and literature [4]. Vehicle motion conditions assumed a rolling resistance coefficient for smooth asphalt (0.012) and air density equal to 1.16 kg/m³[4].

Fig. 1. Test object (FIAT Panda vehicle) [20]

TEST METHODS

The test methods included application of the torque and fuel consumption curves for the external characteristics of FIAT MultiJet 1.3 JTD engine (Fig. 2, Fig. 3). It was obtained by empirical tests using an engine test bench [15]. The parameters of full power characteristics were used as input data for simulation tests based on which the relationships between maximum traction properties and fuel consumption were obtained.

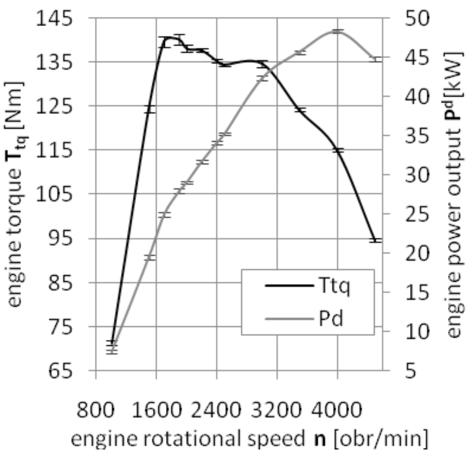

Fig. 2. External characteristic curve of torque and power output for a FIAT MultiJet 1.3 JTD engine

TEST RESULTS

The measurement of operational parameters allowed creation of the external characteristic curves for a FIAT MultiJet 1.3 JTD 16V engine (Fig. 2, Fig. 3).

The presented engine operational parameters (Fig. 2, Fig. 3) characterised its dynamic parameters (maximum performance) and economic characteristics (fuel consumption). The drive unit of a FIAT Panda vehicle obtained the maximum torque equal to 140.1 Nm at the rotational speed equal to 1900 rpm and the maximum power equal to 48.3 kW at the rotational speed equal to 4000 rpm.

Fuel consumption increased with an increase in rotational speed and reached its maximum equal to 3.38 g/s at the rotational speed of maximum power.

Specific fuel consumption, being at the same time a measure of overall engine efficiency, reached its minimum equal to 217.4 g/kWh at the rotational speed of 2400 rpm. The use of torque and fuel consumption curves allowed establishment of the relationship between mileage fuel consumption and maximum acceleration capacity / grade ascending ability.

RELATIONSHIP BETWEEN MILEAGE FUEL CONSUMPTION AND MAXIMUM ACCELERATION CAPACITY OF A VEHICLE

Defining the relationships between fuel consumption and vehicle dynamic properties, being determined by acceleration capacity and grade ascending ability, required a reference to the value of fuel consumption in order to generate the maximum driving force at the wheels needed to overcome specific additional resistance to motion (inertia resistance, grade resistance).

When assuming that total driving force reserve at the wheels (difference between the maximum driving force at the wheels and basic resistance to motion) will be used to overcome inertia resistance, it is possible to determine a maximum acceleration which a vehicle is able to reach under given motion conditions and at a given speed. Applying the values of external characteristics of engine torque and fuel consumption as a function of its rotational speed

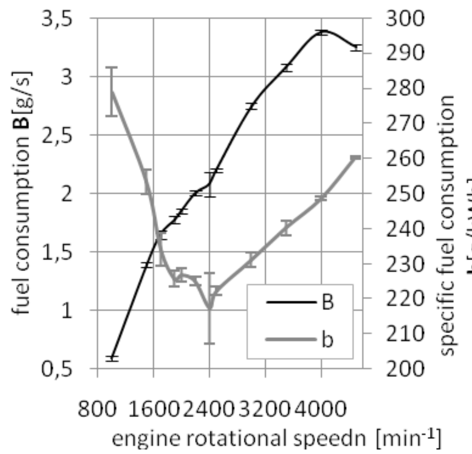

Fig. 3. External characteristic curve of fuel consumption and specific fuel consumption for a FIAT MultiJet 1.3 JTD engine

as well as using the vehicle technical features and motion conditions, a maximum vehicle acceleration was determined according to the following formula [4, 17]:

$$a_{\max} = \frac{F_{N\max} - (F_t + F_p)}{m \cdot \delta} = \frac{T_{tq_{\max}} \cdot \eta \cdot i_B \cdot i_G - (f_t \cdot m \cdot g + 0.579 \cdot c_x \cdot A \cdot v^2)}{r_d \cdot m \cdot (1.04 + 0.03 \cdot i_B^2)}, \quad (3)$$

where:
$F_{N\ max}$ – maximum driving force [N],
F_t – rolling resistance [N],
F_p – air resistance [N],
m – gross vehicle weight [kg] (1455 kg),
d – coefficient of rotating masses,
T_{tqmax} – maximum engine torque [Nm],
h – drive system efficiency
i_B – gear ratio,
i_G – final drive ratio,
f_t – rolling resistance coefficient(0.012),
g – gravitational acceleration (9.81 m/s²),
c_x – air resistance coefficient (0.33),
A – vehicle frontal area [m²] (2.19 m²),
v – vehicle speed [m/s].

Mileage fuel consumption was calculated from the following relationship [4, 17]:

$$Q = \frac{B_h \cdot 100}{\rho_P \cdot v}, \quad (4)$$

where:
Q – mileage fuel consumption [dm³/100 km],
B_h – hourly fuel consumption [kg/h],
ρ_P – fuel density [kg/dm³] (adopted density of DF = 0.82 kg/dm³),
v – vehicle speed [km/h].

The characteristic of vehicle acceleration and its fuel consumption was shown below (Fig.4).

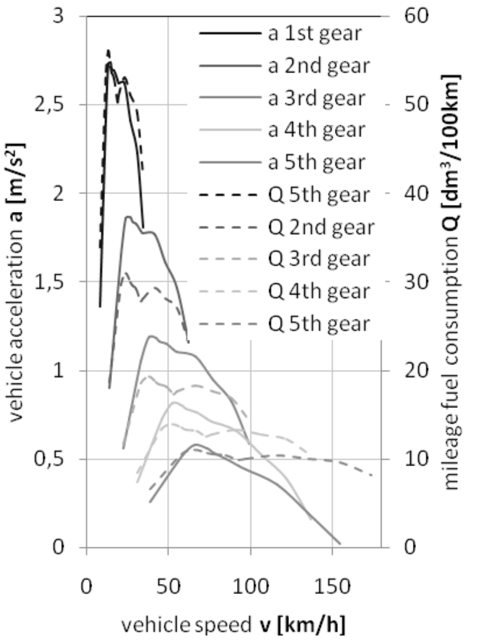

Fig. 4. Characteristic curve of vehicle acceleration capacity **a** and mileage fuel consumption **Q**

Maximum acceleration capacity, amounting to 2.74 m/s², was obtained by the vehicle in the first gear at the maximum driving force reserve at the wheels, consuming at the same time 54.26 dm³/100 km of fuel. The smaller the value of gear ratio in the drive system (higher gear), the lower the vehicle acceleration capacity and its fuel consumption.

The values of vehicle acceleration capacity and its fuel consumption presented in the above figure were the maximum values, being obtainable under given motion conditions. This was induced by the fact that the data used to draw this characteristic curve were appropriate for the maximum fuel delivery (accelerator pedal fully depressed).

The next characteristic curve drawn was the relationship between mileage fuel consumption and maximum vehicle grade ascending ability.

RELATIONSHIP BETWEEN MILEAGE FUEL CONSUMPTION AND MAXIMUM VEHICLE GRADE ASCENDING ABILITY

Mileage fuel consumption was determined based on relationship (4), while a maximum acclivity grade was determined from the following formula (5) [4, 17]:

$$p_{\max} = \frac{F_{N\max} - (F_t + F_p)}{m \cdot g}, \quad (5)$$

where:
symbols and their meanings as in formula (3).

Figure 5 illustrates that the highest fuel consumption occurred for the lowest gears, although fuel consumption decreased with an increase in the gear number.

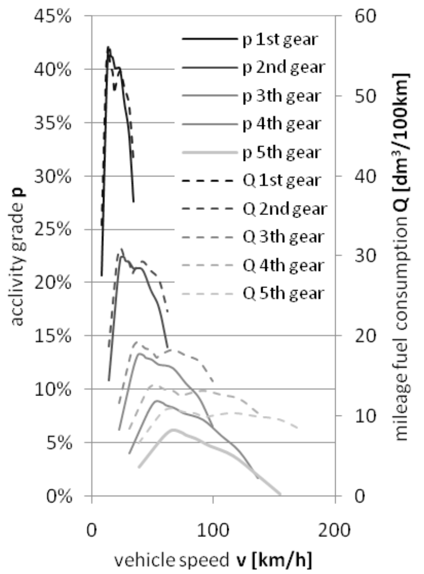

Fig. 5. Traction characteristic curve of fuel consumption Q for constant acclivity grade values p

This parameter also depended on the road slope. The vehicle was able to ascend the maximum acclivity with a gradient of 41.85 % in the first gear at the speed of 14.38 km/h, consuming at the same time 54.26 dm³/100 km of fuel.

With a decrease in the gear ratio value (higher gear), the vehicle grade-ascending ability and the quantity of consumed fuel decreased. In the fifth gear at the maximum speed, the vehicle was not able to ascend any acclivity.

CONCLUSION

Vehicle functional properties are closely associated with their traction properties. Passenger cars are able to reach significant values of traction parameters at total engine load: acceleration from 2.5 m/s^2 to 5.5 m/s^2 grade-ascending ability amounting to 30-50% (in 1st gear) [17]. However, they are the maximum values being obtained in the first selectable gear ratio and are connected with the highest fuel consumption. With the decreasing gear ratio (increase in the gear number), the maximum values of vehicle traction parameters as well as its fuel consumption decrease.

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RELACJE POMIĘDZY WŁAŚCIWOŚCIAMI TRAKCYJNYMI POJAZDU A ZUŻYCIEM PALIWA DLA CAŁKOWITEGO OBCIĄŻENIA SILNIKA

Streszczenie. Artykuł prezentuje wpływ poszczególnych parametrów trakcyjnych (zdolność do przyspieszania pojazdu, zdolność do pokonywania wzniesień) na przebiegowe zużycie paliwa pojazdu. Relacje te określono w warunkach całkowitego obciążenia silnika dla prędkości samochodu osiąganych na więcej niż jednym przełożeniu skrzyni biegów. Wykazano, że maksymalne wartości parametrów dynamicznych pojazdu wiążą się z maksymalnym zużyciem paliwa.

Słowa kluczowe: przebiegowe zużycie paliwa, samochód osobowy, zdolność do przyspieszania pojazdu, zdolność do pokonywania wzniesień.