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DETERMINATION OF THE FUEL CONSUMPTION FOR A PASSENGER CAR THROUGH THE POWER AND SPEED ON IMITATION ROLLER STAND

Fuel consumption is one of the indicators that characterize the operational properties of road vehicles. In this study, the main factors that affect on fuel consumption of vehicles during its operation were analyzed. Most operating conditions can be repeated on the roller stand.

The main mathematical methods that are used to calculate fuel consumption in road conditions and during bench tests were analyzed. It is indicated that for bench tests for fuel efficiency, it is important to correctly set and control the force on the vehicle wheels.

The paper proposes a mathematical model for determining fuel consumption, which the amount of fuel consumption is calculated through the load power mode and vehicle speed. The calculation method is based on obtaining the efficiency of: indicator, mechanical, transmission and wheels, from which the overall vehicle efficiency was obtained. The table shows the results of calculating fuel consumption, wheel power and overall efficiency, as well as its constituent components. All parameters were defined for variable vehicle speed.

A general algorithm and results of calculating fuel consumption in road conditions and on a roller stand with different power on wheels were given. The results of experimental studies were presented, where the fuel consumption was determined for cars of the VAZ brand. Fuel consumption increases in the range of 6 to 11 l/100 km if the wheel power varies in the range of 7 to 21 kW. This is in good agreement with the data calculated in the same range of parameters. Calculations show an increase in fuel consumption if the power is reduced from 5 kW and below. This can be explained by the fact that in this mode the vehicle moves in low gears of the gearbox. It was not possible to repeat this mode during the experiment.

General conclusions and directions for further research were formulated.

Key words: car, fuel consumption, a roller dynamometer, mode of load, mode of speed, efficiency.

INTRODUCTION

In the process of designing and creating a vehicle structure, engineers lay down certain characteristics that will be implemented during its manufacture and manifest themselves during operation. The new machine has both operational and design characteristics. One of the main characteristics of performance characteristics is fuel consumption.

Fuel efficiency depends on several factors, the main of which are: design features and characteristics of the car; operational parameters of the vehicle; technical condition of the vehicle; driving mode and driver class. For new cars, fuel consumption can be reduced by rationally choosing the optimal driving mode. To do this, it is necessary to establish an analytical and experimental relationship between fuel consumption and power-speed mode in the process of vehicle movement.

It is necessary to be able to calculate and provide the necessary test modes (stand speed, stand power, etc.), so that the fuel consumption is identical (on the road and on the stand).

Adequate modeling of road conditions on a roller test bench makes it possible to take into account a variety of design and operational factors that form fuel consumption for a car engine.

ANALYSIS OF LITERATURE DATA AND FORMULATION OF THE PROBLEM

The theoretical foundations of mathematical modeling of the operational properties of a car were laid by researchers in the first half of the last century. At that time, a dependence was proposed for determining road fuel consumption through specific indicator fuel consumption and vehicle power. The principles for evaluating the fuel efficiency of a car in real operating conditions were laid down by prof. Govorushchenko M.Ya. [1]. Further development of the methodology for calculating fuel consumption through various indicators is reflected in the following works: by specific indicators [2], by the efficiency of the vehicle's power units [3], by the uneven movement of the car on the road [4], by the change in the indicator fuel consumption [5] . The papers [5] and [6] present the practical implementation of a new methodology for assessing and automotive diagnostics based on fuel consumption. The papers [6] and [7] give a feature of determining fuel efficiency during bench tests on a roller bench. In works [2-7], fuel consumption was determined from the speed of car on the road or the roller stand. The study of other operational parameters in these works was not considered explicitly.

PURPOSE AND OBJECTIVES OF THE STUDY

The purpose of this work is to obtain a mathematical dependence for definition of fuel consumption through the power on the car wheels. It is necessary to compare the fuel consumption values, which are obtained by mathematical modeling, with the experimental results of the study for bench tests of the car.

RESEARCH RESULT

Fuel consumption in l/100 km for road testing is calculated using the following formula

$$Q = \frac{100 \cdot Q_1}{V_a \cdot \rho_t}, \quad (1)$$

where Q_1 – hourly fuel consumption, kg/h.;

V_a – vehicle speed, km/h;

ρ_t – fuel density, kg/l.

Hourly fuel consumption is determined through the indicator or effective engine parameters:

$$Q_1 = g_e \cdot N_e \ , \quad (2)$$

where g_e – specific effective fuel consumption, kg/kW;

N_e - engine effective power, kW.

The specific effective fuel consumption in g/kW is related to the effective engine efficiency:

$$g_e = \frac{3600}{H_н \cdot \eta_e}, \quad (3)$$

where $H_н$ – lower calorific value, kg/kJ;

η_e – engine effective efficiency.

The engine effective efficiency is a composite index that takes into account the indicator and mechanical losses in the engine:

$$\eta_e = \eta_i \cdot \eta_м, \quad (4)$$

where η_i – engine indicator efficiency;

$\eta_м$ – engine mechanical efficiency.

The effective engine power is related to the wheels power for vehicle as:

$$N_e = N_k / \eta_{тр}, \quad (5)$$

where N_k – power that was brought to the vehicle wheels, kW;

$\eta_{тр}$ – transmission efficiency.

Fuel consumption on the road is determined by the formula, taking into account dependencies (2 - 5):

$$Q = \frac{360 \cdot N_k}{V_a \cdot \rho_t \cdot H_н \cdot \eta_i \cdot \eta_м \cdot \eta_{тр}}. \quad (6)$$

When the car is "moving" on a roller stand, it is convenient to create and measure power not on wheels, but on the stand rollers. Then the formula for determining the fuel consumption of vehicle at the stand, taking into account the loss of energy in the wheels, will be:

$$Q = \frac{360 \cdot N_б}{V_a \cdot \rho_t \cdot H_н \cdot \eta_i \cdot \eta_м \cdot \eta_{тр} \cdot \eta_k}. \quad (7)$$

where η_k – wheel efficiency,

$N_б$ – power on bench rollers, kW. $N_б = N_k / \eta_k$

The components of 4 efficiency: for the engine, transmission and wheels, can be expressed in terms of the general vehicle efficiency, i.e. $\eta_a = \eta_i \cdot \eta_м \cdot \eta_{тр} \cdot \eta_k$. Then formula (7) can be written as follows:

$$Q = \frac{360 \cdot N_б}{V_a \cdot \rho_t \cdot H_н \cdot \eta_a}. \quad (7)$$

In [8], there are calculated dependences for determining the engine indicator efficiency and engine mechanical efficiency and the transmission efficiency and wheels efficiency, as well as the dependence for determining the overall vehicle efficiency.

Table 1 shows the values of the efficiency of the car and its components, which were calculated for the VAZ-2107 when the vehicle is moving on the road.

Table 1 – The results of calculating the fuel consumption for a VAZ-2107 car

V_a, km/h	η_i	$\eta_м$	η_e	$\eta_{тр}$	$\eta_к$	η_a	$P_к$, N	$N_к$, kW	Q, l/100 km
25	0,300	0,380	0,114	0,910	0,480	0,050	261,95	1.819	**11,24**
35	0,304	0,460	0,140	0,870	0,517	0,063	299,30	2.910	**9,04**
60	0,311	0,569	0,177	0,770	0,660	0,090	372,27	6.211	**6,3**
90	0,320	0,728	0,233	0,730	0,452	0,077	473,83	11.846	**7,38**
120	0,330	0,788	0,260	0,737	0,292	0,056	671,24	22.375	**10,2**
150	0,340	0,783	0,266	0,757	0,228	0,046	836,70	34.862	**12,26**

The value of the force on the vehicle wheels was calculated by the formula:

$$P_k = G_a \cdot \psi + 0.077 \cdot kF \cdot V_a^2, \quad (8)$$

where G_a – vehicle weight, N;

ψ – total road resistance coefficient;

kF – streamlining factor, N‣ s^2/m^2.

Values ψ and kF are recommended to be calculated using the following formulas:

$$\psi = \frac{0.01 \cdot V_{max}}{V_a}; \quad (9)$$

$$kF = k \cdot \alpha_t \cdot B_a \cdot H_a, \quad (10)$$

where V_{max} – maximum vehicle speed, km/h;

k – air resistance coefficient, $N \cdot s^2/m^4$;

α_t – frontal area fill factor;

B_a – vehicle width, m;

H_a – vehicle height, m.

If you know the power that is supplied to the vehicle wheels, you can calculate the power at the vehicle wheels in watts.:

$$N_k = \frac{P_k \cdot V_a}{3.6}. \quad (11)$$

Finally we get the power that is supplied to the vehicle wheels in kW:

$$N_k = 2.78 \cdot 10^{-4} \cdot (G_a \cdot 0.01 \cdot V_{max} + 0.077 \cdot k \cdot \alpha_t \cdot B_a \cdot H_a \cdot V_a^3). \quad (12)$$

Table 1 summarizes the values of wheel force and wheel power, which were calculated using formulas (8) and (12). The last column of table 1 shows the calculated values of fuel consumption for the VAZ-2107 when the vehicle was moving along the road in running order.

The following initial data were adopted for the VAZ-2107 vehicle in the calculations of fuel consumption, power to the wheels and efficiency of the vehicle: G_a =10400 H; V_{max} =160 km/h; α_t =0.9; k = 0.36 H•s^2/m^4; B_a =1.6 m; H_a =1.4 m; ρ_t =0.76 g/cm^3; $H_н$ =44000 kJ/kg.

If we substitute the initial data in dependences (6), (8) and (12), then we can obtain simplified formulas in relation to the vehicle VAZ-2107. Then the formulas for calculating the wheel force and wheel power, as well as fuel consumption will take the following form:

– power on vehicle wheels P_k, N:

$$P_k = \frac{15600}{V_a} + 1.13 \cdot V_a^2; \tag{12}$$

– power, which is connected to vehicle wheels N_k, kW:

$$N_k = 4.33 + 3.14 \cdot 10^{-4} \cdot V_a^3; \tag{13}$$

– fuel consumption Q, l/100 km:

$$Q = \frac{0.0108 \cdot N_k}{V_a \cdot \eta_i \cdot \eta_м \cdot \eta_{тр}}. \tag{14}$$

DISCUSSION OF THE RESEARCH RESULTS

A graphical dependence was built, which shows how fuel consumption changes depending on the power supplied to the car wheels, according to the calculated data. The results of the calculation were shown graphically in Figure 1.

As you can see from the graph, the power at the vehicle wheels has an ambiguous effect on fuel consumption. In the wheel power range from 1 kW to 6 kW, fuel consumption decreases with increasing power at the vehicle wheels. When the power at the wheels increases from 6 kW and above, the fuel consumption increases almost linearly. For the VAZ-2107 vehicle, the value of the minimum fuel consumption corresponds to the wheel power, which is 6 kW.

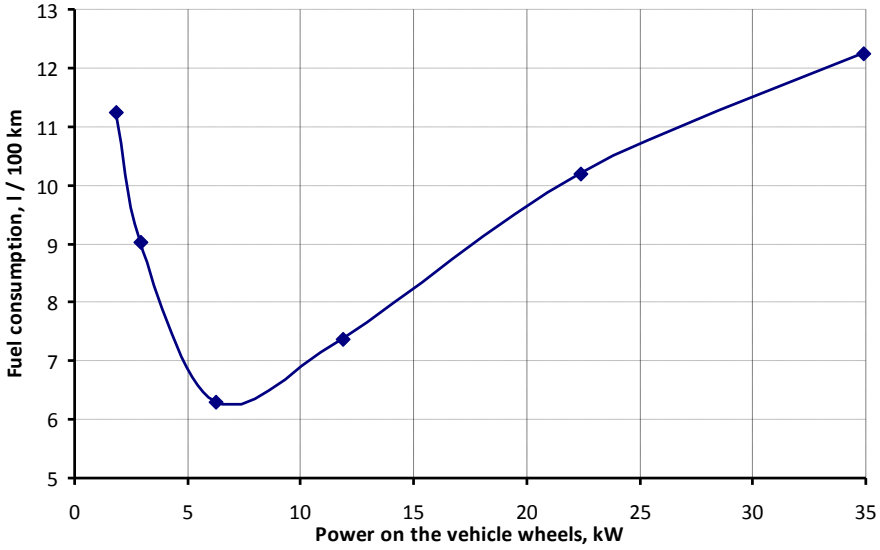

Figure 1 - Theoretical dependence of fuel consumption on wheel power for a VAZ-2107 vehicle

Experimental characteristics were obtained for several vehicles of VAZ models. Figure 2 shows how wheel power affects fuel consumption when cars are driven on a wheel stand. This makes it possible to

compare the results of calculations by the mathematical model with the experimental results. The range of power change from 7 to 20 kW was determined by the technical capabilities of the roller stand. Simulate power less than 7 kW did not allow the design of the stand.

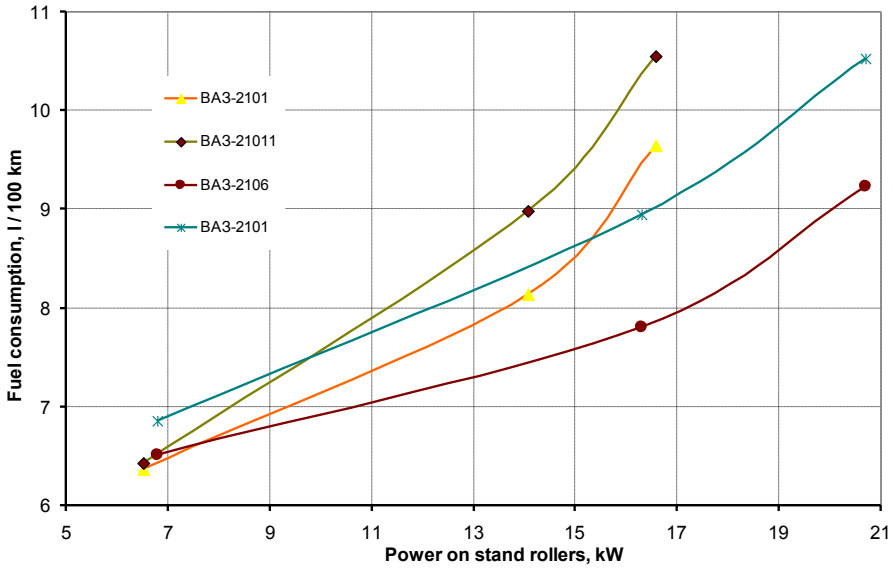

Figure 2 - Graph of fuel consumption in l / 100 km, which varies with the wheel power on the vehicle

From Graph 2 you can see an almost linear fuel consumption versus wheel power curve for a car. The deviation of the theoretical and experimental characteristics of the vehicle VAZ-2107 does not exceed 3 %. The intensity of change in fuel consumption from wheel power varies slightly for different vehicle models.

CONCLUSIONS

The minimum fuel consumption is for the speed range from 60 to 90 km / h for the VAZ 2107 vehicle. When the VAZ-2107 vehicle is moving on the road, the minimum fuel consumption corresponds to the wheel power when it is 7 kW. Then, at this power, fuel consumption will correspond to 6 l / 100 km. In the load range from 7 to 20 kW, the fuel consumption of vehicles increases almost linearly. The results of these studies can be used to improve the methodology for rationing fuel consumption in transport.

LIST OF SOURCES LINKS

1. Говорущенко Н.Я., Туренко А.Н. Системотехника транспорта. Харьков: РИО ХГАДТУ, 1999. 468 с.

2. Говорущенко Н.Я., Кривошапов С.И. Алгоритм оценки топливной экономичности транспортных машин по удельным показателям. *Девета научно-техническа конференция с международно участие "Транспорт, екология – устойчиво развитие" (15-17 май 2003)*. Болгария, Варна: Технически университет, 2003. С. 188-194.

3. Говорущенко Н.Я., Кривошапов С.И. Новая методика нормирования расхода топлива транспортных машин (метод четырех КПД). *Автомобильный транспорт*. Харьков: ХНАДУ, 2004. № 15. С 31-36.

4. Говорущенко Н.Я., Кривошапов С.И. Методика нормирования расхода топлива и выбросов. *Сборник докладов XIV научно-техническа конференция с международно участие "Транспорт, екология – устойчиво развитие"*. Болгария, Варна: Технически университет, 2008.

5. Говорущенко Н.Я., Горбик Ю.В. Методы диагностирования автомобилей по изменению общего и индикаторного расхода топлива и частных КПД в отдельных агрегатах. *XVI научно-техническа конференция с международно участие "Транспорт, екология – устойчиво развитие"*. Болгария, Варна: Технически университет, 2010. С. 442-450.

6. Говорущенко Н.Я., Горбик Ю.В. Методы системного расчетно-аналитического и стендового диагностирования легковых автомобилей. *Автомобильный транспорт*. Харьков: ХНАДУ, 2009. № 25. С. 58-61.

7. Кривошапов, С.И. Определение расхода топлива автомобиля на стенде с беговыми барабанами. *Вісник Національного технічного університету «ХПІ». Серія:Автомобіле- та тракторобудування*. Харків: НТУ "ХПІ", 2010. Вип. 33. С. 72-78.

8. Кривошапов С.І. Розробка методики та алгоритму загального діагностування автомобілів за зміною коефіцієнта корисної дії. *Автореф. канд. техн. наук: 05.22.10*. Харків, 1999. 20 с.

REFERENCES

1. Govorushchenko N.Ya., Turenko A.N. Sistemotekhnika transporta: izd. Har'kov: RIO HGADTU, 1999. 468 s.

2. Govorushchenko N.Ya., Krivoshapov S.I. Algoritm ocenki toplivnoj ekonomichnosti transportnyh mashin po udel'nym pokazatelyam: *Deveta nauchno-tekhnicheska konferenciya s mezhdunarodno uchastie "Transport, ekologiya – ustojchivo razvitie" (15-17 maj 2003).* Bolgariya, Varna: Tekhnicheski universitet, 2003. S. 188-194.

3. Govorushchenko N.Ya., Krivoshapov S.I. Novaya metodika normirovaniya raskhoda topliva transportnyh mashin (metod chetyrekh KPD). *Avtomobil'nyj transport.* Har'kov: HNADU, 2004. № 15. S. 31-36.

4. Govorushchenko N.Ya., Krivoshapov S.I. Metodika normirovaniya raskhoda topliva i vybrosov. *Sbornik dokladov XIV nauchno-tekhnicheska konferenciya s mezhdunarodno uchastie "Transport, ekologiya – ustojchivo razvitie*". Bolgariya, Varna: Tekhnicheski universitet, 2008.

5. Govorushchenko N.Ya., Gorbik Yu.V. Metody diagnostirovaniya avtomobilej po izmeneniyu obshchego i indikatornogo raskhoda topliva i chastnyh KPD v otdel'nyh agregatah. *XVI nauchno-tekhnicheska konferenciya s mezhdunarodno uchastie "Transport, ekologiya – ustojchivo razvitie"*. Bolgariya, Varna: Tekhnicheski universitet, 2010. S. 442-450.

6. Govorushchenko N.Ya., Gorbik Yu.V. Metody sistemnogo raschetno-analiticheskogo i stendovogo diagnostirovaniya legkovyh avtomobilej. *Avtomobil'nyj transport*. Har'kov: HNADU, 2009. № 25. S. 58-61.

7. Krivoshapov, S.I. Opredelenie raskhoda topliva avtomobilya na stende s begovymi barabanami. *Vestnik Nacional'nogo tekhnicheskogo universiteta "HPI". Sersy "Avtomobile- i traktorostroeniya"*. Har'kov: NTU "HPI", 2010. Vyp. 33. S. 72-78.

8. Krivoshapov S.I. Rozrobka metodiki ta algoritmu zagal'nogo diagnostuvannya avtomobiliv za zminoyu koeficiєnta korisnoї dії. *Avtoref. kand. tekhn. nauk: 05.22.10*. Har'kov, 1999. 20 s.

Ю. Горбік, С. Кривошапов. Визначення витрати палива для легкового автомобіля за потужністю і швидкістю на імітаційному роликовому стенді

Витрата палива - один з показників, що характеризують експлуатаційні властивості дорожньо-транспортних засобів. В роботі були проаналізовані основні фактори, що впливають на витрату палива автомобілів у процесі експлуатації.

Більшість умов експлуатації можуть бути повторені на роликовому стегні з біговими барабанами. Проаналізовано математичні методи розрахунку витрати палива у дорожніх умовах та стендових випробуваннях. Вказується, що для стендових випробувань на паливну економічність важливо правильно встановлювати і контролювати навантаження на колесах автомобіля.

У роботі запропоновано математичну модель визначення витрати палива через режим навантаження та швидкість руху автомобіля. Розрахунковий метод заснований на отриманні ККД: індикаторного, механічного, трансмісії та коліс, з яких було отримано загальний ККД транспортного засобу. У таблиці наведено результати розрахунку витрати палива, колісної потужності та загального ККД, а також його складових елементів. Всі параметри були визначені для різної швидкості автомобіля.

Наведено алгоритм та результати розрахунку витрати палива на дорозі та на стенді з біговими барабанами за різної потужності на колесах автомобіля та роликах стенду. Наведено результати експериментальних досліджень щодо визначення витрати палива для автомобілів ВАЗ. Витрата палива зростає в діапазоні від 6 до 11 л/100 км, якщо потужність на колесах змінюється від 7 до 21 кВт. Це добре узгоджується з розрахунковими даними у тому ж діапазоні зміни параметрів. Розрахунки показують збільшення витрати палива, якщо потужності знижується від 5 кВт та нижче. Це можна пояснити тим, що у цьому режимі транспортний засіб рухається на низьких передач коробки передач. Повторити цей режим у процесі експерименту було неможливо.

Сформульовано висновки та напрями подальших досліджень.

Ключові слова: автомобіль, витрата палива, стенд з біговими барабанами, режим навантаження, швидкісний режим, ККД.

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