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Mathematical modeling of the effect of internal combustion engine parameters on vehicle acceleration dynamics

A.A. Ernazarov[1][a], S.S. Musurmonov[2][b]
[1]Jizzakh Polytechnic Institute, Jizzakh, Uzbekistan
[2]Tashkent state Technical University named after Islam Karimov, Tashkent, Uzbekistan

Abstract: Mathematical model has been calculated in the study, which determines the relationship between the engine's operating process and the dynamics of the car. The adequacy of the model was verified using an experimental study of the B15D2 engine to obtain adjustment, load and external speed characteristics.
Keywords: engine workflow, mathematical model, acceleration dynamics; experimental study, speed characteristics

1. Introduction

Mathematical modeling of the influence of internal combustion engine (ICE) parameters on the dynamics of vehicle acceleration is an important task in the automotive industry and transportation engineering. It allows you to evaluate how different engine characteristics affect vehicle acceleration, acceleration time to a certain speed, and other dynamic indicators.

These models are based on the balance of forces acting on the car during its movement. For example, in models [1-3], a car is represented as an elastic-mass oscillatory system. The rolling of the wheel on uneven and flat surfaces is described in detail, the inertial and elastic characteristics of the moving parts of the engine, transmission and wheels are taken into account. These models are characterized by the complexity of implementation and verification, and require the establishment of a number of empirical coefficients based on the results of experimental studies. In addition, there is a lack of information in the literature on the use of such models in car parameter optimization tasks.

When solving a number of tasks, for example, choosing the parameters and settings of an engine and a car, creating a preliminary design of a car, and studying its dynamic qualities, it is advisable to use simpler models [4-7]. These models, for example, the graphoanalytical method make it possible to determine the acceleration and path of a car based on the calculation of the so-called dynamic factor.

In mathematical models of car acceleration, the maximum engine power in the modes of external speed characteristics is usually set according to empirical dependencies. For example, in the Leiderman equation, the current maximum engine power depends on the rated power and rotational speed of the crankshaft, as well as the current rotational speed of the crankshaft. This makes it impossible to optimize the parameters and settings of the engine, while ensuring good dynamic qualities of the car.

An attempt to combine mathematical models of the working process of an engine and a vehicle was made in [8]. The engine operating modes when the car is moving according to the European NEDC test cycle are replaced by quasi-stationary driving modes with a constant speed of 1 s. To reduce the engine parameters in quasi-stationary cycle modes to the parameters of the actual cycle, the calculated engine parameters are multiplied by the empirical coefficients given in [9].

The disadvantage of this approach is the use of empirical coefficients generalized based on the results of experimental tests for a number of engines of a certain class, which makes it impossible to take into account the design features and workflow of a particular engine.

Thus, the aim of the work is to develop a mathematical model of the dynamics of car acceleration, taking into account the influence of the design parameters and adjustments of the internal combustion engine on this process.

2. Research methodology

The methodology of computational research. The mathematical model of the engine workflow includes submodels:

- determination of the thermophysical properties of air, fuel of any component composition, as well as exhaust gases;
- determination of the kinematic characteristics of the movement of the elements of the crank mechanism and the passage sections of the valves;
- simplified calculation of the working process to obtain a first approximation of the parameters of the working fluid in the cylinder at the beginning of the exhaust stroke;
- quasi-stationary calculation of gas exchange, compression and expansion in a cylinder using the volumetric balance method;
- combustion according to the Vibe model [10], in which the indicators of the nature and duration of fuel combustion are set using empirical formulas given in the work;
- heat transfer in the cylinder according to the Gerhard Vosni model [11];
- friction losses as an empirical function of the average piston speed. The feasibility of using this empirical dependence for a research engine was evaluated in the work.

The adequacy of the mathematical model was assessed by comparing the calculation results of specific effective fuel consumption ($\boldsymbol{g_e}$), filling coefficient ($\boldsymbol{\eta_v}$) and hourly air consumption ($\boldsymbol{G_n}$) with experimental data. Figure 2 shows the adjustment characteristics for the composition of the mixture and the ignition timing angle, Figure 3 shows the load and external speed characteristics. It can be seen that

[a] https://orcid.org/0000-0002-4188-2084
[b] https://orcid.org/0009-0009-8618-1722

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the mathematical model provides a sufficiently high accuracy in determining the effective performance of an experimental engine.

The study of the dynamic properties of the car was carried out according to the next method. The range of vehicle speeds from 0 to 100 km/h was divided into sections lasting 1 km/h. It was believed that the car was moving at a constant acceleration in each section. Knowing the speed at the beginning of the section and the average acceleration in the calculated interval, you can determine the speed at the end of the section.

The main factor determining the current acceleration value of the car is the dynamic factor D, which depends on the traction force, the force of air resistance and the weight of the car. Thus, the task of the study was to calculate the parameters that determine the dynamic factor and acceleration of the car.

Unfortunately, the basic methodology does not clearly specify the method for accounting for the effect of vehicle gearshift time on acceleration dynamics, which can be used in machine calculations. The authors proposed to determine the acceleration time $\boldsymbol{\Delta t}$ in the speed range from v_1 to v_2 when shifting gears as follows. Time t can be divided into two intervals (Fig. 1):

$$\Delta t = \Delta t_1 + \Delta t_2, \tag{1}$$

where Δt_1 is the gearshift time; Δt_2 is the acceleration time from speed v_1 to speed v_2

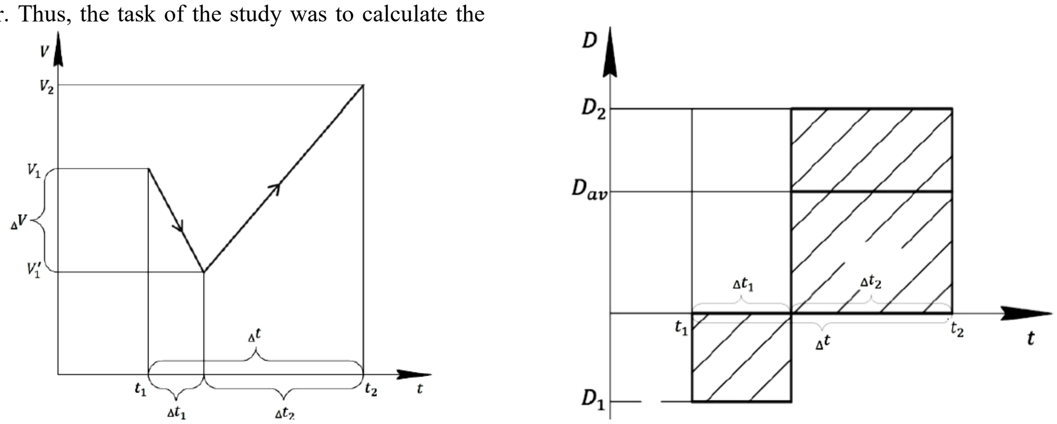

Fig. 1. Diagram for determining the dynamic factor when shifting gears

The time Δt_1 depends on the driver's qualifications and can vary from 0.2 to 3 seconds [5]. During Δt_1, the vehicle's speed decreases by Δv and reaches v_1 at the end of the first interval.

When shifting gears, the car moves by inertia, and the traction force $F_{t1} = 0$. Accordingly, the dynamic coefficient during the interval Δt_1

$$D_1 = -\frac{F_{v1}}{G}, \tag{2}$$

where F_{v1} is the aerodynamic drag; G is the weight of the vehicle.

The dynamic factor D_1 determines the acceleration of the car j_1 in the range Δt_1.

To simplify calculations, we assume that the aerodynamic drag F_{v1} during a gear change is constant and corresponds to the speed in the previous gear. In this case, the acceleration j1 is considered constant, and the speed decrease when shifting gears will be at $\Delta v = j_1 \cdot \Delta t_1$.

During the second interval, after the crankshaft is coupled to the F_{t2} engine transmission, the dynamic coefficient D_2, acceleration j_2 and acceleration time Δt_2 from speed v_1 to speed v_2 are calculated using the formulas of the basic methodology for the case of a vehicle moving with a certain gear.

The average dynamic factor in the calculated interval

$$D_{av} = \frac{D_1 \cdot \Delta t_1 + D_2 \cdot \Delta t_2}{\Delta t_1 + \Delta t_2}, \tag{3}$$

Average speed in the calculated range

$$v_{av} = \frac{(v_1 + v_1') \cdot \Delta t_1 + (v_2 + v_2') \cdot \Delta t_2}{2}, \tag{4}$$

The engine's crankshaft speed is calculated using the vehicle's speed, the current gear ratio from the wheels to the crankshaft, and the radius of the wheels:

$$n = \frac{v \cdot u_k \cdot u_{pb} \cdot u_0}{0.377 \cdot r_{st}}, \tag{5}$$

where v is the speed of the vehicle; u_k is the current value of the gear ratio; u_{pb} is the gear ratio of the transfer case; u_0 is the gear ratio of the main gear; r_{st} is the static radius of the wheel.

The calculations were performed in the MATLAB software environment. The main set of parameters is shown in Table 1.

An example of the results of calculating the loads in the drive of a Chevrolet Gentra car during acceleration is shown in Fig. 2.

Table 1

Chevrolet Gentra Car Parameters

Parameter	value
Vehicle weight m_a, kg	1245
Static wheel radius *rst*, м	0,26
Permissible gross weight. kg	1660
Car height *Br*, m	1445
Car width Hr, m	1725
Coefficient of filling of the frontal area of the car αA	0,78
Transmission efficiency η_T	0,97
Transmission ratio	
uk1	3,818
uk2	2,158
uk3	1,487
uk4	1,129
uk5	0,886
Main gear ratio	3,72

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In each gear, the speed of rotation of the crankshaft increases during acceleration to values above 4,500 rpm. This provides power close to the nominal value and the maximum possible traction force on the wheels for this vehicle.

The most significant component of the resistance to accelerated movement of the car is the inertia force, which at the beginning of the movement of the car exceeds the forces of rolling resistance and aerodynamic drag by more than 50 times. As the speed of the car increases, the force of inertia decreases, and at a speed of 100 km/ h it is only 1.4 times higher than the other components of the load.

Aerodynamic drag increases proportionally to the square of the vehicle's speed and, at a speed of 100 km/h, makes a significant contribution to overall drag. This force limits the maximum speed for the car, which has an estimated speed of 170 km/h. An increase in speed can be achieved mainly by increasing engine power.

The speed of 100 km/h is reached in 11.9 seconds, which corresponds to the passport data of the Chevrolet Gentra car and indicates the adequacy of the calculation methodology.

Thus, the developed complex mathematical model makes it possible to study the characteristics of the engine and vehicle during acceleration, determine the influence of vehicle parameters on these processes, and conduct optimization studies.

Experimental studies were conducted to refine the mathematical model of the working process of an automobile engine. The engine of the Chevrolet Gentra B15D2 car was chosen as the object of the study. This engine has a distributed fuel injection system, a complex of sensors and an electronic control unit.

The technical characteristics of the B15D2 engine are shown in Table 2.

During the experiment, the rotational speed of the crankshaft was measured using an electronic frequency counter and a magnetoelectric tachometer. Fuel consumption is obtained using the weight measurement method. Also, this parameter, as well as the crankshaft rotation speed, air flow, ignition timing angle and excess air coefficient were determined using standard equipment and software of the electronic engine control unit. The exhaust gas temperature was measured with a chromel-alumel thermocouple and a galvanometer. The pressure and temperature of the oil and the temperature of the coolant were also measured. The thermal mode of the engine was set by changing the water circulation of the external circuit through the oil and water cooler.

To identify the mathematical model of the workflow, the load characteristic of the engine at a rotational speed of 3600 min^{-1}, the external speed characteristic, as well as the adjustment characteristics when changing the ignition timing angle and the excess air coefficient were removed.

Table 2

Technical characteristics of the B15D2 engine

Name of the parameter	Value
Engine brand	Chevrolet Gentra B15D2
Engine type	4-stroke, petrol engine
Number of cylinders	4
Number of valves	16
Cylinder placement	inline
Cylinder diameter, mm	74.71
Stroke of the piston, mm	84.7
Working volume, l	1.5
Rated power, kW	40
The speed of rotation of the crankshaft in the rated power mode, min^{-1}	5600
Maximum torque, Nm	141
speed of rotation of the crankshaft in the mode of maximum torque, min^{-1}	3800
Compression ratio	10.2

3. Results

During the calculations, the excess air coefficient and the ignition timing angle for the acceleration of the car were studied from 0 to 100 km/h (Fig. 2). The excess air coefficient was varied from 0.8 to 1.15, and the ignition timing angle of the mixture was from 0 to 60 degrees of the crankshaft position to the HDC.

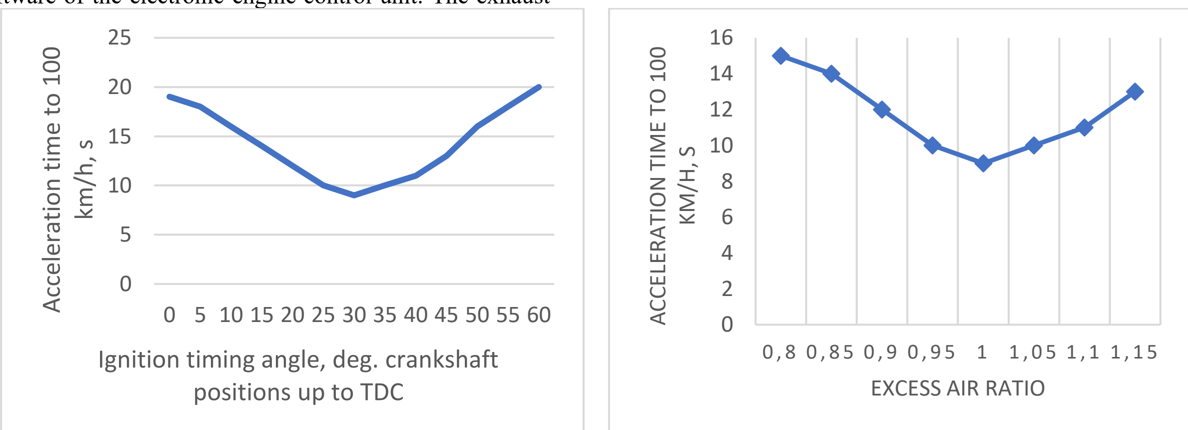

Fig. 2. The effect of engine parameters on the dynamics of car acceleration from 0 to 100 km/h

The increase in the ignition timing angle was increased by detonation and loads on the parts of the crank mechanism, the excess air coefficient was the limits of reliable ignition of the mixture. When changing a certain parameter, other engine parameters were left unchanged as on the base engine (see Table 1).

Increasing the ignition timing angle from 0 to 29 degrees of the crankshaft position to the top dead center, as well as reducing the excess air ratio from 1.16 to 0.99. increase the maximum engine power and acceleration time of the car. An increase in the ignition timing angle, a decrease in the excess air ratio, on the contrary, reduces engine power.

Accordingly, the dynamic properties of the car deteriorate.

Thus, it is shown that optimization studies need to be carried out to determine the rational values of the ignition timing angle and the excess air coefficient.

According to the results of the analysis of the data in Fig. 2, to improve the engine's pick–up, it was proposed to apply a set of parameters: ignition timing angle – 30 degrees of the crankshaft position to the TDC; excess air coefficient - 0.98. Calculations have shown that using the proposed set of parameters on the engine will reduce the acceleration time of the car by almost 10%. Further improvement of the pick-up speed of the car is possible by applying optimization methods to the selection of engine parameters, expanding the number and range of parameter variations.

4. Conclusion

The results of a comprehensive study containing:

- development of a mathematical model of the engine workflow;

- verification of the adequacy of the mathematical model of the engine workflow based on experimental research data;

- refinement of the car acceleration dynamics model, taking into account the influence of gearshift time;

- determination of the effect of changes in engine parameters on the dynamic properties of the Chevrolet Gentra.

References

[1] Теория автомобиля: учебник / В.Н. Кравец; Нижегород. гос. техн. ун-т им. Р.Е. Алексеева. – 2-е изд., переработ. – Нижний Новгород, 2013. – 413 с.

[2] Wickrama Achchige, Dilini & Herath, B & Bowatta, B & Silva, Mr & Jayaweera, Nirosh. (2016). Design and Development of Kinetic Energy Recovery System for Motor Vehicles.

[3] Syed Muzzamil Hussain Shah, Zahiraniza Mustaffa, Khamaruzaman Wan Yusof, Mohd Faizairi Mohd Nor, Influence of forces on vehicle's instability in floodwaters, Ain Shams Engineering Journal, Volume 9, Issue 4, 2018, Pages 3245-3258, ISSN 2090-4479, https://doi.org/10.1016/j.asej.2018.01.001.

[4] Динамические свойства автомобиля. Учебное пособие для студентов специальности 190109 – Автомобили и тракторы / А. Ш. Хусаинов – Ульяновск: УлГУ, 2012. – 32 с.

[5] Zhiqiang Fu, Longquan Sun, Mingyang Zhi, Pengxiao Wang, Duliang Wang, Numerical study on the dynamic characteristics of a vehicle with a multistage load reduction structure during oblique water entry, Ocean Engineering, Volume 295, 2024, 116778, ISSN 0029-8018, https://doi.org/10.1016/j.oceaneng.2024.116778.

[6] Bae, Chul-Yong & Kwon, Seong-Jin & Kim, Chan-Jung & Lee, Bong-Hyun & Na, Byung. (2007). A Study on the Development of Vehicle Dynamic Model for Dynamic Characteristics Analysis of Chassis Parts. Transactions of the Korean Society for Noise and Vibration Engineering. 17. 958-966. 10.5050/KSNVN.2007.17.10.958.

[7] Lei Zhao, Dianyou Jiang, Guotang Zhao, Jianxun Sun, Guotao Yang, Experimental study on the dynamic characteristics of bi-block ballastless track under the combined action of vehicle load and temperature gradient, Construction and Building Materials, Volume 438, 2024, 137107,ISSN 0950-0618, https://doi.org/10.1016/j.conbuildmat.2024.137107

[8] Орехов С. Н. Математическая модель рабочего процесса ДВС и ее идентификация // Машиностроение и компьютерные технологии. 2009. №12. URL: https://cyberleninka.ru/article/n/matematicheskaya-model-rabochego-protsessa-dvs-i-ee-identifikatsiya (дата обращения: 16.02.2025).

[9] Шароглазов Б. А., Клементьев В. В. Теория рабочих процессов ДВС: Учебное пособие к решению задач. – Челябинск: Изд. ЮУрГУ, 2003. – 33 с.

[10] Сеначин, П. К. Моделирование физико-химических процессов и горения в энергоустановках. Книга II. Модели процессов горения в поршневых двигателях: учебное пособие [Текст] / П. К. Сеначин, А. А. Брютов, А. П. Сеначин / Алтайский государственный технический университет имени И. И. Ползунова; Институт теплофизики имени С. С. Кутателадзе СО РАН. – Барнаул: Алт. гос. техн. ун-т, 2019.– 184 с.

[11] Сатжанов Бисенбай Сартбаевич Моделирование теплопередачи в цилиндре поршневого двигателя // Нефтегазовые технологии и экологическая безопасность. 2008. №5. URL: https://cyberleninka.ru/article/n/modelirovanie-teploperedachi-v-tsilindre-porshnevogo-dvigatelya (дата обращения: 12.02.2025).

[12] Бутин Данила Александрович, Беляков Владимир Викторович Частотный метод оценки курсовой устойчивости многомассовой имитационной модели автомобиля // Труды НГТУ им. Р. Е. Алексеева. 2020. №1 (128). URL: https://cyberleninka.ru/article/n/chastotnyy-metod-otsenki-kursovoy-ustoychivosti-mnogomassovoy-imitatsionnoy-modeli-avtomobilya (дата обращения: 10.02.2025).

Information about the author

Ernazarov Aziz Alibaevich	Jizzakh Polytechnic Institute, Associate Professor of the Department of "Vehicle Engineering". E-mail: aziz-ernazarov@mail.ru Tel.: +998939404123 https://orcid.org/0000-0002-4188-2084
Musurmonov Savar Sobir ugli	Tashkent State Technical University named after Islam Karimov, basic doctoral student of the Department of "Service Delivery Technology" E-mail: musurmonovsarvarbek2@gmail.com Tel.: +998991051695 https://orcid.org/0009-0009-8618-1722

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