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VERIFICATION OF THE SYSTEM “DIESEL-POWERED VEHICLE – ROAD - ENVIRONMENT”MATHEMATICAL MODEL ADEQUACY

The paper presents results of verification of the system “Diesel-powered vehicle – road – environment” mathematical model adequacy.

Key words: *mathematical model, adequacy verification, motion time.*

Introduction. Problem set-up. Nowadays usage of mathematical models for scientific research has found wide application.

It enables to conduct wide range of research and save the resource of the object of experimental research. To confirm the adequacy of mathematical model field experiments on real objects are conducted. Adequacy of mathematical model is verified by means of comparison of calculated and obtained experimentally data. Experiments are also conducted for obtaining initial data, used for calculations in mathematical models.

Aim of the research, tasks setting. The aim of the research is verification of mathematical model adequacy of the system “Diesel-powered vehicle – road – environment’ [1]. The basis of mathematical model is known motion equation [2]. Motion equation is the following:

$$F_{wh} = F_f + F_w \pm F_j \pm F_a, \tag{1}$$

where F_{wh} – thrust force on leading wheels of the motor vehicle; F_f – resistance force of wheels rolling; F_w – resistance force of air; F_j – inertial force of motor vehicle; F_α – grade resistance.

For convenience of calculation we will present motion equation of motor vehicle as the sum of moments of force, acting on it. For this purpose it is necessary to multiply motion equation by the radius of wheels.

$$M_{et} = M_f + M_w \pm M_j \pm M_\alpha, \tag{2}$$

where M_{et} – effective torque of the engine, taken from leading wheels of motor vehicle; M_f – moment of force of resistance to wheels rolling; M_w – moment of force of air resistance; M_j – moment of force of motor vehicle inertia; M_α – moment of force of grade resistance.

Moments of force, influencing the motor vehicle are calculated by known equations [2], having substituted them in the formula 2 we will obtain:

$$M_e \cdot i_n \cdot i_0 \cdot i_p \cdot \eta_{tr} = G_a \cdot (f \cdot cos\,\alpha + sin\,\alpha) \cdot r_{wh} + F_w \cdot k_w \cdot V^2 \cdot r_{wh} + m_a \cdot \delta_{rt} \cdot j \cdot r_{wh}, \tag{3}$$

where i_n, i_0, i_p – gear ratio of the n^{th}, main and distributing transmission, correspondingly; η_{tr} – transmission efficiency; G_a – weight of motor vehicle, H; f – rolling resistance coefficient; α – angle of longitudinal slope of road, deg; r_{wh} – dynamic radius of the wheel, m; F_w – frontal area of motor vehicle, m^2; k_w – air resistance coefficient, kg/m^3; V – speed of motor vehicle motion, m/s; m_a – mass of the motor vehicle, kg; δ_{rt} – coefficient account of rotating mass of motor vehicle inertia impact; j – acceleration of motor vehicle, m/s^2.

Necessary torque of engine for overcoming motor vehicle tractive resistance is calculated by the formula:

$$M_e = \frac{G_a \cdot (f \cdot cos\alpha + sin\alpha) \cdot r_к + F_w \cdot k_w \cdot V^2 \cdot r_{wh} + m_a \cdot \delta_{rt} \cdot j \cdot r_{wh}}{i_n \cdot i_0 \cdot i_p \cdot \eta_{tr}}, \tag{4}$$

During uniform motion of motor vehicle, when Va = const necessary torque of engine for overcoming motor vehicle tractive resistance equals:

$$M_e = M_{ld}. \tag{5}$$

During motor vehicle acceleration from dead stop or after shifting gear the clutch is gradually put in and it slips, and rotation speed of the crankshaft of the engine n_{csh} decreases. During decreasing of n_{csh} across the transmission, besides the torque M_e, also inertia moment is transmitted, that is created as a result of kinetic energy release of moving masses of the engine, mainly of flywheel. This moment equals:

$$M_{cl} = M_e + J_e \cdot \varepsilon, \tag{6}$$

where J_e – the inertia moment of engine, kg·m^2; ε – angular deceleration of the engine crankshaft, that depends on the speed of clutch put in .

By means of mathematical model [1] it is possible to study the change of indexes of motor vehicle in different operation conditions. To reach the set-up objectives of experimental research technical-economic factors of motor vehicle in the course of its motion on test section of the road have been determined, namely: speed of motor vehicle motion , time and fuel consumption.

Statement of the main material. Mathematical model of the system "Diesel-powered vehicle – road – environment" [1] was developed to conduct the study of the impact of alternative fuel on technical-economic and ecological indices of motor vehicle when the alternative fuel is used as a fuel for its engine.

Table 1

Technical characteristics of the object of experimental research

Technical characteristics of motor vehicle Volkswagen Passat B6		
1	Curb weight of motor vehicle	1422 kg
2	Bull weight of motor vehicle	2030 kg
3	Width of motor vehicle	1820 mm
4	Height of motor vehicle	1472 mm
Engine 1.9 TDI PD		
4	Volume of the engine	1896 sm^3
6	Quantity of cylinders	4
9	Compression ratio	19
10	Quantity of valves per cylinder	2
11	Power	77 кW (105 h. p) at 4000 rpm
12	Torque	250 N·m at 1900 rpm
13	Type of fuel	Diesel fuel, with cetane number not less than 49, or biodiesel fuel
Transmission		
14	Mechanical transmission	5 speed transmission 0A4 (GQQ)
Operation indices		
15	Maximum speed	188 km/h
16	Acceleration time (0 – 100 кm/h)	12.1 s
17	Fuel consumption (urban cycle)	7.2 l/100 km
18	Fuel consumption (mixed cycle)	5.6 l/100 km
19	Fuel consumption (extra urban cycle)	4.7 l/100 km

To verify the mathematical model adequacy during carrying out experimental research the following indexes were taken:

motor vehicle speed, m/s;

time of motor vehicle motion , s;

dictance, covered by motor vehicle, m;

instantaneous fuel consumption, l/100km.

As the object of experimental research the passenger motor vehicle Volkswagen Passat B6 equipped with 1.9 Liter TDI (PD) Engine with Pump Injection was chosen.

Characteristic of the object of experimental research is shown in Table. 1.

During experimental research summer diesel fuel was used according the GOST(State Standard) 4840:2007 [3] and European standard EN 590:2004 [4].

Research was carried out on test section of the road for motor vehicles with full mass up to 3.2 tons according to GOST(State Standard) 20306-90 [5], the scheme of which is shown in Fig. 1.

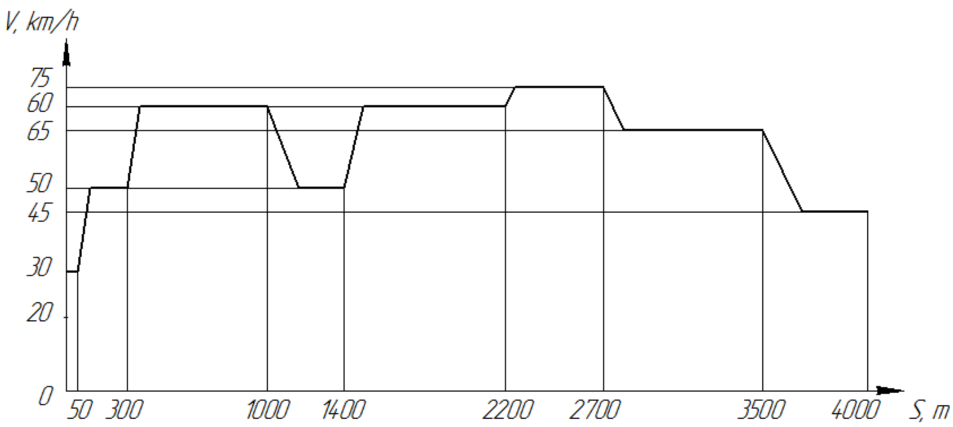

Fig. 1. Diagram of main cycle on the road for motor vehicle with the full mass up to 3.5 tons according to GOST(State Standard) 20306-90

During carrying out experimental research all requirements to object of experimental reserch were kept. In accordance with GOST(State Standard) 20306-90 the mass of motor vehicle was 1726 kg.

Experimental research was carried out on the section of highway M-12, the length of which is 4 km, between settlements Ksaverivka and Lukashivka of Vinnytsia Region (Fig. 2).

Measuring road section was straight, horizontal with asphalt concrete dry covering. Trial rounds on the road were conducted in opposite motion directions two times in each direction.

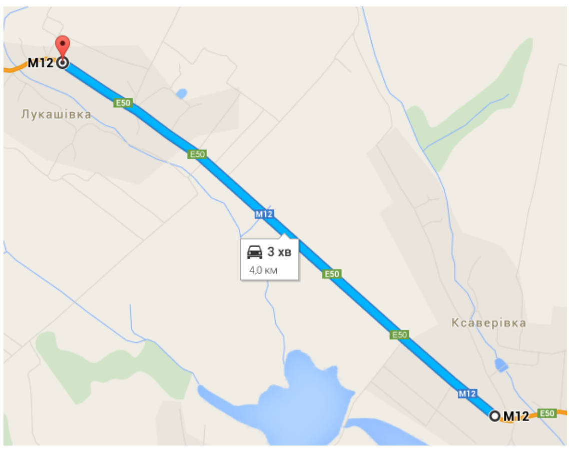

Fig. 2. Measuring road section for determining technical-economic factors of motor vehicle Volkswagen Passat B6 during motion on test section of the road according to the GOST(State Standard) 20306-90

Speed of motor vehicle motion and covered distance were determined by standard speed indicator and odometer, correspondingly. Instantaneous fuel consumption was determined by the indicators of board motor vehicle computer. These indicators were recorded by means of digital camera CANON Digital IXUS 65, that was installed in front of the control panel of the motor vehicle , as it is showed in Fig. 3.

Fig. 3. Installation of the equipment on motor vehicle Volkswagen Passat B6 for carrying out experimental reserch

From the video material taken , screen shot of which is showed in Fig. 4, information was reduced in the tables, then analyzed and generalized.

Fig. 4. Video screenshot

By the results of experimental research the graphics of motor vehicle speed and fuel consumption dependence on time during motion on test section of the road were built, one of them is shown in Fig. 5.

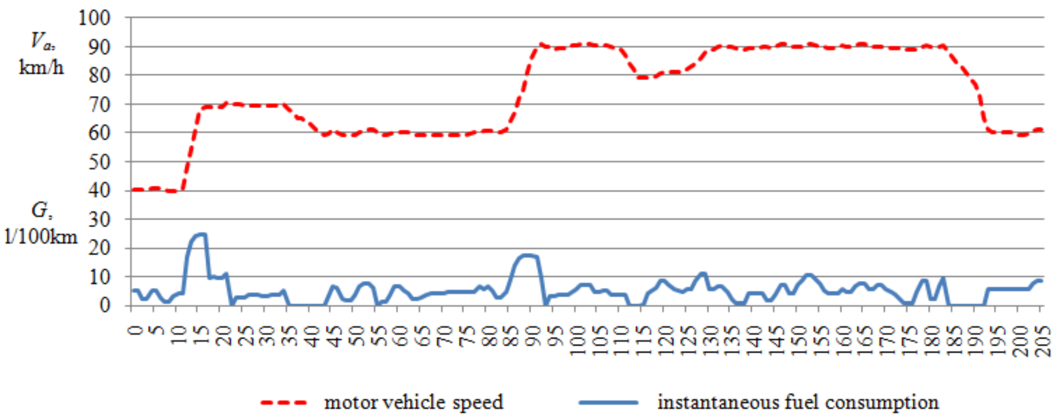

Fig. 5. Dependences of the speed of motor vehicle Volkswagen Passat B6 and fuel consumption on time during motion on test section of the road

While processing the results of experimental research arithmetic mean of the investigated parameter and mean square error were calculated.

The arithmetic mean of the investigated parameter is:

$$\bar{x} = \frac{x_1 + x_2 + ... + x_n}{n} = \frac{\sum_{i=1}^{n} x_i}{n}; \qquad (7)$$

where x_1, x_2, ... x_n – the results of separate measurements; n – the number of measurements.

Mean square error is calculated by the formula:

$$\sigma_x = \pm\sqrt{\frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2}{n-1}}; \qquad (8)$$

The results of experimental research are given in Table 2.

Table 2

Results of experimental research

№	Direction of motion	Time of motion t, s	Fuel consumption G, l/test section
1	Direct (village Ksaverivka – village Lukashivka)	205	0.226
2	Reverse (village Lukashivka – village Ksaverivka)	201	0.202
3	Direct	203	0.217
4	Reverse	200	0.208
$\bar{x}$		202.25	0.2132
σ_x		±2.21	±0.0105

It is seen from Table 2, that the accuracy of experimental study, carried out is rather high, that indicates the reliability of the obtained results.

Table 3

The results of calculation of motion time of Volkswagen Passat B6 motor vehicle on test section of the road

Number of operation	Sequence of operation	Mark of the distance, m	Time t, s	Road S, м
1	Motion at the speed of 40 km/h	0 – 100	9	100
2	Acceleration to the speed of 70 km/h and motion at this speed	100 – 500	21.81	400
3	Deceleration of the engine to the speed of 60 km/h, further motion at this speed	500 – 700	11.3	200
4	Motion at the speed 60 km/h	700 – 1300	36	600
5	Acceleration to the speed of 90 km/h and motion at this speed	1300 – 1900	25.43	600
6	Deceleration of the engine to the speed of 80 km/h, further motion at this speed	1900 – 2200	13.17	300
7	Acceleration to the speed of 90 km/h and motion at this speed	2200 – 3600	56.24	1400
8	Deceleration of the engine to the speed of 60 km/h	3600 – 3800	9.78	200
9	Motion at the speed of 60 km/h	3800 – 4000	12	200
Σ			194.73	4000

By means of mathematical model of the system "Diesel-powered vehicle – road – environment" the time of motor vehicle Volkswagen Passat B6 motion on test section of the road was calculated. Table 3 shows the results of calculation on each mark of the road.

Deviation between calculated and experimental results is determined by the formula:

$$\varepsilon = \frac{t_{cal} - t_{exp}}{t_{cal}} \cdot 100\%; \qquad (9)$$

where t_{cal} and t_{exp} – time of Volkswagen Passat B6 motor vehicle motion on test section of the road, obtained by calculated and experimental means, correspondingly.

$$\varepsilon_1 = \frac{205 - 194,73}{205} \cdot 100\% = 5\%;$$

$$\varepsilon_2 = \frac{201 - 194,73}{201} \cdot 100\% = 3,1\%;$$

$$\varepsilon_3 = \frac{203 - 194,73}{203} \cdot 100\% = 4,07\%;$$

$$\varepsilon_4 = \frac{200 - 194,73}{200} \cdot 100\% = 2,6\%.$$

Hence, difference between values of time of Volkswagen Passat B6 motor vehicle motion on test section of the road, obtained by calculated and experimental means is 2,6…5%.

Conclusions. Experimental research confirmed the adequacy of mathematic model of the system "Diesel-powered vehicle – road – environment" and showed sufficient coincidence of analytical and experimental data.

Thus, this mathematical model can be applied for studying the change of motor vehicle indices when alternative types of fuel are used as fuel for engines.

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