Artículo de investigación

Fuel consumption standardization technique for LiAZ-5256.57 buses using the example of the municipal unitary enterprise “Yakut Passenger Transport Company”, Republic of Sakha (Yakutia)

Методика нормирования расхода топлива для автобусов ЛиАЗ-5256.57 на примере муниципального унитарного предприятия «Якутская пассажирская автотранспортная компания» Республики Саха (Якутия).

Técnica de estandarización del consumo de combustible para los autobuses LiAZ-5256.57 utilizando el ejemplo de la empresa municipal unitaria "Yakut Passenger Transport Company", República de Sakha (Yakutia)

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Abstract

The article analyzes suburban bus transportation with specific routes in the Republic of Sakha (Yakutia). For the experimental study, the route No. 101, “Yakutsk – Tabaga” with a total length of 31 km was chosen. The schedule of buses of Municipal Unitary Enterprise "Yakut Passenger Transport Company (YAPAK)” on the suburban route is shown. The basic technical data of the bus LiAZ-5256.57 was studied. In accordance with international regulations for the buses, the determination of fuel consumption and specific emissions of normalized toxic components is carried out using a riding cycle on running drums. For the calculation of fuel consumption, the technique of modeling of indicators of work of the engine which provide change of traction and speed characteristics of the car according to the set driving cycle was used. Finally, the results of the calculated fuel consumption for the NEDC driving cycle are compared with experimental data. As a comparison of the calculated and theoretical fuel consumption data with practical

Абстрактные

В статье анализируются пригородные автобусные перевозки по конкретным маршрутам в Республике Саха (Якутия). Для экспериментального исследования был выбран маршрут № 101 «Якутск - Табага» общей протяженностью 31 км. Показан график движения автобусов муниципального унитарного предприятия «Якутская пассажирская транспортная компания (ЯПАК)» на пригородном маршруте. Изучены основные технические данные автобуса ЛиАЗ-5256.57. В соответствии с международными правилами для автобусов определено расход топливо и удельные выбросы нормированных токсичных компонентов, осуществляющие с использованием ездового цикла на ездовых барабанах. Для расчета расхода топлива используется методика моделирования показателей работы двигателя, которые обеспечивают изменение тягово-скоростных характеристик автомобиля в соответствии с

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data, the Cummins engine type CG 250 is considered. This internal combustion engine is installed on a LiAZ-5256.57 bus. Experimental data on the fuel consumption of this bus per 100 km. showed 49 nm3, and theoretical calculations of bus fuel consumption per 100 km. by the proposed method showed 48 nm3. Therefore, to assess the traction and speed properties of the bus, the proposed combined method can be used which allows one to obtain calculation of fuel consumption which is closer to the experimental data on a driving cycle. Using the source data of the vehicle, effective engine performance indicators are evaluated. A calculation method is proposed for modeling a test, and experimental driving cycle of automobile transport with a total mass of more than five tons is suggested.

Keywords: Acceleration, deceleration, driving cycle, experiment, fuel consumption, suburban buses.

установленными и заданными циклами движения. Результаты рассчитанного расхода топлива для цикла движения NEDC сравниваются с экспериментальными данными. В качестве сравнения расчетно – теоретических данных расхода топлива с практическими данными рассмотрен двигатель Cummins типа CG 250. Данный двигатель внутреннего сгорания штатно устанавливается на автобус ЛиАЗ-5256.57. Экспериментальные данные расхода топлива данного автобуса на 100 км. показали 49 нм3, а теоретические расчеты расхода топлива автобуса на 100 км. по предлагаемой методике показали 48 нм3. Поэтому для оценки тягово-скоростных свойств автобуса можно использовать предложенный комбинированный метод, позволяющий расчетным путем получить близкий к экспериментальным данным расхода топлива на ездовом цикле. Используя в качестве исходных данных транспортного средства оцениваются эффективные показатели работы двигателя. Предложена методика расчетного моделирование испытательного, экспериментального ездового цикла автомобильного транспорта полной массой более пяти тонн.

Ключевые слова: ускорение, замедление, ездовой цикл, эксперимент, расход топлива, пригородные автобусы.

Resumen

El artículo analiza el transporte en autobús suburbano con rutas específicas en la República de Sakha (Yakutia). Para el estudio experimental, se eligió la ruta No. 101, “Yakutsk - Tabaga” con una longitud total de 31 km. Se muestra el horario de los autobuses de la Empresa Municipal Unitaria "Yakut Passenger Transport Company (YAPAK)" en la ruta suburbana. Se estudiaron los datos técnicos básicos del autobús LiAZ-5256.57. De acuerdo con las regulaciones internacionales para los autobuses, la determinación del combustible El consumo y las emisiones específicas de componentes tóxicos normalizados se llevan a cabo utilizando un ciclo de conducción en tambores en funcionamiento.Para el cálculo del consumo de combustible, la técnica de modelado de indicadores de trabajo del motor que proporcionan el cambio de tracción y las características de velocidad del automóvil de acuerdo con se utilizó el ciclo de conducción establecido. Finalmente, los resultados del consumo de combustible calculado para el ciclo de conducción NEDC se comparan con datos experimentales. Como comparación de los datos de consumo de combustible calculados y teóricos con datos prácticos, se considera el motor Cummins tipo CG 250 Este motor de combustión interna está instalado en un bus LiAZ-5256.57. Datos experimentales sobre el consumo de combustible de este bus p er 100 km. mostró 49 nm3 y cálculos teóricos del consumo de combustible del autobús por cada 100 km. por el método propuesto mostró 48 nm3. Por lo tanto, para evaluar las propiedades de tracción y velocidad del autobús, se puede utilizar el método combinado propuesto que permite obtener el cálculo del consumo de combustible que está más cerca de los datos experimentales en un ciclo de conducción. Utilizando los datos de origen del vehículo, se evalúan los indicadores efectivos de rendimiento del motor. Se propone un método de cálculo para modelar una prueba, y se sugiere un ciclo de conducción experimental del transporte de automóviles con una masa total de más de cinco toneladas.

Palabras clave: Aceleración, desaceleración, ciclo de conducción, experimento, consumo de combustible, autobuses suburbanos.

Introduction

In the long term, bus transportation remains the main type of passenger transportation for most cities and towns of the Russian Federation and is of great social importance. In the city of Yakutsk, about 100% of the total passenger traffic is carried out by ground transport - buses. Of these, city bus transportation has accounted for 94% of traffic in 2018.

Improving the efficiency of enterprises, operating city buses can be carried out by increasing fuel efficiency, in which the issues of rationing fuel consumption by city buses plays a paramount role.

Theoretical framework

Since 1955, a bus fleet has been operating in the city of Yakutsk under the name «Yakut Passenger Vehicle Management» - YAPAK.

In the YAPAK there were not only buses, but also cars (M-20) and the so-called GAZ-51 cargo taxi. The company also had branches in Lensk and Aldan. Buses of the brandZIS-155, later PAZ-651, ZIL-158, ran around the city.

The company produced on the city line up to 200 buses per day, performing 18 city, 7 suburban and 4 country routes. Currently 70 buses of the Municipal Unitary Enterprise «Yakut Passenger Transport Company (YAPAK)» serve 7 suburban, 2 city and 3 country routes. However, the plans of the Yakutsk city administration include the further development of municipal transport.

The company's buses travel along 7 suburban routes:

- Route number 101, Yakutsk - Tabaga with a total length of 31 km;
- Route number 102, Yakutsk - Magan with a total length of 24 km;
- Route number 103, Yakutsk - Khatassy with a total length of 17 km;
- Route number 104, Yakutsk - Kangalassi with a total length of 40 km;
- Route number 105, Yakutsk - Tulagino – Kildyamtsy with a total length of 27 km;
- Route No. 109, Yakutsk - Zhatay - Zakharovka with a total length of 21 km;
- Route number 111, Yakutsk - Zhatay with a total length of 19 km.

For the experimental study, we chose route No. 101, Yakutsk - Tabaga with a total length of 31 km. In figure 1, the red line shows the route diagram with bus-stops between Yakutsk to Tabaga.

Figure 1. Diagram of the route with bus stops between Yakutsk - Tabaga.

Table 1 shows the bus schedule for Municipal Unitary Enterprise«YAPAK» along the suburban route

The route number 101 Yakutsk – Tabaga											
Departure time from the bus station											
6:50	8:05	9:30	11:30	12:30	13:45	15:15	16:45	18:15	19:15	21:00	
DeparturetimefromTabaga											
6:50	8:05	9:20	10:45	12:25	13:45	15:00	16:30	18:00	19:30	20:30	22:10

Table 1. The route number 101 Yakutsk – Tabaga

In this route, LiAZ-5256.57 buses are operated in a total of 6 pcs. Buses make 3 trips in a day, and the average daily mileage of one bus is 93 km.

Figure 2. General view of the LiAZ-5256.57 bus

The LiAZ-5256.57 bus is a large-capacity city bus and is designed to carry passengers on roads with asphalt pavement of category I and II of the country's general network on routes with intensive passenger traffic.

LiAZ-5256.57 was developed and mass-produced at LiAZ LLC. The development of the bus was carried out taking into account market requirements and meets the highest demands of consumers, as well as the requirements of safety and environmental protection. The bus is manufactured with the installation of cylinders on the roof of the bus (Sumatohin D. G., 2012).

The main technical data of the LiAZ-5256.57 bus are shown in table 2.

1	Length	11400 mm
2	Width	2500 mm
	Height: up to Roof	2885 mm
3	Up to the air intake	3065 mm
	Uptogascylinders	3347 mm
4	Frontoverhang	2510 mm
5	Rearoverhang	3050 mm
6	Centerdistance (base)	5840 mm
Engine		
7	Model	Cummins-CG 250
8	Type	Gas, four stroke, turbocharged and intercooled charge air
9	Location	In the rear overhang, longitudinal;
10	Ratedpower	186 kW / 250 h.p. at 2400 rpm crankshaft;
11	Maximumtorque	1013 Nmat 1400 rpm. crankshaft;
12	Numberofcylinders	6, inline, verticalarrangement
13	Workingvolume	8300 cmcube;
14	Cylinderbore	114 mm
15	Pistonstroke	135 mm
16	Compressionratio	10.2
17	Ignitionsystem	Ignition Adapter – RoderWerter, 24 VDC; Ignition Coil - Cummins 3964547; Spark Plugs - Champion 78PYP
18	Minimumgasfuelconsumption	40 Nm^3 / 100km
18	Supplyandexhaustsystem	The engine has a fuel system with external gas-air mixture formation, with injection fuel supply and with spark ignition, which allows to distribute, dose and ignite low-pressure gas fuel - from 0.55 to 1 MPa (from 5.5 to 10 kgf / cm2)
19	Gasfuelsystem	model«SAGA-7 LIAZ», maximum working pressure of 19.6 MPa (200 kgf/cm2), a pressure reducer with the inlet pressure of 4.9 – 19.6 MPa (50 to 200 kgf/cm2) at a flow of 0.8 – 1 MPa (8 – 10 kgf/cm2). Composition: high pressure reducer; filling device with filter, valve, filling hole and sensor (switch) of the presence of the plug; high pressure solenoid valve with filter, pressure gauge and gas pressure indicator; cylinder valves (according to the number of cylinders); main valves (3 PCs.); gas leak detector with sensors (LPG-3); hoses for coolant supply from the engine cooling system to the high-pressure reducer and the liquid heater reducer; corrugated hoses for removal of possible leaks outside the bus; stainless steel high-pressure tubes (with an outer diameter of 8 mm and a wall thickness of 1 mm); tees for connecting high-pressure tubes.

Table 2. Main technical data of the LiAZ-5256.57 bus

However, the operational experience of the LiAZ-5256.57 bus in the conditions of the bus fleet of the MUP «YAPAK» speaks of other indicators of the route fuel consumption by this rolling stock.

In connection with the abovementioned data, studies related to determination of route fuel consumption rates is based on the development of a method of fuel consumption standardization for LiAZ-5256.57 buses are relevant.

A distinctive feature of the work of buses on city routes is a change in the degree of filling of buses with passengers, different distances between stops, a large number of stops, braking and acceleration, passage of regulated and unregulated intersections, etc. Practice shows that in urban conditions, the modes of movement of a shuttle bus are significantly different from the modes of movement of a conventional car. It's enough to note that the number of brakes per km of the path is 1.35 times more than that of the driver, clutch disengages — 2.48 times, and forced stops — 1.54 times. A significant difference in operating conditions is observed both between the route network of several bus depots, and within one fleet (Sumatohin D. G., 2012).

For buses, in accordance with international regulations, the determination of fuel consumption and specific emissions of normalized toxic components is carried out using a driving cycle on running drums (Kanilo P.M., Bey I.S., Rovensky O.I., 2000 & Kulchitsky A.I., 2000).

For buses in accordance with international regulations, the determination of fuel consumption and specific emissions of normalized toxic components is carried out by riding cycle on running drums (Seiffert U. Verkehr, 2000).

At the stage of preliminary selection of optimal parameters of the engine, the rational is the mathematical modelling of the work in conjunction with the car in the driving cycle (Abramchuk F.I., Kabanov A.N., Kuzmenko A.P., Lipinsky M.S., 2011).

Due to the high cost of equipment for the experimental implementation of a test driving cycle on running drums, the need often arises for mathematical modelling of this cycle.

Materials and methods

To accomplish this task, we used a methodology for modelling engine performance indicators, which provide a change in the traction and speed characteristics of the car in accordance with a given driving cycle (Lukanin V.N., Buslaev A.P., Trofimenko Y.V., Yashina M.V., 1998 & Gasparyants G.A. (1978). Simplicity differs from other models in combination with high convergence of the calculated and experimental results.

The initial data for the mathematical model of the riding cycle can be divided into the following groups.

1. Constant vehicle parameters: gear ratios gearboxes (for direct transmissions) uk1, uk2, uk3, and uk4; full mass of automobile m_a.kg; gear ratio of the transfer case u_{pb} (if there is no transfer case, then u_{pb} = 1); final drive ratio u_0; static wheel radius r_{st}.m; the coefficients for constructing VSHD A1, A2 [1]; the coefficients of the total road resistance $\psi_{д}$; Vehicle transmission efficiency $\eta_{т}$; air resistance coefficient K, $(N{\cdot}c^2)/м^4$; vehicle height B_r.m; vehicle width H_r. м; coefficients of filling the frontal area of the car α_A (Lukanin V.N., Trofimenko Yu.V., 1996).
2. Constant engine parameters: fuel density $\rho_т$, kg/м^3; rated engine power N_{e_nom}, kW; rated engine speed n_{nom}, min^{-1}.
3. Parameters of the test mode: number of gear i_u; vehicle speed v, km / h.
4. Engine output parameters: specific effective fuel consumption in the g_e mode, g/(kWh).
5. The scheme of the test cycle, that is, a given time sequence of changes in the parameters of the test mode.

For the study, the European NEDC driving cycle was selected. The choice of this cycle is due to the fact that the CIS countries, including Russia are guided by the EU standards in the development of standards for determining and standardizing the toxicity of motor vehicles, the current driving cycle is starts from 2000 NEDC. The NEDC cycle consists of four successive ECE 15 urban driving cycles and one EUDC suburban

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driving cycle following one after another. The diagram of these cycles are presented in Fig. 3,4, and 5.

The main indicators of the NEDC driving cycle are also given in table 3.

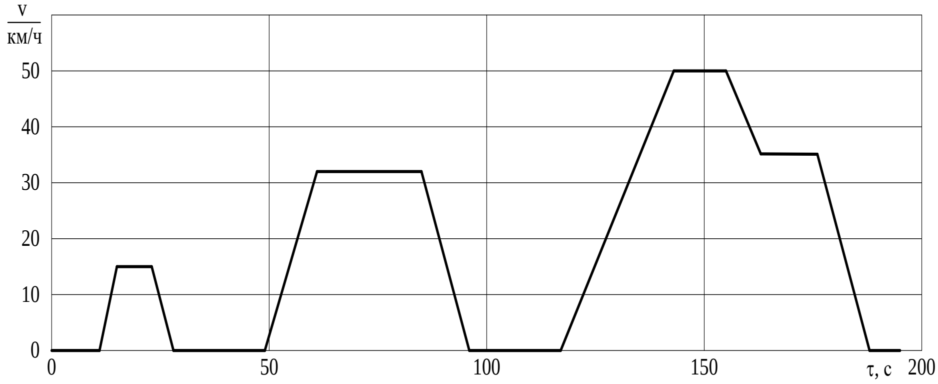

Fig. 3. Diagram of urban driving cycle ECE 15

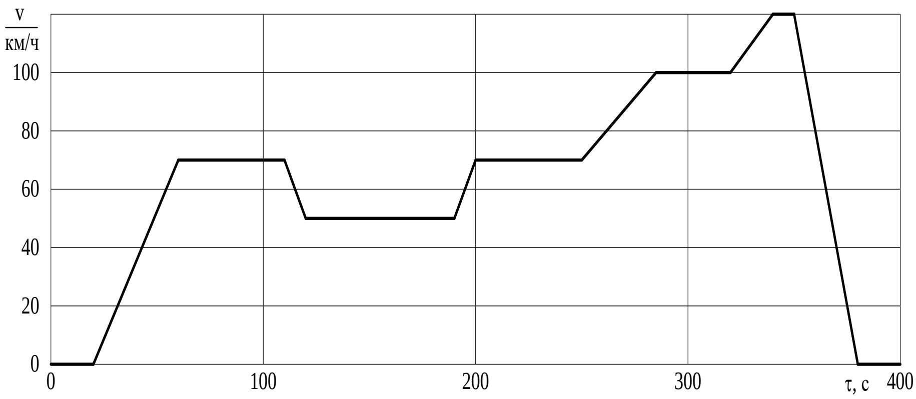

Fig. 4. Diagram of EUDC driving cycle

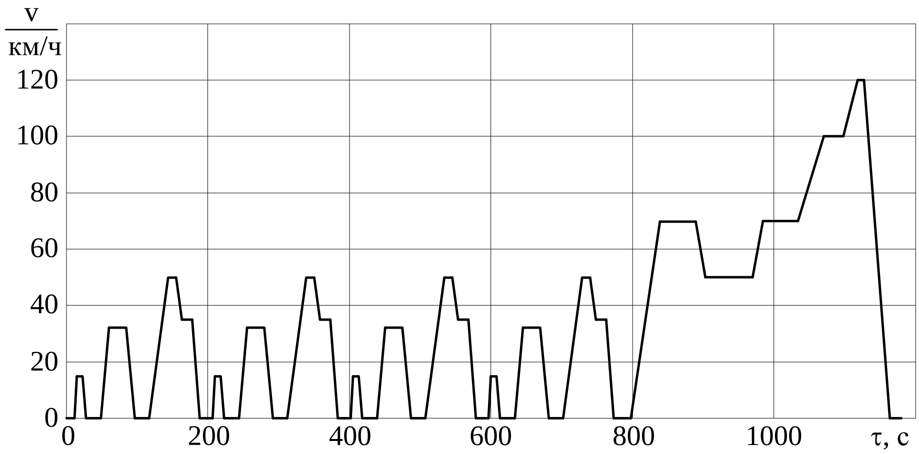

Fig. 5. The diagram of the combined driving cycle NEDC
Key Performance Indicators for the NEDC Driving Cycle

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Value	Unit measurements	Symbol	ECE 15	EUDC	NEDC
Route	км	s_Σ	1,013	6,955	11,007
Time	с	τ_Σ	195	400	1180

Table 3. Key Performance Indicators for the NEDC Driving Cycle

A distinctive feature of the technique proposed in (Gasparyants G.A., 1978) is to simplify the design study, the driving cycle is divided into sections, into which the parameters of the test mode do not change. Thus, the transition mode, during which the car moves with acceleration or deceleration is divided into elementary quasi-stationary modes.

Transient modes of the EUDC cycle are divided into sections with a duration Δτ = 1s, during which the parameters of the test mode also do not change, the speed is conditionally considered constant (Fig. 6). In quasi-stationary modes, changes in the motor adjustment parameters in transient modes (for example, enrichment of the mixture with a sudden increase in load) are taken into account, and such elementary modes are conditionally considered stationary. In addition, empirical correction factors (e.g. proposed in (Heinze G.W., Kill H.H., 1991) are used to calculate emissions of toxic components and fuel consumption by a vehicle in quasi-stationary mode.

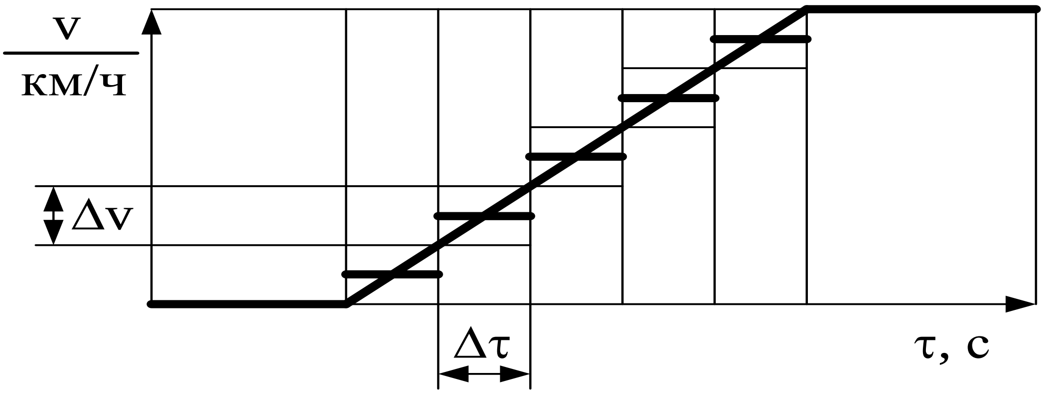

Fig. 6. Transformation of the transition process into a sequence of elementary quasi-stationary modes in the EUDC cycle

Results and discussion

To simplify the computational study, the transition modes in the ECE 15 cycle are replaced by stationary ones according to the scheme proposed (Fig. 7). Studies conducted in (Glagolev N.M., 1950) showed that this diagram allows to ensure maximum compliance with the indicators of efficiency and toxicity of the calculated and experimental cycle.

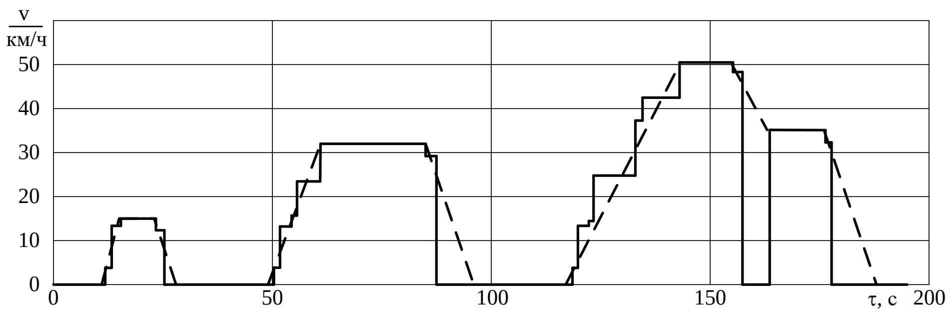

Fig. 7. The design diagram of the simplified urban driving cycle ECE 15:
– – – – – – – standard driving cycle;
————— – simplified driving cycle.

The required frequency of rotation of the engine crankshaft, мin[-1] (Braess H.H., Frank D., Reister D., 1990).

$$n = \frac{\text{v} \cdot u_{ki_u} \cdot u_{pb} \cdot u_0}{0{,}377 \cdot r_{st}}.$$

(1)

Frontal area of the car, $м^2$ [140].

$$F = \alpha_{\text{A}} \cdot B_r \cdot H_r.$$

(1)

Engine power requirement, kW

$$N_e = \frac{m_a \cdot 9{,}81 \cdot \psi_{\ddot{a}} \cdot \text{v}}{3600 \cdot \eta_{\grave{o}}} + \frac{K \cdot F \cdot \text{v}^3}{46656 \cdot \eta_{\grave{o}}}.$$

(3)

Power according to the external speed characteristic at the given revolutions, kW (Braess H.H., Frank D., Reister D., 1990).

$$N_{e\_VSHD} = N_{e\_\text{nom}} \cdot \left[A_1 \cdot \frac{n}{n_{\text{nom}}} + A_2 \cdot \left(\frac{n}{n_{\text{nom}}}\right)^2 - \left(\frac{n}{n_{\text{nom}}}\right)^3\right]. \quad (4)$$

Required specific load on the engine at a given power, %

$$\bar{P} = \frac{N_e}{N_{e\_VSHD}} \cdot 100. \quad (5)$$

The required torque, N.m

$$M_e = 9550 \cdot \frac{N_e}{n}.$$

(6)

The values of n and $\bar{P}$ calculated according to equations (1) and (5) determine the operating mode of the engine. Based on the data of the mode, they are determined experimentally on the brake stand or calculated according to the updated method of I.I. Vibe engine out put parameters g_e, g_{CO}, g_{CH}, and g_{NOx}. When calculating the definition of the listed indicators of the adjustment parameters of the engine are set by a specialist or taken from the characteristic cards.

Fuel consumption by a car in elementary mode, g (Gasparyants G.A., 1978).

$$Q_{\text{т\_mode}} = \frac{g_e \cdot N_e}{3600} \cdot \tau_{\text{mode}}, \quad (7)$$

Where τ_{mode} is the duration of the elementary mode,
If the mode is transient, then this is taken into account using formulas (Gasparyants G.A., 1978).

Calculation of fuel consumption in transition mode l

$$Q_{\text{т\_mode\_overclocking}} = k^{\text{т}}_{\text{overclocking}} \cdot Q_{\text{т\_mode}}, \quad (8)$$

$$Q_{\text{т\_mode\_slowdown}} = k^{\text{т}}_{\text{slowdown}} \cdot Q_{\text{т\_mode}}, \quad (9)$$

where $k^{\text{т}}_{\text{overclocking}}, k^{\text{т}}_{\text{slowdown}}$ are empirical coefficients that take into account the change in fuel consumption of the car during acceleration and deceleration, respectively (Lukanin V.N., Trofimenko Yu.V., (1996).

As an example, consider the Cummins engine type CG 250. This engine is normally installed on the bus LiAZ-5256.57.

According to the classification adopted in (Lukanin V.N., Buslaev A.P., Trofimenko Y.V., Yashina M.V., 1998), the LiAZ-5256.57 bus with the Cummins CG 250 engine installed on it belongs to the M3 category.

The values of the coefficients $k^{\text{T}}_{\text{overclocking}}, k^{\text{T}}_{\text{slowdown}}$ for a vehicle of this category are given in table 4.

Table 4. Coefficient values for vehicles of group M3

Mode	k^{T}
Speed Range 0 ... 20 km / h	
Acceleration	6,05
Deceleration	0,24
Speed range 20 ... 30 km / h	
Acceleration	8,10
Deceleration	0,14
Speed range 30 ... 40 km / h	
Acceleration	7,88
Deceleration	0,10
Speed range 40 ... 50 km / h	
Acceleration	5,80
Deceleration	0,06
Speed range> 50 km / h	
Acceleration	4,08
Deceleration	0,06

Conclusions

The total fuel consumption for the NEDC driving cycle is calculated by the formula, (g/km)

$$\Sigma Q_{\text{T}\_NEDC} = \frac{\sum_k (Q_{\text{T}\_mode})_k}{\tau_{\Sigma\_NEDC}} = \frac{4 \cdot \sum_m (Q_{\text{T\_mode}})_m + \sum_n (Q_{\text{T\_mode}})_n}{\tau_{\Sigma\_NEDC}}, \quad (10)$$

where $\sum_k (Q_{\text{T}\_mode})_k$ is the total fuel consumption during the NEDC cycle, g;

$\sum_m (Q_{\text{T\_mode}})_m$ - total fuel consumption during the cycle ECE15, g; -$\sum_n (Q_{\text{T\_mode}})_n$ – total fuel consumption during the EUDC cycle, g.

Table 5 shows a comparison of the calculated fuel consumption for the NEDC driving cycle with experimental data.

Bus brand	Results of the calculated fuel consumption for the NEDC driving cycleper 100 km.	The results of the experimental fuel consumption per 100 km.
LiAZ-5256.57	48 nм^3	49 nм3

Table 5. Comparison of the calculated fuel consumption for the NEDC driving cycle with experimental data

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Experimental data on the fuel consumption of this bus per 100 km. showed 49 nm3, and theoretical calculations of bus fuel consumption per 100 km. by the proposed method showed 48 nm3. Therefore, to assess the traction and speed properties of the bus, the proposed combined method can be used which allows one to obtain calculation of fuel consumption which is closer to the experimental data on a driving cycle. Using the source data of the vehicle, effective engine performance indicators are evaluated. A calculation method is proposed for modeling a test, and experimental driving cycle of automobile transport with a total mass of more than five tons is suggested.

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