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A METHOD FOR ASSESSING ENERGY EFFICIENCY OF LIGHT-DUTY VEHICLES TAKING INTO ACCOUNT CHANGES IN THEIR DESIGN PARAMETERS

The present stage of development of the world market of vehicles, in particular, light-duty vehicles (LDVs) is marked by an increasing variety of types and designs. Therefore, while validating or renewing fleet vehicle of an enterprise, carriers are faced with the choice of cars setting conditions they can assess using existing fragmentary and cost-effective approaches. However, the latter ones do not meet the concepts of saving energy and resources. Therefore, the task of choosing an efficient car is complex requiring a science-based formation of demands and their satisfaction. Existing approaches to the selection and validation of LDVs are simplified and imperfect in terms of transport technology. They do not take into account a) resource and technical properties of LDVs as a means of transport; b) main design and technical characteristics of LDVs; c) parameters of its operation (running surface, traffic density, length of the driving cycle, etc.). This article considers a method for assessing energy efficiency of light-duty vehicles, which is based on the scheme of the vehicle operation as a dynamic tool. To develop this method, the provisions of the energy and resource efficiency theory of a car have been used, namely the calculation schemes of transport operations based on models of reference prototypes and test operations. These models are able to ensure the reasonable use of the vehicle fleet with design novelty under the given operating conditions. In order to analyse changes in the parameters of new vehicles and improve the parameters of transport technology, a universal design of a light-duty vehicle of a generic type has been developed and considered. This structural pattern covers all options of the vehicle's design basis. New options for the vehicle design are created by changing the number of design modules and their parameters. The method proposed for consideration ensures the technical and technological properties of light-duty vehicles in accordance with the concept of energy and resource conservation in the transport system. The paper develops methods for comprehensive improvement of transport energy efficiency and formation of requirements for transportation projects of LDVs taking into account technical and technological factors within their life cycle.

Key words: *light-duty vehicles, design parameters, energy and resource.*

Гальона І. І., Піцик М. Г., Гусєв О. В., Шапенко Є. М., Сауляк Л. В. Метод оцінки енергоефективності автомобілів малої вантажопідйомності з урахуванням зміни їх конструктивних параметрів

Етап сучасного розвитку світового ринку автотранспортних засобів (АТЗ) зокрема автомобілі малої вантажопідйомності (АМВ) характеризується зростаючим різноманіттям запропонованих видів та різновидів конструкцій.

Для обґрунтування оновлення парку рухомого складу підприємства перевізники знаходяться перед вибором автомобілів, висуваючи до них вимоги, які вони здатні оцінити за допомогою існуючих противитратних підходів, що не відповідають існуючій концепції збереження енергії та ресурсів. Всі відомі існуючі підходи вибору та обґрунтування АМВ є спрощеними та недосконалими з точки зору сучасних транспортних технологій. Вони не враховують ресурсно-технічні властивості АМВ як засобу перевезення, основні конструктивно-технічні характеристики АМВ, параметри його експлуатації. В даній статті розглядається метод оцінки енергетичної ефективності автомобілів малої вантажопідйомності, який засновано на схемі функціонування автомобіля як динамічного засобу праці. Для розробки даного методу було використано положення теорії енергоресурсної ефективності автомобіля, а саме використання розрахункових схем транспортних операцій, що засновані на моделях еталонних прототипів і тестових операціях. Ці модель мають змогу забезпечити обґрунтоване використання рухомого складу з конструктивною новизною в заданих умовах експлуатації. Для можливості аналізу зміни параметрів нових автотранспортних засобів та удосконалення параметрів транспортних технологій, була розроблена та розглянута універсальна структура автомобіля малої вантажопідйомності узагальнюючого типу. Ця структурна схема охоплює всі варіанти конструктивного базису автомобіля. Нові варіанти конструкції автотранспортного засобу формуються за допомогою зміни кількості конструктивних модулів та їх параметрів. Метод, що пропонується до розгляду забезпечує техніко-технологічні якості автомобілів малої вантажопідйомності у відповідності до концепції збереження енергії і ресурсів в транспортній системі.

Ключові слова: *автомобілі малої вантажопідйомності, конструктивні параметри, енергія та ресурси.*

Introduction. Light-duty vehicles (LDV) are increasingly being used by carriers to deliver small-batch cargos. This is especially true for urban transport with heavy traffic of vehicles. It is characterised by energy- and resource-intensive modes, which leads to intensive wear of vehicle parts and assemblies. However, when choosing a new fleet or updating the existing one, carrier customers need to substantiate and evaluate the proposals presented on the vehicle market that would meet the concept of energy and resource conservation. The existing methods for selecting a fleet are very simplified and not perfect in terms of transport technology [1]. These methods do not take into account a) the resource and technical properties of the vehicle as a means of transport; b) basic design and technical specifications; c) parameters of its operation (rolling surfaces, traffic intensity, route length, vehicle load, etc.). Therefore, there is a need in developing and using a new method that will be based on a system of consumer-oriented and coordinated design and transport innovations of a light-duty vehicle [2].

Besides, when choosing a fleet, it is necessary to pay attention to meeting the needs of cargo delivery customers in the provision of road transport services, namely, ensuring continuous operation at a sufficiently high level and with the appropriate quality.

When creating a new fleet, the expenses on design innovations are borne by the buying carrier. The carrier, in their turn, is interested in the long-term improvement of the economic and technical competitiveness of their services, which will be in line with the concept of energy and resource conservation. The fleet competitiveness is determined by a set of its properties that characterise the degree of meeting the needs to the level of consumer and work utility of the vehicle compared to the best analogues of this size [3].

The most important strategic goal of the carrier is to develop the energy-saving technology in road transport systems. This goal can be achieved by using a set of models to manage the energy and resource efficiency of a generic vehicle. This complex is based on the prerequisites necessary to model the of use of vehicle resources in future operating conditions, as well as the principles of resource conservation. Using the models of the target function of energy and resource efficiency, as well as efficiency models of vehicles with variable parameters and methods of theoretical synthesis of the structure of a generic type of motor vehicle, a composite model for future transport conditions is formed based on the principles of resource-saving technology. Such a model makes it possible to substantiate the fleet technical parameters with technical novelty under conditions of future operating parameters [4].

The main part. The efficiency of a light-duty vehicle in the method under consideration is assessed using the provisions of the theory of energy and resource efficiency of the vehicle [5]. This theory allows assessing the vehicle as a carrier of transport technical resources, which has eight properties. Its main properties important for performing transport operations and ensuring adaptive and discrete functioning are a complex machine, a dangerous traffic control object, a vehicle, a potential maintenance object, tools for technological machine effects (machine procedures), and a design and technological basis for resource transformation processes. Therefore, when solving the given tasks, mathematical models of justification of the motor vehicle are used based on the energy scheme of resource transformation in transportation into a transport product as a dynamic tool in movement.

When determining the energy and resource efficiency of LDVs, it is necessary to take into account the factors of the intensity of transient processes (acceleration). This, in its turn, leads to an increased energy consumption, increased wear of units and tyres, and deterioration of environmental performance due to unstable operation of the power train. In addition, during intense transient processes, the stability of the bonds between the wheels and the road is disturbed, which directly affects road safety and increases energy losses in the places where the wheels come into contact with the road surface.

It should also be noted that the main feature of vehicles designed for further sale and use is a change in their design parameters relative to the previous models. This fact is not taken into account in the subsequent vehicle operation. In view of this, a method for assessing energy efficiency of light-duty vehicles with regard to changes in their design parameters has been developed and proposed. The method uses the developed scheme of the parametric structural design of a light-duty vehicle of a generic type (Fig. 1) [5].

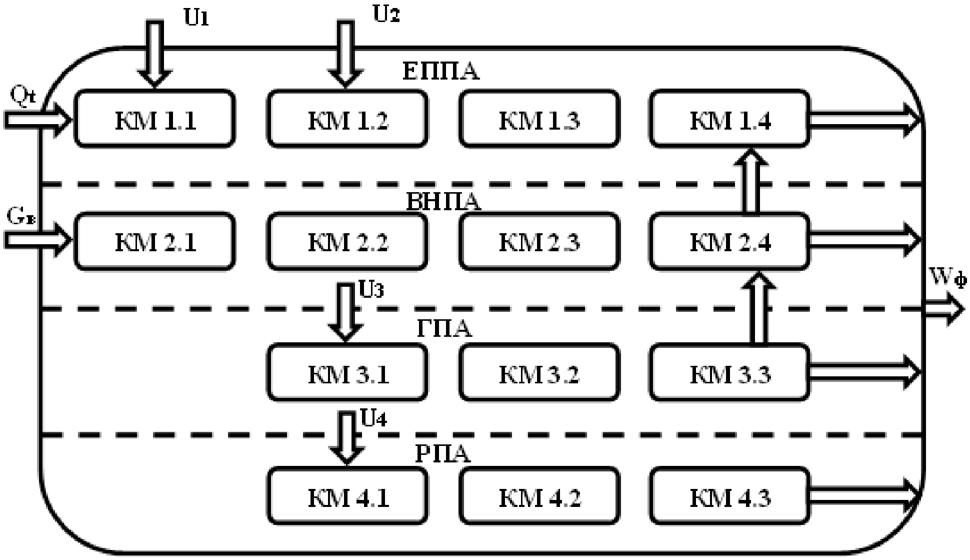

Fig. 1. Scheme of the LDV parametric structural design as a technical means of transport production: U_1, U_2, U_3, U_4 – control; Q_t – fuel flow; G_v – cargo batch mass; W_f – physical product of transport; ЕППА – energy-converting device of LDV; ВНПА – load-carrying device of LDV; ГПА – braking device of LDV; РПА – steering device of LDV; КМ – structural modules; КМ 1.1 – energy source (engine); КМ 1.2 – energy transformation (gearbox, final drive); КМ 1. 3 – energy distribution (inter-wheel differentials, inter-axle differentials, and power take-offs); КМ 1.4 – wheel traction module (a pair of drive wheels); КМ 2.1 – body; КМ 2.2 – frame (skeleton); КМ 2.3 – suspension; КМ 2.4 – chassis modules; КМ 3. 1 – brake pedal and brake actuator; КМ 3.2 – brake mechanism; КМ 3.3 – brake wheels (axles); КМ 4.1 – steering wheel and steering mechanism; КМ 4.2 – steering actuator (steering trapezoid and steering rods); КМ 4.3 – steering wheels (front)

According to this scheme, the vehicle moving with a load is based on converting the internal energy of the engine into a momentum impulse, namely, the carriers of technological resources of transport (in the form of an equipped car) combined with physical (road properties) and mode (movement time) resources create production resources that are converted into energy consumption for moving the vehicle's operating mass. Then energy consumption is converted into a physical product (controlled momentum impulses of the vehicle's operating mass). Part of these impulses is cargo transportation ΔW. The higher the overall level of energy consumption, the longer the route travelled by the vehicle. The greater the intensity of energy consumption, the higher the vehicle speed and the less the amount of transport resource consumed (the travel time factor).

$$E_{дв} \rightarrow P_m \Delta t \rightarrow q \gamma_{cm} V \Delta t \rightarrow \Delta W \qquad (1)$$

where q is the vehicle's carrying capacity; γ_{cm} is the coefficient of using the vehicle's carrying capacity; P_m is the vehicle's traction force; Δt is the vehicle's travel time; V is the vehicle's average speed.

The processes ensuring the vehicle's movement and the conversion of the engine's internal energy are provided by two main devices of the vehicle structure: ECD and LCD. The former converts the chemical energy of the fuel into the kinetic energy of the load, and the latter transfers the load mass to the rolling surface through the wheels. In other words, the generalisation of the vehicle design is achieved by a modular description of its energy-converting and load-carrying devices. The energy conversion and load transportation achieved in the given vehicle design option is ensured by a targeted choice of the structure and parameters of its functional modules. The flexibility of the vehicle's technical parameters within the description of elements of the vehicle size range is based on the representation of the vehicle design as a certain set of parametric structural characteristics. The choice of the characteristics and parameters of these devices should ensure energy efficiency maximisation of the vehicle design [4]. In this case, ECD is the engine and elements of the energy transmission to the wheel-traction module, and the load-carrying device (LCD) is the LDV body.

The scheme of the LDV design base includes four devices: ECD, LCD, BD, and SD. The first two devices consist of four structural modules (SMs). The third and fourth devices include three SMs each.

Assessment and analysis of the technical and economic performance of the fleet should be carried out based on the strategy of improving the energy efficiency indicator accepted as the main indicator of the vehicle consumer property within the concept of saving energy and resources in the transportation process [5]. This indicator is the ratio of transport energy efficiency of the given vehicle in the test operation ρ to transport energy efficiency of the reference vehicle in the reference operation ρ_{et}:

$$\Pi_e = \frac{\rho}{\rho_{em}} = \frac{K_v \gamma_{cm}}{K_e(\eta_\delta + \gamma_{cm})} \to \max , \tag{2}$$

where K_v is the speed coefficient (the ratio of the average speed of the vehicle in the test cycle to the speed of the reference vehicle); γ_{st} is the static load capacity utilisation factor; K_e is the energy mileage coefficient (the ratio of the fuel consumption of the vehicle in the cycle to the fuel consumption of the reference vehicle moving at a constant reference speed); η_q is the curb weight coefficient of the vehicle.

Maximisation of P_e indicator ensures an increase in the level of the energy-saving transport technology in accordance with the concept of energy and resource conservation. This indicator must be considered in conjunction with the fuel efficiency indicator P_{eq}, which is the ratio of the fuel consumption of the vehicle in test operation ρ_p to the fuel consumption of the reference vehicle in the reference operation ρ_{pet}:

$$\Pi_{eq} = \frac{\rho_n}{\rho_{nem}} \to \min \tag{3}$$

To improve the traction and speed properties of vehicles, manufacturers implement a strategy to maximise engine power N_{max}. However, there are no methods for assessing the impact of changes in this feature on the efficiency of light-duty vehicles in small-batch transportation. In their turn, leading auto manufacturers offer engines with different maximum power values for individual orders. It should be noted that these properties are purely promotional, as there is no method to analyse the impact of N_{max} on the performance indicators of LDVs and small-batch transportation.

Having analysed the graphs of the impact of the change in N_{max} on the indicators of its energy efficiency P_e (Fig. 2), it is clear that the curve has a decreasing almost linear nature, and with an increase in the power value, this indicator decreases. This shows that an increase in this feature would be inappropriate, especially since this also has a negative impact on the fuel efficiency indicator P_{eq}.

The mathematical models of the considered indicators have been adapted for modelling and parametric analysis of various factors on the indicator of the transport energy efficiency of LDVs with variable technical and operational characteristics for the requirements of different consumer carriers.

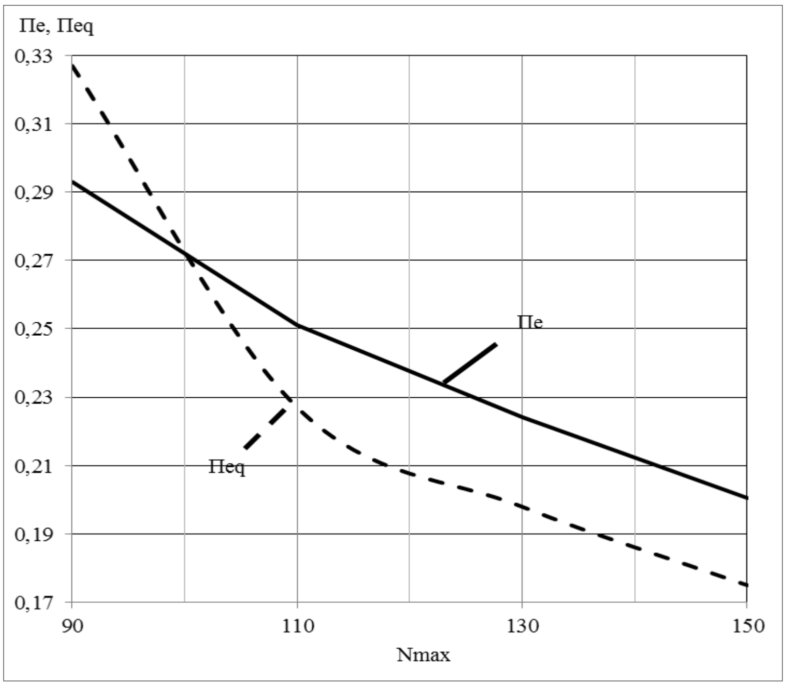

Fig. 2. Graphs of the dependence of the energy efficiency indicators P_e and P_{eq} of Mercedes-Benz Viano on the maximum engine power N_{max} (kW)

Conclusions. It has been established that by creating a system of consumer-oriented and coordinated design and transport innovations of the light-duty vehicle, it is possible to improve the technical and technological properties of the LDVs and the provided road transport services.

The article develops a scheme of the parametric structural design of the LDV, which allows its assessment as a technical means of transport manufacturing, and optimisation of the vehicle parameters to ensure efficient resource-saving provision of road transport services.

The proposed method allows evaluation and selection of the parameters of LDVs that will correspond to the development of the transport system in accordance with the concept of energy and resource conservation.

The results obtained can be used to justify and update the fleet at transport enterprises that serve customers on a regular basis with pre-known routes with specifically defined parameters.

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