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THE ENERGY ESTIMATION OF TRANSPORTATION VEHICLES

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ЕНЕРГЕТИЧНА ОЦІНКА ТРАНСПОРТНИХ МАШИН

Purpose. The research features calculation of analytical methods of management tasks under the condition of rational energy consumption in the transport process performed by the car adhering to the high level of both traffic and environment safety. The work analyses analytical dependence of defining the quality of transportation vehicles which meet customer requirements based on quality performance according to energy estimation.

Methodology. Determination of the analytical model for the evaluation of the hybrid power plant technical condition of the test cycle mode velocities from 30 to 60 km/h is developed. It determines the operation completion of the electrical installation and operation start of the internal combustion engine (ICE) according to car speed motion by means of analyzing the energy loss of hybrid power plant depending on diverse operation conditions to engineering decision.

Findings. The choice of synergistic approach in research performing is grounded. The system of evaluation of technical condition of hybrid vehicles depending on the mode of their working conditions is improved. Simultaneous estimation of the performance of two power flows, from the ICE and electric motor drive, is also provided. The basis of the research of energy costs of electric power unit of a hybrid vehicle is characterized by the steady movement of the vehicle when the control loop based on the energy balance, depending on the average speed.

Originality. For the first time, the interrelation between the technical condition of the hybrid power plant (HPP) and working modes is determined on the basis of the energy principle.

Practical value. The method for determining the hybrid power plant boundary condition, which will improve the system of maintaining and repairing hybrid cars at service stations, is designed.

Keywords: *hybrid power plant, transport machine, energy estimation*

Introduction. The issue of energy saving is important in the energy usage for transportation. In this regard, a vehicle cannot be an exception. Moreover, for vehicles this question is of particular importance because nowadays a vehicle is becoming almost the most common technical tool used by people in their practice.

It is generally accepted to consider that it is not wealth that makes us the great nation, but the way how efficiently we create it. In relation to the vehicle it is possible to say that "it is not about what volume of transportation we perform by car, but how efficiently we make it, what the energy costs are". In this regard,

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the approach to quality assessment of synergistic cars should be different.

Unsolved aspects of the problem. The works of the following authors are the most valuable for the formation of methodological framework of the diagnostics systems of vehicles:

- the general methodology outlined by Miroshnikov L. V. and used in the practice of technical operation, is taken as the basis while developing the methodology for assessing the technical condition of HPP;
- calculation methodology for the basic parameters of HPP designed by Surin E. I., Umniashkin V. A., Alexandrov A. K., and Vasiliev V. A., provided the basis for the mathematical model working to determine the reference values of diagnostic parameters.

Technical condition assessment and finding of HPP defects (based on the results of scanning of an electronic control system) is currently performed by the method of detailed test that does not provide high quality diagnosis, occurring in additional labor costs and the complexity of the diagnosis process. Insufficient level of validity in the diagnosis results in mistakes during repairs and damage of the expensive elements of hybrid drive. Repairs are complicated due to the lack of necessary diagnostic equipment.

Summarizing the existing experience, it is possible to make a conclusion that the developers of HPP diagnostics go through separate control of the technical condition of the internal combustion engine and electric drive systems, albeit without evaluation of their relationship.

The most common types of vehicles are those with HPP of mixed type (about 80 %). Information about HPP failures and the reason for their occurrence is not well known and virtually is not systematic. Since the mixed type scheme is the most common and the most difficult to diagnose, it is paid the largest attention while developing the methodology.

In the mixed HPP scheme the power generated by the internal combustion engine can be transmitted to vehicle wheels depending on the driving mode into two streams: mechanical stream, through the device of power distribution, and electric stream, through electric motors-generators and high-voltage battery. To build power to the drive wheels, the ICE and the high-voltage battery can work both separately and together, which makes the assessment of the technical condition of HPP difficult.

Analysis of the recent research and publications. As it is shown by various studies there is urgent necessity to measure simultaneously both the actual amount made by useful work of a vehicle and the quantity of energy expenditure, and according to it to assess the transport process as a whole with the most important criterion, which is the coefficient of efficiency.

In this regard, it is appropriate to remind the words of the great Italian scientist G. Galilei: “to measure everything that is measurable, and make measurable what is not so”. The great Russian scientist D. I. Mendeleev clearly appreciated the role and importance of measurement and, pointed that “in the nature, the measure and weight are the essence of the main instruments of cognition. Science begins with measurement”.

Fuel oil as an energy source has very high specific characteristics: in particular, 1 kg of gasoline contains 11.6 kWh of energy. Batteries of any possible electro-chemical systems have the theoretical amount of energy which is 6–10 times as small. For this reason, the issues of rational use of available electric energy are essential for electric traction systems of all types.

Let us note that electric traction systems have much smaller energy losses than systems with heat engines, including internal combustion engines. The efficiency coefficient of existing heat engines is 25–30 %, so only about 3 kWh/kg of energy density of the fuel is effectively used at the output of the engine.

The energy consumed by one electric car would approximately be 3.4 MWh/year, or 9.3 Wh/day [1].

The efficiency degree of electrochemical accumulator energy (with the modern state of the equipment) can be much higher and the achieved level of electric motors efficiency is 85–90 %. Thus, the useful energy density level of the electro-chemical sources may reach 25–30 % of the above mentioned values of the heat engine output. The approximate calculation shows that while essentially losing the original theoretical energy of energy carrier, electric traction systems can partially compensate this in implementing existing opportunities for its more effective usage. This fact is important while assessing the prospects of development of environmental friendly vehicles.

Objectives of the article. The purpose of this work is investigation of the management objectives of a power plant with rational energy consumption in the transport process performed by a vehicle following the highest level of safety. The approach to the formation of the hauling rig structure is considered which allows reducing energy costs for transportation work significantly.

Presentation of the main research. In accordance with the principle of its action, a vehicle performs some mechanical work due to the thrust force applied to the drive wheels of the vehicle; based on the expanded equation of the traction balance of the vehicle, which is adopted in the theory of vehicle, for the common case of rectilinear motion of a vehicle the work should be determined by the formula

$$A = F_K \cdot S = [m \cdot g \cdot \psi + W_B(v_a \pm v_b)^2 \pm m \cdot r \cdot a] \cdot S,$$

where A is work, J (N · m); F_K is traction force, H; S is way, m; $m = m_a + m_1$ stands for the gross weight of a vehicle, kg; m_a is proper mass of a vehicle, kg; m_1 is the mass of payload, kg; $\psi = f \pm i$ stands for the coefficient of road resistance; f is rolling resistance coefficient; i is the longitudinal slope of the road (“+” mark corresponds to the movement on rise, “–” mark corresponds to the downhill operation); W_B is factor of streamlining, $N \cdot s^2/m^2$; v_a is vehicle speed, m/s; v_b is wind speed, m/s ("+" mark refers to headwind, "–" mark is for tail-wind); $m \cdot r \cdot a$ stands for inertia force, N ("+" mark corresponds to acceleration, "–" mark corresponds to deceleration); r is the factor of the rotating masses of a car; $a = v_a/dt$ is the absolute value of acceleration or deceleration, m/s^2.

Thus for a vehicle moving in a set mode (motion with constant speed) and while there is no wind, we have

$$A = F_K \cdot S = (m \cdot g \cdot \psi + W_B v^2) \cdot S.$$

Taking into account the fact that a vehicle is a power machine and, as it is known from physics, it is common practice to assess power machine performance according to their capacity, and based on the expanded power balance equation, adopted in the theory of the vehicle, it is necessary to take the power to the drive wheels of the vehicle as a vehicle performance measurement, which at any time of vehicle movement is equal to

$$P = N_K = F_K \cdot v_a \cdot 10^{-3} =$$
$$= [m \cdot g \cdot \psi + W_B (v_a \pm v_b)^2 \pm m \cdot r \cdot a] \cdot v_a \cdot 10^{-3} S,$$

where P is vehicle performance, kV; N_K is vehicle power (power on the drive wheels), kV.

As it is seen, the performance is equal to the product of the force (traction) by speed.

Thus for the case of vehicle movement at constant speed and absence of wind we get

$$P = N_K = F_K \cdot v_a \cdot 10^{-3} = (m \cdot g \cdot \psi + W_B \cdot v_a^2) v_a \cdot 10^{-3}.$$

Currently, among the performance indicators of a vehicle, special place should be taken by fuel efficiency. At the same time it is advisable to use the coefficient of efficiency (CE) as a generalizing (integral) indicator of fuel efficiency of the vehicle.

As it is known, the coefficient of efficiency is determined for any system by the formula

$$\eta = E_a / E,$$

where E_a is the energy absorbed by the system; E is the energy received by the system.

It should be recognized that the efficiency coefficient of a vehicle is a very necessary concept which allows not only estimating the fuel consumption, but also comparing the most completely and "fairly" the vehicles and choosing the right directions of their improvement.

The term the efficiency coefficient of a vehicle denotes the ratio of the power of the N_R, i.e. the power supplied to the drive wheels (developed by the vehicle power) consumed – power $N_K = q \cdot G$, i.e. the power supplied to a car. Therefore, the efficiency coefficient of a vehicle as the power plant is represented by the ratio of power N_R to power N_K

$$\eta = \eta_{cs} = \frac{N_R}{N_K} = \frac{N_R}{q \cdot G},$$

where η_{cs} – the efficient coefficient of a vehicle as a power plant.

Therefore, the fact that the power of N_R is useful is beyond question, if a car is considered as a power plant.

When considering car movement, it is deemed appropriate to deal with the rolling resistance coefficient f rather than with the coefficient of rolling friction f', the former is defined by the formula

$$f = \frac{F_f}{P},$$

where F_f is power applied to the wheel, N; P is the gross vehicle weight, N.

In this approach, the force F_f, required to maintain even motion of a vehicle, should be determined by the formula

$$F_f = f \cdot P = f \cdot m \cdot g.$$

However, in reality the force prevents steady motion. Under real traffic conditions the lifting force and the drag force of the air environment occur.

In accordance with this approach, the common formula characterizing the process of vehicle steady motion, looks like this one

$$F_K = F_f + F_a + F_B =$$
$$= m \cdot g(f \pm i) + W_B \cdot v_a^2 = m \cdot g \cdot \psi + W_B \cdot v_a^2,$$

where F_K is force applied to the drive wheels of a vehicle, N; i is road slope; $\psi = f \pm i$ stands for the coefficient of road resistance.

As it is known, the equation represented by the formula, is called the equation of the traction balance.

As it is seen, the right side refers to the power load external to a vehicle rather than the magnitude of losses; to overcome the former, the force F_K is spent, and consequently a vehicle moves along the road.

If the left and right parts of the equation are multiplied by the value of $v \cdot 10^{-3}$, it is possible to obtain an equation that is called the power balance equation

$$N_R = (m \cdot g \cdot \psi + W_B \cdot v_a^3) \cdot 10^{-3}.$$

Based on the above mentioned material, the efficiency coefficient of a vehicle as a power plant should be determined by the formula

$$\eta = \eta_{cs} = \frac{N_R}{q \cdot G} = \frac{(m \cdot g \cdot \psi + W_B \cdot V_a^3) \cdot 10^{-3}}{g \cdot G}.$$

To substantiate the appropriateness of this approach to the calculation of the efficiency coefficient of a vehicle as power plant, let us consider the fuel consumption changes and electronics of hybrid car depending on the average vehicle speed [2].

Electric traction systems have much less energy loss than systems with internal combustion engines (ICE). The efficiency coefficient of existing internal combustion engine hybrid power units (HPP) is from 32 to 36 %, so only about 3 kWh/kg of energy density of the fuel is effectively used at the output of the internal combustion engine.

The degree of energy usage of an electrochemical battery is much higher, and the efficiency coefficient of electric motors is 85...90 %. Thus, the level of efficiently used energy density of the electrochemical sources reaches 25...30 % of the present value at the internal combustion engine output. This calculation shows that it significantly loses in the original theoretical energy of energy carrier, electrical traction systems can partially compensate for. This occurs at realization of existing opportunities of its more effective usage. This fact is of great importance while assessing the prospects of development and assessing technical condition of electric traction systems and for hybrid approach of its creation.

The method of energy balance was used as the base of the energy cost research for the electric powertrain of a hybrid vehicle. From the analysis of HPP structures and schemes it follows that any electric power plant consists of the following power modules, carrying out consecutive energy conversion: traction batteries, inverter, controller, traction motor, and transmission.

The general equation of electrical power plant balance of a hybrid vehicle in a driving mode with the electric traction will be

$$E_b + E_r = P_a + P_i + P_m + P_r + P_d,$$

where E_b is power from the battery; E_r is energy recovery; P_a, P_i, P_m, P_r are energy losses in the power plant modules – accumulator battery, inverter, motor, and transmission; P_d is energy loss when driving a hybrid vehicle.

In addition to the energy balance, it is approved to consider the equations of power balance that is primary in relation to the energy balance. However, the test conditions of the power plant of a hybrid vehicle are characterized by the steady-state motion of a vehicle at given speed. In this regard, this is the energy balance of the hybrid power plant prepared for the control of the driving movement cycle which is of great value [3].

The most effective hybrid test cycle is within the real speeds of 30...60 km/h. Therefore, it is advisable to carry out assessment of the hybrid powertrain technical condition particularly for this cycle, which determines the powertrain work completion using the vehicle motion speed and the beginning of enabling ICE operation. The equation of energy balance gives much more information for cyclic calculations than the equation of power balance; in addition, the energy consumption per cycle is a very important indicator of assessing the technical condition of HPP. These are the graphs of power consumption depending on average speeds below (Figure).

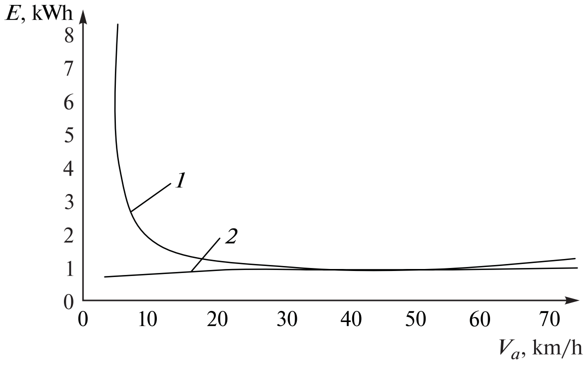

Fig. The energy E change received by vehicle, depending on the average speed V_a:

1 – while running with gasoline; 2 – in EV mode

As it follows from the Figure at average speed of 50 km/h the petrol consumption of the electric vehicle will be at low average speeds up to 40 km/h. At the average speed over 60 km/h it is efficient to use the vehicle in mode with a gasoline engine. This is because the efficiency coefficient of the electric engine reduces when the load is close to maximum, and the efficiency coefficient of a gasoline engine increases and will be maximum at medium loads.

Conclusions and recommendations for further research. On basis of the analysis of the energy loss of a vehicle with HPP, it follows that at low medium speeds of about 5...20 km/h it is very effective to use the driving mode on the electric range, and at medium speeds of above 60 km/h it is worth driving with the use of internal combustion engines. It is obvious that hybrid vehicles use the energy effectively to perform transport work unlike other types of vehicles.

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Мета. Дослідження особливостей розрахункових аналітичних методів задачі керування силовою установкою за раціональної витрати енергії при транспортному процесі, здійсненим автомобілем, дотримуючись високого рівня як безпеки руху, так і екологічної безпеки. Аналіз аналітичних залежностей визначення якості транспортних машин, що відповідають вимогам споживача на основі відбору показників якості за енергетичною оцінкою.

Методика. Визначення аналітичної моделі оцінки технічного стану гібридної силової установки для випробувального циклу в режимі швидкостей руху 30...60 км/год, що за швидкістю руху автомобіля визначає закінчення роботи електроустановки та початок роботи двигуна внутрішнього згоряння (ДВЗ), за допомогою аналізу енергетичних втрат гібридної силової установки в залежності від різноманіття умов експлуатації к технічним рішенням.

Результати. Обґрунтовано вибір синергетичного підходу при виконанні досліджень. Удосконалена система оцінки технічного стану гібридних автомобілів у залежності від режиму та умов їх роботи. А також представлена одночасна оцінка роботи двох потоків потужності: від ДВС і від електроприводу. Основа дослідження енергетичних витрат електричної силової установки гібридного автомобіля характеризується сталим рухом транспортного засобу при контрольному циклі, виходячи з балансу енергії, у залежності від середньої швидкості руху.

Наукова новизна. Уперше на базі енергетичного принципу встановлено взаємозв'язок між технічним станом гібридної силової установки (ГСУ) і режимами роботи.

Практична значимість. Розроблено метод визначення граничного стану гібридної силової установки, що вдосконалить систему сервісного обслуговування та ремонту гібридних автомобілів на станціях технічного обслуговування.

Ключові слова: *гібридна силова установка, транспортна машина, енергетична оцінка*

Цель. Исследование особенностей расчетных аналитических методов задачи управления силовой установкой при рациональном расходе энергии при транспортном процессе, совершаемом автомобилем, соблюдая высокий уровень как безопасности движения, так и экологической безопасности. Анализ аналитических зависимостей определения качества транспортных машин, отвечающих требованиям потребителя, на основе системного отбора показателей качества по энергетической оценке.

Методика. Определение аналитической модели оценки технического состояния гибридной силовой установки для испытательного цикла в режиме скоростей движения 30...60 км/ч, который по скорости движения автомобиля определяет окончание работы электроустановки и начало работы двигателя внутреннего сгорания (ДВС), с помощью анализа энергетических потерь гибридной силовой установки, в зависимости от многообразия условий эксплуатации к техническим решениям.

Результаты. Обоснован выбор синергетического подхода при выполнении исследований. Усовершенствована система оценки технического состояния гибридных автомобилей в зависимости от режимов и условий их работы, а также предоставлена одновременная оценка работ двух потоков мощности: от ДВС и от электропривода. Основа исследования энергетических затрат электрической силовой установки гибридного автомобиля характеризуется установившимся движением транспортного средства при контрольном цикле, исходя из баланса энергии, в зависимости от средней скорости движения.

Научная новизна. Впервые на базе энергетического принципа установлена взаимосвязь между техническим состоянием гибридной силовой установки (ГСУ) и режимами работы.

Практическая значимость. Разработан метод определения граничного состояния гибридной силовой установки, который усовершенствует систему сервисного обслуживания и ремонта гибридных автомобилей на станциях технического обслуживания.

Ключевые слова: *гибридная силовая установка, транспортная машина, энергетическая оценка*

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