ЭЛЕКТРОНИКА

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МЕТОД ОПРЕДЕЛЕНИЯ ЭНЕРГЕТИЧЕСКОЙ ЭФФЕКТИВНОСТИ ГИБРИДНОГО ЭЛЕКТРОМОБИЛЯ В УСЛОВИЯХ ГОРОДСКОГО ДВИЖЕНИЯ

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METHOD FOR DETERMINATION OF THE HYBRID ELECTRIC VEHICLE ENERGY EFFICIENCY IN URBAN TRANSPORTATION

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Экологические, а также экономические проблемы обеспечивают мощный импульс для развития чистых, эффективных и долговечных транспортных средств для городского транспорта. Экологические и экономические преимущества также можно получить, применив альтернативные транспортные технологии к промышленным и коммерческим внедорожникам. Пассажирские транспортные средства составляют неотъемлемую часть нашей повседневной жизни, однако выбросы выхлопных газов обычных автомобилей с двигателем внутреннего сгорания являются основным источником городского загрязнения, которое вызывает парниковый эффект, что в свою очередь приводит к глобальному потеплению. Гибридные электромобили или просто гибридные транспортные средства используют как электродвигатели, так и двигатель внутреннего сгорания для создания энергии движения; эти транспортные средства имеют более низкие выбросы выхлопных газов по сравнению с аналогичным размером обычного транспортного средства с двигателем внутреннего сгорания, что приводит к меньшему загрязнению окружающей среды. Двигатель внутреннего сгорания, используемый в гибридных электромобилях, конечно, уменьшен по сравнению с эквивалентным двигателем внутреннего сгорания. Двигатель внутреннего сгорания в сочетании с электрическим мотором и аккумулятором обеспечивают расширенный диапазон для гибридных электромобилей и снижают загрязнение окружающей среды. Гибридный автомобиль служит компромиссом для решения проблемы загрязнения окружающей среды и ограниченной дальности действия современного электромобиля. Энергоэффективность гибридных электромобилей является главным фактором его преимущества и оценки. В данной работе рассматривается методика определения энергоэффективности гибридных электромобилей городского транспорта. Предложено использование в составе измерительного оборудования для измерения потребляемой мощности гибридных автомобилей магнитоэлектрического датчика тока.

Ключевые слова: гибридный электромобиль, энергия, эффективность, методика, трафик, магнитоэлектрический датчик тока

Environmental as well as economical issues provide a compelling impetus to develop clean, efficient, and sustainable vehicles for urban transportation. Environmental and economical advantages can also be gained by applying the alternative transportation technologies to industrial and commercial off-road vehicles. Passenger vehicles constitute an integral part of our everyday life, yet the exhaust emissions of the conventional internal combustion engine vehicles are the major source of urban pollution that causes the greenhouse effect, which in turn leads to global warming. The hybrid electric vehicles or simply hybrid vehicles use both electric motors and an internal combustion engine for delivering the propulsion power; these vehicles have lower emissions compared to a similarly sized conventional internal combustion engine vehicle, resulting in less environmental pollution. The internal combustion engine used in a hybrid electric vehicles is, of course, downsized compared to an equivalent internal combustion engine vehicle. The internal combustion engine in combination with the electric motor and an energy storage unit battery provide an extended range for hybrid electric vehicles and bring down pollution. The hybrid vehicle serves as a compromise for the environmental pollution problem and the limited range capability of today's purely electric vehicle. The hybrid electric vehicles energy efficiency is the main factor for its advantage and evaluating. This paper considers the method for determining the hybrid electric vehicles energy efficiency in urban transportation. The use of a magnetoelectric current sensor as part of the measuring equipment to measure the power consumption of hybrid cars was proposed.

Keywords: HEV, energy, efficiency, method, traffic, magnetoelectric current sensor

Introduction

The methodology for evaluating the energy efficiency of hybrid electric vehicles (HEVs) is subdivided into the following modules:

1. Choice of HEV and movement modes.
2. Selection of criteria for evaluating the energy efficiency of HEV in urban traffic
3. Selection of measuring equipment.
4. Setting up of measuring equipment.
5. Choosing a route of travel.
6. Select travel time.
7. Determination of mileage and travel time.
8. Measuring and recording of experimental results.
9. Generating of a complex characteristic of the energy efficiency of HEV in urban traffic.
10. Analysis and evaluation. Recommendations. Trends.

Methodology

According to the analysis of the existing various solutions in the structures and the propulsion layout of the HEVs, a representative configuration of a HEV of mixed (series-parallel) arrangement type was selected [1-3]. The scheme of the selected hybrid is presented in Fig.1.

When the HEV is moving in urban traffic, the stop-and-go driving pattern applies. In this case, the primary power source PPS, which is internal combustion engine (ICE) or battery (B), is used too often. With frequent use of B energy, it must be recharged quickly. In this case, maintaining a high state of charge (SOC) of the B is necessary to provide the HEV power. Thus, the battery maximum SOC may be an appropriate control condition [4]. The algorithm of this control together with the modes of motion of HEV is presented in Fig.2.

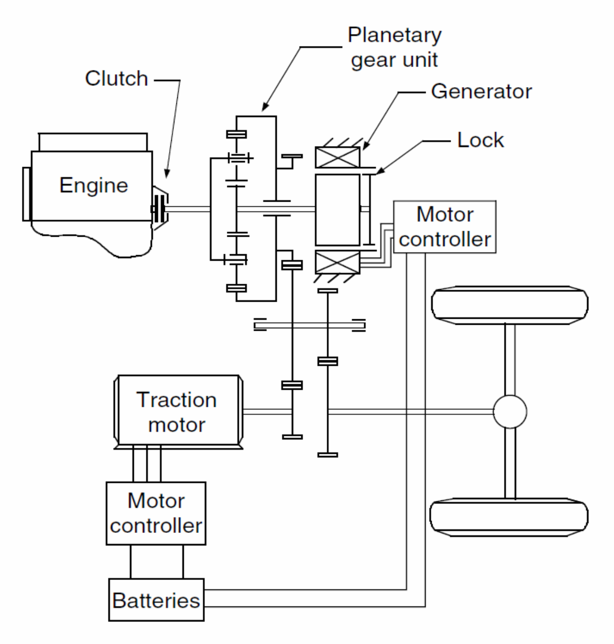

Fig.1. Hybrid propulsion layout for determining energy efficiency

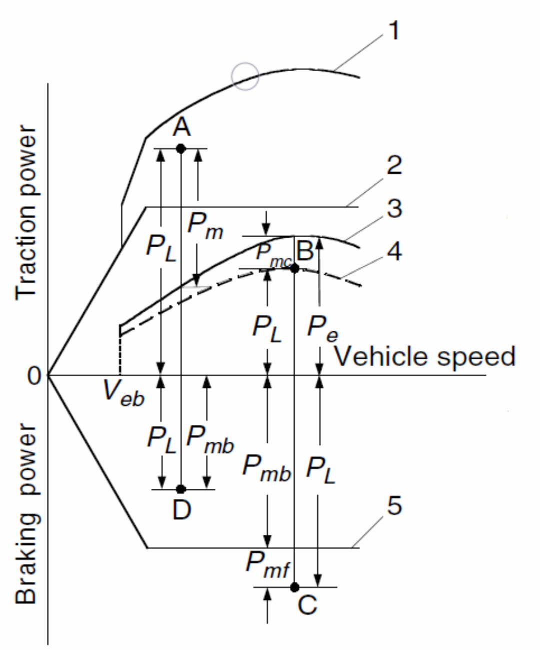

Fig.2. HEV operating modes depending on the required power for movement

The designations in Figure 2 are as follows: 1-Maximum power mode with hybrid mode ICE + electric motors (EM); 2-Maximum power with electric-alone traction; 3-Engine power on its optimum operating line (ICE); 4-Engine power with partial load mode (ICE); 5-Maximum generative power of electric motor; P_l-Load power, traction or braking; P_e-ICE power; P_m-EM traction power; P_{mb}-EM braking (regenerating) power; P_{mf}-Mechanical braking power; P_{mc}-power for B charging (PPS charging power)

The operating modes of the HEV are selected respectively [5-7]:

EM Drive Mode: This mode is performed at an HEV speed lower than the set *Veb*, which is understood as the minimum velocity characteristic under which the ICE cannot operate steadily. In this case, the EM provides power to the driving wheels while the ICE is off or idling. The power of the ICE, the EM, and the dilution of the B can be determined by the following dependencies [8]:

$$P_e = 0, \tag{1}$$

$$P_m = \frac{P_L}{\eta_{t,m}}, \tag{2}$$

$$P_{pps-d} = \frac{P_m}{\eta_m}, \tag{3}$$

where: P_e is the ICE power, kW; P_L — tractive or braking power, kW; $\eta_{t,m}$ — efficiency of the transmission from the EM to driving wheels; P_m — EM power, kW; $P_{pps\text{-}d}$ — consumed power from B, kW; η_m — EM efficiency.

Hybrid Drive (EM + ICE) Mode: The load presented in point A in Fig.2 is greater than the power that the ICE can provide, in which case the ICE and the EM must both provide power to the driving wheels. This mode is called hybrid drive mode. In this case, the ICE is adjusted to the optimum operating mode by adjusting the throttle to obtain power P_e. The required residual power is provided by the EM. The power of EM is determined by (4) and the power consumed by B is according previous (3):

$$P_m = \frac{P_L - P_e \eta_{t,e}}{\eta_{t,m}}, \quad (4)$$

where: $\eta_{t,e}$ is the efficiency of transmission from ICE to driving wheels.

Battery Charge Mode: When the load presented in point B of Figure 2 is less than the power that the ICE can provide under optimal mode, and the SOC of the B is less than the maximum, then the ICE continues to operate in optimum mode, producing P_e power. In this case, the EM is controlled by its controller [9-11] to operate as a generator, driven by the residual power of the ICE. The power of the Em and the charging power of the B are determined by:

$$P_m = \left(P_e - \frac{P_L}{\eta_{t,e}} \right) \eta_{t,e,m} \eta_m, \quad (5)$$

$$P_{pps-c} = P_m, \quad (6)$$

where: $\eta_{t,e.m}$ is the efficiency of transmission from ICE to EM.

ICE Drive Mode: When the load presented in point B of Fig.2 is less than the power that the ICE can provide under optimal mode, and the SOC load rate of the B has reached its maximum value, the propulsion is by ICE only. In this case, the EM is switched off and the ICE provides all the power to move the HEV. The characteristic of the ICE at this partial load is represented by the broken lines in Fig.2. ICE power, EM power, and B power can be represented by [8]:

$$P_e = \frac{P_L}{\eta_{t,e}}, \quad (7)$$

$$P_m = 0, \quad (8)$$

$$P_{pps} = 0. \quad (9)$$

Regenerative Braking Mode: When the HEV stops and the required braking power is less than the maximum regenerative braking power that the EM provides (Fig. 2, point D), then the EM is switched from the controller [12,13] to operate in generator mode and produces brake power that equals the set brake power. In this case, the ICE is off or idling. The EM power and the B charging power are:

$$P_{mb} = P_L \eta_{t,m} \eta_m, \quad (10)$$

$$P_{pps-c} = P_{mb}. \quad (11)$$

Hybride Braking Mode: When the required braking power is greater than the maximum regenerative braking power provided by the EM in generator mode (Fig.2, point C), the mechanical braking system must be applied. In this case, the EM must be controlled by the controller so as to produce maximum regenerative braking power, and the mechanical braking system must provide the remaining braking power. The EM power, the B charging power, and the braking power of the mechanical braking system are:

$$P_{mb} = P_{mb,\max} \eta_m, \quad (12)$$

$$P_{pps-c} = P_{mb}. \quad (13)$$

It should be noted that for better braking performance, the braking forces to the front and rear wheels must be proportional to their normal loads.

Start-Stop Mode: This mode can be used at low travel speeds and low acceleration values. When the ICE is running, the algorithm maintains a maximum SOC of B. When the SOC level of the B reaches its maximum value, the ICE is switched off and the HEV is driven only by the EM. When the SOC level of B reaches the minimum allowable value, the ICE is started and the algorithm is repeated.

The criteria for evaluating the energy efficiency of HEV in urban traffic are related to the amount of fuel consumed by the ICE and to the energy consumed by the EM, respectively regenerated in B. Two criteria are proposed: the power criterion for estimating the fuel consumed $Q_{N,f}$ (14) and the electricity consumed $Q_{N,e}$ (15) relative to the power of the HEV drive source, and the mass criterion for estimating the fuel consumed $Q_{M,f}$ (16), and the electricity consumed $Q_{M,e}$ (17) relative to the HEV mass.

$$Q_{N,f} = \frac{Q_f}{N_{e,\max} L}, \text{ l/kW.km}, \quad (14)$$

$$Q_{N,e} = \frac{Q_{disch} + Q_{rech} - Q_{regen}}{P_{\max} L}, \text{ kWh/kW.km}, \quad (15)$$

$$Q_{M,f} = \frac{Q_f}{G_{HEV} L}, \text{ l/kg.km}, \quad (16)$$

$$Q_{M,e} = \frac{Q_{disch} + Q_{rech} - Q_{regen}}{G_{HEV} L}, \text{ kWh/kg.km}, \quad (17)$$

where: Q_f is the fuel consumed, l; $N_{e,max}$ — ICE maximum power, kW; Q_{disch} — electricity consumed in drive (traction) mode, kWh; Q_{rech} — electricity consumed in network recharging mode (in case of plug-in HEV), kWh; Q_{regen} — electricity regenerated in regenerating or generating mode, kWh; P_{max} — EM maximum power, kW; L — mileage, km; G_{HEV} — HEV mass, kg.

The measuring equipment must meet the conditions for mobility, measurement accuracy within ± 1%, HEV compatibility, pre-test, set up and adjustment with calibrated equipment, placement of displays and monitors inside the HEV, recording of measured results. To measure fuel consumption, it is recommended that a fuel gauge with flow sensors be fitted to the inlet and outlet of the ICE gasoline rail. The measurement of electricity can be carried out with a combined wattmeter connected in series to B. Magnetoelectric current sensor (MECS) proposed by Llc "Magcom" (https://magcom-tech.com/) can be used as part of a wattmeter as a current measuring device. Such sensor has significant advantages over those offered by other manufacturers [14]. The sensor allows us to measure current up to 100 A and is mounted on a clip on the surface of the wire with current. Resistive shunts used by other manufacturers introduce resistance into the current circuit, which cancels the warranty of the car manufacturer, and current clamps are cumbersome in use and do not provide sufficient measurement accuracy. In addition, MECS compared to other types of sensors has a higher sensitivity and lower current consumption.

The traffic route is chosen as a representative run between two endpoints on a pendulum or a roundabout route in a given urban area. For this purpose a city map and the corresponding GPS navigation are used.

The travel time is recorded from the beginning to the end of the journey along the specified route. The distance traveled and the travel time are recorded by the on-board gauges of the HEV and compared with the readings of the GPS navigator system data.

Based on the **obtained data** and results, a **characteristic of the energy efficiency** of HEV in urban traffic conditions is generated. It is a dependence of the amount of fuel consumed Q_f, the electricity consumed Q_{disch} in the (traction) mode and the regenerated electricity Q_{regen} in the regenerating mode, depending on the mileage L, or:

$$Q_f, Q_{disch}, Q_{regen} = f(L). \quad (18)$$

The energy efficiency characteristic of HEV can be generated for a given mode of motion, a given section of motion, for a specified time, for a given cycle of motion [15], for two or several HEVs. In this way, the energy efficiency indicators of several HEVs can be compared and a comprehensive assessment of their efficient use for a given territory can be made.

Application of MECS: It is known that gasoline and electric engines have different power graphs. Therefore, the measurement of HEV power should be carried out on the basis of more thorough measurements. Realization practical tests in an urban cycle is the most appropriate goal. Rapid changes in the battery current, as well as the recovery current in the HEV, can cause changes in operating voltage and temperature. Although the battery can operate with high output (or input) power for a short time, increased current loads often cause it to heat up faster. The battery management system should ensure that it accumulates energy during recovery, but does not overheat. Thus, MECS will be useful both for bench and comparative practical tests, and for installation in existing cars to control the power system of HEVs and electric vehicles.

Conclusion

A methodology for determining the energy efficiency of hybrid electric vehicle powered by gasoline engines in urban traffic is proposed.

The power and mass criteria of fuel consumption and electricity consumption are proposed as quantitative measures of the energy efficiency of one or more HEVs.

The use of a magnetoelectric current sensor as part of the measuring equipment to measure the power consumption of HEVs was proposed.

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