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

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Abstract: *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 (ICE) vehicles are the major source of urban pollution that causes the greenhouse effect, which in turn leads to global warming [1]. The hybrid electric vehicles (HEVs) or simply hybrid vehicles use both electric motors (EM) and an ICE for delivering the propulsion power; these vehicles have lower emissions compared to a similarly sized conventional ICE vehicle, resulting in less environmental pollution. The ICE used in a HEV is, of course, downsized compared to an equivalent ICE vehicle. The ICE in combination with the EM and an energy storage unit (battery B) provide an extended range for HEV 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 HEV energy efficiency is the main factor for its advantage and evaluating. This paper considers the method for determining the HEV energy efficiency in urban transportation.*

INTRODUCTION

The methodology for evaluating the energy efficiency of HEV is subdivided into the following modules:

1. Choice of a HEV and driving modes.
2. Choosing a route of travel.
3. Determination of a driving distance.
4. Recording of a travel time.

5. Selection of a measuring equipment.
6. Setting up the measuring equipment.
7. Measuring and recording of experimental results.
8. Selection of a criteria for evaluating the HEV energy efficiency.
9. 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 [1,2,3]. The scheme of the selected hybrid is presented in Figure 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 ICE or 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 [7]. The algorithm of this control together with the modes of motion of HEV is presented in Fig. 2.

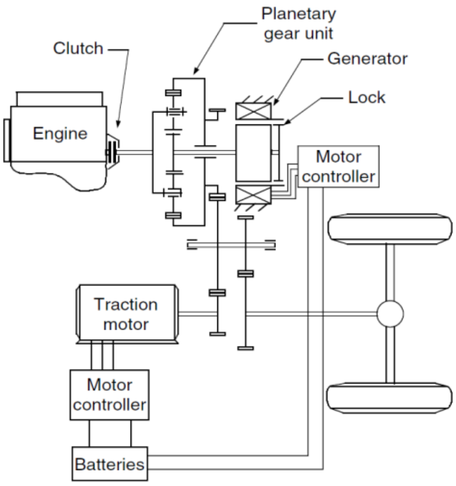

Fig.1. Hybrid propulsion layout for determining energy efficiency

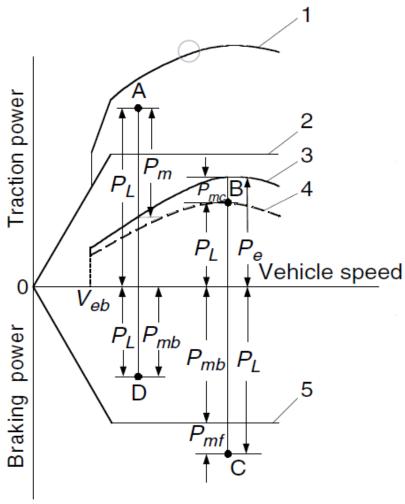

Fig. 2. HEV operating modes depending on the required power for movement

The designations in Figure 2 are as follows: 1-Maximum power mode with hybrid mode(ICE+EM); 2-Maximum power with electric-alone traction (EM); 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 [4,5,6]:

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]:

(1) $P_e = 0$, (2) $P_m = \dfrac{P_L}{\eta_{t,m}}$, (3) $P_{pps-d} = \dfrac{P_m}{\eta_m}$,

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 Figure 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):

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

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 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:

(5) $$P_m = \left(P_e - \frac{P_L}{\eta_{t,e}} \right) \eta_{t,e,m} \eta_m,$$ (6) $$P_{pps-c} = P_m,$$

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 Figure 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]:

(7) $$P_e = \frac{P_L}{\eta_{t,e}},$$ (8) $$P_m = 0,$$ (9) $$P_{pps} = 0.$$

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 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:

(10) $$P_{mb} = P_L \eta_{t,m} \eta_m,$$ (11) $$P_{pps-c} = P_{mb}.$$

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:

(12) $$P_{mb} = P_{mb,\max} \eta_m,$$ (13) $$P_{pps-c} = P_{mb}.$$

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 route of travel is selected as a representative run between two endpoints on a pendulum or a roundabout route in each urban area. For this purpose, a city map and the corresponding GPS navigation are used. At this step must be selected the traffic period, i.e. the clock time of driving the route of travel.

The driving distance is calculated by the selected route of travel according to the map or GPS data. The distance is verified by the HEV board or trip computer.

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.

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. To measure the electricity consumption and battery regeneration, it is suitable to use wattmeter, but it is recommended that a current claw must be used to non-interrupted measurements.

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. According to the previous article [9] the authors are made further development and proposing three criteria, as following:

1) **distance criterion** for estimating the fuel consumed $Q_{D,f}$ (14) and the electricity consumed $Q_{D,e}$ (15) relative to the HEV driving range;
2) **mass criterion** for estimating the fuel consumed $Q_{M,f}$ (16), and the electricity consumed $Q_{M,e}$ (17) relative to the HEV mass;
3) **combined criterion** for estimating the fuel consumed $Q_{DM,f}$ (18) and the electricity consumed $Q_{DM,e}$ (19) relative to the both HEV driving range and HEV mass.

(14) $Q_{D,f} = \frac{Q_f}{100L}$, l/100km, (15) $Q_{D,e} = \frac{Q_{disch} + Q_{rech} - Q_{regen}}{100L}$, kWh/100km,

(16) $Q_{M,f} = \frac{Q_f}{G_{HEV}}$, l/kg, (17) $Q_{M,e} = \frac{Q_{disch} + Q_{rech} - Q_{regen}}{G_{HEV}}$, kWh/kg,

(18) $Q_{DM,f} = \frac{Q_f}{G_{HEV} L}$, l/kgkm, (19) $Q_{M,e} = \frac{Q_{disch} + Q_{rech} - Q_{regen}}{G_{HEV} L}$, kWh/kg.km,

where: Q_f is the fuel consumed, l;

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;

L – distance, km;

G_{HEV} – HEV mass, kg.

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:

(20) $Q_f, Q_{disch}, Q_{regen} = f(L)$.

The energy efficiency characteristic of HEV can be generated for a certain mode of motion, a certain section of motion, for a specified time, for a certain cycle of motion [14], 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.

TRENDS

Energy efficiency measurement devices used in modern cars must have high accuracy parameters for measuring current in real time. There are magnetoelectric (ME) current sensors that can measure these parameters with high accuracy [11]. The development and research of new sensor is one of the modern trend. The sensor operates on the ME effect and can measure current in the range up to 500 A. The sensitive element of such a sensor is materials based on ME magnetostrictive-piezoelectric layered structures. The ME current sensor can operate in different modes, in resonant and non-resonant modes. It is assumed that the use of ME current sensors in HEV will optimize vehicle performance.

CONCLUSION

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

A distance criteria, mass criteria and combined criteria of fuel and electricity consumption are proposed as quantitative measures of the energy efficiency of one or more HEVs.

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МЕТОДИКА ЗА ОПРЕДЕЛЯНЕ НА ЕНЕРГИЙНАТА ЕФЕКТИВНОСТ НА ХИБРИДНИ АВТОМОБИЛИ В ГРАДСКИ УСЛОВИЯ НА ДВИЖЕНИЕ

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Ключови думи: *хибридни автомобили, енергийна ефективност, методика, градско движение*

Резюме: *Проблемите, свързани с околната среда, както и икономическите проблеми осигуряват големи стимули за разработване на чисти, ефикасни и устойчиви превозни средства за градския транспорт. Екологичните и икономическите предимства могат да се получат и чрез прилагане на алтернативни транспортни технологии за промишлени и търговски превозни средства. Пътническите превозни средства са неразделна част от ежедневието ни, но емисиите на отработени газове от конвенционалните превозни средства с двигател с вътрешно горене са основният източник на градско замърсяване, което причинява парниковия ефект, което от своя страна води до глобално затопляне [1]. Хибридните електрически превозни средства (HEV) или просто хибридните автомобили (ХА) използват както електродвигател (ЕД), така и ДВГ за осигуряване на необходимата мощност за движение; тези превозни средства имат по-ниски емисии в сравнение с конвенционалните превозни средства с аналогични размери, което води до по-малко замърсяване на околната среда. ДВГ, използван в ХА е с понижена мощност и размери в сравнение с еквивалентен автомобил. ДВГ в комбинация с ЕД и акумулаторната батерия (АБ) осигуряват разширен пробег на ХА и намаляват замърсяването. Хибридният автомобил служи като компромис за проблема със замърсяването на околната среда и ограничените възможности на днешния изцяло електрически автомобил. Енергийната ефективност на ХА е основният фактор за неговото предимство и комплексна оценка. В тази статия се разглежда методът за определяне на енергийната ефективност на ХА при градски условия на движение.*