2022-01-0667 Published 29 Mar 2022

Dynamics Hybrid Vehicle Driven with Electric Motor Driving Wheels from Batteries

Alexey Bazhinov, Tetyana Bazhinova, Mikhail Podrigalo, and Mykhailo Kholodov
Kharkov National Auto and Highway University

Yevhen Haiek State Biotechnological University

Iryna Sierikova Kharkov National Auto and Highway University

Citation: Bazhinov, A., Bazhinova, T., Podrigalo, M., Kholodov, M. et al., "Dynamics Hybrid Vehicle Driven with Electric Motor Driving Wheels from Batteries," SAE Technical Paper 2022-01-0667, 2022, doi:10.4271/2022-01-0667.

Received: 21 Jan 2022 Revised: 21 Jan 2022 Accepted: 12 Jan 2022

Abstract

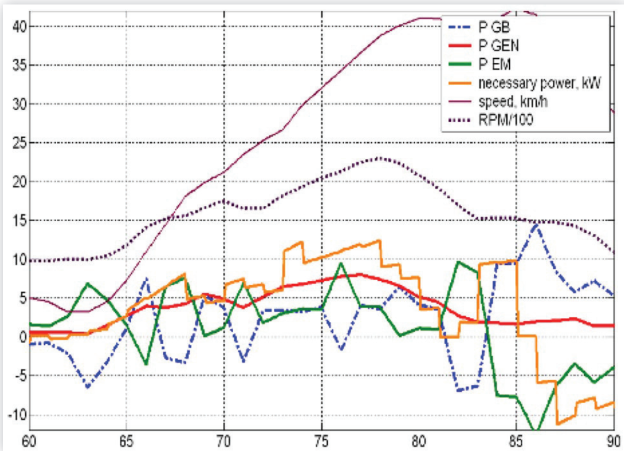
The use of electric energy to drive the drive wheels allows you to improve not only the environment, but also the performance indicators of cars. A hybrid car uses both thermal energy from an internal combustion engine (ICE) and electrical energy from generators or batteries. The authors of the paper have conducted a study on the dynamics of a hybrid car, in which ICE energy is used to charge rechargeable batteries, and the latter provide the driveline. By reducing the amplitude of the traction force oscillations, the energy costs for the forward movement of the car are reduced. The purpose of the study is to determine the energy savings for accelerating a car with a combined power plant with electric engines on wheels using battery power. As a result of the study, a mathematical model of the car acceleration process with a combined power plant and powered electric engines of the driving wheels from the batteries has been obtained. The obtained analytical dependencies allow us to determine the energy savings of a hybrid car of the specified design during acceleration. In the driving mode, with the joint operation of the electric engine and the internal combustion engine with uniform movement, there was a certain synergistic effect of power units (internal combustion engine, traction motor) in relation to the speed and energy reserve in the high-voltage storage battery. For this, measurements were made of the power of the electric engine, the internal combustion engine speed, fuel consumption, speed, and recirculation of the generator's electrical energy. The share of the generator power that goes to charge the battery was determined, and how it affects the specific fuel consumption.

Introduction

The use of electric energy to drive the drive wheels allows you to improve not only the environment, but also the performance indicators of cars [1]. In scientific work [1], the design features of hybrid vehicles, as well as their advantages and disadvantages, are considered. As a disadvantage, it should be noted that not all energy losses were taken into account when braking the hybrid vehicle. That in general does not allow obtaining a complete description of the efficiency of a hybrid vehicle in comparison with other types of power plants of cars. In article [2], the concept of creating a hybrid power plant with an intelligent control system is considered. In this article, there is no optimal distribution of energy flows between the electric motor and the internal combustion engine, which affects significantly on the consumption of energy resources. There are also no data on the use of alternative fuels for the internal combustion engine.

A hybrid car uses both thermal energy from an internal combustion engine (ICE) and electrical energy from generators or batteries. [3]. There are three options for constructing electric transmissions of hybrid power plants of the car: series, parallel and series-parallel circuits. Consider the principle of operation of each of these schemes, the possibility of applying each of them, as well as the requirements for their use. In a series circuit, the internal combustion engine has no kinematic connection with the drive wheels, so the mechanical energy from the internal combustion engine is not used to drive the wheels of the car, and is supplied only to the generator by electric transmission: internal combustion engine - electric generator - traction electric motor. At the same time, the internal combustion engine is set to an environmentally friendly mode of operation and consumes a minimum amount of fuel [1]. The disadvantages of the serial circuit are the reduction of efficiency and efficiency due to the double conversion of energy: the mechanical energy of the internal combustion engine - the electrical energy of the generator or battery - the mechanical energy of the motor [4]. In a parallel circuit, the internal combustion engine and the traction electric motor, which receives energy from the battery, transmit the total torque to the drive wheels [1]. The disadvantage is the obligatory complication of the electric transmission to ensure the supply of power from the traction electric machine, which

FIGURE 5 Distribution of energy flows from 60 to 90 seconds of movement: P GB - battery power, kW; P GEN - generator power, kW; P EM - motor power, kW; necessary power -power required for movement or which is returned during recovery, kW; speed - speed, km / h; RPM / 100 - internal combustion engine speed / 100



In the mode of movement at joint work of the electric motor and internal combustion engine at uniform movement there was a certain synergetic influence of power units (internal combustion engine, traction electric motor) in percentage depending on speed of movement and energy reserve in the high-voltage accumulator battery. To do this, measurements of the power of the electric motor, the speed of the internal combustion engine, fuel consumption, speed, recirculation of electrical energy of the generator. The share of generator power that goes to the battery charge and how it affects the specific fuel consumption was determined.

In the mode of movement at joint work of the electric motor and internal combustion engine for realization of acceleration corresponding to the European city cycle (to $1 m/s^2$) and the maximum acceleration powers of electric cars (engine, generator), turns of internal combustion engines, car acceleration were measured. The percentage of power of the internal combustion engine and the electric motor and its influence on the power indicators of the synergetic power plant are determined.

The main synergetic meaning of a hybrid car, which is involved in the following:

- at low speed up to 40 km/h. using an electric drive with an efficiency of up to 90% and a maximum torque (in the internal combustion engine when driving in traffic jams efficiency does not increase by 5%, according to the large specific fuel consumption and maximum exhaust);
- at speed over 40 km/h. efficient use of internal combustion engines (efficiency up to 35%) is achieved, as well as the use of an electric motor, which limits the small amount of energy in the traction battery.

In this synergistic mode, gasoline consumption in the urban cycle has more than halved and amounted to about 3,8 L/100 km. Thus the full charge of power traction battery is enough for run on the city on distance to 50 km. Electricity consumption in the mode of the electric car makes about 0,07 UAH / km. When driving in traffic jams, fuel consumption decreases because the internal combustion engine does not work, and electricity consumption does not increase significantly, because in this mode, the car has low acceleration and, consequently, current consumption. This improves the ease of driving, because to drive in traffic jams on the electric drive is enough to use only the accelerator and brake pedals, as in an automatic transmission.

Thus, the internal combustion engine does not idle in traffic jams and congestion, as well as at low speeds, when the efficiency of the internal combustion engine is minimal, and emissions are maximum. To achieve a low cost of the electric car, as well as increase mileage, we believe it is necessary to maintain the possibility of using it as a conventional base car with a manual transmission, without the use of an electric drive. In this case, you can reduce the cost of the electric car, through the use of low-power traction electric motor and low-current control system. This, in turn, will not only reduce the cost of the electric drive, but also use a low-power traction battery with a low allowable discharge capacity. The stock of the electric power in power traction battery is calculated proceeding from necessary passed distance of one trip of the car. At the same time, the mass of the synergetic car will be less due to the lower weight of the traction electrical equipment, therefore, the specific energy consumption of such a car will be lower.

Conclusions

1. As a result of the study, a mathematical model of the car acceleration process with a combined power plant and powered electric engines of the driving wheels from the batteries has been obtained
2. The obtained analytical dependencies allow us to determine the energy savings of a hybrid car of the specified design during acceleration.
3. One of the approaches to increase the efficiency of diagnosing the technical condition of a hybrid power plant is to develop and implement to determine the technical condition of intelligent information and control system invariant to different hybrid vehicles, which minimizing energy or resource consumption under specified operating conditions.

References

1. Bazhinov, A.V., Smirnov, O.P., Serikov, S.A., and Hnatov, A.V., *Hybrid Vehicles* (HNADU, 2008), 327
2. Bazhinov, A.V., Smirnov, O.P. "The Concept of Creating an Environmentally Friendly Car," Bulletin of the East Ukrainian National University. Vladimir Dahl 2006, 7, 15-19.
3. Smirnov, O.P., "Analysis of Circuit Solutions for Building a Car with a Hybrid Power Plant," *KhNADU Bulletin* , no. 32 (2006): 41-43.

4. Zhu, D., Pritchard, E., Dadam, S.R. et al. Optimization of Rule-based Energy Management Strategies for Hybrid Vehicles Using Dynamic Programming. *Combustion Engines.* 2021, 184(1), 3-10. https://doi.org/10.19206/CE-131967.
5. Podrigalo, M.A., Bazhinov, A.V., Bisozkii, O.M., Kryvii, V.I., Dun, S.V., Kaydalov, R.O., Nikitin, S.P., and Polyarus, O.V., Electromechanical power plant of a vehicle with energy storage unit, Patent 119713(51), No.4201702166; declared 07/03/17; publ. 10/10/17, Bull. No. 19.
6. Kaydalov, R.O. Evaluation of the Energy Efficiency of Using the Electric Transmission of a Wheeled Car," Visnyk of the National Technical University, Kharkiv Polytechnic Institute". Kharkiv: NTU "KhPI", 2017. 25(1247) 86-89
7. Smirnov, O.P. and Bozhenov, V.S., "Mathematical Modeling of Traction-Speed Characteristics of a Hybrid Vehicle," Collection of Scientific Papers of Kharkov Air Force University 2006, 2 (8) 46-49.
8. Lippa, A.J., Brehob, D.D., Yang, J., Xu, L., Control strategy for an internal combustion engine in a hybrid vehicle, Patent No.: US 6,421,599 B1 - declared 09/08/01; publ. 16/07/02
9. Smirnov, O.P., "Synergetic Approach to the Creation of a Power Plant of the Car," *Journal of the KhNADU* , no. 37 (2007): 131-133.
10. Gerasimov, D.N., Nikiforov, V.O., Paramonov, A.V., and Serov, D.S., "Adaptive Torque Control in Injection Engines of Internal Combustion with Variable Valve Timing," *News of Higher Educational Institutions. Instrument Making* 57, no. 12 (2014): 28-32.
11. Karaoğlan, M.U., Kuralay, N.S., and Colpan, C.O., "The Effect of Gear Ratıos on the Exhaust Emıssıons and Fuel Consumptıon of a Parallel Hybrid Vehicle Powertrain," *Journal of Cleaner Production* 210 (2019): 1033-1041.
12. Zhu, Y., Chen, Y., and Chen, Q., "Analysis and Design of an Optimal Energy Management and Control System for Hybrid Electric Vehicles," in *Proc. of the 19th Electric Vehicles Symposium, Busan, Korea*, 2002, 219.
13. Zhang, R. and Chen, Y., "Control of Hybrid Dynamical Systems for Electric Vehicles," in *Proceedings of the 2001 American Control Conference* (Cat. No. 01CH37148). IEEE, 2001, 2884-2889.
14. Kumar, V., Zhu, D., and Dadam, S., "Intelligent Auxiliary Battery Control - A Connected Approach," SAE Technical Paper 2021-01-1248 (2021). https://doi.org/10.4271/2021-01-1248.
15. Dadam, S.R., Jentz, R., Lenzen, T., and Meissner, H., "Diagnostic Evaluation of Exhaust Gas Recirculation (EGR) System on Gasoline Electric Hybrid Vehicle," SAE Technical Paper 2020-01-0902. https://doi.org/10.4271/2020-01-0902.
16. Crolla, D.A. and Cao, D., "The Impact of Hybrid and Electric Powertrains on Vehicle Dynamics, Control Systems and Energy Regeneration," *Vehicle System Dynamics* , no. 50 (2012): 95-109.
17. Özbek, M. and Söffker, D., "Modeling and Simulation of the Dynamics of Fuel-cell Driven Hybrid Powertrains," in *Proc. 6th Vienna Conference on Mathematical Modeling on Dynamical Systems MATHMOD*, 2009. 1974-1982.
18. Kondratenko, O.P. and Dubina, O.M., "Estimation of the Energy Parameters of the Power Plant of a Hybrid Transmission at Different Speed Modes," *Collection of Scientific Papers of the National Academy of National Guard of Ukraine* 2, no. 14 (2009): 4-9.
19. Williamson, S.S., Emadi, A., and Rajashekara, K., "Comprehensive Efficiency Modeling of Electric Traction Motor Drives for Hybrid Electric Vehicle Propulsion Applications," *IEEE Transactions on Vehicular Technology* , no. 56 (2007): 1561-1572.

Contact Information

Prof. Mikhail Podrigalo
pmikhab@gmail.com

Prof. Alexey Bazhinov
alexey.bazhinov@gmail.com

Phd. Tetiana Bazhynova
tatyana2882@gmail.com

Acknowledgments

The authors are thankful to Kharkiv National Automobile and Highway University (KhNAHU, Kharkiv) as well as Reform Support Team at the Ministry of infrastructure of Ukraine scientists for their cooperation in completing this study.

An Overall Glossary of Terms and Definitions

$\overline{N_i}$ - average engine indicated power;

V_a - car speed;

η_{tr} - transmission efficiency;

ηM_{CE} - mechanical ICE efficiency;

η_{gen} - efficiency of an electric current generator;

η_{BAT} - battery efficiency;

η_{EE} - electric engine efficiency;

S - mileage.

P_{km} - part of a car's total traction force generated by the mechanical drive from ICE;

P_{kel} - part of the total traction force of a car, which is created by a drive from electric engines;

M_e - crankshaft net torque of ICE;

U_k, U_o - gear ratios (transmission ratios) of the gearbox and final drive, respectively;

M_{el} - total torque on the engine shafts;

$r_д$ - dynamic radius of driving wheels;

J_e - ICE rotating mass inertia moment;

ΣJ_k - total inertia moment of all car wheels;

H_{tr}, η_{el} - efficiency of the mechanical and electrical parts of the transmission;