COMPUTATIONAL PROBLEMS OF ELECTRICAL ENGINEERING

Vol. 9, No. 1, 2019

ANALYSIS OF WAYS OF INCREASING THE ENERGY EFFICIENCY OF TRACTION ELECTRIC TRANSMISSION OF SHUNTING DIESEL LOCOMOTIVE

Serhiy Buriakovskyi[1], Artem Maslii[2], Danylo Pomazan[2], Oleksandr Kovalchuk[2]
[1] Scientific Research and Design Institute “Molniya” National Technical University “Kharkiv Polytechnic Institute”,
[2] Ukrainian State University of Railway Transport
sergbyr@i.ua, a.masliy@ukr.net, danil.pomazan@ukr.net

Abstract: The article is devoted to the problems of increasing the energy efficiency of traction electric transmission of a shunting diesel locomotive.

In the context of rising fuel costs, to maintain the competitiveness of rail transport, the issue of energy efficiency of the traction rolling stock, which accounts for about 90 % of the total consumption of hydrocarbons by rail, is quite acute. At present, a number of measures have been investigated to improve the efficiency of diesel engines of locomotives, which allows getting an increase in the efficiency at the level of 1–5 %. The use of new efficient types of electromechanical transducers with static converters, in turn, also enables us to reduce fuel and lubricant consumption by a diesel locomotive. However, solving the problem of energy efficiency in traction transmission of a locomotive requires a comprehensive approach. One of such approaches is the application of new types of diesel generator sets for locomotives – free-piston combustion engines with linear generators. The application of new designs of thermal engines makes it possible to significantly extend the possible limits of increasing the efficiency of diesel traction.

Key words: traction transmission, shunting locomotive, traction motor, traction generator, internal combustion engine.

1. Introduction

Efficient use of fuel and energy resources is one of the most important challenges facing the Ukrainian economy. The Law of Ukraine “On Energy Saving” defines the energy efficiency of the economy as one of the main strategic guidelines of the long-term state energy policy.

Rail transport is one of the largest energy consumers in the country. Energy efficiency in modern conditions is the most important factor for increasing the competitiveness of Ukrainian railways in the domestic and international market of transport services. The Decree of the Cabinet of Ministers of Ukraine approved the Transport Strategy of Ukraine for the period up to 2020, which aims, in particular, to optimize energy consumption while unconditionally performing services for the cargo transportation and maintaning the energy security of the company. The main part of fuel and energy resources in the company is spent on train traction [1]. Today it is 82 % of the total consumption of electricity and 90 % of diesel fuel. Therefore, the emphasis in energy conservation should be made, first of all, on the main activity – the transportation process.

Currently, a large number of shunting diesel locomotives equipped with different types of traction gears are used on the railways of Ukraine and the world [2]. Most of Ukrzaliznytsia’s fleet of shunting locomotives is morally or physically worn out and requires replacement or deep modernization [3].

Taking the above mentioned into consideration, the task of elaborating an integrated approach to the problem of increasing the energy efficiency of traction transmission of a shunting diesel locomotive is quite acute.

2. Measures to improve the energy efficiency of the internal combustion engine

Various organizations are working on the improvement of technical and economic indicators of diesel engines, the results of their research having been reflected in numerous publications [4]. They propose different principles and directions, design and technological solutions. At the same time, the availability of a large number of ways of improving diesel engines now complicates the choice of rational solutions acceptable for widespread implementation at machine-building plants.

One of the main parameters characterizing a diesel engine as a whole is its effective power. That is why leading manufacturers of internal combustion engines (ICE) are striving to constantly increase this characteristic. Moreover, there is a tendency to increase the capacity without increasing the weight-size parameters of the engine, which is especially important for transport ICE [5].

Effective engine power is influenced by the following parameters: cylinder diameter, piston stroke, coefficient of stroke, crankshaft speed, cylinder capacity, average effective pressure.

One of the main ways to increase the effective power without changing the the weight-size parameters is to increase the average effective pressure in the cylinder of a diesel. This can be achieved by increasing the pressure in front of the engine intake, that is, the pressure of the charging.

Gas turbine charger systems of the diesels made in Ukraine, in most cases, are equipped with one high performance turbocharger. However, the charger circuit with one working turbocharger has several significant disadvantages: a narrow range of crankshaft speed; a significant reduction in torque at low speed.

The listed disadvantages of diesel engines with gas turbine supercharging arise primarily because of the inertia of the turbocharger rotor. As a result, the turbocharger works in non-economic modes (with low values of adiabatic efficiency), and this, in turn, leads to a deterioration of the air supply to the diesel engine in all modes of operation. Therefore, in these schemes, it is advisable to reduce the weight of the rotor when the power plant is operating at low crankshaft speed, since at low crankshaft speed, the exhaust gases energy is not enough to spin the turbocharger rotor with the speed necessary for the efficient performance of the power plant as a whole.

Reducing the torque inertia of the turbocharger rotor by reducing its weight will greatly shorten the time of the transient process and to a greater extent reduce the degree of mismatch between the fuel system and the air supply system. Improving the efficiency of the air supply system is achieved by the use of impulse (Figure 1) or register charger systems.

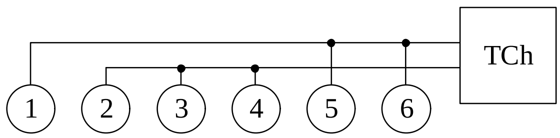

Fig. 1. Block diagram of an impulse charging system.

The greatest effect is achieved with configuration, which ensures the use of short exhaust manifolds. With impulse charging systems, the duration of the transient process is significantly reduced as a result of increasing the energy of the exhaust gas pulse in front of the turbine, which allows obtaining the highest torque at the appropriate speed of the crankshaft.

3. A set of measures for improving the efficiency of the electrical part of traction transmission

In locomotives with electric transmission, the traction (main) generator converts mechanical energy of the ICE into electrical energy to power the traction electric motors. The electric energy received from the traction generator is again converted into mechanical energy by the traction motors to drive the locomotive wheels. In addition to traction electric motors, locomotives are equipped with various additional electric generators and electric motors, electric apparatus and control devices, devices for automatic control of the operation of individual units, devices for protection of equipment from inappropriate operating modes. Based on the above, we can determine the second way of increasing the efficiency of the traction electric transmission of the locomotive – increasing the efficiency of the electrical part. Numerous studies are being conducted in this area, mainly aimed at the use of more efficient electric machines, intelligent control systems or the development of hybrid systems.

One of the ways to increase the energy efficiency of diesel locomotives is the use of traction electric transmission of alternating current, which involves installing an AC traction generator and AC traction electric motors. This type of electric transmission allows the use of more efficient classes of electric machines, which correspond to the IE3 and IE4 classes of energy efficiency according to IEC 60034-30: 2008.

A number of shunting locomotives with AC electric transmission are operated on the railways of the world, which have shown higher traction characteristics compared to locomotives equipped with DC transmission.

The use of AC traction electric transmission can improve locomotives energy efficiency in traction mode, but this solution does not allow us to reveal all possible potential for increasing energy efficiency of electric transmission.

The most promising direction of the development of locomotive engineering in the world is the development of hybrid systems with energy storage units. This makes it possible not only to reduce the power of the diesel but also to use the recovered energy of the diesel locomotive. The world experience in the operation of hybrid-powered diesel locomotives shows that this measure can reduce fuel consumption by 50-60 %.

4. Comprehensive approach to increasing the energy efficiency of diesel locomotives with traction electric transmission

As previously stated, the hybrid system with AC transmission is the most promising system that can significantly improve the efficiency of the electrical part of the traction transmission. At the same time, it is possible to achieve an even greater increase in the efficiency of the system, using a comprehensive approach that involves a change in the design of both the ICE and the electrical part.

It is known that the chemical energy of fuel in the ICE is spent not only on the performance of useful work but also on overcoming the parasitic forces that arise in the engine. The division of the fuel explosion energy in a diesel ICE is presented in Fig. 2.

According to Fig. 2, about 40 % of the energy is spent on the useful work, therefore, the reduction in losses in the engine, can significantly increase its efficiency.

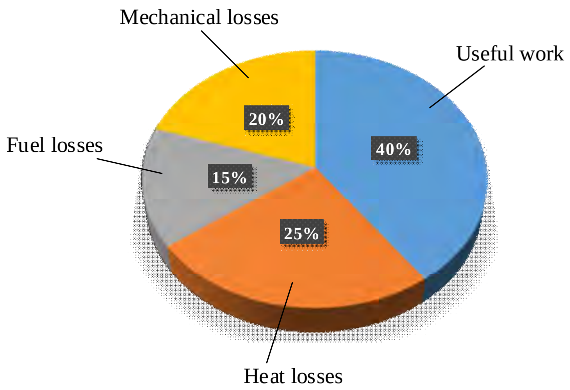

Fig. 2. The division of the fuel explosion energy in the ICE.

All losses in the ICE can be divided into mechanical, fuel and heat. The fuel losses are due to the fact that not all of the fuel is burned, and a small part of it goes out with the exhaust gases. The heat losses are due to the fact that the engine warms itself and many other elements, such as radiators, its body, the fluid in which it circulates, etc., and some of the heat goes with the exhaust gases. The mechanical losses occur when overcoming the friction forces of different parts of the ICE, as well as the actuation of auxiliary mechanisms that ensure the operation of the engine.

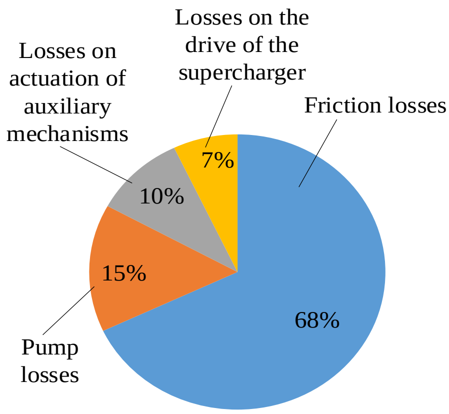

Fig. 3. Division of losses in the ICE.

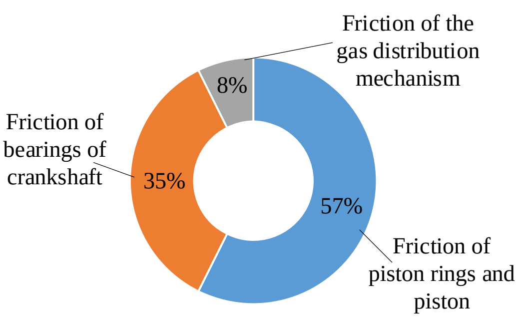

Fig. 4. Division of friction losses in the ICE.

The mechanical losses, in turn, are divided into frictional losses, pumping losses, losses due to auxiliary mechanisms, losses of the superchargers drive (Fig. 3).

As can be seen from Fig. 3, friction accounts for 68 % of all mechanical losses in the ICE. Division of the friction losses is shown in Fig. 4.

The friction losses of the crankshaft bearings is about 35 % of the total friction losses. The use of new engine designes without a crankshaft gives a considerable space for the implementation of measures to increase the efficiency of traction electric transmission of the locomotive.

5. Features of application of free-piston engines on shunting locomotives

One example of an ICE without a crankshaft is a free-piston engine, that is presented in Fig. 5.

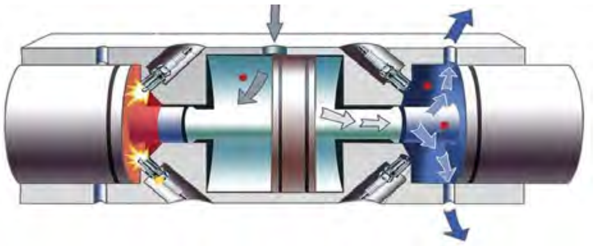

Fig. 5. General view of a free-piston ICE.

The most common use of such ICEs is in combination with linear generators (Fig. 6), this allows the conversion of thermal energy of the explosion of fuel into electrical without converting the forward motion of the piston into the rotational movement of the crankshaft, which leads to an increase in the overall efficiency of the system.

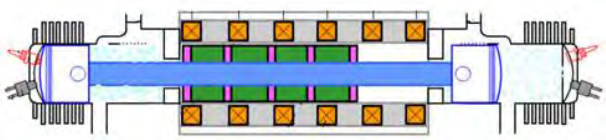

Fig. 6. Free-piston ICE with a linear generator.

The use of free-piston engines with linear generators in traction transmission of shunting locomotives with energy storages can significantly increase the overall efficiency of the system due to reducing mechanical and heat losses in the system that is a very promising direction for the development of domestic and world machine-building industry.

5. Conclusions

The paper analyzes the possible ways of increasing the energy efficiency of traction electric transmission of shunting diesel locomotives. It is determined that the most promising direction of developing locomotive engineering is the application of free-piston ICEs with linear generators as a source of electric energy on the locomotive. At the same time, the use of a system with energy storage devices allows not only more efficient operation of the rolling stock power plant but also the use of regenerative braking energy of the locomotive, which also increases the efficiency of locomotive transportation on railways.

References

[1] S. Yatsko, B. Sytnik, Y. Vashchenko, A. Sidorenko, B. Liubarskyi, I. Veretennikov, M. Glebova, “Comprehensive approach to modeling dynamic processes in the system of underground rail electric traction”, *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 9 (97), pp. 48–57, Feb. 2019.

[2] P. Chystiakov, O. Chornyi, B. Zhautikov, G. Sivyakova, “Remote control of electromechanical systems based on computer simulators”, *Proceedings of 2017 IEEE International Conference on modern electrical and energy systems(MEES-2017)*, Kremenchuk, M. Ostrohradskyi National University, pp. 364–367, 2017.

[3] B. Liubarskyi, A. Demydov, B. Yeritsyan, R. Nuriiev, and D. Iakunin, “Determining electrical losses of the traction drive of electric train based on a synchronous motor with excitation from permanent magnets,” *Eastern-European Journal of Enterprise Technologies*, vol. 2, no. 9 (92), pp. 29–39, Apr. 2018.

[4] S. Buriakovskyi, M. Babaiev, B. Liubarskyi, A. Maslii, N. Karpenko, D. Pomazan, A. Maslii, and I. Denys, “Quality assessment of control over the traction valve-inductor drive of a hybrid diesel locomotive,” *Eastern-European Journal of Enterprise Technologies*, vol. 1, no. 2 (91), pp. 68–75, Feb. 2018.

[5] A. Boretti, “The Future of the Internal Combustion Engine After ‘Diesel-Gate,’” *SAE Technical Paper Series*, Jul. 2017.

АНАЛІЗ ШЛЯХІВ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ ТЯГОВОЇ ЕЛЕКТРИЧНОЇ ПЕРЕДАЧІ МАНЕВРОВОГО ТЕПЛОВОЗУ

Сергій Буряковський, Артем Маслій, Данило Помазан, Олександр Ковальчук

Стаття присвячена проблемам підвищення енергоефективності тягової електричної передачі маневрового тепловоза. В умовах зростання вартості пального для збереження конкурентоспроможності залізничних перевезень досить гостро постає питання енергоефективності тягового рухомого складу, на який припадає близько 90 % загального споживання вуглеводнів залізницею. На сьогодні досліджено низку заходів з підвищення ефективності дизельних двигунів тепловозів, що дає змогу отримати приріст ККД на рівні 1–5 %. Застосування нових ефективних типів електромеханічних перетворювачів зі статичними перетворювачами, своєю чергою, також дає змогу знизити споживання паливно-мастильних матеріалів тепловозом. Проте вирішення питання енергоефективності тягової передачі тепловоза потребує комплексного підходу. Одним із таких підходів є застосування нових типів дизель-генераторних установок для тепловозів – вільнопоршневих двигунів внутрішнього згорання з лінійними генераторами. Застосування нових конструкцій теплових двигунів дає змогу значно розширити можливі межі підвищення ефективності тепловозної тяги.

Serhiy Buriakovskyi – D. Sc. (Eng), Professor, Director of Scientific Research and Design Institute “Molniya” National Technical University “Kharkiv Polytechnic Institute”, Kharkiv, Ukraine. Areas of research: advanced electric drives of railway automation systems, shunting locomotives with hybrid tractions.

Artem Maslii – Ph. D. (Eng), Ass. Prof., Department of Electroenergy, Electrical Equipment and Electromechanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. Areas of research: shunting locomotives with hybrid tractions, systems with energy storages.

Danylo Pomazan – Ph. D. student (Eng), Department of Electroenergy, Electrical Equipment and Electromechanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. Areas of research: shunting locomotives with hybrid tractions, internal combustion engines.

Oleksandr Kovalchuk – student, Department of Electroenergy, Electrical Equipment and Electromechanics, Ukrainian State University of Railway Transport, Kharkiv, Ukraine. Areas of research: shunting locomotives with hybrid tractions.