Application of regenerative braking on electric rolling stock

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Abstract. This article provides an overview of ways to improve the efficiency of regenerative braking on electric rolling stock. The advantages and disadvantages of this type of braking are considered. The requirements for the electric braking system are listed. Some analysis of the work of JSC Russian Railways on the implementation of the Energy Saving and Energy Efficiency Program is presented.

1. Introduction

Electrified railways in Russia are a large consumer of electricity. The approximate indicator of electricity consumption is about 5% of all electricity generated in Russia. One component of the totality of the specificity of the railway industry is continuous, relatively uniform work throughout the day, and due to the trend of constant growth in electricity tariffs, the issue of the relevance of energy conservation and energy efficiency is one of the key issues for Russian Railways Holding [1, 2]. As you know, the key railway company in our country and occupying one of the leading positions in the world is precisely Russian Railways. In the field of traction energy, the most significant way to save resources is to increase the efficiency of the use of electrical energy [3, 9].

2. Materials and methods

Improving the efficiency of regenerative braking is one of the most important tasks in the field of increasing the energy efficiency of the transportation process in railway transport. In the period from 2005 to 2015, the volume of recuperation on the national railway network almost doubled and reached the level of 2.0 billion $kW \cdot h$, thanks to the implementation of a whole range of technical and organizational measures (Figure 1). The choice of the assessment method, with the help of which the effectiveness of each of these measures is determined, seems to be relevant, since each of the known methods has certain disadvantages [4, 16, 17].
Figure 1. The volume of recuperation energy in OAO “Russian Railways” for the period 2003–2015.

3. Results and discussion
With regard to the electric rolling stock, equipped with a specialized system for the implementation of regenerative braking, this type of braking is defined as the process of converting the kinetic energy of train movement into electrical energy by means of traction electric motors (TEM) operating in the generator mode, with its subsequent return to the electrical network [18-21]. The amount of recovered energy depends on the mass of the train, the steepness of the slopes in the braking section, and the operating mode of the electric locomotive [5]. For example, in flat areas, energy savings can be about 10%, and in mountain areas, it can reach 25%.

The advantages of this type of electric braking are as follows:

− Reduction of wear of brake pads and wheels of electric rolling stock.
− Reduction of material costs for maintenance of the mechanical braking system.
− Increasing the maneuverability and flexibility of control, as well as the speed of movement on long slopes.
− Improving traffic safety, especially on lines with a mountain profile.
− The use of automatic regulation of braking modes (the greatest effect is observed in suburban traffic and at high-speed traffic).

There are a number of requirements for an electric braking system [6, 12, 13]:

− The presence of mechanical stability (if at a steady state of motion for any reason the speed changes, then the braking force should also automatically change);
− The presence of external electrical stability (the ability to restore stable electrical equilibrium as a result of any transient process arising from external influences);
− The presence of internal electrical stability (in the presence of parallel electric circuits of motors and a change in current for any reason in one of them, the entire system must come to an equilibrium of currents in these circuits);
− The ability to allow the smallest possible deviations of the currents of parallel electric circuits of motors with permissible differences in the diameters of the wheel rims and the magnetization characteristics of the traction motors [22];
− The presence of high energy performance and high operational reliability [23];
− The providing simple and convenient electric braking control.

The main disadvantages of electric braking are the implementation of the braking effect only by the moving axles of the locomotives, the complication of electrical equipment and the control system for
the operation of the power equipment of the electric rolling stock, and an increase in the heating temperature of the TEM windings [7]. Also, an obstacle to the use of recuperation energy in a larger volume can be malfunctions of electrical circuits, the presence of empty and lightweight cars in the head of the train (danger of squeezing out the cars) [11, 14, 15].

The main factors hindering the increase in the volume of recovered energy can be identified. These include:

- Cases of lack of receivers of recuperation energy.
- Insufficient use of the reserves of the technology of driving electric rolling stock.
- Lack of conditions for the use of recuperation in the traction power supply system.
- Imperfection in the organization of train traffic.
- Malfunctions in the recuperation system along the route.

In Table 2 provides information on the costs of JSC Russian Railways for electricity in 2017 and 2018, electricity consumption in physical and monetary terms. Figure 2 shows an increase in the level of recovery of energy recovery compared to the previous year [8-10].

**Table 1.** The costs of JSC Russian Railways for electricity in 2017 and 2018, electricity consumption in physical and monetary terms.

| Year | Spent on electricity billion rubles | Consumption  | Note                                                                 |
|------|-------------------------------------|--------------|----------------------------------------------------------------------|
| 2017 | 161                                 | 827.7 million kW·h of electricity for the amount of 2670.7 million rubles | An increase in the level of recovery of energy recovery by 10.3% compared to 2016 |
| 2018 | 172                                 | 511.5 million kW·h of electricity for the amount of 1.566.8 million rubles | An increase in the rate of recovery of energy recovery by 8.7% compared to 2017 |

![Figure 2. The energy efficiency of JSC “Russian Railways”](image-url)

Based on the analysis of all the information received, it is possible to identify the main ways to increase the volume of recuperation energy at electric rolling stock (Figure 3).
Figure 3. Methods for increasing the volume of recuperation energy.

4. Conclusion
Regenerative braking is one of the most important sources of energy savings on electrified railway sections. The use of regenerative braking allows you to save up to 30% of energy, which is spent on traction. That is why expanding the use of regenerative braking and increasing its efficiency is one of the main directions of technical measures to meet the specific consumption rates of fuel and energy resources, determined by JSC Russian Railways.

Many companies are interested in improving the efficiency of recuperation. Methods are being developed to make better use of the energy expended in braking.

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