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ANALYSIS OF CHARACTERISTICS OF ELECTRIC BRAKING SYSTEMS

The technical and energy characteristics of the most commonly used electrical braking systems are analyzed, their disadvantages are indicated. An electrical braking system with variable structure and DC motors with the best technical and energy performance is proposed. In the braking mode, the motors operate in series excitation, and the current in the excitation windings is controlled by a DC-DC converter.

Keywords: *electric motor, excitation windings, electrical braking, energy performance, high frequency converter.*

Formulation of the problem

The technical and energy efficiency of the electric braking system largely depends on its structure and method of braking, as well as on how braking energy is used. Most urban electric vehicles in Ukraine are equipped with a traction electric drive with DC motors with sequential excitation and outdated braking equipment. Therefore, the issues of improving the electric braking systems of urban electric rolling stock and increasing their technical and energy characteristics are very relevant.

Analysis of the latest achievements and publications

In the countries of the European Union considerable attention is paid to improving the technical and energy characteristics of vehicles.

In [1, 2], the technical and energy indicators of the traction electric drive of tram cars were improved due to the introduction of electrical equipment such as “TV Progress” based on a pulse converter from ALSTOM.

In [3], the consumption of electric energy in urban public transport systems was reduced by auditing their electrical system.

In [4], various concepts of traction drive in the Czech Republic and in the world are discussed and evaluated, the advantages and disadvantages of the new concept and the possibility of using outdated systems are considered.

The purpose and objective of research

The aim of the work is to increase the technical and energy characteristics of the electric braking system of urban electric rolling stock based on the analysis of the most common electric braking systems with DC motors.

The bulk of research

On electric rolling stock, a system of electric braking, in which electric motors are operated by direct-current generators of independent excitation, was widely used [5]. The excitation windings in this case are supplied from an adjustable voltage source that receives energy from the network, and the armature windings are shorted to the braking resistors (Fig. 1).

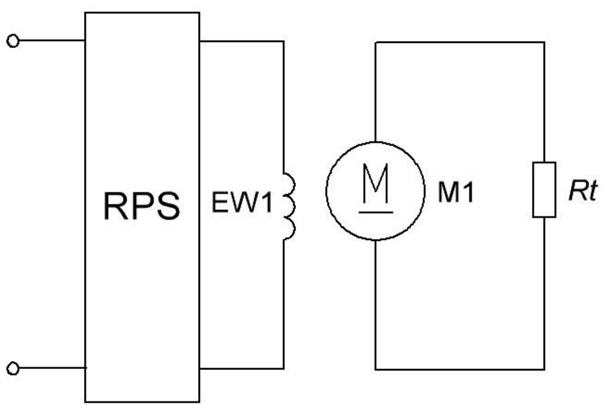

Fig. 1. Scheme of electrical braking during operation of the electric motor by an independent excitation generator

In such a system, a quick entry into the braking mode and smooth regulation of the braking force is provided, since the braking moment of the electric motor is proportional to its excitation current and the armature current. The electric braking system generates braking characteristics (Fig. 2), which is the dependence of the braking force on the speed of movement $B = f(V)$, with restrictions on the maximum excitation current, maximum armature current, commutation – $I \cdot V$, and wheel adhesion to rails. A characteristic limited by the maximum excitation current goes to the origin.

When working on extreme characteristics, the greatest efficiency of electric braking is ensured. However, for stopping braking it is convenient to use the adjusting characteristics with constant force (Fig. 2), since it is possible to set the deceleration of the electric rolling stock regardless of the speed of movement.

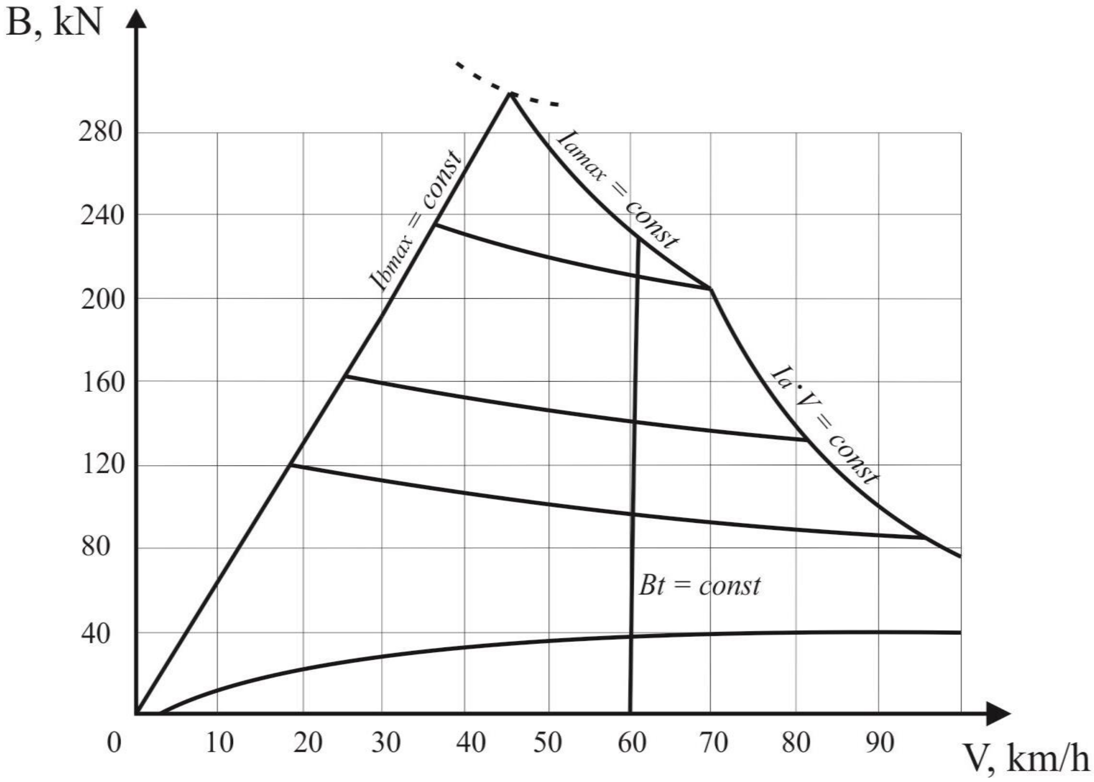

Fig. 2. Braking characteristics of the electric braking system during operation of the electric motor by an independent excitation generator

The disadvantages of such a braking system include the low braking efficiency at low speeds, since the resistance of the braking resistors is not regulated. It has low energy indicators - all braking energy is dissipated in the braking resistors in the form of heat, and electric power from the network is used to excite electric motors. In its absence, electrical braking is generally impossible.

An electric braking system is also used on an electrically rolling stock, in which electric motors operate with dc sequential excitation generators connected to an adjustable resistor (Fig. 3) [6].

The process of rheostatic braking in such a system without additional power to the field windings can begin only if there is a residual magnetic flux that induces an electromotive force proportional to the rotational speed of the traction motor. The duration of self-excitation can be approximately considered proportional to the square of the resistance of the braking resistor. To accelerate the first stage of self-excitation, it is possible to quickly output the rheostat stages or to increase the excitation of electric motors by connecting their field windings to a power source. However, there is a danger of the appearance of excessively high currents, braking force and voltage on the motors in the final stage of the process. This is because the braking torque is proportional to the square of the armature current. To slow down the process of self-excitation in the second stage, you can enter the delay switching stages. However, this will significantly increase the time required to achieve the required braking force when braking at a low initial speed.

The advantages of such a system include the lack of a constant power source for the excitation windings of electric motors. The disadvantages include the formation of characteristics (Fig. 4) that are more suitable for braking on gradients, slow self-excitation, especially at low speeds, the lack of smooth adjustment of the braking force, the dissipation of all braking energy on the braking resistors.

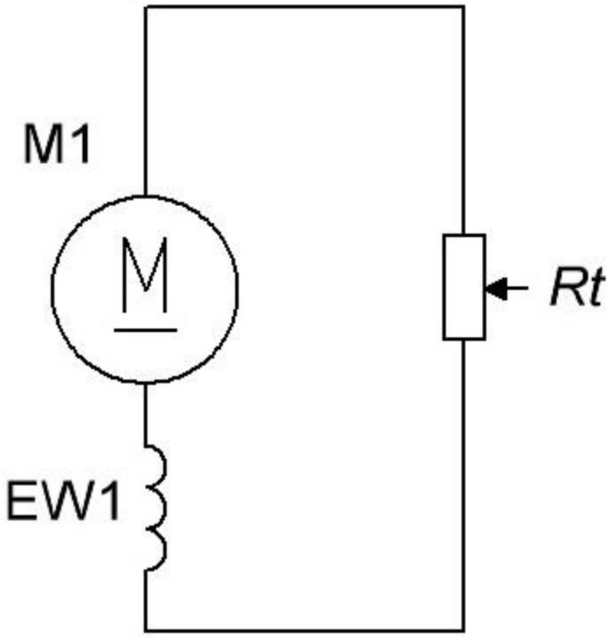

Fig. 3. Scheme of electrical braking during operation of the electric motor by a sequential excitation generator

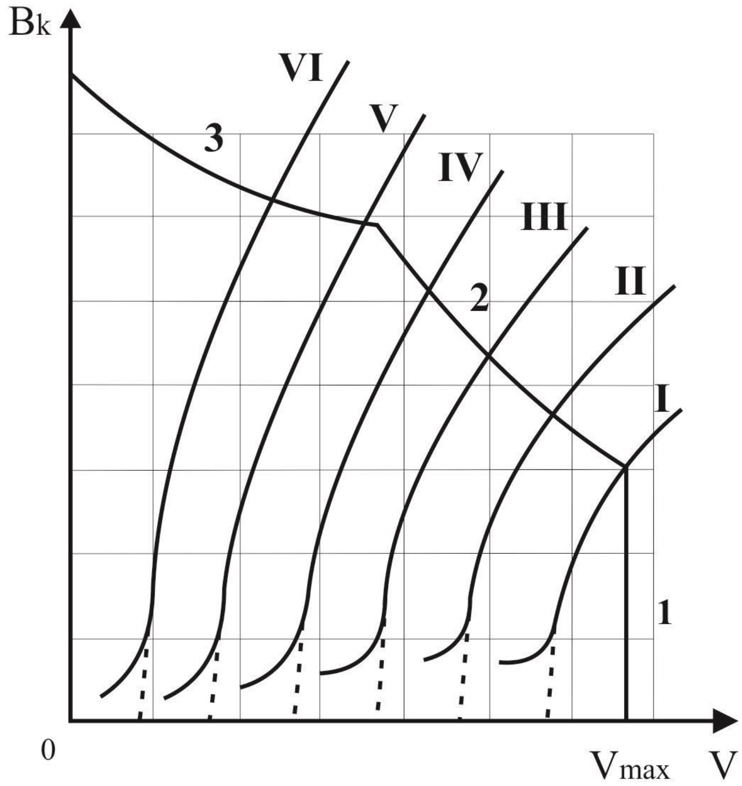

Fig. 4. Braking characteristics of the electric braking system during operation of the electric motor by a series excitation generator

On electric rolling stock, electrical braking systems with adjustable self-excitation are widely used [5]. In such systems, the excitation current of electric motors is regulated during braking using a pulse converter supplied from the armature winding (Fig. 5) or part of the braking resistor. The system generates braking characteristics in the high-speed region as with independent excitation of electric motors (Fig. 6), and in the low-velocity zone the braking region with wider independent excitation.

The disadvantages of a self-excited system include a decrease in braking efficiency at low speeds and the dissipation of all braking energy on braking resistors.

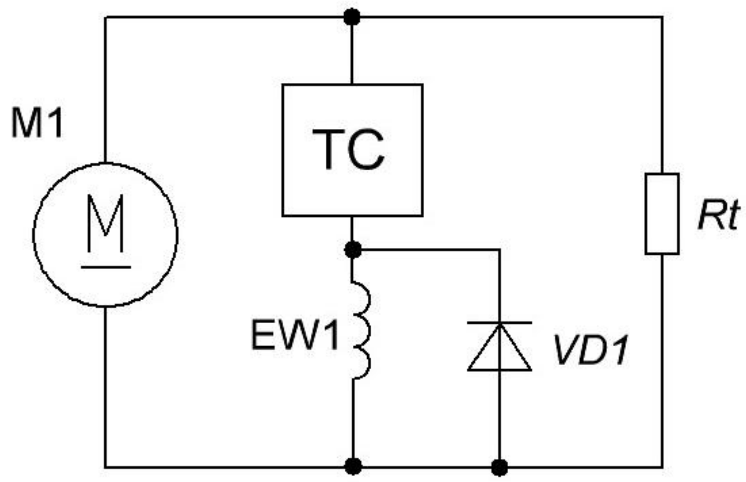

Fig. 5. Electric circuit of adjustable self-excitation of a traction motor

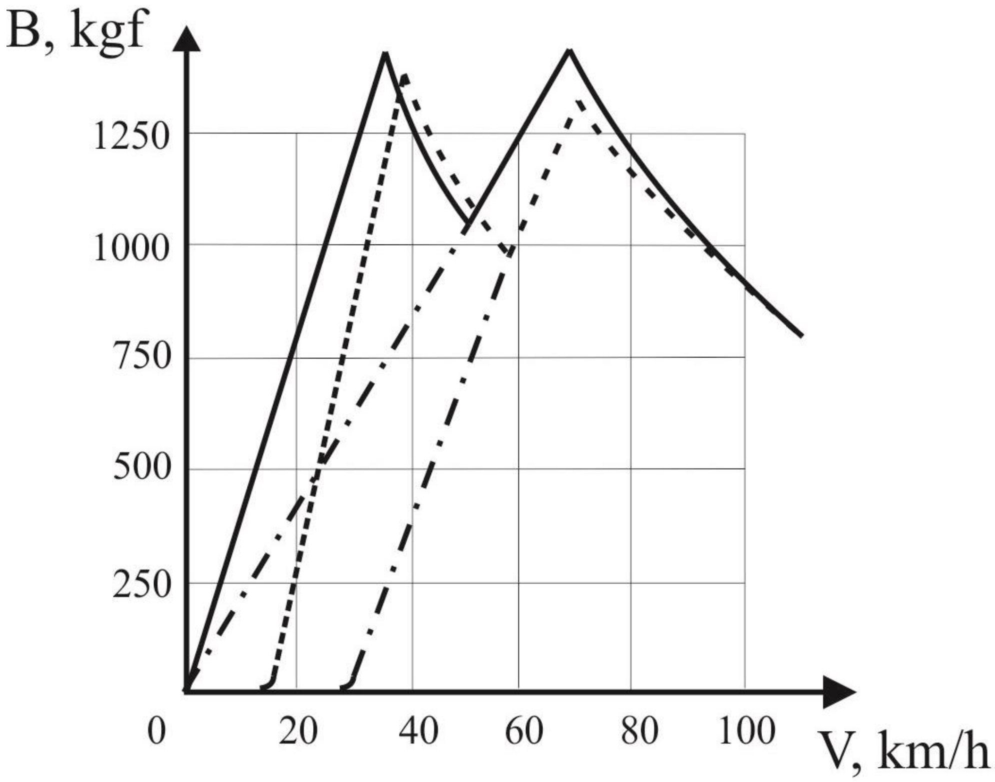

Fig. 6. Braking characteristics of electrical braking systems:
— when the electric motor is operated by an independent excitation generator;
--- with adjustable self-excitation of the traction motor

To increase the technical and energy efficiency of electric rolling stock, a variable structure electric braking system is proposed. Such a system provides a structure at the initial stage of braking, in which the electric motors operate with sequential excitation generators, and then the excitation current of the generators is automatically controlled using a DC-DC converter by shunting the motor excitation windings by the input of this converter [7] (Fig. 7). In this case, the energy taken from the field windings is transmitted through a DC-DC converter for own needs. At low speeds, when the excitation current is equal to the armature current, the resistance of the braking resistor gradually decreases due to shunting by a transistor operating in pulse-width modulation mode.

Thus, it provides an increase in braking efficiency in the low-speed zone and improves the energy performance of the traction electric drive.

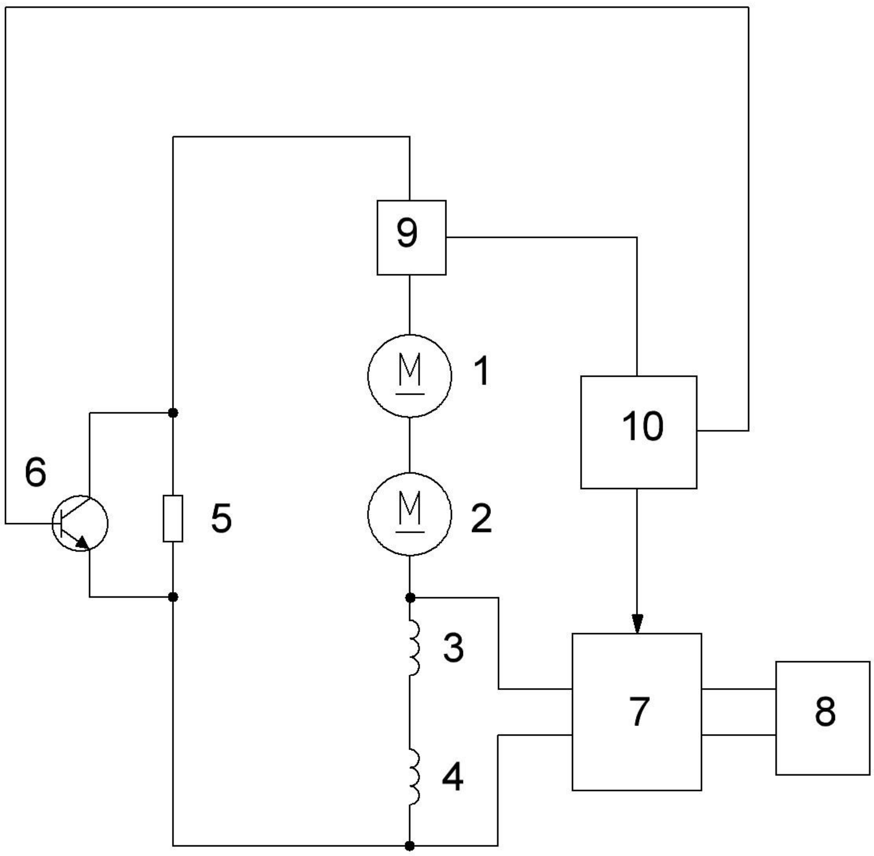

Fig. 7. Variable structure electrical braking system diagram

Conclusions

The paper analyzes the technical and energy characteristics of the most frequently used in practice systems of electrical braking, their disadvantages are indicated. A system of electric braking with a variable structure and DC motors with sequential excitation, which has the best technical and energy performance, is proposed.

Such a system provides a structure at the initial stage of braking, in which the electric motors operate with sequential excitation generators, and then the excitation current of the generators is automatically controlled using a DC-DC converter by shunting the drive excitation windings of the electric motors by the input of this converter.

The proposed electric braking system allows to improve the energy performance of the traction electric drive.

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АНАЛІЗ ХАРАКТЕРИСТИК СИСТЕМ ЕЛЕКТРИЧНОГО ГАЛЬМУВАННЯ ЕЛЕКТРОРУХОМОГО СКЛАДУ

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Тягові електроприводи з двигунами постійного струму послідовного збудження знайшли широке застосування на наземному міському електричному транспорті. Традиційно електропривод регулюється пусковим реостатом з використанням перемикання угруповань двигунів. При електричному гальмуванні тягові двигуни переводяться в генераторний режим і їх момент реалізується у вигляді гальмівної сили на ободі рухомого колеса. Перевагами електричного гальмування в порівнянні з механічним є можливість забезпечення сталого режиму гальмування, відсутність нагріву бандажів і колодок, висока надійність процесу гальмування, зниження експлуатаційних витрат на гальмівну систему. Як правило, на електрорухомому складі використовують комбіноване гальмування – рекуперативно-реостатне. Однак, реостатно-контакторне регулювання функціонально погано відповідає вимогам частих пусків та зупинок транспортного засобу. Значні втрати енергії в реостатах підвищують знос контактних груп.

У роботі проведено аналіз технічних та енергетичних характеристик найбільш часто використовуваних на практиці систем електричного гальмування, вказано їх недоліки. Запропоновано систему електричного гальмування зі змінною структурою та двигунами постійного струму послідовного збудження, яка має кращі технічні та енергетичні показники.

Метою роботи є підвищення технічних й енергетичних характеристик системи електричного гальмування міського електрорухомого складу на основі результатів аналізу найбільш поширених систем електричного гальмування з двигунами постійного струму.

Така система забезпечує структуру на початковій стадії гальмування, при якій електродвигуни працюють генераторами послідовного збудження, а потім відбувається автоматичне регулювання струму збудження генераторів за допомогою DC-DC перетворювача шляхом шунтування входом цього перетворювача обмоток збудження електродвигунів.

Запропонована система електричного гальмування дозволяє покращити енергетичні показники тягового електроприводу.

Ключові слова: *електродвигун, обмотки збудження, електричне гальмування, енергетичні показники, високочастотний перетворювач.*