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CONNECTION DESIGN AND PERFORMANCE CHARACTERISTICS OF TRACTION ELECTRICAL COMPLEXES UNDER MULTIPLE UNIT CONSTRAINED CONTROL

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The results of analysis of traction coordinates varying of four-motor traction electrical complex of mine electric locomotive under multiple unit control are presented. The estimation of reliability of operation mode of electric locomotive based on the computer modelling results is made. The possible connection schemes of traction motors under multiple unit train control are analyzed. The constrains imposed for the pulse control of operation modes of traction motors are grounded with permissible operating conditions of indoor mine transport factored in. The calculated characteristic of the DTN-45/27 traction motor with its operation modes taking into account is recommended for practical use.

Key words: electrical complex, multiple unit control, electric motor characteristic.

СТРУКТУРА З’ЄДНАННЯ ТА ХАРАКТЕРИСТИКИ ФУНКЦІОНУВАННЯ ТЯГОВИХ ЕЛЕКТРОТЕХНІЧНИХ КОМПЛЕКСІВ ПРИ КЕРУВАННІ ЗА СИСТЕМОЮ БАГАТЬОХ ОДИНИЦЬ З УРАХУВАННЯМ ОБМЕЖЕНЬ

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Приведено результати аналізу зміни тягових координат чотирьохдвигунного тягового електротехнічного комплексу рудникового електровозу при керуванні за системою багатьох одиниць. На основі даних комп’ютерного моделювання дана оцінка надійності режимів функціонування електровозоскладу. Проаналізовано варіанти з’єднання тягових електричних двигунів у складі мультиелементної системи управління. Обґрунтовано обмеження, які накладаються при імпульсному регулюванні режимів роботи тягових електричних двигунів з урахуванням допустимих режимів роботи внутрішньошахтового транспорту. Рекомендовано до застосування розрахункову характеристику тягового електричного двигуна ДТН–45/27 з урахуванням режимів функціонування.

Ключові слова: електротехнічний комплекс, система багатьох одиниць, характеристика електричного двигуна.

PROBLEM STATEMENT. Industrial transport at mining development enterprises is one of the directions where further productive efficiency enhancement is available and results in the product cost cutting at the ore mining and smelting enterprises, which are the main source of currency reserves replenishment of the country.

The productivity can be enhanced via implementation of versatile systems of traction electrical complexes (hereafter TEC) of an electric locomotive based on IGBT power supply converters for electric traction motors.

The analysis of productive efficiency enhancement factors of electric transport at enterprises of iron-ore plant of Kryvyi Rig as a typical modern mineral underground mining development enterprise reveals the feasibility of solution of the problem of power supply with simultaneous increasing of adhesive weight through the multi-element system control application for electric locomotives of standard sizes existing with a train-end positioning of the elements of multi-element system.

Such solution implementation allows for locomotive product efficiency enhancement by 50…60 % and additional energy saving by 30…35 % per trip. What is important to notice is that principle of multiple unit locomotive control is only well-known as a system but its advanced design development and investigation of electrical and magnetic processes in such a complex type of multi-motor TEC are the vital problems to be studied in a scientifically brand-new ways.

EXPERIMENTAL PART AND RESULTS OBTAINED. The previous research results indicates that unapproved voltage interruption on some traction units causes the most effects on traction coordinates of an electric locomotive equipped with IGBT-converter, which is typical for multiple unit train control system [1].

Structurally, the multiple unit train control comprises two traction electrical complexes (TEC1, TEC2 in Fig. 1).

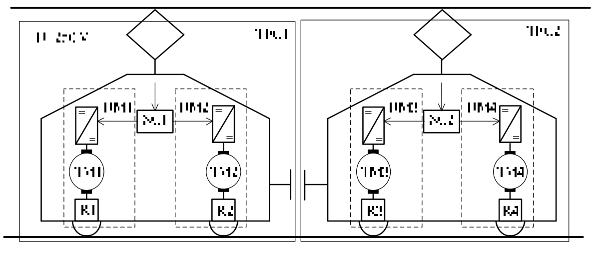

Figure 1 – Structure of traction electric complex of industrial (two-axial) electric locomotives under multiple unit system control

In its turn, each TEC consists of two traction electric modules (TEM–1, 2 and TEM–3, 4), each of them comprises an independent voltage converter (UM1–UM4), common control system shared by all modules (SC1–SC2), and four traction electric motors (TM1–TM4). Each electromotive wheelset is driven by its own traction motors (hereafter TM) through the corresponding independent transmission (R1–R4).

The research series of computer modelling performed aimed the analysis of traction coordinates of four-motor traction electrical complex of electrical locomotive when multiple unit train control is applied and for the cases of local supply failure or erratic supply voltage (with no commands from the control system) on terminals of some TMs.

The computer model of traction electrical complex is shown in Fig. 2.

The computer modelling was performed under the following assumptions made:

– increase of the train speed is linear and smooth and is varying directly as motor speed;

– the train mass remains constant during the observation time;

– TM parameters remain constant during the observation time;

– initial value of TM power supply is *U=0*;

– the parameters of TM and TEM are unaltered from the load level.

The control parameters were electromagnetic torque (*M*), current (*i*), TM's motor speed (*ω*), and flux (*Φ*).

Wheel-rail adhesion coefficient was taking as a constant according to standard recommendations. The electromotive speed rate (V_{EM}) was calculated as a function of motor speed of traction motors operating (w_M), wheel diameter (d_{wheel}), and gear reduction ratio (i_{red}) according to the formula:

$$V_{sost} = p d_{kol} \frac{\omega_{dv}}{i_{red}}.$$

The electric locomotive travelling was analyzing from starting-up to speed.

The performed modelling of all the possible situations revealed that the operating mode with only one TM running (three others are off) correlates to the lowest operational reliability of TEC.

This leads to slowing down of electric locomotive speed nearly in twice, and the TM torque, which is still operating, bursts up to the value of approximately $\approx 4M_{nom}$, when current is almost twofold of the reference one. Alongside this, the supply voltage refreshing on TM–2–TM–4 results in surging of torque, current and flux, and, as a consequence, effects on some traction electrical units and the whole complex [2].

For the first sight, the research results synthesis testify the feasibility of start-up of electric locomotives under multiple unit control with TEC structure with traction motors jointed in series at each electric locomotive. Herewith, the traction locomotives have equal currents providing equal load distribution. However, series connection of TMs elevates the risk and intensity of wheel slipping, which is behavioral for underground traction.

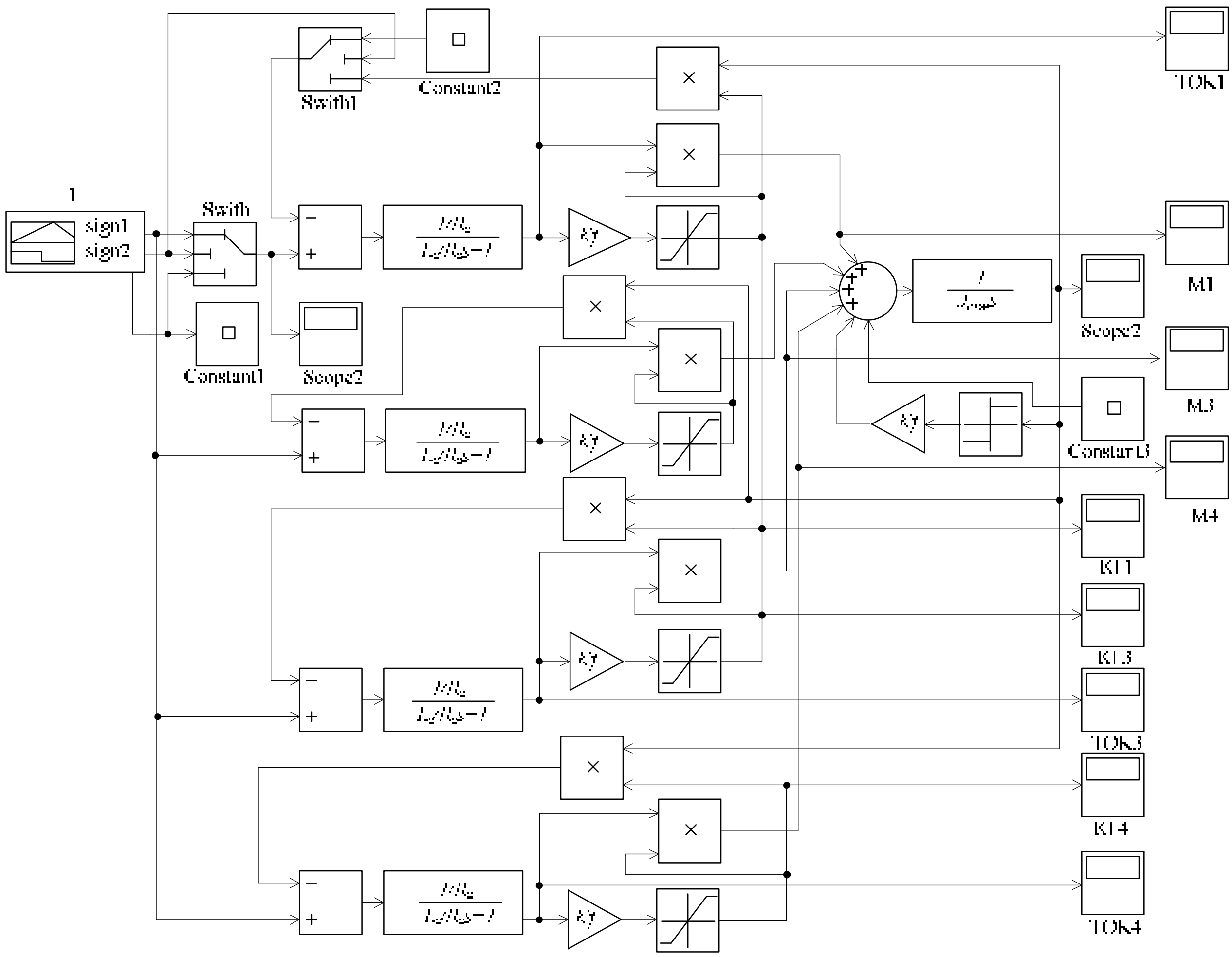

Figure 2 – Computer model of traction electrical complex

In such a case, the motor is jointed to the wage wheels slipping and rotates more rapidly than others, which results in voltage increase on this motor and voltage reduction on those ones connected in series. Also, the total traction force decreases causing the differential slipping at the velocities and voltages unsafe for the traction motor jointed to the wage wheels slipping.

Therefore, parallel jointing-up of motors should be the advantageous one, as in which case each TM voltage does not depend on other traction units operation. Also, the maximum traction effort of the electric locomotive is performing and the risk and intensity of slipping descends.

The pulse control of TM operation allows for obtaining a lot of performance characteristics. The problem of determination of area of probable characteristics, which is constrained by operational modes, emerges. The constrictions are defined by:

– maximal traction effort;
– maximal travelling speed,
– traction motor curve,
– maximum electrical power.

The first factor mentioned above depends on the conditions of wheel-rail adhesion. Regarding to the investigation of Professor A.A. Renhevich, the adhesion coefficient for iron-ore pit environment is within the range from 0.21 to 0.25. Taking into account the low travelling speed of underground transport, the correlation between adhesion coefficient and speed could be ignored. Thus, maximum traction effort of electric locomotives of K–14 type is following:

$$F_{max} = 1000 P\psi = 1000 \cdot 14 \cdot 0.25 = 3500 \text{ kN},$$

or 1750 kN per motor.

It can be seen from the electromechanical curve of DTN-45/27 traction motor that it corresponds to the current 260 A (E point in Fig. 3). It ought to be noted that the type of electric locomotive and motor was selected with the indoor mining transport park available taking into account, where these types of equipment are preferable.

The maximum speed of an electrical locomotive must not exceed the maximum permissible one, which is equal to 20 km/h according to the haulage roadways travelling speed safety regulations for empty train set (A–B line).

The artificial characteristics of motor during the voltage control cannot exceed the natural ones, as pulse converter output voltage cannot exceed nominal voltage, and the field reduction of mining trolley locomotives is not in practice. Therefore, the TM electromechanical curve is a boundary limit for series of artificial characteristics in the area with no other constraints (B-C curve).

In order to reduce the load of traction power supply system and enhance the reliability of traction motors, it is rational to set the maximum electrical power limit equal to the motor nominal performance per hour. It implies that speed is slowing down below the natural characteristics, when current is more than average value per hour. When current increasing from $I_{nom.h}$ to

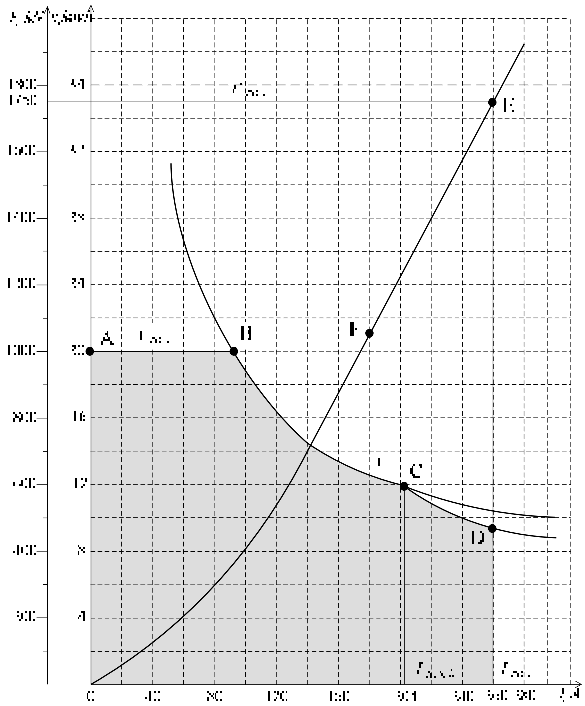

Figure 3 – Recommended calculated characteristics of the DTN–45/27 traction motor with operation modes constraints factored in

I_{max} (204…260 A), to maintain the same power of 45 kW the speed should be reduced from 12.2 km/h to 9.75 km/h (D point).

CONCLUSIONS. The main type of electric motors connection in a traction electrical complex under multiple unit control is assumed to be the parallel connection.

The operation modes should be constrained by the area between ABCDE points: AB – by speed; BC – by natural characteristics; CD – by performance; DE – by adhesion. Usy of the limitations workable for the control system allows for the reliability significant improvement of traction motors due to elimination of differential velocities, inadmissible motor shaft torques, maximum current and power. Also, this providing the diminishing of power transmissions damage, improving the travelling dynamics and loading of traction power supply system.

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СТРУКТУРА СОЕДИНЕНИЯ И ХАРАКТЕРИСТИКИ ФУНКЦИОНИРОВАНИЯ ТЯГОВЫХ ЭЛЕКТРОТЕХНИЧЕСКИХ КОМПЛЕКСОВ ПРИ УПРАВЛЕНИИ ПО СИСТЕМЕ МНОГИХ ЕДИНИЦ С УЧЕТОМ ОГРАНИЧЕНИЙ

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Приведены результаты анализа изменения тяговых координат четырёхдвигательного тягового электротехнического комплекса рудничного электровоза при управлении по системе многих единиц. На основании данных компьютерного моделирования дана оценка надежности режимов функционирования электровозосостава. Проанализированы варианты соединения тяговых электрических двигателей в составе мультиэлементной системы управления. Обоснованы ограничения, накладываемые при импульсном регулировании режимов работы тяговых электрических двигателей, с учётом допустимых режимов работы внутришахтного транспорта. Рекомендована к использованию расчётная характеристика тягового электрического двигателя ДТН–45/27 с учётом режимов функционирования.

Ключевые слова: электротехнический комплекс, система многих единиц, характеристика электрического двигателя.

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