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MODES AND PARAMETERS OF FUNCTIONING OF TRACTION ELECTROMECHANICAL COMPLEXES MINER CONTACT ELECTRIC IN IRON MINES

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Purpose. Development of control algorithm electromechanical traction with complex traffic management automation mine electric locomotives in the iron mines. **Methodology.** Analytical research, analysis, synthesis, experimental research. **Findings.** The electrical parameters and modes of operation of the traction systems in underground mines of the same type are different and never the same. It was found that this discrepancy is due to the influence of traction on complex modes of operation of a number of technological and technical factors peculiar conditions of iron ore mines. It was established that operated contactor-resistor control systems are outdated and in terms of functionality it is not possible to optimize to the required level of operating parameters of traction systems mine electric locomotives, and most importantly can not serve as a basis for traffic management system in the mine. It is recommended to use the research findings in design of development of control algorithm modern mine electric locomotives with the prospect of traction control automation complexes. **Originality**. A composite control algorithm can be used to implement complex control law electromechanical electric traction mine. **Practical value**. An algorithm for the implementation of effective control of complex electro-mechanical traction is described. **Conclusions.** More than 60% of the time is spent on loading and unloading. The level of energy losses in these modes is up to 50%. To improve the efficiency of electric traction in underground mines it is necessary to create and implement a set of smooth start-braking. Efficiency start and stop the electric traction is determined by the control system and the level of implementation of the control algorithm.

Key words: traction electromechanical systems, electric traction, electrical parameters, energy, control.

РЕЖИМИ ТА ПАРАМЕТРИ ФУНКЦІОНУВАННЯ ТЯГОВИХ ЕЛЕКТРОМЕХАНІЧНИХ КОМПЛЕКСІВ РУДНИКОВИХ КОНТАКТНИХ ЕЛЕКТРОВОЗІВ В ЗАЛІЗОРУДНИХ ШАХТАХ

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Наведено результати досліджень режимів функціонування рудничних контактних електровозів і їх тягових електромеханічних комплексів в вітчизняних залізорудних шахтах. Показано, що електричні режими і параметри функціонування тягових комплексів в однотипних підземних виробках різняться і ніколи не повторюються. Встановлено, що така невідповідність є наслідком впливу на режими функціонування тягових комплексів ряду технологічних і технічних факторів, властивих умовам залізорудних шахт. Встановлено, що експлуатуються контакторно-резисторні системи управління, які морально застаріли і за своїми функціональними можливостями не дозволяють оптимізувати до необхідного рівня параметри функціонування тягових комплексів рудничних електровозів, а головне не можуть служити базою для будови систем управління внутрішньошахтного транспорту. Рекомендовано використовувати результати досліджень при конструюванні алгоритму управління при розробці сучасних рудничних електровозів з перспективою автоматизації управління тяговими комплексами.

Ключові слова: тягові електромеханічні системи, рудничний електровоз, електричні параметри, енергія, управління.

PROBLEM STATEMENT. Ukraine is among the countries in the sustainable development of natural resources [1]. Since May 2013 Ukraine ranked fourth worldwide in terms of iron ore exports [2]. Experts predict that in the next 15-20 years underground or combined method of extraction of iron ore will be actively developed.

Since 2001 iron ore production at the mining enterprises has increased. In 2015, the performance of iron ore mines amounted to only 61 % from the level in 1982 [2]. This negative indicator influences not only the specific iron ore businesses, but also the economy of Ukraine. Due to a number of objective reasons, iron ore production costs are constantly increasing [2]. This complicates the competition of iron ore enterprises of Ukraine in the world market of raw materials. Research cost structure ore mining enterprises showed that 20% of the cost amount is spent on transportation from the place of production to raise to the surface [3].

The main form of transport of iron ore raw materials and mine workers – is electric traction K10 and K14. They consume about 12 % of electricity compared with other consumers of iron ore mines [3, 4]. To analyze the state of operation of the mine transport and improve its performance one need to conduct additional studies. Studies conducted in 80 of the last century are outdated.

Key indicators of the functioning of transport mines that need to be improved are the following:

– safety of operation;
– productivity;

– energy efficiency;

– security and reliability.

These indicators can be improved by creating an automated control system electric locomotives [5, 6]. This question is not new. Development of the automated control systems were carried out in the 70–80 of the last century [7]. Methods of constructing circuits control systems depended on the conditions of the enterprise. But the results of scientific publications have not been implemented in practice due to the fact that the research and development carried out on existing electric traction rather than looking for the circuit design. The development of effective tractive electromechanical assembly should be carried out taking into account the specifics of the enterprise, the analysis and evaluation of the operation modes.

Therefore an important task – analysis of electric modes of operation, the development of control algorithm electromechanical traction with complex traffic management automation mine electric locomotives in the iron mines is to be done.

EXPERIMENTAL PART AND RESULTS OBTAINED. Currently operating in the domestic mining electric locomotives do not meet the requirements of the rules of operation.

In Ukraine and the CIS countries in the last decade promising experimental samples of mine electric locomotives with energy efficient pulse voltage level control systems for traction electric motors [6–8] have been created and tested. But the timing of the serial production is not determined because of a number of unsolved problems. They include such a task: it is necessary to adapt the power control algorithm to the specific conditions of electric shafts. An important point in these matters is to take into account dynamic processes in the electrical complex, since they affect the level of quality of electric motion control [9, 10].

Analysis of electric modes of operation being conducted, the development of control algorithm electromechanical traction with complex traffic management automation mine electric locomotives in the iron mines has been done.

The movement of electric locomotive transport in the subsurface horizons of iron ore mines is composed of four types of operations: loading trolleys, motion electric miner to the court, the composition of unloading, empty locomotive in the mining sector. In the analysis of the load operation modes of traction motors ore loading and unloading in mine locomotive courtyard and movement of loaded and empty structure, are considered together. Figure 1 shows the waveform of consumed current electric locomotive K14, Fig. 2 shows the average parameters of the operation and the voltage level on the current collector of an electric locomotive when driving in a mine.

From Fig. 2–3 it follows that the modes and settings of the traction electrical systems in the iron ore mines vary throughout the journey and change. Modes of operation of electric locomotives in places of loading and unloading of iron ore are particularly changing [3, 5, 11].

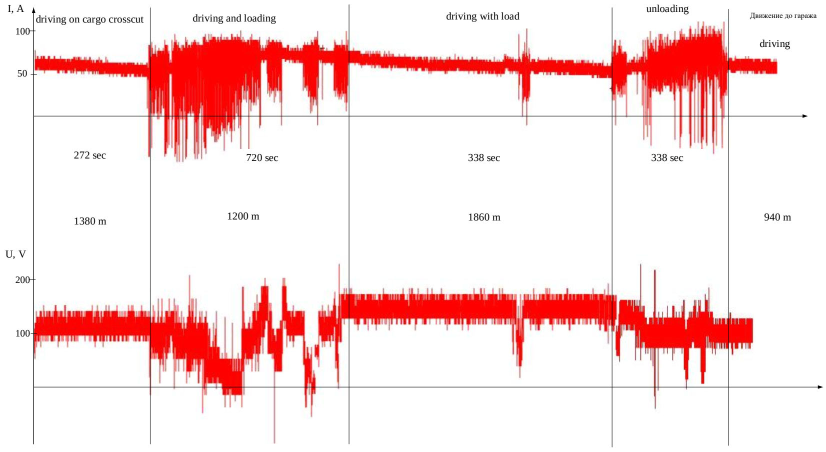
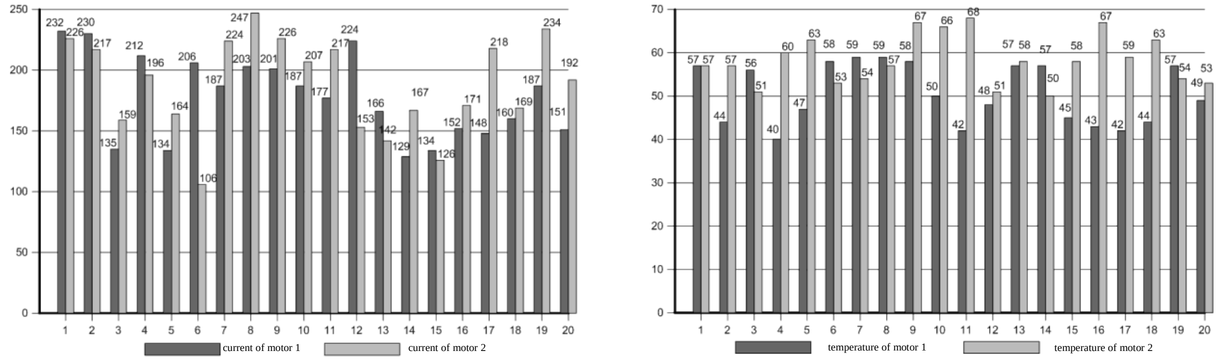
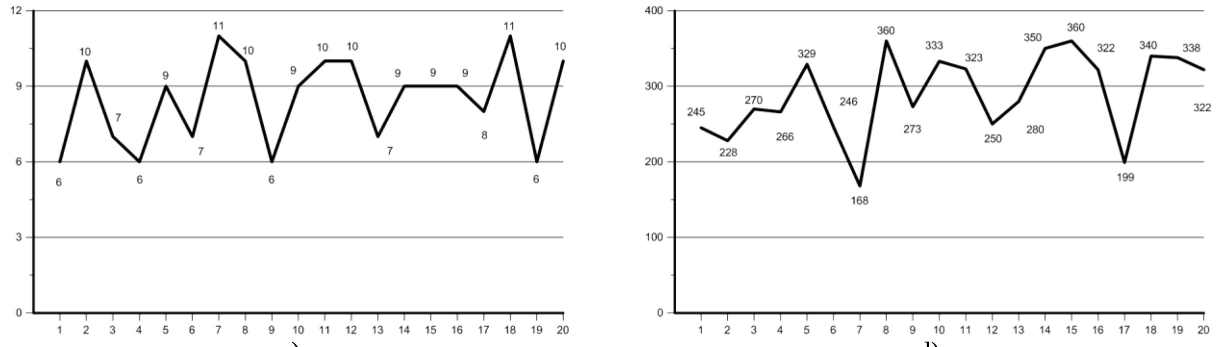


Figure 1 – Current and voltage diagram of traction electric motors electric K14 during the flight when driving electric traction with 7 loaded trolleys (horizon 1320 meters mine «Rodina», Kryvyi Rig)

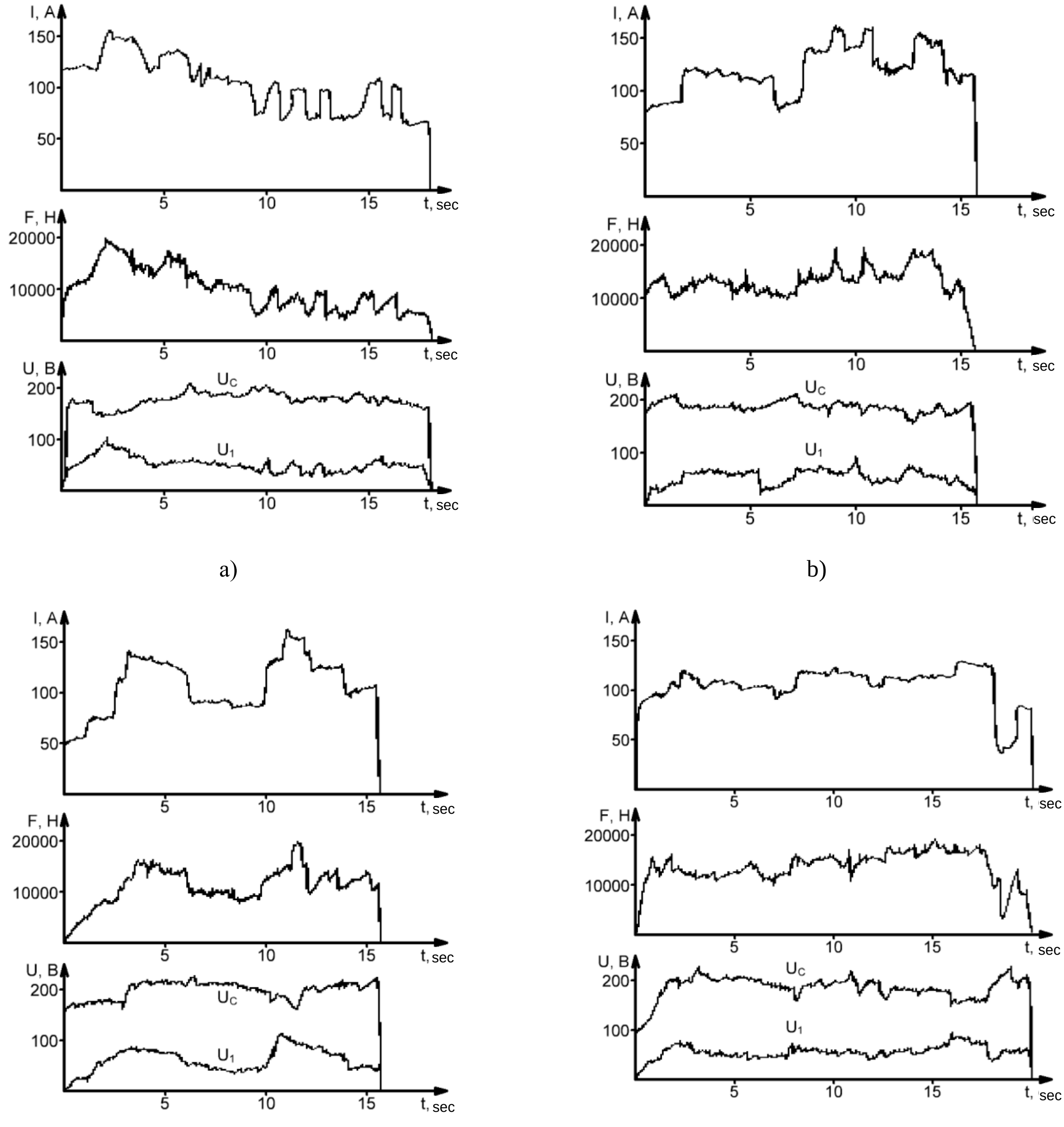


a) b)



c) d)

Figure 2 – Functioning parameters during one shift 8 contact electric traction K14 when driving on cargo crosscut 1320 meters mine «Rodina»:
a) current traction motors; b) the temperature of traction motors; c) speed locomotive; d) voltage catenary



a) b)

c) d)

Figure 3 – Load diagrams of complex electromechanical traction electric K10 at work in horizontal underground mine workings «Gvardeyscaya» (horizon 1510 m). Filing trolley at the door when:
а) Q=52 t; б) Q=62 t; в) Q=52 t; г) Q=92 t

Fig. 4 shows the traction motors of change of current waveform, traction on the electric coupling, the supply voltage and the voltage at the terminals of the first traction motor during loading and unloading of trolleys. Handling is a permutation of trolleys at the door and moving locomotive in mines. Condition of rails in mines is poor, they are poured with ore when driving. This creates a resistance to the movement of an electric locomotive. Figure 4 shows, the same load in different graphics operations.

To move an electric locomotive under the hatch one need 5 kW. This is ten times less than the power of the engine DTN-45/27 – 45 kW. The graph shows that this power is used occasionally when loading locomotive.

Maximum current in the chart indicates that the driver improperly changed the electric switching speed rheostat. Figure 4 shows the acceleration of an electric diagram and controller status. In the first position at the current 52–60 A motor torque is not enough to budge the composition. In an effort to lift 3000 N happens the entire system. In the transition to the second position there is a barely noticeable movement of trolley.

In the transition to the third and fourth position of the controller with the current 150–160 A motor torque is sufficient to move the composition at a rate of 0,2–0,3 m/s. The engine is running in transient mode with position rheostat pointed change in current. Together with the low speed of electric heat processes deteriorate. It passes the electric power consumption in heavy conditions due to the heat of traction motors. Developing the capacity of 4-5 kW at a voltage of 30 V at the terminals of motor (Fig. 4) it is possible only when the current is 140-160 A.

During the loading on the site and supply of trolleys in the dumper engine there is small power and high torque. Rapid changes in the current impact on the rapid changing of the insulation. They lead to an increase in specific loss $\Delta P = I^2 R$. These losses are spent on heating of the motor when it is operating in that mode is similar to the electric motor short-circuit.

When loading ore in the electric voltage in the contact system varies within 170-200 V. This indicates increased resistance of contact network and the distance from the traction substation. Traction motor voltage is 30-60 V, is due to the low speed of movement – of about 1 m/s. When unloading the electric voltage in the contact system is changed in smaller ranges: 230-250 V due to the proximity of traction substation. Traction motors voltage varies within 30-50 due to less resistance movement. Actual fluctuations along the traction network are within 168-360 V (Fig. 3).

These stress ratio in the contact system and traction motors with rheostat control means that most of the consumed electric locomotive power and energy is lost in the ballasts resistors: for loading work about 75 % at discharge – about 80 %, and only 20–25 % is consumed in traction motors. When contact haulage electricity average specific consumption is lower than when using a rechargeable electric types [3]. But it is significant and is 120 W·h/t·km.

Therefore, to reduce the disadvantages of mine electric locomotives one can replace contact-resistor traction electromechanical direct current systems to asynchronous motors with frequency converters [5, 6].

This will:

– increase the efficiency of the traction electric electromechanical systems by eliminating power losses in the start-regulating rheostat;

– reduce the inrush current and traction, which significantly reduce wheel slip during start-up, which is particularly important when loading and unloading;

– modulate significantly reduced maximum currents and the driving forces that increase the reliability of electrical and mechanical equipment.

To increase the efficiency of the electric locomotive one can use the automatic control system. It must have adaptive properties to perform all functions.

Architecture building traction diagrams are described in several papers [3, 6]. Their main feature – is straightness of motion parameters. It is not typical for mine electric locomotives mines due to the specific movements and the presence of coupling devices between the electric elements. This affects the nature of dynamic processes.

They should be offered traction diagrams $F(t)$ and speed mine $V(t)$ locomotive taking into account the characteristics of the coupling devices. These diagrams have the form shown in Fig. 4. The movement cycle consists of a series of time intervals: t_1 and t_5 – selecting the elastic strain in the coupling devices in the early start-up and braking with the changing efforts; t_2 and t_6 – the start-up and braking with a constant force; t_3 – time steady uniform motion; t_4 – stopping time, $F = 0$.

Traction chart at time intervals t_1 and t_5 show features the beginning of start-up and braking – it's time to choose backlashes and elastic deformations in the coupling devices, coupling begins to transmit the force only when it is tighten. The change in traction and electric braking force occurs stages – first starts to move the first trolley, then the second and so on, the number of stages equals to the number of trolleys (in this case 8). When the latter starts moving trolley, the entire composition, tractive effort reaches its maximum at the start $F_П$ and dispersal occurs at a preset rate. Of course, that this "step" deceleration-start and should be different from one another in both time and effort on.

Similarly, there is the braking process – the first trolley is braked first, then the second and so on, the braking force F_T reaches its maximum value when the last trolley roll and pressed against the composition of dynamic force. These processes are usually accompanied by blows. Time selection backlashes and elastic deformations t_1 and t_5 slightly increases the total time of braking start and the composition that must be considered in the calculation of traction, particularly when calculating the braking distance.

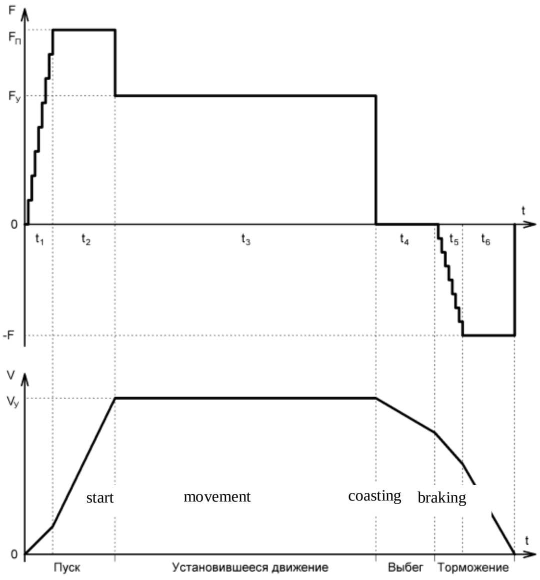


Figure 4 – Chart traction and mining locomotive speed, taking into account the characteristics of coupling devices

Upon reaching the desired speed locomotive driver or automatic control system reduces the traction on the value of dynamic force F_g, acceleration stops and composition over time t_3. It moves at a constant steady speed V_y and a pull F_y.

In areas t1 and t5 increase in effort must take place in a set of exponential curves to select the gap in electric hitch. The increase must take place smoothly, without jerks.

$$F(t)=\begin{cases} \left\lfloor \dfrac{t}{t_1}\cdot n_1 \right\rfloor, & if\ 0\le t\le t_1, \\ \left\lfloor \dfrac{t-t_1}{t_2-t_1} \right\rfloor \cdot \dfrac{F_{n2}-F_{n1}}{n_2}, & if\ t_1\le t\le t_2, \\ F_n & if\ t_2\le t\le t_3, \\ F_n - F_{\partial}, & if\ t_3\le t\le t_4, \\ 0, & if\ t_4\le t\le t_5, \\ -\left\lfloor \dfrac{t-t_4}{t_5-t_4}\cdot n_2 \right\rfloor \cdot \dfrac{F_T}{n_2}, & if\ t_5\le t\le t_6, \\ -F_T & if\ t\ge t_6, \end{cases}$$

$$F = F_1(n-1)t + \sum_{n=1}^{N} F_1 e^{-\frac{t-nt_1}{T}},$$

where F_l – tractive effort one step; N – total number of steps; n – the current number of steps.

Under normal driving conditions to stop the composition typically provide the stick – the time interval t4 in Fig. 5, in order to slow down due to the natural forces of the resistance movement. Then, for the full stop is activated electric or mechanical braking system and structure in the time interval t6 is braked with a braking force FT. As at the start, due to the gaps and the elastic elements in the coupling devices, the braking force increases in steps, accompanied by blows to the coupling devices and directly into the buffers. The greatest power strokes occur when braking maximum tensile structure, immediately after the traction mode, which is typical for emergency braking.

To mitigate the impacts clearances in kinematic links of the coupling devices is expedient to take place with lower accelerations, then the acceleration values can increase to allowable values. The maximum acceleration value during starting and braking decelerations should be limited by the terms of coupling wheels with the rails, in order to avoid slippage.

In drawing up the base algorithm controlling driving complex mine electric contact these factors were taken into account, used piecewise linear approximation acting traction F (t) depending on the functioning of the segment at a particular stage of an electric route.

Composed algorithm can be taken as a preventive for implementing electromechanical complex mine locomotive control law. However, to complete its structure in order to develop on its basis electromechanical complex mine locomotive management program, you need a number of additional studies on modeling the behavior of complex real traction possible situations electric locomotive functioning in conditions of iron-ore mines.

CONCLUSIONS. 1. Operated in iron ore mines miner electric locomotives do not meet modern requirements of mining enterprises. This is evident:

– a high level of electric power losses, especially during handling operations where electric operating more than 60 % of their working time, and where losses of starting-regulating rheostat reach 50 %;

– in the event of surge current and voltage, which is a cause of unwanted vibrations in the locomotive.

2. To improve the efficiency of electric locomotives in underground mines we need to create and implement a set of smooth start-braking.

3. For the implementation of the start-up process of the traction-braking electromechanical complex mine locomotive should be the creation of an algorithm of construction and the level of adaptability depending on the control law.

4. Efficiency of starting and stopping electric algorithm will be determined by management and the level of its implementation. This can make the microprocessor control system with an appropriate program implementation tachograms electric motion.

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РЕЖИМЫ И ПАРАМЕТРЫ ФУНКЦИОНИРОВАНИЯ ТЯГОВЫХ ЭЛЕКТРОМЕХАНИЧЕСКИХ КОМПЛЕКСОВ РУДНИЧНЫХ КОНТАКТНЫХ ЭЛЕКТРОВОЗОВ В ЖЕЛЕЗОРУДНЫХ ШАХТАХ

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Приведены результаты исследований режимов функционирования рудничных контактных электровозов и их тяговых электромеханических комплексов в отечественных железорудных шахтах. Показано, что электрические режимы и параметры функционирования тяговых комплексов в однотипных подземных выработках разнятся и никогда не повторяются. Установлено, что такое несоответствие является следствием влияния на режимы функционирования тяговых комплексов ряда технологических и технических факторов, свойственных условиям железорудных шахт. Установлено, что эксплуатируемые контакторно-резисторные системы управления морально устарели и по своим функциональным возможностям не позволяют оптимизировать до требуемого уровня параметры функционирования тяговых комплексов рудничных электровозов, а главное не могут служить базой для строения систем управления внутришахтного транспорта, рекомендовано использовать результаты исследований при конструировании алгоритма управления при разработке современных рудничных электровозов с перспективой автоматизации управления тяговыми комплексами.

Ключевые слова: тяговые электромеханические системы, рудничный электровоз, электрические параметры, энергия, управление.

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