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Scraper Face Conveyors Dynamic Load Control

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The task of controlling the dynamic loading of scraper face conveyors (SC) is considered and the unsatisfactory state of loading of mechanical and electrical components of the SC is recorded. The possibility of the appearance of a self-oscillatory nature of the entire system load due to the peculiarities of the movement of the traction chain along the lattice frame of the SC is indicated. The property of the system is noted – the cyclic nature of the loading of the circuit during movement, which causes energy exchange processes between the mechanical and electromotive components of the conveyor (when using the head and tail electric drives) through the common cable network of the power supply system of the SC. A high level of dynamic loading of the electromechanical system causes the problem of eliminating the self-oscillating operating mode of the SC that generates it which is proposed to be solved by changing the angular rotation speeds of the SC drive sprockets. Angular speeds can be changed by applying frequency control of asynchronous electric motors. The efficiency of setting the frequency of electric motor stator currents of the head and tail drives of the conveyor is established in proportion to the frequency of rotors rotation to eliminate self-oscillating modes of operation in the main operating mode. The possibility of reducing the starting shock values of the electromagnetic moments of electric motors is considered. The results of the calculation of the start-up and liquidation of the self-oscillating operating mode are presented on the example of the scraper face conveyor Anzhera-34. The results of calculations of the start-up modes and the main operational transportation of coal in an uncontrolled mode of operation and after the introduction of control are compared, based on which it is concluded that it is advisable to use active control of the dynamic loading of SC.

Key words: scraper face conveyor; dynamic loading; electric drive; asynchronous electric motor; frequency control

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Introduction. It is known that the downhole scraper conveyor (SC) is a completely unusual object. Its main feature is that the executive body is presented in the form of closed long round link traction chains with scrapers. It is the traction chain that attracts the attention of many researchers because of the discovery in the 30s of the 19th century by W.Albert [11] of a phenomenon called metal fatigue. W.Albert designed a machine for testing the conveyor chains used at that time in the Clausthal mines in Germany, and found that fatigue is not associated with accidental overloads, but depends on the load and the number of repetitions of its cycles. Further attention to the problem of metal fatigue in various fields of science can be judged by the fact that a large number of bibliographic references were indicated in [17] (554 by 1996).

The load cycles of conveyor chains are traditionally explained by the fact that when the chain links slip on a metal surface (pans), they overcome the resistance to movement – the sliding friction force. This force has a nonlinear character of a change in its value depending on the speed [4, p. 312, 317; 6, p. 290, 297]. This circumstance, from the point of view of the theory of technical control, means the introduction of a nonlinear link into the system, which ensures the possibility of a self-oscillating mode of operation in the system, i.e. the cyclic nature of loading or, according to I.V.Kragelsky, the occurrence of mechanical relaxation vibrations, and according to Ya.G.Panovko – relaxation frictional self-oscillations. These vibrations arise when considering the traction chain of the conveyor as an elastically plastic body, capable of storing, giving and dissipating energy, and in the presence of its source. This phenomenon explanation still prevails [15].

Experimental studies [8, 10] of the state of traction chains of scraper conveyors have long confirmed the existence of a high level of the dynamic component force in them and established that the cyclic nature of the loading of the chain during movement is its property. It causes energy exchange processes between the mechanical components of the conveyor and electromotive (when using the head (drive) and tail (end) electric drives) through a common cable network of the power supply system (PSS) of SC. The electro-mechanical system (EMS) SC is an object that has internal



feedback on the capacitive components of the mechanical system (chain traction member) and the capacitive components of the electromechanical system (induction electric motors with squirrel-cage rotors (IM), cable network of the power supply system). Here, capacitive components are those that can store and give energy.

The situation, from the point of view of the dynamic loading of the entire electromechanical system of the SC, is extremely unsatisfactory and leads to the emergence of numerous works to improve it. The proposed publication is one of them.

Formulation of the problem. A dynamic load high level of SC electromechanical system naturally causes the problem of eliminating the self-oscillating operation mode that causes it. It can be solved in different ways. For example, in [3], it was noted that the introduction of a mechanical intelligent drive system CST (Controlled Start Transmission) into the gearbox of an electric drive SC provides an ideal unloading on the sprocket (in practice since 1995). It is clear that this is achieved by changing (as a reaction to a change in load) the stiffness of the multi-plate clutch included in the CST, which, in turn, changes the magnitude of the resistance moment (elastic moment of the transmission) and the instantaneous speed of the SC drive sprocket. As a result, the CST control system gives SC properties that do not allow self-oscillations in the electromechanical system of SC.

Another direction [2, 12] is based on the introduction of additional electric energy converters, for example, frequency converters, into the power supply system of SC electric motors and, with their help, control of the SC electric motors state, in particular, the values of their electromagnetic moments. Electromagnetic moments of electric motors are sources of power control actions on the mechanical part of SC. The need for work in this direction is described in [9]: «To increase the reliability of the work of the face conveyors produced by «LLC «YURMASH», explosion-proof frequency converters are necessary».

It is possible to suppress self-oscillating sliding movements (stick-slip motion) in mechanical moving systems using an external controlled vibrational action (active vibration control) [16].

It is possible to eliminate the self-oscillatory operating mode of the EMS of SC by introducing control of its state, physically by changing (instantly CST) the instantaneous values of the angular rotation speeds of the drive sprockets of the SC gearboxes. Therefore, by analogy with the principles of CST, we consider the problem of eliminating the self-oscillating mode of operation of the electromechanical system of the SC by changing the angular speeds of rotation of the drive sprockets, but by controlling the state of asynchronous electric motors of the head and tail drives.

Methodology. Let us consider the solution of the problem using the electric drives of the Anzhera-34 (A34) scraper conveyor as an example, allowing operation with frequency converters. A possible variant of the power supply circuit of the conveyor electric motors is shown in Fig.1. Here, a face SC with a stand length of 220 m is used, a 34×126 caliber traction chain with a breaking force of 1450 kN. Electric motors receive power through cable lines (KGESH 3×95) with lengths of 90 m (SC head drive) and 310 m (SC tail drive) from a common source TN 6-PO2.1 (1200/6-1.2). The commonality of power supply means that, firstly, under these conditions, electric motors will operate with different levels of supply voltage, and secondly, when the load changes on their shafts, an electrical circuit appears to exchange electric energy between the motors through their stator circuits. Used motors AD DKV355LB4 with parameters: nominal amplitude of the supply voltage $U = 1612$ V (RMS value – 1140 V); synchronous angular velocity of stator field rotation $\omega_n = 314$ rad/s; active and reactive resistances of stator and rotor windings $R_s = 0.054$ Ohm, $R_r = 0.083$ Ohm, $X_s = 0.183$ Ohm, $X_r = 0.287$ Ohm, inductive resistance of magnetization circuit $X_m = 10.8$ Ohm, number of pole pairs $P = 2$; rotor moment of inertia $J = 4.69$ kg·m², the power of each IM is 315 kW.

The dynamic model of the chain traction organ is synthesized on the basis of the most common principle – the representation of the traction organ as a set of elementary dynamic links [1, 5, 13, 14, 18]. The enlarged model of the electromechanical system of SC according to Fig.1 is im-

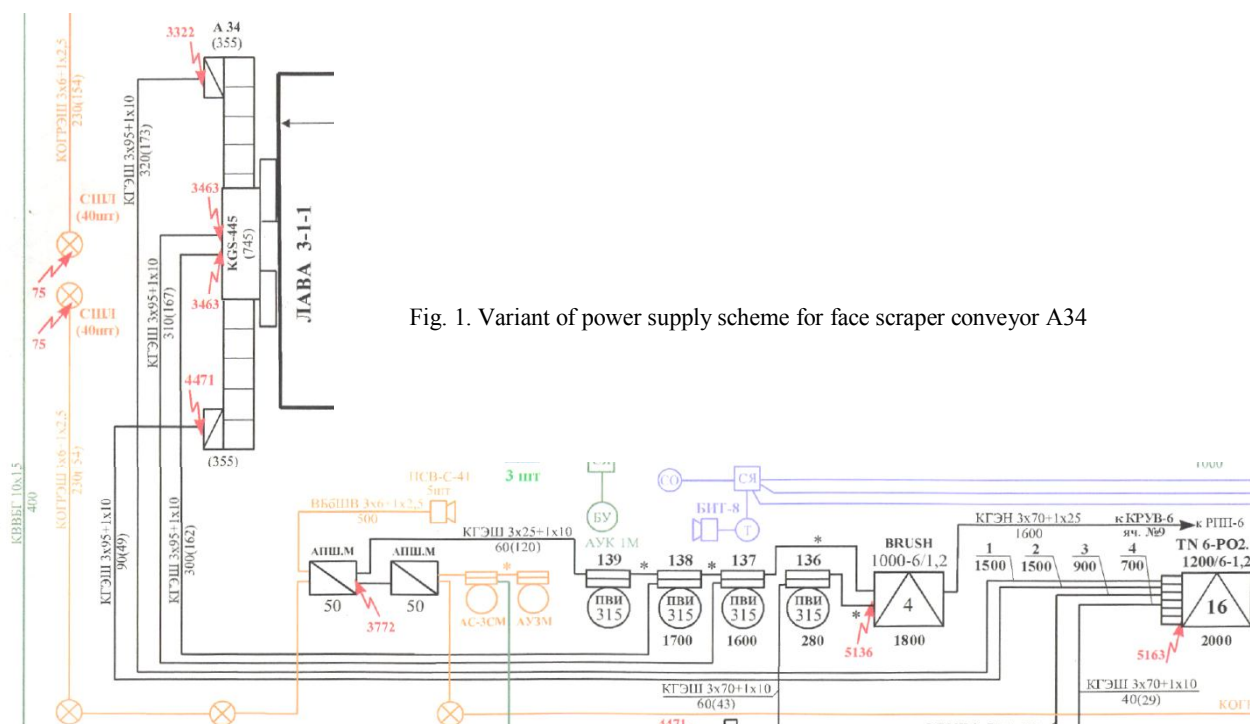


Fig. 1. Variant of power supply scheme for face scraper conveyor A34

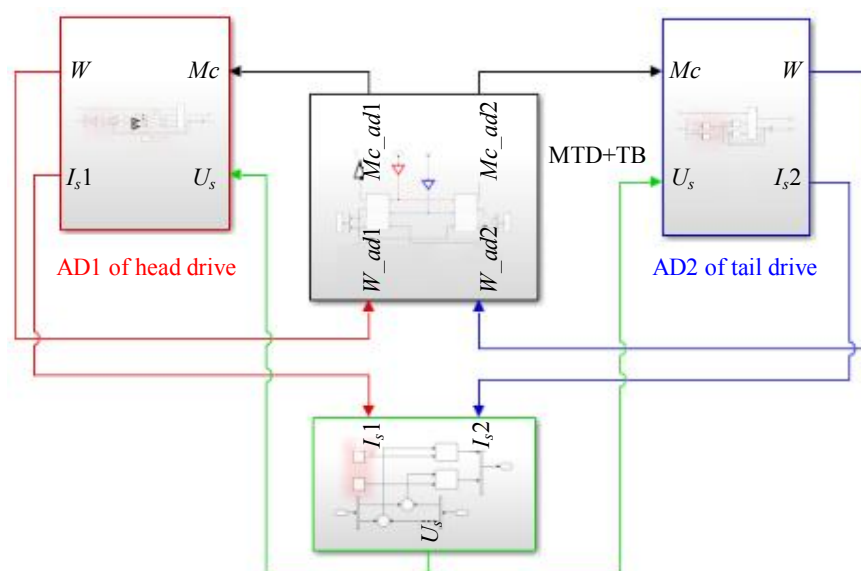


Fig. 2. Enlarged Simulink-model of SC EMS

$W(W_{ad1}, W_{ad2})$ – angular velocity of the head (AD1), tail (AD2) drive of SC; $Mc(Mc_{ad1}, Mc_{ad2})$ – resistance moments on shafts AD1, AD2; I_1, I_2 – currents AD1, AD2; U_s – input cable voltage AD1, AD2; MTD – mechanical transmission devices (gears) of the head and tail drives of SC; TB – traction body

plemented in the graphical environment of simulation modeling Matlab Simulink (Fig.2). The simulation results of the start-up modes of the tail and head drives, as well as the operating mode of cargo transportation (uncontrolled and controlled modes) are presented in Fig.3. Start-up is organized by sequential switching on of tail and then head drives electric motors.

Discussion. The SC electromechanical system starts up at a reduced voltage on the tail IM stator, which receives power through an extended section of the cable network 320 m long (Fig.1). In this case, the maximum loss of voltage amplitude U_s is 12 % (≈ 190 V) in the time range 0-1 s of the nominal value (see Fig.3, a). The head drive engine starts in more comfortable conditions – on a less extended section of the cable network (90 m) and, most importantly, it comes into operation when its rotor is already untwisted by the tail drive engine (see Fig.3, c, fragment W) up to ≈ 50 rad/s.

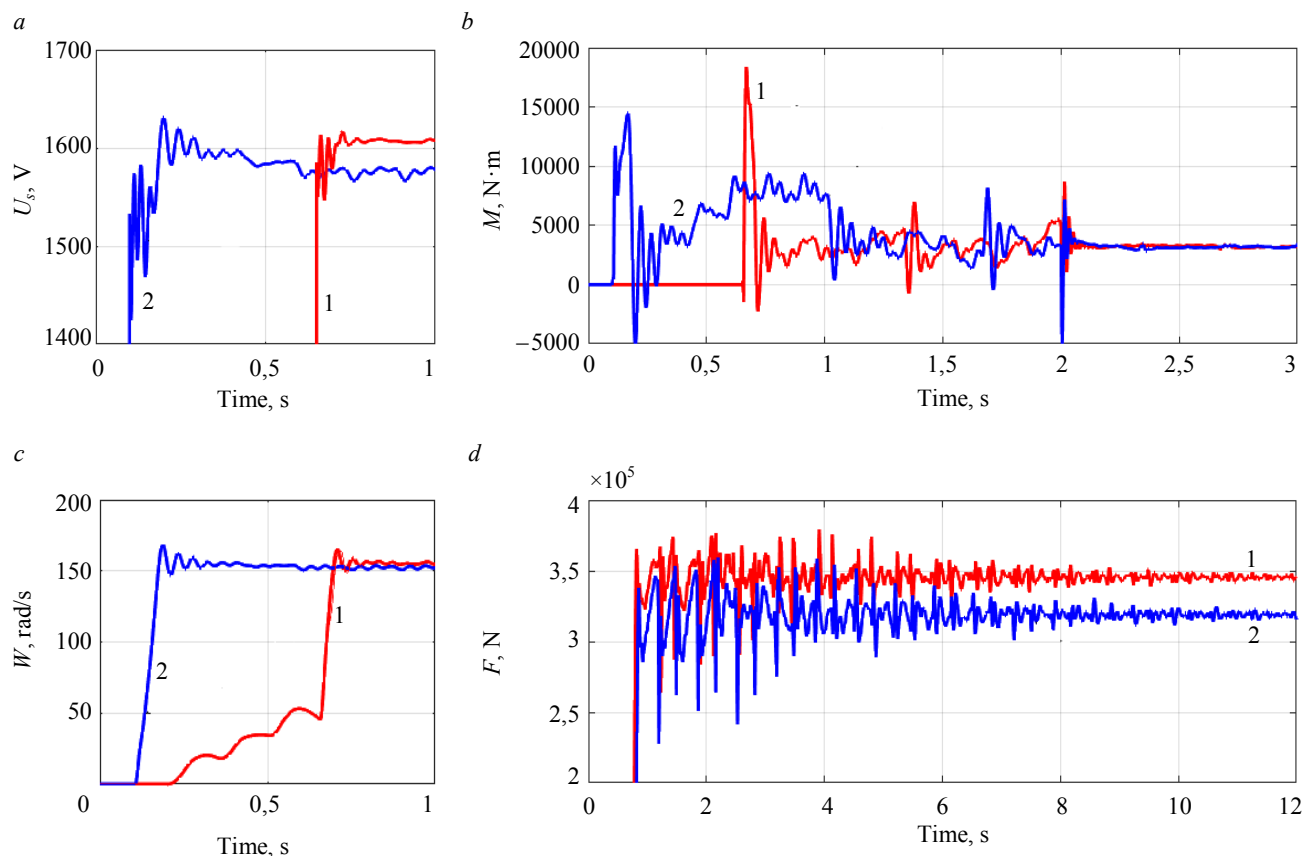


Fig. 3. Dynamics of state control of SC – fragments: *a* – change in the amplitudes of supply voltages during starts head drives (1) and tail (2) SC; *b* – change of electromagnetic moments of electric motors SC at start-up with suppression of shock moments and upon transition (2nd c) to control with suppression of self-oscillating operation mode; *c* – change in the angular speeds of rotation W of the electric motors of the head (1) and tail (2) drives at their consecutive start; *d* – change in effort in sections of the traction chain – cargo (1) and idle (2) when eliminating self-oscillating operation

The result of starting with the untwisted rotor is the exclusion of shock values of electromagnetic moments that are observed when starting the tail IM and reach double maximum values according to the static mechanical characteristic. To exclude starting shock values of the electromagnetic moment of the tail IM it is possible by [7], where it is proposed to preliminarily apply to the engine the full value of the supply voltage in the form of a pulse with a duration of 0.0033 s (at a frequency of the supply voltage of 50 Hz), transfer of IM to the dynamic (magnetic) braking mode for the same time and subsequent supply voltage.

The main task of managing the state of the SC – the elimination of the self-oscillatory mode of operation of the EMS SC – as applied to IM, can be based on the stabilization of their electromagnetic moments. The stabilization of the moments of IM (providing a soft mechanical characteristics) with changing moments of resistance on their shafts consists in the work of IM with a changing angular speed of rotation of their rotors. This means that when the SC operates in the main operating mode, the angular velocities of the drive sprockets of the head and tail shaft will change. In the frequency variant of the control of IM, the motor operates with a set absolute slip value $\alpha = \alpha_r + \beta$, where α – relative stator current frequency; α_r – relative rotor speed; β – absolute slip. With a constant value of β , an ideally soft mechanical characteristic of the IM is ensured, which means that in all controlled modes of engine operation, up to capsizing, it is necessary to fulfill the condition $\beta = \text{const}$, i.e. linear dependency $\alpha = \alpha_r + \beta$, which in the range of working speeds with a sufficient degree of accuracy is also approximated by a linear dependence, but passing through the origin of the coordinate system α , α_r , i.e. $\alpha = k\alpha_r$, where k is found from the condition $\alpha = 1$, $\alpha_r = \alpha_{rn}$, where α_{rn} – the initial relative value of the rotor angular angular velocity at a current frequency in the stator equal to the nominal. In this case, a variant of quasi-optimal stabilization of the electromagnetic moment is realized.



The use of this control option attracts with its simplicity of implementation, since the control system for the dynamic state of the electric drive in this mode is practically absent. The value of the control action (proportional to α) is generated by a discrete speed sensor and transmitted directly to the converter without any additional processing, where the set frequency value is calculated. However, it should be taken into account that if the dynamic component of the IM voltage amplitude is changed in accordance with the frequency of the stator current (which is physically unlikely), then there will be a loss of motor stability, which, depending on the value of the coefficient k , may overturn or «fall apart». This is due to the fact that in this embodiment, the system turns out to be closed positive feedback on speed. But if you change the voltage only according to the conditions of saturation of the magnetic circuit of the IM or technological necessity, for example, to change the speed of the traction body SC, then constructed in this way, the control system of the state of the electric drive will be absolutely stable [2].

In Fig.3, *b*, in the time range of 0-3 s, the transition from the uncontrolled operation mode of the IM to the controlled M is shown according to the rule of regulating the frequency of the IM stator current $\alpha = k\alpha_r$. The inclusion of controlled mode occurs at time 2 s. In the considered design variant of the SC model, the stabilization of the values of the electromagnetic moments of IM in the head and tail drives of the SC occurs. Processing of the calculation data showed that the range of oscillations of electromagnetic moments for a time interval of 10-12 s is $\Delta M \approx 40 \text{ N}\cdot\text{m}$ ($M_{\min} \approx 3140 \text{ N}\cdot\text{m}$, $M_{\max} \approx 3180 \text{ N}\cdot\text{m}$) for the IM of the head drive, and almost the same value – for the IM of the tail drive, i.e. $\approx 1.3 \%$ from average value. The efforts in the traction body (at the head drive) vary in this case in the range $\Delta F = 14 \text{ kN}$ ($F_{\min} \approx 418 \text{ kN}$, $F_{\max} \approx 432 \text{ kN}$), i.e. $\approx 3.3 \%$. For comparison – in uncontrolled operation the same ranges: $\Delta M \approx 5700 \text{ N}\cdot\text{m}$ ($M_{\min} \approx 1100 \text{ N}\cdot\text{m}$, $M_{\max} \approx 6800 \text{ N}\cdot\text{m}$) for IM of the head and tail drive, i.e. about $\approx 162 \%$; $\Delta F = 2010 \text{ kN}$ ($F_{\min} \approx 3520 \text{ kN}$, $F_{\max} \approx 5530 \text{ kN}$) – 45% .

Practical quasistabilization of the values of electromagnetic moments and equalization of their loads takes about 0.5 s, and practical stabilization of forces in the traction chain takes about 8 s due to the significant inertial masses of the traction chain and the load being transported (see Fig.3, *d*) 8-12 s. Three conventionally horizontal lines – efforts in sections of the traction chain at the head drive, in the middle of the conveyor stand and at the tail drive). To assess the effectiveness of control, changes in these moments and forces in the traction chain in uncontrolled operation are also shown here.

Conclusion. Despite a significant increase in the quality and reliability of downhole SCs of the latest generation, they remain objects with an unsatisfactory state of internal dynamic loading of the entire electromechanical system. With a promising increase in the lengths of the SC stakes, the dynamic components of the efforts in the traction chains of the SC and the amplitudes of the pulsations of the electromagnetic moments and currents of the IM, as well as the efforts in the traction organ and gearboxes of the drives of the SC, increase. The work of IM occurs with a constantly changing amplitude of the supply voltage and its different levels of IM of the head and tail drives.

A significant reduction in the dynamic load of the EMS SC can be achieved by organizing starts of the electric motors of the SC drives with suppressing the shock electromagnet of the moments and eliminating the self-oscillating modes of the system by introducing controlled changes in the rotational speeds of the drive chain sprockets of the SC. The latter is realized when driving electric motors with quasi-optimal stabilization of their electromagnetic moments.

REFERENCES

1. Bandurin A.N. Modeling of electromechanical processes of a scraper conveyor. *Vestnik Kuzbasskogo gosudarstvennogo tekhnicheskogo universiteta*. 1999. N 6, p. 30-32 (in Russian).
2. Eshchin E.K. Variant of frequency control of asynchronous electric drive of mining machines. *Elektrotehnika*. 1996. N 1, p. 28-30 (in Russian).
3. Intelligent CST Drive System. URL: <http://s7d2.scene7.com/is/content/Caterpillar/C10332020> (date of the application: 10.12.2018) (in Russian).



4. Kragel'skii I.V. Friction and wear. Moscow: Mashinostroenie, 1968, p. 480 (in Russian).
5. Kondrakhin V.P., Mel'nik A.A., Kosarev V.V., Stadnik N.I., Kosarev I.V. Mathematical model for the study of loads in a two-speed multi-motor drive and traction body scraper face conveyor. *Naukovi pratsi Donets'kogo natsional'nogo tekhnichnogo universitetu. Seriya girnicho-elektromekhanichna*. 2008. Iss. 16(142), p. 132-140 (in Russian).
6. Panovko Ya.G. Fundamentals of the applied theory of oscillations and shock. Leningrad: Mashinostroenie, 1976, p. 320 (in Russian).
7. Eshchin E.K., Sokolov I.A., Kashirskikh V.G., Ivanov V.L., Sokolov D.V. Patent N 2235410 RF. The method of starting an induction motor. Opubl. 27.08.2004. Byul. N 24 (in Russian).
8. Sosnan A.G. Of dynamic forces in scraper chains of multi-drive conveyors. *Prilozhenie k sborniku «Gornye mashiny»*. 1985. N 4, p. 10-15 (in Russian).
9. Technical problems of mechanical engineering that require urgent solutions based on scientific developments in order to ensure the production of competitive equipment that is not inferior to world analogues. URL: <http://auto-ally.ru/informatika/5256/index.html> (date of the application: 10.12.2018) (in Russian).
10. Chugreev L.I. The dynamics of conveyors with a chain traction unit. Moscow: Nedra, 1976, p. 160 (in Russian).
11. Albert W.A.J. Über Treibseile am Harz: Archive für Mineralogie Geognosie Bergbau und Hüttenkunde. 1838. Vol. 10, p. 215-234.
12. Broadfoot A.R., Betz R.E. New Control Strategies for Longwall Armored Face Conveyors. *IEEE Transactions on Industry Applications*. 1998. Vol. 34. Iss. 2, p. 387-394.
13. Chunzhi Z., Guoying M. Dynamic modeling of scraper conveyor sprocket transmission system and simulation analysis. *IEEE International Conference on Mechatronics and Automation*. 2011. Beijing, China, p. 1390-1394.
14. Dolipski M., Remiorz E., Sobota P. Dynamics of non-uniformity loads of AFC drives. *Arch. Min. Sci.* 2014. Vol. 59. N 1, p. 155-168.
15. Karachevtseva I., Dyskin A., Pasternak E. The Cyclic Loading as a Result of the Stick-Slip Motion. *Advanced Materials Research*. 2014. Vol. 891-892, p. 878-883.
16. Neubauer M., Neuber C.-C., Popp K. Control of Stick-Slip Vibrations. *Solid Mechanics and its Applications*. 2005. Vol. 130, p. 223-232.
17. Schlitz W. A history of fatigue. *Engineering Fracture Mechanics*. 1996. Vol. 54. Iss. 2, p. 263-300.
18. Shi J.G., Mao J., Wei X.H. Research on Dynamic Tension Control Theory for Heavy Scraper Conveyor. *Applied Mechanics and Materials*. 2010. Vol. 34-35, p. 1956-1960.

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