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Experimental research of transition processes of asynchronous motors of belt conveyors on mathematical modeling

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Abstract. The purpose of the study. increasing the performance of belt conveyors and reducing transportation costs based on the developed mathematical modeling of transient processes of asynchronous motors of open-pit conveyor transport. The object of the research is the operating modes of asynchronous motors of belt conveyors of mining enterprises. The subject of research is the starting and braking modes of operation of asynchronous motors of belt conveyors of mining enterprises. Research methods are based on the modern theory of electrical machines, methods of linear and nonlinear mathematical programming, mathematical statistics, as well as methods of system analysis. The practical results of the study are as follows: the actual coefficient of resistance to the rotation of the conveyor rollers and the coefficient of resistance to the movement of the belt, leading to a decrease in the tractive effort, were determined; a method was developed for determining the additional power consumption of electric motors of belt conveyors, taking into account the overall volume, weight and speed of transported lumpy cargo; a mathematical model of braking and starting modes of induction motors of belt conveyors of mining enterprises was developed, taking into account the resistance coefficient of the belt and rollers.

1 Introduction

In the global mining industry, it is important to improve the energy efficiency of conveyor belts and save energy. "The use of conveyor belts in quarries around the world is dramatically reducing rock transport distances, reducing shipping costs by 30-40% and doubling labor productivity." In this regard, much attention is paid to the optimization of asynchronous motors of belt conveyor transport, normalization of consumed electricity, the search for combination methods for extracting minerals from the horizons of deep quarries and increasing the reliability of conveyor equipment.

In the world, research is being carried out aimed at increasing the productivity of a quarry, reducing the cost of mining and transporting rocks, developing energy-efficient control algorithms and reducing losses during transient processes of asynchronous motors. In addition, asynchronous motors are considered, including mineral quality metrics to

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improve energy efficiency, as well as starting and controlling an asynchronous drive, determining the additional torque for the asynchronous motor, belt and roller drag coefficients, and determining energy consumption is important.

In the Republic, to improve the efficiency of conveyor transport at open-pit mining enterprises, extensive measures are being taken, including the introduction of cyclic transport technology, frequency regulation of electric drives, as well as the introduction of energy-saving technologies. The development strategy of the Republic of Uzbekistan for 2017-2021 includes the following tasks: "... reduction of energy and resource capacities of the economy as a priority in the near future, widespread introduction of energy-saving technologies in the expansion of renewable energy sources." To solve this problem, including the determination of the actual drag coefficients of conveyor belts and rollers, a method has been developed for calculating the additional power consumption of belt conveyors, taking into account the overall volume, weight and speed of the transported lumpy cargo, as well as the rational use of an asynchronous motor to save energy and efficiently use it in quarrying ... One of the important tasks is the development of a control system and ensuring an energy-saving mode of conveyor transport.

This dissertation research, to a certain extent, serves to fulfill the tasks stipulated in the Decree of the President of the Republic of Uzbekistan No.UP-4947 dated February 7, 2017 "On the Strategy of Actions for the Further Development of the Republic of Uzbekistan", Resolutions of the President of the Republic of Uzbekistan No. PP-3238 dated August 23, 2017 " On measures for the further introduction of modern and energy efficient technologies "and No. PP-3379 dated November 8, 2017" On measures to ensure the rational use of energy resources "and the Resolution of the Cabinet of Ministers of the Republic of Uzbekistan dated January 12, 2018" On additional measures to improve the procedure for using electrical energy and natural gas ”, Resolution of the President of the Republic of Uzbekistan No. PP-3054 dated June 13, 2017“ On the Program for Further Development and Modernization of the Coal Industry for 2017–2021 ”, as well as in other regulatory documents adopted in this area.

2 Methodology

The research methods are based on the modern theory of electrical machines, methods of linear and nonlinear mathematical programming, mathematical statistics, as well as methods of system analysis of conveyors, depending on the length and slope of the conveyor.

Scientific research is aimed at improving the efficiency of belt conveyors using advanced methods for calculating belt conveyors and determining the prospects for their development, are carried out in leading research centers and universities in the world, including Freiberg Mining Academy (Germany), California Institute of Technology (USA), Queen's University Belfast. Great Britain), Turin Polytechnic University, Moscow University of Steel and Alloys (Russian Federation), Tashkent State Technical University, Scientific and Technical Center LLC (Uzbekistan), as well as extensive research is being conducted in other research organizations.

The solution of scientific problems aimed at the development and improvement of systems of electric motors and belt conveyors made a significant contribution by A.O. Spivakovsky, E.E. Sheshko, V.I.Galkin, V.P. Dyachenko, Yu.R. Tarasov, A. Ryzhik. B., Reutov A.A., Aleksandrov M.P., Andreev A.V., Barabanov V.Yu., Zelensky O.V., Belfor V.E., Bilichenko N.Ya., Volotkovsky BC, Vasiliev M V.V., Glukharev E.G., Grudachev A.A., Dzhienkulov S.A., A.V. Ivanov-Smolensky, I.G. Shtokman, prof. L.G. Shaikhmeister, V. G. Dmitriev and others. In the Republic, the following scientists were engaged in the development and implementation of energy-saving technologies based on the use of frequency converters in belt conveyors: Khamudkhanov M.Z., Allaev K.R., Kamalov T.S., Khoshimov O.O., Muminov K., Bobozhanov M.K., Pirmatov N.B., Ishnazarov O.Kh., Toirov O.Z. other.

However, despite significant advances in improving the method for calculating the transient processes of belt conveyors, the determination of the drag coefficients of conveyor belts and rollers, the determination of the overall volume, weight and speed and power consumption of belt conveyors depending on the length and slope of the conveyor have not been studied enough.

3 Discussion

In steady-state modes, asynchronous motors of conveyor belts are characterized by a nominal mode [1,2].

Transient processes are much more diverse and more complex than steady-state processes [1,2].

Transient processes in asynchronous motors of a belt conveyor occur when the frequency and voltages at the motor terminals change and when it is disconnected from the braking network, etc. [1,2].

Belt conveyors as the most economical, productive and reliable type of transport of bulk cargo are widely used in our republic and abroad. With the increase in the length of the conveyors and their productivity, the dynamics of the start-up is of particular importance. Therefore, the start-up of the belt conveyors is very important. Dynamic processes in belt conveyors are characterized by the appearance of dynamic tension, which, algebraically summing up with static, significantly increase the resulting tension in the conveyor belt and the forces in the elements of the conveyor. At start-up, these changes can lead to unstable operation of the drive drum, for example, partial or complete slipping [2, 3].

Slipping is unacceptable for many reasons: heating the drum, a sharp decrease in the coefficient of adhesion, which makes it difficult to start the conveyor, etc. All this can cause emergency situations and even cause a fire, which is unacceptable in the Angren Mine because it leads to property damage, in addition, dynamic forces increase the loads in the tensioning device mechanisms, in the gearbox and other elements of the conveyor. Therefore, the analysis of the processes of starting and braking belt conveyors is of great importance.

An analysis of these processes makes it possible to accurately determine the values of dynamic loads, which will help to avoid irrational technical solutions, increase the reliability of the belt conveyor-motor system, and therefore, sharply reduce the likelihood of emergencies and increase the productivity of the belt conveyor [1,2].

Calculation of starting modes of operation of asynchronous motors of conveyor belts

As you know, the transportation of coal mined from the face at the Angrensky open pit is carried out by combined transport: dump trucks, conveyor transport (downhole and main conveyors) [4].

In Fig. 1 shows the layout of the conveyors of the Angren open-pit mine.Asynchronous motors with squirrel-cage rotors are used as a drive on the belt conveyors of the Angren open pit mine [4].

The power of these motors is as follows: 55 kW (1500 rpm), 75 kW (1000 rpm), 90 kW (1500 rpm), 160 kW (1000 rpm), etc.

In these engines, the starting characteristics of the computer were calculated. Fig. 2. dependences $M_{eм} = f(t)$ and $\omega = f(t)$ are shown when starting an asynchronous motor with a power of 55 kW, $U = 380$V, when there is no load on the conveyor.

In Fig. 3 for the same motor, the current dependences in the stator and rotor $i_{s\alpha}$, $i_{r\alpha} = f(t)$, are shown when there is no load on the conveyor.

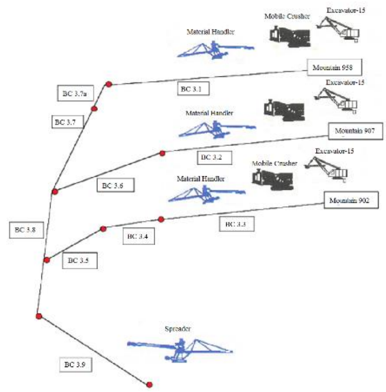

Fig. 1. The layout of the overburden conveyors in the line Cyclic-flow technology.

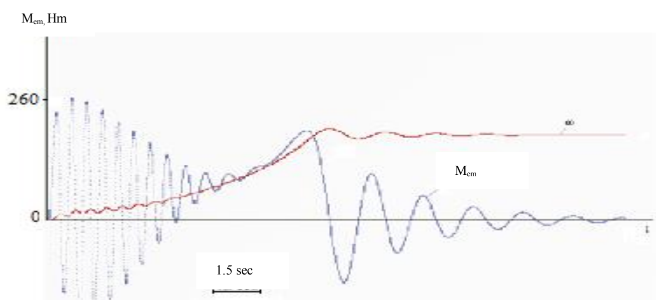

Fig. 2. Dependence $M_{eм} = f(t)$ and $\omega = f(t)$ when starting AM with a power of 55 kW, U = 380 V,$2p = 4$.

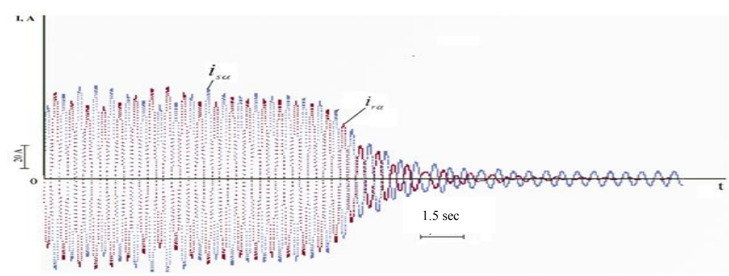

Fig. 3. Dependences of currents in the stator $i_{s\alpha}$ and rotor $i_{r\alpha}$ on time

As seen from Figure 2 and 3 during $e = 0{,}4$ the currents in the stator $i_{s\alpha}$ and the rotor $i_{r\alpha}$ have maximum values, which determines the maximum values of the electromagnetic moment $M_{eм}$. Then the currents $i_{s\alpha}$ and $i_{r\alpha}$ attenuate, the oscillations of the electromagnetic moment $M_{eм}$ are reduced and the value of the rotational speed of the rotor w_r approaches the steady state. The start continues for$t_m = 4{,}5$.

In Fig. 4. dependencies $M_{eм} = f(t)$ and $\omega_r = f(t)$ are given when starting an asynchronous motor with a power of 55 kW, $2p = 4, U = 380$V, when the belt conveyor is loaded.

In Fig. 5. for the same engine, dependencies $i_{s\alpha}$, $i_{r\alpha} = f(t)$, are shown when the belt conveyor is loaded. The starting time is $t_n = 9{,}5$s.

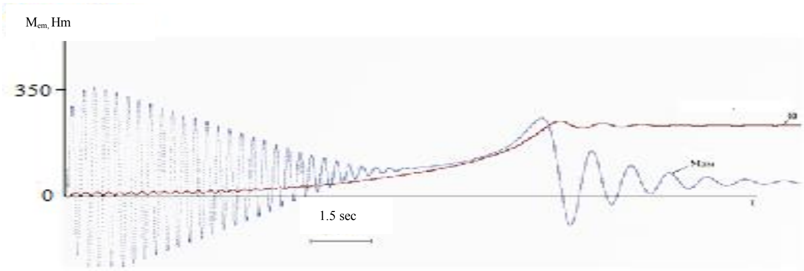

Fig. 4. Dependencies $M_{eм} = f(t)$ and $\omega_r = f(t)$ at start-up of an AM with a power of 55 kW, $2p = 4, U = 380$V, when the belt conveyor is loaded.

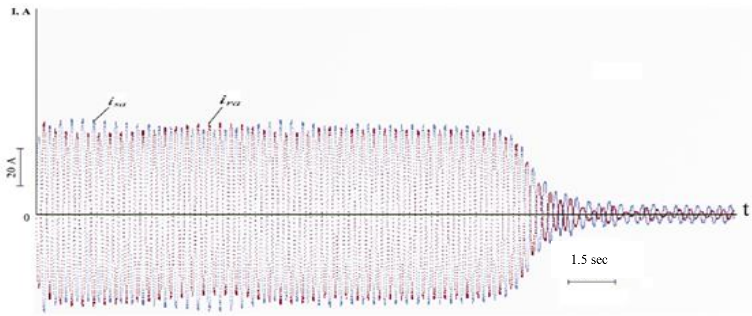

Fig. 5. Dependencies $i_{s\alpha}$, $i_{r\alpha} = f(t)$, when the conveyor belt is loaded.

Fig. 6. shows the dependencies $M_{eм} = f(t)$ and $\omega_r = f(t)$ when starting an asynchronous motor with a power of 75 kW, 380 V, $2p = 6$, when there is no load on the conveyor.

In Fig. 7. for the same motor, the time dependences of the currents in the stator $i_{s\alpha}$ and rotor $i_{r\alpha}$ are shown, i.e. $i_{s\alpha}, i_{r\alpha} = f(t)$, when there is no load on the conveyor.

As seen from Figure 6 and 7 during t = 3.5 s, the currents in the stator$i_{s\alpha}$ and rotor $i_{r\alpha}$ have a maximum value, which determines the maximum values $M_{eм}$.

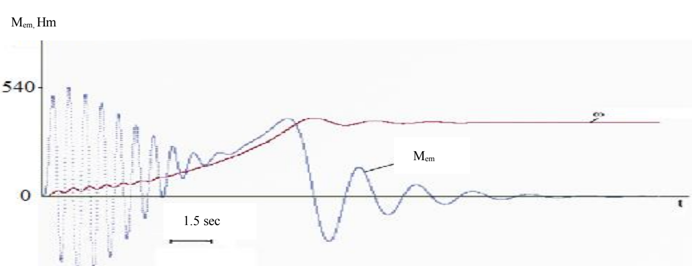

Fig. 6. Dependencies $M_{eм} = f(t)$ and $\omega_r = f(t)$ when starting an asynchronous motor with a power of 75 kW, 380 V, $2p = 6$, when there is no load on the conveyor.

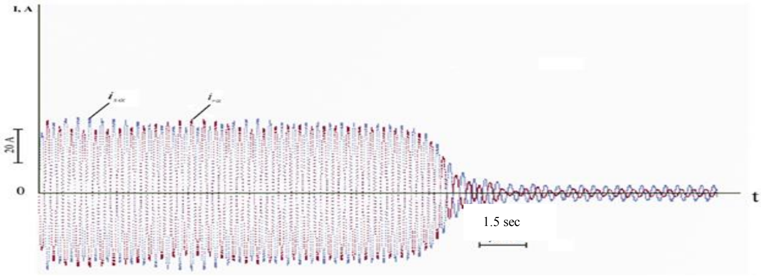

Fig. 7. Dependences of currents in the stator $i_{s\alpha}$ and rotor $i_{r\alpha}$ on time, i.e. $i_{s\alpha}, i_{r\alpha} = f(t)$, when there is no load on the conveyor.

In Fig. 8. shows the dependences $M_{eм} = f(t)$ and $\omega_r = f(t)$ when starting an asynchronous motor with a power of 75 kW, $2p = 6$, $U = 380$V, when the belt conveyor is loaded.

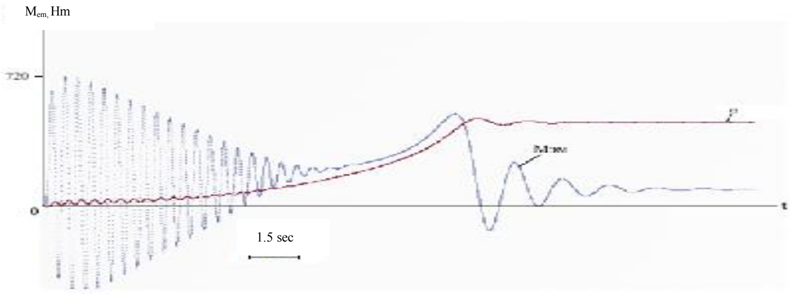

Fig. 8. Dependencies $M_{eм} = f(t)$ and $\omega_r = f(t)$ when starting an asynchronous motor with a power of 75 kW,$2p = 6$, $U = 380$V, when the belt conveyor is loaded.

In Fig. 9 for the same engine shows the dependencies$i_{s\alpha}$, $i_{r\alpha} = f(t)$, when the belt conveyor is loaded. The starting time is $t_n = 7{,}5$ s.

In Fig. 10-13 show the dependences, $M_{eм} = f(t)$, $\omega_r = f(t)$ and $i_{s\alpha}$, $i_{r\alpha} = f(t)$ at idle and at the load of an asynchronous motor with a power of 90 kW,$2p = 4$, 380 V.

In Fig. 14-17 shows the dependences $M_{eм} = f(t)$, $\omega_r = f(t)$ and $i_{s\alpha}$, $i_{r\alpha} = f(t)$ at idle and at load of an induction motor with a power of 160 kW, $2p = 6$, 380 V.

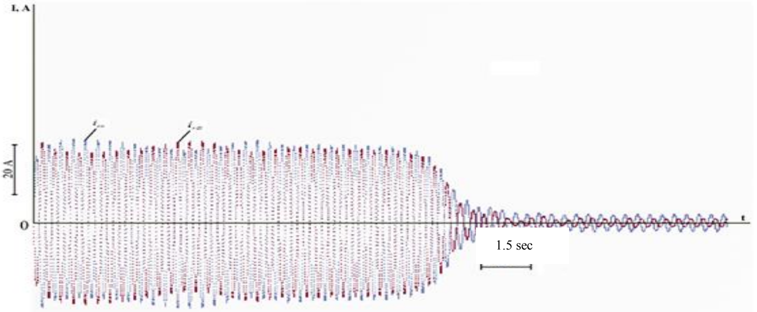

Fig. 9. Dependencies $i_{s\alpha}$, $i_{r\alpha} = f(t)$, when the conveyor belt is loaded.

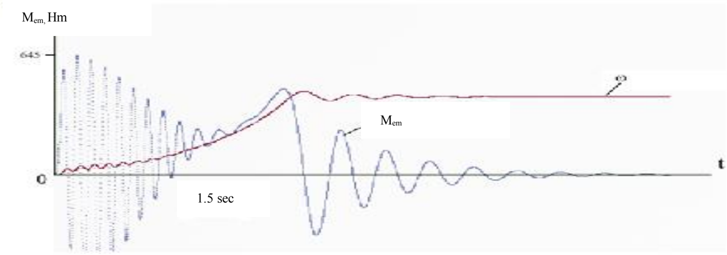

Fig. 10. Dependencies $M_{eM} = f(t)$, $\omega_r = f(t)$, when starting up an AM with a power of 90 kW, $2p = 4$, $U = 380$ V, when the belt conveyor is not loaded.

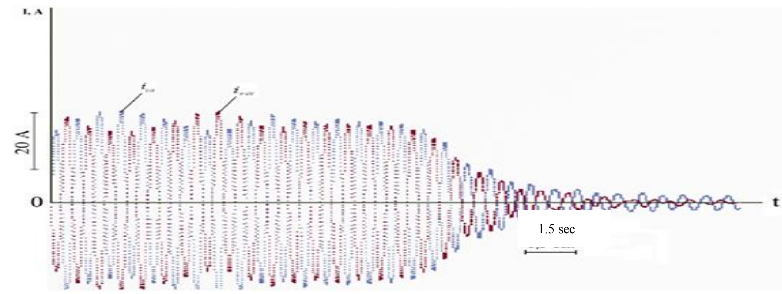

Fig. 11. Dependences $i_{s\alpha}$, $i_{r\alpha} = f(t)$ when starting an AM with a power of 90 kW,$2p = 4$, $U = 380$V, when the belt conveyor is not loaded.

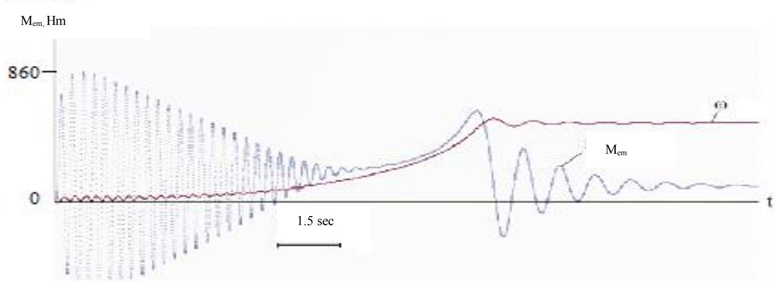

Fig. 12. Dependencies $M_{eM1}\omega = f(t)$, when starting an AM with a power of 90 kW, $2p = 4$, $U = 380$ V, when the belt conveyor is loaded.

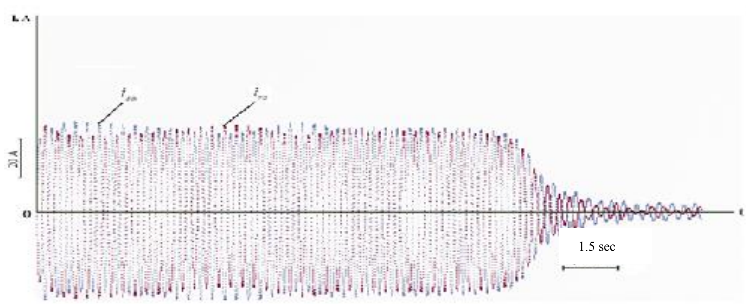

Fig. 13. Dependencies of currents $i_{s\alpha}$, $i_{r\alpha} = f(t)$ when starting an AM with a power of 90 kW, $2p = 4$, $U = 380$ V, when the belt conveyor is loaded.

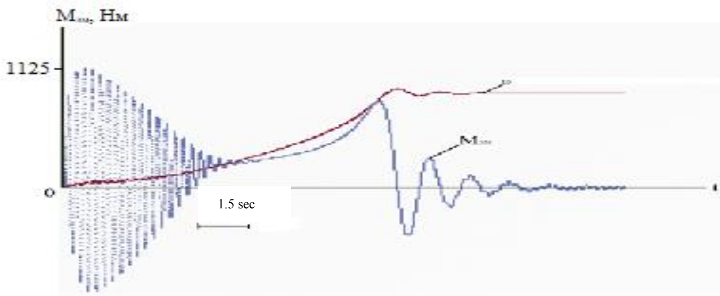

Fig. 14. Dependences $M_{eм1}\omega = f(t)$, when starting up an AM with a power of 160 kW, $2p = 6$, $U =$ 380 V, when the belt conveyor is not loaded.

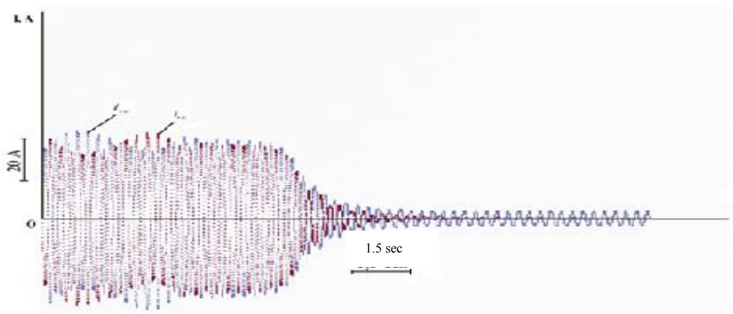

Fig. 15. Dependencies of currents $i_{s\alpha}$, $i_{r\alpha} = f(t)$ when starting an AM with a power of 160 kW, $2p = 4$, $U = 380$ V, when the belt conveyor is not loaded.

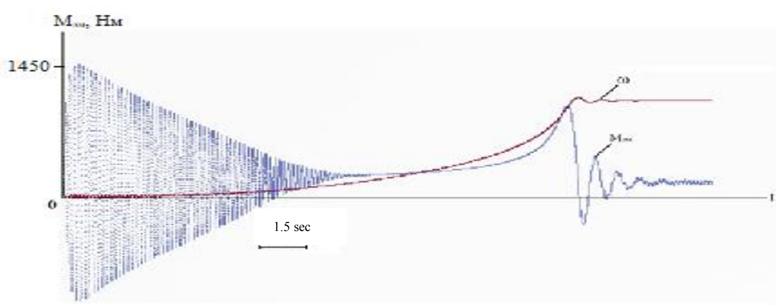

Fig. 16. Dependencies $M_{eм1}\omega = f(t)$, when starting an AM with a power of 160 kW, $2p = 6$, $U =$ 380 V, when the belt conveyor is loaded.

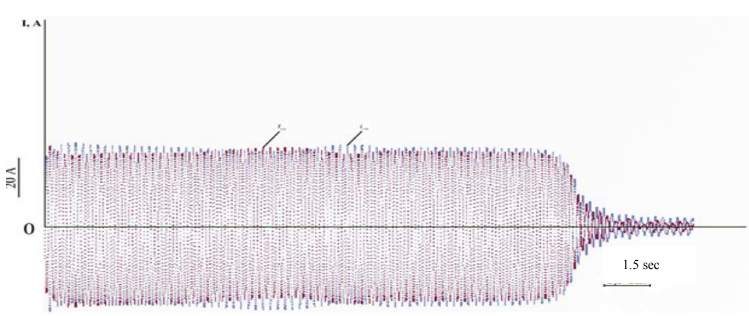

Fig. 17. Dependencies $i_{s\alpha}$, $i_{r\alpha} = f(t)$, when starting an AM with a power of 160 kW,$2p = 6$, $U =$ 380V, when the belt conveyor is loaded.

From a qualitative analysis of the start-up of asynchronous motors of belt conveyors, it follows that these processes differ from each other in the nature of the change in currents, shock torques and angular velocity.

Modeling an asynchronous motor in the Matlab package. When modeling asynchronous motors of belt conveyors, the program in the Matlab package is used, which shows the model of the conveyor electric drive in Fig. 18. To do this, differential equations are collected in a certain order, based on the principles of analog modeling [5].

The following differential equations are used to describe dynamic processes in asynchronous motors.Dynamic process in the stator [6-12]:

$$\begin{cases} U_{1a} = i_{1a} \cdot R_1 + \partial \Psi_{1a}/\partial t; \\ U_{1b} = i_{1b} \cdot R_1 + \partial \Psi_{1b}/\partial t; \\ U_{1c} = i_{1c} \cdot R_1 + \partial \Psi_{1c}/\partial t; \end{cases} \quad (1)$$

From a qualitative analysis of the start-up of asynchronous motors of belt conveyors it follows that these processes differ from each other in the nature of changes in currents, shock moments and angular velocity.

Simulation of an induction motor in the Matlab package. When modeling asynchronous motors of belt conveyors, the program is used in the Matlab package which shows the model of the conveyor electric drive in Fig. 18. To do this, differential equations are collected in a certain order, based on the principles of analog modeling [5].

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Dynamic processes in the rotor:

$$\begin{cases} U'_{2a} = i'_{2a} \cdot R'_2 + \partial \Psi_{2a}/\, \partial t; \\ U'_{2b} = i'_{2b} \cdot R'_2 + \partial \Psi_{2b}/\, \partial t; \\ U'_{21c} = i'_{2c} \cdot R'_2 + \partial \Psi_{2c}/\, \partial t; \end{cases} \quad (3)$$

The flux linkage is determined by the expression:

$$\left. \begin{array}{l} \Psi_{s\alpha} = L_s i_{s\alpha} + M \cos\theta \, i_{r\alpha} + M \sin\theta \, i_{rb}; \\ \Psi_{s\beta} = L_s i_{s\beta} + M \cos\theta \, i_{rb} - M \sin\theta \, i_{ra}; \\ \Psi_{ra} = L_r i_{ra} + M \cos\theta \, i_{s\alpha} - M \sin\theta \, i_{s\beta}; \\ \Psi_{rb} = L_r i_{rb} + M \cos\theta \, i_{s\beta} - M \sin\theta \, i_{s\alpha}; \end{array} \right\} \quad (4)$$

where Ls and Lr are the inductance of the stator and rotor winding, respectively; M - is the mutual inductance between the stator and rotor windings (the s index refers to the stator winding, and the r index refers to the rotor winding).

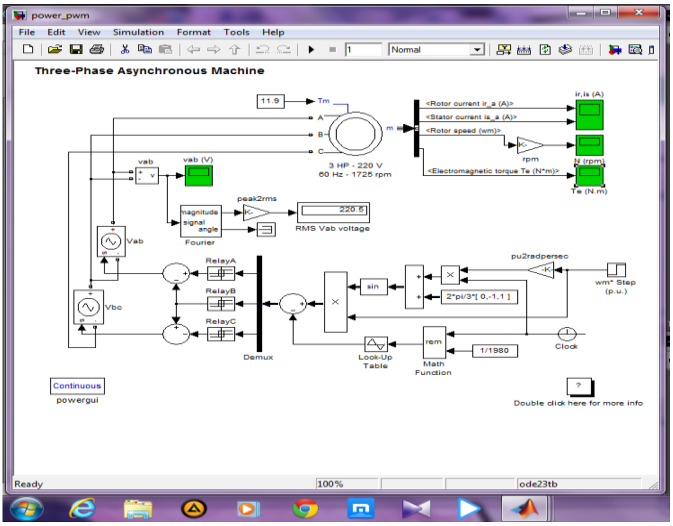

Fig. 18. Modeling blood pressure in the Matlab package.

In Fig. 19 - 21 shows the transient processes obtained on the model for stator and rotor currents, speed and torques on the shaft asynchronous motor at start-up with busy work areas.

Waveform analysis in Fig. 19 allows one to determine [13]:

- when starting with loaded tapes, the starting current of the stator of an asynchronous motor is 850 A and exceeds the rated current value by 3,5 times, such a current flows in the stator circuit for 6,5 seconds; in the future, the current transient is of an oscillatory nature with damping, the time of the current transient to a steady-state value of 250 A is 12 sec;
- when starting with loaded tapes, the starting current of the rotor of the asynchronous motor is 800 A and exceeds the rated current value by 10 times, such a current flows in the stator circuit for 5 seconds; in the future, the current transient is oscillatory with damping, the current transient to a steady state value of 80 A is 11 seconds;

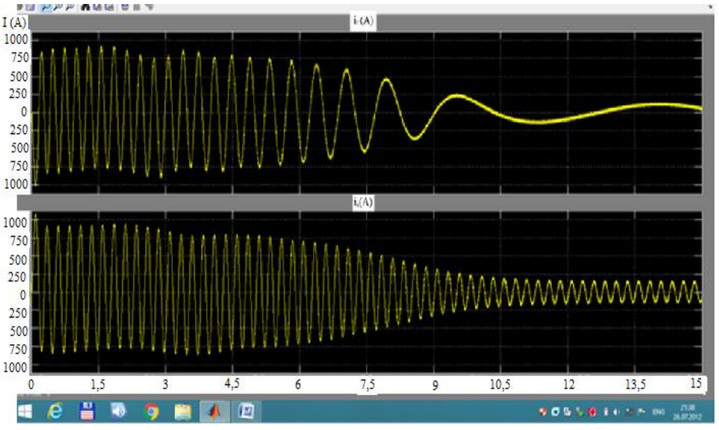

Fig. 19. Starting the AM belt conveyor: changes in the current of the stator and rotor.

Waveform analysis in Fig. 20 allows you to determine - when starting with loaded belts of the belt conveyor, the speed of the asynchronous motor increases smoothly, the time of the transient process in speed is 9,5 seconds;

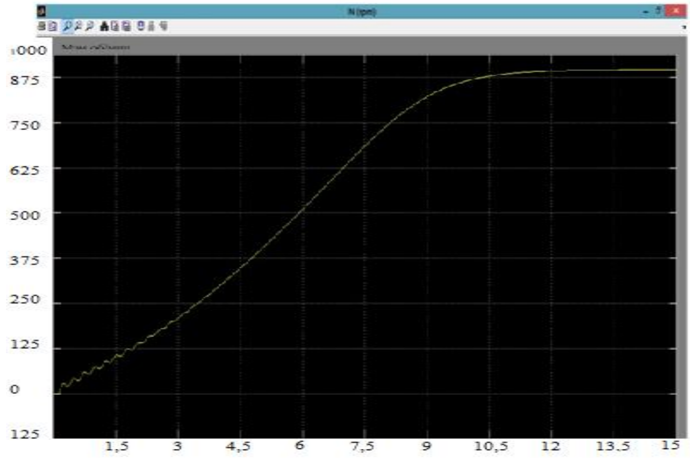

Fig. 20. Starting the AM of the belt conveyor: changing the speed.

Waveform analysis in Fig. 21 allows you to determine - when starting with loaded belts, the maximum torque of the asynchronous motor is 1250 N.m, and exceeds the nominal torque value by 4,5 times; further the transition process in time is oscillatory in nature with the damping, the time of the transition process in time to a steady state of 280 N.m is 12,5 seconds;

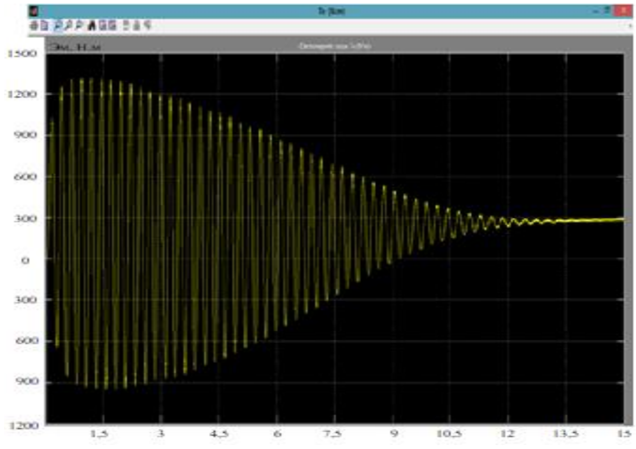

Fig. 21. Starting AM conveyor belt: changes in torque.

A mathematical model was developed on the Matlab package of an asynchronous belt conveyor motor, taking into account the following parameters distributed along the length of the conveyor, namely: mass of the transported load, mass and elasticity of the traction member, and forces of static and dynamic resistance.

Modes and oscillograms of transient processes are calculated for the parameters of the stator and rotor current of the motor, speed, torques and resistance forces on the shaft of an asynchronous motor when starting a belt conveyor.

The developed mathematical model of the belt conveyor makes it possible to study the static and dynamic modes of operation of both the drive motor and the mechanical part of the conveyor, on each of which the tension forces can be calculated at starts with different loads.

4 Conclusion

1. The calculation and modeling on the Matlab package of the mode of starting the asynchronous motors of belt conveyors, taking into account the resistance coefficient of the belt and rollers.

2. From the analysis of the start-up of asynchronous motors of belt conveyors, it follows that these processes differ from each other in the nature of changes in shock currents, shock moments and angular velocity.

3. The developed mathematical model of the belt conveyor makes it possible to study the static and dynamic modes of operation of both the drive motor and the mechanical part of the conveyor, on each of which the tension forces can be calculated at starts with different loads.

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