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DAMPING OF SUDDENLY CHANGING LOADS BY DRIVE MEANS OF THE DRIVING MECHANISM OF THE SCRAPER CONVEYOR

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Abstract: *An electromechanical method is proposed to avoid peak dynamic loads in a steady state, the condition of smooth start and emergency stop, as well as correction of the scraper conveyor productivity depending on the load flow level of the blasting combine, which will increase the reliability and reduce the energy and metal consumption of the transport link of the mining complex.*
Keywords: *scraper conveyor, chain transmission, transmission of traction force by coupling, adjustable AC drive, adaptive communication, original control method, dynamic loads, soft start, emergency stop*

1. Introduction

The trend towards a relentless increase in the production of coal raw materials usually requires a steady increase in the pace of cleaning operations. This prompts mining enterprises to introduce modern mechanized cleaning complexes with greater total energy and metal capacity into the existing technological process. Thus, the power consumption of the latest models of coal mining combines can reach 1 MW of power. This makes it possible to ensure effective separation from the bottom of both the coal pack and associated rocks, which increases the loading of the transport and technological equipment with the mined rock mass. In the chain of technological devices, the most problematic element of the complex is the scraper conveyor, aggregated with mechanized fastening. From a constructive point of view, it is one of the most imperfect elements of the complex. The specificity of transmission of the traction force by the engagement in the contact zone of the chain with the drive sprocket leads to high dynamic loads, which significantly limit the speed of movement of the scrapers. At the same time, the desired strength parameters are achieved by overestimating the mass-dimensional indicators of the traction chain, which limits productivity, and the presence of a turbo clutch in the drive significantly reduces the efficiency of the conveyor complex. Under such conditions, improving the conveyor drive system, increasing its reliability and energy efficiency, becomes a key task of maintaining the necessary productivity of the mining complex.

2. Review of literary sources

A review of known methods of modernization of scraper conveyor designs showed that most works are devoted to the study of extreme dynamic loads in the traction chain, which arise because of its interaction with scrapers and rock mass. At present, the main goal of the researchers is to determine the influence of the load dynamics in the engine-reducer-coupling-sprocket-chain system on the intensity of wear of the structural elements of the scraper conveyor and to study the possibilities of improving the drive mechanism and the coupling to ensure the levelling of the effects of unwanted oscillating loads.

The difficulties of directly determining several operating parameters of the scraper chain [1] gave impetus to the creation of a strategy for detecting defects in the chain based on the analysis of vibrations of the conveyor belt.

The established regularities made it possible to propose a diagnostic system, which is based on a comparison of the amplitudes of fluctuations of actual measurements at certain points with those obtained

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with modelling, and a forecast of the probable time of failure of the conveyor. The authors did not consider measures to eliminate and prevent emergency modes of operation of conveyors.

Research [2] of the movement of the chain using mathematical modelling, based on the Kelvin-Vogit model, took into account not only the extreme dynamic loads from the scrapers stopping and the loaded rock mass, but also the system dynamic loads arising as a result of the contact of the chains with the drive sprockets. Considering the Fogit model in the AMESim environment, it was possible to build a model that most fully reflects the full set of dynamic loads in the scraper chains during operation.

In the source [3], the case of one-sided chain breakage under the conditions of the presence of mining mass on the conveyor and its effect on the vibrations of scrapers and chains is considered. Particular attention was paid to determining the influence of the location of the rock mass relative to the place of the scraper chain break. Based on the results of research, it was established that the presence of a load behind a broken chain maximizes the longitudinal load and vibration of the scrapers, and the variation of the chain speed reaches 543.1% compared to normal operation. Separately, it should be said that the presence of the load before the break significantly reduces the load, and its presence on both sides minimally affects the process.

To study the influence of dynamic loads on the scraper conveyor and its characteristics, the authors of the publication [4] built a full-scale stand and conducted a series of experiments to determine the effect of the vibrations of the gearbox shafts at different chain speeds, loads and profiles of the conveyor belt. On this basis, the high sensitivity of the output shafts of the engine and gearbox to external loads was recorded. It was established that in the conditions of bending of the conveyor both in plan, during successive shift, and in profile, due to the corresponding topography of the formation, the traction system of the scraper conveyor has the greatest sensitivity to five main frequencies: the speed of rotation of the engine and the output shaft of the reducer with a secondary gear, engagement of the sprocket with the chain and the frequency of interaction of the scraper with the middle chute. At the same time, it was found that with an increase in the speed of the chain, the amplitude of the engine rotation frequency gradually increases to the maximum value, and this, accordingly, contributes to the increase in the dynamics of the scraper conveyor.

Using a test bench and a mathematical model, the author's team [5] compared the results of the experiments that were obtained in both ways. In the end, it was established that during acceleration, the longitudinal speed of the elementary link of the chain changes sharply, which increases the contact force by 5.4 times. When the drive is stopped, the direction of movement of the chain changes abruptly, which leads to vibration of the front sprockets. In this case, contact forces increase by 7.2 times.

In the source [6], a finite element model of the chain drive system was developed, which was implemented using LS-DYNA software. During the rotation of the sprocket from rest, the maximum Mises voltage in the dangerous zones, where the horizontal link engages with the sprocket, is more than 1100, and the maximum contact pressure is more than two thousand MPa. At the same time, in the vertical link of the chain, the contact pressure is significantly different from the previous one, which is due to the movement of the vertical ring from the mode of translation to rotation. Therefore, the characteristics of the material of the zones with the highest voltages in the vertical link must be improved to prevent the chain from breaking.

The work [7] presents the results of original studies of the power transmission system of a mining scraper conveyor in combination with an innovative highly flexible coupling, which was performed under operational conditions. The research consisted in establishing the static characteristics of the elastic coupling, determining the torsional oscillations and vibration levels of the gearbox housings of the test stand. And attention was also paid to checking the correctness of work and evaluating the strength of the mechanical connection between the innovative clutch and the typical drive units of the scraper conveyor. In addition, it was experimentally established that with an increase in the flexibility of the metal coupling, a significant decrease in root mean square (RMS) values of linear vibration accelerations was observed compared to the locked state of the coupling.

The proposed mathematical model [8] of determining the dynamic loads in the drive and traction body at the scraper conveyor start-up area revealed that the oscillations that occur during the start-up after reaching a steady state gradually subside. At the same time, it should be noted that the start-up mode is accompanied by high-intensity fluctuations, which contributes to the emergence of significant dynamic loads in the traction body of the conveyor and, as a result, leads to the premature destruction of the traction structure.

The developed algorithm [9] made it possible to obtain a multidimensional interpretation of the data of vibration signals of the system monitoring of the state of the transmission operating in difficult conditions. Based on them, a preliminary assessment was obtained regarding the possibility of using vibration signals for

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diagnosis and assessment of the technical condition of the power transmission system in the drive transmission of the scraper conveyor.

A flexible metal coupling with high torsional resistance [10] allows reducing the vibrations of multi-stage gears acting on the bearings of the gear wheels, as well as the forces between the gear spaces. As a result, a significant service life of individual components of energy transmission systems of mining scraper conveyors is ensured.

The study [11] is based on the analysis of the scraper conveyor loads. A multi-objective optimization model and a particle swarm optimization (PSO) algorithm are presented, and a multi-objective PSO-based processing method for speed planning is developed. A simulation example shows that the proposed method is superior to the traditional speed setting mode.

The dynamic properties of the chain drive system under various loads and eccentricities [12] are considered in detail by combining dynamic and discrete-element analyses of the scraper conveyor coupling. Simulation analysis of the transportation process under different loads and eccentricity showed that the transverse vibration of the chain is positively correlated, and the longitudinal one is negatively correlated with the amount of transported coal.

In the source [13], the characteristics of the longitudinal and torsional pendulum oscillations of the scraper conveyor in the conditions of work on the section with a bend were investigated for the first time. The findings of this work provide a theoretical basis for a better understanding of the performance characteristics of a scraper conveyor in a coal mine.

The purpose of the conducted research [14] and modelling was to determine the effect of the non-parallelism of the shaft axes on the vibration activity of the reducer and the contact area of the interacting teeth. The results showed that the change in the non-parallelism of the shaft axes significantly affects the vibrations of individual elements of the working gearbox and the contact area of the working teeth.

The aim of the proposed systems is focused on the compensation of oscillations, which are partly aimed at model methods of research and prevention of accidents in the traction element of the scraper conveyor. Unfortunately, this approach does not prevent, but regulates long and expensive capital repairs.

The use of elastic couplings allows damping shock vibrations in the drive mechanism, although such a system does not demonstrate their reliability and does not show the results of the compensation effect on the drive electric motor at all. Therefore, it should be assumed that the known methods of extinguishing sharply changing loads in the transmission and the conveyor chain cannot be applied to solve the problem.

The purpose of the paper to provide recommendations on electromagnetic damping of sharply changing forces, guaranteed start-up conditions and increasing the efficiency of the stable mode by means of an adjustable asynchronous drive, which will allow ensuring an increase in productivity and rational energy consumption of the scraper conveyor.

3. The main content of the work

The transmission of the traction force by the coupling of the drive sprocket and the chain of mechanisms such as a scraper conveyor or similar devices with a chain transmission, allows you to realize the torque, which is limited only by the following design parameters: the strength of the chain and sprocket, gear elements and engine power. Technical systems of the described class are characterized by a prominent level of dynamic loads and can have a destructive effect on both the chain and all other elements of the transport unit.

Usually, dynamic loads are because the conveyor chain is driven by a sprocket that rotates with an unregulated drive with a constant angular velocity ω (Fig. 1 a, b), where the teeth of the sprocket coupled with the chain links. Conditionally, it is possible to replace the vertices of the teeth with the vertices of an equivalent polyhedron (Fig. 2). Then, during the turn to the central angle 2α, which in this case corresponds to one face of the equivalent, a condition automatically arises in which the contact radius of the sprocket and the chain changes periodically. Under such conditions, the linear speed of its rotation is equal to:

$$\upsilon_L = \omega R, \text{(mps)} \tag{1}$$

where: R is radius of the initial circle, sprocket, m.

When the sprocket is turned by an angle φ (Fig. 2), which varies from α at the beginning to +α at the end of coupling with the teeth of the sprocket, the speed of the chain movement is determined by the equation:

$$\upsilon = \upsilon_L \cos\varphi = \omega R cos\,\varphi \tag{2}$$

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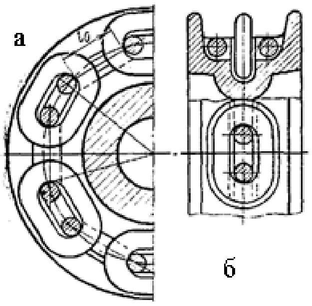
That is, the speed of the chain within one coupling period varies according to the sine wave, and the acceleration $a=dv/dt$ according to the cosine wave. At the same time, the maximum acceleration of the chain is equal to:

$$a_{max} = \omega^2 R \sin\varphi \tag{3}$$



a - side view, b - section

Fig.1. Sprocket of drive mechanism

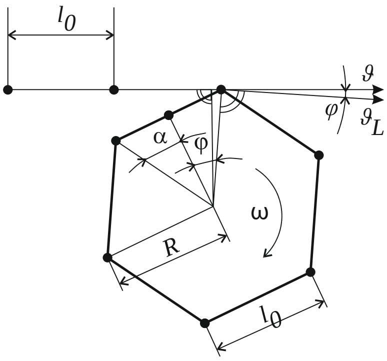


Fig.2. Calculation scheme of the drive mechanism

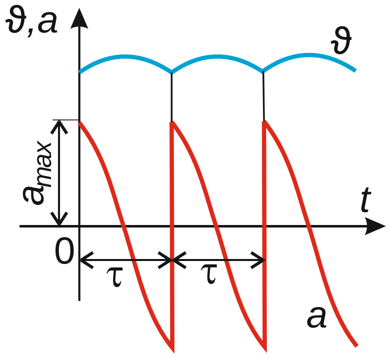


Fig.3. Time speed diagrams and chain acceleration

The increase in acceleration at the moment of coupling is a dynamic shock. That is, dynamic loads act on the conveyor even when the conveyor is put into idle mode. However, most of the time it works in conditions of unevenly distributed load, and the conveyor belts are constantly distorted due to their movement in a bending manner after the unit passes. When moving the material by dragging on the conveyor, due to the incomplete connection with the traction body, not all the material distributed on the conveyor participates in the uneven movement of the chain, but only some part, which can be considered attached to the chain. This attached part of the mass can be defined:

$$m_{load} = \frac{1}{g} cqL \tag{4}$$

where: c is 'participation coefficient', q is the weight of the moved material located on 1 meter of the chute length (running weight of the material), L is the length of the conveyor, m.

The size of the attached mass is one of the parameters that determine the number of dynamic loads acting on the traction chain. During the slow movement of the chain, which precedes the start of coupling, "compressive" dynamic and static loads occur in the chain:

$$S'_{chain} = S + m_{1-x}\ j_{min} \tag{5}$$

where: S is static tension, m_{1-x} are masses of moving chain and material located on the section from point 1 to point x, j_{min} is minimum acceleration of the chain.

At the moment of acceleration following the start of the clutch, dynamic forces arise in the chain:

$$S''_{chain} = S + m_{1-x}\ j_{max} \tag{6}$$

where: j_{max} is the maximum acceleration of the chain.

As a result, it turns out that at the moment of coupling, a dynamic load is instantly added to the chain:

$$S'_{chain} - S''_{chain} = m_{1-x}\ (j_{max} - j_{min}) \tag{7}$$

Given the short-term effect of this force, its value must be doubled.

In a real traction chain, which is an elastic body with finite stiffness and uniformly distributed mass, elastic oscillations occur under the influence of unevenness of motion.

There are two factors of oscillations: forced, under the action of transport load movements, and external - due to uneven movement of the chain.

The first ones are described by the formula:

$$a^2 \frac{\partial^2 u}{\partial x^2} - \frac{\partial^2 u}{\partial t^2} = j \tag{8}$$

where: a is average speed of elastic wave propagation on both branches, $\partial^2 u / \partial x^2$ is acceleration of longitudinal chain deformation, $\partial^2 u/\partial t^2$ is acceleration during elastic displacement.

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The inherent oscillations of the chain, arising because of its imbalance at the moment of coupling, are described by the equation:

$$a^2\frac{\partial^2 u}{\partial x^2}-\frac{\partial^2 u}{\partial t^2}=0 \quad (9)$$

The dynamic loads that act on the centrally doubled chains differ due to the skew of the scrapers due to the uneven distribution of the load along the conveyor and pressing it to the sides. Therefore, the movement of the scrapers relative to the conventional height of the conveyor also makes a certain contribution to the occurrence of additional voltages.

However, the worst situation for conveyor operation occurs when resonance occurs in traction chains.

The period of irregularity of the chain is an external disturbance or the period of coupling of the tooth of the sprocket:

$$2\tau = 2\pi/\omega Z = l_0/v \quad (10)$$

Resonance occurs if the period of the natural oscillations of the chain is equal to or a multiple of the period of the external disturbance:

$$m = T/2\tau = L_c/a_\tau = 1; 3; 5; 7 \ldots \quad (11)$$

Dynamic loads at resonance reach their greatest value. This mode is the most destructive for chains. But in reality, taking into account the load on the chains, which are affected by the uneven distribution of the load both along the length and in the cross-section, the clamping by the sides during the shift of the conveyor in a bending manner, the more difficult it is to determine the conditions for the occurrence of resonance. Therefore, for practical purposes the maximum static force acting on the contour of the conveyor is determined. To do this, a conveyor design scheme (Fig. 5) is built, characteristic points are placed on it, and after the tension in the branches is determined and assuming a constant tension force, a tension diagram is built (Fig. 6).

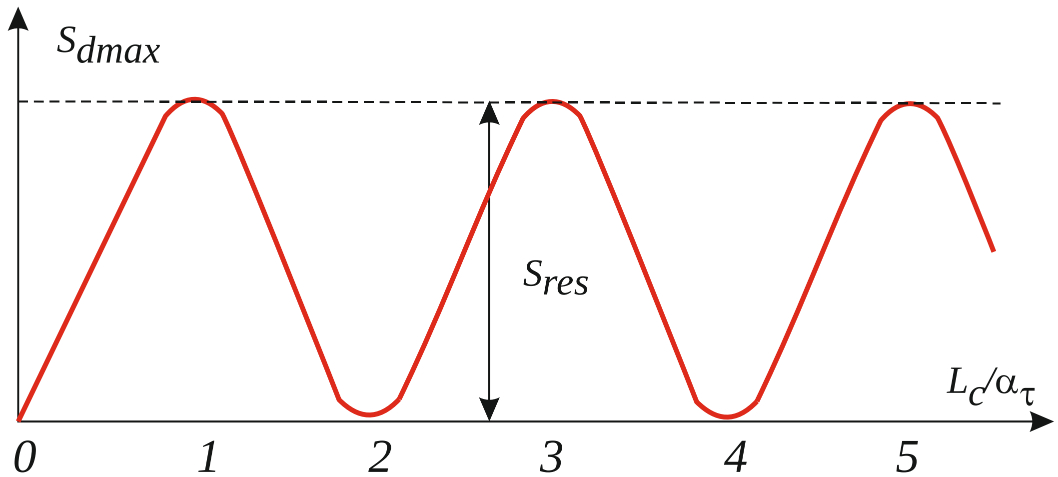

Fig.4. The nature of changes in dynamic loads as a function of the length of the conveyor

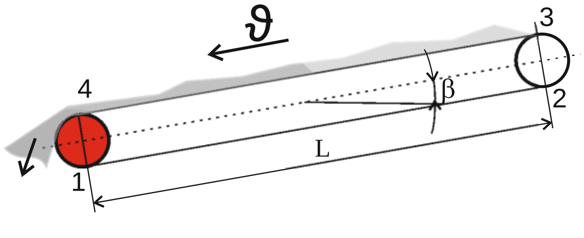

Fig.5. Calculation scheme of the scraper conveyor

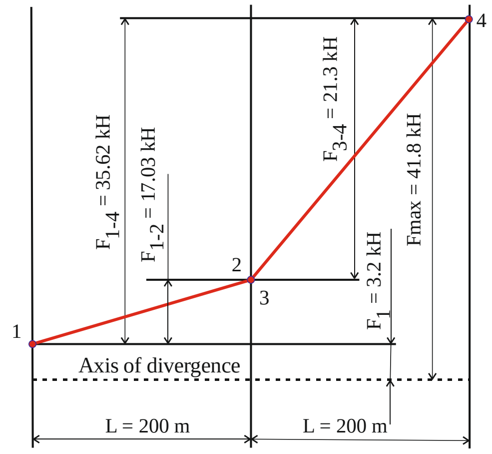

Fig.6. Chain tension diagram of the scraper conveyor

Having determined the maximum static tension along the contour of the conveyor, as the distance between the lowest axis and the highest point of the diagram, the ability of the selected chains to resist the breaking load is checked. At the same time, the influence of dynamic loads, which are not considered during calculations, is compensated by the introduction of a safety margin of chains n=1.5-2. The consequence of this is an increase in the caliber of the links and the total weight of the chain and the use of stronger alloyed grades of steel. Dynamic loads lead to the tired destruction of the conveyor elements, most often - to the breaking of the chain and the temporary withdrawal of the conveyor from operation.

There are known attempts to reduce dynamic loads due to the introduction of an additional chain transmission into the drive unit (Fig. 7).

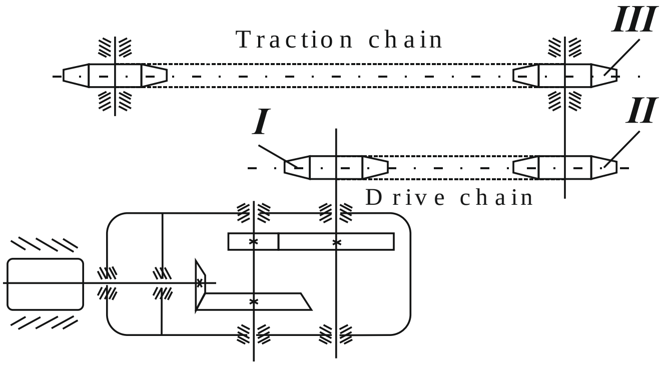

Fig.7. Scheme of a scraper conveyor with an intermediate chain drive as part of the drive (scrapers are not conventionally shown)

I, the intermediate chain on the drive and scraper chain has a certain unevenness of movement, which is determined by the angular speed of rotation of the stars and the number of teeth on them. When choosing the ratio of the radii of sprockets II and III, provided that the number of teeth is large, they can be considered as a circle, which theoretically will ensure a constant speed of the scraper chain.

$$\vartheta_{chain\ II} = \frac{\omega_1 R_1 R_3}{R_3} = cons \qquad (12)$$

However, in practice, if the number of teeth of sprockets II and III does not match, the speed of movement of the chains contacting the sprockets is constantly changing. In addition, the introduction of an additional chain transmission complicates the design of the drive units, increases their size, and limits the possibilities of placing the equipment in the dimensions of the coupling of the bench and the stretcher.

A separate problem that reduces the efficiency and complicates the design of the drive unit is the introduction of a turbo coupling into its composition. In addition, the use of lubricant as a connecting body leads to its inevitable spills, which is accompanied by environmental pollution. All this has consequences that are unacceptable for the modern quality of mechanisms of this type.

From the operation analysis of the drive mechanism of the scraper conveyor, it was established that to avoid periodic shock loads, which are caused by the non-cylindricity of the traction sprockets, it is necessary to ensure the stability of the chain tension with a previously known force. At the same time, it is possible to eliminate the disadvantages of using a turbo coupling by replacing it with electromagnetic damping devices, which are additionally able to ensure smooth start-up, speed regulation, system protection against stalling and significant overload.

The authors propose to solve the specified problems of the drive unit using a modern electric drive system with the support of absolutely soft mechanical characteristics of the motor, or a system that uses speed regulation according to the law that acts in the opposite phase of the speed of the mechanism of Fig. 3. The moment stabilization system is considered the most successful of the two proposed control options, and the one that meets the requirements as much as possible. A model implementation example is a frequency converter system of an asynchronous motor with direct vector control of the motor moment Fig. 8. It includes:

1 stands for asynchronous motor, 2 stands for speed sensor, 3 stands for autonomous voltage inverter; 4 stands for speed feedback channel, 5 stands for current negative feedback, 6 stands for motor cross-connection compensation block, 7 and 8 stands for current regulators along the X and Y axis, 9 stands for flux coupling regulator, 10 stands for negative feedback on the flux coupling, 11 stands for moment task limit block, divider and proportional link for receiving the current task along the Y axis. The issue of soft start of the system can be implemented from the intensity setter, which is set at the input of the moment tмask, and blocking of the drive in the event of a stall - by current cut-off when the limit value of the current in the stator windings is reached.

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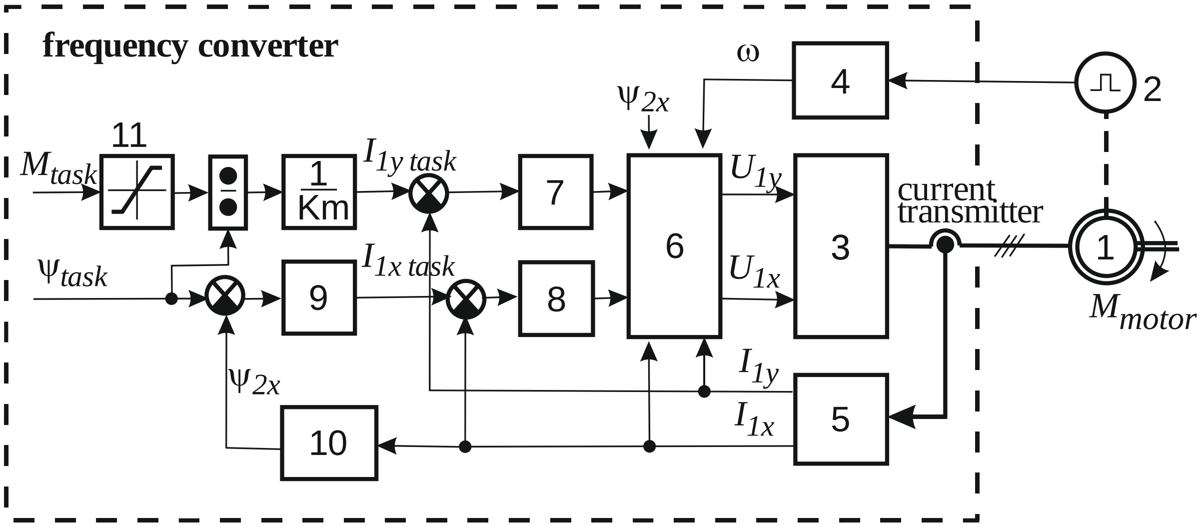

Fig.8. Functional scheme of the vector control of the moment of the movement mechanism of the chain conveyor

The next stage of research plans to prove the capability of the electromagnetic method of damping shock loads based on a mathematical model that is built in the MatLAB environment of the Simulink component (Fig. 8), and the goal is a control system that is ready for practical implementation.

The scientific novelty of the paper consists in providing recommendations on the method of electromagnetic damping of dynamic forces in the chain of the scraper conveyor, which will significantly simplify the design of the drive unit, increase its efficiency, extend its service life, and thereby reduce the costs of transporting rock mass.

4. Conclusions

The performed research work gave reasons to assert:

- The imperfection of the transmission of scraper conveyors requires the use of twice the strength of the traction chain of the drive mechanism, which leads to an increase in its metal content and eliminates the possibility of increasing productivity;
- The standard use of a turbo clutch in the conveyor complicates the drive mechanism and significantly reduces the efficiency of the electromechanical unit;
- Model methods of predicting the emergency of the scraper conveyor chain do not allow warning, but fix already existing defects and regulate the procedure for carrying out repair work;
- Methods of compensating sharply changing loads due to elastic couplings are quite effective, but have limited reliability terms, and their influence on the electric drive system has not been studied enough;
- Analysis of the forms of speed changes and acceleration of the scraper conveyor chain made it possible to form the requirements for the regulation law in the automated control system of the asynchronous electric drive;
- Electromagnetic methods of damping shock loads have advantages due to the absence of unreliable mechanics, which are subject to intensive wear and tear during continuous mechanical vibrations. In addition, electrical methods allow for smooth start-up, speed control and emergency stop of the mechanism in the event of its stalling quite simply.
- Thus, the development of recommendations for changing the design of the drive unit due to the improvement of the electric drive system with electromagnetic damping of shock loads will ensure a significant reduction in emergency situations, downtime and, as a result, will allow to increase profits due to a larger number of finished products that are produced during production time.

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