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KINEMATIC AND DYNAMIC ANALYSIS OF MOTION TRANSMISSION PROCESSES THROUGH ROLLER MECHANISMS WITH FLEXIBLE ELEMENTS IN BELT CONVEYOR SYSTEMS

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Abstract: The article presents a comprehensive kinematic and dynamic analysis of a belt conveyor equipped with roller mechanisms incorporating bearing supports with flexible elements. The conducted research theoretically and experimentally investigates the deformation characteristics of flexible elements within the roller mechanisms, their influence on the motion-transmission process, and the conditions required for dynamic stability of the system. Additionally, mathematical models are developed to describe the interrelations among the main structural components of the belt conveyor the belt, roller mechanism, drums, supporting units, and power-transmission components. Using kinematic expressions, the linear and angular velocities of the mechanism, elastic stress parameters, and the effects of inertial factors are determined. The dynamic analysis evaluates system vibration behavior, operational stability under load, and sources of energy dissipation. Laboratory experimental tests were compared with theoretical predictions, revealing a satisfactory degree of correlation.

Keywords: flexible element, bearing, roller mechanism, belt, conveyor, kinematics, dynamics, deformation, motion, drum, mathematical model, angular velocity, elastic stress.

Annotatsiya: Maqolada qayishqoq elementli podshipnik tayanchi bo`lgan rolikli mexanizmlari bo`lgan tasmali konveyerning kinematikasi va dinamikasi har tomonlama tahlil qilingan. Olib borilgan tadqiqotlarda tasmali konveyer qayishqoq elementli podshipnik tayanchi bo`lgan rolikli mexanizmlar tarkibidagi qayishqoq elementlarning deformatsiyasi, ularning harakat uzatish jarayoniga ta’siri hamda dinamik barqarorlik shartlari nazariy va amaliy jihatdan o‘rganilgan. Bundan tashqari, izlanishlar davomida tasmali konveyerning asosiy konstruktiv tarkibiy qismlari – tasma, rolikli mexanizm, barabanlar, tayanch va kuch uzatuvchi qismlar o‘rtasidagi o‘zaro bog‘liqlik matematik modellar orqali ifodalangan. Kinematik ifodalar yordamida mexanizm harakatining chiziqli va burchak tezliklari, elastik kuchlanishlar hamda inersiya omillarining ta’sir mexanizmi aniqlangan. Dinamik tahlil natijasida tizimning tebranish holatlari, yuklanishlar ostida ishlash barqarorligi hamda energiya yo‘qotish omillari baholangan. Shuningdek, laboratoriya sharoitida o‘tkazilgan eksperimental sinovlar nazariy natijalar bilan solishtirilib, ularning moslik darajasi aniqlangan.

Kalit so‘zlar: qayishqoq element, podshipnik, rolikli mexanizm, tasma, konveyer, kinematika, dinamika, deformatsiya, harakat, baraban, matematik model, burchak tezlik, elastik kuchlanish.

Аннотация: В статье всесторонне выполнен кинематический и динамический анализ ленточного конвейера, оснащённого роликовыми механизмами с подшипниковыми опорами на упругих элементах. В проведённых исследованиях теоретически и практически изучены деформационные свойства упругих элементов в составе роликовых механизмов, их влияние на процесс передачи движения, а также условия динамической устойчивости системы. Кроме того, в ходе исследования математически формализованы взаимосвязи между основными конструктивными компонентами ленточного конвейера лентой, роликовым механизмом, барабанами, опорными и силопередающими элементами. На основе кинематических выражений определены линейные и угловые скорости движения механизма, параметры упругих напряжений и характер воздействия инерционных факторов. Результаты динамического анализа позволили оценить вибрационные режимы системы, устойчивость работы под нагрузками и факторы энергетических потерь. Экспериментальные испытания, проведённые в лабораторных условиях, сопоставлены с теоретическими расчётами и продемонстрировали удовлетворительную степень соответствия.

Ключевые слова: упругий элемент, подшипник, роликовый механизм, лента, конвейер, кинематика, динамика, деформация, движение, барабан, математическая модель, угловая скорость, упругие напряжения.

INTRODUCTION

Belt conveyor mechanisms play an important role in the process of organizing technological processes in a continuous, automated and energy-efficient manner, mainly in mining enterprises. These mechanisms are one of the main technical systems for the continuous transportation of materials, ensuring the smooth operation of production lines and facilitating human labor. In recent years, the issues of increasing the efficiency of conveyor systems, ensuring their reliability and dynamic stability have been considered as one of the current directions in engineering and scientific research. In particular, a deep study of the kinematic and dynamic characteristics of conveyor roller mechanisms is of great importance in optimizing the accuracy of operation, load distribution and energy losses of mechanical systems.

Failure to properly account for deformations, vibration states and elastic stresses in the working process of belt conveyor roller mechanisms leads to the economical operation of the system, as well as premature failure of belts and rollers. Therefore, the analysis of their kinematics and dynamics in a theoretical and experimental direction, the determination of the optimal parameters of the mechanism are a necessary scientific and practical task.

This study analyzes the structural structure of conveyor mechanisms, motion transmission processes and deformation properties under load. In this study, the dynamic response of the system is studied through mathematical modeling, analysis based on differential equations and experimental measurements. The results of the study are aimed at improving the structural solutions of belt conveyors, reducing vibration, increasing the accuracy of motion transmission and increasing energy efficiency. At the same time, the scientific results obtained in the work are of practical importance for transport mechanisms, mechanical engineering technology and automated production systems.

LITERATURE REVIEW

Many domestic and foreign scientists have conducted scientific research on the kinematic and dynamic properties of belt conveyor systems, their roller supports and belt elements. These studies are mainly focused on the issues of mechanical vibrations, deformation processes, energy transfer efficiency and stable operation of the system.

A lot of experimental and theoretical work has been devoted to calculating dynamic loads on the rollers of belt conveyors transporting large loads in mining enterprises [1], as a result of which it is necessary to take into account two approaches to the formation of the causes of dynamic loads. In the first approach, the main mechanism of the impact of large pieces of cargo on the rollers is the impact due to the mismatch of the velocity vector of the piece and the direction of impact on the roller surface

at the point of contact of the belt rollers. A number of works [2] show that at sufficiently high values of belt tension (from about 110 N for a gap width of 1 mm), the interaction force between the load segments and the rollers ceases to depend on the value of the belt tension.

This means that another interaction mechanism - impulse - becomes the main one. Within the framework of this approach, the interaction of the transverse compression zones of the conveyor belt that appear under the contact points of the load segment with the roller is considered. When these zones approach each other, starting from a certain distance between the centers of the contact points (approximately 1-2 times the belt thickness), a sudden tightening of the contacts occurs, which is externally manifested as a shock pulse. [3].

In addition to the destruction of rolling elements and tracks by contact fatigue, abrasive and friction-fatigue wear are also characteristic of conveyor roller bearings. This type of wear is predominant for the upper bearings of the working network rollers. It is this type of wear that determines the technical life of the bearings. The reason for this phenomenon is considered to be poor-quality production of the roller bearing elements. However, conveyor rollers are such a mass-produced product that, apparently, saving on the cost of the rollers is justified, therefore, a type of wear that is not typical for bearings should be taken into account [4, 5].

DISCUSSION

The results of the study revealed the complex kinematic and dynamic characteristics of the motion transmission processes through roller mechanisms with belt elements of belt conveyors. Kinematic analysis showed that the rotation speed of the rollers and the belt tension are decisive factors for the transmission accuracy and stable operation of the system. Optimal friction forces under high tension reduce the risk of belt slippage and increase the operational reliability of the mechanisms.

Dynamic analysis revealed the vibration behavior of the system. The study showed that the elastic and viscoelastic properties of the rollers and the deformation behavior of the belt have a significant impact on the vibration amplitude and frequency of the mechanisms. Changing the load parameters can increase or decrease energy losses. Thus, the need to optimize each structural element in the design of conveyor mechanisms was confirmed.

Mathematical models and dynamic equations serve as an important tool for assessing the efficiency of the system in real conditions. The results of the study show that the structural and parametric optimization of roller mechanisms with belt elements [6, 7]:

reduces the risk of belt slippage;

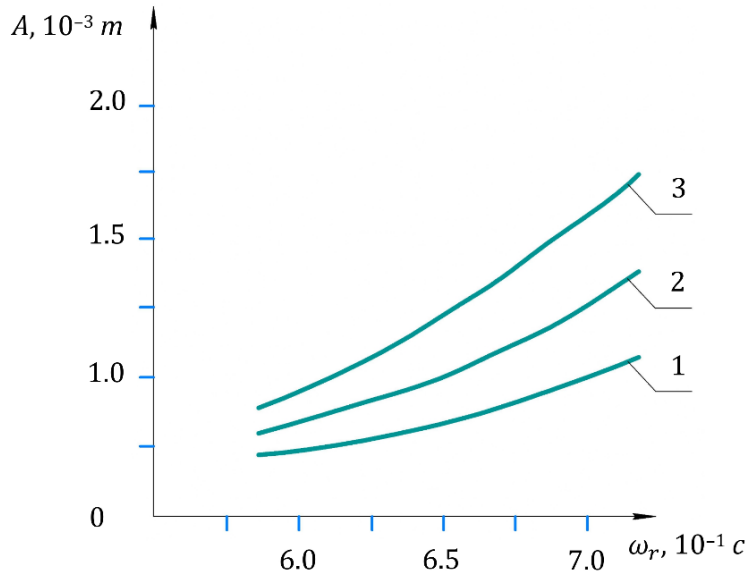
increases vibration stability;

ensures the accuracy of motion transmission.

In addition, the energy efficiency and operational reliability of the system depend not only on the quality of individual elements, but also on their integrated operation. Thus, the results discussed expand the possibilities of increasing the energy efficiency of belt conveyor mechanisms, ensuring their reliability, and automating production processes.

RESULTS

A comprehensive investigation was carried out to evaluate the kinematic and dynamic characteristics of the motion-transmission process in belt conveyors equipped with roller mechanisms incorporating bearing supports with flexible elements. The obtained results enabled the identification of fundamental relationships governing linear and angular velocities, elastic deformations, inertial forces, load redistribution, and the operational stability of the system under various loading conditions [8, 9].



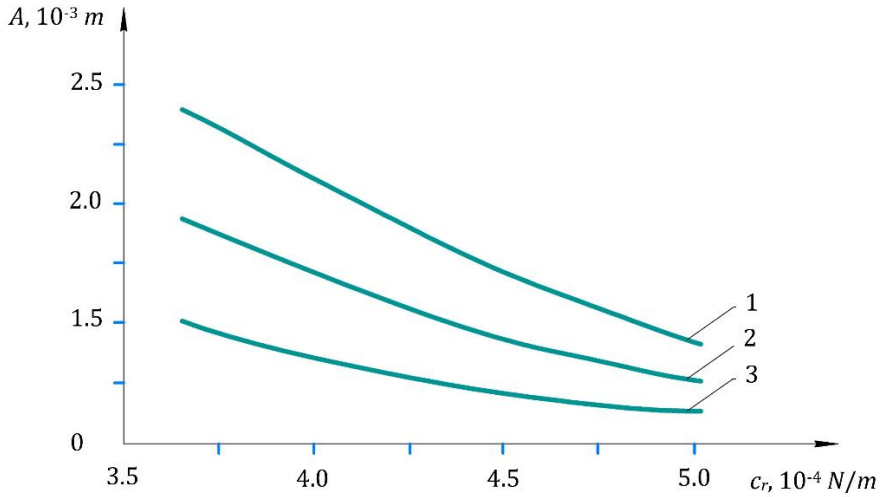
where, 1 – m_{sh} = 0.35 *kg*, 2 – m_{sh} = 0.45 *kg*, 1 – m_{sh} = 0.55 *kg*.

Figure 1. Graphs of the dependence of changes in the amplitude of vibrations on the belt supports of the roller mechanism and the change in angular speed

Figure 1 shows graphs of the dependence of the amplitude of the vibrations on the belt supports of the roller mechanisms and the change of the angular speed. In this case, the increase in the angular velocity of the roller mechanism causes its nonlinear vibration amplitude to hang. As a result, when changing from 68 c^{-1} to 80.2 c^{-1}, the amplitude of vibrations with the mass of the roller mechanism bearing shell and the outer flange of the belt element increases from $0.205 \cdot 10^{-3}$ *m* to $0.61 \cdot 10^{-3}$ *m*. When the mass of the bearing shell is m_{sh} = 0.5 kg and the mass of the outer flange of the belt element is m_f = 0.350 *kg*, the amplitude *A* increases from $0.42 \cdot 10^{-3}$ *m* to $1.409 \cdot 10^{-3}$ *m*. The results of the experimental studies show that the vibration amplitude of the support of the roller mechanism with a belt element is in the range of $(0.3 \div 0.38) \cdot 10^{-3} m$. To ensure these values, values $m_{sh} = (0.450 \div 0.5)$ *kg*, $m_f = (0.3 \div 0.350)$ *kg* are recommended [10, 11].

Figure 2 shows graphs of the dependence of the variation of the vibration amplitude of the pulley mechanism on the variation of the stiffness coefficient of the supports with strap elements. The given graphic correlation graphs show that as the coefficient of friction of the belt element bearing support increases from $4.64 \cdot 10^4$ *N/m* to $6.2 \cdot 10^4$ *N/m*, the vibration amplitude of the roller mechanism decreases from $1.317 \cdot 10^{-3}$ *m* to $0.42 \cdot 10^{-3}$ *m* it decreases linearly up [12-14].

To ensure that the vibration amplitude of the roller mechanism is in the range of $(0.3 \div 0.38) \cdot 10^{-3}$ *m* c = (5.2 ÷ 6.0) 103 *N/m*; ω_c = (7.2 ÷ 7.6) 10 c^{-1}; It is recommended that *k* = 0.3 ÷ 0.5.



where, 1 – k = 0.6; ω_c = 80 c^{-1}; 2 – k = 0.4; ω_c = 76 c^{-1}; 1 – k = 0.2; ω_c = 70 c^{-1};

Figure 2. Graphs of dependence on changes in the vibration amplitude of the roller mechanism

It can be seen from the resulting connection graphs in figure 3 that when the load increases from 0.26 N to 1.9 N and the mass of the bearing shell is $0.3 \cdot 10^2$ kg, the vibration amplitude of the roller mechanism is increases from $0.4 \cdot 10^{-3}$ m to $0.250 \cdot 10^{-3}$ m. If the mass of the bearing shell decreases to $0.275 \cdot 10^2$ kg, the displacement amplitude of the roller mechanism reaches from $0.5 \cdot 10^{-3}$ m to $0.74 \cdot 10^{-3}$ m.

Therefore, to ensure that the vibration amplitude of the roller mechanism does not exceed $0.4 \cdot 10^{-3}$ m, it is advisable to make $m_s \leq (0.275 \div 0.325) \cdot 10^2$ kg and $F_0 \leq (1.02 \div 1.25)$ N. Studies have shown that an increase in the coefficient of uniformity of the bearing belt bushing not only decreases the vibration amplitude z and $\dot{z}$, but also causes an increase in the vibration frequency of the roller mechanism. When the force increases to 1.8 N, the value of A_z decreases linearly from 0.59 10^{-3} m to 0.24 10^{-3} m. Accordingly, the vibration amplitude of the speed of the roller mechanism also decreases nonlinearly, and the coefficient of uniformity of the belt element support of the roller mechanism bearing increases (see Fig. 2). The recommended values of the uniformity coefficient of the bearing belt support are $c_1 = (5.0 \div 5.5) \cdot 10^4$ N/m; $c_2 = (0.1 \div 0.12) \cdot 10^4$ N/m, where the vibration amplitude $A_z = (0.09 \div 0.14) \cdot 10^{-3}$ m/s, $A_{\dot{z}} = (0.08 \div 0.11) \cdot 10^{-3}$ m/s it is guaranteed to be between [15, 16].

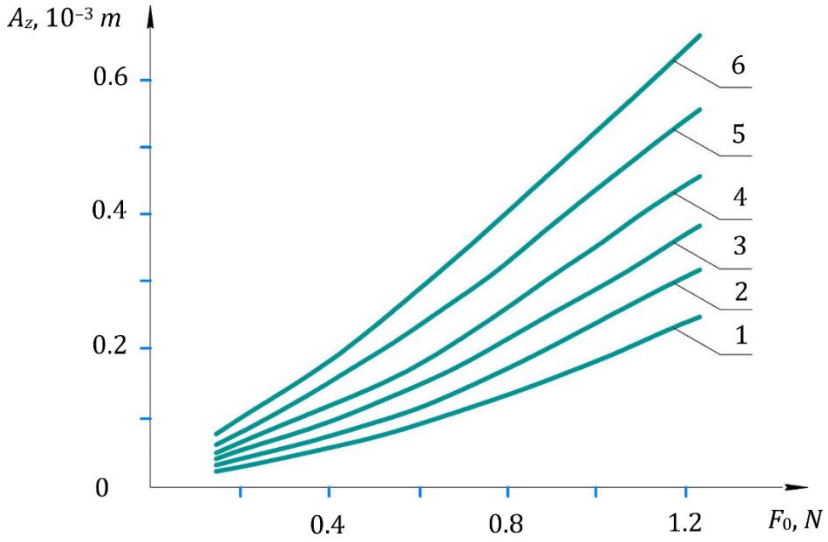


Figure 3. Dependence graphs of the influence of the change in the vibration amplitude of the roller mechanism on the bearing flange and the shell of the roller mechanism

The analysis demonstrates that roller mechanisms equipped with flexible elements have a significant impact on the operational stability, energy efficiency, and load-bearing capability of belt conveyor systems. Deformation and dynamic vibrations were identified as the primary limiting factors influencing performance. The results provide a theoretical and practical foundation for optimizing conveyor structure stiffness, reducing energy losses, and improving overall mechanical reliability.

CONCLUSION

In this research work, the kinematic and dynamic characteristics of motion transmission processes through roller mechanisms with belt elements of belt conveyors were studied in a comprehensive manner. As a result, the kinematic and dynamic characteristics of the roller mechanisms, the rotation speed of the belt, the friction coefficient and the load parameters directly affect the accuracy of motion transmission, vibration stability and energy efficiency of the system. The developed mathematical models and dynamic equations made it possible to determine the operation of the system in real conditions, estimate energy losses and optimize the design parameters. The results of the research confirmed that by implementing the design and parametric optimization of the roller and belt, the risk of belt slippage is reduced, vibration stability is increased and the accuracy of motion transmission is ensured to the maximum. In conclusion, this work made it possible to conduct a deep

scientific and technical analysis of the motion transmission processes through roller mechanisms with belt elements of belt conveyors and developed recommendations to ensure the efficient, reliable and energy-optimized operation of the mechanisms.

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