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## **IN REFERENCE TO THE RESEARCH OF PIPE BELT CONVEYOR**

**Abstract.** The article considers the initial provisions of the research and design of conveyor transport that allows to transport bulk cargo in safety.

At the same time, it is noted that there is a need for a harmless impact on the environment, especially in long-distance routes transporting with vertical and horizontal bends, as well as with a minimum number of reloading nodes.

The review and analysis of the standard sizes of existing conveyors shows certain advantages of the technological nature of the pipe belt conveyor (PBC).

The considered construction of PBC, in comparison with existing ones is formed with a closed belt tray due to support devices placed along the perimeter of the transportation line of bulk cargo.

It is indicated that when the belt with the load moves simultaneously behind the roller support, due to some collapse of the belt the relationship between the cargo particles and the belt decreases and the system "transported cargo – conveyor belt" is in an active stress state. This circumstance makes it possible to ignore the active phase at high transport speeds.

It is revealed that the main advantages of conveyor transport are a high level of labor productivity, achieved by automating the operation of equipment and low production costs. The problems are the need to split the transported cargo, accurate reconciliation of transition areas, coordination of drives and synchronization of movements, easily adjustable in the course of work, subject to certain initial construction conditions.

The tractive calculation of the PBC by circumventing the contour, as with traditional conveyors, allowed us to determine the force of resistance to the movement of the belt, the load pressure along the cross section, and the forces acting on the lower and side rollers.

A computer 3D model of the PBC was created by using the SolidWorks software product, which includes: creating special support elements and roller supports that twist the belt into the pipe, selecting metal construction elements and calculating their strength, roller supports, and supporting conveyor devices.

The stress-strain state of the belt is shown and a model of the PBC under load is constructed, a load map that allows analyzing the distribution of various internal reactive force factors, i.e. forces and moments that occur in the elements of the design model.

**Key words:** bulk cargo transportation, conveyor belt, pipe belt conveyors, ring roller supports, computer modeling, stress-strain state of the belt.

**Introduction.** Nowadays a modernized type of conveyor systems called pipe belt conveyors (PBC) are becoming widely used in production [1,2].

It is characterized by the efficiency of in-line transportation of bulk cargo over long distances having routes with vertical and horizontal bends with a minimum number of reloading nodes.

Elimination of losses of transported cargo, isolation of dust-like, hot, aerating and chemically aggressive cargo from the impact on environment are the main prerequisites for creating new highly

efficient systems for horizontal and steeply inclined movement of bulk cargo [2-4]. The closed transport system not only protects the transported material from external influences, but also allows to avoid loss and leakage of cargo.

This type of conveyor system serves cement and power plants, port loading and unloading complexes, as well as the chemical, steel and mining industries [5].

The first PBC concept was introduced in 1978 by the Japan Pipe Conveyor Company, which received patents worldwide.

The basis for the patent was the ability to form a so-called conveyor pipe using a unique belt design and special pipe-forming roller supports.

Bridgestone Corporation acquired all rights to the system developed by the Japan Pipe Conveyor Company and granted Krupp Robins, Inc. exclusive marketing rights in the United States., Bridgestone in cooperation with Krupp Robins, Inc. has developed and refined the limited original technology [6].

Today, PBC systems are used by such companies as: Koch, ContiTech (Germany), Noyes (France), Nova (Italy), Dosco (UK), Simplicity (India), Krupp Robins (USA), Young Poony (Korea) and Sistemas (America), etc. [5,6].

In the Republic of Kazakhstan, there are many industrial sectors that transport various materials by bulk density on both mountain landscapes and plain quarries (Temirtau, Sokolov-Sarbay), where the use of this type of conveyor is advisable [2,7]. The issues of separating sand from water and transporting them to the working body of a mini and small hydroelectric power station due to the energy of a swirling jet are set out in [8,9]. All this shows the relevance of the problem under consideration in the Republic of Kazakhstan, as well as on a global scale.

**Description of the considered construction.** In general the PBC is a closed curved system for transporting bulk materials. The technological novelty of the conveyor construction (figure 1) is forming a closed belt tray using support devices placed along the perimeter of the tray intended for transporting bulk cargo. For this novelty the patent of the Republic of Kazakhstan No. 32227,2015 was obtained [7].

It consists from a drive 1; a grooved support 2; a belt 3; a metal structure 4; a tubular part of the belt 5; a support 6 and a tension station.

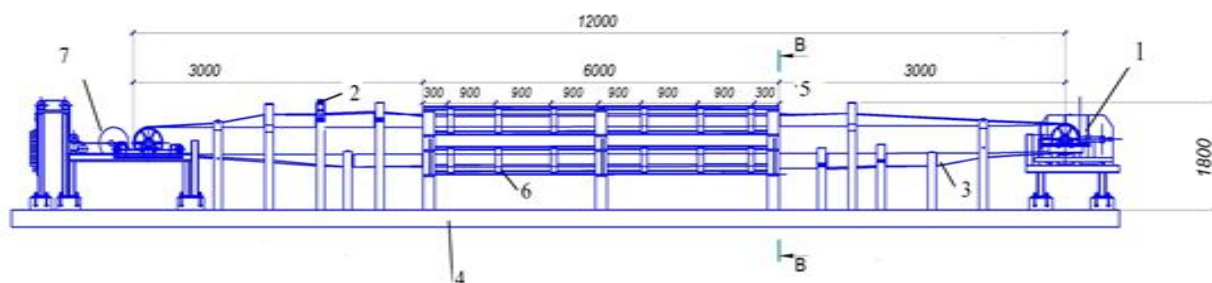


Figure 1 – Pipe belt conveyor

In the loading and unloading zones the system is in an open belt conveyor form. After loading the bulk cargo, the belt is formed into a pipe shape overlapping with special roller supports at a certain distance and then guided by the same roller supports. In the unloading zone, the belt automatically opens after the idle end station and transfers the material to the destination.

The main problems of such conveyor systems are the need of the transported cargo fragmentation, accurate reconciliation of transition sections, coordination of drives and synchronization of movements, which are easily regulated in the operation process, subject to certain initial design conditions [2].

When using PBC, it is possible to transport materials at an angle. Because of the special belt and its orientation, the conveyor can change the trajectory with a radius of less than one meter. The transported material is isolated, easily loaded and unloaded in the necessary places, and you can also use the reverse branch to transport other material in the opposite direction [3,4,10].

**The results of traction calculation.** The PBC traction calculation was performed using the contour bypass method as for traditional conveyors.

Due to changes in the structure of the stands, the distributed forces of movement resistance that occur on the loaded and empty branches of the linear part of the PBC differ significantly from similar forces that occur on traditional belt conveyors.

At the same time the belt is supported by grooved roller supports and when moving inside the ring roller supports it is deformed which leads to a force of resistance to movement and vice versa [11-14].

Analytically, it is extremely difficult to solve the problem of deformation of a pipe-shaped belt with sides connected by overlapping and loaded with an uneven load along and across [15-18].

There is also a second task to determine the force of movement resistance from pressing the supporting rollers into the lower lining of the pipe-shaped belt and vice versa.

When the loaded belt is moving, immediately behind the roller support due to some collapse of the belt the relationship between the cargo particles and the belt is reduced, and the system "transported cargo-conveyor belt" is in an active stress state. Therefore, at high transport speeds, the active phase can be ignored.

Then the force of resistance to the movement of the belt can be determined by the formula:

$$W_x = (a + bv) \cdot \dot{u}(0) + C_p \cdot P + C_f \cdot F_0, N \quad (1)$$

where  $P$  and  $F$  – radial and axial loads, N;  $C_p$ ,  $C_f$  – radial and axial load coefficients,  $C_p = 16 \cdot 10^{-5}$ ,  $C_f = 1.5 \cdot 10^{-5}$ ;  $\dot{u}(0)$  – ambient temperature coefficient during the rotation of the rollers;  $a$ ,  $b$  – coefficients considering the constructive sealing of assembly and the amount of lubrication [12].

The pressure from the cargo across the cross section is distributed as follows [7,11,13]:

$$p'(\varphi, \alpha) = R \cdot \rho \cdot g \int C(\alpha) d\alpha, Pa \quad (2)$$

where  $C(\alpha) = (\cos 2\varphi + \cos\alpha) \cdot (\cos^2\alpha + \frac{\sin^2\alpha}{m})$  – passive pressure function;  $C(\alpha) = (\cos 2\varphi + \cos\alpha) \cdot (\cos^2\alpha + m \cdot \sin^2\alpha)$  – active pressure function;  $\varphi$  – the angle that characterizes the filling degree of the belt cross section;  $m$  – the mobility coefficient of cargo;  $\alpha$  – the current inclination angle of the considered site to the horizontal;  $\rho$  – bulk density of cargo, kg/m<sup>3</sup>;  $R$  – radius of the pipe-shaped belt, m.

$$p_{pas}(\alpha) = p'_{pas} \frac{l'_p}{2} = \frac{1}{2} R \rho g l'_p \int C_{pass}(\alpha) d\alpha, N/m \quad (3)$$

$$p_{act}(\alpha) = p'_{act} \frac{l'_p}{2} = \frac{1}{2} R \rho g l'_p \int C_{act}(\alpha) d\alpha, N/m \quad (4)$$

Then the equation of total load is determined as follows:

$$p_\Sigma(\alpha) = p_{pas}(\alpha) + p_{act}(\alpha) = \frac{1}{2} R \rho g l'_p \int (C_{pas}(\alpha) + C_{act}(\alpha)) d\alpha, N/m \quad (5)$$

The equivalent concentrated load acts on the roller from the load within the angle  $\Delta\delta$ , and on the section of the belt width  $\Delta B = R\Delta\delta$ , (Figure 2).

A force that acts on the lower roller:

$$P_{p1} = 2P_1 = 2 \cdot \frac{\pi}{6} \cdot 0,0075 \cdot 1.27 = 0.00996 kN = 9.06 N$$

Loads that are applied to the lower side rollers:

$$P_{p2} = P_{p6} = \frac{\pi}{3} R^2 \rho g \frac{l'_p}{2} = \frac{1}{2} R \rho g l'_p \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} (C_{pas}(\alpha) + C_{act}(\alpha)) d\alpha, N \quad (6)$$

$$P_{p3} = P_{p5} = \frac{\pi}{3} R^2 \rho g \frac{l'_p}{2} = \frac{1}{2} R \rho g l'_p \int_{\frac{\pi}{2}}^{\frac{5\pi}{6}} (C_{pas}(\alpha) + C_{act}(\alpha)) d\alpha, N \quad (7)$$

At the moment DS-SolidWorks software is one of the most popular and widely used software packages in the world. It includes a wide range of integrated CAD/SAM modules and more than 500 specialized applications. In this regard, PBC modeling was performed using DS-SolidWorks.

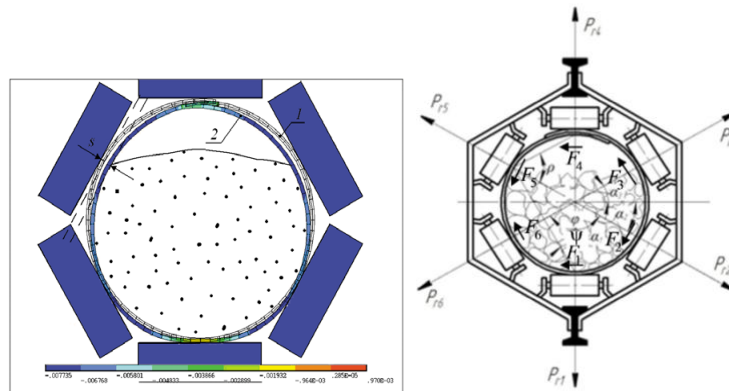


Figure 2 – B-B cross section of a loaded pipe belt with loads

Figure 3 shows the stress-strain state of the belt with a width of 800 mm and a load transport speed of 2.5 m/s. It can be seen that the middle part under the belt is the most loaded. The constructed model of PBC is loaded at various cargo, the material density is 1.1-1.6 t/m<sup>3</sup>.

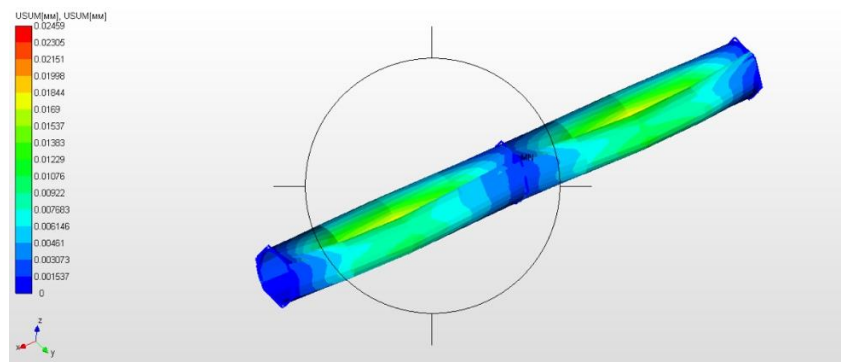


Figure 3 – Stress state of the loaded pipe belt

The map of loads made it possible to analyze the distribution of various internal reactive force factors (forces and moments that occur in the elements of the construction model). Using the settings of the dialog box, the results of the components and normal stresses in the X and Y axes plane of the local coordinate system of the structure can be viewed (figure 4).

The stress map showed the maximum stress at the joints of the construction, but there is a sufficient strength reserve  $\sigma_{max} = 179$  MPa.

A 3D computer model of a pipe belt conveyor was performed using the SolidWorks software product, which includes: creating special support elements and roller supports that twist the belt into the pipe, selecting metal construction elements and calculating their strength, and roller supports - supporting conveyor devices.

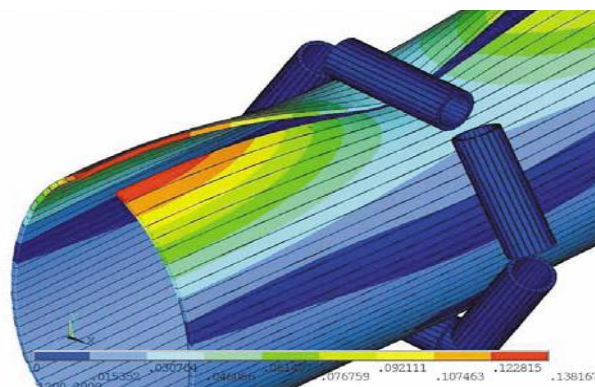


Figure 4 – Stress-strain state of the belt

Torsional oscillations of the PBC occur during the operation of the PBC, so research have been carried out using the finite element method. As the speed of the conveyor belt increases, the lowest natural frequency decreases and tends to zero [10,14]. The Hamilton-Ostrogradsky principles are used to describe the PBC movement. To determine the rotational movement of the tubular conveyor belt, consider a linear section of the PBC.

To illustrate the application of the developed approach, consider a straight section of pipe belt conveyor with the following parameters:  $a = 16 \text{ m}$  – linear section length of the conveyor;  $R = 0.108 \text{ m}$  – average radius of the pipe circumference;  $\delta = 0.06 \text{ m}$  – belt thickness;  $G = 0.16 \cdot 10^6 \text{ Pa}$  – shift modulus;  $\psi = \pi$  – the angle that characterizes the filling degree of the belt cross section with a load;  $\rho = 800 \text{ kg/m}^3$  – coal density;  $\rho_b = 1200 \text{ kg/m}^3$  – belt density;  $\rho = 1223 \text{ kg/m}^3$  – given density;  $I_{p.rot.} = 5.12 \cdot 10^{-4} \text{ i}^4$  – moment of inertia of the pipe rotation;  $I_{c.rot.} = 0.15 \cdot 10^{-4} \text{ i}^4$  – moment of inertia of the cargo rotation;  $\rho I_0 = 0.63 \text{ kg} \cdot \text{m}$  – linear mass moment of inertia;  $GI_k = 29.3 \text{ N} \cdot \text{m}^2$  – torsional cross-section stiffness;  $v = 0 \div 5 \text{ m/s}$  – speed of the conveyor belt.

The inertia and stiffness matrices of the  $n^{\text{th}}$  rod element having a length  $a_n$ , the torsional stiffness of the section  $(GI_k)^{(n)}$ , and the linear mass moment of inertia  $(\rho I_0)^{(n)}$ , where  $\rho$  is the reduced density of the pipe with the load,  $I_0$  is the polar moment of inertia of the pipe cross section with the cargo, taking into account (6) are equal to:

$$M_n = \rho I_0 \int_0^{a_n} H_n(z)^T H_n(z) dz = \rho I_0 \int_0^{a_n} \begin{bmatrix} 1 - \frac{z_n}{a_n} \\ \frac{z_n}{a_n} \end{bmatrix} \begin{bmatrix} \left(1 - \frac{z_n}{a_n}\right) & \frac{z_n}{a_n} \end{bmatrix} dz =$$

$$K_n = \int_{a_{n-1}}^{a_n} B_n^T(z) (GI_k)_n B_n(z) dz - v^2 \int_0^{a_n} B_n^T(z) (\rho I_0)_n B_n(z) dz =$$

Let's consider a section of the PBC as two finite elements containing three nodes. The inertia and stiffness matrices of individual finite elements using the formulas (9) are equal to:

$$M_1 = M_2 = \frac{\rho I_0 a_n}{12} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \quad (10)$$

$$K_1 = K_2 = \frac{2GI_k}{a} \left[ 1 - \left(\frac{v}{v_0}\right)^2 \right] \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad (11)$$

The corresponding global degrees of freedom have the form:

$$f_1 = \begin{bmatrix} \varphi_1(t) \\ \varphi_2(t) \end{bmatrix} \quad (12)$$

$$f_1 = \begin{bmatrix} \varphi_2(t) \\ \varphi_3(t) \end{bmatrix} \quad (13)$$

In node 1 of the PBC, the rotation angle  $\varphi_1(t)$  is zero.

By satisfying the boundary conditions we obtain a characteristic equation for determining the eigenfrequencies of torsional vibrations can be obtained in the form:

$$\det \left\{ \frac{2GI_k}{a} \left[ 1 - \left(\frac{v}{v_0}\right)^2 \right] \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} - \omega^2 \frac{\rho I_0 a}{12} \begin{bmatrix} 4 & 1 \\ 1 & 2 \end{bmatrix} \right\} = 0 \quad (14)$$

By taking into account the dimensionless frequency parameter  $v_0 = \sqrt{\frac{GI_k}{\rho I_0}}$  equation (14) can be rewritten as:

$$\det \left\{ \begin{bmatrix} 2 & -1 \\ -1 & 1 \end{bmatrix} - \left(\frac{\omega}{v_0}\right)^2 \beta \begin{bmatrix} 4 & 1 \\ 1 & 2 \end{bmatrix} \right\} = 0 \quad (15)$$

$$\beta = \frac{a^2}{24 \left[ 1 - \left( \frac{v}{v_0} \right)^2 \right]} \quad (16)$$

By solving the quadratic equations (10) and (11), we obtain the eigenfrequencies  $\omega_1 \leq \omega_2$  for the finite element model of the PBC can be obtained:

$$\omega_1 = \frac{v_0}{a} \sqrt{\frac{5 - 3\sqrt{2}}{7} 24 \left[ 1 - \left( \frac{v}{v_0} \right)^2 \right]}$$

$$\omega_2 = \frac{v_0}{a} \sqrt{\frac{5 + 3\sqrt{2}}{7} 24 \left[ 1 - \left( \frac{v}{v_0} \right)^2 \right]}$$

These values are the upper bound for the true natural eigenfrequencies.

In the intermediate cases, figure 5 shows the dependence of the lower dimensionless eigenfrequency  $\xi = \frac{\omega_1 a}{v_0}$  from parameter  $v$  for different values of  $a$ . The solid line corresponds to  $a=5$  m, dotted –  $a=10$  m, dashed –  $a=20$  m, dash-dotted –  $a=40$  m.

Consideration shows that as the speed of the conveyor belt increases, the lowest natural frequency decreases and tends to zero. As the length of the straight section of the conveyor increases, the lower frequency decreases.

The computer simulation was performed in the SIMULINK system, which is included in the MATLAB application package. Using typical SIMULINK blocks a block diagram of the system was assembled, including a conveyor belt contour, a drive and tensioning device. A mathematical model of the PBC movement was created:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (17)$$

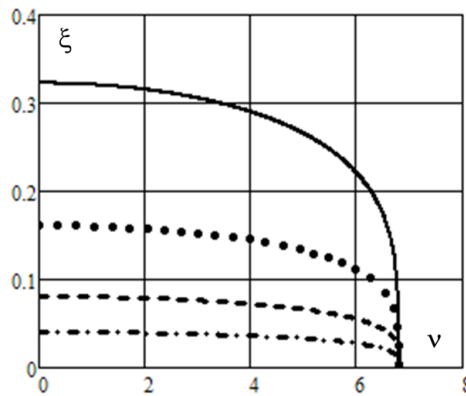


Figure 5 – Dependence of the dimensionless lower eigenfrequency on the speed of the conveyor belt

where  $\dot{x}$  – belt speed;  $Ax$ ,  $Cx$  – static tractive force ("tractive force" in short) that must be applied to a tractive organ in order to move it at a constant speed, N;  $Bu$  – the inertial resistance to movement of the belt, N;  $y$  – total tractive force developed by the drive, N;  $Du$  – braking force that occurs when the brakes are closed, N.

All forces in (2) are applied to the circumference of the drum drive.

Equation of motion in the start-up phase:

$$y = F_{max} = \lambda F_{nom} = \frac{1000\eta N}{g} \quad (18)$$

where  $F_{max}$  – the maximum tractive force that can be approximated based on the nominal tractive force  $F_{nom}$  and the multiplicity of the starting torque of the engine  $\lambda$ ;  $N_{nom}$  – nominal capacity of the drive, kW;  $\vartheta$  – nominal speed of the traction body, m/s;  $\eta$  – drive efficiency coefficient.

The development of the PBC movement model allowed us to determine transient processes by the speeds of generalized coordinates when starting the conveyor at a speed of 2.5 m/s. Determination of rational technological parameters is the task of further research.

**Conclusion.** As the world experience shows, PBC are one of the alternative installations for transporting bulk cargo in a closed way.

The results of the traction calculation of the developed conveyor by circumventing the contour, to the necessary extent allows to set the movement resistance force of the belt, the pressure from the cargo along the cross section, the forces acting on the lower and side rollers.

The results of PBC computer modeling in 3D using the SolidWorks software product and the developed mathematical model allows to describe the change in the tension of the PBC along the linear part of the PBC and reveal the essence of the ongoing process when using the conveyor.

The research of the stress-strain state of the belt with a width of 800 mm, a transportation speed of 2.5 m/s and a material density of 1.1-1.6 t/m<sup>3</sup> shows that the middle part under the belt is the most loaded.

In further improvements to the conveyor and its operation technology it is necessary to ensure accurate reconciliation of the transition sections, synchronization of movements, easily adjustable during operation if the initial conditions are met.

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### **ҚҰБЫРЛЫ ТАСПАЛЫ КОНВЕЙЕРДІ ЗЕРТТЕУ МӘСЕЛЕСІ**

**Аннотация.** Мақалада сусымалы жүкті жол бойында сақтап, тасымалдауға мүмкіндік беретін конвейерлі көлікті зерттеуге және жобалауға негіз болатын бастапқы жағдайлар қарастырылған. Сонымен қатар, қоршаған ортаға зиянсыз әрекеті, әсіресе, трассадағы тік және көлбеу бұрылыстармен алыс қашыққа тасымалдау және тиіп-түсіру түйінінің аз кездесетіні жайында айтылады.

Қолданыстағы конвейерлердің пайдаланылатын стандартты өлшемдеріне жүргізілген шолу мен талдау жұмыстары құбырлы таспалы конвейердің (ҚТК) технологиялық сипатының белгілі артықшылықтарын көрсетеді.

Қарастырылған ҚТК конструкциясының қазіргі қолданыстағы түрінен ерекшелігі, тасымалданатын сусымалы жүк периметрі бойымен орналасқан тірек құрылғылары есебінен тұйықталған таспа лотоктардан тұрады.

Таспа жүкпен бірге бір уақытта қозғалғанда роликті тіректен кейін таспаның кейбір тұстары жалпаятындықтан, жүк пен таспаның бөліктері арасында өзара байланыс әлсірейді және «тасымалданатын жүк – конвейерлік таспа» жүйесі активті кернеулі жағдайында болады. Бұл жағдай тасымалдаудың жоғары жылдамдығындағы белсенді фазаны есептемеуге мүмкіндік береді.

Конвейерлік көліктің басты артықшылығы – жабдық жұмысын автоматтандыру және өндірістік шығынды азайту жолымен қол жеткізетін еңбек өнімінің жоғары деңгейі екендігі анықталған. Бұған қатысты басты мәселелер – кейбір бастапқы конструктивтік шарттарды жұмыс барысында сақтау арқылы жеңіл реттейтін тасымалданатын жүк ұсақтау қажеттілігі, ауысатын учаскелерді дәл анықтау, жетектерді сәйкестендіру және қозғалысты синхронизациялау.

Контурдың бойымен айналу әсерінен жүзеге асқан ҚТК тартымдық есебі дәстүрлі конвейерлерді пайдалану кезіндегідей, таспа қозғалысына кедергі күштерді, көлденең қимасына жүк қысымын, астыңғы және бүйірлік роликтерге әсер ететін күштерді анықтауға мүмкіндік береді.

SolidWorks бағдарлама өнімін пайдалана отырып, 3D КЛК-да компьютерлік модель жасалды, оған мыналар кіреді: лентаны құбырға айналдыратын арнайы тірек элементтері мен роликпоралар жасау, металл конструкция элементтерін таңдау және олардың беріктігіне есептеу, роликпор, конвейердің қолдау құрылғылары.

Таспаның кернеулік-деформацияланған күйі және ҚТК-дің жүкпен салмақ түсірілген моделі тұрғызылған, түрлі ішкі реактивті күштік факторлар бөлінісін, яғни конструкция моделінің элементтерінде пайдаланылатын күштер мен сәтті талдауға мүмкіндік беретін жүктемелер картасы көрсетілген.

**Түйін сөздер:** сусымалы жүктерді тасымалдау, конвейерлік таспа, құбырлы таспалы конвейер, сақиналы роликті тіректер, компьютерлік модельдеу, таспаның кернеулік-деформацияланған күйі.

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## К ВОПРОСУ ИССЛЕДОВАНИЯ ТРУБЧАТОГО ЛЕНТОЧНОГО КОНВЕЙЕРА

**Аннотация.** В статье рассмотрены исходные положения к исследованию и проектированию конвейерного транспорта, позволяющего транспортировать сыпучие грузы в сохранности.

При этом отмечена необходимость безвредного воздействия на окружающую среду, особенно при транспортировке на большие расстояния трассы с вертикальными и горизонтальными изгибами, а также минимальном числе перегрузочных узлов.

Выполненный обзор и анализ используемых типоразмеров существующих конвейеров показывает определенные преимущества технологического характера трубчатого ленточного конвейера (ТЛК).

Рассматриваемая конструкция ТЛК, в отличие от существующих, сформирована с замкнутым лотком ленты за счет опорных устройств, размещенных по периметру линии транспортирования сыпучих грузов.

Указано, что при движении ленты с грузом одновременно за роликкоопорой, вследствие некоторого развала ленты, взаимосвязь между частями груза и лентой снижается и система «транспортируемый груз – конвейерная лента» находится в активном напряженном состоянии. Это обстоятельство позволяет не учитывать активную фазу при высоких скоростях транспортирования.

Выявлено, что главные достоинства конвейерного транспорта – высокий уровень производительности труда, достигаемый путём автоматизации работы оборудования, и низкие производственные затраты. А проблемами, присущими им, являются необходимость дробления транспортируемого груза, точная выверка переходных участков, согласование приводов и синхронизация движений, легко регулируемые в процессе работы при соблюдении некоторых первоначальных конструктивных условий.

Выполненный тяговый расчет ТЛК методом обхода по контуру, как при использовании традиционных конвейеров, позволил определить силу сопротивления движению ленты, давление от груза по поперечному сечению, силы, действующие на нижние и боковые ролики.

Составлена компьютерная модель в 3D ТЛК с использованием программного продукта SolidWorks, включающая: создание специальных опорных элементов и роликкоопор, закручивающих ленту в трубу, выбор элементов металлоконструкции и расчета их на прочность, роликкоопор, поддерживающих устройств конвейера.

Показано напряженно-деформированное состояние ленты и построена модель ТЛК при нагружении грузом, карта нагрузок, позволяющая проанализировать распределение различных внутренних реактивных силовых факторов, т.е. сил и моментов, возникающих в элементах модели конструкции.

**Ключевые слова:** транспортировка сыпучих грузов, конвейерная лента, трубчатые ленточные конвейеры, кольцевые роликкоопоры, компьютерное моделирование, напряженно-деформированное состояние ленты.

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