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RESEARCH OF THE MATHEMATICAL MODEL OF THE TRIBOSYSTEM HEAD ROD-BUSHING OF THE TRACTION ORGAN OF ROD TRANSPORTERS

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Abstract. *The service life and durability of transport and assembly machines depends on structural, technological and operational factors. The wear and tear of parts and working bodies causes a violation of the level and stability of the fulfillment of technical requirements, a decrease in reliability and efficiency, and a reduction in the service life of machines. Any technical means, in particular agricultural ones, can be considered as a system of serially or parallel connected units, aggregates and elements operating under conditions of load dynamics and wear and tear. The failure of one of the elements of the friction unit leads to the loss of its performance. The result is a complete or partial loss of machine performance as a whole. The most rational way to increase the durability of machines is to reduce wear and tear. This can be achieved by developing methods for evaluating the wear of friction parts. The paper proposes a model for evaluating the wear of the rod head-sleeve conjugation of the conveyor traction body of the rod conveyor of root-harvesting machines. The developed model of the tribosystem provides an opportunity to determine the estimated service life of the bars, that is, the conveyor as a whole. The geometric, kinematic and power factors affecting the wear processes of the tribo coupling under study were analyzed. The assessment of the maximum contact stresses of the contacting surfaces of the tribocoupler was performed to prevent premature destruction. The evaluation was performed in the initial stage of the transport machine, when the contact areas are minimal. The average statistical stresses arising in the contact zones, at which the wear process reaches critical values, are determined. Such studies make it possible to unify the dependence for determining the service life of a rod conveyor based on a sleeve-roller chain. Taking into account that the contact stresses depend on the force and geometric parameters, it is advisable to use the obtained mathematical model for the design of the rod-sleeve connection structures to ensure the specified service life of the mechanism.*

Key words: *rod conveyor, sleeve-roller chain, contact stresses, work resource, mathematical model, rod, sleeve, tribocoupling.*

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1. INTRODUCTION

Statement of the problem. The reliability and durability of mechanical systems, in particular agricultural machinery, can be improved by mechanics of solids. The basis for this is theoretical and experimental studies of material fracture processes and tribocontact interaction based on the theory of fatigue wear. Such studies allow us to make rational design decisions regarding the joints of contacting parts and correctly choose the materials, and, based on experimental and analytical studies, to give recommendations for extending the service life of machines.

The solution of a practical tribotechnical problem, such as assessing the wear of the rod heads of conveyor belts, can be determined based on the known fundamental principles of wear models. It is necessary to build a mathematical model for assessing the durability of the tribosystem under consideration. In rod conveyors with a traction organ based on sleeve-roller chains, sliding friction is observed. Based on the results of tribological studies, it can be argued that the most common mechanism for such friction is fatigue failure [14, 15, 16].

Analysis of available research. The working branch of a rod conveyor consists of hinged joints, the wear resistance of which determines the durability of the conveyor as a whole. The friction of the parts of the hinged joints of the conveyor is caused by the loading mode, the number of abrasive particles that fall into the contact plane of the friction parts. Conveyor links operate mostly without lubrication.

When designing new mechanisms with hinged joints or improving the existing models, it is necessary to use the gained experience to study their wear resistance.

Constructive solutions that would ensure the wear resistance of hinge joints are implemented by improving the friction conditions of the hinge parts: reducing the load on friction surfaces, increasing the nominal contact area of friction parts in a hinged joint, protecting the surfaces of parts from abrasives, using materials with increased wear resistance for parts manufacturing, changing the types of friction in joints (rolling is replaced by sliding), eliminating external friction in joints through the use of elastic elements, etc. [1, 5, 6, 7].

It is possible to increase the durability of metal-intensive structures by using replaceable parts, which restores the operability of hinge joints by replacing worn hinge elements with new ones.

Objective of the investigation. To create a mathematical model that would allow to determine the geometric parameters of the head rod-bushing conjugation of the traction device according to the predicted service life and technological load on the working parts of the rod conveyor.

Statement of the task. To investigate the mathematical model of the head rod-bushing tribosystem of the conveyor's traction body and to perform analytical studies of geometric, kinematic and power factors that affect the service life of the mechanism.

The results of the investigation. Rod conveyors are essential working units of agricultural machines designed for harvesting root crops and vegetables. Such conveyors move root and tuber crops, and depending on the harvesting technology, take them from the digging mechanisms and feed them into storage hoppers or onto the bodies of machines or tractor trailers. Root crops are transported by rod conveyors and are simultaneously cleaned from soil residues. The web of such conveyors is made of steel rods, and the traction elements are sleeve-roller chains. For the purposes of this study, we will consider a rod conveyor with rods made of calibrated steel 35 with a diameter of 10.8 mm. The chain axes are constructively replaced by the conveyor rods (Fig. 1).

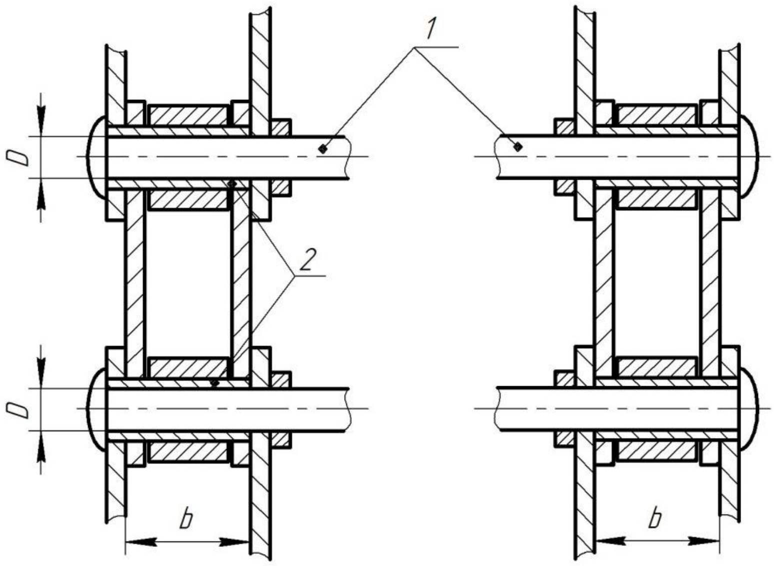


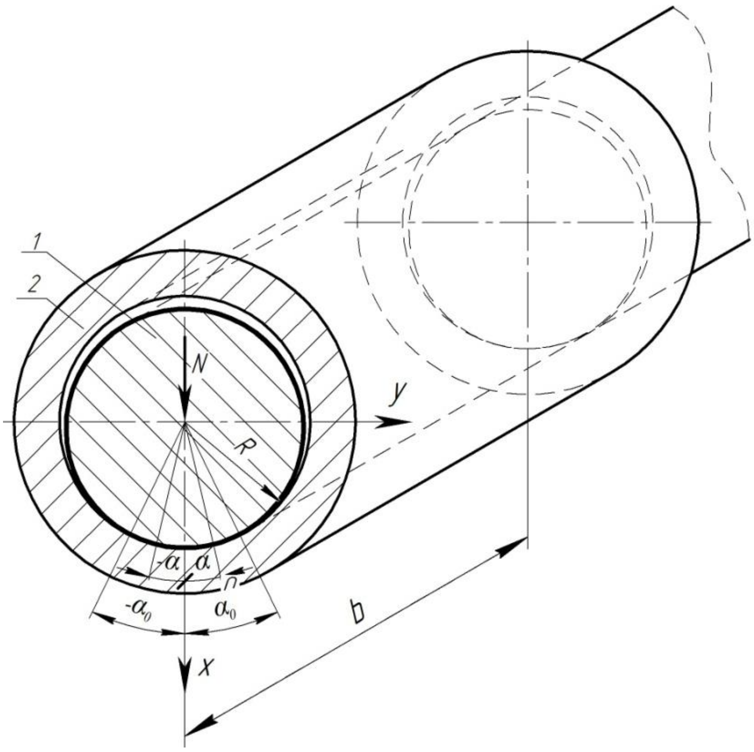
Figure 1. Schematic diagram of the rod-sleeve connection of the traction body of the conveyor 1 – rod; 2 – sleeve

2. EXPERIMENTAL METHODS

The technological design of the one-piece connection of the rods to the chains is carried out by flaring the ends of the rods. This allows the rods to act as chain axles and the functional purpose of the traction unit is not impaired. The parts of the rods that are fixed in the holes of the links and serve as chain axles are the most heavily loaded, and we consider them to be the heads of the rods.

During the transportation of root crops, the heads of the rods are fixed in relation to the chain sleeves, experiencing a radial load from the weight of the transported mass. When the raw material is unloaded into the hopper, which is the upper position of the rods, the rods partially rotate around their axes in relation to the fixed chain sleeves. The friction in the contact area between the rod head and the chain bushing causes wear. Long-term usage of the conveyor causes wear, which, when it reaches critical values, can lead to a conveyor shutdown due to the release of the rod heads from the chain sleeves [1, 4, 6, 7, 8, 10].

The links of rod conveyors based on sleeve-roller chains operate in a metal-to-metal pair (Fig. 2) under conditions of significant abrasive wear, which is typical for agricultural harvesting machines.



$0 < \alpha \le \alpha_0$;

$l_0 = \alpha_0 \cdot R$ – maximum line of contact;

$l = \alpha \cdot R$ – working line of contact;

$2\alpha_0$ – the angle that determines the maximum contact surface of the parts to be joined;

N – force acting on the rod head during operations.

Figure 2. Schematic diagram of the tribo coupling of the head of the rod and the conveyor link 1 – rod head; 2 – bushing of the traction body

During the technological process, the outer surface of the rods and the inner surface of the bushings wear out.

The conveyor becomes unusable when the total wear inside the joint is from 1.5 to 3 mm. To study the service life of the rod conveyor, namely, the time of wear of the rod head in the chain bushings, we accept the value of critical wear of the rod head surface as $h = 1$ mm [13, 14, 15].

The time of abrasion of the conveyor rod head before it leaves the mounting holes, i.e., the service life of the conveyor is

$$T = \frac{t_0}{h}, \tag{1}$$

where t_0 is the time for the actively loaded part of the rod head to complete a full rotation in the chain bushing;
h is the cutoff value of the surface of the conveyor rod head, it is assumed to be $h = 1$mm.

The most loaded rods of the conveyor will be those with scrapers that support the transported mass. Let's consider the conditions under which the greatest load on the rods is possible. The scrapers approach the unloading zone (upper position) of the conveyor periodically

$$t = \frac{L_{П}}{V_T}, \tag{2}$$

where $L_{П}$ is the total length of the conveyor web;
V_T is the linear speed of the conveyor web .

Over time t, the active zone of the rod surface is rotated by an angle θ that is equal to the angle of inclination of the conveyor to the horizon. Accordingly, one complete active rod rotation requires $2\pi/\theta$ cycles.

The time for the actively loaded part of the rod head to make a full rotation is

$$t_0 = \frac{L_{П}}{V_T} \cdot \frac{2\pi}{\theta}. \tag{3}$$

The wear kinetics of a cylindrical head of a rod for the case under study is

$$\Phi(\tau)\frac{dh}{dL_{TP}} = 1. \tag{4}$$

We assume that the head of the rod is worn evenly along the contour during the operation of the conveyor. At each point of the contour, wear will occur as the rod head passes the active contact zone. Using the kinetic wear equation (4) to determine the amount of linear wear of the head contour of the rod for one rotation $h(2\pi R)$, we obtain the following dependence

$$h(2\pi R) = 2\frac{1}{\int_0^{l_0} \Phi^{-1}(\tau)\,dl} = 2\int_0^{l_0} \Phi^{-1}(\tau)\,dl. \tag{5}$$

The resource of the head of the rod is respectively

$$T = \frac{2\pi}{\theta} \cdot \frac{0{,}5\, L_{П}\, B\, \tau_0}{V_T} \left\{ \int_0^{l_0} \left[\frac{f\, G}{R(1-\mu)} \cdot \sqrt{\frac{N\, R(1-\mu)}{\pi\, b\, G} - l^2} - \tau_0 \right]^m dl \right\}^{-1}, \tag{6}$$

where τ_0, m, B are the wear resistance parameters of the tribo-conjugation.

During operation, the web of rod conveyors is loaded in different ways. The effect of uneven distribution of external loads from the transported mass was investigated for typical loading cases (Fig. 3). According to the results of the study, we obtained radial forces that arise on the contacting surfaces – in the range of 100 to 400 N [3, 4, 7, 8].

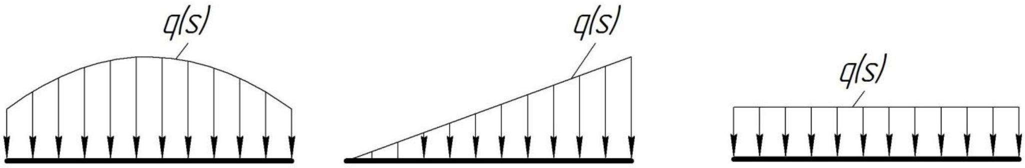


Figure 3. Characteristic diagrams of the distribution of external loads on the belt conveyor belt

3. RESULTS AND DISCUSSION

Let's consider the structural and force components of the rod conveyor joint that affect its service life. We will perform an analytical study of the change in the areas of the contacting surfaces of the tribo-conjugation. We will vary the pressure forces in the supports and the length of the supports to track their impact on the lifetime of the conveyor.

The maximum contact surface area of the head of the rod-sleeve chain is

$$A = l_0 \cdot b, \quad (7)$$

where l_0 where is the maximum length of the contact line of the surfaces

$$l_0 = \sqrt{\frac{2N \cdot R(1-\mu)}{\pi \cdot G \cdot b}}, \quad (8)$$

here N is the radial load that occurs in the contact area, which varies depending on the distribution of the process mass on the conveyor belt; R is the radius of the guiding circle, which depends on the size of the head of the rod, R =5.4 mm; b is the contact line; μ is the Poisson's ratio, μ =0.3; G is the shear modulus, $G = 8{,}1 \cdot 10^4$ N/mm^2.

Let us investigate the change in the maximum contacting surface areas (Fig. 4) depending on the change in pressure forces and contact width in the contact zones of the rod-bushing connection.

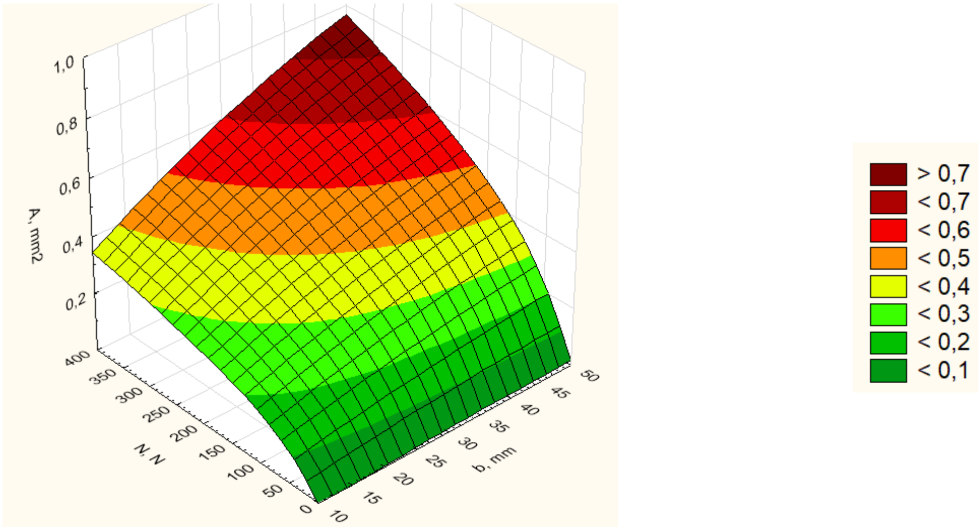


Figure 4. Dependence of maximum contact areas on pressure forces and contact width

The performance of the head rod-bushing conjugation of a conveyor has a significant impact on the depth of their diffuse layer. The cementation depth of the rod heads should be greater than that of the bushings. The cleanliness of the contact surfaces of the rollers, sleeves and plates should be at least class seven.

The wear of the contact surfaces between the rod and the chain bushing largely depends on the maximum stresses that occur on their surfaces during operation. To assess the strength of the connection under study, let us determine the maximum contact stresses in this friction pair [9].

$$\sigma_{H\max} = \frac{G}{R(1-\mu)} \cdot \sqrt{\frac{2N \cdot R(1-\mu)}{\pi \cdot G \cdot b}} . \tag{9}$$

For typical operating conditions of a rod conveyor, we will determine the maximum contact stresses in the contact zones of the head rod-bushing chain. Let's study the change in stresses depending on the size and distribution of the transported process mass and the geometric parameters of the connection (Fig. 5) and compare them with the ultimate stresses. The ultimate contact stresses for the contact surfaces under study are within $\sigma_H = 570...670$ MPa. If they are exceeded, the contact surfaces will be destroyed.

The active contact line head rod-bushing chain is within the limits $0 \le l \le l_0$ (Fig. 2). Accordingly, the actual contact stresses during operation vary from the maximum to the final stresses at which the conveyor is out of service. For the accepted mathematical model of tribocontact interaction of deformable bodies (head rod-bushing chain link), the operating contact stresses are

$$\sigma_H(\alpha) = \frac{G \cdot \sqrt{\frac{2N \cdot R(1-\mu)}{\pi \cdot G \cdot b} - l^2}}{R(1-\mu)} . \tag{10}$$

Average contact stresses for the period of operation of the rod conveyor is

$$\sigma_{H.CP} = \frac{1}{l_0}\left\{\frac{G}{R(1-\mu)} \cdot \int_0^{l_0}\left(\sqrt{\frac{2N \cdot R(1-\mu)}{\pi \cdot G \cdot b} - l^2}\right) dl\right\} . \tag{11}$$

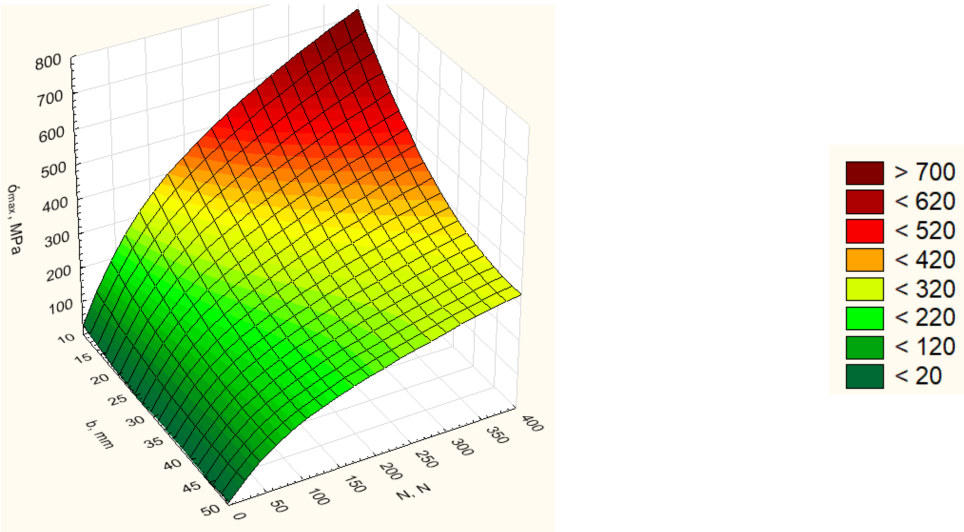


Figure 5. Dependence of maximum contact stresses on pressure forces and contact width

The change in the average contact stresses in the contact zones of the rod heads and chain bushings depending on the loads on the contact zone and the length of the bushings is shown in (Fig. 6).

Having comprehensively studied the parameters that affect the service life of the rod conveyor, the dependence (6) can be written as follows

$$T = \frac{\pi L_{\Pi} B \tau_0}{\theta V_{\Pi}} \cdot \frac{1}{\left(f \cdot \sigma_{HCP} - \tau_0\right)^m}. \quad (12)$$

Using (12), we obtain a dependence for determining the calculated average contact stresses in the head rod-bushing conjugations for the predicted service life of the conveyor

$$\sigma_{H\,CP} = \frac{1}{f}\left(\sqrt[m]{\frac{\pi L_{\Pi} B \tau_0}{\theta V_{\Pi} T}} + \tau_0\right). \quad (13)$$

For the considered tribo-conjugation head rod-bushing chain, the parameters of wear resistance of the tribo-conjugation were determined by a well-known method [14, 15]. The steel 35-steel 35 friction pair was studied by reproducing the effect of an abrasive sandy-clay environment to simulate the technological conditions of operation of rod conveyors of root harvesters. As a result, we obtained: $B = 4{,}25 \cdot 10^8$, $\tau_0 = 0{,}1$ MPa, $m = 0{,}93$.

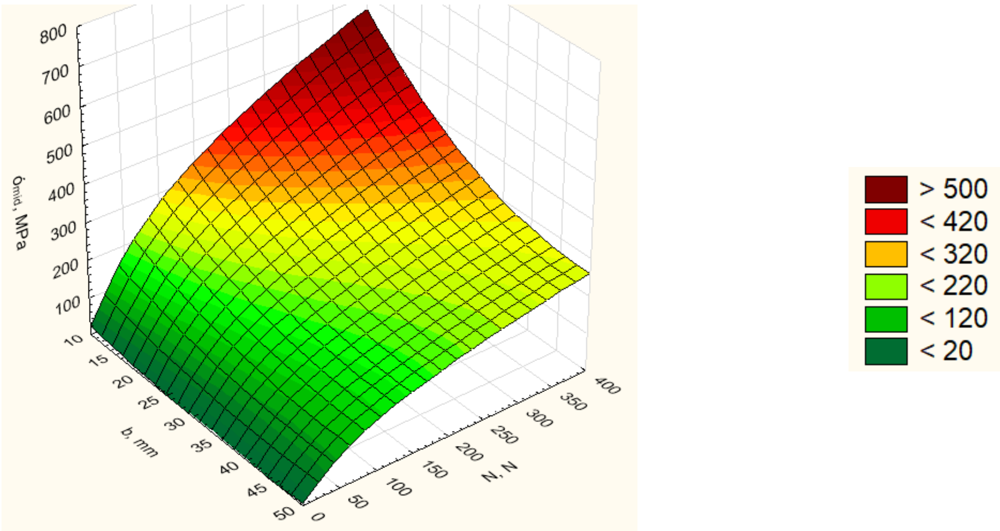


Figure 6. Dependence of average contact stresses on pressure forces and contact width

The force in the contact zone of a head rod-bushing chain during the operation of a rod conveyor varies from 100 N to 400 N. Let us assume for the real design of the longitudinal conveyor of a six-row root harvester N =200N; $L_{\Pi} = 4800$ mm; $V_T = 1140$ mm/sec; $f = 0{,}08$; $G = 8{,}1 \cdot 10^4$ MPa; $\mu = 0{,}3$; $R = 5{,}4$ mm; $\theta = 55°$.

The obtained results of average contact stresses $\sigma_{H\,CP} = f(T)$ are shown graphically (Fig. 7).

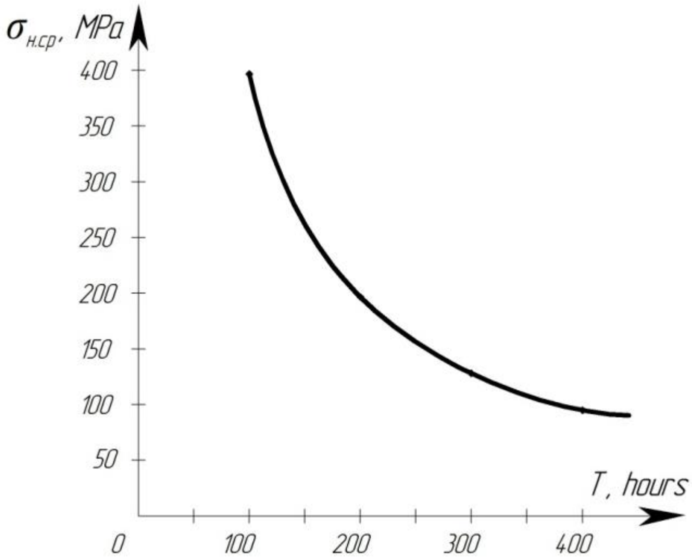


Figure 7. Dependence of the average contact stresses on the service life of the conveyor

Using the dependences (Figs. 4, 5, 6, 7), it is possible to select the necessary design parameters of the rod-bushing connection of the rod conveyor traction unit to ensure the predicted service life under the appropriate loading conditions.

4. CONCLUSIONS

The paper investigates the parameters that affect the wear of rod heads and bushings of the traction units of rod conveyors of root harvesters. The geometrical and power parameters that affect the service life of the studied tribo-conjugation were determined. The obtained results are appropriate for the design of geometrical parameters of connections of the head rod-bushing type of the traction unit. Due to the selected parameters of rod conveyors used for certain technological processes of transporting and separating root and tuber crops, it is possible to obtain structures with a predictable service life.

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УДК 621.855

ДОСЛІДЖЕННЯ МАТЕМАТИЧНОЇ МОДЕЛІ ТРИБОСИСТЕМИ ГОЛОВКА ПРУТКА-ВТУЛКА ТЯГЛОВОГО ОРГАНУ ПРУТКОВИХ ТРАНСПОРТЕРІВ

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Резюме. *Ресурс роботи й довговічність транспортуючих і збиральних машин залежить від конструктивних, технологічних та експлуатаційних факторів. Зношування деталей і робочих органів спричиняє порушення рівня й стабільності виконання технічних вимог, зниження надійності й коефіцієнта корисної дії, скорочення терміну служби машин. Будь-які технічні засоби, зокрема* *сільськогосподарські, можна розглядати як систему послідовно або паралельно з'єднаних вузлів, агрегатів та елементів, що працюють в умовах динаміки навантаженості й зношування. Відмова одного з елементів вузла тертя призводить до втрати його працездатності. Наслідком є повна або часткова втрата працездатності машини в цілому. Найраціональніший шлях підвищення довговічності машин – зменшення зношування. Досягти цього можна розробленням методів оцінювання зношування деталей тертя. Запропоновано модель для оцінювання зношування спряження головка прутка-втулка транспортера тяглового органу пруткового транспортера коренезбиральних машин. Розроблена модель трибосистеми забезпечує можливість визначати розрахунковий ресурс роботи прутків, тобто транспортера в цілому. Проаналізовано геометричні, кінематичні та силові фактори, що впливають на процеси зношування досліджуваного трибоспряження. Виконано оцінювання максимальних контактних напружень контактуючих поверхонь трибоспряження для запобігання передчасних руйнувань. Оцінювання виконано у початковій стадії роботи транспортної машини, коли контактні площі мінімальні. Визначено середньостатистичні напруження, що виникають у зонах контакту, за яких процес зношування досягає критичних значень. Такі дослідження дозволяють уніфікувати залежність для визначення ресурсу роботи пруткового транспортера на основі втулково-роликового ланцюга. Враховуючи, що контактні напруження залежать від силових та геометричних параметрів, отриману математичну модель доцільно застосовувати для проектування конструкцій з'єднання пруток-втулка для забезпечення заданого ресурсу роботи механізму.*

Ключові слова: *прутковий транспортер, втулково-роликовий ланцюг, контактні напруження, ресурс роботи, математична модель, пруток, втулка, трибоспряження.*

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