ізофлавонів ЕКСО, не підвищуючи вміст в кормі кальцію, а нормалізуючи обмінні процеси в організмі, що дозволить уникнути захворювань і патологій, зумовлених надлишковим надходженням кальцію.

Ключові слова: мінеральний обмін, сільськогосподарська птиця, соя, ізофлавони, остеобіотики, кісткова тканина, комбікорм.

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INNOVATIVE DESIGN SOLUTIONS FOR IMPROVING THE ENERGY EFFICIENCY OF SCRAPER CONVEYORS

Abstract

The article examines the issue of improving the energy efficiency of scraper conveyors in transport, logistics and transshipment systems of flexible automated production facilities. The relevance of the work is determined by current trends in industrial development within the framework of Industry 4.0, which involves the introduction of digitalisation, automation and intelligent management technologies for the stable operation of production processes. One of the key tasks in this direction is to minimise energy consumption and increase equipment reliability while ensuring flexibility and efficiency of material flows. The advantages and disadvantages of traditional belt and scraper conveyors are analysed, with an emphasis on the operational limitations of the latter – increased energy consumption, cargo fragmentation, wear and tear of components, etc. The feasibility of using continuous action machines (CAM) as a key element in cargo handling systems is substantiated. A new design of a scraper conveyor with a movable trough bottom is proposed, which eliminates relative friction between the cargo and the bottom of the transport surface, as well as between individual cargo particles in the scraper zone. This design solution makes it possible to reduce energy consumption by more than 70% compared to traditional systems, as well as significantly increase the durability of the equipment and ensure careful transportation of fragile and solid materials. The paper presents a mathematical model for determining the coefficient of resistance to cargo movement, taking into account the reduced contact area, and develops formulas for determining the traction force and drive power. A theoretical justification for the reduction in energy consumption has been provided, confirmed by relevant calculations. The modified design eliminates a number of operational shortcomings of traditional scraper systems. The results obtained are of practical importance for engineers and designers of modern automated transport systems.

Keywords: continuous machines; scraper conveyor; belt conveyor; innovative design; mechanization, cargo flows; digital production; wear; ergonomics; safety; transportation; modernization, transport equipment.

Introduction

In transport-handling and transport-storage systems of flexible automated production, it is expedient and promising to use continuous-action machines (CAM) as key elements for moving cargo flows. CMMs increase the efficiency of transportation in flexible production facilities and contribute to the achievement of Industry 4.0 goals – digitalisation, automation and optimisation of all stages of the production process, including the following areas:

– continuity and stability of transportation – MBDs ensure uniform and continuous movement of goods, which is especially important for automated systems where maintaining the rhythm of production processes is critical.

– compatibility with automated logistics schemes – MBDs are easily integrated into cargo flow management systems, including robotic warehouses, automated sorting centres and digitally controlled lines;

– increased productivity thanks to continuous operation and minimal delays between MBD cycles;

– flexibility of layout in technological lines (flows);

– improved ergonomics and safety.

Among continuous-action machines, belt and scraper conveyors are the most widely used due to their relative simplicity of design, reliability and wide range of applications. At the same time, when each type of these conveyors is used separately, along with their advantages – in particular, high productivity, the ability to transport goods over long distances and ease of maintenance – there are also significant operational disadvantages. For belt conveyors, these limitations include the inability to transport bulk cargo with high moisture content, lumpy and abrasive cargo, as well as the risk of material spillage.

Scraper conveyors are character ised by the movement of cargo along a chute, flat deck or bedding

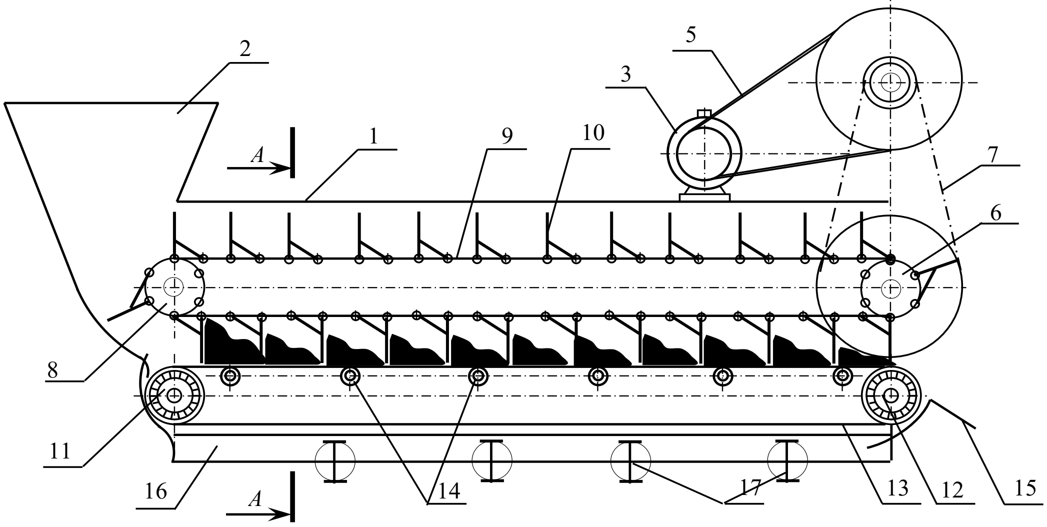

Fig. 1 – Front view of a scraper conveyor

from the cargo by dragging it with scrapers attached to a traction element. It appears to have a simple design. However, it is less common than belt conveyors. This is due to a greater number of design and operational limitations, namely:

– increased energy consumption due to friction between the load and the chute;

– internal friction between particles of cargo moving between the scrapers leads to crushing and additional energy consumption.

– inability to transport fragile materials.

– complications in transporting high-strength lumpy cargo, which can get stuck between the scrapers and the walls of the chute, leading to damage to the scrapers;

– insufficient durability due to intensive wear of the scrapers and the bottom of the chute.

This raises an urgent engineering question: is it possible to integrate the advantages of both types of conveyors into a single design while eliminating their inherent disadvantages? The answer to this question lies in a new scraper conveyor design, which is protected by a Ukrainian patent [1, 2].

The proposed model provides for a significant reduction in energy consumption and eliminates additional crushing of cargo particles during transport due to the absence of relative movement between the cargo and the chute.

The design solutions are shown in Figs. 1–3, where Fig. 1 is a front view of the scraper conveyor, Fig. 2 is a horizontal view (cross-section A-A in Fig. 1), and Fig. 3 is a top view.

With the modernisation, the new design of the scraper conveyor has a body 1, to which the loading device 2 is rigidly attached. An electric motor 3 is fixedly mounted on the body 1, which transmits rotational motion to the gearbox 4 via a belt drive 5, and the gearbox, in turn, transmits motion to the drive sprocket 6 of the scraper conveyor via a chain drive 7. A drive sprocket 8 with a tensioning device (not shown in the figure) is installed in the housing at a distance equal to the distance over which the load is moved. Sprockets 6 and 8 are kinematically connected to each other by a roller chain 9 on which scrapers 10 are located.

The scraper conveyor trough replaces a wireless belt conveyor, which has cylindrical drums 12 and 11 with axes of rotation parallel to the axes of rotation of sprockets 6 and 8 and has a rubber-fabric or steel belt (depending on the type of cargo) 13, which rests on the movable cylindrical rollers 14 of the working branch of the belt. These rollers prevent the belt from stretching under its own weight and the linear gravitational force of the cargo. The belt moves due to the friction forces between the load and the belt simultaneously with the scrapers. This eliminates friction between the load and the bottom of the conveyor in the form of a belt, as well as between the load particles located between the scrapers. To ensure the movement of the load by the scrapers, it is necessary to control the centre-to-centre distance between the sprocket and the drum, which should be equal to the sum of the average radius of the sprocket, the radius of the drum, the total height of the scraper and the width of the belt.

A hopper 16 is installed under the lower (idle) branch of the belt, which has a slide valve 17 along its length for automatic removal of excess cargo that accidentally entered the hopper during transportation.

The proposed design contributes to a significant reduction in energy consumption during cargo transportation by eliminating friction between the cargo and the

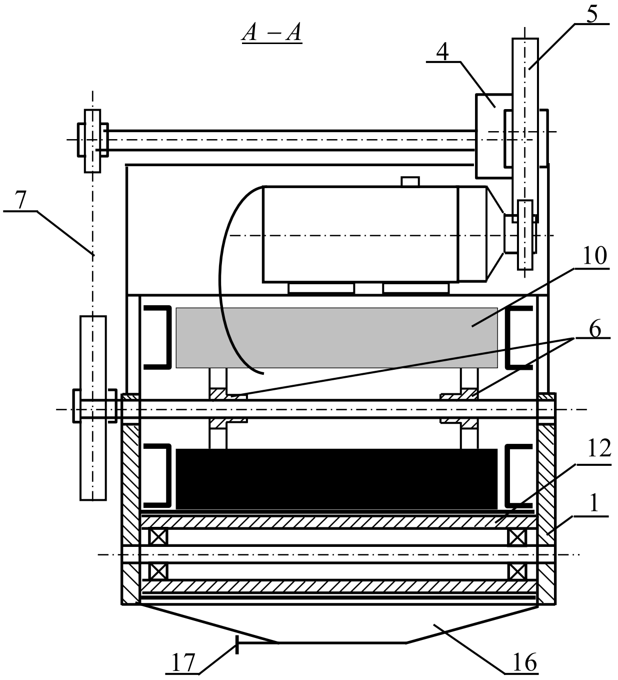

Fig. 2 – View of the scraper conveyor in section A-A in Fig. 1

surface of the chute, as well as between individual cargo particles moving within the scraper zone. This prevents the crushing of material, which is critical for the transportation of cargo that cannot be structurally damaged. In addition, the design ensures increased equipment durability and reliable movement of fragile and solid materials without the risk of damage or jamming.

To justify the effectiveness of the proposed design, we will perform a theoretical calculation of energy consumption during horizontal movement (angle of inclination 0°) of an average piece load under the conditions of an improved conveyor with minimised friction.

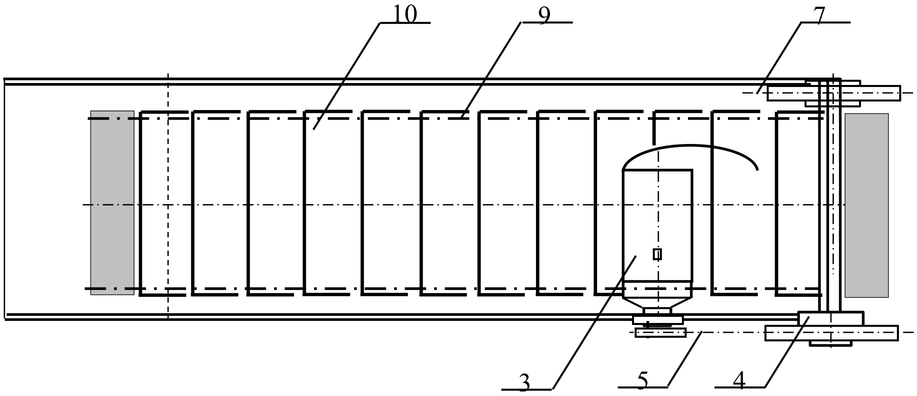

Fig. 3 – Top view of a scraper conveyor

Results and discussion

The required power of the scraper conveyor is determined as

$$P = \frac{K_з \cdot W_0 \cdot \upsilon}{1000 \cdot \eta_0}, \tag{1}$$

where W_o – is the circumferential tensile force, H; $K_з$ = 1,15…1,20 – reserve ratio; υ – speed, m/s; η_0 – total efficiency of the conveyor drive.

In technical literature and textbooks [3], the circumferential traction force is determined by calculating the tension at characteristic points along the route using the bypass method, based on the selected route diagram. For calculations, we chose a simple route, since the route does not affect the energy efficiency of the proposed new scraper conveyor design. By means of simple transformations, instead of step-by-step calculations, a single expression for the circumferential traction force was obtained:

$$W_0 = (K_3^2 + K - 2)\, S_0 + K_3 \cdot g \cdot q \cdot \omega \cdot L_р \cdot (K_2 + 1 + \frac{\omega_ж}{K'\omega}) \pm$$

$$\pm\ q_0 \cdot (1 + \frac{1}{K'}) \cdot H, \tag{2}$$

where K_3 – coefficient of resistance to rotation of the drive sprocket of the scraper conveyor (at $\alpha_п$ = 180°, K_3 = 1,08); $q = Q/3,6$ – calculated distributed mass (linear gravitational force of the load), kg/m; Q – scraper conveyor capacity, tonnes per hour; $q_0 = K'\ q$ – distributed mass of a scraper conveyor (for single-chain conveyors) K' = 0,55), kg/m; ω – coefficient of distribution of the running gear on flanged rollers (can be selected from work [3]); g = 9,81 m/s^2 – acceleration of free fall; $\omega_ж$ – coefficient of resistance to cargo movement along the chute; $L_р$ – track length, m; $S_0 = S_{min}$ – minimum chain tension (selected based on the condition of preventing scraper rotation and the specified productivity) ($S_0 = S_{min}$ = 3000…10000 H); H – height of cargo lift on conveyor.

The coefficient of resistance to cargo movement along the chute can be determined as:

$$\omega_ж = f_В \cdot \left[1 + \frac{K_C(1{,}2 + V) \cdot h}{(1 + 2f^2) \cdot B} \right], \tag{3}$$

where K_C – empirical coefficient (usually K_C = 1); B – gutter width, m; $f_В$ – coefficient of friction between the transported cargo and the walls of the chute; f – coefficient of internal friction of bulk cargo; h – height of the cargo layer in the chute, m.

From the analysis of dependence (3), it follows that $\omega_æ$ at constant values of coefficients $f_В$ and f for the transported cargo, it significantly depends on the ratio h/B.

The design of the proposed scraper conveyor provides for a movable bottom of the trough with fixed (stationary) side walls. In this regard, in order to correctly determine the power losses associated with the movement of cargo along the trough, it is advisable to make the following initial assumptions:

- the coefficient of lateral resistance of the cargo to the fixed sides remains unchanged;
- the area of friction between the load and the chute is reduced by the width of the chute.

Usually, in conveyors, the total area of friction between the load and the chute is equal to

$$A = 2h + B. \tag{4}$$

We take into account that $h = h_{ж}\psi$ and $h_{ж} = B/K_h$, let's determine

$$h = \frac{B}{K_h}\psi, \tag{5}$$

where K_h – gutter height coefficient; ψ = 0,01 $(\beta' - \beta)$ – overall utilisation rate. β' – conditional angle for heavy bulk cargo (β' = 85°), and β – conveyor inclination angle.

Taking into account dependencies (5) and (4), we obtain:

$$A = B(\frac{2\psi}{K_h} + 1). \tag{6}$$

If the bottom of the chute is movable, then the total area of friction between the load and the chute is equal to

$$A^* = A - B = B(\frac{2\psi}{K_h} + 1) - B = 2 \cdot B \cdot \frac{\psi}{K_h}. \tag{7}$$

Summarising the above, expression (3) takes the form:

$$\omega_{ж} = f_{В}\left[1+\frac{K_c(1,2+\upsilon)\psi}{(1+2f^2)K_h}\right]. \qquad (8)$$

Within the framework of the calculation model, it is assumed that the friction force is linearly dependent on the contact area between the load and the moving surface of the bottom. Considering the technical feasibility and sufficient accuracy of this approach for engineering calculations, this assumption is considered reasonable.

Based on this assumption, we will calculate the coefficient of resistance to motion for a scraper conveyor with a moving trough bottom.

$$\omega_{ж}^{*} = \frac{\omega_{М}}{А/_{А^*}}. \qquad (9)$$

Taking into account dependencies (6) and (7) with the ratio of areas, we obtain

$$\frac{A}{A^*} = В\left(\frac{2\psi}{K_h}+1\right)/B\frac{2\psi}{K_h} = \frac{2\psi+K_h}{2\psi} = 1+\frac{K_h}{2\psi}.$$

Then expression (9), taking into account (8) and the absence of external internal friction between the particles of the transported cargo (*f* = 1), will have the form

$$\omega_{ж}^{*} = \frac{f_{В}\left[1+\frac{K_c(1,2+V)\psi}{3K_h}\right]2\psi}{2\psi+K_h} =$$

$$= \frac{2\psi\cdot f_{В}\left[3K_h+K_c(1,2+V)\psi\right]}{3K_h(2\psi+K_h)} \qquad (10)$$

Conclusions:

1. The proposed design of the scraper conveyor is more efficient in terms of energy efficiency, which is due to the reduction of power losses during cargo transportation, in particular due to the design solution with a movable bottom of the trough.

2. The elimination of friction between the transported cargo and the side walls of the trough, which is particularly relevant when transporting large-sized or lumpy materials, makes it possible to reduce the overall energy consumption of the transportation process by more than three times, as confirmed by the relevant calculations.

3. The use of a conveyor with a movable bottom when transporting bulk materials provides a significant reduction in the required drive power – more than 70% compared to traditional designs, which indicates the high efficiency of the proposed technical solution in practical application.

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ІННОВАЦІЙНІ КОНСТРУКТИВНІ РІШЕННЯ ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ СКРЕБКОВИХ КОНВЕЄРІВ

Анотація. *У статті досліджено питання підвищення енергоефективності скребкових конвеєрів у складі транспортно-логістичних і перевантажувальних систем гнучких автоматизованих виробництв. Актуальність роботи зумовлена сучасними тенденціями розвитку промисловості у рамках концепції Індустрії 4.0, яка передбачає впровадження цифровізації, автоматизації та інтелектуальних технологій управління для стабільної роботи виробничих процесів. Одним із ключових завдань на цьому шляху є мінімізація енергоспоживання та підвищення надійності обладнання при одночасному забезпеченні гнучкості та ефективності матеріалопотоків. Проаналізовано переваги та недоліки традиційних стрічкових і скребкових конвеєрів, з акцентом на експлуатаційні обмеження останніх – підвищене енергоспоживання, подрібнення вантажу, зношування елементів тощо. Обґрунтовано доцільність використання машин безперервної дії (МБД) як ключового елемента в системах переміщення вантажів. Запропоновано нову конструкцію скребкового конвеєра з рухомим днищем жолоба, яка дозволяє усунути відносне тертя між вантажем і дном транспортуючої поверхні, а також між окремими частками вантажу в зоні скребків. Це конструктивне рішення дає змогу знизити енергоспоживання понад 70% у порівнянні з традиційними системами, а також значно підвищити довговічність обладнання й забезпечити дбайливе транспортування крихких і твердих матеріалів. У роботі наведено математичну модель для визначення коефіцієнта опору руху вантажу з урахуванням зменшеної площі контакту, розроблено формули для визначення тягового зусилля та потужності приводу. Проведено теоретичне обґрунтування зниження енергоспоживання, підтверджене відповідними розрахунками. Модифікована конструкція дозволяє усунути низку експлуатаційних недоліків традиційних скребкових систем. Отримані результати мають практичне значення для інженерів та конструкторів сучасних автоматизованих транспортних систем.*

Ключові слова: машини безперервної дії; скребковий конвеєр; стрічковий конвеєр; інноваційна конструкція; механізація, вантажопотоки; цифрове виробництво; знос; ергономіка; безпека; транспортування; модернізація.

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