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THEORETICAL STUDIES OF THE EXPANDER WORKFLOW FOR THE PRODUCTION OF FARM ANIMAL FEED

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The article runs about the issues of improving the design and operating parameters of the machine for the production of expanded animal forage. Based on the analysis of the research and classification of design solutions, a promising model of a single-screw press was substantiated and the direction of improving its design was determined. The main four compaction zones of the forage mixture in the expander are presented. The modes of operation of the installation without a damping spring on the output head and with a spring were presented. Mathematical expressions of the capacity of the output head of the expander with and without a damping spring are also presented. The main adjustable design parameter of the expander is determined – the width of the annular channel depending on the maximum pressure in the third sealing zone. The productivity of the machine screw at the end of the third pressure zone is presented. The main condition of the material flow sustainability ensuring the stable operation of the expander was determined.

Key words: expansion, compression, auger, energy intensity, research, temperature, humidity.

ТЕОРЕТИЧЕСКИЕ ИССЛЕДОВАНИЯ РАБОЧЕГО ПРОЦЕССА ЭКСПАНДЕРА ДЛЯ ПРОИЗВОДСТВА КОРМОВ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЖИВОТНЫХ

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В статье рассмотрены вопросы совершенствования конструктивно-режимных параметров машины для производства экспандированых кормов сельскохозяйственных животных. На основании анализа исследований и классификации конструктивных решений была обоснована перспективная модель одношнекового винтового пресса и определено направление совершенствования его конструкции. Представлены основные четыре зоны уплотнения кормовой смеси в экспандере. Рассмотрены режимы работы установки без демпферной пружины на выходной головке и с пружиной. Также представлены математические выражения пропускной способности выходной головки экспандера с демпфирующей пружиной и без нее. Определен основной регулируемый конструктивный параметр экспандера – ширина кольцевого канала в зависимости от максимального давления в третьей зоне уплотнения. Представлена производительность шнека машины в конце третьей зоны давления. Определено основное условие непрерывности потока материала, обеспечивающую устойчивую работу экспандера.

Ключевые слова: экспандирование, сжатие, шнек, энергоемкость, исследование, температура, влажность.

АУЫЛ ШАРУАШЫЛЫҒЫ ЖАНУАРЛАРЫНЫҢ АЗЫҒЫН ӨНДІРУГЕ АРНАЛҒАН ЭКСПАНДЕРДІҢ ЖҰМЫС ПРОЦЕСІН ТЕОРИЯЛЫҚ ЗЕРТТЕУ

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Мақалада ауылшаруашылық жануарларының экспандерленген жемін өндіруге арналған Машинаның құрылымдық және режимдік параметрлерін жетілдіру мәселелері қарастырылған. Зерттеулерді талдау және құрылымдық шешімдерді жіктеу негізінде бір бұрандалы бұрандалы пресстің перспективті моделі негізделді және оның дизайнын жақсарту бағыты анықталды. Экспандерде Жем қоспасын тығыздаудың негізгі төрт аймағы ұсынылған. Шығу басына және серіппеге демпферлік серіппесіз қондырғының жұмыс режимдері қарастырылады. Сондай-ақ, демпферлік серіппесі бар және онсыз экспандердің шығу басының өткізу қабілеттілігінің математикалық *өрнектері ұсынылған. Экспандердің негізгі реттелетін дизайн параметрі анықталады-үшінші тығыздау аймағындағы максималды қысымға байланысты сақиналы арнаның ені. Үшінші қысым аймағының соңында машина бұрандасының өнімділігі ұсынылған. Экспандердің тұрақты жұмысын қамтамасыз ететін материал ағынының үздіксіздігінің негізгі шарты анықталды.*

Түйінді сөздер: экспандирлеу, қысу, шнек, энергия сыйымдылығы, зерттеу, температура, ылғалдылық.

Introduction. One of the most important conditions for increasing the production of livestock products is the growth of the production of high–quality feed and, based on this, the organization of a full-fledged balanced feeding of animals.

One of the most effective ways of thermomechanical processing of feeds to increase their nutritional value is expansion. The main advantages of expanders are lower energy consumption, longer service life of working bodies, high level of liquid components input, improved feed quality and digestibility, elimination of components harmful to nutrition.

Improving the design and operating parameters of the expander is a complex, but important and urgent task, the solution of which contributes to the study of the influence of various factors on increasing the efficiency of the expansion process [1, pp. 62-70, 2, pp. 103-110, 3, pp. 60-72, 4, pp. 30-46].

The analysis of the works of Melnikov S.V., Kartashov L.P., Zavrazhny A.I., Zubkova T.M., Mirzoev R.G., Gruzdev I.E., Yankov V.I. and other authors allowed us to substantiate the direction of improving machines and their workflow in the production of feed by expansion.

Considering that feed is one of the most important factors affecting the production of livestock products, their preparation is an urgent task. The feed must be easily digested and well digested, which becomes possible using the technology of expansion of multicomponent raw materials.

Based on the analysis of research and classification of design solutions, a promising model of a single-screw expander is substantiated and the direction of improving its design-mode parameters is determined.

Materials and methods of research. The experimental installation is a cylindrical body with a diameter of 80 mm with a screw inside. A die with holes is fixed at one end of the pipe, and at the other end there is a coupling connecting the screw shaft to the drive motor. To change the rotation speed, three different sprockets and a chain tensioner mechanism were installed on the screw shaft. The electric motor was installed on the sled, which made it possible to ensure the alignment of the drive sprockets by moving the engine. For additional heating of the housing at the end of the third area of the feed seal (see Figure 1) an electric heater was installed, providing the required temperature expansion mode, which was connected to a 220 V AC network and heated the output part of the installation to 130 oC. From the analysis of the design of screw machines, it is recommended to bring the electric heater as close as possible to the output head of the installation. A landing socket has been installed for a temperature sensor measuring the temperature in the feed outlet area. Seats were made for load cells that register the pressure being pumped into the output head. The following design changes were made to the design of the output head of the installation: the output holes of the head were tripled (to reduce resistance), an additional spring and cones were installed, necessary for pressure stabilization and compliance with the feed expansion mode. The choice of the spring was made taking into account the stiffness coefficient. Initially, short springs with a high stiffness coefficient and a small diameter were used, but the analysis showed that such springs are unsuitable for this installation, since they require precise adjustment of the clamping force, slightly change the length, thereby preventing the feed from escaping. When installing springs with a larger diameter and length and a lower stiffness coefficient, a smoother adjustment of the output gap occurs, the operation of the screw supercharger becomes more uniform, the pulsations and beats of the screw decrease, thereby saving electricity and increasing the performance of the expander. The optimal value of the spring stiffness was determined by calculation and adjusted experimentally, and the necessary geometric dimensions of the installation were also selected.

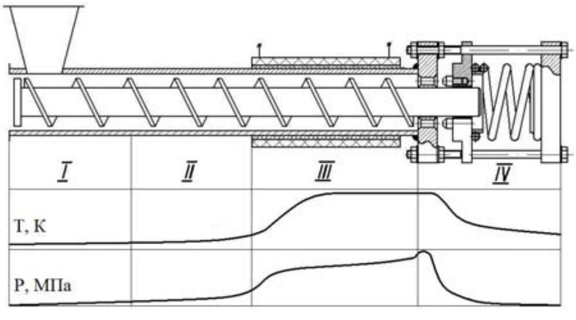

Figure 1 – Feed compaction zones in the expander and changes in the physical properties of biological raw materials during movement in the working organ

Research results. The process of compaction of feed in the expander can be divided into four zones: 1st – mixing, moving the feed mixture along the screw and the beginning of compaction; 2nd – pressure build–up, pressing and destruction of particles; 3rd - further increase in pressure, temperature and transition of feed into a viscoplastic state; 4th – pushing through the mass through the holes of the output head of the machine [5, pp. 30-37, 6, pp.61-67].

Consider the operating mode of the installation without a spring on the output head. The inner radius at the beginning of the channel r_k and the length of the annular channel of the expander head Lk change when the cone is moved. Let the length L_k be equal to L_{ko} (maybe $L_{ko} = 0$) when the output is closed (see Figure 2).

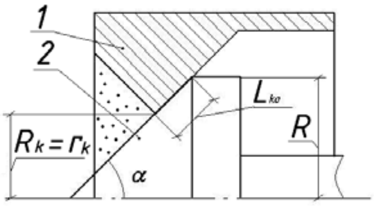

Figure 2 – The initial position of the expander head:
1 – the expander body; 2 – the shut-off cone of the expander head

At the same time $r_{ko} = R_k$. The outer radius at the beginning of the channel R_k does not change when the cone is moved, R_k = const. Move the cone a distance Δx to the right (Figure 3).

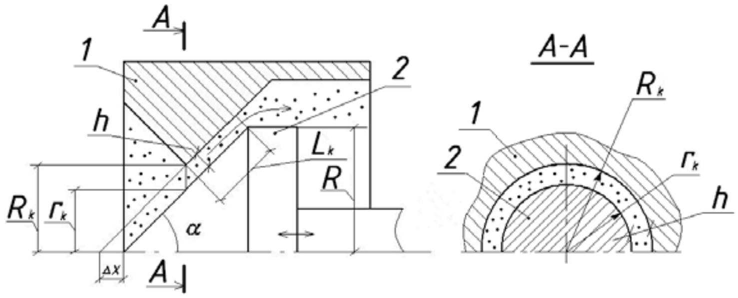

Figure 3 – Working position of the expander head:
1 – expander body; 2 – shut-off cone of the expander head

Then $r_k = R_k - \Delta x \cdot tg\alpha$ and $L_k = L_{ko} + \Delta x \cdot \cos\alpha$. For example, at $\alpha = 60^0$, there will $r_k = R_k - \sqrt{3}\,\Delta x$, $L_k = L_{ko} + \Delta x/2$, where Δx is the axial displacement of the cone.

Throughput of the expander output head, kg/s:

$$Q_{ЭКСП.} = \frac{\pi \cdot (P_{III} - P_{ATM}) \cdot \rho_{III} \cdot m}{8 \cdot \eta \cdot L_k} \left\{ R_k^4 - r_k^4 + \frac{(R_k^2 - r_k^2)^2}{\ln \frac{R_k}{r_k}} \right\} \cos^4\alpha, \qquad (1)$$

where L_k – length of the annular channel, m; R_k, r_k – external and internal radii at the beginning of the channel, m; α – angle between the generatrix of the regulating cone and its height; ρ_{III} – density of the mixture at the end of the 3rd zone, kg/m^3; m – number of channels of the expander head; P_{III} – maximum possible the pressure of the treated mixture at the last turn of the screw at the end of the 3rd zone, Pa; η – dynamic viscosity of the mixture in the 3rd zone, Pa·s.

From equation (1), the dependence of the main adjustable design parameter of the expander – the width of the annular channel ($R_k - r_k$) on the pressure P_{III} at R_k = const is determined.

An important parameter set depending on the required quality and type of feed being processed is the pressure of the P_{III} mixture at the end of the 3rd zone, as much as possible along the entire length of the auger. It depends on the width of the annular output channel.

With the outlet head openings completely closed, the pressure of the P_{III} mixture at the end of the 3rd zone will be maximum, and, assuming that there is practically no pressure between the 1st and 2nd zones, is determined by the formula (Figure 1), Pa:

$$P_{maxIII} = (z_{II} + z_{III}) \frac{4 \cdot \pi^2 \cdot D^2 \cdot \omega \cdot \eta}{(D-d)^2}, \quad (2)$$

where z_{II}, z_{III} – number of turns of the screw in the 2nd and 3rd zones; D, d – outer and inner diameters of the screw, m; ω – rotation frequency of the screw, s^{-1};

Formula (1) can be written in the form, kg/s:

$$Q_{ЭКСП.} = \frac{P \cdot \rho}{\eta} \xi, \quad (3)$$

where P – pressure (the average pressure above atmospheric $(P_{III} – P_{ATM})/2$), Pa; ρ – density of the mixture, kg/ m^3; ξ – geometric parameter (depends on R_k, r_k, L_k, α, m).

Given R_k, L_{ko}, α – it is possible to tabulate the dependence ξ(Δx) and graphically depict this dependence. When Δx = 0, it will be $\xi_o = 0$ (because $R_k = r_k$).

At $r_k = 0$, $\xi_{max} = \dfrac{\pi R_k^4 \cos^4\alpha \cdot m}{4 \cdot \left(L_{ko} + \dfrac{R_k \cdot \cos\alpha}{tg\alpha} \right)}$. For Δx > R_k·cosα/tg α, the formula for $Q_{ЭКСП.}$ it will be different.

Auger capacity at the end of the 3rd zone, kg/s:

$$Q_{ШН.} = 0{,}25 \cdot \pi \cdot \left(D^2 - d^2\right) \cdot \left(h_{III} - e\right) \cdot \omega \cdot P_{III} \cdot \varepsilon_{III}, \quad (4)$$

where h_{III} – pitch of the screw turns in the 3rd zone, m; e – thickness of the screw turn, m; ε_{III} - coefficient of axial displacement of the mixture by the last turn of the screw in the 3rd zone, determined by turning the mass relative to it.

The condition of continuity of material flows, which ensures stable operation of the expander, is determined by the equality of the throughput capacity of the output head (3) and the productivity of the screw (4):

$$Q_{ЭКСП.} = Q_{ШН.}. \quad (5)$$

From here we can find the ε – coefficient of product displacement. When the output is closed $Q_{ЭКСП.}$ = 0, means $Q_{ШН.}$ = 0 and ε = 0, i.e. the product does not move.

To calculate the productivity of the auger, the formula is more effective, where the shape coefficients for counterflow and average viscosity in the flow, kg/ s, are taken into account:

$$Q_{ШН.} = \pi \cdot D \cdot w \cdot (h - \delta) \cdot \omega \cdot \cos(\theta) \cdot (f_d / 2) - \left(h^3 \cdot w \cdot f_{ps} f_{pd} / 12 \cdot n \cdot \mu_c\right) \cdot \left(\frac{dP}{dx}\right), \quad (6)$$

where D – outer diameter of the screw, m; h – depth of the turn, m; w – width of the turn (through the step S, w = S cos(θ)), m; δ – gap between the edge of the turn and the surface of the screw, m; θ = arctg S/π(D-2δ) – angle of inclination of the thread of the coil, rad.; n – exponent of the power law in the equation of the flow of a non-Newtonian fluid (material), for example, for non-crushed rapeseed seeds, n = 0.1298; μ_c – viscosity of a non–Newtonian fluid, (Pa·s); P – pressure, Pa; X – distance along the screw channel, m; $f_d = 1- (0{,}487n^2 – 0.948n + 0.972)h/w$ – coefficient of the forced flow shape; $f_{ps} = 1-(0{,}949n^2 – 1{,}87n + 1{,}59)h/w$ – shape coefficient for the counterflow caused by the resistance of the output device; f_{pd} – correction coefficient for the average viscosity in the flow (f_{pd}=0,98).

The pressure gradient along the axis of the screw $\left(\frac{dP}{dx}\right)$ can be approximately replaced by $\left(\frac{P}{L}\right)$.

Formula (6) can be written in the form, kg / s:

$$Q_{ШН.} = A \cdot \omega - B \cdot P, \quad (7)$$

where, $A = \pi \cdot D \cdot w \cdot (h - \delta)\cos(\theta) \cdot (f_d/2)$, $B = h^3 \cdot w \cdot f_{ps} \cdot f_{pd}/12 \cdot n \cdot \mu_c \cdot L$ – values depending on the geometric parameters of the screw. The parameters A and B are approximately constant for this screw; L – length of the screw, m.

Equation (5) can be written as:

$$\frac{P \cdot \rho}{\eta} \xi = A \cdot \omega - B \cdot P. \quad (8)$$

This equation allows you to calculate the operating characteristics (pressure, speed and expander performance). The values of p and n are considered approximately constant, then equation (3) will take the form, kg/s:

$$Q_{\text{ЭКСП.}} = P \cdot \xi', \tag{9}$$

$$\text{где } \xi' = \xi \cdot \rho / \eta; \quad \xi = \frac{\pi \cdot m \cdot \cos^4 \alpha}{4 \cdot L_k} \cdot \left(R_k^4 - r_k^4 + \frac{\left(R_k^2 - r_k^2\right)}{\ln \frac{R_k}{r_k}} \right).$$

Based on mathematical transformations, the performance of the experimental expander can be represented by the expression, kg/s:

$$Q_{\text{ЭКСП.}} = \frac{C \cdot \left(\Delta x + \lambda\right)}{F_{\text{эф}}} \xi', \tag{10}$$

where λ – deformation with a constant gap, m; Δx – displacement of the expander head, m; C – spring stiffness coefficient, N/m; $F_{\text{эф.}}$ – effective cross–sectional area, m^2.

Expander efficiency, $\eta_э$, is equal to:

$$\eta_э = \frac{P_{III} \cdot Q_{\text{эксп.}}}{N_{\text{эк}} \rho}, \tag{11}$$

where P_{III} – pressure of the mixture of the output head of the expander, Pa; $Q_{\text{эксп.}}$ – capacity of the expander, kg/s.

As a result of theoretical studies of the expander workflow, the dependence of productivity and energy intensity on its design-mode parameters during feed processing is substantiated.

Fragments of the experimental device are shown in Figure 4.

Figure 4 – Fragments of the experimental device

Conclusions. Based on the results of the studies of the expansion process under consideration, changes in the characteristics of the feedstock during its passage through functional areas (feed compaction zones) were determined, as well as analytical expressions of productivity (equation 10) and energy intensity of the expander with a damping device, as well as the equation of the expander efficiency (equation 11) were clarified.

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ВОЗДЕЛЫВАНИЕ ЯРОВОЙ ПШЕНИЦЫ В УСЛОВИЯХ ОРГАНИЧЕСКОГО ЗЕМЛЕДЕЛИЯ

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В статье описаны проведенные исследования в ТОО «СХОС «Заречное» по возделыванию яровой пшеницы в севооборотах в системе органического земледелия в 2021 г.

В исследованиях были представлены 4 схемы различных севооборотов.

В экспериментальных вариантах предпочтение отдавалось применению современной техники и орудиям, позволяющим полностью выполнять минимальную технологию на вариантах, снизить при этом расход энергоресурсов на возделывание зерновых культур и оказывать положительное воздействие на водно-физические свойства почвы и плодородие в целом.

Пшеница, возделываемая в 4-х польном зернопаровом севообороте (схема I), имела самый высокий показатель урожайности в среднем 5,21-5,49 ц/га, в отличие от остальных севооборотов.

Все превышения или же понижения урожайности пшеницы остальных севооборотов были несущественны. За исключением пшеницы, возделываемой в 4-х зернопаровом севообороте (схема II) после биологизированного пара (овес), урожайность ее составила 7,06 ц/га.

Хороший урожай гороха получен в обоих севооборотах, который составил в среднем 13,78-14,20 ц/га.