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Improving The Efficiency Of The Livestock Feed Preparation Process

B.U.Urinov

Bukhara State Technical University, Republic of Uzbekistan, Bukhara, K. Murtazaev Avenue, 15, Uzbekistan

K. Kh. Majidov

Bukhara State Technical University, Republic of Uzbekistan, Bukhara, K. Murtazaev Avenue, 15, Uzbekistan

Sh. Sh.Toimurodova

Bukhara State Technical University, Republic of Uzbekistan, Bukhara, K. Murtazaev Avenue, 15, Uzbekistan

ABSTRACT

Research has been conducted and the design of a grain mixture grinder has been improved, and the technological parameters of raw material grinding have been optimized. A rotor-ventilator crusher has been developed and proposed for preparing mixed feed and mixing the components of grain additives. Mixing of wet feeds was carried out at the optimal values of the factors found during the study of mixing of dry bulk feeds. Methods for increasing the efficiency of the feed production process and creating optimal airflow conditions in all elements of the mixed feed unit have been substantiated. Dependencies are obtained that allow:

- determine the productivity of pneumatically loaded grain crushers depending on the design of the loading device (ejector);

determine the conditions for introducing grain meal into the grinding chamber of the crusher with rigidly fixed beams, in which the peripheral and end sieves are loaded uniformly.

KEYWORDS

Grain mixtures, grinder, technological perimeters, optimization and modeling of processes.

INTRODUCTION

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Modern livestock farming focuses on increasing animal productivity and maximizing economic efficiency through the concentration of production [1, 2]. However, along with this, logistical issues related to fodder procurement, environmental problems, and the degradation of agricultural lands are arising, leading to a sharp decline in the productive longevity of livestock, which is the reason for frequent herd renewal and a worsening demographic situation [3, 4]. The state is implementing the program for the development of agriculture for 2020-2025. A program for the development of agriculture for 2020-2025 has been adopted, aimed at ensuring the growth of agricultural production, including through the application of technologies for the production of high-quality feed, feed additives for livestock, processing and storage of agricultural products, raw materials, and food [5]. At the same time, the level of import dependence should be reduced through the introduction and use of technologies for the production of high-quality feed, feed additives for livestock.

Modern feed preparation equipment offered by the industry is highly specialized and, mainly, highly productive, has high metal and energy intensity, and the quality of feed prepared on such equipment, in some cases, does not meet the zootechnical requirements and GOST recommendations.

As a result of the analysis of scientific works, a conclusion was made that the evaluation of feed preparation equipment operation should be carried out systematically, comprehensively, through several criteria - energy efficiency of feed production with simultaneous quality assessment.

The purpose of the work is to research and develop a design for improving the grain mixture grinder and to optimize the technological parameters of raw material grinding.

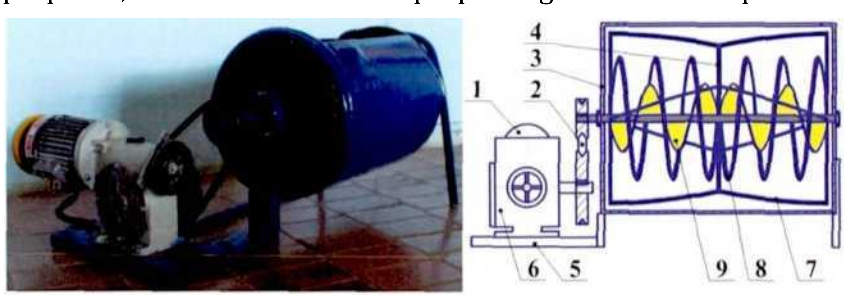
The objects of the research are grain mixtures, centrifugal force thresher, and technological parameters.

METHODS

To optimize the technological parameters of mixture grinding, statistical processing of experimental results using full-factor planning and modeling methods were used.

RESULTS AND DISCUSSION

For the preparation of mixed feed and mixing of the components of grain additives, a rotor-ventilator crusher has been created and proposed, and the scheme of the proposed grain crusher is presented in Figure 1.



a b

Figure 1 - Laboratory mixer installation:

a - general view; b - diagram; 1 - electric motor; 2 - belt drive;

3 - hopper; 4 - working mixing organ; 5 - frame; 6 - reducer;

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7 - scrapers; 8,9 external and internal screws

At the first stage, the process of mixing dry loose fodder was investigated. To determine the optimization area, a series of single-factor experiments was conducted to study the influence of the rotational frequency of the working part and its operating time on the mixer's operating characteristics, the optimal values of the rotational frequency of the working mixing part, the helicoid angle of the screws, and the mixing time were determined, the values of which were: n = 45 min^{-1}, θs = 50° and tsm= (60... 100) s. To determine the optimal design of the mixing organ, multifactorial experiments were conducted at optimal values. n = 45 mip^{-1} and θ_c = 50°. The optimal values of the screw's structural elements were determined: the height and pitch of the turns.

In order to determine the optimal values of the outer coil pitch (x_1) and internal (x_2) screw, mixing time (x_3), implemented the Box - Benkin plan for 3 factors [6]. Regression models built on the basis of experimental data have the form:

$$y_1 = 4{,}7 + 0{,}52 \cdot x_1 + 1{,}28 \cdot x_2 - 0{,}82 \cdot x_3 - 0{,}93 \cdot x_1^2 + 3{,}89 \cdot x_2^2 + 2{,}21 \cdot x_3^2, \quad (1)$$

$$y_2 = 1 - 0{,}34 \cdot x_1 - 0{,}34 \cdot x_2 + 0{,}4 \cdot x_3 + 0{,}29 \cdot x_1^2 + 0{,}25 \cdot x_1 \cdot x_2 -$$

$$- 0{,}31 \cdot x_1 \cdot x_3 + 0{,}19 \cdot x_2^2 - 0{,}29 \cdot x_2 \cdot x_3 \quad (2)$$

The optimal values of the factors were found using the method of superimposing two-dimensional cross-sections when solving a compromise problem, the goal of which was to obtain high-quality feed with minimal specific energy consumption. When mixing dry bulk feeds: rotational frequency of the working mixing organ n = 45 min^{-1}; helicoid cone angle of the screws θ_c = 50°; height of the outer and inner auger turns h_2= 50 mm and h_3 = 75 mm; outer and inner thread winding pitch S_2= 105 mm and S_3 = 135 mm; mixing time tsm = (84...108) s.

Mixing of wet feeds was carried out at the optimal values of the factors found during the study of mixing of dry bulk feeds. Preliminary studies have shown that the moist feed, at the accepted design and operating parameters, does not mix but moves along the housing wall. Therefore, the rotational speed of the mixing organ was reduced, and scrapers 7 (Fig. 1) were replaced with blades arranged in a spiral with a step equal to half the body length. A series of single-factor experiments was conducted. The influence of the blade length on feed quality was determined, which was varied within the range of 20 to 80 mm, and the shaft rotation frequency, the value of which was reduced to 25 min-1. Based on the analysis of the experimental data, the following values of the studied factors can be recommended: rotational speed of the working part (30...40) min-1, blade length (20...60) mm, mixing time (80... 160) p.

To determine the optimal operating mode of the mixer and the blade length, the Boks-Bsnkip plan was implemented [7]. The limits of variation of factors were selected based on the results of single-factor experiments. The effectiveness of the work process was assessed by the mixing heterogeneity coefficient and specific energy consumption. The operating process of the developed mixer, evaluated by the selected optimization criteria, is described by regression models:

$$y_1 = 3{,}2 + 4{,}56 \cdot x_4 - 6 \cdot x_3 + 13{,}56 \cdot x_4^2 - 7{,}14 \cdot x_5^2 + 13{,}1 \cdot x_3^2, \quad (3)$$

$$y_2 = 0{,}37 + 0{,}02 \cdot x_4 + 0{,}09 \cdot x_5 + 0{,}12 \cdot x_3 - 0{,}06 \cdot x_5^2 - 0{,}04 \cdot x_5 \cdot x_3 \quad (4)$$

Where x_4 -blade length; x_5 - rotational frequency of working parts.

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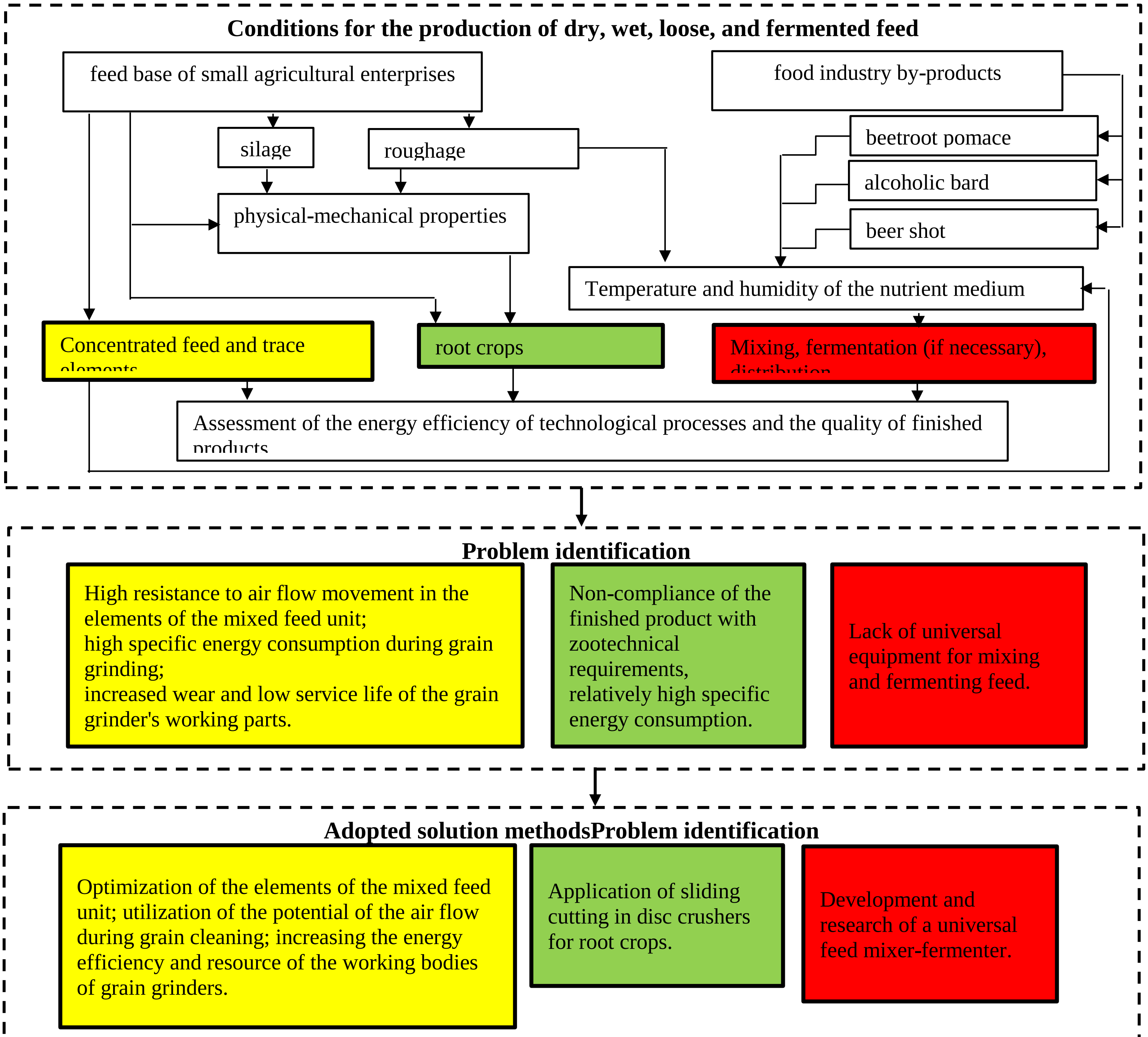
As a result of the conducted research, a model for feed preparation was proposed (Figure 2)



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Justification of optimal operating conditions and modes of feed preparation machines should be carried out taking into account theoretical prerequisites and experimental studies of their technological processes (Fig. 3).

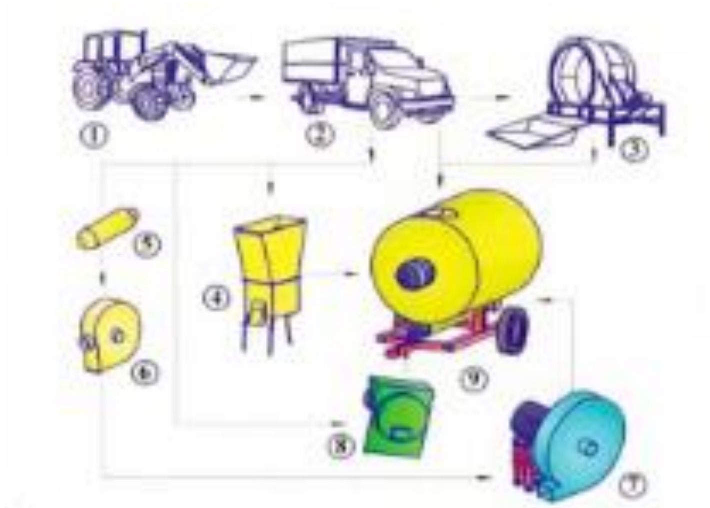

Figure 3 - Technological line for preparing various types of feed under small-scale farming conditions:
1 - loading; 2 - transportation; 3 - grinding of roughage; 4 - crushing of root crops; 5 - loading grain piles with airflow; 6-cleaning the grain meal in an air stream; 7 - Grinding of grain meal in a pneumatically fed grain grinder; 8 - grinding of grain in a crusher with forced feed;

9 - mixing (mixing and fermentation)

Further, the results of theoretical research on substantiating the design and technological parameters of feed preparation machines are presented.

Analysis of the operation of the concentrated feed processing technological line with pneumatic grain feed revealed a problem - high air resistance of the line elements. They can be reduced by creating optimal airflow conditions in each element of the mixed feed unit. One of the elements of the technological line is the ejector, which is designed to feed grain from the bulk into the grinding chamber of the crusher.

Expressions were obtained for calculating the throughput capacity of loading devices, which are elements of the mixed feed unit and serve to supply grain meal to the fan-equipped crusher (Figure 4).

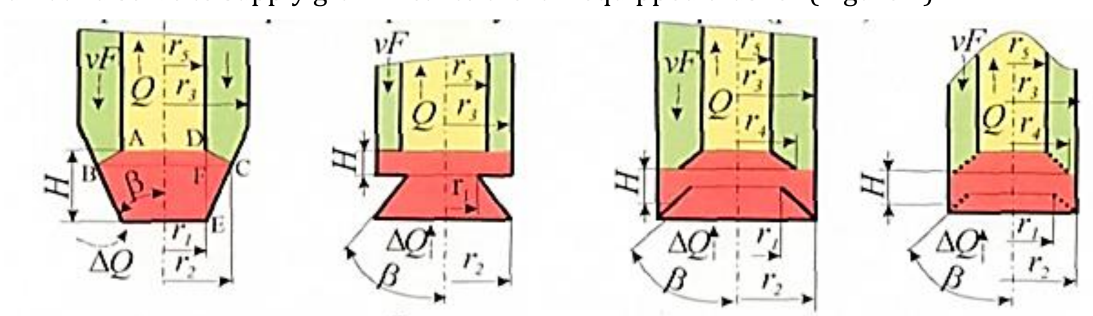

Figure 4 - Diagrams for determining the lateral area of the input ring gap in ejectors of various designs

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The expression for determining the conductivity of the ejector shown in Figure 4a has the form:

$$Q_э = \sqrt{2\cdot\rho}\cdot\kappa\cdot\pi\cdot\left(\sqrt{\frac{\Delta p_1}{\xi_1}}\cdot(2r_5 + H\cdot\sin\beta\cdot\cos\beta)\cdot\kappa\cdot H\cdot\sin\beta + \sqrt{\frac{\Delta p_2}{\xi_2}}\cdot r_1^2\right). \qquad (5)$$

цруку Δp_1 - total air pressure losses associated with the ejector design, Pa; Δp_2 - total air pressure losses associated with grain layer resistance, Pa; ξ_1- resistance coefficient associated with the ejector design; ξ_2 - grain layer resistance coefficient; ρ air density, kg/m^3.

The throughput capacity of the loading device shown in Figure 4b is determined by the formula:

if $H \geq r_3 — r_5$, then

$$Q_э = \left(\sqrt{\frac{2\cdot\rho\cdot\Delta p_1}{\xi_1}}(r_3^2 - r_5^2) + \sqrt{\frac{2\cdot\rho\cdot\Delta p_2}{\xi_2}}\cdot r_1^2\right)\cdot\pi\cdot\kappa. \qquad (6)$$

if $H < r_3 — r_5$, then

$$Q_э = \left(2\cdot r_5\cdot H\cdot\sqrt{\frac{2\cdot\rho\cdot\Delta p_1}{\xi_1}} + \sqrt{\frac{2\cdot\rho\cdot\Delta p_2}{\xi_2}}\cdot r_1^2\right)\cdot\pi\cdot\kappa. \qquad (7)$$

For the loading devices shown in Fig. 4 c, d, provided that the perpendicular connecting the confuzors is less than the value r_3 - r_4,the throughput capacity is determined by expression (5). Otherwise - according to the formula:

$$Q_э = \left((r_3^2 - r_4^2)\cdot\sqrt{\frac{2\cdot\rho\cdot\Delta p_1}{\xi_1}} + \sqrt{\frac{2\cdot\rho\cdot\Delta p_2}{\xi_2}}\cdot r_1^2\right)\cdot\pi\cdot\kappa. \qquad (8)$$

Using expression (5), the theoretical carrying capacity of the ejector (Fig. 4, a) was calculated at a grain concentration coefficient of k=3 and a diffuser angle of 30°. Figure 5 shows comparative graphs of the ejector's throughput capacity depending on the annular clearance area.

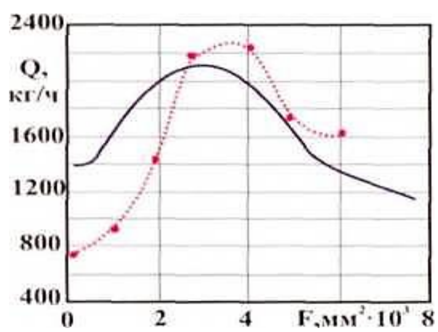

Figure 5 - Comparative characteristics of the ejector's throughput capacity according to scheme 4, a with a diffuser angle of 30°

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The graphs show that the shapes of the curves are completely identical. With high bandwidth values, the error in calculations does not exceed 10%. At the area of the annular gap 2-10^3 mm_2 the experimental curve is significantly lower than the theoretical one, indicating a change in the magnitude of the grain concentration coefficient in the air depending on the installation's operating mode.

Since mineral impurities are carried away by the air along with the grain, which negatively affects the quality of the finished feed and the service life of the working bodies, there is a need for its purification. In this case, to reduce energy consumption and metal consumption, and to simplify the design of cleaning machines, it is necessary to clean grain meal using the potential of the air flow. For this purpose, we have developed a pneumatic separator, in which the separation of large impurities is carried out in a vertical separating channel (VSK) due to different aerodynamic properties, and small impurities - on the separating grate under the influence of inertia forces due to the difference in geometric dimensions of the grain and impurities.

The movement of the single particle of the air-product flow in the vertical separation channel (VSK) (Fig. 6) is described by the equations:

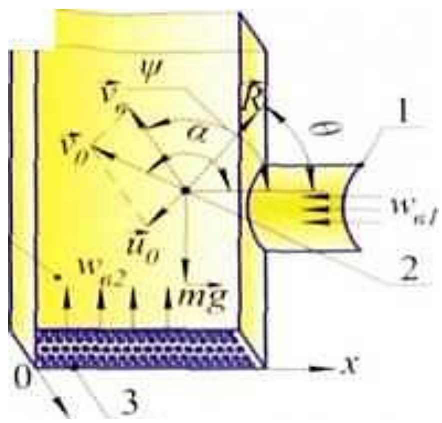

Figure 6 - Diagram of forces acting on a grain particle in a vertical separation channel:

1 - inlet pipe; 2 - particle; 3 - perforated bottom;

4 - vertical separation channel

$$\begin{cases} X(\Delta t) = x_0 + (-k_n u_{01} x_0 + k_n u_{01}(0,23y^4 + 0,23y^3 - 0,03xy^2 + 0,14y^2))\Delta t; \\ Y(\Delta t) = y_0 + (-k_n u_{01} y_0 + k_n u_{01}(0,25y^4 + 0,26y^3 + 0,03xy^2 + 0,11y^2) - g)\Delta t; \\ Z(\Delta t) = z_0 - k_n u_{01} z_0 \Delta t. \end{cases} \quad (9)$$

$$\begin{cases} x(\Delta t) = x_0 \Delta t + (-k_n u_{01} x_0 + k_n u_{01}(0,23y^4 + 0,23y^3 - 0,03xy^2 + 0,14y^2))\dfrac{\Delta t^2}{2}; \\ y(\Delta t) = y_0 \Delta t + (-k_n u_{01} y_0 + k_n u_{01}(0,25y^4 + 0,26y^3 + 0,03xy^2 + 0,11y^2) - g)\dfrac{\Delta t^2}{2}; \\ z(\Delta t) = z_0 \Delta t - k_n u_{01} z_0 \dfrac{\Delta t^2}{2}. \end{cases} \quad (10)$$

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The expressions for determining the velocity and position of the particle in the curvilinear channel (CCC) (Fig. 7) have the form:

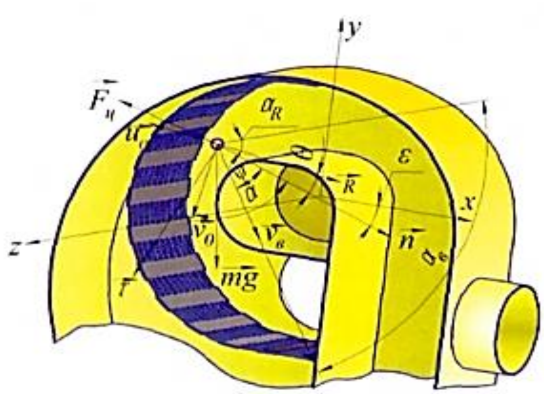

Figure 7 - Diagram of forces acting on a particle of raw cotton in a curved separation channel.

$$\begin{cases} N(\Delta t) = n_0 + (-\frac{u_{01}^2}{r} - k_n u_{01} n_0 + k_n u_{01}(3,62r^4 + 3,25r^3 + 2,51r^2 + 2,55r + 1,33\varepsilon r) \\ +g\sin\varepsilon)\Delta t; \\ T(\Delta t) = \tau_0 + (-k_n u_{01}\tau_0 + k_n u_{01}(3,54r^3 + 2,25r^2 + 3,53r) - g\cos\varepsilon)\Delta t; \\ Z(\Delta t) = z_0 - k_n u_{01} z_0 \cdot \Delta t. \end{cases} \quad (11)$$

$$\begin{cases} n(\Delta t) = n_0\Delta t + (-\frac{u_{01}^2}{r} - k_n u_{01} x_0 + k_n u_{01}(3,62r^4 + 3,25r^3 + 2,51r^2 + 2,55r + 1,33\varepsilon r) \\ +g\sin\varepsilon)\frac{\Delta t^2}{2}; \\ \tau(\Delta t) = \tau_0\Delta t + (-k_n u_{01}\tau_0 + k_n u_{01}(3,54r^3 + 2,25r^2 + 3,53r) - g\cos\varepsilon)\frac{\Delta t^2}{2}; \\ z(\Delta t) = z_0 - k_n u_{01} z_0 \frac{\Delta t^2}{2}. \end{cases} \quad (12)$$

Based on the derived dependencies (9), (10), (11), (12) the trajectories of particle motion with different sail coefficients were constructed.

(Fig. 8).

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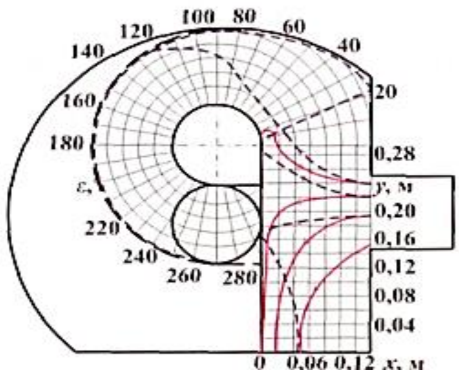

------ - **Kp**=0,05m-1

———— - Kp=0,8m-1

Figure 8 - Trajectories of particle movement in pneumatic separator channels

As can be seen, heavy impurities (CP - 0.05m-1) settle in the chamber for large impurities. Moreover, the maximum height of the vertical channel on which large irimeses rise does not exceed 0.4 m. Grains and small impurities (KP=0.8 m-1) depending on the entrance coordinates to the vertical separation channel, flying through part of the KSK, move along the separating grid (Fig. 9), the required cell length of which is determined by the expression:

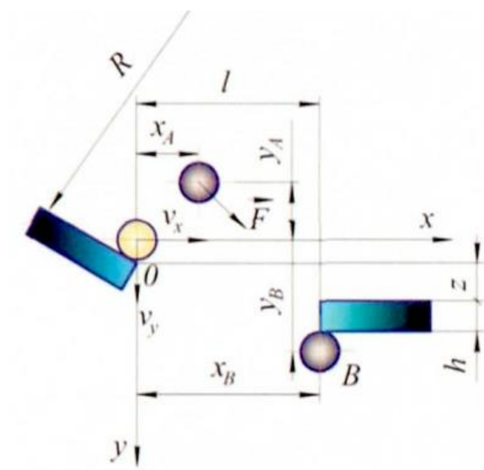

Figure 9 - Diagram for determining the conditions for particle passage through the separating grate opening

$$x_B = x_A + v_x \cdot \left(\frac{-v_y + \sqrt{v_y^2 + 2a_y \cdot (y_B - y_A)}}{a_y} \right) + \frac{a_x}{2} \cdot \left(\frac{-v_y + \sqrt{v_y^2 + 2a_y \cdot (y_B - y_A)}}{a_y} \right)^2. \qquad (13)$$

Using expression (13), we determined the average value of the separating lattice aperture sizes: 25 mm for particle movement from horizontal to vertical, and 26 mm for movement from vertical to horizontal.

The grain cleaned of impurities from the pneumatic separator enters the grain grinder for grinding. The efficiency of its working process can be increased by timely removal of the finished product from the grinding chamber by creating optimal air flow conditions. The air flow is generated by the combined unit of the crusher (Fig. 10). The air moves from the center of the fan to its periphery due to the action of centrifugal force. The kinetic energy of the relative air movement, as well as the work of the centrifugal force, is converted into the total air pressure on the channel walls (Figure 10).

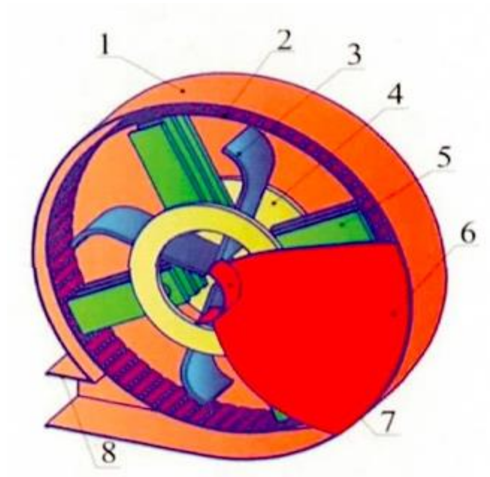

Figure 10 - Grain crusher model with combined rotor and fan:

1 - housing; 2 - lattice; 3 - scapula; 4 - rotor; 5 - hammer; 6 - cover;

7 - suction nozzle; 8 - exhaust pipe

When moving through a channel formed by two blades, the air receives energy from the fan, which leads to a change in its absolute velocity from the value of v_1 to v_2. In turn, the absolute velocity v is composed of the relative and transferred velocities vp. Solving the Bernoulli equation, taking into account the total losses of air pressure in the channel, allowed us to obtain the following dependence:

$$P = (A - h_0) + (B - k_1) \cdot Q - k_2 \cdot Q^2 \quad (14)$$

where h_0, k_1, k_2 –empirical ratios:

$$h_0 = A - a;\ k_1 = B - b;\ k_2 = -c, \quad (15)$$

where a, b, c –approximation coefficients.

CONCLUSIONS

Methods for increasing the efficiency of the feed production process and creating optimal airflow conditions in all elements of the mixed feed unit; combining the operations of grinding and cleaning grain meal with the possibility of using the potential of the airflow created by the grain grinder fan; creating conditions for the timely removal of the finished product from the grinding chamber of the grain grinder have been substantiated. Dependencies were obtained that allow:

- determine the productivity of pneumatically loaded grain crushers depending on the design of the loading device (ejector);

- determine the conditions for introducing grain meal into the grinding chamber of the crusher with rigidly fixed beams, in which the peripheral and end sieves are loaded uniformly.

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