THEORETICAL STUDIES OF TECHNOLOGICAL PROCESS OF GRINDING STALKED FEED

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Abstract. Currently, the technological process of grinding stalked feed in a multi-plane horizontal grinding machine has not been studied enough, and the physics of the process remains poorly understood. The purpose of theoretical research is to study the physics of the process of material movement in a vertical-type cutting grinding machine, and the tasks are to determine the absolute speed of particle movement and the vertical speed of material passing through the grinding chamber. The hypothesis of the physics of the process of stalked feed grinding was put forward, an analytical model of the functioning of the grinding machine was developed and the forces affecting the stems in the inlet chamber and the grinding chamber were revealed. Material in the inlet chamber in spiral air flow descends along the screw line onto rotating knives and presses against the inner surface of the grinding chamber, along the perimeter of which segment contradictions are installed. The knives of the grinding drum for each phase make the selection of the material and its subsequent grinding from the impact in flight and when interacting with contradictions. Based on the analysis of the trajectory of particles, the mathematical model and theoretical value of absolute speed of particle movement along the inner surface of the grinding chamber – 23.25 $m \cdot s^{-1}$, values of vertical speed of material passing through the grinding chamber – 3.95 $m \cdot s^{-1}$ and the dropping angle of the helical line – 10º are obtained. The obtained results confirm the hypothesis of the physical essence of the process of grinding stalked feed about the possibility of regulating the vertical speed of material passing through the grinding chamber, the degree of grinding, energy intensity and productivity of the grinding machine. Due to this, the investigated multi-plane horizontal grinder has significant advantages over special and universal hammer grinders of stalked feed.

Keywords: stalked feed, grinding machine, material speed, functioning model.

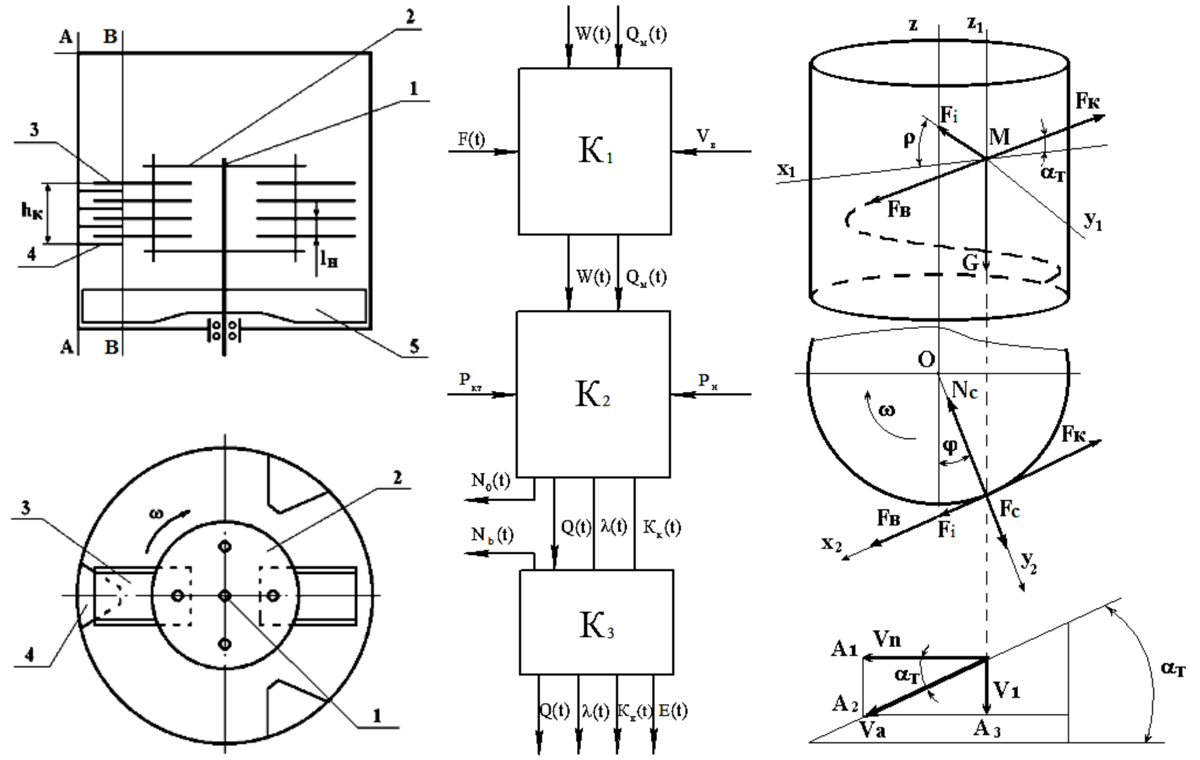
Introduction

Currently, the food industry has a significant influence on the solution of the food issue, the main task of which is stable production of all types of feed, taking into account the energy saving and economic efficiency of livestock enterprises. At the same time, it is important to increase the technical level of mechanization of feed preparation processes, where the use of various fodder mixtures using coarse stalked feeds occupies a significant place, since they are a mandatory component of the feed diets of most animals [1]. When preparing feed for feeding, one of the main and labor-intensive operations is to crush it into particles that meet zootechnical requirements [1]. An effective grinder should efficiently crush plant species and varieties with different mechanical and technological properties [2]. For grinding of coarse stalked feed, the most common are special grinders with a knife (straw cut, paste manufacturers) or pin (disintegrators, dismembers) working organs, as well as a universal hammer [3; 4]. Grinders with vertical arrangement of shafts and multi-plane horizontal scheme of drum cutting machine are promising.

The purpose of the theoretical research is to study the physics of the process of material movement in a vertical-type cutting grinding machine, and the tasks are to determine the absolute speed of particle movement and the vertical speed of material passing through the grinding chamber.

Materials and methods

To study the physics of the process of grinding stalked feed in the investigated vertical-type grinding machine, it is necessary, first of all, to find out the nature of the bunker loading of the ground material into the inlet chamber. During the bunker loading, a chaotic supply of feed particles to the inlet chamber is characteristic, when the stems are equally distributed in space. Therefore, in order to obtain high-quality cutting, the stems must be forcibly reoriented. Suppose that in the inlet chamber the stems will be affected by gravity and the force of the air flow created by the blower and drum, which force the material to move in a spiral air flow and descend along a helical line into the grinding chamber onto rotating knives. In the grinding chamber, under the influence of centrifugal inertia forces, Coriolis forces and air flow, the material will be pressed to its internal surface, along the perimeter of which segment contradictions are installed (Fig. 1, *a*).



a) b) c)

Fig. 1. **Multi-plane horizontal grinding machine of stalked feed:** a – diagram of the mashine; b – model of functioning; c – scheme of forces acting on a moving particle and direction of speeds; 1 – vertical shaft; 2 – grinding drum with four axes of knives suspension; 3 – grinding knife; 4 – segment anti–cut; 5 – blade blower

The process of extraction of stalked material by the grinding drum for grinding when it leaves the loading tray proceeds so that the drum knives capture a certain part of the material of different classes of fractions along the length for each passage. The knives of the grinding drum for each phase perform two main operations: selection of material for grinding and subsequent grinding from an impact in flight and when interacting with an anti-cut. When knives are struck, the stems are partially crushed and broken. Final grinding and splitting of material occur at interaction of drum knives with segments of anti-cut. In this case, the stem will be cut or split if two events coincide at the same time: the stem and the drum knife or the stem, the drum knife and the anti-cut segment must come into contact with each other.

Suppose that during the interaction of the working elements of the horizontal multi-plane grinding machine at the moment of cutting the stems will be located between planes A-A and B-B (Fig. 1, *a*). There will be more long stems in this zone, since the bounding planes will not allow them to be located differently. The limiting plane A-A is the inner surface of the grinding chamber, and the plane B-B exists figuratively and is formed by the air flow and centrifugal forces of the rotating drum. At the moment of cutting the stems are pressed against the fixed segments, which create an anti-cutting support. As a result, stems will be held on segments, which will lead to their reorientation.

An analysis of the physical nature of the process of grinding stalked feed in the studied grinding machine made it possible to formulate some assumptions:

- under all forces, the material particles will be oriented and flow along the helical line along the inner cylindrical surface of the grinding chamber, gradually descending;
- the final material will focus on the anti-cuts that will hold the stems and strive to arrange them parallel to the axis of rotation of the drum, which will create better conditions for their cutting;
- the use of a cutting pair consisting of self-rolling knives and segment anti-cuts will replace the more energy-intensive processes of breaking the stems by bending and breaking with a mostly less energy-intensive process with the predominance of impact sliding cutting;

- during the operation of the blade blower due to the suction effect in the inlet and grinding chambers the processes of material supply and grinding will intensify, and in the unloading chamber the air flow will contribute to more reliable transportation and unloading of the crushed feed.

On the basis of the above, one can hypothesize the physical nature of the process of grinding stalked feed in the investigated grinding machine of the vertical type: due to changing the speed of air or the radius of the grinding chamber, it is possible to adjust the absolute speed and speed of material passing through the grinding chamber and affect the degree of grinding of stalked feed, energy intensity and throughput of the grinding apparatus.

Results and discussion

It is impossible to obtain full-fledged results of theoretical studies without the presence of an analytical model of the operation of the entire machine and the identification of the relationships of the links of this machine. The design model of the functioning of the multi-plane horizontal grinding machine of stalked feed (Fig. 1, b) is developed in accordance with the structural and technological diagram (Fig. 1, a) and consists of an inlet chamber (K_1), grinding chambers (K_2) and unloading chamber (K_3). The combination of these elements characterizes the sequence of operations of the process of grinding stalked feed.

The studied multi-plane horizontal grinding machine of stalked fodders is a complex stochastic system operating under conditions of varying external influences. The input actions (signals) in the model of operation of the grinding machine are variables that determine the conditions of its operation: the amount of supply $Q_м(t)$ and the humidity $W(t)$ of the ground material. The model also takes into account the energy characteristics of the grinding process: power for the drive of grinding working elements $N_о$ and power for the drive of the blade blower $N_ω$. The output variables, that is, the reactions of the system to the effects, are quantitative and qualitative indicators of its operation: the productivity $Q(t)$, the degree of grinding of the material $\lambda(t)$, the quality indicator of ground particles $K_к(t)$ and the energy intensity of the grinding process $E(t)$. In addition to the parameters reflecting the physical and mechanical properties of the ground material $F(t)$, the output parameters of the system operation are influenced by structural and technological $P_{кт}$ and adjustment parameters $P_н$, which characterize the initial position of the working elements of the grinding machine before the start of operation. These include the circular speed of the knives, the speed of air, the diameter of the grinding drum, the number of axes of the suspension of the knives, the number of knives and anti-cuts, the spacing of the knives and anti-cuts, the clearance in the cutting pair (Fig. 1, b).

During operation of the grinding machine, the initial stalked material with initial characteristics in terms of physical and mechanical composition $F(t)$ and humidity $W(t)$ is supplied to the inlet chamber K_1. The amount of material supply $Q_м(t)$ depends on the physical and mechanical characteristics of the material to be ground and the air flow speed $V_в$ generated by the grinding working parts and the blade blower. Under the influence of own weight and the air flow, the ground material is supplied to the grinding working parts to the chamber K_2, and after grinding - to the unloading chamber K_3, where it is unloaded from the grinding machine by the blades of the blower (Fig. 1, b).

The relationship between the parameters of the studied system is expressed by the functional (1).

$$\Phi\ \{Q_м(t), W(t), F(t), V_в, P_{кт}, P_н, N_о, N_ω, Q(t), \lambda(t), K_к(t), E(t)\} = 0. \quad (1)$$

The process of functioning of the studied system proceeds in time t and is described as functional from the output variables according to the equation (2).

$$\Phi\ (t) = F\ \{Q(t), \lambda(t), K_к(t), E(t)\}. \quad (2)$$

Since the output variables are interconnected, in order to increase the productivity of the studied system, reduce energy consumption and obtain a high quality of the feed grinding process, it is necessary to ensure an optimal combination of them.

The constructed model of functioning of a multi-plane horizontal grinding machine of stalked feed allows to determine the sequence of theoretical and experimental studies on justification of the parameters of the grinding machine.

The results of the research on the analysis of material movement in the stalked feed grinding machine [5-11] are not enough to achieve the purpose and tasks set in our work. To do this, it is necessary to determine the trajectory and compose equations of movement of material particles inside the grinding chamber.

In steady motion, the particle is influenced by several forces that change the direction and magnitude depending on the location of the particle relative to the knife and chamber. The particle of material when moving in the grinding chamber relative to the drum knife can be, for example, in three provisions: in front of the knife, on top and between the knives. Suppose that the particle in the first position moves in a horizontal plane along the knife and it does not roll down from the knife. In the second case, the particle moves first in a horizontal plane with a slight rise up the face of the knife, and then only horizontally. The particle of material, being between the knives, is pressed against the inner cylindrical surface of the grinding chamber and is able to drop down the helical line. In this position, the particle is more than 90% of the time. The absolute speed of its movement $v_а$ includes the portable speed $v_п$ and axial speed v_1, the vector of which is directed vertically downward (Fig. 1, c).

Consider the pattern of forces acting on a moving particle of material with mass m along the inner cylindrical surface of the grinding chamber with the angular speed ω and the direction of speeds (Fig. 1, c).

With steady motion, the following forces will act on the particle:

- gravity of particle G, determined according to the known formula (3)

$$G = m \cdot g, \tag{3}$$

where m – particle mass, kg;
g – acceleration of free fall, $m \cdot s^{-2}$;

- centrifugal force F_c in absolute motion according to the known formula (4)

$$F_с = \frac{m \cdot v_а^2 \cdot \cos^2 \alpha_т}{r_к}, \tag{4}$$

where $v_а$ – absolute particle speed, $m \cdot s^{-1}$;
$\alpha_т$ – dropping angle of helical line, grad;
$r_к$ – inner radius of grinding chamber, m;

- friction force of the particle $F_к$ on the inner surface of the grinding chamber in the form of an equation (5)

$$F_к = f_к \cdot F_с, \tag{5}$$

where $f_к$ – friction coefficient of the particle against the surface of the grinding chamber;

- inertia force F_i;
- force of influence of the air flow $F_в$ on the basis of [12] on a formula (6)

$$F_в = m \cdot k_р \cdot (v_в - v_а)^2, \tag{6}$$

where $v_в$ – air speed, $m \cdot s^{-1}$;
$k_р$ – wind resistance coefficient, m^{-1}, determined according to the known formula (7)

$$k_р = \frac{g}{v_к^2}, \tag{7}$$

where $v_к$ – critical speed of particle winding, we accept $v_к = 3\ m \cdot s^{-1}$ [5].

If the point M is taken as the origin of the coordinate system x_1, y_1, z_1, then the equations of the particle equilibrium can be found by projecting all the forces acting on the particle onto the axis z_1 parallel to the axis of the drum, and the axis x_1 lying in a plane tangent to the surface of the grinding chamber in the form of equations (8) and (9).

$$\sum z_1 = F_i \cdot \sin \rho + F_к \cdot \sin \alpha_т - F_в \cdot \sin \alpha_т - G = 0, \tag{8}$$

$$\sum x_1 = F_\text{i} \cdot \cos\rho - F_\text{к} \cdot \cos\alpha_\text{т} + F_\text{в} \cdot \cos\alpha_\text{т} = 0, \tag{9}$$

where ρ – friction angle of material against the inner surface of the grinding chamber.

Solving equation (9) regarding to F_i we get in the form of an equation (10).

$$F_\text{i} = \frac{F_\text{к} \cdot \cos\alpha_\text{т} - F_\text{в} \cdot \cos\alpha_\text{т}}{\cos\rho}. \tag{10}$$

Substituting equation (10) in (8), we have the equation (11).

$$\frac{f_\text{к} \cdot m \cdot v_\text{a}^2 \cdot \cos^2\alpha_\text{т}}{r_\text{к}} - m \cdot k_\text{p} \cdot (v_\text{в} - v_\text{a})^2 - \frac{m \cdot g}{\cos\alpha_\text{т} \cdot \text{tg}\rho + \sin\alpha_\text{т}} = 0. \tag{11}$$

Hence, the absolute speed of the particle is expressed by the formula (12).

$$v_\text{a} = \frac{-2 \cdot k_\text{p} \cdot v_\text{в} + \sqrt{(k_\text{p} \cdot v_\text{в})^2 + \left(\dfrac{f_\text{к} \cdot \cos^2\alpha_\text{т}}{r_\text{к}} - k_\text{p}\right) \cdot \left(k_\text{p} \cdot v_\text{в}{}^2 + \dfrac{g}{\cos\alpha_\text{т} \cdot \text{tg}\rho + \sin\alpha_\text{т}}\right)}}{2 \cdot \left(\dfrac{f_\text{к} \cdot \cos^2\alpha_\text{т}}{r_\text{к}} - k_\text{p}\right)}. \tag{12}$$

The equation (12) relates the absolute speed of the particle on the inner surface of the grinding chamber to the wind resistance coefficient, the air speed, the radius of the grinding chamber and the dropping angle of the helical line along which the particle moves.

The dropping angle of the helical line defined by the expression (13).

$$\sin\alpha_\text{т} = \frac{v_1}{v_\text{a}}, \tag{13}$$

where v_1 – axial speed of material dropping, m·s^{-1}.

The vertical speed of material passing through the grinding chamber is defined by (14).

$$v_1 = v_\text{a} \cdot \sin\alpha_\text{т}. \tag{14}$$

Accepting the basic data: k_p = 1.09 m^{-1}, $v_\text{в}$ = 50 m·s^{-1}, $\alpha_\text{т}$ = 10º, ρ = 25º, $f_\text{к}$ = 0.28, $r_\text{к}$ = 0.185 m and substituting them into expressions (12) - (14), we obtain the theoretical values of the absolute speed of the particle along the inner surface of the grinding chamber – 23.25 m·s^{-1}, vertical speed of material passing through the grinding chamber – 3.95 m·s^{-1} and the dropping angle of the helical line – 10º. At the same time, due to a change in the speed of the air or the radius of the grinding chamber, it is possible to adjust the vertical speed of the material passing through the grinding chamber and affect the degree of grinding of the material, the energy intensity and productivity of the grinding machine that confirms the hypothesis put forward by the physical nature of the process of grinding stalked feed.

Thus, the obtained results on the rate of material passage through the grinding chamber confirm the international scientific trends in the development of structures of modern stem feed grinders [3; 5; 11]. A promising scientific direction is the development and creation of universal multi-plane grinding machines of the vertical type with a material flow rate through the grinding chamber of more than 3 m·s^{-1} [5], which have significant productivity advantages over similar devices of the horizontal type.

Conclusions

1. A model of functioning of a multi-plane horizontal grinding machine of stalked feed was developed and the relationship between the input effects and output indicators of its operation was revealed.
2. Parameters of functionals characterize the conditions and predefine methods of improvement of the output parameters of the process of operation of the studied stalked feed grinding machine.
3. Mathematical models and values of absolute speed of particle movement along the inner surface of the grinding chamber – 23.25 m·s^{-1}, vertical speed of material passing through the grinding chamber – 3.95 m·s^{-1} and the dropping angle of helical line are obtained – 10º.

4. The possibility of controlling the vertical speed of material passing through the grinding chamber and due to this degree of grinding, energy consumption and productivity of a multi-plane horizontal grinding machine is justified.

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