Operating features of a small capacity grain grinder with a hex rotor for agricultural farms

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Abstract. This article emphasizes the essential need for technical solutions in small-scale electromechanization tailored for private and small farms to efficiently manage labor-intensive tasks related to caring for farm animals and poultry. The focus is on utilizing single-phase electric motors of low power known for their simple and reliable design, available at a competitive market price. The paper introduces a design and technological diagram, structure, and operational principles of a versatile rotary grain crusher specifically engineered for grinding grain feed. The study gives a theoretical analysis of grain deformation processes within the grain crusher and the movement of grains within the working chamber. Through a concise theoretical examination of the machine's working chamber, the research validates the potential of the proposed design and technological scheme for the grain feed grinder. This analysis underscores the machine's promise in delivering the desired quality of the technological process while significantly reducing specific energy consumption compared to existing production models.

1 Introduction

Across the globe, the forefront of enhancing livestock production efficiency through the provision of complete and nutritious feed is driven by the adoption of innovative resource-saving technologies and technical solutions. With the global demand for livestock products, particularly meat, having tripled in recent years and projected to double by 2030 [1], ensuring livestock farms have access to well-rounded nutrition stands as a critical objective. Consequently, significant focus is directed towards the development of energy-efficient feed grinding devices to support this endeavor.

For private farms and small farms, it is extremely necessary to have technical means of small-scale electromechanization to perform labor-intensive work on servicing farm animals and poultry, which would be based on the use of single-phase electric motors of low power, characterized by a simple and reliable design at an affordable market price.

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Manufacturing enterprises producing such equipment pay little attention to this issue, do not know the market well and do not have promising developments. Due to this it is necessary to develop and substantiate the parameters of a rotary grain grinder that ensures minimum specific energy consumption, obtaining crushed grain products that meet zootechnical requirements for the type and age of livestock and, on this basis, ensuring a dust fraction not exceeding 5%.

2 Materials and methods

The research work is underway around the world aimed at creating new types of resource-saving technologies and technical means for preparing feed by grinding grain materials in livestock farms and justifying their technological work processes [2-7].

This paper examines one of the design and technological schemes of a feed grain grinder, which is characterized by its simplicity of design and manufacture. Figure 1 shows a technological diagram of the grinder with a cross-section of the working chamber [2].

The structure of the machine is clear from the diagram. The work process is as follows. The grain enters the hopper 1, and then into the grooves 3 of the housing 2. The grooves are made by drilling at an angle $\alpha$ to the vertical axis of the work piece chamber 2, which is then bored to the size of the hexagonal rotor 4. In the upper part, the groove allows the passage of grain, i.e. the hole diameter should be $d_{\text{max}}$, where $d_{\text{max}}$ – maximum size of whole grains. In the lower part, the cross-sectional area of the groove becomes equal to zero.

An increase in the grinding module relative to the calculated one is possible by moving housing 2 down relative to rotor 5 due to the threaded connection of housings 2 and 8.

In the groove 3 of the housing 2, the grain, under the influence of gravity, falls down until it meets the surface of the rotor, while the forces of pressure, reaction and friction create compression, shear and torsion stresses in the particle being destroyed. The shape of the rotor and groove we adopted allows for complex deformation of the particle, leading to a reduction in the work of destruction by 25-30% compared to the destruction of particles by compression.

Fig. 1. Shredder circuit: 1-loading hopper; 2- adjusting valve; 3-working chamber housing; 4-groove housing; 5-rotor; 6-flange electric motor; 7-unload disk; 8- unloading chamber housing; 9-discharge tray.
After grinding, the grain mass enters the cavity of the housing 8 and is unloaded by disk 7 through tray 9.

3 Results and discussion

To analyse the processes of particle destruction and their movement in the working chamber, let us consider the diagram in Figure 2.

Grain particle 2 gets into the groove of stator 1 and moves downward under the influence of weight until it becomes pinched. At the moment of pinching (Fig. 2, a), the particle stops, and then when the rotor face rotates, its destruction occurs. The destroyed particle, decreasing in size, rushes down the groove until the next stop and destruction, etc. before leaving the working chamber.

![Diagram](image)

**Fig. 2.** Position and movement of grain particles in the working chamber.

Since the stator slots are filled with grain while the rotor is rotating, the required radius \( R_r \) along the outer edges of the grooves can be determined from the relationship:

\[
R_r = R_s \geq d_{\text{max}}
\]

where \( R_s \) – stator radius; \( d_{\text{max}} \) is the maximum average grain diameter that is supplied for grinding.

The degree of grinding or grinding modulus is determined by the maximum gap size \( \delta \) between the edge of the rotor and the cylindrical surface of the stator. This value can be represented through design parameters as the expression:

\[
\delta = R_s \left( 1 - \cos \frac{180}{z} \right)
\]

where \( z \) – number of rotor faces.

Since the rotor slot is inclined vertically at an angle \( \alpha \), then in order for the pinched particle not to be pushed upward, the following condition must be met: \( \alpha \leq \varphi_s \)

where \( \varphi_s \) – angle of particle friction along the stator groove.

Thus ensuring reliable pinching for particle destruction, we find the necessary parameter ratios:

\[
R_f - R_s = H \cdot \tan \alpha
\]

\[
R_f - R_s = f \cdot H
\]

(3)
where \( f = \tan \varphi_s \) is the friction coefficient of particles along the stator groove.

Fig. 2 shows that the maximum value of particle compression is determined from the condition:

\[
\delta_S = R - R_S - d,
\]

(4)

where \( d \) is the current value of the particle diameter as it moves along the rotor slot.

From this expression it is clear that \( \delta_s \) are a constant value and equal to:

\[
\delta_S = \delta = R_S \left(1 - \cos \frac{180^\circ}{2}\right).
\]

(5)

Therefore, to ensure a stable process of destruction from the moment of entry to exit of the particle, it is very important to provide the necessary deformation for the first destruction.

If \( d_{\text{max}} < R_r - R_s \), then the grain before the first destruction will move down the groove by a certain amount:

\[
h = \frac{R_v - (R_s + d_{\text{max}})}{\tan \alpha} = \frac{R_v - (R_s - d_{\text{max}})}{f},
\]

(6)

and the current value of the radius \( R \):

\[
R_r = R_s + d_{\text{max}}
\]

(7)

Since the permissible value of deformation \([\delta]_s\) is available in the literature, we can assume from the condition of reliable destruction:

\[
R_s = \frac{1 - \cos \frac{180^\circ}{2}}{[\delta]_s}.
\]

(8)

However, to ensure a given quality of grinding, it is also necessary to meet the following condition (with the condition that it is possible to increase the grinding module by adjusting the position of the stator in height relative to the rotor):

\[\delta \leq M,\]

where \( M \) is the specified grinding module.

From the above listed dependencies, it is obvious that the geometric parameters of the rotor and stator must be determined from the conditions of the physical and mechanical properties of the grain material (diameter, friction coefficient, etc.), the given quality of grinding (grinding modulus), the required value of fracture deformation.

Working chamber performance:

\[
Q = q \cdot Z_p \cdot k \cdot n,
\]

(9)

where \( q \) is the productivity of one groove; \( Z_p \) – number of slots on the stator; \( n \) – rotor speed; \( k \) is a coefficient that takes into account the influence of rotation speed on the speed of movement of the crushed material in the stator groove.

Necessity of introduction \( n \) is explained by the fact that the time of exposure of the rotor face to the particle is:

\[
t = \frac{60}{n_z}.
\]

(10)

During this time, the particle moves under the influence of gravity by the amount:
\[ h = \frac{g-t^2}{2}, \quad \text{or} \quad t = \sqrt{\frac{2h}{g}}, \]  

Hence the amount of movement:

\[ h = g \left( \frac{60}{nz} \right)^2, \]  

\( n \) increases the value of \( h \) decreases, and the particle does not have time to descend to a position where it is ensured reliable destruction from the condition \([h]\). In this case, the impact of the rotor on the particle does not lead to its destruction, but to a delay in downward movement.

To assess the nature of the deformation of a particle during its compression and destruction, consider the diagram of forces in Figure 3.

![Fig. 3. Scheme of loads on a particle during deformation and destruction.](image-url)

When the rotor face rotates, a normal force \( N \) arises on both the rotor and the stator. The direction of these forces and their magnitude change as a function of time (rotor rotation). Friction forces \( F_1 \) and \( F_2 \) create together with a couple of forces \( N \) torques that cause complex stress on a particle during deformation and fracture. The diagram shows that, along with compressive deformation, the particle experiences shear and torsion deformations. It is known that the most energy-intensive process is compression destruction. It is also known that with shear and torsion, the energy intensity of the destruction process decreases.

Moisture content of the soil of the experimental area where potatoes are grown is 12-14%, the hardness is 0.98 MPa.

The furrow profile for harvesting potato tubers had the following dimensions: the width of the lower base of the furrow \( V_g \) ranged from 60-70 cm, the width of the upper base \( b_1 \) was between 10-14 cm, and the height of the furrows \( h_g \) measured from 10-14 cm. These dimensions can be adjusted within a certain range. The angle of inclination of the furrow's side surfaces \( \phi \) was found to vary between 26-32 degrees.

Each bush of the potato crop in the field of experiment is 1077.7 grams, including the mass of potato tubers is 524.4 g the mass of the stem is 553.3 g, the number of tubers is 9.4 pieces on average, the number of the stem is 6.2 pieces, the yield of potato tubers is 24 t/ha, the yield of the stem is 1.42 t/ha.

The average length of potato tubers of Sante variety was \( a_{kl} = 64.4 \) cm, (mean square deviation \( \sigma_{kl} = 15.8 \) cm), average width \( b_{kl} = 51.8 \) cm (mean square deviation \( \sigma_{kl} = 11.3 \) cm), average thickness \( c_{kl} = 64.4 \) cm (mean square deviation \( \sigma_{kl; \gamma} = 10 \) cm).
4 Conclusion

Based on the aforementioned factors, it is apparent that the geometric parameters of the rotor and stator must be established based on the physical and mechanical properties of the grain material, such as diameter and friction coefficient, as well as the desired grinding quality (grinding modulus) and the required level of fracture deformation.

The preliminary analysis of the machine's working chamber indicates the potential of the proposed design and technological scheme for the grain feed grinder. This scheme is promising in delivering the specified quality of the technological process and creating a machine with a significantly lower specific energy intensity compared to existing production samples.

References

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