Theoretical study of the process of grain materials grinding in agriculture machinery

Djabpar Alijanov[1], *Shavkatjon* Abdurokhmonov[1*], *Kamoliddin* Usmonov[1], *Azatbay* Kamalov[1], and *Kenzhemirza* Baimakhanov[2]

[1]Tashkent Institute of Irrigation and Agriculture Mechanization Engineers, Tashkent, Republic of Uzbekistan
[2]South Kazakhstan University named after M. Auezov, 5, street Tauke-Khana, Shimkent, 160012, Kazakhstan

Abstract. This paper outlines the findings of theoretical investigations into the grain materials grinding process in agriculture, focusing on the particle breakdown occurring at the moving edge of the rotor groove relative to the fixed edge of the stator. The choice of grinding methods is influenced by the processed feed, its intended purpose, the adopted feed preparation technology, and the specific farm animals involved. The study highlights the significant variations in the grinding process due to differences in dimensional characteristics and strength properties of grain materials, which impact the selection of working chamber parameters and operating modes. The paper introduces a hexagonal rotary crusher design and technological scheme, which offers the flexibility to adjust the amplitude-frequency characteristics of the working elements, energy of the process, and grinding quality within a wide range. Further research on the system dynamics requires experimental studies of grain material grinders utilizing diverse destruction methods. This study aims to advance understanding of the grain materials grinding process and optimize feed processing techniques for improved livestock productivity and product quality.

1 Introduction

One of the pressing problems of modern agricultural production is providing the population with sufficient quantities of high-quality livestock products. In order to successfully meet the growing needs for meat and dairy products, it is necessary to develop cattle breeding, which in turn is directly related to the creation of a strong food supply. Providing animals with complete feed, nutritionally balanced in accordance with planned productivity, is one of the decisive conditions for increasing production and improving the quality of livestock products. The quality of feed, the degree of balance, as well as feeding rations have a significant impact on the productivity of animals, on the quality of the resulting products, as well as on the health of the animals themselves.

* Corresponding author: abduroxmonov.shavkatjon@bk.ru

It is known that nutrients are actively absorbed by animals in crushed form, since the active surface of particles in crushed feed increases. This helps speed up the digestion process and absorption of nutrients.

Depending on the processed feed and its purpose, the adopted feed preparation technology, and the type of farm animals, different grinding methods are used. The planned work is devoted to theoretical studies of the process of grinding grain materials [1-4].

2 Materials and methods

Many studies of the strength properties of cereal grains show a significant nonlinearity in the dependence of the deformation force on stress and the relative magnitude of grain compression, which indicates the variability of the characteristics of their elastic-viscoplastic properties. The data on destructive forces and deformation given in this and other sources for various types of grain and the main schemes of their loading make it possible to obtain an equation for the process of grinding grain materials and to estimate the parameters of the working chamber depending on the minimum possible size of the crushed particle [5,6,7,8].

The process of grinding grain materials varies significantly. This is due to the difference in their dimensional characteristics and strength properties. This significantly influences the choice of parameters and operating modes of the working chamber.
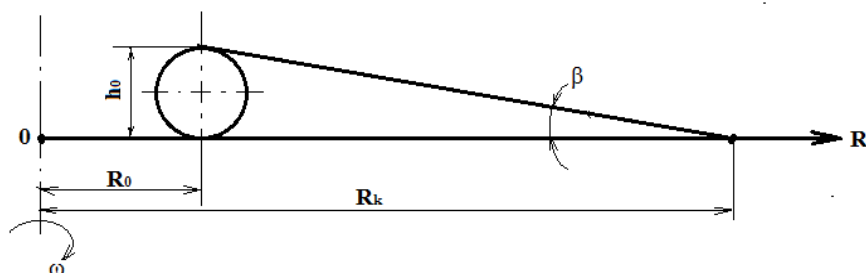

Fig.1. Scheme for studying the movement of grain along the rotor groove relative to the stationary edge of the stator.

In order for a particle of weight G to begin moving along the radial slot of the rotor, the following condition must be met:

$$\frac{G}{g}R\omega^2 \geq f2\frac{G}{g}\omega\dot{R} * sin\alpha + fG \tag{1}$$

those, the centrifugal force must be greater (relative motion) or equal to the frictional forces on the bottom of the groove (weight of the particle) or on the vertical wall of the groove (from the Cariolis rotation force). If we take the relative speed $\dot{R} = 0$ at the beginning of movement, then from (1) we obtain the critical speed of rotation of the rotor:

$$\omega_{kr} \geq \sqrt{\frac{fg}{R_0}} \tag{2}$$

where R_0 is the radius of the feed neck for feeding particles into the working chamber.

For example, with $f = 0.3$ and $R_0 = 0.02$ m, $\omega = 116.3$ r/s, the minimum required $\omega = 12.13$ 1/s or n =115.89 rpm [9,10,11,12].

3 Results and discussion

When a particle moves from the moment it enters the rotor groove at a distance R0 (Figure 1), the process of impact destruction begins at a speed V = ωR. A feature of the technological

process in the working chamber is the discrete movement of a particle in the rotor groove. After the first destruction of a particle, its relative motion begins at $\dot{R}_1$=0 and increases to $\dot{R}_2$=max by the time of the next destruction and further until the moment of exit from the working chamber (Figure 2).
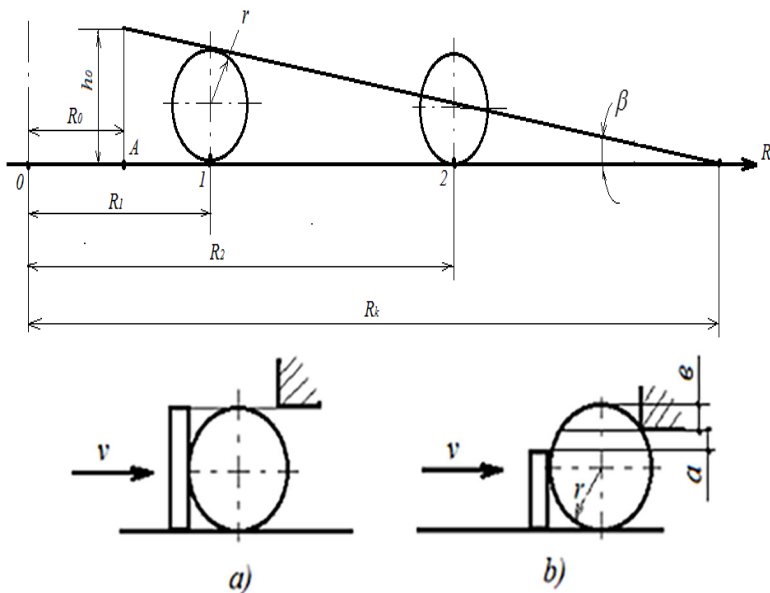

Fig.2. Determination of the movement of a particle between two destruction R_1-R_2. a) with zero gap between the rotor and stator (fine grinding); b) with a gap Δh (depending on the grind size).

Since the second destruction (point 2 in Figure 2) is possible with a full rotation of the rotor at $t = \frac{n}{60}$, where n is in rpm, the traveled path R_2-R_1 of the particle can be determined from the equation:

$$m\ddot{R} = mR\omega^2 - f2m\omega R\sin\alpha - fmg$$

or at equal angles of friction of particles against the bottom and wall of the groove of a radially located groove:

$$\ddot{R} = R\omega^2 - f\left(2\omega\dot{R} + g\right), \qquad (3)$$

in this case, the angle $\alpha = 50°$, because the Cariolis force vector is directed against the direction of rotation of the rotor and perpendicular to the plane of the groove edge. The design of the rotor slot is determined by the presence of the power supply system, the size of the grain material at the inlet and outlet of the working chamber. From Figure 2 it is clear that the initial movement of the grain before the first destruction (point 1, Figure 2):

$$R_1 = R_k - \frac{2r}{h_0}(R_k - R_0) \qquad (4)$$

and the distance of the particle from the entrance to the working chamber to point 1 is equal to (R_1-R_0).

To determine the lengths of sections between points A-1, 1-2, 2-3, etc. it is necessary to solve equation (3) in general form and then use it. Using the standard technique for solving linear differential equations, we determine the coefficients of the characteristic equation:

$$\lambda^2 + 2f\omega\lambda - \omega^2 = 0, \qquad (5)$$

we get two roots:

$$\lambda_1 = (-f + \sqrt{1 - f^2})\,\omega > 0 \quad \text{and} \quad \lambda_2 = (-f + \sqrt{1 - f^2})\,\omega < 0,$$

and the general and particular solution:

$$R' = C_1 l^{\lambda_1 t} + C_2 l^{\lambda_2 t}, \tag{6}$$

$$R'' = \frac{fg}{\omega^2} \tag{7}$$

From here we get

$$R' = C_1 l^{\lambda_1 t} + C_2 l^{\lambda_2 t} + \frac{fg}{\omega^2} \tag{8}$$

and speed

$$\dot{R} = C_1 \lambda_1 l^{\lambda_1 t} + C_2 \lambda_2 l^{\lambda_2 t}, \tag{9}$$

From the joint solution of (8) and (9) at t = 0, R=R_0 and $\dot{R}$ =0 we obtain:

$$C_1 = \frac{\lambda_2}{\lambda_1 - \lambda_2}\left(R_0 - \frac{fg}{\omega^2}\right), \qquad C_2 = \frac{\lambda_2}{\lambda_1 - \lambda_2}\left(R_0 - \frac{fg}{\omega^2}\right)$$

Substituting the resulting C1 and C2 into equation (8), we obtain the equation for the relative motion of a particle along the rotor groove, provided that it is radially located and the friction coefficients against the bottom and walls of the groove are equal:

$$R = R_k - \frac{fg}{\omega^2}; \tag{10}$$

$$R = \frac{1}{\lambda_1 - \lambda_2}\left(R_0 - \frac{fg}{\omega^2}\right)\left(\lambda_1 l^{\lambda_2 t} + \lambda_2 l^{\lambda_1 t}\right) + \frac{fg}{\omega^2}; \tag{11}$$

$$\dot{R} = \frac{\lambda_1 \lambda_2}{\lambda_1 - \lambda_2}\left(R_0 - \frac{fg}{\omega^2}\right)\left(l^{\lambda_1 t} - l^{\lambda_2 t}\right). \tag{12}$$

From (11), the time t at the moment of the particle's position at point 1 (Figure 2) is easily calculated, which determines the number of rotor revolutions before the first destruction.

For example: when R_0=0,02*m,* ω=12.5', *f*=0.03, R_l=0.08, R_k=0.2m, h_0=0.015, *r*=0.005, λ_1=10.15, λ_2=-1.4

When using equations (11) and (12), it is necessary to take into account the features of the discrete movement of the crushed product in the working chamber. From Figure 2 it is clear that the movement of a particle into the working chamber begins at point A at t = 0, R=R_0 =0) and ends at point 1 in accordance with (4). Next comes section 1-2, 1-3, etc. until the particle leaves the working chamber. The length of each section will be a constant value at:

$$R_i = R_k - \frac{2r - (a+b)i}{h_0}(R_1 - R_0) \text{ at } (i=1,2,3,…) \tag{13}$$

At the moment the particle leaves the working chamber, the value is 2*r*-(*a*+*в*)*i*=0 and the residual particle leaves freely from the working chamber. If the set gap "a" and the height of the chipped product "b" are equal to 2r in total, i.e. *a+b=2r* destruction of the particle is impossible and the working chamber operates with maximum productivity as a transporting device.

The use of the working chamber can be represented as a coefficient:

$$K = \frac{R_1 - R_0}{R_к - R_0}$$

where R_l-R_0 is the distance from the moment the particle enters the working chamber and before the start of grinding;

$R_к$-R_0 – design length of the working chamber. 1 ≥ K ≥ 0, K=1 for h_0 ≤ 2r; K=0 at 2r-(*a*+*в*)=0.

4 Conclusion

In the context of agricultural production, the developed design and technological scheme of a hexagonal rotary crusher offers significant advantages in optimizing the grain materials

grinding process. This crusher design allows for a wide range of adjustments to the grinding modes, working element characteristics, energy consumption, and grinding quality, which can be tailored to the specific needs of different feed types, intended purposes, and farm animals.

The crusher's ability to vary the amplitude-frequency characteristics of the working elements and the energy of the grinding process can contribute to enhanced efficiency and productivity in livestock feed processing. Furthermore, the quality of grinding can be optimized to improve nutrient absorption and digestion in animals, leading to better animal health, productivity, and product quality.

To further advance the understanding of the system dynamics, experimental studies of grain material grinders employing various destruction methods are necessary. This research can provide valuable insights into the grain materials grinding process and inform the development of more effective and efficient feed processing techniques, ultimately contributing to the sustainability and success of agricultural production.

References

1. M. Zhang, M.L. Sword, D.R. Buckmaster, Transactions of the ASAE **46(6)**, 1503-1511 (2003)

2. M.A. Ball, R.D. Shaver, A.G. Jirovec, K.J. Shinners, J.G. Coors, Article in Journal of Dairy Science **6(83)**, 1264-1273 (2000)

3. M.A. Momin, P.A. Wempe, T.E. Grift, A.C. Hansen, Transactions of the ASABE **5(60)**, 1551-1560 (2017)

4. D. Alijanov, Sh. Abdurokhmonov, Y. Jumatov, IOP Conf. Series: Materials Science and Engineering **883** 012155 (2020)

5. C.A. Tang, X.H. Xu, S.Q. Kou, P.A. Lindqvist, H.Y. Liu, International Journal of Rock Mechanics and Mining Sciences **38(8)**, 1147-1162 (2001)

6. A. Borotov, IOP Conference Series: Materials Science and Engineering **883** 012160 (2020)

7. A. Borotov, IOP Conference Series: Earth and Environmental Science **868** 012035 (2021)

8. Sh. Abdurokhmonov, N. Umirov, K. Ismaylov, E3S Web of Conferences **486** 05003 (2024)

9. M. Thomas, W.H. Hendriks, A.F.B. van der Poel, Animal Feed Science and Technology **240**, 11-21 (2018)

10. D. Alijanov, Sh. Abdurokhmonov, N. Umirov, IOP Conference Series: Materials Science and Engineering **883** 012117 (2020)

11. O.V. Nanka, Agrotechnics and energy supply **1**, 204-209 (2014)

12. D. Alijanov, V.V. Sakharov, A.S. Sirojiddinov, Sh.T. Turaev, S.A. Saidkhodjaev, Patent No. IAP 03209 Rotary grinder, October 27, 2006