Numerical simulation of the operation of the disc shredder

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Abstract. The purpose of the work is to model the performance of the disk grain shredder by numerical methods of determining the performance of the device and its components, and to establish the existing trends in the influence of the size of the initial particles on the components of the shredder performance. The increase in the initial particle size leads to an increase in the initial angular velocity of the particle movement, which increases as the particle is compressed, while the increase in particle size does not significantly reduce the productivity of the shredder due to the worsening conditions of particle capture by the disks as they increase in size. The increase in the initial spring compression force ensures a reduction in the thickness of the resulting flattened particles and at the same time reduces the productivity.

1. Introduction
Grinding is a mandatory process step in the production of mixtures or composites [1, 2]. Based on the characteristics of the material to be ground, different types of grinders are used [3, 4, 5]. To improve the assimilation of nutrients by animals, plant grains are ground [6, 7]. The most common types of shredders are impact shredders [8, 9, 10]. However, the dust fraction negatively affects the health of animals. Shredders of crushing type are devoid of the specified drawbacks and do not require high energy inputs [11]. In work [12] the design of a disk shredder for grains of agricultural plants is offered, and also the conclusion of necessary theoretical expressions is carried out. At the same time, there is no numerical analysis of the influence of the size of particles of the shredded material on the productivity and the influence of the size of particles on the geometric parameters of the shredder elements, which determine its productivity, is not studied.

2. Materials and Methods

2.1. Study object
The purpose of the study is to simulate the work of the disk shredder based on the analysis of the work of the disk shredder of grain by numerical methods of determining the productivity of the device and its components, and to establish the existing trends in the influence of the size of the initial particles on the components of the shredder productivity.
2.2. **Research tools**
As the main modeling tool, a modern computer based on the Microsoft Windows 8 platform was used. On the basis of theoretical expressions, the work of the shredder’s disk working body is described and numerical modeling of the existing tendencies of parameters change in the Mathcad computer program is made.

3. **Results**
The disk shredder of grain (Figure 1) contains the base 1 on which the driving shaft 2 is established, receiving the torque from the electric drive 3. Through the shaft 2 the torque is transferred on a shaft 5 and a tubular shaft 4 of the drive of the shredding mechanism. The drive 6 is mounted on shaft 5. Inside the tubular shaft 4 there is a rod 7 on which the disc 8 is fixed. Disc 8 is pressed against disc 6 by spring 9. Loading of the material is carried out through the hopper 10 and feeding device 11, and unloading of the product through the tray 12.

![Figure 1](image)

**Figure 1.** Disc shredder of grain: 1 - base; 2 - driving shaft; 3 - electric drive; 4 - tubular shaft; 5 - driven shaft; 6.8 - disk; 7 - rod; 9 - spring; 10 - hopper; 11 - feeding device; 12 - discharge chute; 13 – cover

Productivity of the disc shredder (kg/s):

\[ Q = L \cdot V_3 \cdot \rho \cdot \Psi \cdot \Delta = (R - R_0) \cdot V_3 \cdot \rho \cdot \Psi \cdot \Delta, \quad (1) \]

where \( L = (R - R_0) \) – length of the working area of the conditioning zone, m (Figure 2); \( R \) – outer working radius of the conditioner disc, m; \( R_0 \) - inner working radius of the conditioner disc, m; \( \rho \) – volumetric density of initial grain material, kg/m\(^3\); \( \Psi \) – is the factor that takes into account the degree of filling of the conditioning zone (\( \Psi = 0.1...0.2 \)).

Based on the condition that the material particle (1) is pinched and the initial diameter of the material (\( \theta \leq \phi_1 \)) and the initial diameter of the material particle \( d \) can express the minimum radius of the catch zone:

\[
R_0 = \frac{d \cdot (1 + \cos \phi) - 2 \cdot \Delta}{2 \cdot (1 - \cos \phi)}.
\]
Figure 2. Scheme for determination of a number of geometrical parameters of a disk shredder of grain material

where \( \Delta \) – disc spacing, m; \( \phi \) – angle at the top of the cone disk, deg..

Due to the different particle size and radius of the particle-disc contact point, the particle velocity and angular velocity between the discs are not constant.

Material velocity between discs for the current disc radius \( R_i \) (\( R_0 \leq R_i \leq R \)), m/s:

\[
V_{i} = \frac{\omega \cdot R_{i} \cdot (1 - \sin(\psi/2)) \cdot \frac{1}{\sin(\psi/2)} + 1}{\frac{1}{\sin(\psi/2)} - 1} \cdot \frac{\omega \cdot R_{i} \cdot \sin(\psi/2) + d/2}{R_{i} \cdot \sin(\psi/2) + d/2}
\]

where \( \omega \) – angular velocity of the particles between the discs, rad./s; \( R_{i} \) – operating radius of the shredder disc on the i-th section, m; \( \psi \) – angle at the top of the cone, hail.

Change in the angular velocity of a particle from its initial size \( d \) (m) and subsequent thickness \( \Delta \) (m) is shown in Figure 3. Depending on the particle diameter \( d \) (digital value corresponds to the initial particle size, mm), the distance between the discs varies from the initial size to the gap between the discs \( \Delta = 0.001 \) mm. Increasing the initial particle size leads to a higher initial angular velocity of the particle (aspiring to the angular velocity of the disk).
Figure 3. Dependence of the angular velocity of a particle on its initial size \( d \) (m) and subsequent thickness \( \Delta \) (m)

The initial diameter of the particle \( d \) (m) determines the condition of its capture by the discs:

\[
d = \frac{2(R_1 \cos \theta - R_1 + \Delta)}{1 + \cos \theta}
\]

where \( \theta \) – starting angle of particle capture, deg.

\[
\theta = \arcsin \left( \frac{\sin \beta}{\sin(\psi/2)} \right)
\]

The smallest distance between the points of contact \( \ell \) (m) of the particles with disks is calculated (Figure 4):

\[
\ell = \sqrt{\left(\frac{d}{2} (1 + \cos \theta)\right)^2 + \left(\frac{d}{2} \sin \theta\right)^2}
\]

According to the calculation (Figure 4), the particle diameter has almost no effect on the distance between the discs at the points of contact with the particle. As the particles are flattened, the differences are completely levelled out (disappear). The initial angle of grip of the particles increases as the size grows, i.e. the grip conditions deteriorate. This will reduce the shredder's productivity. With particle sizes greater than 2 mm, the angle of gripping increases from 15 to 18 degrees, i.e. insignificantly.

Angle \( \beta \), where the grain particle with the initial diameter \( d \) is clamped by the discs at a distance \( R_i \) from the top of the cone is:

\[
\beta = \arcsin \left( \frac{1 - \left(\frac{2 \cdot R_1 + 2 \cdot \Delta - d}{-2 \cdot R_1 - d}\right)^2}{\sin \left(\frac{\psi}{2}\right)^2} \right)
\]

The current value of the shredder disc radius capacity will be recorded, kg/s:
\[
Q_i = \omega \cdot \rho \cdot \Psi \cdot \Delta \cdot \frac{(1-\sin(\psi/2)) + 1}{2 \cdot \frac{1}{\sin(\psi/2)} - 1} \cdot \frac{\sin(\psi/2)}{\sin(\psi/2)+d/2} \cdot (L_i \cdot R_i).
\]

Figure 4. Dependence of the distance between the points of contact \( l \) (m) of particles with disks from the particle compression thickness \( \Delta \) (m)

Figure 5. Dependence of the initial particle capture angle (deg.) on the subsequent particle compression thickness \( \Delta \) (m)

Since the diameter of the particles coming to the grinding can be different, let’s determine the influence of this factor on the productivity of the shredder in the elementary parts of the working zone (Figure 6). Comparing the numerical values, we see that the increase in particle size slightly reduces the shredder capacity by area, which is due to the deterioration of particle capture conditions as their size increases.
Figure 6. Dependence of the capacity $Q$ (kg/s) of the elementary length of the shredder conditioning zone on the current radius $R$ (m) of the shredder disc: $Q'_1$, $Q'_2$, $Q'_3$, $Q'_4$, $Q'_5$ – capacity depending on the initial particle diameter $d$ (mm).

The total capacity of all sections will be, kg/s:

$$Q = \omega \cdot \rho \cdot \Psi' \cdot \Delta \cdot (1 - \sin(\varphi/2)) \cdot \frac{1}{2} \cdot \frac{(\sin(\varphi/2) + 1)}{\sin(\varphi/2)} \cdot \sum(L_i \cdot R_i).$$

On the basis of the data of theoretical calculations and the results of experimental researches graphic dependences of productivity of a disk shredder of grain (figure 7) at an angle at a top of a cone 165 ° at various frequency of rotation of working elements and force of compression $F_o$ (H) of disks by a spring have been constructed. An increase in the initial spring force reduces the average thickness of the resulting crushed particles $a$ (mm) and at the same time reduces the productivity.

The results of comparison of the calculated productivity of the conditioner and the experimental values presented in Figure 7, indicate sufficient reliability of analytical dependencies. The difference between the results is less than 6%. Data from $\chi^2$-test – 0.989861; F-test – 0.972286.
4. Conclusion

The increase in the initial particle size leads to an increase in the initial angular velocity of the particle (aspiring to the angular velocity of the disk). At the size of particles more than 2 mm the angle of capture increases from 15 to 18 degrees, that is insignificantly that promotes decrease in productivity of a shredder. The increase in particle size slightly reduces the shredder capacity due to the deterioration of particle capture conditions as they increase in size.

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