Factors affecting the efficiency of the rod shredder and the analytical expression of its productivity

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Abstract. Shredding is one of the most energy-consuming operations in the feed preparation process. Among the methods of shredder materials, precise cutting is a less energy-consuming process and provides a higher quality of the ready product. The efficiency of grain shredders is usually evaluated as a combination of qualitative and quantitative indicators. When improving the shredding process, it is necessary to ensure that the finished product meets the zoo technical requirements, and the shredder provides high productivity with minimal energy consumption. Quantitative indicators include the productivity of the shredder and specific energy consumption. In practice, it is necessary to separate the energy consumption of the shredding process and the energy consumption of the process, taking into account the degree of shredding. The design of a shredder capable of providing oblique cutting with greater efficiency is proposed. The shredder has a truncated rod that is located on a shaft inside a cylinder with longitudinal holes. In the longitudinal holes of the cylinder there are removable counter-cutting knives. The productivity of the given rod shredder generally depends on the mass of crushed particles passing through the hole per rotation of the rod; the frequency of rotation of the rod and the number of holes. As a result, an analytical formula is expressed that allows calculating the productivity of the rod shredder based on these parameters. The results obtained can be used in the design of shredding machines and will be used in the future when creating an experimental installation of a shredder.

1. Introduction
Shredding is one of the most energy-consuming operations in the process of feed preparation [1]. For shredding grain, hammer crushers are used, which have a simple device and reliability. However, they also have disadvantages, including over-shredding of the material, intensive wear of working bodies, and relatively high energy costs.

That’s why research aimed at developing new design shredders that will provide high quality of the finished product and at the same time consume a small amount of energy is promising.

2. The purpose of the study
The purpose of this work is improving the efficiency of the grain shredding process. To achieve this goal, the following tasks are set: to consider existing methods of shredding; to identify criteria for evaluating the efficiency of the shredders; to propose a promising design of the rod shredder; to...
identify factors that affect the efficiency of the rod shredder; to express a formula for determining the productivity of the rod shredder.

3. The object of the study
The object of the research is the rod shredder.

4. Materials and methods

4.1 The analyze of the shredding methods
Research of processes of movement of grain and the shredding have been studied by many authors [2-6]. There are known methods of shredding (figure 1). Existing shredder designs typically use a combination of these methods. For example, a hammer mill effectively uses direct impact and abrasion. The study of the shredding process in other ways was carried out by the authors, who note the advantages of cutting before impact [1, 7, 8, 9]. Precise cutting is a less energy-consuming process and provides a higher quality of the finished product.

![Diagram of shredding methods]

Figure 1. The methods of shredding: (a) – pressing; (b) – abrasion; (c) – free kick; (d) – constrained kick; (e) – splitting; (f) – fracture; (g) – sawing; (h) – punch cutting; (i) – cutting with a blade; (j) – cutting with a cutter.

Pressing is the result of applying an external load that exceeds the material’s tensile strength during compression. Abrasion is performed by the sum of complex deformations simultaneously: compression and shear. Kick refers to a concentrated short-term dynamic load that destroys the material. Splitting of solid particles occurs at the concentration of dynamic loads transmitted by the wedge-shaped working body. Fracture implies destruction under the action of loads acting on unsupported areas of solid particles. Sawing consists in applying a special sawing tool to the material. Cutting is the division of material into parts using different cutting tools. At the same time, cutting is distinguished by the blade, punch and cutter, which differ in the working body and the location of the support surface relative to it.

4.2 Assessment of the efficiency of the shredders work
The efficiency of grain shredders is usually evaluated as a combination of qualitative and quantitative indicators [10]. Qualitative indicators include: the weighted average particle size of the shredder material; the number of whole grains in the shredder material; the percentage of the dust fraction in the shredder material. Thus, when improving the shredding process, it is necessary to ensure that the
finished product meets the zoo technical requirements, and the shredder provides high productivity with minimal energy consumption.

Quantitative indicators include the productivity of the shredder and specific energy consumption. In practice, it is necessary to separate the energy consumption of the shredding process and the energy consumption of the process, taking into account the degree of shredding. The degree of shredding is the ratio of the size of the initial particles to the size of the particles after shredding. In addition, when creating shredders, it is also necessary to pay attention to: the ability to quickly and easily adjust the degree of shredding; fast and continuous removal of the finished product from the shredding chamber; possibility of quick replacement and increase of wear resistance of working parts; reduction of metal consumption.

4.3 Describing of the rod shredder

On the basis of the GBOU VO NGIEU, a shredder (11) with a truncated rod that is located on a shaft inside a cylinder with longitudinal holes was developed. In the longitudinal holes of the cylinder are removable knives-counter-cuts.

The shredder (12) works as follows: the material to be shredded enters the cylinder on the truncated surface of the rotating rod 1, then the material particles are pinched between the surface of the rod and the counter-cutting knife 5, crushed and withdrawn through the hole 4. Due to the angle of inclination of the section, oblique cutting is performed, which has a greater efficiency (link to work with). The knives can be used several times turning them over to use the new working edges. The resource of the rod can be changed itself by changing the direction of its rotation with the appropriate installation of knives.

![Figure 2](image)

**Figure 2.** The scheme of the rod shredder: (a) – main view of the rod shredder; (b) – cross section of the rod shredder; (c) – longitudinal section of the rod shredder; 1 – truncated rod; 2 – shaft; 3 – cylinder; 4 – holes; 5 – counter-cutting knife; 6 – bolts for fastening knives; 7 – knife stands.

4.4 Factors affecting the efficiency of the rod shredder

To study the shredding process, it is necessary to take into account the influence of various factors on the characteristics of the shredder [12]. It is known that the most significant influence on the granulometric composition of the ready product in hammer crushers is: the physical and mechanical properties of the grain; the circumferential speed of the hammers; their number, size and shape; the
distance between the ends of the hammers and the sieve; the shape and size of the sieve holes; the method of feeding and removing the material.

Taking into consideration the design of the shredder, it is possible to identify the main factors that affect its efficiency: frequency of rotation of the rod; the angle of the cross section of the rod; the angle of the counter-cutting knife; the gap between the edge of the truncated stem and the edges of the counter-cutting knife; the geometric dimensions of the holes, number of the counter-cutting knife.

5. Discussion of the results
In general sense the productivity of the given rod shredder depends on the following parameters: mass of crushed particles passing through the hole in one rotation of the rod: \( M' \), kg; rod rotation speed: \( v \), s\(^{-1}\); number of holes: \( i \), units.
There is a formula for defining the productivity of the given rod shredder:
\[
Q = M' \cdot v \cdot i. \tag{1}
\]
For a simplified calculation of the mass of crushed particles passing through the hole will make a number of assumptions: as of crushed particles will take balls of the same size; the impact on the surface of the ball is directly supported by the rod plane; the bowl slide along the plane of the holes is absent; the gap between the working plane of web and plane of counter - cutter is infinitely small; opening width less than the diameter of the ball.
The mass of the crushed particles can be expressed as follows:
\[
M' = \rho \cdot V \cdot n; \tag{2}
\]
where \( \rho \) – density of a particle, kg/m\(^3\); \( V \) – volume of a particle, m\(^3\); \( n \) – number of particles, units.
If the width of the hole \( h \) is less than the diameter of the ball, a segment of the ball will be extracted through the hole after the ball is exposed to the working bodies. The volume of the segment will be:
\[
V = \pi \cdot H^2 \cdot (R - \frac{1}{3} \cdot H); \tag{3}
\]
where \( R \) – ball radius, m; \( H \) – segment height, m.
The segment height is defined according to the ball radius and the width of a hole:
\[
H = R - (R^2 - (\frac{1}{2} \cdot h)^2)^{0.5}. \tag{4}
\]
There is a formula for defining of the number of particles moving through the hole:
\[
n = \frac{l}{D} \cdot k; \tag{5}
\]
where \( l \) – hole height, m; \( D \) – ball diameter, m; \( k \) – the coefficient of uniformity.
So there is a formula for defining productivity \( Q \) (t/h) for the given rod shredder:
\[
Q = \rho \cdot \pi \cdot H^2 \cdot (R - \frac{1}{3} \cdot H) \cdot \frac{l}{D} \cdot k \cdot v \cdot i; \tag{6}
\]
Substituting the expression of the segment height (4) in formula (6), we obtain a general formula for defining the productivity of the given rod shredder:
\[
Q = \frac{\rho \cdot \pi \cdot i \cdot v \cdot k \cdot l \cdot (2 \cdot R - (4 \cdot R^2 - h^2)^{0.5})^2 \cdot (4 \cdot R + (4 \cdot R^2 - h^2)^{0.5})}{24 \cdot D}. \tag{7}
\]
This formula can be used with theoretical calculations of the productivity of the rod shredders.

6. Conclusion
As a result of this work, the need to change the law is justified and the methods of grinding are considered. Criteria for evaluating the efficiency of the grain shredder are given. A new design of the shredder with knife working bodies is proposed, which allows more efficient and high-quality grinding of grain. For this design, the factors that influence the qualitative and quantitative performance indicators of the shredder are described. An analytical expression for calculating the productivity of a rod shredder is proposed. The results obtained can be used in the design of shredding machines and will be used in the future when creating an experimental shredder installation.

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