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Evaluation of the degree of shredding and granulometric composition of roughage by the disk working body of the shredder

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Abstract. The article discusses theoretical and experimental studies of the evaluation of the degree of shredding and granulometric composition of roughage by the disk working body of the shredder. The article gives a constructive-technological scheme of a shredder with a disk working body. The paper also presents the results of the research.

1 Introduction

Proper feeding of animals with roughage, especially in winter, is of paramount importance for the preservation and increase of animal productivity. For better digestibility, grinding of the material is required, but the technological process of grinding is labor-intensive and energy-intensive. The share of manual labor is especially high in small forms of farming, and there is a lack of resource-saving technical means.

It is known that the reduction of costs for the preparation of roughage is achieved by mechanizing this process. Currently, shredded material in stalls is widely used as bedding for animals [1,2]. The issue of mechanization of litter application has not been sufficiently resolved, it is necessary to have technical means that combine several technological operations. Currently, the design of technical means is being improved in order to increase the efficiency of the process and reduce energy costs.

Unshredded roughage (hay, straw) winds up on the working bodies of feeders, dispensers disturb the normal process. After shredding, the feed is easier to dose, mix more evenly, have a flowing that is especially important for the smooth movement of certain types of feed inside the technological lines. Feed always contains a certain amount of foreign impurities (clumps of soil, stones, wood, metal impurities), so their separation is a concomitant grinding process that improves the quality of the feed.

Shredding is the separation of a solid body into parts by the application of external forces greater than the molecular bonding forces of the body particles.

The size of particles of roughage with a length of 2 to 3 cm provides a dry matter intake of 3.8 kg per 100 kg of weight. Increasing the particle size from 5 to 8 cm provides a dry matter intake of up to 4.1 kg. Therefore, the optimal size of crushed particles is from 5 to 8

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cm, which significantly affects the productivity of the animal-milk yield increased to 23.1 liters [3].

2 Materials and methods

The hay used in the machine test must be obtained by machine mowing, compressed into rolls. The color of hay should be yellowish-green. The admixture of weeds should be no more than 5 %. The color of hay should be characteristic of this crop, high-quality, not faded, harvested in the best agrotechnical terms, having a pleasant smell.

The humidity of hay should be from 10 to 30 % inclusive. Hay for testing should be selected in the daytime, in natural light, with special attention to its physical and mechanical condition and quality.

The average sample for testing the machine must be selected so that it accurately and objectively characterizes the entire batch of material.

To do this, we select one roll from every 15-20 rolls of hay. Then, from the selected rolls, we choose the best in terms of physical and mechanical properties and quality. From the latter, we select 5-8 rolls for testing the machines [4].

To determine the granulometric composition and weighted average length of the roughage, it is planned to make a collection tray. The shredded product is collected in the steady state mode of the working bodies. Samples are collected by quartering methods according to the methodology of the All-Union Institute of Agricultural Engineering. The method is as follows. A grid of 20...50 squares is placed on the crushed product, distributed evenly. From these squares is taken 3...4 samples with a predetermined volume and then the results are averaged. These samples are placed in polyethylene bags, provided with tags indicating the date, number of the experiment.

Then the collected samples, with the help of manual disassembly, are separated into fractions by particle length: up to 10 mm, 10...20, 20...30, 30...40, 40...50, 50...60, 60...70, 70...100, 100...150, over 150 mm [5].

Each of the fractions is weighed on a scale, then the average particle length, which characterizes the degree of shredding, is determined by the arithmetic mean of the variation series:

$$l_{cp} = \frac{\sum_{i=1}^{n} m_i l_{cpi}}{\sum_{i=1}^{n} m_i}, \qquad (1)$$

where l_{cp} – average particle length, mm;

l_{cpi} – fraction particle length, mm;

m_i – mass of particles within each fraction, g.

To assess the uniformity of the shredded feed according to the industry standard 70.19.2-83, the standard deviation of the particle size is calculated:

$$\sigma = \sqrt{\frac{\sum \left(l_i - l_{cp}\right)^2 q_i}{\sum q_i}}, \qquad (2)$$

where l_{cpi}, l_{cp} – average particle sizes, respectively, fractions and weights, mm;

q_i – mass of particles of each fraction, g.

And the coefficient of variation according to the formula:

$$v = \frac{\sigma}{l_{cp}} 100\%. \qquad (3)$$

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It is customary to call the particles of the initial material for shredding as chunks, and the final material as particles of the shredded material (sod). Specific surface area $S_{уд}$ characterizes the surface development of material particles and is the ratio of the total surface area of particles to their volume or mass.

If you shred cubic pieces with edge length L, to cubes with edge length l or spherical pieces with diameter D to particles with diameter d, then for cube particles the volume specific surface area is: $S_{уд} = 6d^2/d^3 = 6/d$ (S and V denote the total surface area and total volume of particles).

The degree of shredding λ is the ratio of the characteristic particle size D of the feed material to the corresponding particle size d of the shredded product, $\lambda = D / d$ for spherical materials and $\lambda = L / l$ for cubic or elongated particles.

During grinding there is a large increase in the surface area of the particles, so the process can be characterized by the ratio of the specific surface area of the final product particles $S_{кон}$ to the specific surface area of the initial one $S_{нач}$.

However, in practice it is difficult to determine the surface area of bulk materials, so the size ratios are used.

In the multi-stage processes that have been used in feed shredding technologies and machines in recent years, the final degree of shredding $\lambda_{кон}$ is determined by the product of the partial degrees of shredding, that is $\lambda_{кон} = \lambda_1\lambda_2...\lambda_i$.

Real feed particles do not have any regular geometric shape and for practical purposes their coarseness is estimated by one characteristic measure – the diameter. For grain feeds, the concept of equivalent diameter is used. The equivalent diameter of a grain D, is the diameter of the sphere, the volume of which is equal to: the actual volume of the grain. If the volume of one grain is $V_з$ and the volume of an equal-sized sphere $V_з = D^3/6$, then the equivalent diameter of the grain is:

$$D_з = 1.24\sqrt[3]{V_з} \;. \tag{4}$$

In the total mass, the shredded particles have a wide variety of sizes and in varying amounts. Particle size is a random value, so only methods of mathematical statistics can be used for objective characterization.

The size of the shredded product is evaluated by its granulometric composition. The method of sieve analysis is most widely used to determine the granulometric composition. The minimum required amount of shredded material is dispersed, on sieves of different sizes. The sieves are set in a package from the bottom upwards from the sieves with small mesh size to large. When the sieving is finished, the mass of the residues on all sieves G_i is determined, by weighing to within hundredths of a gram [6].

3 Results and discussion

Shredding of roughage with a disc-shaped working body, which is equipped with combined cutting segments.

The roll is loaded into a vertical hopper and enters the disk working body of the grinder, which contains combined grinding knives, namely, toothed grinding elements, grinding double-plane arc profile segments and grinding toothed segments located along the perimeter of the disk working body [7].

A distinctive feature of the proposed technical tool (Figure 1) is a cone-type disk working body, equipped with combined cutting segments, which allows you to uniformly act on the material in the longitudinal-transverse directions (multi-plane cutting); reduce the energy intensity of the process by cutting with sliding and transporting feed to feeders or bedding to stalls by air flow; improve the quality of grinding; improve operational reliability and service life.

Fig. 1. Shredder with disk-shaped working body.

Table 1 shows the technical characteristics of the proposed shredder.

Table 1. Technical characteristics of the shredder.

Indicators	Values
Productivity, *t / h*.	1.5-2.0
Size of shredded particles, mm	20-60
Power consumption, kW	5.0
Hopper capacity, m^3	5
Angular rotation speed of the working body speed, s^{-1}	4.8
Weight, kg	1420
Overall dimensions, mm: length width height	 570 570 755

Control of changes in the weighted average length fraction of the shredded product was carried out by taking apart the obtained portions of the feed over 20 mm by hand, and fractions from 2 to 20 mm on the grid classifier, followed by weighing each fraction on the scale “KERN” (Figure 2).

Fig. 2. Tracking the change in the average weighted fraction length of the shredded product from 2 to 20 mm on the screen classifier.

A single feed was collected in one second in a specially made tray (Figure 3), and then it was weighed on a “KERN” brand sale.

Fig. 3. Tray.

Analyzing the graph of experimental dependencies of the average weighted length of particles of the shredded fodder L_{cp} (Figure 4) on the angular speed of rotation of the shredding working body one can see that at low angular speed $\omega = 1.6$ s^{-1} of the shredding working body the size of particles is 80 mm and more, that is caused by friction resistance forces, the inertness of the working body.

As angular speed increases, the mechanical energy is transferred to the stalks of the unshredded feed. Under the action of centrifugal forces, the feed falls on the shredding two-plane arc profile segments and toothed segments, located along the perimeter of the shredding working body, on the cutting edges of which the shredding occurs both along and across the fibers. At angular speed of rotation $\omega = 3.14$ s^{-1} and higher, the average weighted length of the particles is L_{cp} = 45 mm, which meets zootechnical requirements. According to the requirements when shredding straw and hay particle size should be for cattle in the range L_{cp} = 20…50 mm.

Analysis of the productivity Q showed, that when the angular rotation speed of the shredding tool ω = 2.1…5.2 s^{-1}, the productivity of the machine increases from 1.1 to 6 t/h and higher. Due to the mechanical energy, as well as the additionally created airflow, suction effect, and centrifugal forces, shredding of fodder is faster than at the low rotational speed of the shredding unit.

The graph of the experimental dependence of the specific energy consumption $W_{уд}$ in Figure 4 shows that the maximum cost of the specific energy consumption $W_{уд}$ = 0.0079 kWh/kg (7.9 kWh/t) is at the angular speed of rotation of the grinding working body equal to $\omega = 3.14$ s^{-1}. At the initial moment of time, the energy consumption is minimal and is $W_{уд}$ = 0.005 kWh/kg (5 kWh/t), therefore, at first, the specific energy intensity is low, and then it increases.

Analyzing the graph (Figure 5) of the experimental dependencies of the productivity Q, we can note that at the number of shredding two-plane arc profile segments, $n = 6$ value of $Q = 1.1\, t\ /\ h$, the analysis of the dependence of the average weighted particle length L_{cp} showed that L_{cp} = 50 mm also at $n = 6$, and the dependence of the specific energy intensity at $Z = 6$ shows the minimal value $W_{уд}$ = 0.002 kWh/kg (2 kWh/t).

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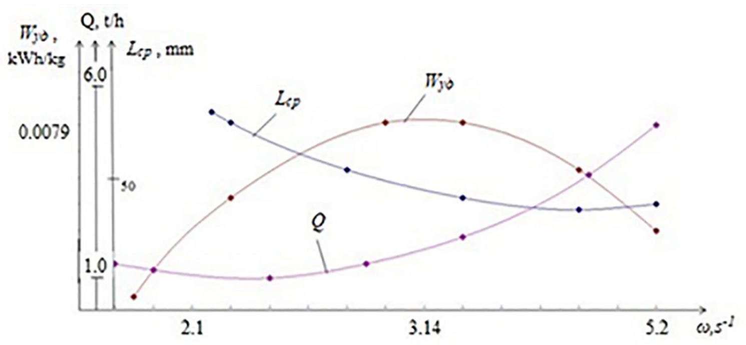

Fig. 4. Diagram of experimental dependencies of average weighted particle length, specific energy consumption, productivity on angular rotation speed of the shredding tool.

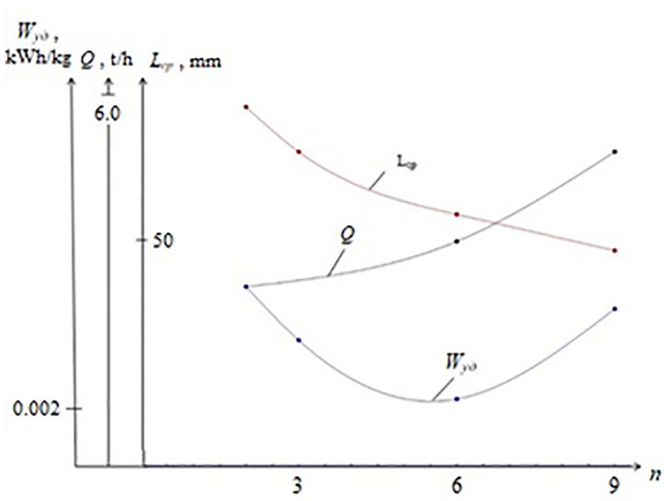

Fig. 5. Diagram of experimental dependences of average weighted particle length, specific energy intensity, productivity on the number of shredding two-plane arc profile segments n.

4 Conclusion

Thus, to reduce the energy intensity of the grinding process, it is effective to use a grinder with a disk working body.

As a result of the research, the following parameters were selected: the rational number of cutter segments, located along the cutter perimeter $Z = 6…9$; the number of segments of two-plane cutter arc profile $n = 7…9$; the angle between the tapered working body of the cutter and the horizontal cutter elements $\alpha = 300…350$ with an average weighted particle length, which meets zootechnical requirements, 50 mm.

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