Rotary-centrifugal shredder for forage preparation

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Abstract. Existing grain shredders have disadvantages, the main of which are the following: high metal and energy consumption, uneven granulometric composition of the crushed product, high percentage of pulverized fraction, rapid wear of working bodies, product heating. To eliminate the disadvantages, the design of a rotary-centrifugal grain shredder is proposed. The presented design requires optimization of a number of structural and kinematic parameters. To solve this problem, the method of a multifactor experiment was chosen. The feed of grain material, the rotor speed, the opening of the separating surface, and the number of knives on the inner and outer rings were taken as factors that varied at two levels. As optimization criteria, the plant performance, power consumption during grain grinding, and compliance of the resulting product with zootechnical requirements were considered. As a result of data array processing, adequate and reliable mathematical models were obtained. As a result of model analysis, the influence of factors on optimization criteria was established.

1 Introduction

Feed intended for animals must be prepared in accordance with zootechnical requirements. When preparing feed mechanically, grinding is mandatory.

Grinding is considered more energy-intensive and labor-intensive operation, which takes up more than 50% of the total labor costs in the preparation of compound feeds

The development, research and creation of an optimal and efficient way to grind grain feed encourages many researchers to create new designs for shredders [1-6].

The resulting scientific task is to improve the most efficient machines for grain crops grinding, one of which is a centrifugal-rotary shredder.

The purpose of the research is to reduce the specific energy consumption of forage grain grinding and increase the uniformity of the granulometric composition of the finished product by improving the main design parameters of the centrifugal-rotary shredder.

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2 Materials and methods

During the research, the following was used: forage grain, centrifugal-rotary shredder. The experiment was planned using the Box-Benkin matrix. The Excel data analysis package was used to analyze the data array and build mathematical models.

3 Results and Discussion

Of practical interest for grain grinding are the designs of shredders operating in the border area, combining the process of grinding by chipping and cutting with timely output of the finished product [1, 4, 7, 8].

Based on the results of theoretical research, the design of a rotary-centrifugal grain shredder is proposed. The schematic diagram is shown in Figure 1.

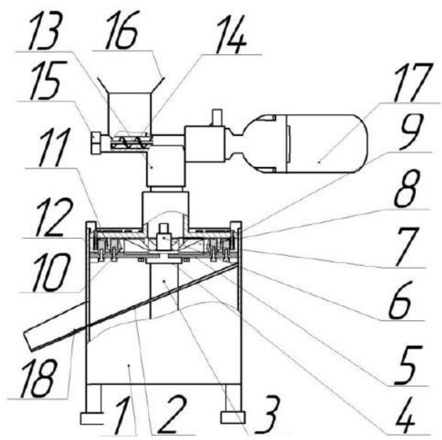

Fig. 1. Schematic diagram of a rotary - centrifugal grain shredder: 1 - body, 2 - inclined bottom, 3 - bearing assembly, 4 - drive shaft, 5 - rotor, 6 - nut - cutter, 7 - distributor, 8 - ring protrusions, 9 - ring protrusions, 10 - knives, 11 - knives, 12 - outer row of knives, 13 - dispenser housing, 14 - screw, 15 - plug, 16 - loading hopper, 17 – screw dispenser electric motor, 18 - upload window.

In the course of the study, barley of conditioned humidity was used as the initial grain material. Adjustment of the grain supply to the device x_1 was carried out by changing the speed of the motor shaft of the blade feeder. The x_2 rotor speed was regulated by changing the speed of the electric motor by a frequency converter. Opening of the separating surface x_3 — by setting the appropriate size between the parallel planes of two adjacent knives on the outer ring 9 (Fig. 1 and 2). The number of knives on the inner x_4 and outer x_5 ring — as a result of adding or removing them.

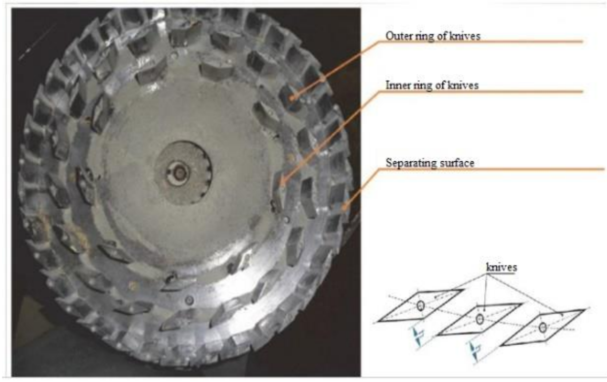

Fig. 2. General view of the upper disk of the shredder with a separating surface and installed knives, scheme for controlling the separating surface opening

To reduce the volume of research, a matrix of fractional factor of experiment type 2^{5-2} was used. The experiment planning matrix and results are presented in table 1.

Table 1. Experiment planning matrix and results of fractional factor experiment

	Factors					Optimization criterion			
	Grain feed, q, Hertz of the feeder	Roto speed, n, s^{-1}	Opening value of separating surface, h, mm	Number of knives on the inner ring, n_{nv}	Number of knives on the outer ring, n_{nv}	Power consumption, kW /Power input	Through put, Q, kg/min	Content of dust fraction, m_2, %	Screening residue Ø3mm, m_2, %
Experience number	x_1	x_2	x_3	x_4	x_5	y_1	y_2	y_3	y_4
1	30	800	3.2	9	9	1.80	0.75	8.78	8.52
2	60	1200	3.2	9	9	3.00	1.51	11.54	6.50
3	60	800	3.2	3	9	5.16	1.16	18.1	6.59
4	30	1200	3.2	3	9	2.43	0.79	14.95	7.65
5	60	800	3.2	9	18	3.33	0.64	12.29	7.38
6	30	1200	3.2	9	18	3.60	1.01	17.04	5.73
7	30	800	2.5	3	9	1.95	0.71	12.34	4.60
8	60	1200	2.5	3	9	4.02	1.59	16.80	4.72
9	60	800	2.5	9	9	2.70	1.46	7.83	20.71
10	30	1200	2.5	9	9	1.83	0.84	8.08	16.63
11	30	800	3.2	3	18	2.49	0.73	12.40	17.58
12	60	1200	3.2	3	18	3.87	1.67	13.65	3.60
13	60	800	2.5	3	18	5.94	1.19	18.88	10.08
14	30	1200	2.5	3	18	2.43	1.08	11.59	4.14
15	30	800	2.5	9	18	3.12	0.67	9.83	8.77
16	60	1200	2.5	9	18	5.07	1.57	14.78	9.44

Analysis of zootechnical requirements for concentrated feed for various groups of animals allowed to identify several main criteria for evaluating the quality of the product. This is the grinding size, the percentage of particles in the grinding more than 3 mm and the presence of whole grains in the grinding. However, the results of sieving on a vibrating screen of selected samples showed that the most critical parameter for the resulting product is the content of particles in the grinding more than 3 mm. At the same time, the presence of whole grains and the grinding modulus were not considered, since no whole grains were observed in the sieving, and the modulus value corresponded to coarse grinding. It should be noted that the grinding modulus largely depended on the particle content of more than 3 mm, so, for example, their content varied in the range from 0.4 to 60.8%

The data was analyzed in Excel. The results of data analysis in Excel are written as regression equations (1), (2), (3), (4) and are presented in table 2. Based on the results, it is concluded that the coefficients of the regression equations are significant at the 5% level; mathematical models (1), (2), (3), (4) due to the variation of the selected factors, they are statistically significant and cannot describe the processes occurring only at the 5% level. During the analysis, attention was paid to the normalized R-square, Fisher test results, t-statistics, and p-value (significance) for each coefficient of the equation [9-10]. The normalized R-square, unlike the R-square, can decrease when new explanatory variables are introduced into the model that do not significantly affect the dependent variable, while the R-square can increase when new explanatory variables are added, although this does not necessarily mean that the quality of the regression model improves. We give the regression equations and below the equation a table with the main indicators for each of the results y_1, y_2, y_3, y_4.

$$y_1 = -12,85 + 0,284x_1 + 4,318x_3 - 0,485x_4 + 0,552x_5 - 0,00006x_1x_2 - 0,04x_1x_3 - \\ -0,008x_1x_4 + 0,0005x_2x_4 - 0,2048x_3x_5 + 0,0214x_4x_5 \quad (1)$$

$$y_2 = 0,742 + 0,042x_1 - 0,0029x_2 + 0,1578x_4 - 0,032x_5 - 0,0105x_1x_3 - 0,005x_1x_4 - 0,0009x_1x_5 + \\ +0,0005x_2x_3 + 0,0001x_2x_5 - 0,027x_2x_4 - 0,005x_4x_5 \quad (2)$$

$$y_3 = -7,98 + 0,851x_1 + 8,05x_3 - 4,706x_4 - 0,0002x_1x_2 - 0,167x_1x_3 - 0,0187x_1x_4 + \\ +0,0018x_2x_4 + 0,573x_3x_4 - 0,1799x_3x_5 + 0,1123x_4x_5 \quad (3)$$

$$y_4 = -56,32 + 0,87x_1 + 18,15x_2 + 9,328x_4 - 0,312x_1x_3 - 0,00067x_2x_5 - \\ -2,339x_3x_4 + 0,53x_3x_5 - 0,159x_4x_5 \quad (4)$$

Table 1. Results of data analysis in Excel

Results output	y_1	y_2	y_3	y_4
Multiple R	0.996812151	0.999658	0.995507	0.939077
R-square	0.993634465	0.999316	0.991034	0.881866
Normalized R-square	0.980903396	0.996582	0.973101	0.746856
Standard error	0.172532606	0.021698	0.573001	2.55956
F	78.48	365.5	55.263	6.53
F Significance	0.0000745	0.00021	0.00017	0.0113

After analyzing the regression models of power consumption (1), productivity (2), as well as the dust fraction content (3) and the content of particles in the finished product more than 3 mm (4), then using the Solution search tool, we obtained the following conclusions.

Optimal values of factors under the condition of minimizing energy consumption, increasing throughput, reducing the content of the dust fraction and the screening residue:

$x_1 = 30$, $x_2 = 1200$, $x_3 = 2,5$, $x_4 = 3$, $x_5 = 18$. Average predicted values of the results for these values of factors: $y_1 = 2,8056$, $y_2 = 0,6034$, $y_3 = 10,8952$, $y_4 = 2,9885$ at the 95% significance level. The achievement of individual results compared to the optimal values for each of the results separately is 43%, 70%, 100% and 87%, respectively, the total achievement of results is 75%.

4 Conclusions

1. The most significant influence on the energy consumption y_1 is exerted by factor x_1, followed by factors x_3 and x_5. An increase in the grain feed x_1 increases the power consumption y_1, an increase in the opening value x_3 and a decrease in the number of knives on the outer ring x_5 leads to a decrease in the power consumption y_1.
2. The most significant influence on the throughput y_2 is exerted by factor x_2, followed by factors x_1 and x_4. The increase in speed x_2 and the number of blades on the inner ring x_4 leads to a decrease in the throughput y_2, the increase in grain feed x_1 leads to increase of the throughput y_2.
3. Factors x_1 and x_4, followed by factor x_3, have the most significant influence on the percentage of the y_3 dust fraction. The increase in the grain feed x_1 and the opening value x_3 increase the percentage of the dust fraction y_3, the increase in the number of knives on the inner ring x_4 leads to a decrease in the percentage of the dust fraction y_3.
4. The most significant influence on the percentage of particles with a diameter of more than 3 mm y_4 is exerted by factor x_4, followed by factors x_1 and x_3. Increasing the number of knives on the inner ring x_4, grain feed x_1 and increase of the opening of the separating surface x_3 increases the content of particles with a diameter of more than 3 mm.
5. The factor that significantly affects all results is the grain feed factor x_1. There are no factors that could be excluded from consideration.

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