Increasing performance of feed grinder in obtaining pelleted sunflower cake

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Abstract. One of the options for improving the protein feed (the feed in the form of sunflower cake) grinders, for which Russian Federation patent No. 2648392 was obtained, is the modernization of the working surface of knife packages. They include knives in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of its entire surface of cutting edges. This will reduce the energy intensity of the process and improve the grinding quality. In literary sources, the values of the performance quantities and the energy intensity of the grinder in obtaining pelleted sunflower cake are absent. As a result of mathematical modeling of the grinding process of sunflower cake in the pelleted form, the optimal parameters of the studied factors were determined. In the indicated ranges of factors changing, the obtaining of pelleted sunflower cake is provided, it meets the zootechnical requirements for cattle with a minimum energy intensity of the grinding process \( E = 1.03 \) kWh/t and its performance \( W = 2.3 \) t/h.

1. Introduction
Grinding is one of the most energy-intensive processes in the mixed feed industry. Beater grinders, which, when fine grinding, give up to 30% of the dust fraction, and when coarse grinding – up to 20% of the uncrushed fraction, are used for grinding grain raw materials. Regrinding results in additional energy losses ranging from 10 to 15 kW-h/t. Grinding increases the grain surface area, leading to an improved interaction of the feed with digestive enzymes, leading to a decrease in energy intensity and an increase in the quality of mixing components. However, fine grinding increases energy costs [1].

Concentrated feed in cattle diets is 25-60% in terms of nutritional value [5]. In the structure of livestock production cost, concentrated feed accounts for 60-70% of the cost. The effectiveness of their use depends on the quality of the preparation. The main operations in the feed preparation are cleaning, grinding, dosing and mixing. One of the energy-intensive operations is grinding, which must meet the requirements of GOST and zootechnical recommendations for the degree of grinding and fractional composition, as well as for the content of the dust fraction. Deviation from these technological requirements leads to a decrease in the efficiency of using expensive feed by up to 30%. Analytical review and analysis of literary sources are devoted to the issues of processing and increasing the efficiency of the use of mixed feed in animal husbandry. The studies carried out to improve grinders make it possible to improve the energy-technological characteristics of grinding processes [2-5, 7].

The disadvantages of grinders are their unsuitability for grinding sunflower cake in a granular form. Since grain and sunflower cake have different physical and mechanical properties, cake, unlike grain, has the property of hygroscopicity and is used for its immediate feeding to farm animals.
The grinding method affects the quality of the final product, which is the leading one in the process of concentrated feed preparation for feeding farm animals. According to the statistical average data, the process of grinding concentrated feed is energy-intensive and labor-intensive, accounts for 60% of the total labor costs in the forage conservation and preparation [8].

To reduce the energy intensity of the process and improve the quality of crushing sunflower cake, a feed grinder design was proposed (RF Patent No. 2648392).

2. Materials and methods

The protein feed grinder (Fig.1) has a charging hopper 2, a damper 3, a body 1, a frame 9, an electric motor 10, a rotor 8 with disks 4 and 5, knife packages 6 with knives 7 in the form of flat geometric shapes formed by circles.

![Figure 1. The protein feed grinder: a – scheme; b – knife cutting face](image)

The grinder has an even number of knife packages with knives installed parallel in a staggered arrangement, the surface of the cutting edges of which is made in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of the entire surface of the cutting edge. The height of these teeth is not less than the thickness of the process material. Thus, the teeth inclination angle is no more than 30°, and the teeth of the knives of the subsequent knife packages are directed in the opposite direction from the knives of the previous knife packages and at the same angle, and the knives are installed with the possibility of adjusting the distance between them depending on the size of the process material. Knives are selected for various feed, both in a pelleted and crumbled form.

The technological process of the protein feed grinder is conducted as follows.

When grinding the material, for example, the obtained sunflower cake, it is poured into the charging hopper 2 and the electric motor 10 is turned on, after which the damper 3 is opened. The crushed product contacts knives 7 in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of the entire surface of the cutting edge, which will improve the quality of grinding, and the entire surface of the knife cutting edge participates in the technological process and sliding cutting takes place, while the energy requirement decreases.

On the basis of the conducted literary analysis, theoretical studies [6], the factors (Table 1) affecting the grinding process according to RF Patent No. 2648392, were assigned. The routine of a multi-factor experiment is provided in the study [9].
Table 1. Factors affecting the quality of obtaining sunflower cake on an improved grinder, their symbols and intended levels of variation

| Factors                        | Symbols | Coded designation | Natural designation | Variation step | Level of variation |
|--------------------------------|---------|-------------------|---------------------|----------------|-------------------|
| Material thickness, mm         | $x_1$   | $h$               | 2                   | 8              | 10                |
| Tooth inclination angle, deg.  | $x_2$   | $\beta$           | 5                   | 20             | 25                |
| Number of knife packages, pcs. | $x_3$   | $n$               | 2                   | 2              | 4                 |

As an optimization criterion, the productivity ($y_1$) of the grinder was chosen in obtaining sunflower cake in a granular form (t/h) and the energy intensity ($y_2$) of the grinding process.

3. Results

After the experiment, the calculation of the regression coefficients, the regression equations describing the productivity and specific energy intensity of the improved grinder in obtaining granulated sunflower cake were derived:

– the performance

$$y_1 = 2.5 - 0.112x_1 + 0.45x_2 - 0.075x_3 - 0.1x_1x_2 - 0.024x_1x_3 - 0.1x_2x_3 - 0.412x_1^2 + 0.25x_2^2 + 0.34x_3^2;$$  (1)

– the energy intensity

$$y_2 = 1.04 - 0.021x_1 + 0.04x_2 - 0.035x_3 - 0.125x_1x_2 - 0.024x_1x_3 - 0.08x_2x_3 - 0.125x_1^2 + 0.075x_2^2 + 0.1x_3^2.$$  (2)

where $y_1$ – the grinder performance in obtaining granulated sunflower cake, t/h;

$y_2$ – the energy intensity of the grinding process in obtaining sunflower cake in a pelleted form, kWh/t;

$x_1$ – the thickness of sunflower cake in a pelleted form, mm;

$x_2$ – the tooth inclination angle on knife packages of the grinder, degrees;

$x_3$ – the number of knife packages on the grinder, pcs.

The verification of the obtained mathematical models (1) and (2) has been conducted by using the Fisher test. Tabular value of the Fisher criterion at a 5%-significance level for the grinder performance and the number of degrees of freedom were $f_1 = 4$, $f_2 = 8$ and $F_{0.05} = 4.82$ and the energy intensity of the grinder – $f_1=4$, $f_2 = 9$ and $F_{0.05} = 4.78$, respectively. Fisher criterion in calculations for mathematical models (1) and (2) was for:

– the grinder performance in obtaining pelleted sunflower cake:

$$F_{\text{calc}} = \frac{5.185}{1.225} = 4.23,$$

– the grinder energy intensity in obtaining pelleted sunflower cake:

$$F_{\text{calc}} = \frac{0.1192}{0.0429} = 2.78,$$

i.e., models (1) and (2) validation is confirmed.

To find the maximum of the response function, we equate its partial derivatives to zero and solve the resulting system of equations [9].
Solving the system of equations gives the following coordinates of the maximum point (coded values):

– the grinder performance in obtaining pelleted sunflower cake:

\[ x_1 = -0.025; \quad x_2 = 0.91; \quad x_3 = -0.024. \] (3)

– the grinder energy intensity in obtaining pelleted sunflower cake:

\[ x_1 = 0.075; \quad x_2 = -0.384; \quad x_3 = 0.338. \] (4)

Substituting the obtained results of the coded values (3) and (4) into equations (1) and (2), we determine the maximum grinder performance and the minimum energy consumption in obtaining pelleted sunflower cake, which were \( y_s = 2.3 \) t/h and \( y_s = 1.03 \) kWh/t, respectively.

As a result of processing a full factorial experiment for the performance and energy intensity of the grinder, the regression equations in the canonical form (5-10) were obtained for:

– the grinder performance in obtaining pelleted sunflower cake:

\[ y - 2.3 = -0.412X_1^2 + 0.228X_2^2; \] (5)

– the material thickness and the tooth inclination angle:

\[ y - 2.3 = -0.412X_1^2 + 0.362X_3^2; \] (6)

– the material thickness and the number of knife packages:

\[ y - 2.3 = 0.228X_2^2 + 0.362X_3^2. \] (7)

– the tooth inclination angle and the number of knife packages:

\[ y - 1.03 = -0.125X_1^2 + 0.122X_2^2; \] (8)

– the material thickness and the tooth inclination angle:

\[ y - 1.03 = -0.125X_1^2 + 0.053X_3^2; \] (9)

– the tooth inclination angle and the number of knife packages:

\[ y - 1.03 = 0.122X_2^2 + 0.053X_3^2. \] (10)

The response surface is an ellipsoid (Fig. 2a, Fig. 3a), and its center is an extremum, since the canonical coefficients of equations (7) and (10) have the same signs.

The response surface is a paraboloid (Figure 2-3 b, c), and its center is an extremum (maximum), since the canonical coefficients have different signs.
**Figure 2.** Two-dimensional surface cross-sections of the dependence of the grinder performance in obtaining pelleted sunflower cake: a – the material thickness and the tooth inclination angle; b – the material thickness and the number of knife packages; c – the tooth inclination angle and the number of knife packages

**Figure 3.** Two-dimensional surface cross-sections of the dependence of the grinder energy intensity in obtaining pelleted sunflower cake: a – the material thickness and the tooth inclination angle; b – the material thickness and the number of knife packages; c – the tooth inclination angle and the number of knife packages
To determine the parameters of the factors values in natural form, we will use the expression given in the study [10]:

– the grinder performance:

\[
\begin{align*}
X_1 &= -2 \cdot 0.025 + 10 = 9.95 \text{ mm}; \\
X_2 &= -5 \cdot 0.91 + 25 = 20.45 \text{ deg.}; \\
X_3 &= -2 \cdot 0.024 + 4 = 3.952 \text{ pcs};
\end{align*}
\]

– the grinder energy intensity:

\[
\begin{align*}
X_1 &= 2 \cdot 0.075 + 10 = 10.15 \text{ mm}; \\
X_2 &= -5 \cdot 0.384 + 25 = 23.08 \text{ deg.}; \\
X_3 &= 2 \cdot 0.338 + 4 = 4.676 \text{ pcs}.
\end{align*}
\]

4. Conclusion

One of the options for improving the protein feed (the feed in the form of sunflower cake) grinders, for which Russian Federation patent No. 2648392 was obtained, is the modernization of the working surface of knife packages. They include knives in the form of an Archimedes Arbelo curvilinear triangle with saw-edged teeth along the perimeter of its entire surface of cutting edges, which will reduce the energy intensity of the process and improve the grinding quality. In literary sources, the values of the performance quantities and the energy intensity of the grinder in obtaining pelleted sunflower cake are absent. As a result of mathematical modeling of the grinding process of sunflower cake in a pelleted form, the optimal parameters of the studied factors were determined:

– the sunflower cake thickness in a pelleted form \( h = 9.95 \ldots 10.15 \text{ mm}; \)
- the tooth inclination angle on a knife package \( \beta = 20.45 \ldots 23.08 \text{ deg.}; \)
– the tooth inclination angle on a knife package \( n = 4 \ldots 6 \text{ pcs}. \)

In the indicated ranges of changing factors, the obtaining of pelleted sunflower cake is provided, it meets the zootechnical requirements for cattle with a minimum energy intensity of the grinding process \( E = 1.03 \text{ kWh/t} \) and its performance \( W = 2.3 \text{ t/h}. \)

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