Improvement of the efficiency of sunflower cake grinding

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Abstract. The provision of animals and poultry with complete feed balanced in nutrition according to productivity is one of the key conditions for additional production and improvement of livestock quality and increase of protein. An improved sunflower cake grinder was proposed based on the given grinding techniques, which eliminates a number of disadvantages typical for serial products. Taking into account huge volumes of ground fodders, the problem of improving these grinders in terms of reducing their energy consumption is quite relevant. Besides, all known grinders are not suitable for sunflower cake grinding due to its physical and mechanical properties compared to other fodders. The paper describes the motion of the prepared sunflower cake along the surface of the cutting edge of knives in the form of a curved triangle of Archimedes arbelos with saw teeth in order to obtain it in a granular form. The Russian Patent 2648392 was obtained for the proposed design of the grinder, which allows expanding functional capabilities, reducing energy consumption of the process and improving the quality of grinding sunflower cake, which cannot be made by similar technical facilities. The knives in the grinder can be adapted for different fodder, both in granulated and dispersed form due to adjustment of distance between them depending on dimensions of processed material, which perform sliding cutting thus improving the efficiency of technological process. The obtained efficiency formula of the improved grinder allows increasing it depending on its design parameters and physical and mechanical properties of the material.

1. Introduction

One of the most pressing issues of modern agricultural production is the supply of sufficient quantity and quality of livestock products to the population. In accordance with the Strategy for Modernization of Agriculture, priority national projects and sectoral programs, its development is directly linked to the creation of a solid feed base – the most important managing resource for productive and reproductive functions of biological objects. The provision of animals and poultry with complete feed balanced in nutrition according to productivity is one of the key conditions for additional production and improvement of livestock quality and increase of protein [1].

The research carried out by Loshkomoynikov I.A. allowed establishing that their shortage in animal diets in winter period makes more than 30%. When providing animals with protein according to scientifically based zootechnical standards, without increasing feed consumption, it is possible to obtain 25-30% more livestock products, significantly increasing the economic indicators of the industry. The protein provision to animals in accordance with detailed standards is a relevant task for the successful development of livestock production. An important reserve for increasing protein production is oilseeds: sunflower, soybean, rapes, hustle, flax, red, etc., which combine high potential productivity of seeds with high content of oil and protein with its optimal balance in amino acid composition. The products of oilseed processing (cakes, oilseed residues) are high-energy and protein components of diets for farm animals and poultry [2].
According to the patent 2248243, there is a device to grind solid bar materials, which consists of a case with a bed knife fixed on its side surface, a shaft with knives arranged horizontally inside the case with the possibility of rotation, and two feeding rollers, working surfaces of bed and movable knives have semi-cylindrical grooves.

The disadvantage of the device is its inability to grind feed products from vegetable raw materials, namely sunflower cake.

According to the patent 2263542, there is a grinding device, which includes a loading hopper, a shutter, a housing, a frame, an electric motor, a rotor with disks, knife packages with knives, a rotor equipped with at least three knife packages with knives made in the form of a salinon, and the inner working surface of the housing represents an ovoid.

The disadvantage of the device is that it is not suitable for grinding sunflower cake, both in dispersed and granulated form, since grain and sunflower cake have different physical and mechanical properties, the cake as opposed to grain is hygroscopic and is used for its immediate feeding to farm animals [3].

The process of cutting with a blade was first theoretically considered by academician V.P. Goryachkin. Then, the theory of grinding was developed by V.A. Zheligovsky, N.E. Resnik, P.L. Polozov, V.A. Zyablov, M.A. Sulima, S.V. Melnikov, A.I. Zavrazhnov, D.I. Nikolaev, S.A. Pritchenko, S.F. Kolesnikov, A.A. Afanasiev, V.I. Perednya, etc. Their studies contributed to the development of modern grinding machines of several types: wheel, drum, pin, beater-knife and others, the operation principle of which is based on grinding by cutting, breaking, etc. [4].

Each of these scientists conducted research in different agricultural production zones. Different operating conditions lead to different interactions of machine tools with agricultural materials having different mechanical and technological properties, and accordingly, different experimental data are obtained [5].

Therefore, the key problem is that the main disadvantage of grinding by cutting with modern stem feed grinders is high energy intensity of the process, which makes up to 70% [6, 7]. Taking into account the huge volumes of ground fodders, the problem of improving these grinders in terms of reducing the energy consumption of the process is relevant [4], as well as all known grinders are not suitable for grinding sunflower cake due to its physical and mechanical properties compared to other fodders.

2. **Hypothesis**

In order to solve this problem, it is necessary to develop an improved grinder that provides a process for grinding sunflower cake at the lowest energy cost due to the new knife cutting surface design.

3. **Results**

In order to reduce power consumption and improve the quality of sunflower cake grinding the grinder design was proposed according to patent No. 2648392 [1, 3], which contains a feed hopper 2, a gate 3, a case 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 geometrical figures, formed by circles (Figure 1).

A grinder has even number of knife packages with knives installed in parallel in staggered order, surface of cutting edges, which are made in the form of a curved triangle of Archimedes arbelos with saw teeth along perimeter of whole surface of a cutting edge. The height of these teeth is not less than the thickness of a processed material. Besides, the inclination angle of teeth is not more than 30°, and the knife teeth of subsequent knife packages are in opposite direction from knives of the previous knife packages and at the same angle, the knives are also installed with the possibility of adjusting the distance between them depending on dimensions of the processed material. The knives are selected for different feed, both granulated and dispersed.
Let us consider the motion of the prepared sunflower cake along the surface of the cutting edge of the knives in the form of a curved triangle of Archimedes arbelos with saw teeth to obtain it in a granular form.

Let us present the process of grinding sunflower cake in a granulated form (Figure 2, 3).

The angular speed of grinder knife wheels (Figure 3) are equal

$$\omega_1 = \omega_2,$$

since the linear speed of the sunflower cake motion between its knife wheels 1 and 2 is determined by the known formula

$$v_1 = \omega_1 \cdot r_1,$$

$$v_2 = \omega_2 \cdot r_2.$$
The following condition is thus met

$$\vartheta_1 > \vartheta_2,$$  \hspace{1cm} (4)

since

$$r_1 > r_2,$$  \hspace{1cm} (5)

we receive

$$\frac{\vartheta_1}{\ell + x} = \frac{\vartheta_2}{x},$$  \hspace{1cm} (6)

$$\vartheta_1 \cdot x = \vartheta_2 (\ell + x),$$  \hspace{1cm} (7)

$$(\vartheta_1 - \vartheta_2) \cdot x = \vartheta_2 \cdot \ell,$$  \hspace{1cm} (8)

through mathematical transformations we find the distance ($x$) at which the instantaneous center pole will be located

$$x = \frac{\vartheta_2}{(\vartheta_1 - \vartheta_2)} \cdot \ell.$$  \hspace{1cm} (9)

The maximum size of sunflower cake will be determined by the expression

$$\ell_{\text{max}} = d + h,$$  \hspace{1cm} (10)

where $d$ – wheel thickness, mm; $h$ – clearance width between wheels 1 and 2, mm.

Let us define the area of impact of knife wheel tooth on sunflower cake granule by expression as a half of a tooth lateral surface

$$S = d \cdot \frac{h}{2}.$$  \hspace{1cm} (11)

Let us consider that the tooth is half stuck in a granule of sunflower cake. Let us determine the mechanical stress that occurs on the sunflower cake granule by expression

$$\sigma = \frac{F}{S},$$  \hspace{1cm} (12)

where $F$ – force with which a tooth acts on a sunflower cake granule, H.
Let us consider the options of the knife tooth effect of knife packages on sunflower cake granule. During operation of the grinder, protein feed (Figure 2 b) is supplied for processing in various positions, both in longitudinal and transverse positions (Figure 4).

**Figure 4.** Effect of force on protein feed in longitudinal (a) and transverse (b) positions

The permissible stress on the sunflower cake granule (Figure 4) is determined on the basis of expression (66) for two positions by the following formula:

- longitudinal:

\[
\sigma_{long} = \frac{F_{max}}{\pi r^2}, \quad (13)
\]

- transverse:

\[
\sigma_{trans} = \frac{F_{max}}{2r \cdot \ell}, \quad (14)
\]

Thus, the following condition shall be met

\[
[\sigma] = \min\{[\sigma_{long}]; [\sigma_{trans}]\}. \quad (15)
\]

Let us determine the number of teeth \((k)\) required for grinding sunflower cake (Figure 2 b), which is supplied for processing in different positions, both in longitudinal and transverse:

- transverse:

\[
k_{trans} = \frac{2r}{2h_t} \text{ or } k_{trans} = \frac{4r}{h_t}, \quad (16)
\]

where \(h_t\) – tooth thickness on a knife of grinder blade wheels, mm;

- longitudinal:

\[
k_{long} = \frac{\ell}{h_t} \text{ or } k_{long} = \frac{2\ell}{h_t}. \quad (17)
\]

The height of tooth \((h_t)\) on a knife of grinder blade wheels at transverse position of sunflower cake
\[ h_t = R_{top} \cdot \varphi, \quad (18) \]

where \( R_{top} \) – radius of tooth top on a knife, mm; \( \varphi \) – angle by which the tooth was turned during its action on sunflower cake granule, deg;

\[ h_t = R_{top} \cdot \frac{2\pi}{N}, \quad (19) \]

The weight of sunflower cake \((m)\), which is supplied for grinding, is determined by expression

\[ m = N_{gr} \cdot m_{gr}, \quad (20) \]

where \( N_{gr} \) – number of crushed granules over time \( t \), pcs; \( m_{gr} \) – weight of the 1\(^{st}\) sunflower cake granule, g.

The number of crushed granules per 1 revolution \((N_{rev}^{cr})\) will be

\[ N_{rev}^{cr} = \frac{N}{k}, \quad (21) \]

Under conditions \( n = \text{const} \Rightarrow \omega = \text{const} \) the time of one turn is determined by expression, where \( n \) – rotation speed of a knife wheel

\[ T = \frac{2\pi}{\omega}, \quad (22) \]

or

\[ T = \frac{60}{n}, \quad (23) \]

where \( \omega \) – angular rotation speed of a knife wheel, min\(^{-1}\).

The number of revolutions \((N_{rev})\) is determined by expression

\[ N_{rev} = \frac{t}{T}, \quad (24) \]

The number of crushed granules over time \( t \) is determined based on expressions (24) and (21) and then

\[ N_{gr} = \frac{t \cdot N}{T \cdot k}. \quad (25) \]

Let us substitute the expression (23) to (25) and obtain the number of crushed granules over time \( t \)

\[ N_{gr} = \frac{t \cdot 60 \cdot N}{n \cdot k}. \quad (26) \]

or when the sunflower cake is in the longitudinal position we get

\[ N_{gr} = \frac{60 \cdot N \cdot t}{n \cdot k_{long}}. \quad (27) \]

Let us substitute the expression (27) to (20) and finally get the weight of sunflower cake \((m)\), which is supplied for grinding

\[ m = \frac{60 \cdot N \cdot t}{n \cdot k_{long}} \cdot m_{gr}. \quad (28) \]

Let us determine the productivity of the grinder during processing of sunflower cake. Let us assume that during grinding the protein feed comes in the longitudinal position and then the productivity will be
\[ Q = \frac{m}{t}, \quad (29) \]

where \( t \) – crushing time, sec.

Let us substitute the expression (28) to (29) and determine the productivity of the grinder when processing sunflower cake

\[ Q = \frac{60 \cdot N}{n \cdot k_{lon}} \cdot m_{gr}. \quad (30) \]

4. Discussion

The obtained expression (30) allows determining the productivity of the grinder in processing sunflower cake depending on its structural parameters and physical and mechanical properties of the material.

The improved grinder design ensures the grinding of sunflower cake at the lowest energy costs due to the new knife surface design in the form of a curved triangle of Archimedes arbelos with saw teeth.

5. Conclusion

1. The RF Patent 2648392 is obtained for the proposed grinder design, which allows expanding functional capacities, reducing power consumption and improving the quality of grinding sunflower cake, which cannot be done by similar technical facilities.

2. The knives in the grinder are selected for different feed, both granulated and dispersed, by adjusting the distance between them depending on the size of the processed material, the sliding cutting making it possible to increase the efficiency of the process.

3. The obtained formula (30) increases the efficiency of the improved grinder depending on its design parameters and physical and mechanical properties of the material.

References

[1] Priporov I E 2018 Universal grinder for the preparation of sunflower cake in granular form for cattle Science News in the Agricultural Complex: Sci. and Pract. J. [in Russian – Novosti nauki v APK] in 2 volumes No 2(11) vol 1 108–113 (Stavropol: AGRUS Stavropol SAU)

[2] Loshkomyonikov I A 2009 Reserves of increasing production of high-protein fodders and their rational use in feeding cattle and poultry, doctoral dissertation (Omsk: Omsk State Agrarian University) Available at: http://www.lib.ua-ru.net/diss/cont/454439.html.

[3] Priporov I E, RF Patent No. 2648392, MPK В02С18/06 Sunflower cake grinder Applicant and patent holder: Kuban State Agrarian University named after I. T. Trubilin, No. 2017112634 (26 March 2018) Bulletin No. 9

[4] Kiryatsev L A and Romanyukha I E 2010 Drum-wheel grinder of stem fodders Sci. and Technological Progress in Agricultural Production: Materials of the Int. Sci. and Pract. Conf. in 2 volumes, pp 37–42

[5] Braginet N V and Vertiy A A 2013 Improving the efficiency of grinding coarse and stem fodders Scientific works of the Southern Branch of the National University of Biological Resources and Natural Resources Management of Ukraine “Crimean Agricultural Technology University” 153 96–99

[6] Fedorenko I Ya and Sadov V V 2012 Resource-saving technologies and equipment in animal husbandry: educational manual (St Petersburg: Lan) pp 34–64

[7] Shkondin V N 2018 Development of fodder grain grinding method and justification of parameters of a two-stage grinder, candidate dissertation extended abstract (Zernograd)