Theoretical and experimental aspects of studying the disc working body of the feed chopper

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Abstract. The article discusses the issue of preparing stalk feed for feeding cattle in small-scale farming with an energy-saving technical means, a stalk chopper with a disk working body. A constructive-technological scheme of a disk working body of a grinder equipped with combined cutting segments is proposed. The main results of theoretical and experimental studies of the process of milling stem feed are presented.

1. Introduction
Agriculture is a large sector of the Russian economy, which needs to be developed through state support for personal subsidiary plots, small farms, and peasant farms. To solve this problem, it is necessary to provide the livestock sector with modern resource-saving technical means, especially in the conditions of small-scale farming, where the share of manual labor is especially high.

In the Krasnodar Territory, programs to support small businesses have been developed, grants and subsidies are allocated for the production of livestock products, the purchase of breeding animals and their raising.

Animal products, which are in great demand among most Russians, contain many micro and macro elements necessary for the human body. Meat, milk and eggs contain many vitamins that the body needs all year round. For example, vitamins of group B (B1, B5, B2, B6), PP, K, A, C, affect the functioning of the nervous, cardiovascular, endocrine and other systems [1].

The number of livestock of all cattle, all agricultural producers in farms by the end of September 528.4 thousand heads, including 209.9 thousand heads of cows. According to the survey, in the regions there are 626 thousand pigs, 220 thousand sheep and goats, and poultry about 26.7 million heads. The milk yield per cow in the months from January to September 2019 was 6,000 kg Milk, compared to last year, this figure increased by 2.7%.

Small business is a small enterprise of any form of ownership, characterized by a limited number of employees and occupying a small share in the overall activity, which is the basis for national or regional enterprises [1].

There are two main subjects of the IFC:

- personal subsidiary farming is a form of non-entrepreneurial activity for the production and processing of agricultural products, carried out by the personal labor of a citizen and his family members;
• peasant (farm) economy is an association of citizens who are related, have common ownership of property and jointly carry out production activities. The use of technical means for the preparation of feed in conditions with a high proportion of manual labor is associated with solving the problem of reducing labor and other costs of production.

When feeding animals, about 60% of the resources and time is spent on the preparation of feed [2], [3], [4], [5]. This process is the most time consuming and energy consuming, which also requires financial costs. When crushing feed, the machines use various working bodies in design, mainly knives that perform oblique and sliding cutting.

This working mechanism is less energy intensive than hammers and crushing.

In order to minimize losses, it is necessary to use technical means in combination with various technical operations: loading feed, drying, grinding, mixing, etc.

Analysis of technical means according to literary sources showed the presence of such means. The main technical characteristics of such machines are performance and specific energy consumption. Table 1 shows the comparative characteristics of some feed grinders.

### Table 1. Comparative characteristics of some forage grinders.

| Model | Overall dimensions LKHSHKHV, mm | Productivity, t / h | Drive power, kW | Specific energy consumption, kW * h / t | Grinding apparatus |
|-------|---------------------------------|---------------------|-----------------|----------------------------------------|-------------------|
| RIK-88 | 3400x4636x3200                  | 5.0                 | 55              | 11                                     | Hammers           |
| KR-01  | 500x460x555                     | 0.15                | 0.8             | 5.3                                    | Knives            |
| IIS-180 | 1800x2600x3300            | 2.5                 | 49              | 19.6                                   | Knives, hammers   |
| ISN-1,8 | 4190x2150x2640               | 1.85                | チョ 50         | 27.02                                  | Hammers           |
| IKV-F-5A "Volgar" | 2420x1375x1205          | 6.5                 | 22              | 3.38                                   | Knives            |
| IRK-145 | 3800x2400x2500              | 3.18                | 50              | 15.7                                   | Knives            |
| IR-1,8  | 6100x2875x3100                | 3.9                 | 55              | 14                                     | Hammers           |
| DKU-05  | 780x330x330                   | 0.28                | 4.8             | 17                                     | Knives            |
| IR-88   | 3625x2830x2300                | 5.5                 | 54              | 9.8                                    | Knives            |
| Zubr-2  | 395x355x300                   | 0.18                | 25              | 139                                    | Knives            |
| IRM-50  | 2915x1951x2130                | 30-37               | 90              | 3                                      | Knives            |
| IRT-165 | 11500x3025x3630              | チョ 16             | 100             | 6.25                                   | Hammers           |
| IST-3   | 7030x1730x3580                | 12                  | 37.0            | 3.08                                   | Knives            |
| IKB-5A  | 2420x1375x1205                | 9.75                | 22              | 2.25                                   | Knives            |
| "Volgar-5" | 2420x1375x1205             |                     |                 |                                        |                   |
| KDU-2   | 2800x550x3000                 | 2.7                 | 30              | 11.1                                   | Knives            |

In the conditions of small businesses, according to the technical characteristics, such machines are suitable as: RIK-88, KR-01, IIS-180, ISN-1,8, IKV-F-5A "Volgar", IRK-145, IR-1,8, DKU-05, IR-88, Zubr-2, KDU-2.

Currently, a large number of studies have been carried out on the process of grinding stalk feed. But there is little research into the process of grinding stalk feed, proposed by a chopper with a disc working body, equipped with cutting segments of various types.

2. Materials and methods

In this work, the object of research is a stalk feed chopper, which has a disk working body. On the disk working body, there are different types of cutting segments that carry out sliding, oblique cutting. Since the solution to the issue of energy saving is relevant for the grinding process, the subject of research is
the dependence of specific energy consumption on the parameters of the grinder [1]: angular velocity of the grinding working body, the angle of inclination of the knives to the disk surface, and others. In the course of the research, tasks were set for the development of a structural and technological scheme of a stalk feed chopper, as well as theoretical and experimental studies to determine the productivity, specific energy consumption of the chopper, rational parameters of cutting segments. In theoretical studies, we used the mathematical apparatus of higher mathematics, theoretical mechanics, and experimental studies in accordance with existing methods and were based on planning a multifactor experiment.

A distinctive feature of the proposed technical means (figure 1) is a cone-type disk working body, equipped with combined cutting segments, which allows you to uniformly affect the material in longitudinal-transverse directions (multi-plane cutting); reduce the energy intensity of the process by cutting with sliding and transporting feed to feeders or bedding in stalls by air flow; improve the quality of grinding; increase operational reliability and service life. The working body of the chopper is cone-shaped, on which the combined cutting segments are fixed. Rotating on a cone-shaped working disc, as the material is cut off, the lower part of the roll moves apart on a cone and multilevel cutting segments of various types 11, 12, 13 cut the layers of feed in a spiral. The main factors on which the energy consumption of the feed grinding process depends are: type and moisture content of the material, cutting speed, sliding angle, type of cutting segment and its location, geometric parameters of the cutting segment, productivity and others.

![Grinding working body](image.png)

**Figure 1.** Grinding working body.

To highlight the significant factors, a one-factor screening experiment was carried out, which allows you to highlight the significantly influencing factors on the optimization of the grinding process (table 2).

| Factors                                      | Factor designation | Dimension | Variation level |
|----------------------------------------------|--------------------|-----------|-----------------|
| The number of toothed segments located along the perimeter of the grinding working body, Z | X₃                 | Pcs.      | 3 6 9           |
| The number of grinding two-plane arc profile segments, n | X₄                 | Pcs.      | 3 6 9           |

*Table 2. The most significant factors and levels of variation.*
The angle between the cone-type grinding working body and horizontal gear grinding elements, $\alpha$

| $\alpha$ (rad.) | 30 | 35 | 40 |

Angular speed of rotation of the grinding working body, $\omega$

| $\omega$ ($s^{-1}$) | 1.6 | 3.2 | 4.8 |

The value of the specific energy consumption of the process can be determined from the formula:

$$ W_{ud} = \frac{1.1 \cdot h \cdot h_{p} \cdot (\cos \tau)^{3} \cdot (1 + \tan \tau)}{0.45 \cdot R \cdot n \cdot L \cdot \sin \alpha \cdot \rho \cdot (1 - \varepsilon)} $$  \hspace{1cm} (1)

Grinder capacity (t / h):

$$ Q = 0.45 \cdot R^{2} \cdot n \cdot L \cdot \sin \alpha \cdot \rho \cdot \omega_{2} \cdot (1 - \varepsilon). $$ \hspace{1cm} (2)

For experimental studies, a laboratory sample of a stalk chopper was made. The diameter of the grinding bunker was 0.56 m, the diameter of the conical grinding working body was 0.45 m, the height of the bunker was 0.75 m, and the size of the grinding segments located along the perimeter of the grinding working body was 0.055 m. Bale size 50*50*70 cm with a weight of about 6 kg.

In the process of experimental research, it was necessary to establish the influence of "the design-mode parameters of the grinder on the quality and energy indicators of the grinding process" [1].

3. Results and discussion

To confirm the assessment of the influence of factors on the process according to the experimental data, the regression equations were obtained:

$$ W_{ud} = 2.571283 + 0.582433 \omega + 0.061233 Z + 0.798067 n + 0.753 \omega - 0.0002 \omega \cdot Z + 0.0001 \omega \cdot \alpha - 0.0001 \alpha - 0.0055 \omega^{2} - 0.0006 Z^{2} - 0.0077667 n^{2} - 0.0073 \alpha^{2} $$

$$ T = 18.43992 - 11.41393 \omega + 1.47030 Z - 5.33787 n - 1.92323 \alpha - 0.0001 \omega \cdot Z - 0.0008 \omega \cdot n + 0.0000475 \omega \cdot \alpha - 0.0017 Zn - 0.00007 Z \cdot \alpha + 0.0009 n \cdot \alpha + 0.1089 \omega^{2} - 0.0139 Z^{2} + 0.0521667 n^{2} + 0.0184667 \alpha^{2} $$

$$ L_{av} = 5.633467 - 1.953067 \omega - 1.8963 Z - 2.908 n - 0.2482 \alpha - 0.0003 \omega \cdot Z - 0.0005 \omega \cdot n + 0.00003 \omega \cdot \alpha + 0.0002 Z \cdot n - 0.00007 Z \cdot \alpha + 0.0000068 n \cdot \alpha + 0.0191 \omega^{2} + 0.018 Z^{2} + 0.0283 n^{2} + 0.00247 \alpha^{2} $$

As a result of exploratory research, the optimal number of toothed segments was selected, located along the perimeter of the grinding working body $Z = 6-9$; the number of grinding two-plane arc profile segments $n = 7-9$; the angle between the cone-type grinding working body and horizontal toothed grinding elements $\alpha = 30^0$ to $35^0$. Therefore, further experimental studies to optimize the design-mode parameters of the stalk feed chopper” [1].

**Figure 2.** Section of the surface of the weighted average length of the particles of crushed feed on the plane $X_{2} = -1$ ($Z = 3$) and $X_{4} = -1$ ($\alpha = 30^0$).
The analysis of the surface section in figure 2 showed that at \( L_{av} = 50 \text{ mm} \), “the optimal is the angular speed of rotation of the grinding working body in the range \( \omega = \) from 3.2 to 3.89 \text{ s}^{-1} \), and the number of grinding two-plane arc profile segments, \( n = 8-9 \)”[1].

The divergence of the results for the productivity and specific energy consumption of the grinder (figures 3, 4), obtained experimentally and theoretically, was determined according to Fisher's criterion and does not exceed 7%.

The models are adequate with a confidence level of 95%, and some of them with a confidence level of 90%. The correlation of the calculated values with the experimental data was higher than 0.9.

![Figure 3](image3.png)

**Figure 3.** Convergence of theoretical and experimental values of the grinder productivity from changes in the angular velocity of the grinding working body.

![Figure 4](image4.png)

**Figure 4.** Convergence of theoretical and experimental values of the specific energy consumption of the grinder from the angle of inclination between the grinding working body and horizontal gear grinding elements.
4. Conclusion

The theoretical and practical significance of the research is as follows: constructive and technological parameters of the stalk feed grinder, allowing to reduce the specific energy consumption of the grinding process by 41.5% in comparison with IRR-1M; constructive and technological scheme of the stalk feed chopper.

Theoretical studies have established rational design and technological parameters of the combined cutting segments: angular speed of the grinding working body from 2.4 to 3.3 s⁻¹, with a productivity equal to 2 to 3 t / h, respectively; the angle of inclination between the grinding working body and the horizontal toothed segments is from 30° to 32°; the number of toothed segments located along the perimeter of the grinding working body equal to Z = 9; the number of grinding two-plane arc profile segments equal to n = 6. The specific energy consumption of the technological process is from 2.0 to 2.5 kW • h / t.

On the basis of the research carried out, a method for calculating the crusher of stalk forage in a pressed form has been developed, which allows at the design stage of the grinder to obtain the numerical values of the design and technological parameters, such as: radius of the grinding working body R, m; width of the horizontal toothed grinding segment L, m; angular velocity of the grinding working body, s⁻¹; grinder capacity, t / h.

The novelty of the proposed technical solutions is confirmed by RF patents for invention No. 2581488 and utility model No. 163827.

References

[1] Tumanova M I 2018 On the issue of substantiation of the design and operating characteristics of a disk working body equipped with cutting segments Bulletin of Agrarian Science of the Don 41 65–70

[2] Kotelevsky S A, Petunina I A and Kotelevskaya E A 2016 Separation of ears of seed corn by roughness Scientific support for the agricultural sector. Collection of articles on the materials of the IX All-Russian Conference of Young Scientists 2016 1165-6

[3] Petunina I A and Kotelevskaya E A 2015 Installation for separating cobs by color codes 71st scientific and practical conference of teachers based on the results of research for 2015 2016 231-2

[4] Frolov V Yu, Sysoev D P and Tumanova M I 2016 Improvement of the livestock a production efficiency British Journal of Innovation in Science and Technology 1(1) 25-34

[5] Gavrilov M D, Tumanova M I, Sysoev D P and Frolov V Yu 2016 In the collection Scientific support of the agro-industrial complex Collection of articles on materials of IX All-Russian Conference of Young Scientists St. Odavateley of research results for the 2016 year pp.330-1