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Development of small-sized articulated hammers for feed mill applications

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ABSTRACT

This study focuses on the development of optimized working elements for feed crushers, specifically articulated hammer designs that efficiently process plant-based agricultural waste into feed for animals and poultry. The primary objective is to design small-sized feed crusher hammers that enhance comminution efficiency while reducing material usage. Four hammer prototypes with varying sidewall inclination angles (15°, 30°, 45°, and 60°) were developed and tested. Experimental results indicate a significant correlation between sidewall angle and hammer mass, with the most substantial weight increase (13.5%) observed between 15° and 30°. Further increases to 45° and 60° resulted in 5.3% and 1% mass gains, respectively. Grinding tests on corn grain revealed that hammers with a 15° inclination provided superior particle size distribution, achieving 92.6% of particles under 3 mm and only 7.4% in the 3–4 mm range. These findings suggest that lower sidewall angles yield more steady and finer grinding performance. Moreover, geometric and surface area analysis confirmed that smaller angles contribute to reduced metal consumption, with the novel hammer designs using up to 31% less material than conventional rectangular hammers. The proposed designs present a promising approach to improving feed crusher efficiency through geometry-based hammer optimization, aligning with sustainability and cost-reduction goals in agricultural machinery development.

Keywords: articulated hammer, sidewall inclination angle, metal reduction, grinding performance, feed processing, corn grain crushing.

INTRODUCTION

The compound feed industry is a branch that uses agricultural products (for example, fodder grain and fodder raw materials [1]) processed manually or with the help of machines as raw materials. One type of technological machine and equipment that should be noted in feed mills is crushers [2–5]. As it is known, in market economy conditions, small businesses and farming are developing, and therefore, the demand for small-sized agricultural machinery is increasing significantly. At the same time, the working elements of feed mills are important in such small-sized agricultural machinery [6].

Hammer crushers are important among different types of feed mills at combined feed mills [7–8], the main working organs of which are hinged and suspended hammers [9–11]. Among the developed articulated-suspended hammers are: rectangular hammers with smooth working surfaces [11–14]; V-shaped hammers with a hammerhead inclination angle of 160° [15]; hammers with side cutting edges covering one-third of the hammer length [16]; hammers with an oblique bevel [17]; hammers with stepped corners [18–19]; hammers with five protrusions [20]; ring hammers [21]; hammers with two inclined angles [22]; and hammers with sharp ends on three upper and side sections [23]. Based on this, it becomes evident that the development of hinged-suspended hammers optimizes the construction of working faces and surfaces, thereby contributing to increased grinding efficiency.

The impact is accidental or purposeful during the grinding process of fodder raw materials in the hammer crusher. In the process of accidental impact, crushed pieces at the moment of rebound from the inner walls of the body of the hammer crusher are accidentally exposed to the action of instantaneous and destructive forces. The targeted action of the articulated hammer primarily influences the grinding process [25]. Therefore, the purposeful destruction of fodder particles is more important [26], and at the same time, it significantly depends on the impact of hinged and suspended hammers. Therefore, considerable attention should be paid to the design and construction of new, more effective technical solutions to meet the requirements for improving the grinding process. The development of a small-sized construction of hinged-suspended hammers of a fodder crusher implies a purposeful value for intensifying the impact-destructive effect on the crushed fodder raw material. Therefore, further research in this area is considered highly relevant.

MATERIALS AND METHODS

The objects of research are the developed constructions of hinged-suspended hammers used in feed mills (Figure 1), the process of destroying feed particles by impact, and the design of working surfaces of impact-destroying elements.

Designs of articulated-suspended hammers for feed mills were developed using automated application programs, including KOMPAS-3D V22.0.0.1302 (ASCON JSC is a Russian company specializing in the development of engineering software, headquartered in Saint Petersburg, Russia) and AutoCAD 2025 (Autodesk, Inc. is an American multinational company that develops software for design and engineering, with its headquarters based in San Francisco, California, USA). Grinding of fodder raw materials was carried out in a hammer fodder crusher DIK-1.5. The hammer's length is a = 96 mm, and the width is b = 48 mm. The thickness of the hammers is equal to 4 mm. According to the recommendations, hammers are made from alloyed, heat-treated, wear-resistant steel 30KHCA (carbon content: 0.28–0.34%, manganese: 0.5–0.8%, silicon: 0.2–0.4%; tensile strength: up to 980 MPa, yield strength: up to 780 MPa, relative elongation: up to 15%). After such heat treatment, the hammer has a hardness of 45 HRC. The blanks were obtained from sheet steel material with a thickness of 4 mm. The hammers are produced on a metal-cutting laser machine with numerical program control, a Bodor 6m 1.5 kW machine, using a special computer program called CypCut. After production, the hammers underwent heat treatment to increase their hardness. Control and measuring devices were used to control the production of hammers, including clamps and calipers. Hammers with different angles of inclination of the sides were weighed using special electronic scales, MW-300T. The number of rows of hammers corresponded to kr = 2 pcs. The number of hammers in one row corresponded to kmr = 9 pieces. The rotor shaft was directly driven by a Kelet AIR100S4 electric motor (power: 1.5 kW) at a rotation speed of n = 2830 rpm, with a rotor diameter of 280 mm, a crushing chamber of 330 × 200 mm, and a nominal capacity of 150 kg/h. Tests were conducted at different angles of inclination of the side walls of the hammers (15°, 30°, 45°, and 60°), which are hit by grinding feed raw materials using a series of hammers. Studies of fine grinding of fodder grain were carried out in a hammer crusher DIK-1.5 (Figure 2). The experiment was conducted with a maximal linear size of the fodder grain raw material, d_n = 8 mm, which was loaded into the hopper hammer mill. During the experimental tests and work, the series of hammers was changed using a special removable device. Figure 3 presents a photograph of the assembled rotor with two axes of hammers with angles of inclination of the sides of 60°.

The feed corn grain, watermelon seeds, and feed wheat grain were ground according to the specifications listed in Table 1. The experiments were carried out in triplicate, and the average value was calculated.

The sizes of crushed particles are determined using sieve analysis, measuring instruments, electronic scales MW-300T (measurement range 0–300 g, accuracy ± 0.01 g, manufacturer – MASSEBO, China), and a sieve (the holes

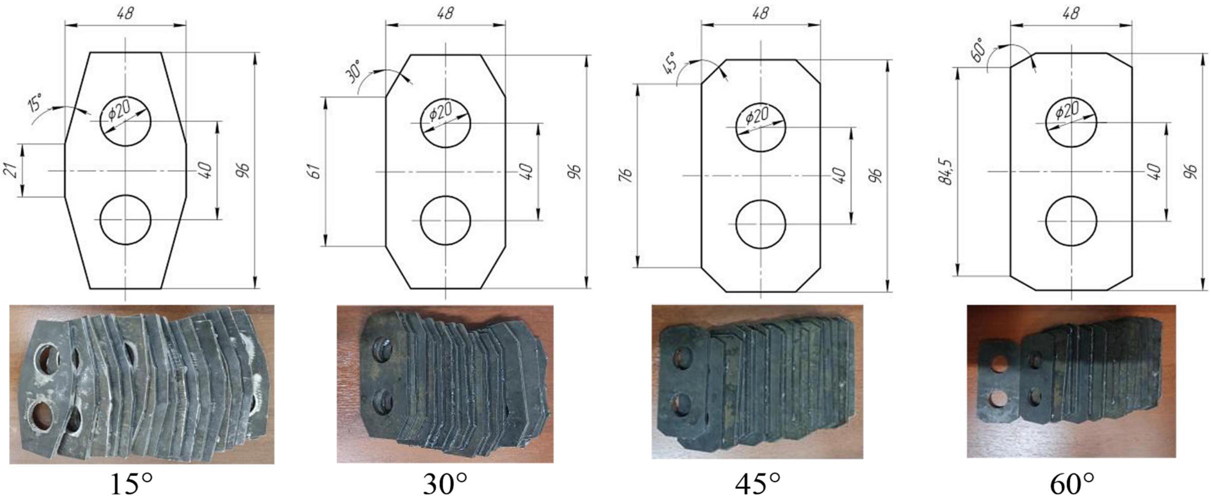

Figure 1. Hammers with different angles of inclination of the sides

Figure 2. Hammer crusher DIK-1.5: a – overall view; b – grinding chamber

corresponded to the GOST 4403-77 standard, with a hole diameter deviation of ±0.05 mm). The fractional composition of crushed particles was carried out by the method of sieve analysis, which involves sieving particles of fodder flour through standard sieves with holes (1.0, 2.0, 3.55 mm), the size of which decreases from top to bottom. Regulation of the supply of raw materials in the lower part of the input hopper of the feed mill was carried out with the help of a control valve. Weighing of individual portions of raw material and feed was carried out with natural moisture content at room temperature. The size of the product coming out of the crusher was limited using an inner sieve with a diameter of holes of 4 mm.

RESULTS AND DISCUSSION

As a result of our research, we have developed hammers with different angles of inclination on the sides for fine grinding. For comparative characteristics, hammers with different angles of inclination of the sides of the hammers and a serial flat rectangular hammer were made and weighed. Table 2 presents the mass of the tested hammers selected from each series.

A conclusion can be drawn from the work conducted and the analysis of the studies in Table 1. In particular, it is visible that an increase in the angle of inclination of the side of the hammer leads to an increase in the mass of the hammer,

Figure 3. Rotor with two sets of hammers with angles of inclination of 60° on both ends

i.e., The mass of the hammer with the angle of inclination of side 15° is 90.19 g, the mass of the hammer with the angle of inclination of side 30° is 104.17 g, the mass of the hammer with the angle of inclination of side 45° is 109.93 g, the hammer with the angle of inclination of side 60° is the mass of 111.04 g. It can be seen that a significant increase in the hammer's mass occurs when the angle of inclination of the sides is changed from 15° to 30°, representing a 13.5% increase. The increase in the hammer's weight when changing the angle of inclination of the sides from 30° to 45° increased by 5.3%. The increase in the hammer's weight when changing the angle of inclination of the sides from 45° to 60° was 1%. At the same time, it should be noted that the above hammers were designed with two hinged holes, which have certain advantages regarding their service life. Therefore, it is worth noting their lower weight and lower metal content. For comparison, it can be seen from Table 1 that the serial flat rectangular hammer has a mass of 124.57 g, which is noticeably heavier than the other hammer. Here, it is worth noting that the feed mill has two axes, each equipped with nine hammers, which accordingly increases the mass of the set in the series of hammers. Hammers are installed on the axis. The axles are attached to the rotor. The grip is mounted on the rotating shaft in the working area of the forage grinder. Special importance should be paid to the bushings, which are also installed on the axis between the hammers. The fixation of installed hammers and bushings to the axles is achieved using rings.

The technical result is compact, small-sized hammers of a hammer feed mill, which intensify grinding performance.

The hammers of the hammer feed mill have two holes on the longitudinal axis of symmetry and working areas in the form of different angles of inclination on all four surfaces of the hammer. The hammers are hingedly suspended in one of the holes using an axis inserted into the rotor, which rotates on the rotor shaft of the feed mill. As one side of the hammer wears out, the corresponding hole for the hinged suspension must be repositioned or replaced. In hammer mills, the grinding process involves the fodder grain entering the chamber and being crushed through repeated impacts – both with the rapidly rotating hammers and with the deck or inner walls of the mill. This interaction causes gradual wear, particularly at the edges and sidewalls of the hammer heads. The electric motor rotates the rotor shaft. The crushed

Table 1. Inclined face angle in a hammer with two hinged holes

№	Names of various types of hammers	Type of raw material to be crushed
1	A hammer with two hinged holes and an inclined face of 15°	Forage corn grain
2	A hammer with two hinged holes and an inclined face of 30°	Forage corn grain
3	A hammer with two hinged holes and an inclined face of 45°	Forage corn grain, forage wheat grain
4	A hammer with two hinged holes and an inclined face of 60°	Forage corn grain, watermelon seeds

Table 2. Weight of investigated hammers

№	Names of various types of hammers	Hammer weight, g
1	A hammer with two hinged holes and an inclined face of 15°	90.19
2	A hammer with two hinged holes and an inclined face of 30°	104.17
3	A hammer with two hinged holes and an inclined face of 45°	109.93
4	A hammer with two hinged holes and an inclined face of 60°	111.04
5	Hammer serial flat rectangular	124.57

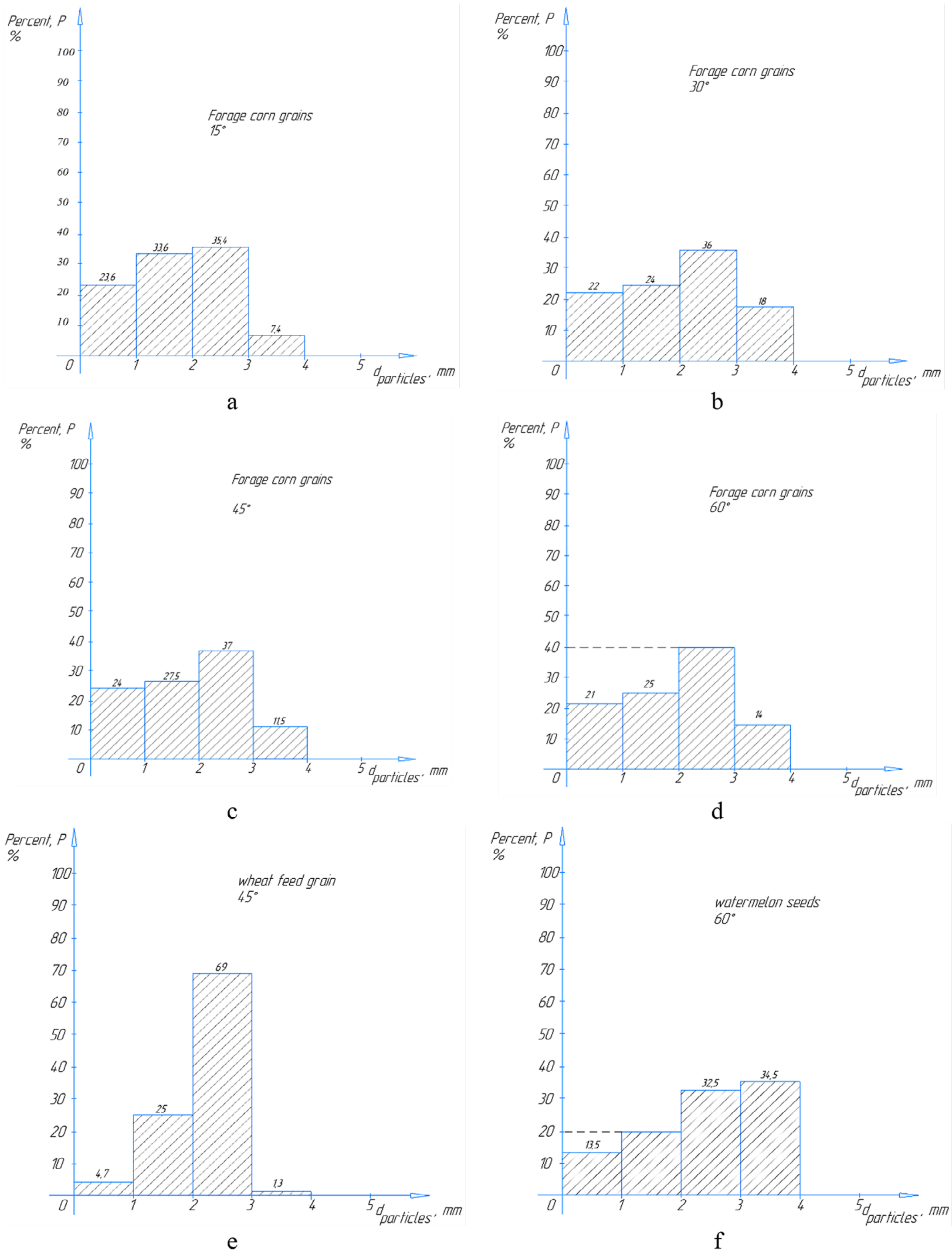

Figure 4. Histograms of the distribution of crushed particles of fodder raw material with the use of developed hammers with different angles of inclination of the side face: a – corn grain hammers with side angles of 15°; b – corn grain hammers with side angles of 30°; c – corn grain hammers with side angles of 45°; d – corn grain hammers with side angles of 60°; e – wheat grain with hammers with side angles of 45°; f – fodder grain wheat with hammers with side angles of 60°

fodder product passes through the holes of the grid of the output pipe of the hammer fodder crusher. The hammer design includes working areas with different angles of inclination on its sides. These inclined surfaces create a shock-cutting effect on the crushed particles. As a result, the fodder particles are destroyed more efficiently, which increases the grinding intensity of the hammer-type crusher. The results of the sieve analysis were presented in histograms, as shown in Figure 4.

The analysis and comparison of the constructed histograms for grinding fodder corn grain (Figures 4a-d) showed that the use of hammers with a 15° angle of inclination on the sides yielded the best result in terms of grinding quality. In particular, the size of particles in the range of 3–4 mm was 7.4%, i.e., the lowest percentage compared to other angles of the side of the hammer. At the same time, the size of particles less than 3 mm was 92.6%. The most significant result was achieved using hammers with a 45° side angle, where particles in the 3–4 mm range accounted for 11.5%, and those smaller than 3 mm accounted for 88.5%. Even less significant was the use of hammers with a side angle of 60°; specifically, particles in the range of 3–4 mm made up 14%, while particles smaller than 3 mm made up 86%. The last one used hammers with an angle of inclination of the side hammer of 30°, i.e., the size of particles in the range of 3–4 mm was 18%, and the size of particles less than 3 mm was 82%. In addition to the above, it should be noted that the preferred size of fodder particles for farm birds is 2–3 mm and less than 1 mm for chickens. However, using hammers with different angles of inclination of the sides demonstrated a fairly effective distribution of crushed particles. They also conducted several experiments comparing the distribution of crushed particles of different fodder raw materials. In particular, Figure 4e shows a histogram of the distribution of crushed fodder wheat particles using hammers with a 45° side angle. Here, the size of particles in the range of 3–4 mm made up 1.3%, the size of particles in the range of 2–3 mm made up 69%, the size of particles in the range of 1–2 mm made up 25%, and the size of particles less than 1 mm made up 4.7%. Here, it can be concluded that compared with the grinding of fodder corn grains, fodder wheat grain was smaller; therefore, the distribution of crushed particles was smoother. Additionally, it can be related to the hardness of the fodder. Regarding the conclusions on hardness, we experimented with grinding more solid raw materials, such as watermelon seeds, which also have a more flat shape. Figure 4f presents a histogram of the distribution of the crushed particles of watermelon seeds with hammers with an angle of inclination of the sides of 60°. Here it is seen that the size of particles in the range of 3–4 mm made up 34.5%, the size of particles in the range of 2–3 mm made up 32.5%, the size of particles in the range of 1–2 mm made up 19.5%, and the size of particles less than 1 mm made up 13.5%.

Thus, the test results showed that the grinding performance depends on the angle of inclination of the hammers' sides. The distribution of particles by size due to grinding with hammers at a smaller angle of inclination of the sides was steadier, and its productivity in the distribution of crushed particles was higher than that of hammers with large angles of inclination. Therefore, it is worth noting that the hammer's average geometric volume and specific surface area with a smaller inclination angle have a lower metal capacity.

The working surfaces of the hammers are the impact-destructive angles of the sides of the hammers. It should be noted that the design with two hinged holes allows four options for attaching the hammer during its service life. This means that two holes allow up to four working edges versus two on a hammer with one hole. Moreover, it is worth noting the decrease in the hammer's mass.

Figure 5–7 shows the pictures of the results of a sieve analysis of ground corn, wheat, and watermelon seeds.

Acomparison of the research results presented in Figures 5–7 reveals that grinding watermelon seeds is less effective than grinding fodder corn and wheat grain, which is directly related to the properties and characteristics of the raw materials.

Each series of hammers was weighed using a different angle of inclination on the sides of the hammers to determine the weight of the designed hammers. At the same time, the mass values of each hammer were determined separately and included in the set of hammer series (Table 3).

Each series of hammers included 18 individually manufactured samples with identical geometric dimensions, differing only in the angle of inclination of the side face (15°, 30°, 45°, 60°, as well as a flat control series). The mass of the hammers was determined with an error of ± 0.01 g. To reduce the statistical data, Table 2 presents the calculated values that were obtained for each series by calculating the arithmetic mean and standard deviation.

Thus, in the series with an angle of 15°, the hammer weight varied from 89.92 g to 91.26 g. The calculation yielded an average weight of 90.60 g and a standard deviation of ± 0.36 g, indicating high precision and stability in the production process. For comparison, in the control series of rectangular hammers, the spread was from 123.57 g to 130.31 g, with an average weight of 127.55 g and a standard deviation of ±1.76 g, indicating greater variability due to both

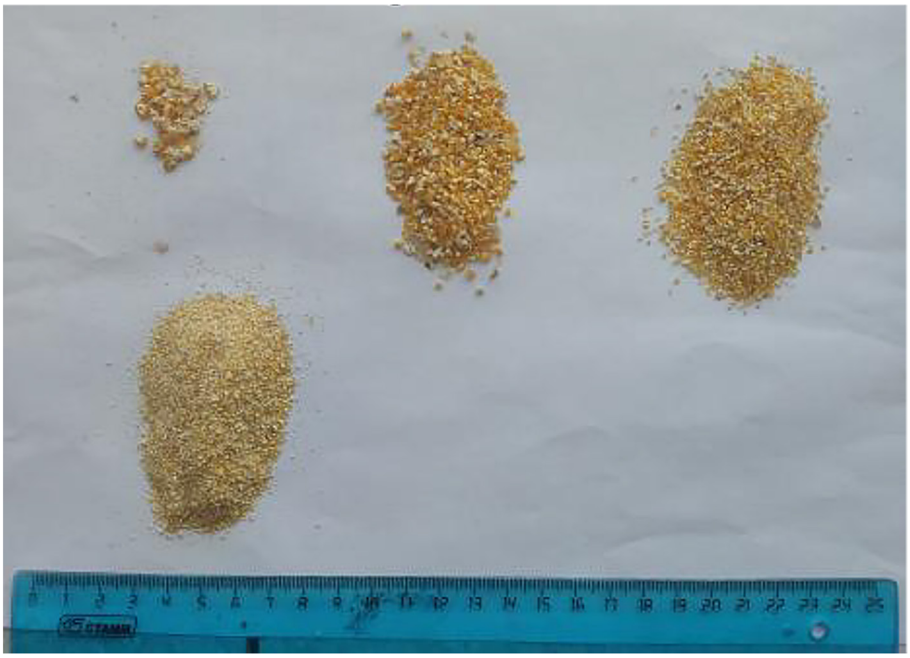

Figure 5. Photo of the results of the sieve analysis of the crushed grain corn

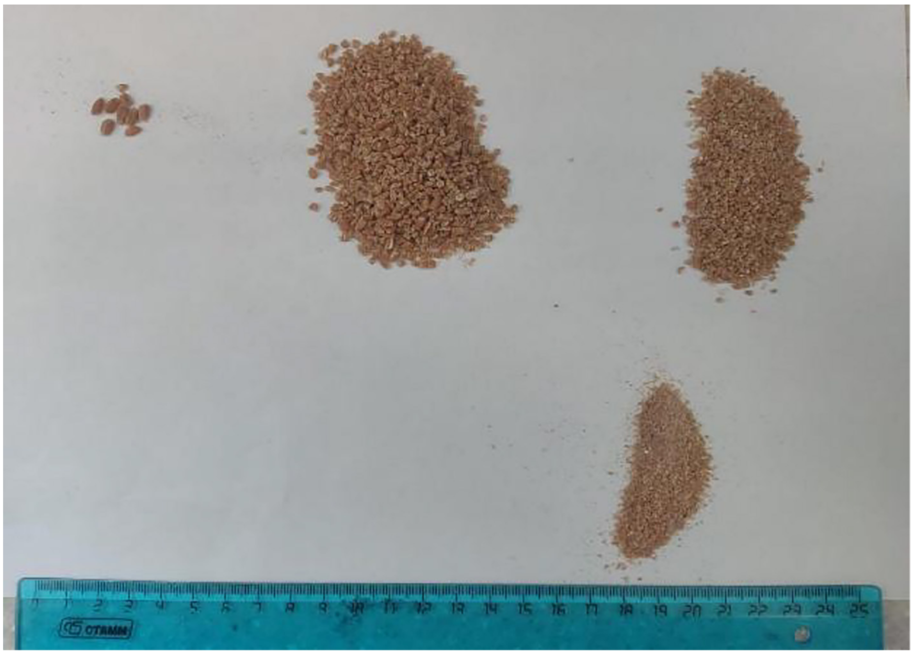

Figure 6. Photo of the results of the sieve analysis of the crushed wheat grain

the design and the higher metal content. The obtained values confirm the stability of the technological process (laser cutting and heat treatment) in the manufacture of hammers.

It is enough to use working bodies with lighter-weight hammers for fine grinding. Therefore, in our studies, metal-intensive hammers were developed and tested to reduce the metal mass of the hammers at the angles of the hammer faces. As a result of the conducted research, it is worth noting that the crushed particles, as indicated in the histograms in Figure 4, correspond to the sizes of particles suitable for feeding agricultural animals and birds [27]. At the same time, for large cattle, the size of the particles of crushed grain should be no more than 4 mm [28], which we obtained during experimental work. To compare the obtained research results, it is worth

Figure 7. Photo of the results of the sieve analysis of ground watermelon seeds

Table 3. Average weight and standard deviation of different hammer series

№	Hammer series (Side angle)	Mean weight, g	Standard deviation, g
1	15°	90.60	±0.36
2	30°	104.85	±0.57
3	45°	109.74	±0.45
4	60°	111.65	±0.47
5	A series of flat rectangular hammers	127.55	±1.76

noting that flat rectangular hammers [29–31] are significantly inferior in weight to developed hammers with inclined faces, as we have experimentally proven. Therefore, the developed designs of hammers with different angles of inclination of the hammer sides are less metal-consuming and quite effective.

CONCLUSIONS

In scientific research, several small designs of hinged-suspended hammers of feed mills were developed, constructed, and tested. In particular, hammers with an angle of inclination of the sides of 15°, 30°, 45°, and 60° of the shock-scaling type. Experimental results indicate a significant correlation between the angle of inclination of the side wall and the weight of the hammer, and the most significant increase in weight (13.5%) was observed between 15° and 30°. A further increase to 45° and 60° resulted in mass increases of 5.3% and 1%, respectively.

Comparative results of the mass of hammers showed that the hammers with a side angle of 15° had the lowest mass, followed by those with a side angle of 30°, then those with a side angle of 45°, and finally those with a side angle of 60°, which were considered heavier. Here, the design with two hinge holes contributes to weight reduction. Regarding serial rectangular hammers and developed hammers, a noticeable difference in mass can be affirmatively noted. Tests on grinding corn grain showed that hammers with an inclination of 15° provide an excellent distribution of particle sizes, with 92.6% of particles measuring less than 3 mm and only 7.4% in the range of 3–4 mm. These results indicate that smaller sidewall angles yield steadier and finer grinding. At the same time, the developed hammers are less metal-consumptive and make a difference of up to 31% compared to serial rectangular hammers. As a result of the conducted research, we cannot exclude the possibility that a decrease in the mass of the hammers causes better fragmentation, since the contact surface area of the crushed raw material with the hammers increases due to an increase in the cutting edges, which contributes to the impact-cutting effect. The developed hammers were successfully tested in the laboratories and workshops of the Technical Faculty at the Kazakh Agrotechnical Research University named after Saken Seifullin. Therefore, the developed constructions of hammers with different angles of inclination of the sides of the hammer are less metal-consumptive and can be successfully used in hammer crushers at compound feed plants.

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REFERENCES

1. Wang, D., He, C., Tian, H., Fei, L., Tao, Z., Zhang, H. Parameter Optimization and Experimental Research on the Hammer Mill. Inmateh-Agricultural Engineering 2020; 62(3), 341–350. https://doi.org/10.35633/inmateh-62-36
2. Zhang, J., Feng, B., Guo, L., Kong, L., Zhao, C., Yu, X., Luo, W., Kan, Z. Performance test and process parameter optimization of 9FF type square bale straw crusher. International Journal of Agricultural and Biological Engineering, 2021; 14(3), 232–240. https://doi.org/10.25165/j.ijabe.20211403.5970
3. Iskakov, R.M., Mamirbaeva, I.K., Gulyarenko, A.A., Silaev, M.Y. and Gusev, A.S. Improved Hammers for Crushers in feed production. Russian Engineering Research, 2022; 42(10), 987–992. https://doi.org/10.3103/S1068798X22100124
4. Cotabarren, I., Fernández, M.P., Di Battista, A., Piña, J. Modeling of maize breakage in hammer mills of different scales through a population balance approach. Powder Technology, 2020; 375, 433–444. https://doi.org/10.1016/j.powtec.2020.08.016
5. Teryushkov, V.P., Chupshev, A.V., Konovalov, V.V., Rodinov, Y.V., Gumarov, G.S. Numerical Simulation of the Operation of the Disc Shredder. 6th International Conference on Agriproducts Processing and Farming, 2020; 422, 012110. https://doi.org/10.1088/1755-1315/422/1/012110
6. Iskakov, R., Gulyarenko A., Hyla P., Bembenek M. Working parts for intensive crushing and grinding of feed from waste raw materials: A review. Advances in Science and Technology Research Journal, 2025; 19(7): 98–131. https://doi.org/10.12913/22998624/203643
7. Diop, M., Thiam, M., Kebe, A., Gueye, I. Effects of hammer configurations on pearl millet grinding system with a hammer mill: theory and experiment. Indonesian Journal of Electrical Engineering and Computer Science 2024; 34(1), 658–665 https://doi.org/10.11591/ijeecs.v34.i1
8. Ämmälä, A. Comparison of pin mill and hammer mill in the fine grinding of *Sphagnum* Moss. *Energies*, 2023; *16*(5), 2437. https://doi.org/10.3390/en16052437
9. Paraschiv, G., Moiceanu, G., Voicu, G., Chitoiu, M., Cardei, P., Dinca, M.N., Tudor, P. Optimization issues of a hammer mill working process using statistical modelling. Sustainability, 2021; 13, 973. https://doi.org/10.3390/su13020973
10. Sumardi, S., Nurjaman, F., Isnugroho, K., Junaedi, A., Handoko, A.S. The Alloy Steel from Manganese-Chrome-Copper as an Alternative Material to Make Hammer. Proceedings of the 3rd International Seminar on Metallurgy and Materials (ISMM 2019): Exploring New Innovation in Metallurgy and Materials. 2020; 2232. https://doi.org/10.1063/5.0001925
11. Ciężkowski, P., Bąk, S., Caban, J., Seńko, J., Waśkowicz, M.A. Preliminary research to assess the possibility of grinding selected plastics using crushers. Polymers, 2024; 16, 3104. https://doi.org/10.3390/polym16223104
12. Double Ended Hammer Mill Hammer. [online] [10.04.2017]. Available at: https://g3hammers.com/product/double-ended-hammer-mill-hammer/
13. Bian, W.L., Rong, S.F., Zhu, Y.C., Zhou, H.T. Research and application of dual liquid bimetal composite casting hammer. Applied Mechanics and Materials 2012; 271–272. https://doi.org/10.4028/www.scientific.net/amm.271-272.268
14. Zhang, J., Feng, B., Guo, L., Kong, L., Zhao, C., Yu, X., Luo, W., Kan, Z. Performance test and process parameter optimization of 9FF type square bale straw crusher. International Journal of Agricultural and Biological Engineering, 2021; 14(3), 232–240. https://doi.org/10.25165/j.ijabe.20211403.5970
15. Li, H., Jiang, S., Zeng, R., Geng, J., Niu, Z. Numerical simulation and analysis of the airflow field in the crushing chamber of the hammer mill. ACS Omega. 2024; 9(30), 32674–32686 https://doi.org/10.1021/acsomega.4c02187
16. Zhang, H., Qian, Y., Tian, H. Design and experimental optimization of v-shaped hammer for hammer mill. Inmateh-Agricultural Engineering, 2024; 73(2), 191–200. https://doi.org/10.35633/inmateh-73-16
17. Abilzhanuly, T., Iskakov, R., Abilzhanov, D., Darkhan, O. Determination of the average size of preliminary grinded wet feed particles in hammer grinders. Eastern-European Journal of Enterprise Technologies, 2023; 1(1(121)), 34–43. https://doi.org/10.15587/1729-4061.2023.268519 https://doi.org/10.15587/1729-4061.2023.268519

18. Liu, H., Rong, S.F., Wu, Y.H., Yang, P.H., Duan, X.L., Zhu, Y.C. Study on Diagonal Hammer of Three Kind Metals Composite Casting With Block Protecting Handle. International Conference on Mechatronics, Manufacturing and Materials Engineering, 2016; 63, https://doi.org/10.1051/matecconf/20166303011
19. Moiceanu, G., Voicu, G., Paraschiv, G., Vladut, V., Cardei, P., Dinca, M. Relationships analysis between the grinding parameters of miscanthus giganteus stalks using a hammer mill. Proceedings of the 47th International Symposium on Agricultural Engineering, Opatija, Croatia, 5–7 March 2019; Kovacěv, I., Bilandžija, N., Eds.University of Zagreb, Faculty of Agriculture: Zagreb, Croatia, 2019; 399–407.
20. Moiceanu, G., Chitoiu, M., Voicu, G., Paraschiv, G., Vladut, V., Gageanu, I., Dinca, M. Comparison between *Miscanthus* and willow energy consumption during grinding. Proceedings of the 46th International Symposium on Agricultural Engineering, Opatija, Croatia, 27 February - 1 March 2018; University of Zagreb, Faculty of Agriculture: Opatija, Croatia, 2018, 369-378.
21. Viňáš, J., Brezinová, J., Brezina, J., Hermel, P. Innovation of Biomass Crusher by Application of Hardfacing Layers. Metals, 2021; 11, 1283. https://doi.org/10.3390/met11081283
22. Kyekyere, E., Olakanmi, E.O., Prasad, R.V.S., Matshediso, B., Motimedi, T., Botes, A., Pityana, S.L. Analysis of failure characteristics of screen plates of ring hammer crusher used in coal handling applications. Engineering Failure Analysis, 2024; 162. https://doi.org/10.1016/j.engfailanal.2024.108351/
23. Wang, D., Tian, H., Zhang, T., He, C., Liu, F. DEM simulation and experiment of corn grain grinding process. Engenharia Agricola, 2021; 4(5), 559–566. https://doi.org/10.1590/1809-4430-Eng.Agric.v41n5p559-566/2021
24. Mou, X., Wan, F., Wu, J., Luo, Q., Xin, S., Ma, G., Zhou, X., Huang, X., Peng, L. Simulation analysis and multiobjective optimization of pulverization process of seed-used watermelon peel pulverizer based on EDEM. Agriculture, 2024; 14, 308. https://doi.org/10.3390/agriculture14020308
25. Sossa J.W.Z., Pérez P.J.P., Piedrahita J.C.P. and Mesa A.F.R. Trends in grinding of agroindustrial products – A literature review. Bentham Science, 2021; 12(1), 19–28 https://doi.org/10.2174/2212798411666201125114243
26. Wang D., He C., Wang H., Liu F., Tian H., Ma L. Design and experimental optimization of airfoil-Triangle sieve for hammer mill. Inmateh – Agricultural Engineering, 2020; 61(2), 315–322. https://doi.org/10.35633/inmateh- 61-34
27. Polonsky V.I., Sumina A.V. Influence of physical characteristics of grain raw materials functional value of fodder for birds // Bulletin of the Russian University of Friendship of Peoples. Series: Agronomy and animal husbandry. 2021; 16(2), 167–175. https://doi.org/10.22363/2312-797X 2021-16-2-167-175. (In Russian).
28. Volgin V.I., Romanenko L.V., Prokhorenko P.N., Fedorova Z.L., Korochkina E.A. Complete feeding of dairy cattle is the basis for the realization of the genetic potential of productivity. - M.: RAN, 2018; 11. (In Russian).
29. Zhamash K.Sh., Ashimkhan B., Kakabayev N.A., Orazalina B.K. Analysis of the situation and ways to solve the problem of feed production for livestock in Kazakhstan // Proceedings of the International Scientific and Practical Conference "Shokan Readings-28 New Scientific Paradigm: Collaboration, Digitalization and Commercialization". – Kokshetau, 2024; 2, 195–200. (In Kazakh).
30. Kakabayev N.A., Kravchenko R.I., Zolotukhin E.A., Zhamash K.Zh. Comparative analysis of designs and productivity of hammer mills for grain grinding and the quality of the finished product // Materials of the multidisciplinary scientific journal "KMPI Zharshsy" – Kostanay, 2024; 4, 122–128. (In Kazakh).
31. Iskakov, R.M., Issenov, S.S., Iskakova, A.M., Halam, S. and Beisebekova, D.M. Microbiological appraisal of feed meal of animal origin, produced by drying and grinding installation. Journal of Pure and Applied Microbiology, 2015; 9(1), 587–592.