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Working parts for intensive crushing and grinding of feed from waste raw materials: A review

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ABSTRACT

Processing of waste into feed involves the need to grind it. Therefore, the study of research on this problem is relevant. The study aims to summarize scientific data on developing working parts for grinding feed from waste. In this regard, we analyzed scientific publications. As a result, it was revealed that the trend in grinding feed raw materials is the use of all types of food production and agricultural waste. Ten types of plant waste from the food industry and seven types of animal waste are indicated. It was found that the main working parts for grinding feed are technical devices for cutting, impact, abrasive-crushing, splitting-breaking, and impact-cutting action. It was revealed that an evident trend is improving working parts for intensive grinding based on optimal design developments of working parts, increasing the efficiency of working surfaces and design and technological parameters, and combining several methods of destroying feed raw materials using one type of working part. In general, the disadvantages and advantages of saws (4 types), rollers and disks (7 types), hammers and knives (21 types), and shredder disk knives (4 types) are analyzed and summarized in tables.

Keywords: crushing, crumbling, waste comminuting, waste disintegrating, grinding.

INTRODUCTION

A study by the World Food Programme shows that the total number of undernourished people on our planet is approaching one billion [1]. In this regard, feed production growth can be ensured by increasing the number of livestock and poultry from which the necessary amount of food products can be produced. One of the rational and most effective methods of preparing feed is the production of feed from raw waste materials.

As is known, the work of agricultural and food enterprises is accompanied by the receipt of a large amount of waste, which should be properly disposed of or subjected to additional processing to obtain useful products. It should be noted that a large amount of waste of plant and animal origin is widely used in the production of sunflower, extraction and vegetable oils, halva, sugar, starch, potato dishes, carrot puree, beer, alcohol, yeast, juices, and drinks, tea, coffee, cocoa, food flour, in the processing of livestock products, etc. The optimal option for using waste from agricultural and food enterprises is feed production. It should be noted that when feeding animals, plants and animal proteins are used effectively [2].

The most necessary process in processing agricultural waste and feed production is the crushing and grinding of raw materials. Crushing plays a vital role in waste processing [3]. Crushing and grinding include changing the particle size from large to small [4]. Productive crushing and grinding can be done using process equipment. For example, a crusher has become a significant part of animal feed production [5]. Feed manufacturers must use process devices to ensure efficient grinding and select a grinding device by its specific grinding task (fine, coarse, or with a specific particle size distribution) [6]. At the same time, in the designs of process equipment for grinding feed meal particles, the working parts are noticeably important [7], with the help of which a specific impact occurs, leading to the destruction of pieces and particles of feed raw materials.

In general, raw materials can be crushed in various ways. The solid material is often crushed to a given particle size by a constrained or free impact. Crushing, splitting, and tearing are used to obtain lump materials and are usually used in preliminary operations. Cutting and sawing are used when obtaining pieces of material of a specific size and shape. Attrition is used for fine grinding and is often combined with crushing or impact [8]. For example, when processing powdery materials, the raw material is pre-compacted in a roller press and then crushed in a hammer mill or disintegrator [9].

Waste shredding also positively affects the environment, i.e., new useful feed products are created from potentially oriented waste by shredding waste. Scientists widely use the study of this issue due to its relevance. The paper [10] considers a method for determining shredders' characteristics in the waste processing field. The design of a branch shredder is improved in [11]. The results of a study of the quality of feed meal from animal waste using shredding equipment are given in [12]. The distribution of particles of feed meal waste raw materials of different granulometric compositions in the working zones of shredding and drying tends to decrease the particle sizes at the outlet of the drying and shredding apparatus as a result of the impact-splitting method of shredding [13]. First, reducing the size of the crushed particles should be a technological process by which feed is produced [14]. The paper [15] draws attention to the wear of the hammers of feed crushers. In this case, the hardening of the working elements can be achieved by plasma hardening, which will increase the strength characteristics of the working elements by 3 to 3.5 times [16]. Introducing effective surface hardening methods [17] of the working elements for grinding will help increase the service life of crushing and grinding equipment. It is worth noting that the physics of the grinding process still needs to be better understood [18]. However, scientific methods of computer modeling can come to the rescue. The study [19] applied the simulation of seed behavior and calibration of the interaction properties of seeds using the modern discrete element method (DEM) [20]. However, it is worth noting that the modeling of crushing machines is rarely reported in the literature. This is often due to the requirement to include destruction directly in the modeling to allow particles to pass through the equipment. Often, DEM particles physically can only pass through the machine if they break down into smaller particles during the modeling process. Since most DEM programs do not include this feature, crusher modeling is performed less frequently [21]. At the same time, it should be noted the importance of the impact of grinding on growth rates, the development of the gastrointestinal tract of birds and the digestibility of nutrients [22], as well as the development of effective methods for crushing and grinding feed raw materials from a waste of plant and animal origin. Therefore, this area of research is of great scientific and practical importance and is relevant for systematic analysis and generalization.

The study aims to generalize scientific data in developing working parts for intensive feed grinding from plant and animal-origin waste. To achieve the goal, the following research tasks were set:
- to identify the most common types and names of waste of plant origin from the food industry, as well as waste of animal origin;
- analyze the most critical working parts for crushing and grinding waste of plant and animal origin: saws, disks, rollers, hammers, chains, needle impact elements, cutters, and knives.

Based on the above, it is necessary to pay significant attention to advanced research on crushing and grinding waste generated by food enterprises, meat processing plants, poultry processing factories, livestock farms, public catering points, etc. Because of the importance of this area of research, many scientists are actively conducting scientific and experimental design work to develop and justify effective crushing and grinding devices, which should be generalized and analyzed for rational waste processing.

MATERIALS AND METHODS

The scientific, systematic study was conducted to analyze open source data, including scientific publications and data from Internet portals (multifunctional platforms with a variety of interactive services that combine information from various sources), scientometric databases

Web of Science, Scopus, and patent office websites. In the process of analyzing scientific, technical, and patent-licensing literature, waste of plant and animal origin for feed preparation was noted; trends in the development of working parts for preliminary crushing of waste feed raw materials using saws, for fine crushing of waste raw materials into feed meal using crusher disks and rollers, for fine crushing of waste raw materials into feed meal using crusher hammers, for crushing waste raw materials into feed meal using shredder disks were considered; an assessment was made of the dynamics of development of saw designs, crusher disks and rollers, crusher hammers, shredder disks, identifying their disadvantages and advantages; key segments and technologies for the use of types and names of waste raw materials of plant and animal origin for feed preparation were analyzed. In writing this systematic review, over 300 papers on developing working parts for the preliminary and final grinding of waste raw materials of plant and animal origin were analyzed. In order to reflect the most important points, the review provides 153 references to the most valuable scientific and technical information published over the past 10 years. The criteria for inclusion of materials in this systematic review were studies related to the design of practical working parts for crushing and grinding waste of plant and animal origin to prepare feed, mainly for the period 2014–2024. Most of the documents analyzed in the review are written in English. The keywords used in the search for scientific and technical information were the following: crushing, grinding, sawing, crusher hammers, shredder discs, destruction, waste of plant and animal origin, and feed.

RESULTS AND DISCUSSION

Consideration of waste of plant and animal origin for the preparation of feed

Several enterprises process multi-component raw materials, often of plant origin, to extract some components from them: sugar – from sugar beet, starch – from potatoes and grain, vegetable oil – from sunflower seeds, etc. At the same time, waste of plant origin is obtained, presented in Table 1, which is also valuable, especially in feed preparation. All these wastes contain significant amounts of valuable substances – vitamins, fiber, protein, microelements, etc. And therefore, it is more rational to use these wastes for feed production.

The brewing and alcohol industries produce significant waste. Therefore, processing the main waste from brewing and alcohol production is essential for providing the agro-industrial complex's feed base and preventing environmental pollution. Ethyl alcohol for the food industry is produced by fermentation from vegetable starch- and sugar-containing raw materials from cereal grains, potatoes, and molasses. Beer is prepared using grain and barley. This is where grain waste appears [23].

The feed molasses obtained in sugar production – molasses, beet tops, and cake – can be used as livestock feed [24]. Pea waste is often used as feed. Trimmings of carrots, beets, sweet

Table 1. Types and names of waste of plant origin from the food industry

No.	Types of plant waste from food enterprises	Name of waste of plant origin	The average size of plant waste, mm
1	Waste from sugar beet, sugar cane, and refined sugar production	Beet tops, pulp	20–70
2	Waste from alcohol and liquor production	Fruit and berry pomace	5–15
3	Waste from starch and molasses production	Barda, corn waste, wheat extract	4–200
4	Waste from confectionery, bakery, pasta and yeast production	Bones, flour scraps	3–8
5	Waste from the oil and fat industry	Husk, cake, meal, husk	25–85
6	Waste from the wine industry	Grape seeds, pomace	5–7
7	Waste from the production of beer, soft drinks	Grain waste, yeast	6–15
8	Waste from vitamin production	Pulp, seeds	5–40
9	Waste from canning, vegetable drying, and food concentrate production	Waste from juice production (leaves, peel), tops	10–700
10	Waste from the tobacco and tea industries	Molding material	15–500

corn, cabbage, squash, eggplant, and onions can be used as livestock feed. Corn cobs and leaves are used as livestock feed. Pod flaps and tops are used as livestock feed in the canning industry. Malt sprouts are a highly productive feed for farm animals. Brewer's grain is good raw and dry feed for livestock. Grape pomace is partially used as livestock feed [25]. Animals easily digest molasses stillage together with grain-potato stillage. Of particular value are waste products of oil and fat production – cake, meal, and husk [26].

Experiments were conducted on different types of waste: bran, brewer's grain, crushed straw, beet pulp, sunflower husk, distillery dregs, etc. Positive results were obtained in all experiments; in particular, the technology allows for improving the quality indicators of plant materials, i.e., increasing the protein component with essential amino acids by one and a half times or more, reducing the amount of fiber with a directly proportional increase in monosaccharides. During the life of the microflora, vitamins D, E, PP, and the entire group of B vitamins are synthesized, and the feed is enriched with enzymes that promote the breakdown of fiber and proteins. In these types of feed, the microflora is a natural probiotic, which also positively affects the stability of beneficial microflora in the gastrointestinal tract of animals [27].

Molasses is used in the feed industry as an additive to animal feed. The pulp is the pulp of beets. The yield of pulp is about 5 kg per 100 kg of beets. The dry matter of the pulp consists of pectin substances (45%), cellulose and hemicellulose (approximately 20% each), proteins, ash, and sugar (2–4% each). The pulp is an excellent feed for livestock; for this purpose, it is used fresh and dried [28].

The oil extraction industry also supplies livestock with high-protein concentrated waste for feed in the form of cakes and meals. Oil from oilseeds is produced in two ways: by pressing and by solvent extraction. When oil is extracted from seeds by pressing, the waste is in the form of solid cakes; when oil is extracted from crushed seeds by extraction with special solvents, the waste is in the form of loose flour meals. Cakes and meals are one of the most concentrated sources of protein, exchange energy, and essential amino acids, are included in most compound feed recipes, and are partially used as independent feed [29].

Cucumber straw waste is scattered haphazardly in fields, roadsides, and river ditches, wasting valuable resources and causing large-scale agricultural pollution [30].

Animal waste recycling involves transformation into valuable products and potential environmental and economic benefits [31]. Often, animal waste must be sterilized [32]. Animal waste recycling generally involves using a process line that includes several devices, including a power grinder for preliminary crushing and a crusher for fine grinding [33]. In Mexico, positive results were obtained in feeding lambs with poultry and pig waste feed. In this case, the waste was crushed into particles of 2 mm [34]. There is a transition from traditional to local feed production in Africa due to the cost-effectiveness and availability of raw materials for aquafeed production. In this case, shrimp and blood waste are used from the waste [35].

More attention and measures are being paid to managing and utilizing animal waste [36]. At the same time, some animal waste can be processed [37], i.e., finely ground for producing animal feed meal. All kinds of animal waste are presented in Table 2.

Thus, food and animal waste from the food industry and agriculture have valuable properties, and they can be optimally used as fodder raw materials to prepare feed for agricultural animals and birds.

Analysis of the working parts for preliminary fragmentation of outgoing feed raw materials using saws

As you know, preliminary crushing is often necessary for animal waste, especially the bones of agricultural animals and wood waste. At the same time, saws are essential.

In the study [38], an innovative mechanism of a swinging saw is proposed, effectively preventing the emergence and accumulation of shock forces and avoiding contact with the workpiece at a negative inclination angle. An electric strip saw for bones produces a vast number of aerosol particles with a diameter of less than 5 microns [39], which negatively affects inhalation by people. It should be noted that the sharp blades of the saw, compared to the stupid (blunt blades) and medium blades of the saw, form much smaller aerosol particles. When sawing with dry saw discs, it was established that almost twice as many particles are formed compared to sawing with a continuous water supply to the saw disk.

Table 2. Types and names of animal waste

No.	Types of animal waste	Name of waste of animal origin	The average waste size of animal origin, mm
1	Waste of poultry	Eggshell, feathers, hair, meat-bone remains, beaks, bones, paws, cases	10–300
2	Waste of fish processing, marine mammals, crustaceans, invertebrates, as well as waste obtained during their processing	Heads, leather, scraps, fins, scales, insides and bones of fish, meat-bone residues; by-products of crab production, crustaceans, mussels of Charra, macunum and shells of oysters (Charru Mussel-, Maçunim- and Oystershell Meals)	10–200
3	Sino of slaughter cattle	Veterinary confiscates blood, bones, wool waste, hooves, horns, nails, meat-bone meat residues	15–300
4	Waste obtained by slaughtering and processing rabbits	Blood, intestines, stomachs, heads, ears, legs, skin flap, and cuts of meat and fat from skins	50–150
5	Food waste of animal origin	Meat, bone, and meat-bored residues, egg waste, eggshells, expired products	10–200
6	Secondary raw materials of the dairy industry	Waste production waste, cheese, and cottage cheese	3–8
7	Waste of the leather industry	Mesdra raw materials and gross, rawhide, chrome shavings, trim	10–30

In [40], the effect of the parameters of the tape saw on the feast temperature and surface roughness was experimentally investigated. Among the parameters of the tape-saw machine, three types of teeth and nine levels of feed speed were selected. When sawing the natural cortical bone of cattle 4 mm thick with a sawing speed of 15 m/s, according to the temperature and roughness prediction model, using a teeth pier 8.46 mm and the proper feed rate (30–40 mm/s) is recommended. With increased supply speed, the sawing temperature decreases and then increases. In addition, the sawing temperature decreases with an increase in the step of the teeth. The feed rate and the step of the teeth depend on the sawing temperature. However, the influence of the speed of feeding on it is more significant. This is because the bone crumb's regime is changing with an increase in the feed's speed.

Figure 1 shows three canvases of a strip saw with different teeth steps. Within a unit of length (1 inch), the canvas of the tape saw S1, S2, and S3, and the number of teeth is 3, 4, and 6. The depth of the teeth h1 > h2 > h3, the area of the reverse side (without a sawing zone) A1 < A2 < A3. Thus, with the same supply speed, hooking angle, and reverse angle, reducing a step in the teeth of the teeth saws involved in sawing increases per unit time, and the contact area of a sawn tooth with a cortical bone decreases. In addition, in the process of sawing, the back of the saw is in contact with the surface of the bone cut, and the contact area between the surface of the bone cut and the back of the saw increases as the teeth are reduced. The efficiency of heat transfer is affected by the contact area and the number of saws of the saw. Thus, the sawing temperature has a non-linear negative correlation with the steps of the teeth.

The work [41] presents a new macrophilia with builtin teeth (Figure 2) made using photolithography and galvanic openings. One of the most important parameters is the mechanical strength of the manufactured macrophilia. The test for pressing the manufactured micropile shows the hardness and elasticity of 211 GPa and 6.75 GPA, respectively.

Particular attention should be paid to the correct choice of cutting element, depending on the

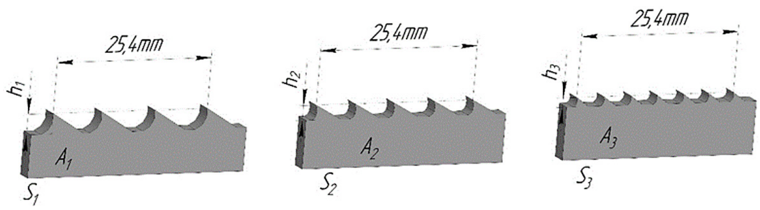

Figure 1. The main shape and distribution of the teeth of the tape-saw canvas: S1 with a tooth pitch of 8.46 mm; S2 with a tooth pitch of 6.35 mm; S3 with a tooth pitch of 4.20 mm; h – is the depth of the teeth [40]

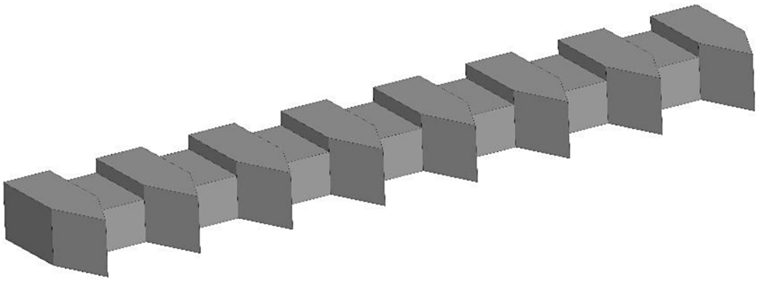

Figure 2. Micropilia with builtin teeth [41]

type of raw materials used for sawed fodder. To do this, it is necessary to determine the correct geometry of the cutting element (step and height of the tooth, the depth of the groove, the angle of the tooth, the angle of attack and fall) and the feed rate [42]. In [43], the results showed that the cutting speed and feed rate affect the cross-cutting process with a saw chain.

Preparation of wood waste feeds is possible using saw canvases. The work [44] assessed the effect of the speed and parameters of the saw canvas on the cutting power P C C of spruce wood, pine (*Pinus Sylvesfris*), and Buka (*Fagus Silvatica*) when sawing using a guiding circular saw. For research, two types of disk saw paintings were used, one of which had an incorrect step of teeth. The results showed that disk saws with the wrong step of teeth consume more energy than disc saws with the usual teeth step. As an alternative method, longitudinal and transverse sawing may find possible applications [45].

The cutting force of the disc saw the vertical effort, and the horizontal force increased with an increase in the distance between two disk saws. However, the axial force decreases [46]. In [47], attention is paid to saw discs with a different number of teeth (16 and 24) and the angle of inclination (100 and 200) when cutting up (in the usual way) and down (with a set of heights) with different speeds (4000 min^{-1}, 5000 min^{-1}, 6000 min^{-1}) and feed speed (15 m/min, 20 m/min, 25 m/min). In [48], a disc saw with alternating teeth was chosen as a cutting tool.

It is possible to predict the onset of tape saws due to cliffs using the conclusions of the adjusted linear hypothesis of the summation of fatigue damage by state standards. On the growth rate of fatigue cracks, the cyclic durability of tape saws up to 20–25% render tangent voltages (stresses arising in the plane of the section, i.e. in other words, this is the intensity of internal transverse forces per unit area at a given point of the section under consideration) of not more than 450 MPa. Even though the level of tangential stresses does not exceed 3–5% of the total stress state of tape saws, their effect is crucial because The strip saw is significantly loaded with normal stresses [49].

One of the significant disadvantages of tape-fed machines is the low durability of strip saws. During operation, due to fatigue phenomena in the interdental cavities of tape saws, cracks are formed, leading to the destruction of saws. The strength of the strip saws is considered to be secured if the coefficient of the strength of the strength is no less required. It is recommended to take the coefficient of margin of strength equal to 2. Calculations for the strength of tape saws are made using a schematized diagram of limit amplitudes. The formula is displayed to calculate the coefficient of the strength of the ribbon saw. According to the presented formula, the coefficient of the margin of the strength of the strip saws, which is used in dividing tape saw machines, is calculated. The resulting coefficient of margin of strength is 1.44. This value is meager for tape saws because it is much less than required. For the long and reliable operation of the strip saws, their regular sharpening is necessary to ensure the required severity of the teeth and turn the interdental cavities to remove the defective layer formed due to fatigue phenomena. Other recommendations are also given to increase the durability of tape saws. The durability of a new type with curved aerostatic guides and teeth equipped with a solid alloy was evaluated. Calculations showed that the coefficient of margin of strength, in this case, is 2.4, and prolonged and reliable operation of such a machine without periodic processing of interdental cavities is possible. Ribbon saws have low durability because of their increased emergency consumption. This negatively affects their wear resistance and increases the costs of preparation and acquisition [50].

Generally, the saws considered for preliminary crushing are reduced to Table 3, indicating their disadvantages and advantages.

Based on the preceding, the issues of crushing outgoing fodder raw materials are scientifically insufficiently studied worldwide. As a result of the analysis of the working parts for preliminary crushing of the outgoing feed raw materials using saws, it was established that the trends in improving the cutting process are the design and technological parameters of the saw. In particular, this is the severity of the blade and the teeth of the saw, the speed of the feed, the step and depth of the teeth, the angles of the gear, the angles of the teeth, the angles of the attack and the fall, the area of the contact, the number of teeth. It has been established that the nature of the development work in the development of saws depends on the level of unification of design conclusions, technical equipment, the structure of the developer and manufacturer, and the required complexity and originality of design developments.

Analysis of the working organs for small grinding of venue raw materials in fodder flour using disks and rollers of the crusher

As is known, working organs for fine grinding are elements that change the quality of the processed material. One of the main methods of preparing feed, including cereal feed for feeding, is grinding. During crushing and grinding, a hard shell is destroyed, the availability of nutrients to the action of digestive juices increases, digestibility accelerates, and complete absorption of feed energy occurs. The most impact on the energy consumption of grinding coarse feed is the frequency of rotation of the cutting knives (Figure 3), the gap between the cutting and the counters, and the feed rate of feed raw materials. Theoretical studies have shown that an increase in the energy efficiency of grinding gross feed is possible due to the use of two parallel shafts in the aggregate - the main and feeder, on the cylindrical surface of which six teeth are cut by a width of 0.02 m and a length of 0.04 m, which are located at the angle, which is located at an angle 600 relative to each other and distributed along the entire length of the cylindrical surface of the shafts with a step of 5 cm, which is included in the hook with each other with a gap of 0.01 m [51].

The grinding of rice and corn grains can be carried out in the five-disc mill RWT-KZ5. The working knot of the mill consists of five discs with holes of different diameters in each of the disks and different distances between the holes (Figure 4), as shown in Table 4. Disks are installed on one shaft and placed in the grinding chamber at an angle [52].

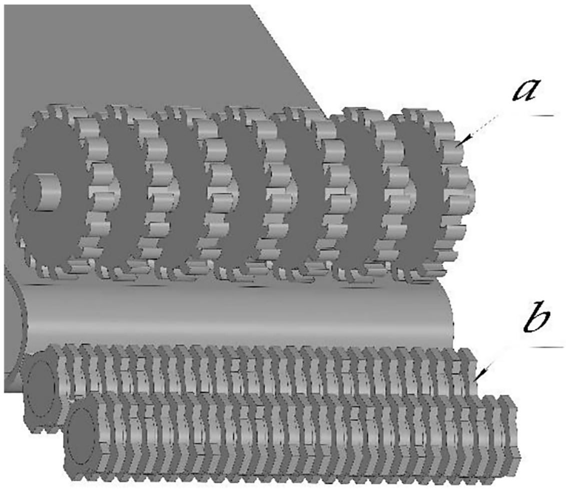

Figure 3. General view of the shaft of the chopper of rude feeds with circulation discs (a) and grinding drums (b) [51]

Table 3. Disadvantages and advantages of saws

No.	Type saw	Disadvantages saw	Advantages of saw
1	Swinging saws	Limit the thickness of the sawing raw materials	Prevent the emergence and accumulation of shock forces
2	Ribbon saws	Produce a vast number of aerosol particles of small diameter	High cutting speed, accurate and high quality cut of sawing raw materials, minimal losses of raw materials
3	Disk saws	Problems when cutting the width of raw materials	The exact cut of raw materials
4	Micropyls with built-in teeth	Limited power, fast battery discharge, short work at low temperatures	High indicators of the accuracy of sawing. Ergonomic design, minimal vibration, convenient change of teeth, mobility
18	Swinging saws	Limit the thickness of the sawing raw materials	Prevent the emergence and accumulation of shock forces

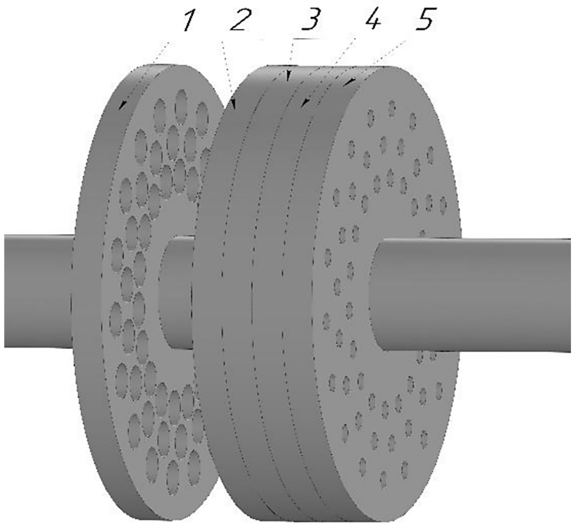

Figure 4. Scheme of structural features of a grinding unit; Figures from 1 to 5 indicate sequential discs [52]

To improve the rice grinding coefficient with multi-disc grinding, reducing the gap between the disks, increasing the number of holes, and reducing the diameter are recommended [53].

In work [54], to assess the effect of the diameter of the holes of the sieve, the gap between the rolls, the supply speed and the rotation speed of the rolls for the protein content, the release of the fraction and the consumption of energy for grinding used the central component scheme. The most impact on the output of the fraction was the diameter of the holes of the sieve, followed by the gap between the rolls and the feed speed. The gap between the rolls was the only input factor significantly influencing energy consumption during grinding.

Unlike smooth rolls, toothed rolls improve grinding conditions so larger particles can be crushed. In addition, gear rolls produce less small material, which can benefit certain subsequent processes and reduce the specific energy at this stage [55].

Feeding from forage grain can be obtained by vying with two rollers of the crusher (Figure 5). Open grain is the optimal size for uniform distribution when feeding cows [56].

The integrated system allows you to determine the chopper's permissible range of variables (structural properties) in laboratory conditions through a computer experiment, design, and operation. For an objective assessment of effectiveness in work [57], a measuring system was used, which includes registration of instantaneous torque and instant values of the frequency of rotation of the drive shaft (Figure 6). The test station was designed to ensure the possibility of replacing the working unit (knife, disk, or bit system) and changes in orientation (from horizontal to vertical). As a result of the automated design of

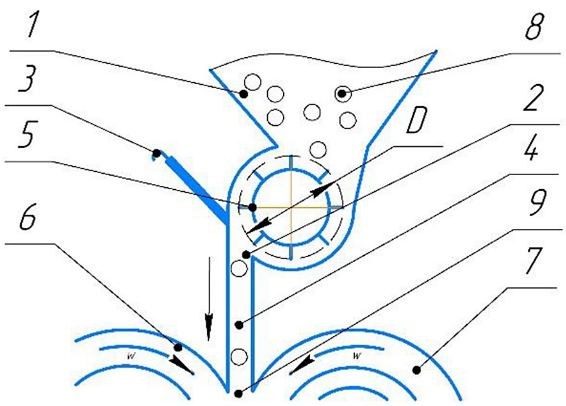

Figure 5. Scheme of the supply device of vying fodder grain PZ – 1M: 1 – loading funnel; 2 – window; 3 – damper; 4 – grain supply channel; 5 – feeding vault; 6, 7 – rollers for plumbing; 8 – grain for plumbing; 9 – interculed gap [56]

Table 4. Details of the design of the grinding disks [52]

Parameter	Unit of measurement	Disk 1	Disk 2	Disk 3	Disk 4	Disk 5
Disk diameter	mm	274	274	274	274	274
The number of holes	pcs	14	22	27	33	39
The diameter of the hole	mm	30	23	21	17.5	17.5
Number of rows with holes	pcs	2	2	3	3	3
Number of holes in the row	pcs	7	11	9	11	13
Disk diameter	mm	274	274	274	274	274
The radius of the location of the holes in the row	R1, mm	101.7	107.4	110.8	114.8	117
Disk diameter	R2, mm	85	82.3	95.8	99.8	102
The number of holes	R3, mm	-	-	79.8	79.8	82

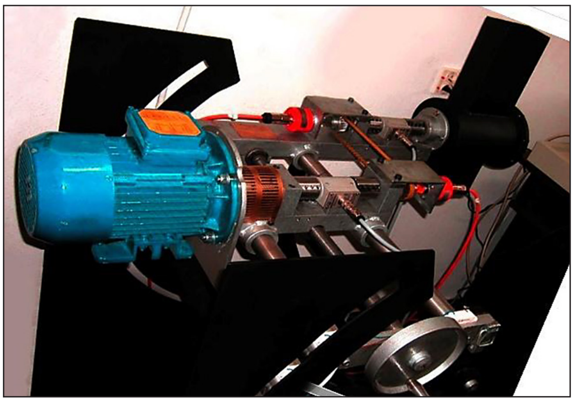

Figure 6. The general type of laboratory stand for grinding research [57]

the chopper, it was estimated that the gap between the rotating disks should be minimal.

The main parameters of the crusher rollers are length, diameter, and type of working surface. The diameter of the rollers of machines used at present is between 200 and 450 mm, and the length is between 100 and 1200 mm. With an increase in the length of the waltz, the performance grows directly in proportion, and the energy intensity decreases [58].

Energy can be employed by more rough grinding of corn before granulating and using a roller mill instead of a hammer. From the point of view of the quality of granules, it is better to use a roller mill when using a more rough grinding. The grinding of corn crushed on a roll mill leads to a more uniform distribution of particles in sizes in granules, which provides the best quality of granules [59].

In the work [60], the main technological operation is the abrasion of the soaked soy grain to a finely dispersed state through a truncated cone with curved grooves and an abrasive applied throughout its surface. Abrasive discs with curved grooves are presented in Figure 7, where the grooves are made at different angles of the intersection of the grooves (α=60°, α=90°, α=120°). The gap between the abrasive disks was exhibited by applying the washers between the upper abrasive cone and the cover of the grinder part (the clearances between the abrasive disks 3, 4, and 5 mm). The roughness of the abrasive surface of the discs was achieved by applying corundum to an abrasive stone. The roughness value was chosen Ra = 50, Ra = 250, Ra = 450 μm. An increase in the angle of inclination of the grooves, the roughness of the abrasive, and a decrease in the gap between the disks can lead to an increase in the resistance moment to 20%.

In general, the discs and rollers of the crusher are reduced to Table 5, which indicates their disadvantages and advantages.

Based on the preceding, the issues of small grinding of raw materials into fodder flour using discs and rollers of crushers are scientifically insufficiently studied in the world. The analysis of the working parts for small grinding of the waste food raw materials using disks and rollers of crushers established that the development trends of disks and rollers are structural, technological, and operational parameters of crushing equipment. From structural parameters, it is appropriate to note the gaps between the working parts, the geometry, and the design of the disks and rollers. It should also be noted that automated design and computer modeling are effective when developing crushing equipment.

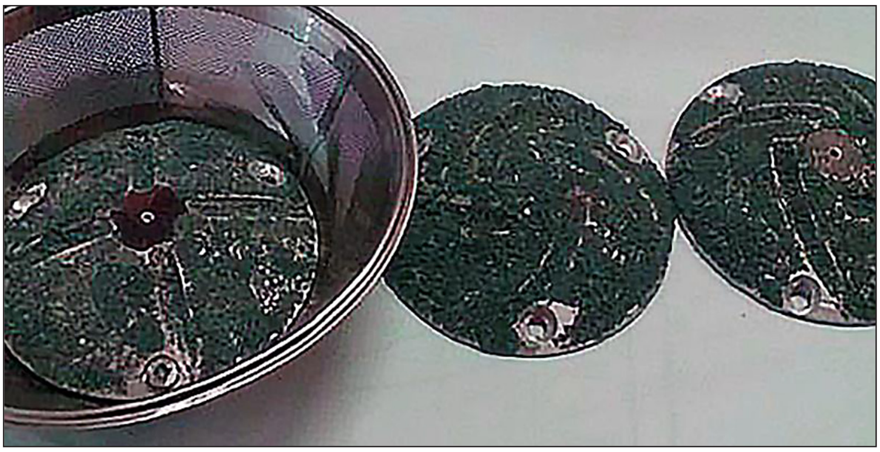

Figure 7. Abrasive discs with curved grooves [60]

Table 5. Disadvantages and advantages of discs and rollers of the crusher

No.	Type of discs and rollers crusher	Disadvantages of discs and rollers crusher	Advantages of discs and rollers crusher
1	Circulation discs	Overheating of working surfaces	Low noise, energy intensity, compact dimensions
2	Grinding drums	High energy intensity, wear of the working parts, heterogeneity of crushed particles, taking into account refinement	Simplicity of design, high reliability, compactness, economic efficiency
3	Wheels with holes by the mill	Clogging holes with raw materials reduces the effectiveness of grinding	Adjustment of the size of the holes, which affects performance
4	Smooth rollers	The uneven wear is mainly in the middle part of the rolls, slipping raw materials, sticking wet raw materials	Reliability, simplicity of design, ease of operation, high performance, uniformity of grinding
5	Toar rollers	Wet raw materials sticking, teeth wear	Ease of operation, uniformity of grinding
6	Plusing with two rollers of a crusher	When plunging wet raw materials, raw materials are sticking to parts. High spacer efforts of rollers. The need to calibrate raw materials in size	The finished food does not dust. High digestibility of talked feed with an increase in animal productivity
7	Abrasion with a truncated cone	Inappropriateness to grind viscous raw materials, complexity of design	Lack of dynamic loads, calm move, lower energy consumption

Analysis of working parts for fine grinding of waste raw materials into feed flour using hammers and crusher knives

Hammer and knife-cutting elements are most often used for grinding feed. In work [61], the hammers are made from a sheet 10 mm thick and have two cutting edges (Figure 8). They are installed in rows with a certain pitch and have a 65–68 m/s speed.

The work [62] examines the determination of the influence of the pitch of the hammers with cutting edges on the average length of feed crushed from by-product stem raw materials in hammer crushers. Figure 9 shows the calculation results in the value of the average length of crushed particles depending on the distance between the edges of adjacent hammers. Figure 9 shows that when changing the distance between the edges of adjacent hammers, the average length of crushed

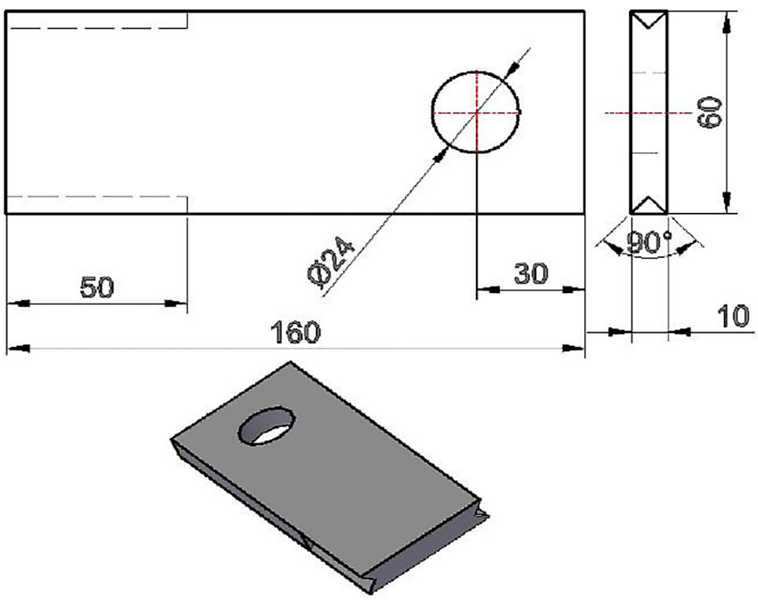

Figure 8. Diagram of the cutting edges of the hammer working element [61]

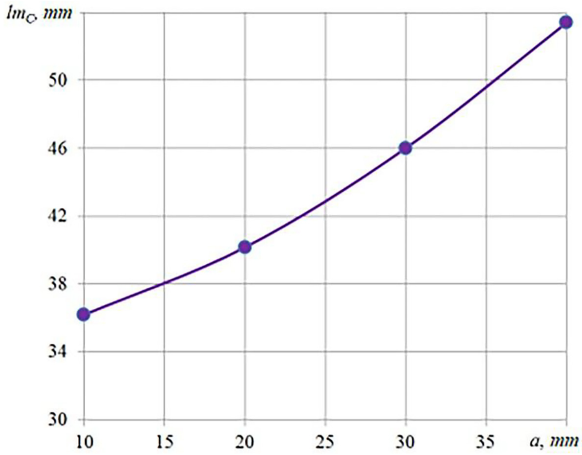

Figure 9. Effect of the distance between the faces of adjacent hammers on the average length of crushed particles [62]

particles varies from 36.19 to 53.39 mm. At the same time, for sheep, the length of crushed stem feed should be within the range of 20–30 mm, and for cattle – 30–50 mm.

The operation of the crusher can be affected by many factors, such as uneven feed, feed splitting, material rigidity and shape, and feed segregation. Segregation, when it comes to differences in particle size, is caused by granule convection [63]. A fluidized bed can help reduce gas and solid particle segregation and enhance gas and solid particle interactions [64]. In this case, the rotational motion of the working elements of the process equipment is often created by electric motors [65]. The process of crushing the feed mass can be carried out in a crushing, mixing, and drying device, where two gear motors and one electric motor are used [66]. As a result of studying such a device, the critical impact speed on an eggshell was determined. It was also found that a screw with knives crushes and moves the feed raw material, and an impact-spreading finger shaft ensures partial crushing and mixing (Figure 10) [67].

Many scientific publications report impact-crushing studies. In [68], the impact in the crusher is provided by two intersecting rods attached to a spindle driven by a column drilling machine with an adjustable rotation speed (Figure 11). To achieve a significant reduction in particle size, it is necessary to subject them to multiple crushing at lower rotor speeds or in one pass at higher speeds.

In [69], the specific fracture rate increased with the increase of the hammer speed. As the rotor speed increases, causing more significant impact and pressure, the energy density gradually increases, helping to release more energy, thereby increasing the impact contact energy for more efficient particle fracture [70]. In pin mill and

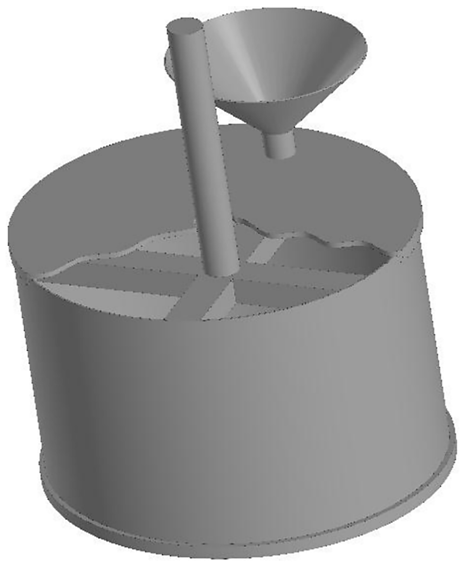

Figure 11. Cross bar crusher [68]

(a) (b)

Figure 10. Operation of the impact-spreading finger shaft [67]: (a) idling; (b) working with eggshells

hammer mill grinding, the rotor speed determines the specific energy consumption [71].

Among the mechanization means of grinding grain waste, universal impact crushers with hinged hammers are the most common. They can grind various raw materials, are relatively simple in design, and are easy to maintain and operate. Their design allows easy replacement of wearing parts (hammers, decks, grates). At the same time, modern designs have significant drawbacks: high metal consumption and energy consumption of the units, uneven granulometric composition with an increased content of dust particles, intensive wear of the working parts, and the associated decrease in productivity and quality of grinding [72]. The blows applied to the hammer must not be transmitted to the hinge joint. The position of the hammer hinge should be determined so that the impact caused by collision with material particles falls on the center of the impact. Since the operating conditions of the impact center are only sometimes met, imbalances arise depending on the impact joints, which create additional disturbances. These effects are assessed by the coefficient of transmission of impacts to articulation. This is verified by measuring increased vibration levels under high-impact conditions [73]. The design of the hinged hammers has a slightly negative effect on the dynamic performance of the hammer mill. Once the rotor starts rotating, the hammers rotate along it while simultaneously pivoting around their hinges. Although the hammers move further in the circumferential direction due to centrifugal force as the angular velocity of the rotor increases, they still swing back and forth around the hammer hinges due to the hammers' inertial mass and hinged design. During the crushing process, there is a constant collision of the hammers with the raw material, which upsets the stability of the hammers and increases their swinging. Such hammer motion characteristics constantly affect the rotor's angular velocity, making it unstable due to stronger vibration [74].

One way to improve the productivity of crushers is to use vibration [75]. Vibration impact type machines are widely used in agricultural production, being one of the most essential subclasses of modern technological machines. These include traditional machines (crushers and others) and modern ultrasonic technological devices. When setting up a machine, as a rule, the working element must vibrate with maximum amplitude since the maximum possible energy must be put into the processed medium [76].

The classic method of preparing grain for feeding is crushing it using hammer mills [77]. The impact-centrifugal crusher model has proven effective for crushing feed grain [78]. When crushing grain in hammer mills, less effective types of impact crushing of grain are used: impact on a sieve and collision of particles [79].

The main working parts of hammer crushers are hammers. The V-shaped hammer developed in [80] meets the requirements of strength and rigidity during operation and has good dynamic characteristics. This hammer can effectively improve the performance of the hammer crusher, and the research results serve as a theoretical basis for optimizing the design of the hammer crusher. The conical hammer design offers promising improvement in energy efficiency, as detailed in the DEM modeling work [81]. In [82], the MC-22 hammer mill was equipped with hammers arranged in parallel. The hammers used for testing were 153 mm long and 60 mm wide, and had different edges, as shown in Figure 12. It is also noted there that the grinding process in the hammer mill requires much work to optimize, given the random nature of the material movement inside the grinding chamber. The results showed that using hammers with multiple edges could be better. The research found that a single-stage hammer was

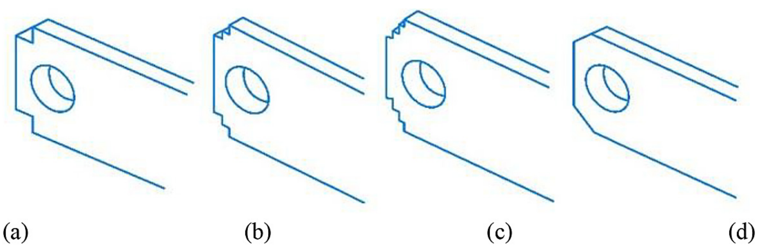

Figure 12. Four types of hammers are used for testing: (a) single-step hammer, (b) two-step hammer, (c) three-step hammer, and (d) triangular-edge hammer [83–84]

more effective in crushing *Miscanthus giganteus* biomass than crushing willow chips.

With the increase in the number of hammers, the amount of particles crushed by the hammers increases significantly. The number of particles broken by the hammers increases slightly with the increase in hammer thickness. With the increase in the number and thickness of the hammers, the power consumption of the crusher tends to increase, and with the increase in the gap between the hammers and the screens, the power consumption of the crusher tends to decrease. When the thickness of the hammers is 4 mm, the maximum power consumption per ton of material is 312.70 kWh/t; when the thickness of the hammers is 5 mm and 6 mm, the maximum power consumption per ton of material is 375.24 and 531.60 kWh/t, respectively, which increases by 20% and 70%, respectively. The reason is that with the increase of the thickness and number of hammers, the total mass of the rotor increases, and the total power consumption increases with the increase of the amount of crushed particles (Table 6).

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As the number of hammers increases, the rotor mass increases, so the idle power becomes more extensive, and the adequate power decreases relatively. In addition, the number of impacts on the material will increase, resulting in finer particle size, causing over-grinding and greater energy consumption. Therefore, there is a tendency to reduce the number of hammers in the design of grinders. It should be noted that as the thickness of the hammer increases, the impact force and impact area increase [85].

A rectangular design of a hammer with an oblique bevel is known, as shown in Figure 13. The hammer handle is made of high-carbon, high-chromium steel with better abrasion resistance, and the end of the hammer has high abrasion resistance of high-chromium cast iron. The hammer handle has the strength of low-alloy steel [86].

In [87], a two-fluid bimetallic composite casting hammer was developed. Its service life is three times longer than that of high-manganese steel. This improves wear resistance and production efficiency, which users highly appreciate. The hammer model is modeled as a set of spherical particles of different sizes to represent the destruction process during the collision between the agglomerate and the hammer as a process of particle interaction (Figure 14).

Table 7 shows the simulation results obtained for the collision of the hammer and the raw material being crushed by changing the

Table 6. Effect of hammer parameters on crushing performance [85]

Parameters	P1, kWh/t	P2, kWh/t	%
N = 16	312.7	344.16	10.06
N = 24	656.68	339.15	-48.35
N = 32	663.88	683.52	2.96
H = 4 mm	312.7	344.16	10.06
H = 5 mm	375.24	373.15	-0.56
H = 6 mm	531.6	448.62	-15.61
l = 8 mm	312.7	344.16	10.06
l = 12 mm	281.43	322.7	14.66
l = 16 mm	259.78	293.37	12.93
l = 20 mm	173.19	354.56	104.72

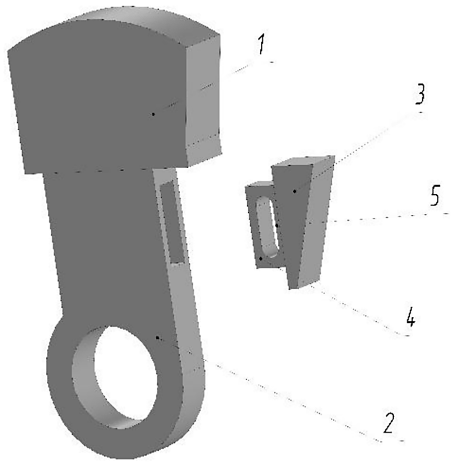


Figure 13. Hammer [86]: 1 – side part; 2 – hammer handle; 3 – protective part of the handle; 4 – jack; 5 – waist-type hole

hammer mass to 0.5, 1, and 1.5 kg and changing the rotor speed to 500, 625, 750, 875, 1000, 1125, and 1250 rpm. As shown in Table 7, the hammer mass does not affect the relationship between the specific destruction energy and the agglomerate destruction coefficient. In addition, it shows that the required specific destruction energy increases exponentially depending on the agglomerate damage coefficient. Thus, much more destruction energy can be expended simultaneously to obtain a significant damage coefficient [88].

In the study [89], a hammer with sharp toothed edges was used. A sharp pointed tooth with an angle α at the top instantly acts on the crushed element with a force F. Graphs of the dependence of the force F on the angle α were obtained (Figures 15–16). These graphs allow one to determine the optimal angle at the top of the tooth if the friction coefficient η is known.

To improve the hammer mill's performance, the cutting-edge hammer and the oblique hammer were designed and manufactured (Figure 17). The cutting edge hammer has sharp blades on both sides, which can increase the shear force of the corn grain (Sun, 2013; Tang et al., 2007). The oblique hammer has a tip angle of 135° and sharp blades, which can increase the shear force when theAccording to the theoretical analysis, the cutting hammer can increase the shear force of the corn grain and improve the crushing efficiency. The inclined hammer can reduce the falling angle of the corn grain and improve the sifting efficiency.

The simulation results showed that the cutting hammer had the highest bond-breaking efficiency in the corn grain model under the same rotor speed conditions. The inclined hammer could reduce the falling angle of the corn grain, and the average falling angle was 48.7° when the inclined hammer was used. The experimental results showed that both the cutting hammer and the inclined hammer could improve the performance of the hammer mill. When the inclined hammer was used in the hammer mill, and the rotor speed was 4400 rpm^{-1}, the comprehensive performance was the best [90].

In biomass crushers, a steel chain is usually used for crushing (Figure 18). Its advantage is its low cost, but its service life is significantly limited. Depending on the crushing volume, the average service life of the chain is 420 working hours. Several tribodegra-dation factors influence its service life. The main effect is abrasive wear

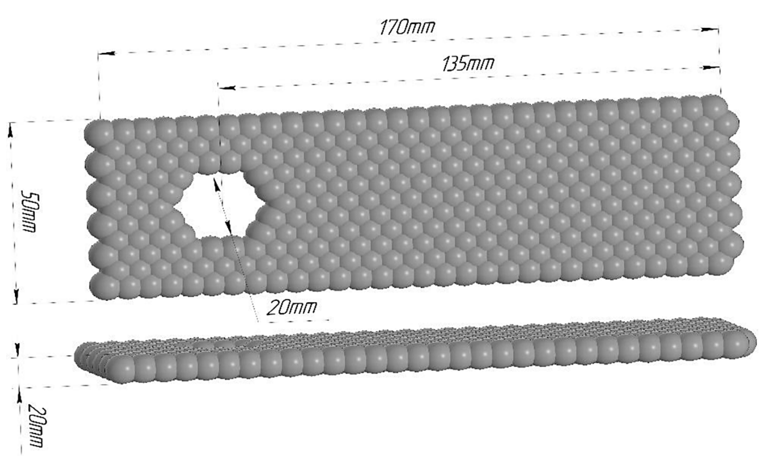


Figure 14. Hammer model [87]

Table 7. Agglomerate damage coefficient is estimated by particle size [88]

Hammer weight, kg	Rotor speed, rpm	Specific destruction energy, J/kg	Damage coefficient, %
0.5	500	34.311	78.32
	625	53.595	83.03
	750	76.872	86.98
	875	104.88	89.86
	1000	138.68	91.67
	1125	177.7	93.27
	1250	222.45	94.65
1	500	39.075	79.89
	625	60.618	84.47
	750	87.17	88.43
	875	119.4	91.08
	1000	158.42	92.49
	1125	202.15	94.24
	1250	252.91	95.10
1.5	500	40.844	80.42
	625	63.35	84.93
	750	91.181	88.58
	875	125.02	91.31
	1000	165.71	92.91
	1125	211.75	94.36
	1250	265.78	95.20

during waste crushing. A secondary effect is combined abrasive-adhesive wear, which occurs as a result of abrasion of the inner surfaces of individual chain loops, but especially the inner surface of the first eye, by the pin rod with which the chain is attached to the crusher head [91].

During the research, four chains were replaced by two hammers made of wear-resistant material Hardox 400 (Figure 19). In addition to preventing the crusher from being destroyed when the chain breaks, the innovation was also driven by the possibility of restoring the functional surfaces of the hammers using arc welding processes. By applying surfacing layers to the functional surfaces, the service life of the hammers can be increased several times. Surfacing layers are used in practice for the friction surfaces of crushers.

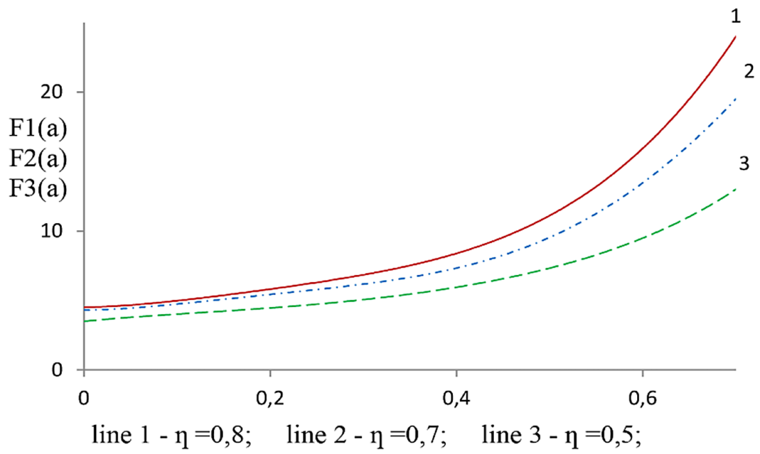


Figure 15. Dependence of the expanding force on the angle of the tooth tip at different friction coefficients (bird bone raw material) [89]

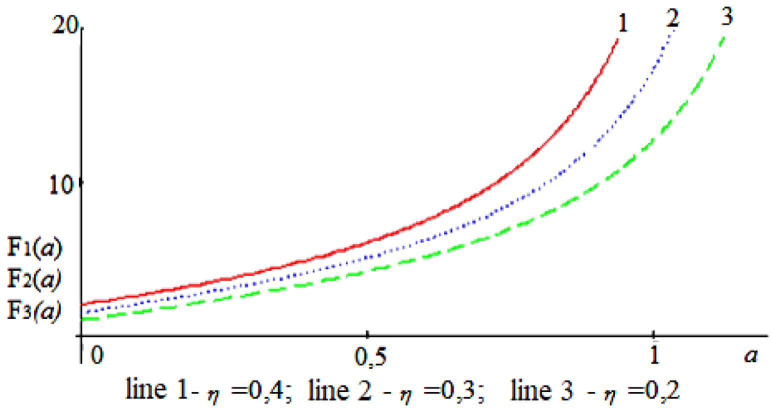


Figure 16. Dependence of the expanding force on the angle of the tooth tip at different friction coefficients (fishbone raw material) [89]

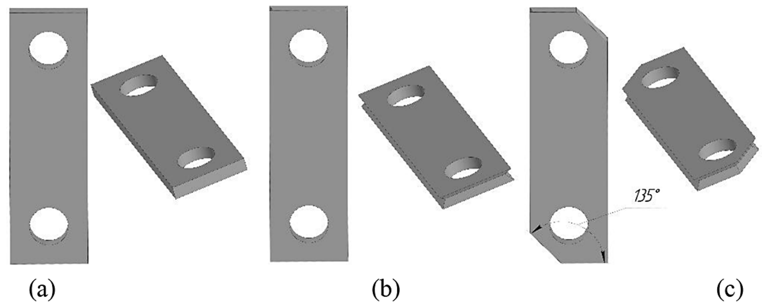


Figure 17. Hammers: (a) common hammer; (b) cutting edge hammer; (c) oblique hammer [90]

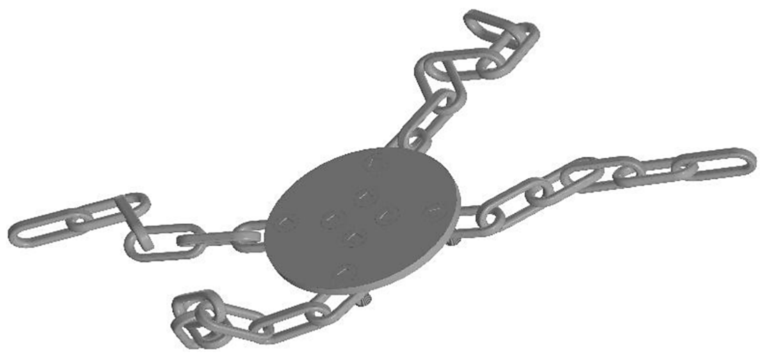


Figure 18. Steel chain for crushing [91]

The hinged shape of the crushing hammers was chosen because it provides higher crushing efficiency compared to the smooth hammer shape (Figure 20). The hammer dimensions are given in millimeters, as shown in Figure 21.

The paper used high-speed photography [92] to record the instantaneous states of hammers to investigate their actual state of motion. Comparative analysis of the images taken at three different operating speeds showed that for each hammer in the hammer mill, there is a phenomenon of random static deviation. For all hammers, there is chaos with the relative rest position in the range of a certain angle.

The following working tool of the hammer mill is shown in Figure 22 [93]. Its main parts are the cutting head one and the screen 2. The cutting head 1 has knives 3 and hammers 4 attached to it. The knives are primarily intended for crushing the biomass, and the hammers perform the final crushing of the biomass. There are different shapes and sizes of hammers, but very often rectangular hammers with two symmetrically located holes for articulation with

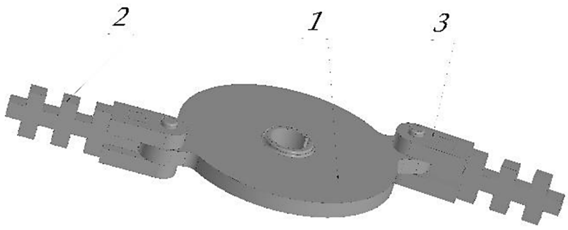


Figure 19. Innovative crusher head design [91]: 1 – crusher head, 2 – crushing hammer, 3 – pin

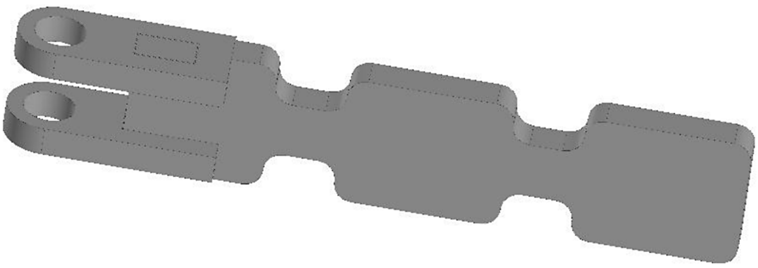


Figure 20. Welded crusher hammer [91]

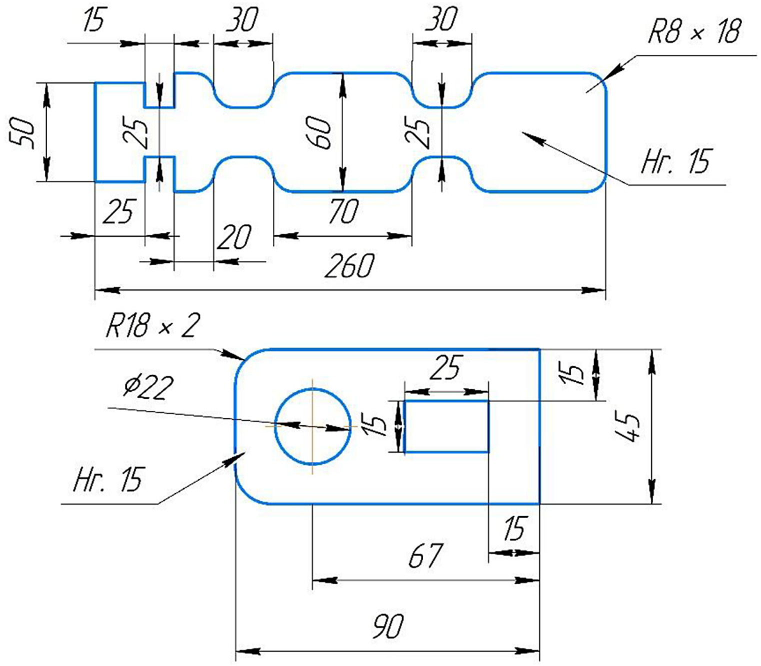


Figure 21. Hammer dimensions [91]

the cutting head are used. The design with two mounting holes (Figure 23) allows four options for fixing the hammer during its service life [94]. This means that two holes allow up to four working angles versus two on a hammer with one hole.

In the work [95], it was established that it is preferable to shift the hammer mass to the periphery of the crushing chamber. However, the hammer must have a specific size and suspension axis to ensure its impact balance. There are cases of crushing when the crushed particles hit the impact rectangular hammers without much friction. There are cases when the friction of the crushed particles increases, the loss of kinetic energy of the particles increases accordingly, and the impact load from the particles on the impact organs of the crusher decreases [96].

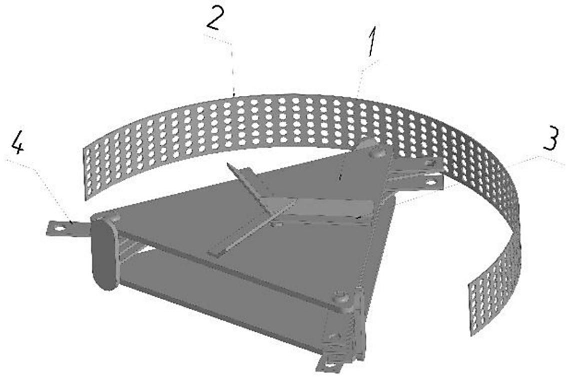


Figure 22. Working tool of a hammer crusher [93]

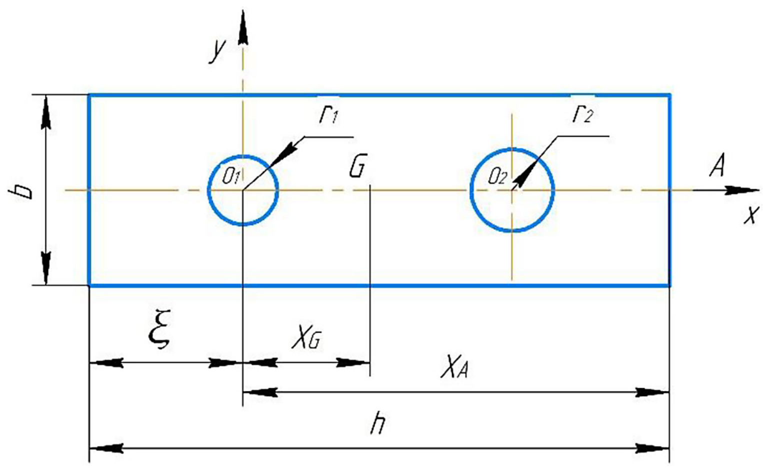


Figure 23. Hammer [94]

The process of the hammer action on the crushed material in the impact crusher can be simulated by the MSC.Dytran V2019.0 software (MSC Software Corporation is an American simulation software technology company based in Newport Beach, California, that specializes in simulation software). Based on the analysis of the stress distribution in the hammer and the square plate, the area in which the stress is more significant was determined, and the maximum stress relaxation was established. The simulation result will be a basis for improving the crusher performance [97]. In optimizing the process parameters of the impact crusher, work is known with a numerical model for simulating the crushing effect [98], and work [99] in the form of a dynamic model reflects the response to multiple changes in the feed to the crusher.

The vibratory-rotor crusher for grinding feed grain implements the idea of a combined interaction of vibration and rotational movement of the actuators, which allows for a significant increase in the power of impact on the raw material [100].

A hammer crusher is known for crushing waste watermelon, melon peels, and seeds. The crusher's working parts are the crushing hammers' blades (Figure 24). It is noted here that the crusher speed and the number of hammers on the spindle torque greatly influence the result, i.e., the higher the spindle speed and the greater the number of hammers, the greater the corresponding torque [101].

Ring hammers that rotate freely along suspension rods mounted on the ends of the rotating rotor arms are known [102]. Hammer crushing results in more intensive crushing of olive pits than in a disc crusher, which leads to a more significant increase in the outlet temperature [103].

Exciting research is being conducted to increase the service life of hammers. Based on ANSYS V11.0 software (Ansys, Inc. is an American multinational company with its headquarters based in Canonsburg, Pennsylvania), it

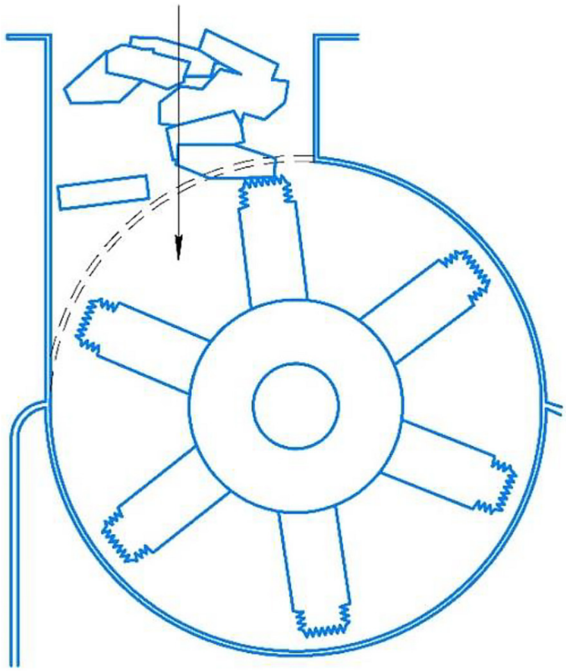


Figure 24. Working parts of a hammer crusher [101]

is possible to analyze the laser coating applied to the hammer. It has been found that the service life of the hammer can be increased [104]. A hammer head made of high-vanadium cast iron has been developed [105]. Both technologies – welding of a high-chromium cast iron rod and a plate with the prevention of splitting – were used for overlap welding of the hammerhead. The results showed that the service life of the improved hammer head is 8 times longer than before the experiment [106].

Some crushing devices have cutting or cutting-impact working parts. The combination of crushing by cutting and chipping with the feed of forage grain to the cutting pairs due to inertial forces has an advantage in designing a centrifugal rotor crusher [107]. The speed of the crusher knife varies linearly depending on the specific volume, and it was found that its change with weight loss is a second degree polynomial [108]. For example, the optimal values of the knife and blade speed during crushing in a forage harvester are within 35–40 m/s [109]. Shear tests affect the strength of the raw material, which decreases with increasing particle size [110]. A portable crusher was proposed in [111], a modified design that introduced two-shaft cutters with 7-jaw technology. Here, the generally accepted number of cutting jaws is 3, 5, 7, and 9, with the output length of the fiber decreasing accordingly with the increase in the number of jaws. Semi-conical knives were developed for chopping

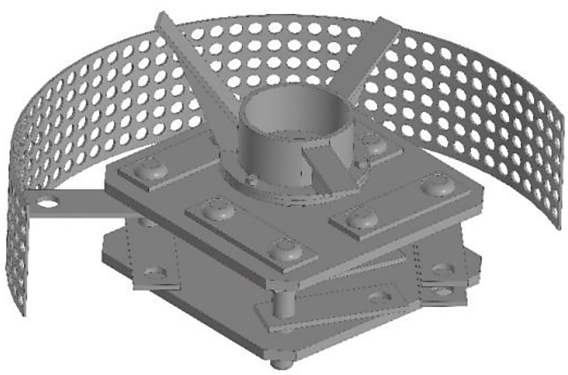


Figure 25. Working parts in the form of semi-conical knives and hammers [112]

straw in square bales, as shown in Figure 25. At the same time, hammers were also used for chopping and mixing feed raw materials [112].

Many needle impact elements and their uniform distribution around the rotor circumference contribute to the fact that there is a smaller amount of crushed raw material per working element. This prevents the accumulation of particles, which occurs in serial crushers between the hammer packs. As a result, the intensity of crushing increases [113]. In this case, the number of needle impact elements can be 170–460 pcs. (Figure 26) [114].

It should be noted that the number of working elements significantly impacts the operation of the equipment, and each piece of equipment has a variation in its number. Compared to needle impact elements, the number of hammers in the mill is 24 [115]. At the same time, the grinding in hammer mills is also affected by such design parameters as the design and placement of the hammer (i.e., the distance between the hammers and the screen) [116].

It is worth noting that when the crusher is operating, an increase in the initial particle size leads to an increase in the particle's initial angular velocity. With a particle size of more than 2 mm, the capture angle increases from 150 to 180, decreasing the crusher's productivity [117]. In this case, the granulometric composition depends not only on the material's properties but mainly on the design and operating parameters [118] and the working parts of the crusher.

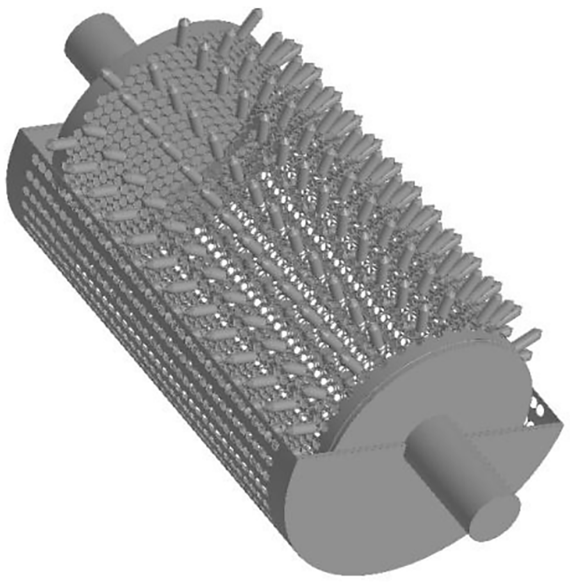


Figure 26. Needle impact elements [114]

Credit should be given to the development and modernization of Griffiths' theory [119–125], wave theory [126], rebound [127], first-order shear deformation theory [128], Hertz's conical crack theory [129], thermal shock [130], and elimination of imbalance and vibration of the crusher [131]. When crushing with hammers, it is necessary to limit the overload of the crushing equipment [132], optimally organize the crushing process in production areas [133], and take into account the dynamics of a solid body under large deformations and thermoelasticity [134]. Of great importance in the crushing process are the phenomena of collision [135], free impact [136], increase in the crushing speed [137], use of counter-hammers [138], use of mini-crushers [139], destruction of side stems [140], justification of the parameters of the hammer rotor [141], interaction of hammers inside the crusher [142], adjustment of hammers [143]. Hammer mills are of no minor importance [144], distinguished by high technical and economic indicators and other equipment for processing waste feed raw materials [145–148].

In general, Table 8 summarizes the hammers and crusher knives considered for fine grinding and indicates their disadvantages and advantages.

Thus, the predominant application was hammers and chains of impact action, pins and rods of impact-destructive action, hammers of impact-cutting action, hammers and pins of impact-abrasive action, knives, and cutters. The combination of cutting and impact in a hammer takes place when grinding wet feed raw materials. In the course of scientific research, it was found that using various designs of hammers and knives tends to increase the intensification of the grinding process, taking into account the growth of the quality of the ground feed of a predetermined granulometric size.

Analysis of the working organs for grinding venue raw materials in fodder flour using the discs of this Shredder

Of particular importance in increasing feed production is the use of all types of waste and the confiscation of feed value for agricultural animals and birds. At the same time, various feed production methods are used, and new shredders with various working parts are developed and produced.

Table 8. Disadvantages and advantages of hammers and crusher knives

No.	Types of hammers and knives	Disadvantages of hammers and knives	Advantages of hammers and knives
1	Double edge hammers	The probability of cutting yourself on the cutting edges when in contact, the dullness of the cutting edges, noise	Possibility of crushing wet feed raw materials with cutting edges, combined impact-cutting crushing
2	Impact-crushing fingers	Requires replacement when worn out, increased energy consumption, noise	Low percentage of over-crushed feed
3	Impact crushing rods	As the speed increases, the intensity of rod wear and noise increases.	Less wear, which reduces rod replacement costs
4	V-shaped hammers	High noise and vibration levels, wear	Strength and rigidity during operation, good dynamic characteristics
5	Single Step Hammers	Rapid wear of hammers when crushing harder raw materials, noise	Grinding efficiency, high speed
6	Two-stage hammers	Intensive wear of steps, noise	Ability to grind quickly, high speed
7	Three-stage hammers	Intensive wear of steps, noise	The high degree of grinding, high-speed
8	Triangular edge hammers	Rapid wear of hammers, noise, less effective in obtaining fine fractions	High-speed impact crushing, high speed
9	Hammers with increased thickness	As the thickness of the hammers increases, the total mass of the rotor and noise increase	The impact area increases, and the number of particles increases with the thickness of the impact hammers
10	Hammers with a bevel	High noise and vibration levels, wear and tear	Accuracy and power of impact, high speeds
11	Two-fluid bimetallic composite casting hammers	Much more destructive energy may be expended, high noise and vibration levels	Long service life, improved wear resistance and production efficiency, high crushing degree, and speed
12	Hammers with sharp edges	High noise and vibration levels, tooth breakage, wear	High productivity, high speeds, rapid crack formation in raw materials
13	Slanted hammers	Dullness of cutting sharp blades, noise	Sharp blades can increase the shear force of the material being ground
14	Steel chains	Limited service life, abrasive wear	Low price, low operating costs
15	Hammers made of Hardox 400 material	High noise and vibration levels, fragile under strong vibrations	Extended hammer life, high crushing efficiency
16	Rectangular shaped hammers	Subject to intense wear, high noise and vibration levels	Simple design, low operating costs, and easy maintenance
17	Ring hammers	The degree of crushing is small, wear	Suitable for grinding medium-hard raw materials
18	Needle impact elements	The power of the impact needles does not allow the use of massive equipment	High impact power, free axial movement of needles, low noise level
19	Pins	Do not provide the required degree of grinding	Production of fine particles, impact, and abrasion
20	Knives	Rapid wear, damage to knives when hit by metal objects and stones	High-cutting quality, wear resistance to abrasion and impact
21	Milling cutters	Low level of hardness	Stability in operation

A shredder is known [149] (Figure 27) and is designed for processing wood waste. A schroeder with rolls has various disk parameters, which are characterized in that to combine several stages of crushing, discs with the same parameters are located on each roll. The fork consists of shaft 1, various discs 2 and 3, and intermediate rings 4.

The working organs of the schredder are known [150] (Figure 28). The main details of the Shredder are shafts 1, discs 2, separated by intermediate rings 3 and additional inter-mediate rings 4. Additional intermediate rings 4 are installed on adjacent rolls, forming pairs 5 of the additional intermediate rings 4. Additional inter-mediate rings 4 are equipped with pins 6.

The shredder knife with double and triple edges is known [151] (Figure 29). The cutting angle was recorded at 35°, and the cutting edge length was recorded at 10.44 mm, both for knives with a double and triple edge. The

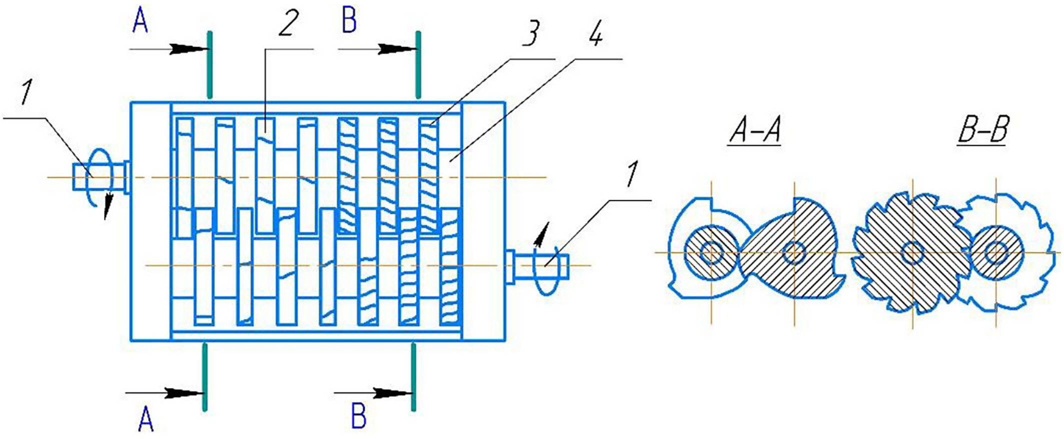


Figure 27. Shredder [149]: 1 – shaft, 2, 3 – various discs, 4 – intermediate rings

optimal combination of geometry and orientation of the knife is a knife with a double edge and spiral orientation.

The knife of the double-sized Shredder is known [153] (Figure 30). The double-sized integrated Shredder has a machine case with a grinding knife connected to the power system.

Figures 31–32 present the working area of the two rot Shredder of the EB180 brand. The work of this Shredder is ensured by the oncoming rotation of two rotors, on which massive disk knives with cutting edges are fixed.

Experiments were carried out on crushing wood waste, meat-bone contexts, and bone residues using the Shredder EB180. Figure 33 shows the distribution of fragmented pieces due to crushing wood waste of various masses, diameters, and lengths using the Shredder EB180.

Figure 33a is a small part of pieces with a size of less than 5 mm (10%, m = 1.07 g) and 8–12 mm (18%, m = 1.92 g). A significant part of the fragmented pieces is a size of 27–30 mm, mass m = 7.69 grams, due to most of the geometry of the disk knife. In particular, there are several cutting edges on the disk knife, the distance between which is 30 mm, and from this, it follows that the captured branch with disk knives is thrown and cut through a step equal to 30 mm. However, some pieces comprise a slightly smaller 30 mm, most likely associated with slipping. As a result of crushing, tinyness is observed, which is associated with the separation of particles and their cutting on the sharp edges under the force. Figure 33b no longer dominates the composition of fragmented pieces with a size of 27–30 mm (reaches 36%, m = 8.22 g), which is because the raw material, the wood waste, has a diameter of 14 mm and in its size covers the width of two disk knives. Thus, a neighboring disc knife is also involved in crushing. Here, neighboring knives act simultaneously, in which the cutting edges are not parallel but with a step of 10 mm. Although on each disk

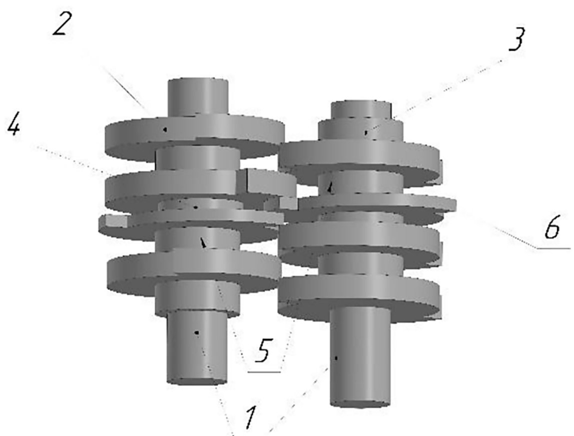


Figure 28. Schredder’s working organs [120]: 1 – shafts, 2 – discs, 3 – visual rings, 4 – additional intermediate rings, 5 – pairs, and 6 – pins

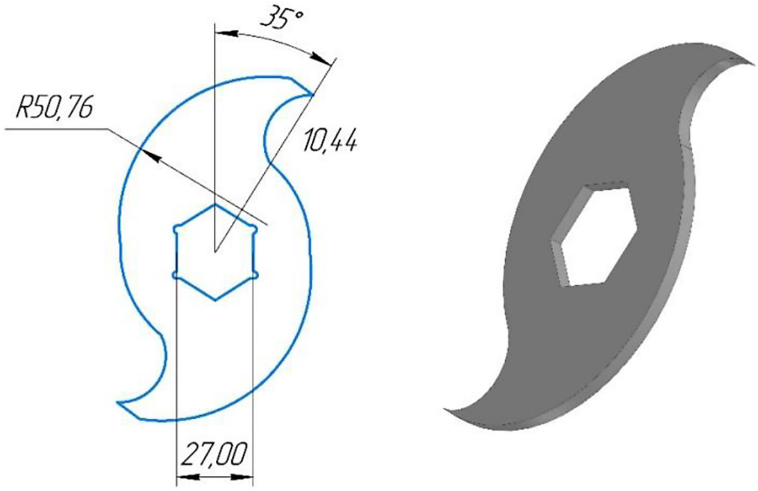


Figure 29. Shredder knife [152]

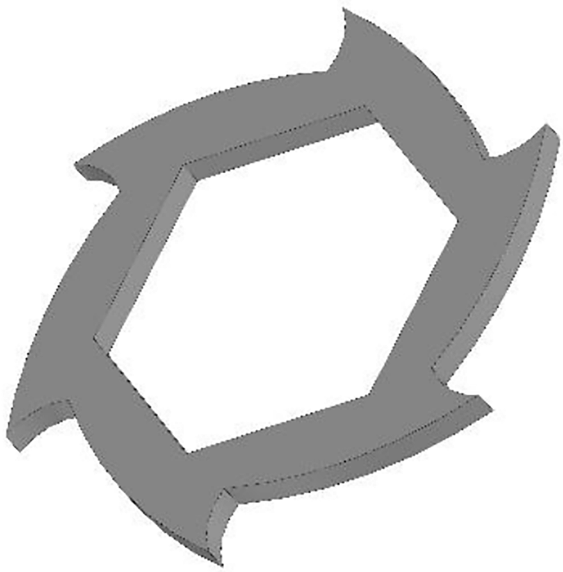


Figure 30. Knife of a double-sized shredder [153]

knife, the step between the cutting edges remains the same, equal to 30 mm, at the same time, it does not stand strictly concerning the neighboring knife, in which the cutting edge is 10 mm, which affects the incision and cutting with branching of the branch. Therefore, the combination of the exposure of the cutting edges of two disk knives affects the distribution of fragmented pieces. Here, as a result of crushing, pieces with a size of less than 5 mm are obtained (39%, m = 8.91 g), with a size of 8–13 mm (11%, m = 2.51 g), and with a size of 18–23 mm (14%, m =3.2 g). Thus, an uneven but minor crushing is observed, caused by the influence of a more significant number of cutting edges available in two disk knives, but with a lesser step between the cutting edges of the same disk knife concerning the cutting edges of the neighboring disk knife [154].

Figure 34 presents the results of crushing bone residues with different widths and lengths. Figure 34a dominates the composition of fragmented pieces with a size of 14–18 mm (reaches 36%, m = 15.76 g), which is because the raw materials of the bone residue have a width of 40 mm and cover the width of three disc knife in its size, including distances between knives. Here, neighboring knives act simultaneously along the width of the bone residue, in which the cutting edges are not parallel. A step of 30 mm does not withstand strictly concerning the neighboring knife, which affects the incision and cutting with the broken

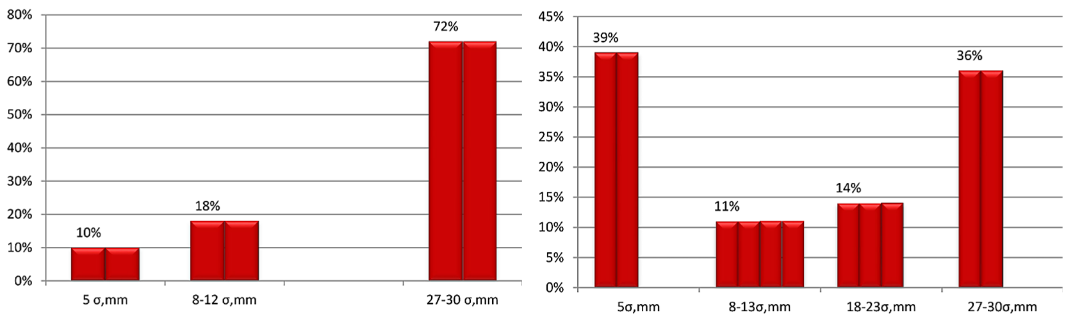
(a) (b) (c)

Figure 31. Fragments of the destruction of meat-bone confiscate In shredder EB180 [154]: (a) the working parts of the shredder; (b) the destruction of meat-bone confiscate by cutting cromakms of the shredder discs; (c) fragmented pieces of meat-bone confiscate

(a) (b) (c)

Figure 32. Fragments of the вestruction of wood waste in the shredder EB180 [154]: (a) wood waste and crushed wood pieces; (b) the destruction of the wood waste by the cutting kromakmi discs of the shredder knives; (c) fragmented pieces of wood waste

bone residue. Therefore, the combination of exposure to cutting edges of disk knives affects the distribution of fragmented pieces. Here, as a result of crushing, pieces with a size of less than 5 mm are obtained (22%, m = 9.6 g), with a size of 8–12 mm (14%, m = 6.18 g), with a size of 19–23 mm (28%, m = 12.19 g). There is also an uneven but minor crushing caused by the influence of a more significant number of cutting edges of three disc knives. Figure 34b is a small part of pieces with a size of less than 5 mm (18%, m = 6.48 g) and with a size of 17–21 mm (17%, m = 6.44 g). A significant part of the fragmented pieces is a size of 24–27 mm, the mass m = 24.80 grams, and this is due to the most part with the width of the bone residue,



(a) (b)

Figure 33. The results of crushing the wood waste by the shredder EB180 [154]: (a) distribution of fragmented pieces of the wood waste with m = 10.68 g, diameter 6 mm, l = 400 mm; (b) distribution of fragmented pieces of the wood waste with m = 22.84 g, diameter 14 mm, l = 240 mm

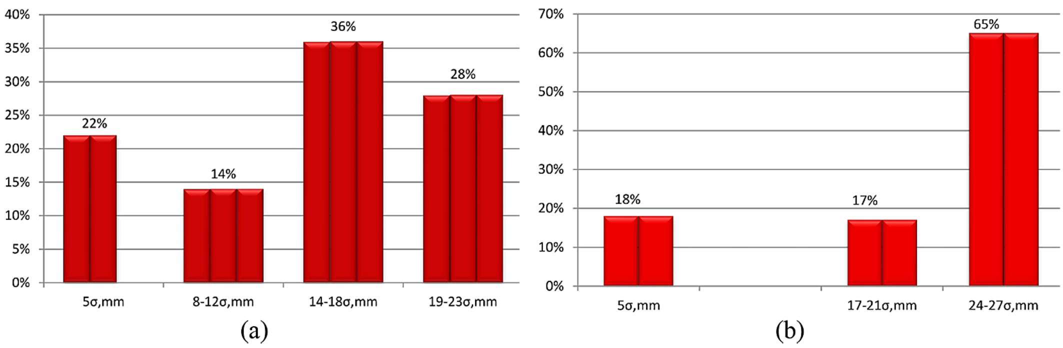


Figure 34. The results of crushing bone residues by the shredder EB180 [154]: (a) the distribution of fragmented pieces of the bone residue with m = 43.73 g, l = 120 mm, b = 40 mm, c = 8 mm; (b) distribution of fragmented pieces of the bone residue with m = 37.72 g, l = 125 mm, b = 28 mm, c = 8 mm

Table 9. Disadvantages and advantages of schredder discs

No.	Type of shredder discs	Disadvantages of shredder discs	Advantages of shredder discs
1	Disco knives of a single shredder	The occurrence of congestion or seals in the working space	Low rotation of the shaft rotation, small energy consumption, low price
2	Disco knives of the double-sized Shredder	High cost, limited amount of raw materials for simultaneous loading, the possibility of jamming	The low rotation speed of the shafts carries out uniform grinding without severe noise and dust, high performance
3	Disk knives with three edges	When giving up non-removable knives and chips on blades, the shaft is required	Low speed of disk knives, comparative noiselessness
4	S-shaped disc knives	The labor intensity of sharpening (both edges should be sharpened evenly), high cost	Safety (smaller size of the blade reduces the risk of injuries), versatility, durability

corresponding to the width of 28 mm, covering the width of two disk knives, including the distances between the knives. However, in addition to the difference in the width of bone residues, there is a discrepancy compared to the fragmentation of Christmas tree branches because bone residues have greater weight.

Generally, the examined shredder discs aimed at destruction are reduced to Table 9, indicating their disadvantages and advantages.

In the Shredder, discs play a significant role in destroying solid crums of raw materials. At the same time, shredder discs, in addition to the cutting function, combine the accompanying crushing with the cracking of the destroyed raw materials. All this determines the size of fragmented pieces. Requirements in which destruction for smaller pieces in the schredder is not identical. As a result, there is a specific contact cycle of the working parts with the raw materials exposed to destruction, expressed in various phenomena.

CONCLUSIONS

Thus, the review and analysis of modern scientific research conducted in the world and related to the topic under study – working parts for crushing and grinding waste feed raw materials, allows us to state that without the use of working parts for crushing and grinding waste of plant and animal origin, it is impossible to provide all farm animals and birds with the necessary feed. This is often due to the need for mass feed preparation, where technical crushing and grinding devices are paramount due to their high productivity. Waste raw materials of plant and animal origin are a valuable raw material resource in feed preparation because they contain all the biologically necessary substances for the growth and development of farm animals and birds. In addition, the rational use of raw waste materials is a resource-saving technology that positively affects the preservation of a favorable, sustainable ecology. At the same time, by-products must be used following the rules of the European Union, especially in the production of feed.

It should be noted that the trends in grinding raw waste feed materials include using all kinds of waste from food production and agriculture, both plant and animal origin. The most common types and names are: waste from beet sugar, cane sugar and refined sugar production (beet tops, pulp), waste from alcohol and vodka production (fruit and berry pomace), waste from starch and molasses production (stillage, corn waste), waste from confectionery, bakery, pasta and yeast production (pits, flour waste), waste from the oil and fat industry (husks, cake, meal, husks), waste from the wine industry (grape seeds, pomace), waste from the production of beer and soft drinks (grain waste), waste from the production of vitamins (pulp, seeds), waste from canning, vegetable drying and food con-centrate production (leaves, peel, tops), waste from the tobacco and tea industries (leaves, branches), waste from poultry processing (eggshells, feathers, hair, meat and bone remains, beaks, bones, paws, death), waste from fish processing, marine mammals, crusta-ceans, invertebrates, as well as waste obtained during their processing (heads, skin, trim-mings, fins, scales, entrails and bones of fish, meat and bone remains; by-products of crab production, crustaceans, charru mussel-, maçunim- and oystershell meals), waste from slaughterhouse animals (veterinary confiscations, blood, bones, wool waste, hooves, horns, nails, meat and bone meat scraps), waste obtained from the slaughter and processing of rabbits (blood, intestines, stomachs, heads, ears, legs, skin scraps and trim-mings of meat and fat from skins), food waste of animal origin (meat, bone and meat and bone scraps, egg scraps, shells, expired products), secondary raw materials from the dairy industry (waste from the production of cheese, cheese products and cottage cheese), waste from the leather industry (raw and gol skin, rawhide, chrome shavings, trimmings).

At the same time, processing plant and animal-origin waste indicates the intensification and improvement of vital processes such as crushing and grinding, which are necessary to prepare the feed. Based on the analysis of modern scientific publications, the optimal working parts for crushing and grinding waste feed raw materials are saws, rollers, disks, hammers, impact-splitting fingers and rods, knives, pins, cutters, disk knives, which will significantly crush and grind the raw material to the required size, increase the productivity of feed products due to compelling technical devices. It is also worth noting that most of the above mentioned working bodies for crushing and grinding have practical industrial applications. It is also worth noting that the trends in improving working bodies for crushing and grinding consist of new optimal design developments of working bodies for crushing and grinding. This is based on the use of computer modeling, automated design, increasing the efficiency of working surfaces and design and technological parameters, the influence of technological parameters on the operating parameters of crushing and grinding equipment, calculations, experiments, and forecasts, combining several methods of destroying waste feed raw materials with one type of working element, theoretical justification for the designs of working elements, and the use of strengthening of working elements. More specific information on the scientific study of crushing and grinding waste-feed raw materials must be provided in the currently available scientific and technical literature sources. An acute shortage of knowledge exists on crushing and grinding wet and fatty waste feed raw materials. The existing positive results of combining grinding methods using one type of working element of crushing and grinding equipment put forward prerequisites for further expansion of the research area in this area.

At the same time, as a result of empirical studies, it is worth highlighting the promising use of a combination of impact and cutting in the impact-cutting edges of a hammer with an angle of concavity of edges of 90°. In addition, this hammer can be used for both dry and wet raw materials. The pitch of the hammers in a row has a significant effect on obtaining a fraction of a particular granulometric size. The experimental studies of knife grinding with impact-finger destruction and mixing of the feed mass help to reduce energy costs and increase the intensity of feed preparation. The hammers with sharp edges that we used showed an instant effect on the efficiency of bone waste destruction in order to obtain feed meal. The conducted studies on the use of disk knives of the shredder allowed to obtain dependencies on the distribution of crushed pieces of fir branches and bone remains on the dimensions and weight of waste feed raw materials, the cycle of contact of disk knives with the raw materials arriving for destruction. It was revealed that a significant part of the crushed pieces of a fir branch with a diameter of 6 mm is 27–30 mm in size (72%). In this case, one disk knife with a thickness of 8 mm and a step between the cutting edges on the disk knife of 30 mm was used in a row. In the case of crushing a fir branch or bone remains with a width equal to the thickness of 2–3 disk knives, uneven but finer crushing was observed due to a decrease in the distance between the edges of adjacent disk knives. In addition, it was found that the main factors leading to the efficiency of the shredder are the reduction in the duration of the formation of cuts, cracks and crevices in the shredded pieces; a change in the design of the disk knives by changing the number of edges, reducing the step between the edges, the sharpness and configuration of the edges, as well as increasing the thickness of the disk knives, which ensures the width of the capture of the shredded raw material and the uniformity of the resulting fraction.

Based on the review conducted, the following specific areas can be identified that require further experimental research. This is a study of the angles of inclination of band saw teeth, sharp edges of impact-cutting hammers, and shredder knife disks. Here, it is also worth paying attention to the further prospects of combining destruction methods in one type of working element. Considerable attention should be paid to identifying and eliminating passive areas on various crushing and grinding working elements.

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