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INVESTIGATION OF DESIGN FEATURES AND WAYS TO IMPROVE VERTICAL AUGERS OF FEED MIXER-DISTRIBUTORS

Ihor KUPCHUK, Candidate of Technical Sciences, Associate Professor
Vinnytsia National Agrarian University

КУПЧУК Ігор Миколайович, к.т.н., доцент
Вінницький національний аграрний університет

In modern livestock production, the efficiency of farming largely depends on the quality of total mixed rations (TMR). Vertical TMR mixers occupy a leading position among technical equipment for this process, as they are capable of simultaneously working with coarse, succulent, and concentrated feeds. Nevertheless, their operation still exhibits certain limitations, such as the formation of stagnant zones in the hopper, uneven mixing of components, and excessive grinding of some ingredients. These shortcomings reduce overall productivity and increase energy consumption, which underscores the relevance of a systematic analysis of existing design solutions.

The research was carried out on the basis of patent searches and a review of scientific and technical information. The analysis covered inventions registered in leading patent offices (USPTO, EPO, WIPO, Canadian Patents Database), as well as the practical experience of major agricultural machinery manufacturers. The review demonstrated that the most common improvements are aimed at optimizing auger performance in the lower part of the hopper, where the main feed flows are formed. Among such solutions are the use of guiding plates and segments, variation of flight pitch along the auger height, application of multi-flight configurations, asymmetric edges, and auxiliary disc elements. A significant improvement is the integration of continuous cutting edges along the entire periphery of the flight, ensuring uniform cutting of fibrous feed. Some companies also introduce multifunctional knives and adaptive components that simultaneously cut and direct feed material. These solutions improve mixing intensity, shorten the cycle time, and reduce energy use, although in most cases they remain localized and do not ensure a systemic improvement.

The analysis of patent claims and technical sources revealed several directions that remain promising for further engineering developments. These include the creation of integrated augers combining multiple known principles into a single design, development of flights with innovative curvature and profiles, and application of adjustable or adaptive elements capable of modifying operating parameters depending on feed composition. Promising prospects also lie in the formation of combined vertical and horizontal flow circulation of feed material through guiding components and specific geometric configurations. Future ***research*** *should focus on mathematical modeling and experimental testing to assess the influence of such solutions on feed quality, equipment durability, and overall energy efficiency. This opens a path toward developing next-generation high-performance feed mixers.*

Key words: *helical surface, design parameters, cutting edges, guiding segments, adaptive elements, multi-flight configurations, flight profile, mixing.*

Fig. 14. Ref. 20.

1. Problem formulation

Modern livestock production largely relies on technologies for preparing and distributing total mixed rations (TMR), which help maintain proper productivity levels and preserve herd health. An important element of these technologies is the feed mixer wagon, in which vertical augers play a key role. The parameters of these augers determine the quality of component mixing, the degree of fibrous material shredding, and the machine's energy efficiency performance [1].

Vertical screw systems have become widespread due to their versatility and ability to process both bulky fibrous and concentrated feeds [1]. At the same time, certain drawbacks may arise during their operation, including the formation of stagnant zones in the hopper, uneven mixing, and excessive shredding of individual ingredients. Altogether, these factors affect the quality of the feed mixture, the level of energy consumption,

and the service life of key machine components [2].

2. Analysis of recent research and publications

Research results indicate that the efficiency of the mixing process is largely determined by the structural parameters of the screw: the geometry of the flights, their pitch, height, and diameter, as well as the shape and arrangement of the knives [3]. These characteristics influence the mixing intensity, the discharge rate of the mixture, the load on the drive, and the durability of the working elements. Industrial practice demonstrates the implementation of various solutions to optimize these parameters, including the use of asymmetric knives, variable-pitch flights, wear-resistant materials, and modern welding technologies [4]. However, an analysis of the performance characteristics of base models from leading manufacturers (Kuhn, Seko, Marmix, Italmix, DeLaval, Patz, JayLor, etc.) shows that their operation often requires considerable drive power (over 30 kW), which in some cases exceeds the effective working capacity of class 1.4 tractors—the most common type on Ukrainian farms. This necessitates reducing the screw's rotational speed (for example, from 35 to 29 rpm), which in turn decreases shredding and mixing efficiency and may lead to incomplete discharge of the feed [2, 4].

In this context, improving the operational efficiency of feed mixer wagons remains an urgent task, particularly in addressing challenges related to the formation of stagnant zones in the hopper, incomplete feed discharge, uneven ingredient distribution, poor cutting or excessive shredding of fibrous components, accelerated wear of working parts, drive overload, and the need to aggregate the machines with high-power energy units.

To overcome these limitations, it is advisable to conduct a comprehensive analysis of scientific, technical, and patent sources, which will allow systematizing existing design solutions, identifying their advantages and drawbacks, and outlining directions for further development. Such an approach provides the basis for the creation of advanced engineering solutions aimed at improving energy efficiency, ensuring uniform mixing, and extending the service life of the equipment.

3. The purpose of the article

The aim of the research is to substantiate the directions for improving the design of vertical augers of feed mixer wagons based on the analysis of their structural parameters derived from patent-information research.

To achieve this aim, the following objectives were defined:

- to review scientific and technical sources regarding design solutions of vertical augers and identify key parameters influencing mixing quality and the energy efficiency of their operation;
- to conduct a patent-information analysis of technical solutions related to the design of vertical augers for feed mixers;
- to assess the advantages and limitations of existing design approaches in terms of energy efficiency, mixing uniformity, and operational reliability;
- to analyze patent claims in order to determine the technical solutions under patent protection and identify "free zones" for engineering developments;
- to formulate promising directions for the modernization of vertical augers aimed at improving the efficiency of feed mixer operation.

4. Results and discussion

The research methodology is based on a combination of bibliographic and patent-information analysis, which makes it possible to comprehensively assess the current state of design solutions for vertical augers of feed mixer wagons and to identify directions for their improvement.

At the first stage, an analysis of scientific and technical literature was carried out, focusing on the design parameters of vertical augers and their impact on feed mixing quality, the degree of fibrous material shredding, energy efficiency, and equipment durability. Particular attention was paid to the geometry of the flights, screw pitch, height and diameter, as well as the shape and orientation of the knives.

The second stage involved patent-information searches in major international and national databases (USPTO, Espacenet, WIPO, CNIPA, Canadian Patents Database, UkrNOIVI). The search covered documents from the last 20–25 years. Keywords (vertical auger mixer, feed mixer, screw geometry, knives for auger, staggered rotor, etc.) and relevant IPC indices were used.

At the third stage, patent solutions were selected and classified according to the following criteria:

- geometry of the flights (single, double, or variable pitch; conical auger design);
- shape and orientation of knives (straight, asymmetric, adjustable);
- presence of additional cutting or guiding elements.

The fourth stage included an analysis of patent claims for key patents. Independent and dependent claims were examined to identify technical solutions under legal protection and to determine "free zones" available for new engineering developments.

The fifth stage involved evaluating the advantages and limitations of existing designs according to the following criteria:

- energy efficiency (reduction of drive load, specific energy consumption);
- mixing quality and homogeneity;
- durability of working elements.

At the final stage, promising directions for the improvement of vertical augers were formulated.

The company «Jay-Lor» holds a patent [5] concerning an improvement of the vertical auger in a feed mixer (Fig. 1), in which the upper part of the auger's central post is made at an angle to the vertical axis (3). Such a configuration ensures that, during loading, a bale of hay or straw does not hang on the vertical post but gradually slides down into the working zone of the flights. The upper edge of the flight, which protrudes above the inclined part of the post (4), cuts into the surface of the bale during rotation, promoting its mechanical tearing and the intake of material into the feed mixture. This solution enables the efficient operation of the mixer without the need for additional pre-loosening of the bales, which is particularly relevant when working with whole pressed feedstocks.

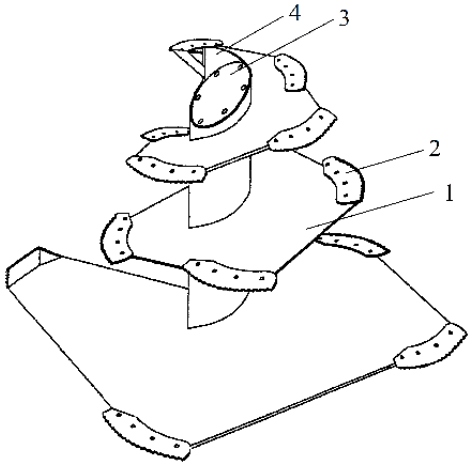

Fig. 1. Auger with rectangular flights by «Jay-Lor» [5]: 1. rectangular edges; 2. knives; 3. inclined top of the post; 4. upper edge of the flight

The auger design also incorporates an original form of the flight (1), in which the outer perimeter of the spiral is made in the shape of a polygon (for example, an octagon). Each side has its own leading edge, while horizontal knife-blades (2) are positioned at the corners, protruding beyond the contour of the flight. When rotating, such a "square-shaped" flight performs several functions: it creates additional cutting zones through the corner-mounted knives that slice long forage stems; it generates turbulence in the flow due to the angular breaks in the flight shape, thereby promoting more uniform mixing of the mass; and it ensures more intensive bale disintegration and accelerates the integration of coarse forages into the mixture.

The combination of the inclined top of the central post with the polygonal flight equipped with cutting elements produces an integral technological effect, manifested in improved bale capturing and directing into the cutting zone, intensification of shredding of long-fiber feeds, enhanced uniformity of mixing within a shorter time, and reduced likelihood of stagnant zones forming in the feed mass inside the hopper.

An important improvement in the design of the vertical auger by «Jay-Lor» (Fig. 2), described in patent CA2653746C [6], is the use of a special sliding plate (1) attached to the leading edge of the lower flight (2). This plate extends from the plane of the flight at a small angle β to the floor of the hopper. Owing to this configuration, it serves to direct the feed mass from the peripheral zone of the hopper toward the central part of the auger, where the material is captured by the cutting elements. The design may include one or several such plates positioned at different angles around the circumference of the lower flight, which prevents the formation of stagnant zones near the walls, reduces the degree of feed compaction, and ensures more uniform circulation of the mass during the mixing process.

The second design solution described in the same patent is the use of a variable-pitch flight along the height of the auger. In particular, the lower flight (2) has a smaller pitch, which ensures intensive pickup of feed from the bottom and its gradual upward movement. Above it, the upper flight (3) with a larger pitch accelerates the vertical movement of the feed mass into the upper part of the auger and promotes its faster discharge [6].

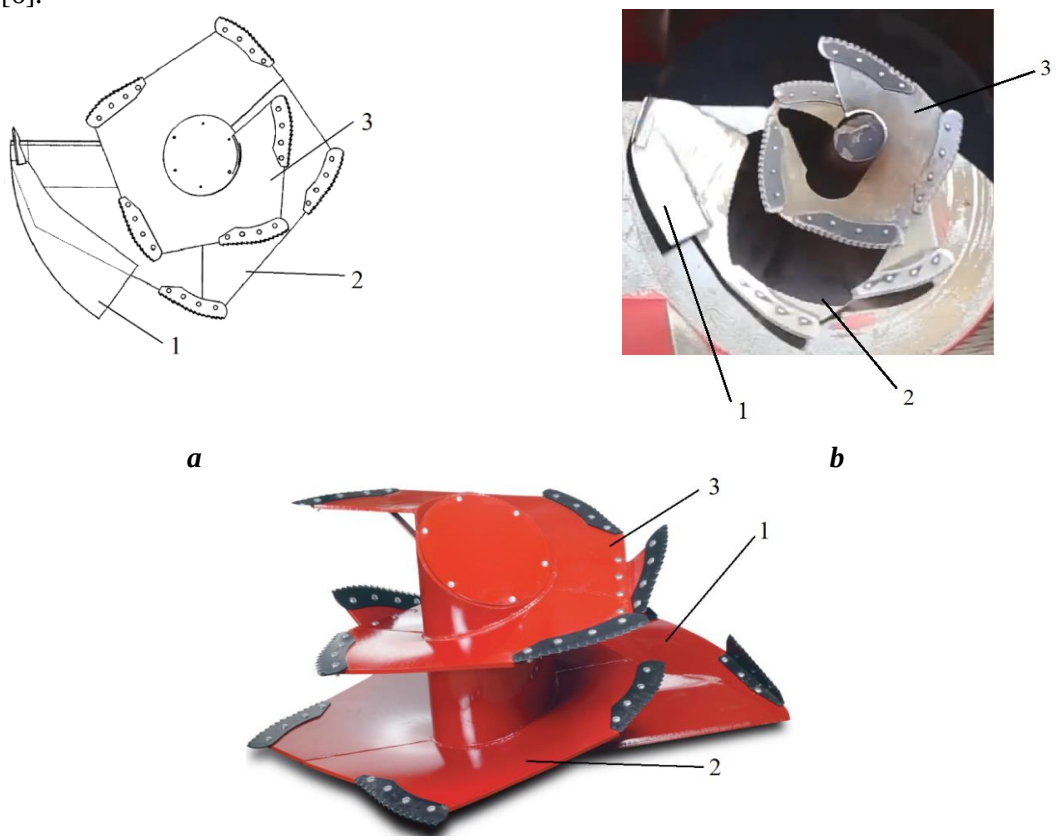

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Fig. 2. Auger with a sliding plate and variable-pitch flights by «Jay-Lor» [6, 7]:
a – diagram from patent CA2653746C; b – screenshot from the video demonstration of the feed mixer wagon in operation; c – model presented on the official website; 1 – sliding plate; 2 – lower flight; 3 – upper flight

The overall technological effect of combining these structural improvements lies in enhancing the uniformity of the feed mixture, reducing the mixing time required, and decreasing energy consumption by optimizing the movement of feed within the hopper [7].

The company «Supreme International», in patent US7507016B2 [8], proposes the design of a cylindrical vertical auger for TMR mixers that differs significantly from traditional multi-flight solutions (Fig. 3, a). The main improvement is the use of a two-flight auger (1, 2), in which the total winding is less than 720° around the central post, with each flight having a width of approximately 0.46 m (18 inches). This results in a compact auger in terms of height but "deep" in profile. Such geometry ensures rapid transport of feed mass from the bottom of the hopper to the upper part with a minimum number of revolutions, thereby intensifying the mixing process.

The reduced number of flights decreases the intensity of mechanical impact on the grain components of the feed mixture, which helps preserve their granulometric structure and prevents excessive formation of fine fractions. This is particularly important for ground corn and other concentrated ingredients that do not require further breakdown. The technical result of such a design solution is to provide high mixing speed while preserving the structure of grain ingredients.

In the same patent, several auxiliary elements are provided to improve feed circulation. On the upper surface of the lower flight, a kicker plate (4) – a curved blade oriented forward in the direction of rotation – is attached. It directs feed toward the center of the auger, preventing accumulation or wrapping of long-fiber components at the base. In addition, the raised trailing edge of the upper flight (3) deflects feed away from the

auger toward the walls of the hopper, forming a horizontal flow. As a result, a combined circulation of the feed mass is created: vertical circulation due to the flights, and horizontal circulation due to the raised edge.

The combination of a two-flight auger with a wide profile and limited winding (1, 2), a kicker plate (4) mounted on the lower flight, and the raised edge of the upper flight (3) forms a highly efficient mixing system. It provides rapid lifting and uniform mixing of the feed, prevents the formation of stagnant zones, minimizes the risk of long fibers wrapping around the auger, and preserves the structure of grains and concentrated feeds. At the same time, such a design is characterized by technological limitations when processing long-fiber forages (hay, straw, silage), which require more intensive mechanical action to achieve the necessary degree of shredding and uniformity of mixing. This creates the need to apply additional technical solutions in the design of mixers or other combinations of working elements, which has been addressed by installing cutting elements (5) of various configurations on the described auger design (Fig. 3, b).

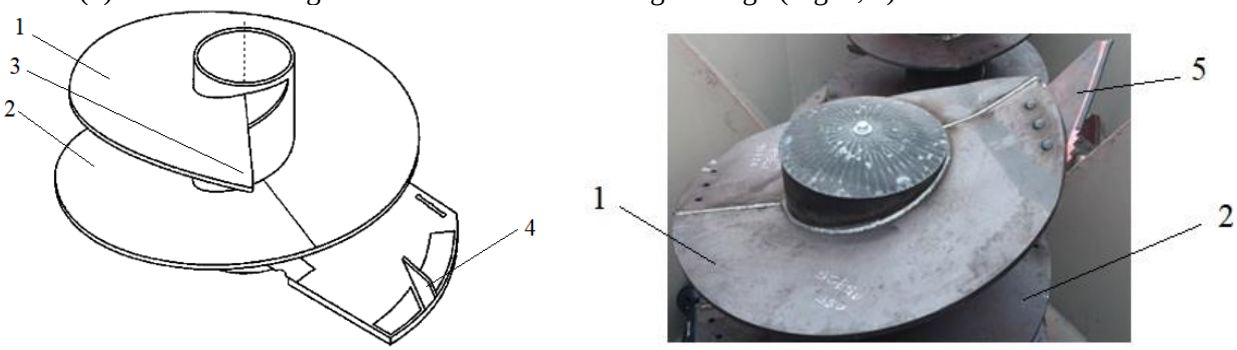

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Fig. 3. Cylindrical auger by «Supreme International» [8]:
1 – upper flight; 2 – lower flight; 3 – raised edge of the upper flight; 4 – kicker plate; 5 – cutting element

An analysis of patents obtained by Kuhn shows the evolutionary development of constructive solutions for vertical augers of feed mixer wagons, aimed at improving the efficiency of feed capturing, transporting, and mixing processes.

In patent US6905238B2 [9], developed by Kuhn's engineers, the concept of using two vertical augers of different geometry within a single mixer is proposed (Fig. 4). One auger is characterized by a more aggressive shape of flights and auxiliary elements for intensive feed pickup from the lower zone of the hopper, while the other performs the function of stabilizing the flow and leveling the mass.

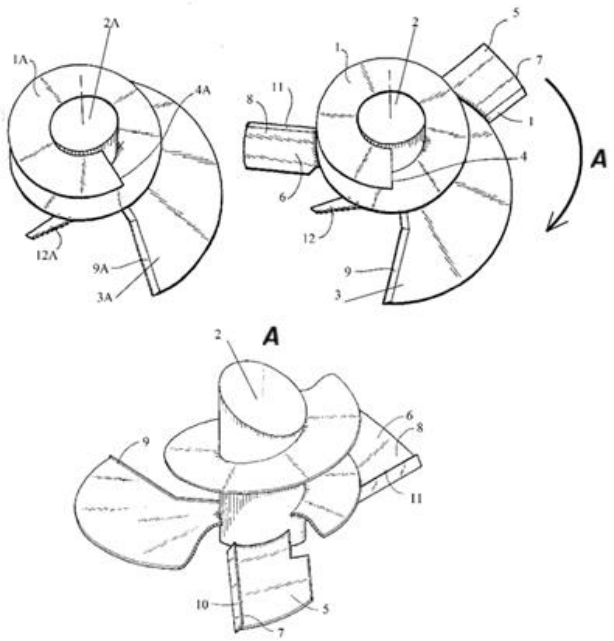

Fig. 4. Screw system with different geometric characteristics by «Kuhn» [9]:
1, 1A – helical flights; 2, 2A – vertical posts; 3, 3A – leading edges; 4, 4A – trailing edges; 5, 6 – flow activators; 7, 8 – guiding sections; 9, 9A, 10, 11 – outer edges; 12, 12A – knives

The main elements of the design are helical flights (1, 1A) on vertical posts (2, 2A), which form the working organs of the system. Each flight has a leading edge (3, 3A) and a trailing edge (4, 4A), with the leading edge positioned so that during rotation it approaches the hopper bottom and performs the function of feed pickup, directing it along the flight to the upper layers. The first auger is equipped with flow activators (5, 6), which have guiding sections (7, 8) and outer edges (9, 10, 11). These capture the feed mass even before the flight completes a full revolution, producing a "pseudo-boiling" effect of the medium. Thus, the first auger forms multiple working leading edges that act at different points of rotation, intensifying the continuous mixing process. The second auger is built according to a traditional scheme and has a single outer edge (9A). Feed pickup and transport occur exclusively under the action of the flight, without auxiliary guiding elements. In this configuration, the material more frequently "overflows" across the flight and returns to the hopper bottom before being captured by the flights again. For breaking down the structure of fibrous materials (coarse forages), the design of both augers includes knives (12, 12A).

The same company also holds patent US7347616B2 [10], in which the key improvement is a dart-shaped guiding plate (5) – a specially curved deflecting blade (Fig. 5, a). Positioned low relative to the hopper floor, its geometry enables "sweeping" of the feed even before the leading edge (3) of the flight (2) completes a full revolution. This allows the auger to re-capture the portion of feed mass that would otherwise overflow across the flight (2) and fall back onto the floor. In this way, the dart-shaped guiding plate (5) creates an additional circulation cycle, accelerating mixing and reducing the formation of stagnant zones.

During unloading, the dart-shaped guiding plate (5) operates together with the leading edge (3) of the flight, steadily pushing the feed mass through the discharge opening. A particularly important role is played by the outer section of the dart-shaped guiding plate (6), which maintains an acute angle ($\alpha < 90°$) along almost its entire length. As a result, the feed is expelled outward in a continuous flow with minimized pulsations.

Another patent, US6863433B2 [11], owned by «Kuhn», protects a technical solution concerning the improvement of flight geometry through modification of the configuration of the leading cutting edge (Fig. 5, b). Unlike classical designs, where the edge is oriented radially, in this construction it is shifted forward in the direction of rotation, forming a wedge. This facilitates penetration into dense feed mass, reduces the traction load on the drive mechanism, and decreases the likelihood of long-fiber components winding around the auger. The technical result is an increase in mixer productivity and a reduction in specific energy consumption when working with hard-to-mix feeds.

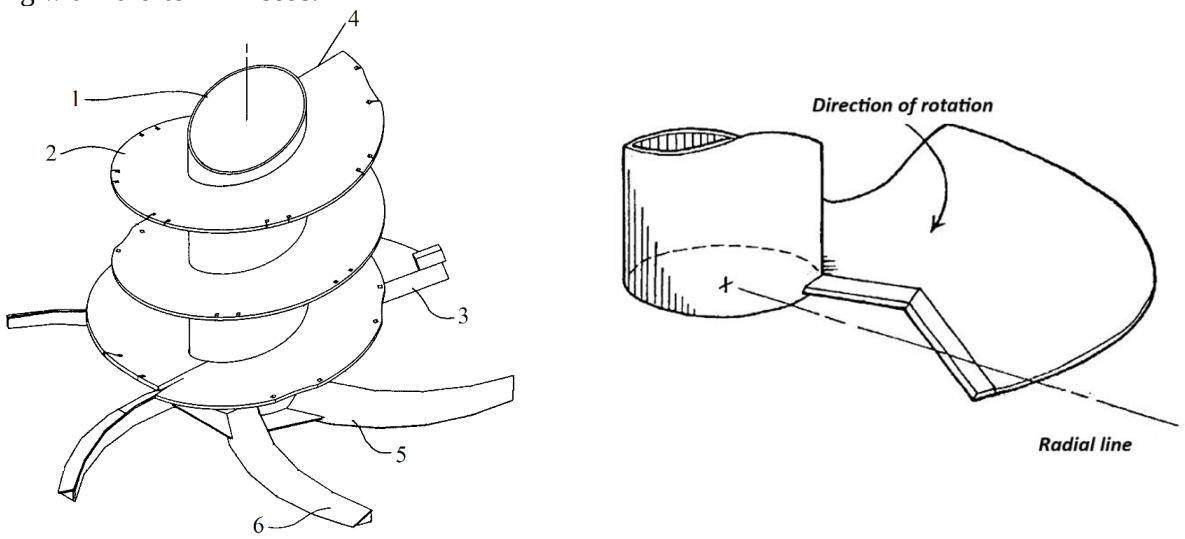

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Fig. 5. Technical solutions by "Kuhn":

a – auger with a dart-shaped guiding plate [10]: 1 – post; 2 – helical flight; 3 – leading edge; 4 – trailing edge; 5 – dart-shaped guiding plate; 6 – outer section of the dart-shaped guiding plate; b – first flight with a wedge-shaped edge [11]

In the technical solution proposed by «Penta Equipment» [12], the auger, formed by a helical flight (1) and mounted on a vertical shaft (2), includes an outer helical edge (3) along which cutting blades (4) alternate with slots (5), thereby combining the functions of shredding and intensifying feed circulation (Fig. 6). The cutting blades (4) are positioned at a small angle (up to approximately 8°) relative to the tangent of the

flight edge, which promotes gradual penetration into fibrous material and reduces impact loads compared to straight cutting. The slots (5) have an arc-shaped profile, with their front and rear sections oriented at an angle to the flight edge (for example, up to 40°). The rear part of the slot is close to the outer edge, which ensures the capture and retention of fibrous particles in the contact zone with the subsequent cutting element. The depth of the slot is determined in such a way as to provide maximum radial displacement without reducing the effective working profile of the flight.

Thus, through the interaction of the cutting blade (4) and the slot (5), the feed mass can fall through the slot under gravity, be picked up by the next blade on a higher flight, or remain in the slot long enough for effective cutting. Such a structural combination makes it possible to intensify the shredding of long-fiber materials, prevent their winding around the shaft, and improve mixture circulation.

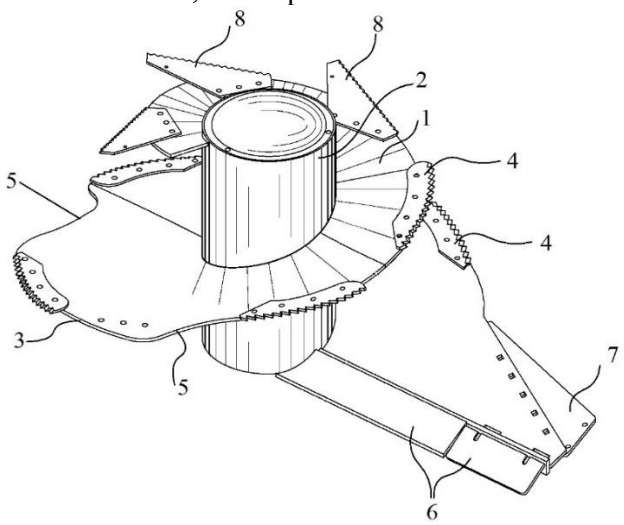

Fig. 6. Auger design by «Penta Equipment» [12]: 1 – helical flight; 2 – vertical shaft; 3 – outer helical edge; 4, 8 – cutting blades; 5 – slots; 6 – scraper; 7 – guiding plate (kicker)

In patent EP2119345A1 [13], owned by «Trioliet Mullos BV», a structural improvement of the vertical auger is presented (Fig. 7), aimed at increasing the efficiency of feed pickup, circulation, and discharge. The main element is a spiral flight (2) mounted on a vertical shaft (1), at the lower part of which a pickup segment (3) is provided. This segment contacts the bottom of the hopper and performs the function of collecting feed from the surface of the floor.

The pickup segment (3) has a leading edge (4), which captures the feed mass during rotation, a trailing edge (5) that defines the end of the working zone, a peripheral edge (6) located near the wall of the hopper, and a supporting surface (7) that ensures stable contact with the bottom of the mixer. Behind the leading edge (4), there is a guiding element (8) with two working surfaces: surface (9) directs the feed mass toward the central axis of the auger, ensuring efficient lifting of the material along the flight, while surface (10), inclined at an angle from the inner part to the periphery, promotes feed movement toward the hopper wall.

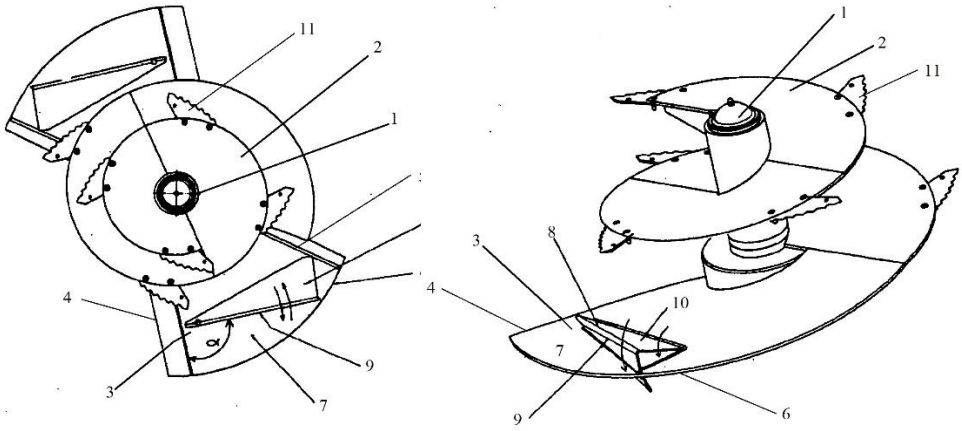

Fig. 7. Variants of auger design according to patent EP2119345A1 [13]: 1 – spiral flight; 2 – vertical shaft; 3 – pickup segment; 4 – leading edge; 5 – trailing edge; 6 – peripheral edge; 7 – supporting surface; 8 – guiding element; 9, 10 – working surfaces of the guiding element; 11 – cutting elements

The interaction of surfaces (9) and (10) creates a combined circulation of the feed mass: vertical—due to the lifting along the flight, and horizontal – due to deflection toward the periphery. Thus, the combination of the pickup segment (3) with multifunctional edges (4, 5, 6, 7) and the guiding element (8) ensures intensive feed pickup, prevents the formation of stagnant zones, increases mixing uniformity, and accelerates discharge through the bottom opening. Such a technical solution improves the productivity of the auger while simultaneously reducing energy consumption and ensures stable formation of a homogeneous feed mixture.

In patent WO2007083998A1 [14], a screw design for a biomass processing machine is proposed (Fig. 8), in which a spiral blade (2) is rigidly attached to a vertical post (1). At the lower part of the blade, a rotating disc knife (3) is mounted, supported on the blade and protruding slightly so that its peripheral part forms the leading edge of the mixing element, while the adjacent section of the blade further constitutes the outer edge. Functionally, the disc (3) serves as the entry segment of the mixing blade: its peripheral edge picks up feed from the bottom and lifts it onto the blade surface, regardless of whether the blade itself is in contact with the feed mass. This significantly increases the auger's ability to initiate the upward movement of feed mass even in areas where a traditional spiral does not ensure proper capture and transport of material. At the same time, the disc reduces the level of friction between the feed and the main blade, since part of the material first interacts with its surface before moving onto the main flight. As a result, shredding intensity increases, mixing efficiency improves, and energy consumption for rotation during feed processing decreases.

In patent US20040071045A1 [15], owned by «Kuhn», a vertical auger is proposed (Fig. 9) with a post (1) around which two helical surfaces are arranged: the first helical surface (2) and the second helical surface (3), mounted so that the flights of the second surface (3) are positioned between the flights of the first surface (2), alternating along the height. This configuration creates a combined fine pitch, which increases the filling of the working space with feed mass. Both helical surfaces interact with the bottom of the hopper, simultaneously picking up the feed mass from the lower plane. As a result, during a single revolution, two active pickup elements operate, synchronously lifting the material upward.

The proposed auger design allows a larger volume of feed to be captured per revolution compared to a traditional single-spiral design, which significantly reduces mixing time. The reduced pitch between the flights ensures denser filling of the space with feed mass, preventing losses and increasing the intensity of transport. Consequently, higher mixing speed and productivity are achieved at the same energy consumption, while the heterogeneity of the feed mixture is reduced due to more uniform feed pickup from the hopper bottom.

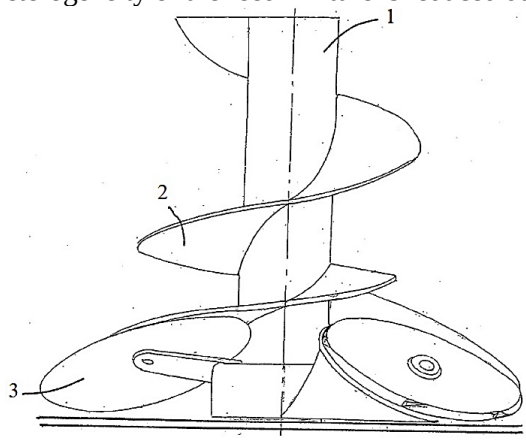

Fig. 8. Auger design according to patent WO2007083998A1 [14]: 1 – vertical post; 2 – spiral flight; 3 – disc knife

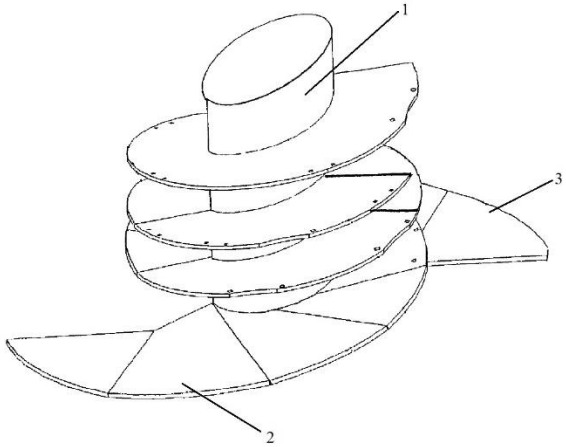

Fig. 9. Design of the double-spiral auger by «Kuhn» [15]: 1 – vertical post; 2 – first helical surface; 3 – second helical surface

In patent CA2852592C [16], owned by «Jay-Lor», an improvement of the vertical auger is presented (Fig. 10), which consists in the use of a knife with a continuous cutting edge (1) along the outer edge of the flight (2). The blade is mounted around the periphery of the helical surface (3) and may consist of several adjacent sections arranged to form a continuous cutting line. The knives are fixed through special holes in the flight, which ensures precise positioning and simplifies replacement in case of wear.

Due to the continuity of the cutting edge, the knife (1) eliminates the "dead zones" between segments typical of traditional designs, thus providing uniform and efficient shredding of long-fiber forages. At the same time, the risk of tearing or excessive crushing of the feed mass is reduced, since the cutting occurs evenly along the entire length of the spiral. As a result, the homogeneity of the final feed mixture is improved, energy

consumption for shredding is reduced, and the optimal structure of fibrous components is preserved. The main technical result lies in combining enhanced cutting efficiency, energy economy, and durability of the design.

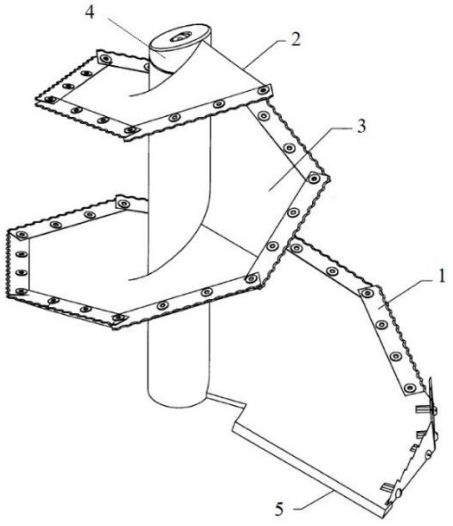

Fig. 10. Auger design with a continuous cutting element by «Jay-Lor» [16]: 1 – continuous cutting edge; 2 – outer edge of the flight; 3 – helical surface; 4 – vertical post; 5 – leading edge of the flight

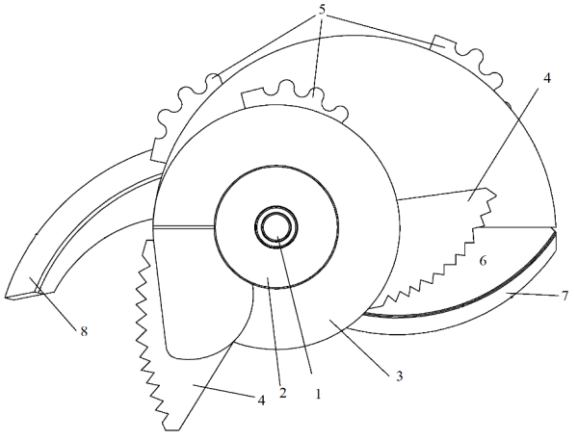

Fig. 11. Auger design with variable configuration of cutting elements [17]: 1 – shaft; 2 – core; 3 – spiral surface; 4 – elongated knives; 5 – short knives; 6 – segment; 7 – leading edge; 8 – scraper

In patent NL2008677C2 [17], a structural improvement of the vertical auger for a feed mixer is proposed (Fig. 11), aimed at increasing the efficiency of feed pickup and circulation. The basis of the auger is a shaft (1) with a core (2) fixed to it, which functions as a supporting element for the spiral surface (3) and defines the spatial geometry of the working parts. Along the outer contour of the spiral surface (3), elongated knives (4) and short knives (5) are mounted. This combination of cutting elements allows for more intensive processing of the feed mass in the lower zone of the hopper, ensuring cutting while simultaneously lifting the material smoothly.

At the lower part of the auger, a segment (6) with a leading edge (7) is provided, which facilitates feed pickup from the bottom of the hopper, as well as a scraper (8) that removes feed residues from the hopper floor and prevents the formation of stagnant zones. Owing to this combination of structural solutions, a uniform movement of the feed mass is achieved, energy losses are reduced, and the homogeneity of the final mixture is improved.

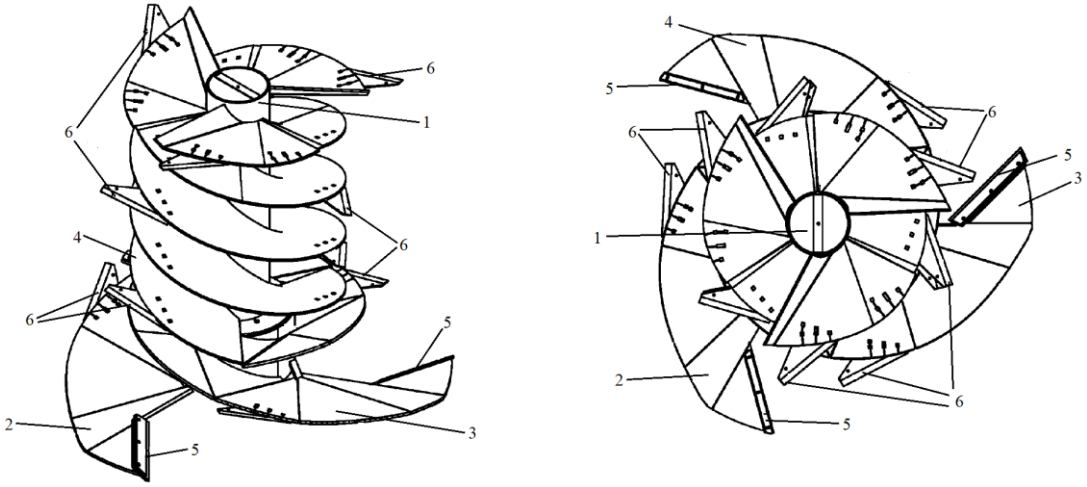

Fig. 12. Multi-flight auger by «ROTO-MIX LLC» [18]:1 – central shaft; 2, 3, 4 – flights; 5 – guiding knife; 6 – knife

The multi-flight auger (Fig. 12), the structure and operating principle of which are described in patent US20110121114A [18] by «ROTO-MIX LLC», consists of a central shaft (1) around which three flights (2), (3), (4) are arranged, each offset from the others by an angle of 120°. The lower sections of the flights have a variable pitch, which promotes intensive upward movement of the feed mass. For active feed pickup from the hopper bottom, guiding knives (5) are mounted on the leading edges of the flights, shifting the material toward

the center of the auger and eliminating stagnant zones. Additionally, along the periphery of the flights, knives (6) are installed to cut long feed particles that were not captured by the main spiral. The functional improvement of such a design lies in combining the multi-flight configuration (2, 3, 4), which reduces pulsations and vibrations, with active elements (5) that enhance feed pickup from the bottom and knives (6) that cut and shred long-fiber components. As a result, a more uniform material flow is achieved, energy consumption is reduced, and the homogeneity of the feed mixture is significantly improved.

In patent US7040801B2 [19], owned by «Kuhn», a structural improvement of the vertical auger is proposed (Fig. 13), aimed at increasing the efficiency of feed circulation and mixing. The basis of the design is a lower core (1) with a rotation axis (2), on which a lower flight (3) is mounted. Above it, an upper core (4) is positioned, equipped with its own upper flight (5) and fixed knives (6), with its axis of rotation (7) being either offset relative to the axis (2) of the lower core (1) or inclined.

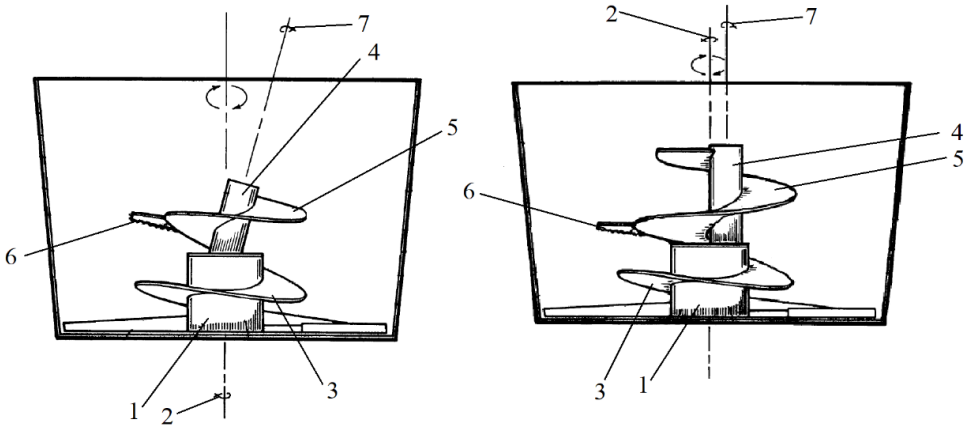

Fig. 13. Auger design with asymmetric flight arrangement by «Kuhn» [19]:1 – lower core; 2 – rotation axis of the lower core; 3 – lower flight; 4 – upper core; 5 – upper flight; 6 – knife; 7 – rotation axis of the upper core

The key feature is that, in the case of an offset or inclined axis (7), the upper flight (5) moves along an asymmetric trajectory, creating variable gaps between the spiral surface and the hopper walls. This generates a restriction zone, where feed is compressed and cut by the knives, and an opposite discharge zone, through which the mass freely descends. Positioning the upper core (4) at an angle further enhances the turbulence of material movement, promotes horizontal circulation, and reduces the likelihood of stagnant zones forming. Thus, an auger with an upper core whose axis may be offset or inclined combines intensive cutting with active vertical-horizontal circulation of feed mass, which shortens the time needed to achieve mixture uniformity and reduces energy consumption.

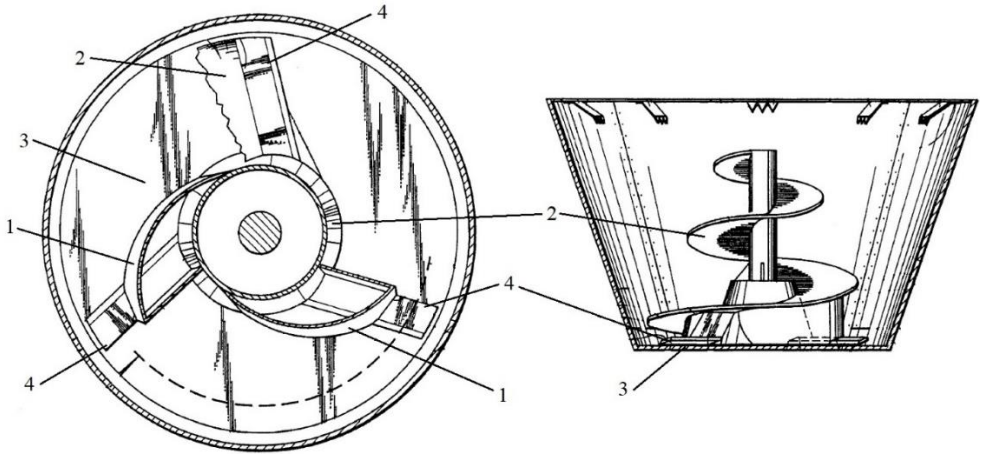

Fig. 14. Vertical mixing auger with an improved feed pickup and discharge system [20]: 1 – guiding segments; 2 – flight; 3 – hopper bottom; 4 – leveling knives

In patent US5647665A [20], an improvement of the vertical auger is proposed (Fig. 14), which consists in the use of guiding segments (1) installed in the lower part between the flight (2) and the hopper bottom (3).

Each segment has a vertical wall that increases in height from the central part toward the periphery, and a rear wall that prevents feed accumulation.

Additionally, leveling knives with a cutting edge (4) are provided, positioned in the hopper bottom area to ensure stable discharge of the feed mixture. The technical effect consists in improving feed pickup from the hopper bottom, preventing feed mass from "hanging" between the flight and the floor, increasing mixing uniformity and discharge stability, which together reduce energy consumption and ensure higher quality of the final mixture.

The conducted patent-information analysis has shown that the key directions of improvement for vertical augers relate to the geometry of the flights, the configuration of cutting elements, and the use of special guiding components. A significant number of patents protect solutions aimed at optimizing auger operation in the lower part of the hopper: the use of guiding plates or segments on the lower flight helps prevent feed accumulation near the walls and directs the mass toward the center, where it is more intensively captured by the knives (CA2653746C; US20110121114A1). Another common solution is the variation of flight pitch along the auger height – from smaller at the bottom to larger at the top – which accelerates feed circulation and reduces mass compaction (CA2653746C).

Several patents propose two-flight or multi-flight configurations, which shorten the path of feed mass movement from the hopper bottom to the upper part of the auger, ensuring a faster mixing process (US7507016B2; US20040071045A1; NL2008677C2). At the same time, particular attention is paid to reducing excessive mechanical impact on grain components, thus preserving their granulometric structure. Other developments focus on cutting elements: instead of segmented knives, continuous cutting edges along the flight perimeter are applied, cutting feed uniformly across the entire profile and improving the shredding efficiency of long-fiber forages (CA2852592C). The use of additional shredding knives mounted directly on the flights or on the auger post is also common (US20110121114A1).

Promising structural solutions also include the modification of feed flow configuration through guiding plates, curved deflector blades, or asymmetric flight edges. Such elements create additional flows that enhance feed circulation, reduce the risk of long-fiber wrapping, and prevent the formation of stagnant zones (US6905238B2; US7347616B2; US6863433B2; US8540177B2). Special attention is also given to augers with asymmetric positioning or inclination of the upper core relative to the lower one, which ensures alternating zones of increased pressure and unloading, creating turbulence in the flow (US7040801B2). Similarly, the use of pickup segments and guiding elements of complex shape allows for the formation of combined feed circulation and intensification of discharge (EP2119345A1). Another direction is the application of auxiliary discs and segments for preliminary cutting of feed mass (WO2007083998A1).

Further development of vertical auger designs should be directed toward the integration of already known principles into comprehensive solutions. While most patents focus on individual elements, it is promising to create designs that combine several improvements simultaneously, for example: variable flight pitch combined with an asymmetric leading edge, spiral slots, and guiding plates. Such combinations can provide new technical effects without duplicating known patented solutions.

Another direction may involve the use of optimized configurations and non-standard geometric forms of the spiral surface and the post. These may include flights with variable curvature not only along the height but also along the radius, profiles with wave-shaped or toothed edges to intensify cutting, or hollow posts with openings of different shapes actively participating in the mixing process. Such configurations have the potential to increase productivity and energy efficiency.

A separate niche is the application of adaptive or movable elements that change position under load. These may include elastic knives or guiding blades that automatically adjust the depth of feed pickup, or operator-controlled guiding plates to adapt mixer operation to different feed types. Hybrid solutions that combine vertical and horizontal mixing are also promising. For example, placing additional blades at an angle to create lateral flows, or integrating an auxiliary auger of smaller diameter with opposite rotation into the central post. This makes it possible to generate counterflows of feed, intensify circulation, and achieve more uniform mixture homogeneity.

Thus, the prospects for further development lie in the comprehensive integration of known solutions, the search for new spiral geometries, the application of adaptive working elements, and the creation of hybrid mixing schemes. This provides the foundation for engineering developments focused on energy savings, faster mixing processes, and improved quality of the final feed mixture.

5. Conclusion

The review of scientific and technical sources, together with the patent-information analysis, has made it possible to identify the main directions for improving vertical augers of feed mixers. It was found that most

technical solutions are focused on enhancing auger performance in the lower zone of the hopper, where the primary feed flows are formed. Optimization of flight geometry, the use of guiding elements, and cutting edges ensure more intensive feed pickup, uniform circulation, and prevention of stagnant zones. In summary, it can be stated that modern engineering developments are primarily aimed at increasing mixing efficiency and reducing energy consumption; however, most of them implement local improvements of individual elements.

The analysis of patent claims made it possible to distinguish technical solutions currently under legal protection and to determine directions that remain open for new engineering developments. Promising approaches include the creation of flights with new geometric profiles or variable curvature, the application of adjustable and adaptive elements responsive to feed properties, as well as the formation of combined vertical-horizontal feed flows. Of particular importance are integrated designs that combine several different principles, providing a synergistic effect not realized in known solutions.

Further research should be focused on the practical testing of such solutions under production conditions. Important directions of such studies include modeling feed flow dynamics depending on variations in flight geometry, optimizing cutting-edge parameters for long-fiber feed types, developing movable or adjustable segments, and applying modern wear-resistant materials. This will create the foundation for the development of highly efficient next-generation vertical augers capable of ensuring high-quality feed preparation while simultaneously minimizing operating costs.

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ДОСЛІДЖЕННЯ КОНСТРУКТИВНИХ ОСОБЛИВОСТЕЙ ТА ШЛЯХІВ УДОСКОНАЛЕННЯ ВЕРТИКАЛЬНИХ ШНЕКІВ КОРМІЗМІШУВАЧІВ-РОЗДАВАЧІВ

У сучасному тваринництві ефективність виробництва значною мірою залежить від якості приготування повнораціонних кормових сумішей. Вертикальні змішувачі-кормороздавачі посідають провідне місце серед технічних засобів для цієї технології, адже вони здатні одночасно працювати з грубими, соковитими та концентрованими кормами. Разом з тим, у їхній роботі зберігаються певні недоліки: формування застійних зон у бункері, нерівномірне перемішування компонентів та надмірне подрібнення окремих інгредієнтів, що знижує продуктивність і підвищує енерговитрати. Це зумовлює актуальність системного аналізу існуючих конструктивних рішень.

Дослідження проведено на основі узагальнення результатів патентного пошуку та аналізу науково-технічної інформації. Розглянуто винаходи, зареєстровані у провідних патентних відомствах (USPTO, EPO, WIPO, Canadian Patents Database), а також досвід провідних виробників техніки для тваринництва. Огляд патентів показав, що найпоширеніші напрями удосконалень стосуються оптимізації роботи шнека в нижній частині бункера, де формуються основні потоки корму. Серед конструктивних рішень – застосування напрямних сегментів і пластин, варіація кроку витків по висоті, використання багатозахідних конфігурацій, асиметричних кромок та дискових елементів. Важливим удосконаленням є інтеграція ріжучих елементів по всій периферії витка, що забезпечує рівномірне підрізання волокнистих кормів. Окремі компанії впроваджують багатофункціональні ножі й адаптивні деталі, які одночасно подрібнюють та спрямовують кормову масу. Встановлено, що такі рішення підвищують інтенсивність змішування, зменшують тривалість циклу та скорочують енергоспоживання, проте здебільшого вони мають локальний характер і не створюють комплексного ефекту.

Проведений аналіз дозволив виявити напрями, перспективні для подальших інженерних розробок. До них належить створення інтегрованих шнеків, що поєднують кілька відомих принципів у єдиній конструкції, розробка витків із новими варіантами кривизни та профілю, застосування регульованих або адаптивних елементів, здатних змінювати параметри роботи залежно від складу корму. Перспективним видається формування комбінованої циркуляції кормової маси за рахунок напрямних сегментів і спеціальних геометричних конфігурацій. Подальші дослідження доцільно орієнтувати на використання математичного моделювання та експериментальних випробувань для оцінки впливу нових рішень на якість кормосумішей, довговічність обладнання та енергоефективність процесу. Це відкриває шлях до створення високопродуктивних кормозмішувачів нового покоління.

Ключові слова: *гвинтова поверхня, конструктивні параметри, різальні кромки, напрямні сегменти, адаптивні елементи, багатозахідні конфігурації, профіль витка, змішування.*

Рис. 14. Літ. 20.

INFORMATION ABOUT THE AUTHORS

Ihor KUPCHUK – Candidate of Technical Sciences, Associate professor, Associate Professor of the Department of Engineering Mechanics and Technological Processes in the Agricultural Industry, Faculty of Engineering and Technology, Vinnytsia National Agrarian University (3, Sonychna St., Vinnytsia, 21008, Ukraine, e-mail: kupchuk.igor@i.ua; http://orcid.org/0000-0002-2973-6914).

КУПЧУК Ігор Миколайович – кандидат технічних наук, доцент, доцент кафедри інженерної механіки та технологічних процесів в АПК, інженерно-технологічний факультет, Вінницький національний аграрний університет (вул. Сонячна, 3, м. Вінниця, 21008, Україна, e-mail: kupchuk.igor@i.ua; http://orcid.org/0000-0002-2973-6914).