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ANALYSIS OF DESIGN FEATURES AND DEVELOPMENT TRENDS OF SPIRAL SCREW CONVEYORS FOR BULK MATERIALS

This paper presents the results of a comprehensive analysis of the design features, technical characteristics, and current development trends of spiral screw conveyors for bulk materials that are widely used in agricultural production. An analysis of modern conveyor system designs and the specific features of their application for conveying grain, compound feed, seeds, mineral fertilizers, feed mixtures, and other bulk materials was conducted. It was established that spiral screw conveyors are characterized by structural simplicity, compactness, high reliability, a sealed conveying process, the capability to transport materials in horizontal, inclined, and vertical directions, as well as relatively low operating costs.

A comparative analysis of conventional screw conveyors, shaftless spiral screw conveyors, belt conveyors, bucket elevators, and chain conveyors was carried out according to productivity, energy efficiency, structural complexity, conveying tightness, and suitability for operation under the conditions of Ukraine's agricultural industry. Current design solutions for mobile and stationary conveying systems were summarized, and the specific features of screw conveyor applications in grain cleaning complexes, grain elevators, feed preparation systems, livestock production, and post-harvest processing lines were analyzed.

Particular attention was devoted to the analysis of modern electric drive systems and automated control systems for spiral screw conveyors. The operating principles of adjustable electric drives based on induction slip couplings, automated variable-speed control (AVC) systems, and variable-frequency electric drives were examined, and their advantages in terms of improving energy efficiency, reducing dynamic loads, and ensuring the stability of conveying and technological processes were identified.

Based on the generalization of previous research findings, a comparative evaluation of the technical characteristics of conveying systems was performed, relationships between conveying capacity and design and operating parameters were established, and the specific energy consumption of different conveyor types was assessed. It was determined that the most promising solution for the conditions of Ukraine's agricultural production is represented by shaftless spiral screw conveyors equipped with variable-frequency electric drives, which provide increased conveying capacity, reduced energy consumption, improved operational reliability, and adaptability to different physical and mechanical properties of bulk materials. The obtained results can be applied in the design, modernization, and operation of modern conveying and technological systems for the agro-industrial sector.

Keywords: spiral screw conveyor, screw conveyor, bulk materials, conveying and technological processes, agricultural production, conveying capacity, electric drive, automation, energy efficiency, design parameters, conveying systems, shaftless spiral.

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Introduction. Under the current conditions of agricultural production development, improving the efficiency of conveying and technological processes is one of the key factors in ensuring the competitiveness of agricultural enterprises. A significant proportion of grain, compound feed, mineral fertilizers, and other bulk materials is transported using screw conveyors and spiral screw conveyors, which are characterized by compact design, structural simplicity, the ability to convey materials in horizontal, inclined, and vertical directions, as well as high operational reliability. An analysis of current engineering solutions indicates that these conveying systems have become widely adopted in grain harvesting machinery, grain cleaning facilities, grain elevators, feed mills, and other agro-industrial enterprises.

The improvement of screw conveyor designs, the investigation of bulk material conveying processes, and the enhancement of the efficiency of conveying and technological systems have been the subject of extensive research by numerous Ukrainian and international scientists, including those reported in [1–4] and other studies. Their research has addressed the mechanisms of bulk material movement in screw conveyors, the influence of screw geometric parameters on conveying capacity and the energy consumption of the conveying process, as well as the improvement of drive systems and automated control systems..

At the same time, an analysis of the scientific literature indicates that the majority of existing studies have focused on conventional shafted screw conveyors, whereas the issues of comprehensive analysis of modern spiral screw conveyor designs, the specific features of their application, their design advantages, electric drive systems, and prospects for further development remain insufficiently systematized. Furthermore, current requirements for improved energy efficiency, conveying capacity, and operational reliability necessitate the generalization of existing engineering solutions and the identification of the most promising directions for the development of spiral screw conveyors. This is confirmed by the analysis of contemporary conveyor designs, the requirements for electric drive systems, and automated conveyor control systems.

In this context, a comprehensive analysis of modern spiral screw conveyor designs for bulk materials, the generalization of existing research findings, and the identification of promising directions for their structural and technological improvement are of particular relevance. Such an analysis is aimed at increasing conveying capacity, reducing energy consumption, and ensuring the stability of conveying and technological processes.

Review of recent research and publications. An analysis of recent scientific publications indicates that the conveying of bulk

materials by means of screw conveyors and spiral screw conveyors remains one of the key research areas in the field of conveying and technological systems. Considerable attention has been devoted to improving the design of conveying elements, increasing conveying capacity, reducing energy consumption, enhancing operational reliability, and expanding the functional capabilities of conveying equipment.

Previous studies have investigated the design features of screw conveyors and spiral screw conveyors, their operating principles, the mechanisms governing the interaction between the conveying element and bulk materials, as well as the influence of design and operating parameters on conveying performance. It has been established that the efficiency of conveying systems is largely determined by the geometric parameters of the spiral, its rotational speed, the conveyor inclination angle, the characteristics of the drive system, and the physical and mechanical properties of the conveyed material.

A separate area of research has focused on the improvement of electromechanical systems for screw conveyors. Particular attention has been paid to the application of adjustable electric drives, variable-frequency speed control, automated control systems, and technologies for monitoring process parameters. The implementation of modern control systems enables smooth starting and stopping of the conveyor, stabilization of operating conditions, reduction of dynamic loads, and improvements in both energy efficiency and operational reliability.

At the same time, an analysis of the published literature shows that the vast majority of studies have focused on improving individual structural components of conveyors or specific aspects of their electric drive systems. Comparatively little attention has been given to a comprehensive analysis of contemporary spiral screw conveyor designs, their classification, the comparative evaluation of the advantages and limitations of different design configurations, and the generalization of promising directions for their further development. Additional research is also required on the integration of modern structural solutions with automated control systems, the improvement of energy efficiency, and the adaptation of conveyors to the handling of bulk materials with different physical and mechanical properties.

Therefore, conducting a comprehensive analysis of modern spiral screw conveyor designs, systematizing existing engineering solutions, and identifying promising directions for their structural and functional improvement are highly relevant research objectives.

Research objective. The objective of this study is to conduct a comprehensive analysis of

modern design solutions for spiral screw conveyors used for bulk material handling, including their structural features, operating principles, technical characteristics, electric drive systems, and automated control systems, as well as to identify promising directions for their further development aimed at improving conveying capacity, energy efficiency, and the reliability of conveying and technological processes.

To achieve this objective, the following tasks were defined:

- to analyze contemporary spiral screw conveyor designs and the specific features of their application for bulk material conveying;
- to examine the structural characteristics of conveying elements and identify the factors affecting their operational efficiency;
- to investigate modern electric drive systems and automated control systems for spiral screw conveyors;

to summarize the advantages and limitations of existing engineering solutions and identify promising directions for the structural and functional improvement of spiral screw conveyors.

Main Research Results.

Application of Screw Conveyors. Screw conveyors are extensively used in agricultural production due to their versatility, simplicity of design, and reliable operation. They are widely employed in feed preparation systems, manure handling, the conveying of grain, feed products, root crops, and other bulk materials, as well as in combine harvesters and various other agricultural machines [3].

The system of machinery developed for the comprehensive mechanization of agricultural production provides for the use of lightweight mobile, portable, and stationary conveyor systems for warehouses and grain elevators.

In particular, portable and mobile screw conveyors are widely used (Figures 1–2).

Figure 1 shows a grain loader with a maximum conveying height of up to 2.5 m. Depending on the model, the screw diameter ranges from $D = 88\text{--}110$ mm, with a rotational speed of $n = 550$ rpm. The installed drive power is ($N_d = 0.6\text{--}1.0$) kW, while the conveying capacity is ($Q = 4\text{--}10$) t/h

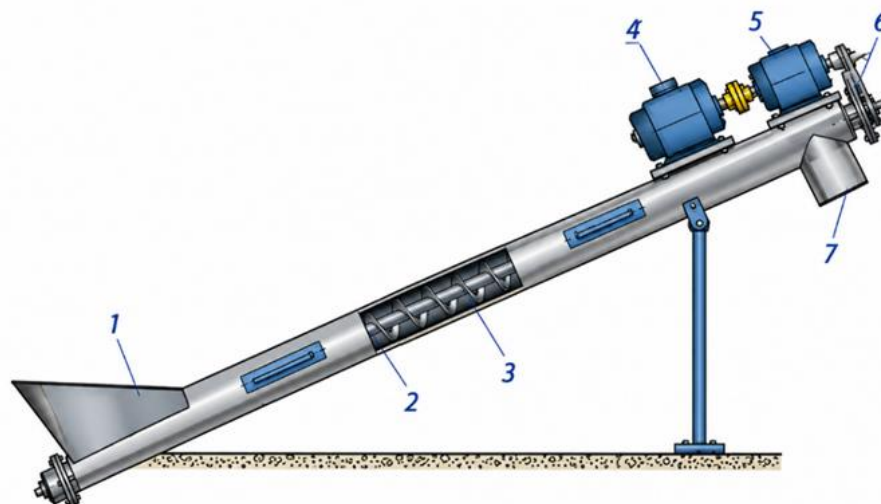


Fig. 1. Portable inclined screw conveyor: 1 – loading hopper; 2 – casing; 3 – screw; 4 – electric motor; 5 – gearbox; 6 – chain drive; 7 – discharge spout.

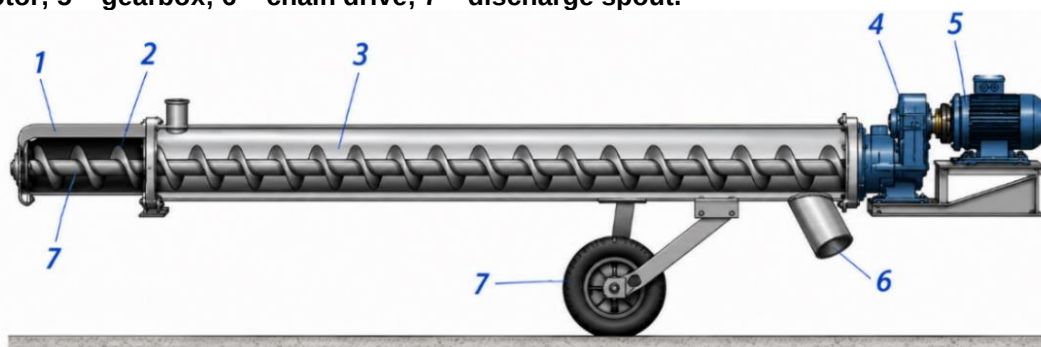


Fig. 2. Mobile screw conveyor: 1 – loading section; 2 – screw; 3 – casing; 4 – transmission; 5 – electric motor; 6 – discharge spout; 7 – two-wheel chassis.

Specialized loaders equipped with screw conveyors and mounted on truck chassis have

become increasingly widespread in modern agricultural production. These machines are

primarily used for the mechanized loading of grain into seed drills, transport vehicles, storage hoppers, and other technological containers. Their application substantially reduces manual labor requirements, increases the productivity of loading and conveying operations, and ensures the continuity of sowing and material-handling processes.

In the design of such loaders, as illustrated in Figure 3, horizontal and inclined screw conveyors are integrated to ensure the efficient conveying of bulk materials in different directions. The horizontal screw conveyor feeds grain to the receiving section of the conveying system, whereas the inclined conveyor elevates the material to the required height and subsequently loads it into a seed drill or transport vehicle. This design configuration optimizes the bulk material handling process and ensures a uniform material feed.

A distinctive feature of these conveying systems is their adaptation for mobile operation under agricultural conditions. The loader hopper, fabricated from sheet steel and structural steel sections, is mounted directly on the truck frame. This design provides sufficient structural strength, resistance to dynamic loads, and relatively low weight. The steel framework ensures structural rigidity and enhances the operational reliability of the conveying system under intensive service conditions.

An important advantage of mobile loaders equipped with screw conveyors is the possibility of rapidly replacing the loading hopper with a standard truck body after the completion of sowing operations. This significantly increases the versatility of the truck chassis and enables more efficient utilization of transport vehicles throughout the production cycle. As a result, the costs associated with maintaining specialized equipment are reduced, while the economic efficiency of mechanized agricultural operations is improved.

The application of mobile conveying systems with spiral screw conveying elements provides high equipment maneuverability, rapid execution of technological operations, and the capability to operate directly under field conditions. At the same time, the operational efficiency of such machines largely depends on the design parameters of the screw conveyor, its operating conditions, and the coordinated interaction of the individual components of the conveying system.

Therefore, particular attention should be paid to research aimed at substantiating the optimal design and operating parameters of spiral screw conveyors for bulk materials used in mobile loading machines. The rational selection of the screw geometric parameters, rotational speed, and loading unit design makes it possible to increase conveying capacity, reduce energy consumption, and ensure stable conveying of grain materials during conveying and technological operations.



Fig. 3. Screw loader.

In modern agricultural production, self-propelled crawler-mounted grain loaders are becoming increasingly widespread. In these machines, conventional scraper-type intake mechanisms are replaced by more reliable and productive screw conveying elements. The use of right-hand and left-hand screw flights ensures the uniform gathering of grain toward the central section of the conveying system, thereby improving the efficiency of the loading process. This design solution reduces grain losses, enhances the stability of material feeding, and ensures continuous operation of the conveying equipment.

In such grain loaders, the right-hand and left-hand screw conveyors are connected to the lower shaft of a double-chain scraper conveyor, which serves as the primary conveying element. During operation, the screw conveyors gather grain from both sides of the pile and deliver it to the central conveying section. The scraper conveyor subsequently transfers the material to a discharge belt conveyor, which loads the grain into transport vehicles or storage bins. The use of such a combined conveying system enables efficient handling of large volumes of bulk materials while maintaining stable conveying capacity.

The intake screw conveyors of these machines typically have a diameter of approximately 300 mm and a screw pitch of about 215 mm. These parameters are selected to achieve an optimal balance between conveying capacity, energy consumption, and the uniformity of material feeding. The geometric parameters of the screw conveying element directly influence the movement characteristics of the grain mass, the intensity of material flow, and the loading imposed on the drive mechanisms.

Some grain loader designs incorporate intake screw conveyors in combination with a bucket elevator, while retaining a belt conveyor as the discharge conveyor. In such systems, all mechanisms are mounted on a self-propelled wheeled chassis, providing high equipment mobility and allowing operation directly under field conditions. These machines are characterized by reliable performance during the loading of grain, maize ears, and other bulk or lumpy materials.

In mechanized loading and unloading systems, screw conveyors are employed both as mobile inclined conveyors and as portable vertical screw conveyors. Their application makes it possible to mechanize the loading, unloading, and conveying of bulk materials within grain handling facilities, warehouses, livestock farms, and other agro-industrial production facilities.

One example of such engineering solutions is a tractor-mounted grain loader for wheeled tractors, the design of which is shown in Figure 4. This machine employs screw conveying elements with right-hand and left-hand flights to transport grain toward the scraper conveyor. A specially designed plow mechanism is used to gather grain into the intake zone of the screw feeder, thereby improving loading efficiency and minimizing residual material remaining on the ground.

All mechanisms of the loader are driven from the tractor power take-off (PTO) shaft through a system of chain drives. This design solution ensures the compactness of the conveying system, simplifies its operation, and allows the tractor to serve as a universal power source. The conveying capacity of such grain loaders may reach 100 t/h, demonstrating their high efficiency in mechanized grain-handling operations.

Mobile screw conveyors, the design of which is shown in Figure 5, are also widely used for grain-loading operations. The conveying element of these conveyors may have a length of up to 10 m and is driven by an electric motor with a rated power of approximately 7 kW and a rotational speed of 1400 rpm through V-belt and chain transmissions. The conveyor frame is mounted on a wheeled chassis, providing mobility and ease of operation under practical working conditions.

Depending on the conveyor inclination angle, the material discharge height may vary from 2.6 to 7.2 m. At an inclination angle of 13–25°, the conveying capacity reaches 80 t/h. Such conveying systems are characterized by structural simplicity, high mobility, and the ability to be rapidly relocated between production sites, making them an effective means of mechanizing conveying and technological processes in agriculture.

An analysis of contemporary screw conveyor designs indicates that their operational efficiency is largely determined by the design parameters of the conveying element, its operating conditions, and the characteristics of the interaction between the bulk material and the conveying surface. Therefore, the substantiation of the optimal design and operating parameters of spiral screw conveyors for bulk materials is of particular importance for increasing conveying capacity, reducing energy consumption, and ensuring the stability of conveying and technological processes in agricultural production.

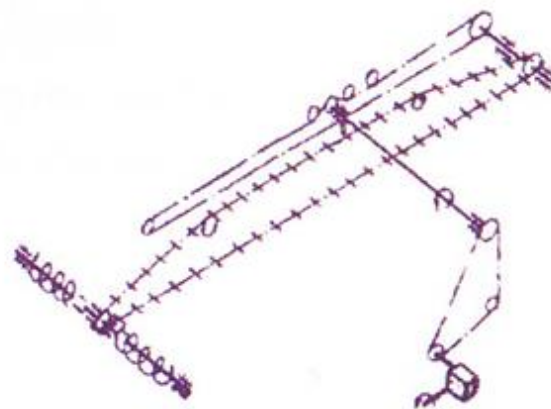


Fig. 4. Schematic diagram of a tractor-mounted grain loader



Fig. 5. Screw conveyor E-1500 (PJSC CherkasyElevatorMash)

The inclination angle of the screw conveyor is adjusted by means of a manual winch (3) within the range of $\delta = 10^\circ\text{--}45^\circ$. The screw has a diameter of 230 mm, a pitch of 250 mm, and operates at a rotational speed of $n = 480$ rpm. In the self-propelled screw conveyor–grain loader configuration, the screw conveyor is assembled from three sections: a lower section with a receiving hopper, a middle section, and an upper section with a discharge spout. The inclination angle of the screw axis relative to the horizontal can be adjusted within the range of $\delta = 18^\circ\text{--}60^\circ$, depending on the operating conditions and intended application. When operating as part of a conveyor line, the inclination angle is $\delta = 18^\circ$. For loading grain into trucks, the angle is adjusted to $\delta = 25^\circ\text{--}45^\circ$; for loading grain into railway wagons through roof hatches, $\delta = 43^\circ\text{--}45^\circ$; and for conveying grain to an upper conveyor in a grain storage facility, the inclination angle is set to $\delta = 60^\circ$.

The screw conveyor shafts are supported by rolling-element bearings, which provide stable operation and reduce friction. The screw sections

are interconnected by means of toothed couplings, allowing convenient handling, maintenance, and assembly of the individual sections, thereby simplifying conveyor installation and disassembly. The screw conveyor is supported by rear wheels, while the front wheels are connected through a lifting boom pivotally attached to the conveyor casing. This arrangement facilitates convenient adjustment of the screw inclination angle. The conveyor is driven by an electric motor that transmits torque through a worm gearbox to an intermediate shaft and subsequently through a coupling and chain drive to the drive wheel.

A dedicated lifting mechanism is incorporated into the design to enable manual raising and lowering of the screw conveyor, thereby increasing operational flexibility. Horizontal and

inclined screw conveyors are integrated into a mobile receiving hopper equipped with a screw feeder designed to receive grain discharged from trucks and transfer it to a belt conveyor. This design provides high conveying capacity and ensures efficient operation in agricultural material-handling processes.

The screw conveyors have a diameter of 250 mm, a screw pitch of 250 mm, and operate at a rotational speed of $n = 300$ rpm. They are driven by an electric motor with a rated power of 7 kW, providing a conveying capacity of up to 80 t/h. The inclination angle of the discharge screw conveyor relative to the horizontal is $\delta = 25^\circ$. The conveyor shafts are interconnected by means of a universal joint coupling. Power is transmitted from the electric motor through V-belt and chain drives.

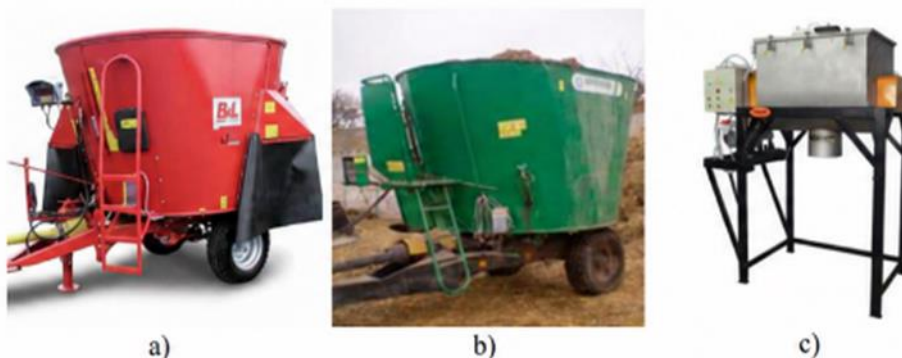


Fig. 6. Screw mixers: a) Agilo V-MIX (BvL); b) KSP-9 (Bratslav); c) SPP-2500 (Tekhnolog).

The single-screw feed mixer Agilo V-MIX (Fig. 6a) is the smallest model in the V-MIX range manufactured by BvL. It is available in two configurations with hopper capacities of 3.5 and 5 m³. Despite its compact dimensions, this feed mixer provides performance comparable to that of full-scale feed mixing machines while offering high maneuverability and being suitable for use in livestock facilities of various types. BvL also manufactures twin-screw V-MIX Plus feed mixers with capacities ranging from 13 to 30 m³, as well as triple-screw V-MIX Plus 3S feed mixers with capacities ranging from 25 to 40 m³.

Practical experience with conveying systems used in modern combine harvesters confirms that screw conveyors generally exhibit higher operational reliability than belt conveyors, which are also employed in combine harvester designs. This advantage is attributed to the structural characteristics of the screw conveying element, the nature of its interaction with the conveyed grain mass, and its resistance to demanding operating conditions. The use of screw conveying systems ensures stable material transport even under conditions of elevated moisture content, irregular grain inflow, and a high proportion of plant residues, which are characteristic of agricultural production.

One of the important advantages of screw conveyors is their high resistance to operation in humid environments. Unlike belt conveying systems, in which moisture may cause belt slippage, impair the operation of tensioning devices, and accelerate the wear of drive components, screw conveyors maintain stable performance under demanding operating conditions. This is particularly important when harvesting grain crops during periods of elevated humidity or when handling materials containing plant residues and dust.

Another significant structural advantage of screw conveyors is the absence of rotating rollers around which straw, plant residues, or fibrous contaminants may become entangled during operation. In belt conveyors, such phenomena can frequently result in drive overload, disruption of uniform material conveying, and the need for frequent cleaning of operating components. In screw conveying systems, this problem is considerably less pronounced, which positively affects equipment reliability and reduces the time required for maintenance.

Screw conveyors used in combine harvesting machinery are subject to stringent technical and operational requirements. This is due to the need to ensure stable operation of the

conveying system under significant dynamic loads, irregular grain flow, and continuous vibration. The manufacturing and installation accuracy of the screw conveyor directly affects its conveying capacity, service life, and the quality of bulk material transport.

The casings of screw conveyors must be rigidly and securely attached to the machine frame. At the same time, gaps and clearances at the joints between structural components should not exceed 1 mm, since excessive clearances may result in grain losses, ingress of foreign matter, and deterioration of the operating conditions of the conveying system. The accuracy of the relative positioning of the casings is also an important parameter, with the permissible misalignment of the structure not exceeding 5 mm.

Particular requirements apply to the installation of screw conveyor shafts. The permissible axial displacement of the shafts is limited to 2 mm, which is necessary to ensure uniform rotation of the conveying element and reduce additional loads on the bearing assemblies. In addition, screw flight runout should not exceed 3 mm, since exceeding this value may cause irregular movement of the bulk material, increased vibration, and accelerated wear of conveyor components.

An important factor in the effective operation of screw conveyors is the proper balancing of the conveying element. An unbalanced screw generates additional dynamic loads during rotation, which adversely affect the bearing supports, drive components, and structural mounting elements of the conveying system. As a result, vibration levels increase, energy consumption rises, and the service life of the equipment is reduced. For spiral screw conveyors used for bulk material handling, proper balancing is of particular importance, since the stability of the conveying element rotation directly affects the uniformity of material movement and the overall efficiency of the conveying process.

The technical requirements outlined above indicate that achieving high conveying capacity, reliability, and service life of screw conveyors is directly associated with the accuracy of their

design, manufacture, and installation. This is particularly relevant to spiral screw conveyors for bulk materials, whose performance is determined not only by the geometric parameters of the conveying element but also by the rational selection of the operating conditions of the conveying system. Therefore, the substantiation of the design and operating parameters of spiral screw conveyors is an important prerequisite for improving the energy efficiency, reliability, and technological stability of modern conveying and technological equipment used in the agro-industrial sector [7]. Screw conveyors can also be used for conveying liquid materials. Figure 7 shows the NSH-50 screw conveyor, which is mounted on a tractor and used for unloading liquid manure. Its conveying capacity can reach 50 t/h at a rotational speed of $n = 1000\text{--}1400$ rpm.

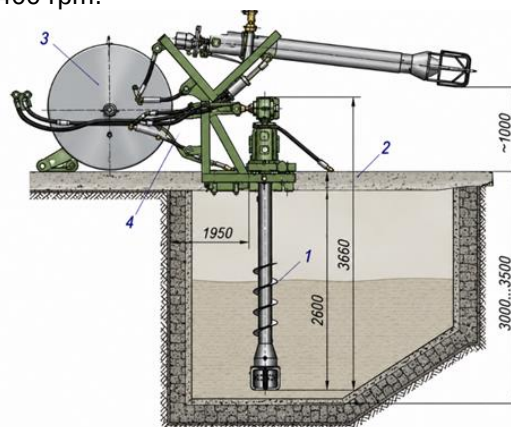


Fig. 7. Tractor-mounted screw conveyor for liquid manure: 1 – screw; 2 – frame; 3 – hydraulic system; 4 – tractor power transmission mechanism.

The hopper is made entirely of metal, hermetically sealed, and conical in shape. A longitudinal screw conveyor is mounted at the bottom of the hopper, while a rotary paddle agitator is positioned above it [8] (Figure 8). The screw conveyor is driven by the tractor power take-off (PTO) shaft through a bevel gearbox, providing a rotational speed of 170 rpm.



Fig. 8. Mixers with horizontally arranged ribbon screw conveyors: a) single-screw mixer; b) twin-screw mixer with oppositely rotating screws.

The mixing screw, which receives feed from the longitudinal screw conveyor and discharges it into the feeding troughs, is pivotally connected to the frame and can be positioned horizontally by means of a hydraulic cylinder when filling feeding troughs with a height of up to 500 mm [2,3,4].

Flexible, shaftless spiral screw conveyors are widely used for unloading railway wagons, transloading grain, grain treatment, and feed mixing (Figure 10).



Fig. 9. Flexible shaftless spiral screw conveyors: a) Machine-Building Plant "Vityaz" LLC; b) Industrial Equipment Plant "Progress" LLC; c) "Technik" LLC.

Screw conveyors are used in equipment for drying hay and feed. In foreign agricultural machinery, screw conveyors are commonly employed as universal conveying units with lengths ranging from 3 to 16 m, driven by either an electric motor or an internal combustion engine, with conveying capacities of 2–40 t/h [2].

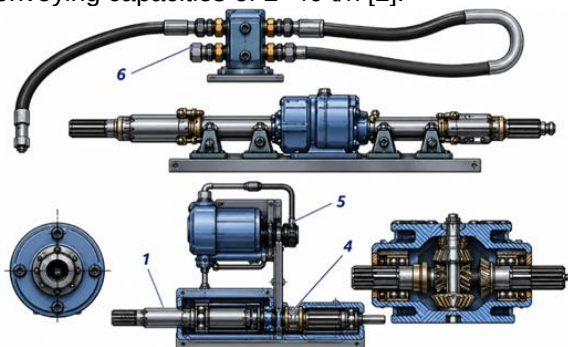


Fig. 10. Structural diagram of a screw conveyor drive: 1 – screw shaft; 2 – support frame; 3 – hydraulic motor; 4 – reduction gear transmission mechanism; 5 – electric drive; 6 – hydraulic system for supplying the working fluid.

Analysis of Possible Electric Drive Systems for a Spiral Screw Conveyor. In modern conveying and technological systems used in agro-industrial production, ensuring stable and energy-efficient operation of the drives of conveying equipment is of particular importance. This is especially relevant for spiral screw conveyors for bulk materials, whose operational efficiency is largely determined by the characteristics of the electric drive, its operating modes, and the possibility of regulating the rotational speed of the conveying element. The current level of development of electrical

engineering systems makes it possible to employ automated variable-speed electric drives capable of maintaining specified material-conveying conditions with high accuracy and adapting the conveying system to varying load conditions.

An analysis of modern domestic and international control systems indicates that automated electric drives are widely used in pumping installations, ventilation systems, conveyors, and other technological systems. In such systems, the controlled parameters may include pressure, fluid flow rate, material conveying speed, or rotational speed of the working element. For spiral screw conveyors, the primary controlled parameter is the rotational speed of the screw, which directly determines the conveyor capacity, the intensity of bulk material movement, and the energy consumption of the conveying process.

Modern automatic control systems make it possible to maintain the specified rotational speed of the drive motor with high accuracy. However, excessive sensitivity of the control system may result in continuous fluctuations in motor speed and the occurrence of alternating dynamic loads on the drive components. In conveying systems, this adversely affects couplings, bearing assemblies, gearboxes, and the structural elements supporting the conveying element, ultimately leading to accelerated wear. Therefore, when designing electric drives for spiral screw conveyors, it is necessary to consider not only control accuracy but also the stability of the conveyor operating modes and the reduction of dynamic loads acting on its structural components.

The operating principle of automatic control systems is based on varying the rotational speed of the drive motor according to the load on the conveying system. When the material feed rate or load decreases, the control system automatically reduces the screw rotational speed, thereby reducing energy consumption and the load on the drive mechanisms. As the intensity of bulk material feeding increases, the rotational speed of the conveying element is correspondingly increased, ensuring that the required conveyor capacity is maintained.

For bulk material conveying systems, maintaining stable drive operation under variable loads is of particular importance. In some cases, it is necessary to employ additional fixed-speed drives or backup conveying sections that are activated when the throughput of the technological line increases significantly. This approach ensures stable operation of the conveying system and prevents overloading of the main drive.

When selecting the type of electric drive for a spiral screw conveyor, it is necessary to consider the characteristics of the conveyed material, conveyor length, inclination angle, system capacity, and operating conditions. For conveyors operating



under high-intensity conditions, electric drives with continuously variable speed control are preferable, as they reduce starting loads and ensure stable material conveying. When high-speed operating modes are employed, the motor must have a sufficient power reserve to compensate for variable loads and ensure stable operation of the conveying system [12].

Despite the significant advantages of variable-speed electric drives, their application in conveying systems has not yet become sufficiently widespread. However, recent advances in semiconductor technology and power electronics make it possible to develop reliable and economically efficient automated electric drive control systems. This is particularly relevant given the need to reduce energy consumption and improve the efficiency of conveying and technological processes in agro-industrial production.

The use of modern electric drive systems in spiral screw conveyors for bulk materials enables smooth regulation of conveying capacity, reduction of dynamic loads on the conveying elements, improvement of conveying system reliability, and reduction of the energy intensity of the conveying process. Therefore, substantiating the electric drive parameters and selecting rational operating conditions constitute an important component of the study of the design and operating parameters of spiral screw conveyors for bulk materials.

Spiral Screw Conveyors with Variable-Speed Electric Drives Based on Induction Slip Couplings. In modern conveying and technological systems used in agro-industrial production, the application of variable-speed electric drives is of considerable importance, as they enable the operating modes of spiral screw conveyors to be adapted to changing load conditions. One promising approach is the use of electric drives based on induction slip couplings (ISCs), which provide smooth regulation of the rotational speed of the conveyor conveying element and ensure stable conveying of bulk materials. The use of such systems contributes to reduced energy consumption, improved equipment reliability, and more favorable operating conditions for conveying mechanisms.

In such systems, the converter is connected to the electrical grid through a step-down dry-type transformer, while the electric motor is connected through a step-up transformer of the same type. The converter also incorporates a thyristor power supply unit for the excitation system of the synchronous electric motor. This configuration provides smooth regulation of the drive motor rotational speed and stable operating conditions of the conveying system.

The automatic control system operates according to the principle of maintaining specified

technological process parameters. An air bell combined with a differential pressure gauge is used as the control sensor, with an output signal of 0–5 mA. A P-17 PI controller is employed to stabilize the operating conditions. The use of an automated variable-speed electric drive makes it possible to significantly reduce electricity consumption, decrease dynamic loads on the drive mechanisms, and improve the operating conditions of the conveying system. Analysis of the operation of such systems indicates that equipping additional units with similar electric drives can nearly double the energy savings and improve the overall efficiency of conveying and technological equipment.

Spiral Screw Conveyors with Variable-Speed Electric Drives Based on the AVK Configuration. One of the modern approaches to automated control systems is the use of electric drives based on the AVK configuration. Such a system comprises a wound-rotor induction motor, an AVK converter incorporating a rectifier and an inverter, a smoothing choke, a transformer, a control station, and starting resistors. In addition, the system is equipped with a level transducer consisting of an air bell and a differential pressure gauge, as well as a PI controller that maintains stable operating conditions of the conveying system.

The automatic control system ensures stabilization of the operating conditions of the spiral screw conveyor and maintains the required parameters for bulk material conveying. However, increasing control accuracy may lead to higher dynamic loads on drive components, particularly on flexible couplings connecting the electric motor to the conveyor conveying element. Such loads contribute to accelerated wear of the drive components; therefore, during operation, it may be necessary to increase the deadband of the automatic control system and somewhat reduce the accuracy of operating-condition stabilization.

The principle of regulating the rotational speed of the drive unit is similar to that of the systems considered above. The number of operating units is adjusted by operating personnel depending on the load of the conveying system and the required throughput of the technological process. Practical experience with electric drives based on the AVK configuration indicates that the use of such systems can result in annual energy savings of approximately 4–5% of total energy consumption, which is an important indicator for modern agro-industrial enterprises.

Spiral Screw Conveyors with Variable-Frequency Electric Drives. One of the most promising directions for improving control systems for spiral screw conveyors is the application of variable-frequency electric drives. The use of such systems makes it possible to smoothly vary the rotational speed of the conveying element, reduce



starting loads, and optimize the operating conditions for bulk material conveying.

The control system of a variable-frequency electric drive operates on the principle of automatically regulating the rotational speed of the drive motor according to the load on the conveying system. Unlike the systems considered above, an ultrasonic level sensor is used to monitor the process parameters, providing high measurement accuracy and stable operation of the automation system.

The use of a variable-frequency electric drive makes it possible to reduce electricity consumption by approximately 5%, which is an important factor in improving the energy efficiency of conveying and technological processes. To ensure uniform utilization of the drive units, such systems incorporate a dedicated switching device that allows individual drive units to be alternately connected to a single frequency converter.

Such systems widely employ PChR-2 frequency converters, SAMI converters manufactured by the Finnish company Stromberg, as well as domestic PChT and EKT frequency converters. Their use provides smooth speed regulation, stable bulk material conveying, and reduced operating costs of the conveying system.

Requirements for the Automated Electric Drive of a Spiral Screw Conveyor. Spiral screw conveyors belong to the category of mechanisms designed for continuous-duty operation, characterized by a large number of operating hours per year and a relatively small number of starts. The load on the drive motor shaft is generally steady and does not involve significant overloads. However, variations in load may occur during bulk material conveying due to changes in conveyor capacity or in the physical and mechanical properties of the conveyed material.

Conveying systems are characterized by a fan-type dependence of the resistance torque on rotational speed, in which the static resistance torque is proportional to the square of the rotational speed. Therefore, the electric drive must provide smooth rotational speed control and stable operating conditions of the conveyor.

The electric drive of a spiral screw conveyor must provide a speed control range of at least 3:1, have an overload capacity of not less than 1.5, provide smooth starting and acceleration of the conveying system, and allow coast-down braking. In addition, the drive must operate reliably under conditions of elevated humidity and temperature, comply with the UHL4 climatic version, and have a degree of protection of at least IP44.

Requirements for the Automation System of a Spiral Screw Conveyor. Automation of conveying and technological processes makes it possible to improve the accuracy of controlling the operating conditions of a spiral screw conveyor,

ensure stable conveying of bulk materials, and reduce the influence of human factors on equipment operation. Modern automation systems are based on microprocessor-based devices and programmable logic controllers (PLCs), which make it possible to replace rigid relay-based control circuits with flexible software-based control algorithms.

The automated control system must provide smooth starting and acceleration of the drive motor, maintain the required conveying capacity, and stabilize the operating conditions of bulk material conveying by regulating the rotational speed of the screw. Important functions of the automation system include automatic activation of a standby drive in the event of an overload or emergency condition, automatic restart after restoration of the power supply, and protection of the electric motor against thermal overloads.

In addition, the automation system must ensure uniform utilization of the drive units, monitoring of minimum, maximum, and emergency operating conditions of the conveying system, and stable operation of the spiral screw conveyor under variable load conditions. The use of modern automated control systems makes it possible to increase the productivity of conveying equipment, reduce energy consumption, and ensure the reliability of conveying and technological processes in modern agro-industrial production.

Modern agricultural production in Ukraine is characterized by significant volumes of grain, compound feed, seeds, mineral fertilizers, and other bulk materials that require conveying. The efficiency of conveying and technological processes has a substantial influence on production capacity, level of mechanization, energy consumption, and the cost of finished products. Therefore, the selection of appropriate conveying equipment is one of the important factors in ensuring the efficient operation of agricultural enterprises.

An analysis of existing conveying systems indicates that spiral screw conveyors are among the most widely used types of equipment in farms, grain-processing enterprises, grain elevators, and feed-production facilities. This is attributable to their simple design, high reliability, compactness, ability to convey materials in horizontal, inclined, and vertical directions, low operating costs, and suitability for handling a wide range of bulk materials. In addition, conveyors of this type can be readily integrated into existing technological lines and are characterized by relatively low manufacturing and maintenance costs.

Unlike belt, chain, and bucket conveyors, spiral screw conveyors transport material within an enclosed conveying space, thereby minimizing product losses, dust generation in production facilities, and adverse environmental effects. This is

particularly important when conveying grains, compound feeds, oilseed crops, and other bulk materials subject to sanitary and hygienic requirements.

The results of the analysis of modern designs indicate that shaftless spiral screw conveyors are among the most promising solutions for the agro-industrial sector of Ukraine. They are

characterized by lower mass, reduced energy consumption, the absence of material accumulation around a central shaft, increased conveying capacity, and the ability to handle materials with high moisture content or a tendency to compact and form agglomerates. These characteristics make them suitable for use both on small farms and at large-scale grain-processing enterprises.

Table 1

Comparative Characteristics of Conveying Systems

Conveyor type	Conveying capacity	Energy consumption	Enclosure	Maintenance	Suitability for farms
Belt conveyor	High	Medium	Low	Moderate	+
Bucket conveyor	High	High	Medium	Difficult	±
Chain conveyor	Medium	High	Medium	Difficult	±
Spiral screw conveyor	High	Low	High	Simple	+++

Table 2

Advantages of Spiral Screw Conveyors

Indicator	Value
Compactness	High
Reliability	High
Material intensity	Low
Enclosure	High
Automation	Simple
Energy efficiency	High
Versatility	High

as well as

The classical relationships can be used

$$Q = 60 \cdot \frac{\pi D^2}{4} \cdot S \cdot n \cdot \varphi \cdot \rho \quad (1)$$

$$N = \frac{Q \cdot L \cdot k}{367 \eta} \quad (2)$$

where D - spiral diameter; S - spiral pitch; n - rotational frequency; φ - filling coefficient; ρ - bulk density of the material.

Where N - drive power; L - conveyor length; k - conveying resistance coefficient; η - drive efficiency.

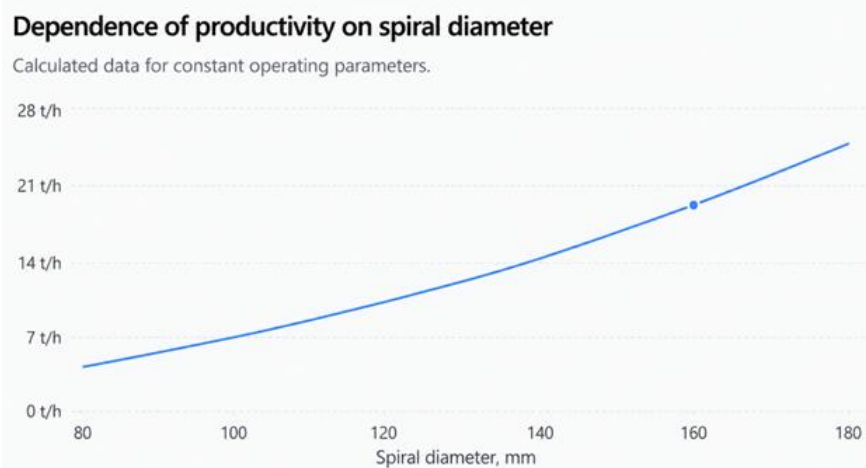


Fig. 11. Dependence of the Capacity of a Spiral Screw Conveyor on Spiral Diameter

Among the conveying systems considered, the spiral screw conveyor is characterized by the lowest specific energy consumption, which is one of the main reasons for its widespread use in the Ukrainian agro-industrial sector.

Comparative efficiency of conveying systems

Generalized expert assessment for agricultural production conditions.

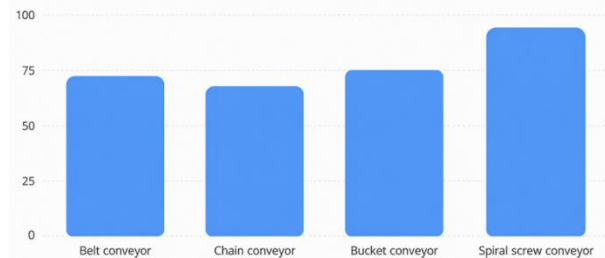


Fig. 14. Efficiency of Using Different Conveyor Types in Agricultural Production

The comparative data presented indicate that spiral screw conveyors are the most suitable for the conditions of agricultural production in Ukraine. They combine a simple design, compactness, enclosed conveying, low material intensity, reduced specific energy consumption, and the ability to efficiently handle a wide range of bulk materials. Therefore, they should be considered as a basic type of conveying equipment for farms, grain elevators, grain storage facilities, and feed-production enterprises.

For publication in a specialized scientific journal, the graphs should be presented either as the authors' own calculations or as a synthesis of data from literature sources, with the appropriate reference provided in the figure caption.

Table 3
Dependence of Conveying Capacity on Spiral Diameter

Spiral Diameter	Conveying Capacity
80	4,5
100	7,2
120	10,4
140	14,1
160	18,8
180	24,3

Table 4
Dependence of Conveying Capacity on Rotational Speed

Rotational Speed	Conveying Capacity
200	5
300	7,8
400	10,6
500	13,3
600	15,9

Table 5
Specific Energy Consumption of Conveying Systems

Conveyor type	Energy consumption
Belt conveyor	1,8
Chain conveyor	2,4
Bucket conveyor	2,1
Spiral screw conveyor	1,3

Table 6
Comparative Efficiency of Conveying Systems

Conveyor type	Efficiency score
Belt conveyor	72
Chain conveyor	68
Bucket conveyor	75
Spiral screw conveyor	94

The comparative data presented indicate that spiral screw conveyors are the most suitable for the conditions of agricultural production in Ukraine. They combine a simple design, compactness, enclosed conveying, low material intensity, reduced specific energy consumption, and the ability to efficiently handle a wide range of bulk materials. Therefore, they should be considered as a basic type of conveying equipment for farms, grain elevators, grain storage facilities, and feed-production enterprises.

Conclusions. The analysis of modern designs of spiral screw conveyors has shown that this type of conveying system is one of the most effective means of mechanizing bulk material handling processes in agricultural production. Their simple design, high reliability, enclosed conveying process, compactness, and ability to operate in horizontal, inclined, and vertical positions ensure their widespread use in grain elevators, grain-cleaning complexes, feed-production enterprises, livestock facilities, and farms.

The comparative analysis has demonstrated that spiral screw conveyors have advantages over belt, bucket, and chain conveyors in terms of energy efficiency, ease of maintenance, conveying enclosure, and versatility of application. Shaftless spiral screw conveyors are the most promising for modern agro-industrial production conditions due to their increased conveying capacity, lower energy consumption, absence of material accumulation on a central shaft, and ability to convey materials with increased moisture content and a tendency to compact and form agglomerates.

It has been established that conveyor performance is determined by a combination of design and operating parameters, among which the spiral diameter and pitch, rotational speed, conveyor inclination angle, filling coefficient of the conveying space, and physical and mechanical properties of the conveyed material have the

greatest influence. Analysis of modern electric drive systems has confirmed the feasibility of using variable-frequency drives, which provide smooth capacity control, reduced starting currents, lower dynamic loads, and increased energy efficiency of conveying systems.

The generalization of the research results has substantiated the feasibility of widespread implementation of spiral screw conveyors in conveying and technological processes of the agro-industrial sector of Ukraine. Further research should focus on mathematical modeling of bulk material conveying processes, optimization of the design and operating parameters of shaftless spiral screw conveyors, and development of intelligent automatic control systems for electric drives, which will enable further improvements in the productivity, reliability, and energy efficiency of conveying systems.

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АНАЛІЗ КОНСТРУКТИВНИХ ОСОБЛИВОСТЕЙ ТА ТЕНДЕНЦІЙ РОЗВИТКУ СПІРАЛЬНИХ ШНЕКОВИХ КОНВЕЄРІВ ДЛЯ СИПУЧИХ МАТЕРІАЛІВ

У даній роботі наведено результати комплексного аналізу конструктивних особливостей, технічних характеристик та сучасних тенденцій розвитку гвинтових спіральних конвеєрів сипучих матеріалів, які широко використовуються в сільськогосподарському виробництві. Проведено аналіз сучасних конструкцій конвеєрних систем та особливостей їх застосування для транспортування зерна, комбікормів, насіння, мінеральних добрив, кормових сумішей та інших сипучих матеріалів. Встановлено, що спіральні шнекові конвеєри характеризуються конструктивною простотою, компактністю, високою надійністю, герметичним процесом транспортування, можливістю транспортування матеріалів у горизонтальному, похилому та вертикальному напрямках, а також відносно низькими експлуатаційними витратами.



Проведено порівняльний аналіз традиційних шнекових конвеєрів, безвальових спіральних шнекових конвеєрів, стрічкових конвеєрів, ковшових елеваторів та ланцюгових конвеєрів за продуктивністю, енергоефективністю, конструктивною складністю, герметичністю транспортування та придатністю до експлуатації в умовах сільськогосподарської промисловості України. Узагальнено сучасні конструктивні рішення для мобільних та стаціонарних конвеєрних систем, а також проаналізовано особливості застосування шнекових конвеєрів у зерноочисних комплексах, елеваторах, системах кормопідготовки, тваринництві та лініях післязбиральної обробки.

Особливу увагу приділено аналізу сучасних систем електроприводу та автоматизованих систем керування спіральними шнековими конвеєрами. Розглянуто принципи роботи регульованих електроприводів на основі індукційних ковзних муфт, автоматизованих систем регулювання швидкості (АСРШ) та електроприводів зі змінною частотою, а також визначено їх переваги з точки зору підвищення енергоефективності, зниження динамічних навантажень та забезпечення стабільності конвеєрних та технологічних процесів.

На основі узагальнення результатів попередніх досліджень було проведено порівняльну оцінку технічних характеристик конвеєрних систем, встановлено взаємозв'язки між конвеєрною продуктивністю та конструктивними та експлуатаційними параметрами, а також оцінено питоме енергоспоживання різних типів конвеєрів. Було визначено, що найперспективнішим рішенням для умов сільськогосподарського виробництва України є безвальні спіральні шнекові конвеєри, оснащені електроприводами зі змінною частотою, які забезпечують збільшення конвеєрної продуктивності, зниження енергоспоживання, покращену експлуатаційну надійність та адаптивність до різних фізико-механічних властивостей сипучих матеріалів. Отримані результати можуть бути застосовані при проектуванні, модернізації та експлуатації сучасних конвеєрно-технологічних систем для агропромислового сектору.

Ключові слова: спіральний шнековий конвеєр, шнековий конвеєр, сипучі матеріали, конвеєрно-технологічні процеси, сільськогосподарське виробництво, конвеєрна продуктивність, електропривод, автоматизація, енергоефективність, конструктивні параметри, конвеєрні системи, безвальний спіральний конвеєр.

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