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IMPROVEMENT OF THE SEEDER ROW UNIT DESIGN BASED ON DEM-MODELING

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The article addresses a pressing scientific and technical problem–improving the operational stability of seed drill row units under conditions of variable field topography and heterogeneous soil physical-mechanical properties. Modern designs of ground-following and damping mechanisms are analyzed, along with their limitations in maintaining a consistent seed placement depth, as well as design solutions applicable to different types of openers. Particular attention is given to the shortcomings of traditional experimental studies, which do not fully reproduce the real dynamic processes of opener–soil interaction.

It is shown that a significant portion of existing designs loses efficiency at higher operating speeds or on uneven field sections, resulting in unstable seeding depth and reduced emergence uniformity. The analysis includes recent research findings related to opener wear, the influence of disk type on seeding quality, the development of combined working tools, and the use of sensor-based depth-control systems.

The study identifies the high potential of the Discrete Element Method (DEM) for simulating the dynamics of seed drill row units, as it enables evaluation of furrow formation processes, soil particle behavior, reactive forces, and opener motion stability without the need for numerous physical prototypes.

Based on the conducted analysis, a new structural and technological concept of a row unit is proposed, incorporating coordinated operation of the downforce mechanism, damping device, and depth-control system. This configuration provides effective vibration attenuation, reduced impact loads, and improved stability of seed placement depth. The developed design is justified for further optimization and verification using DEM simulation.

Key words: *row unit, opener, DEM simulation, seed drill, ground-following, damping, interaction dynamics, seed placement depth, knife opener, vibrations, structural optimization, seeding system.*

Fig. 9. Ref. 33.

1. Problem formulation

The stability of seed placement depth and the accuracy of furrow formation are key factors determining uniform emergence and the effectiveness of early crop development. According to numerous studies [1, 2], variations in surface topography, changes in soil physical and mechanical properties, the presence of crop residues, and the dynamics of machine movement significantly affect the opener's performance and may cause seeding depth deviations of up to 20–30%. This underscores the need to develop row units capable of compensating for external disturbances and ensuring stable seed placement across a wide range of field conditions.

Modern ground-following mechanisms are classified into passive and active systems. Passive designs, such as parallelogram linkages, provide simple and reliable field-surface tracking but lose effectiveness at high speeds or on uneven terrain [1, 2]. Active systems using hydraulic or electromechanical actuators improve depth-control accuracy to ±5–7%, but are characterized by high cost and structural complexity [3, 4, 5]. Similar limitations apply to damping systems–spring, elastomeric, and hydraulic dampers [6]. These devices partially reduce vibration-induced disturbances but fail to ensure comprehensive stabilization of opener motion.

At the same time, numerous studies highlight that traditional opener designs–double-disk, single-disk, shovel-type, and combined–demonstrate varying effectiveness depending on soil type, moisture content, residue level, and operating speed [7, 8]. Most experiments are carried out in model or laboratory conditions, which do not fully reflect real-world production scenarios. Considerable attention is also given to opener wear and service life [9, 10, 11], although such studies typically focus on narrow groups of materials or only specific design types.

In this context, the Discrete Element Method (DEM) is regarded as one of the most promising tools for

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studying opener–soil interaction dynamics and analyzing furrow formation [12, 13, 14, 15]. DEM makes it possible to model soil particle behavior, reactive force distribution, processes of soil fracturing and compaction–phenomena that are practically inaccessible to traditional experimental techniques. For this reason, DEM is increasingly needed to justify new design solutions aimed at improving the operational stability of row units.

Given the identified shortcomings of existing systems and the limitations of traditional research methods, the development of a new-type row unit with an improved kinematic and damping structure, optimized through DEM simulations, is a highly relevant task. This scientific work is dedicated to addressing this problem.

2. Analysis of recent research and publications

In modern seeding systems, one of the key factors ensuring high-quality sowing is the ability of the working tools to accurately reproduce the microrelief of the soil and consistently maintain the required seed placement depth. Surface unevenness, crop residues, variations in soil density, and local elevation changes significantly influence the position of the opener relative to the working surface. For this reason, various ground-following and damping systems are widely used in seed drill designs to reduce the impact of external disturbances and improve the stability of the seeding process [1, 2].

Ground-following mechanisms are conventionally divided into passive and active systems. Passive mechanisms reproduce field topography mainly through the structural layout and natural interaction of the working tools with the soil. They typically include the frame geometry, gauge wheels, and elastic elements that provide the required freedom of movement for the row units. The most common technical solution is the parallelogram linkage, which allows the opener to move vertically without changing its angle of attack or the spatial position of the metering device (Fig. 1). In such systems, the height position of the opener is determined by the movement of the gauge wheels, which track the field surface directly.

The main advantages of passive systems are structural simplicity, high operational reliability, and relatively low cost. At the same time, their effectiveness decreases significantly at operating speeds above 10–12 km/h and on fields with pronounced uneven topography, where inertial loads may cause row-unit oscillations and instability in seed placement depth.

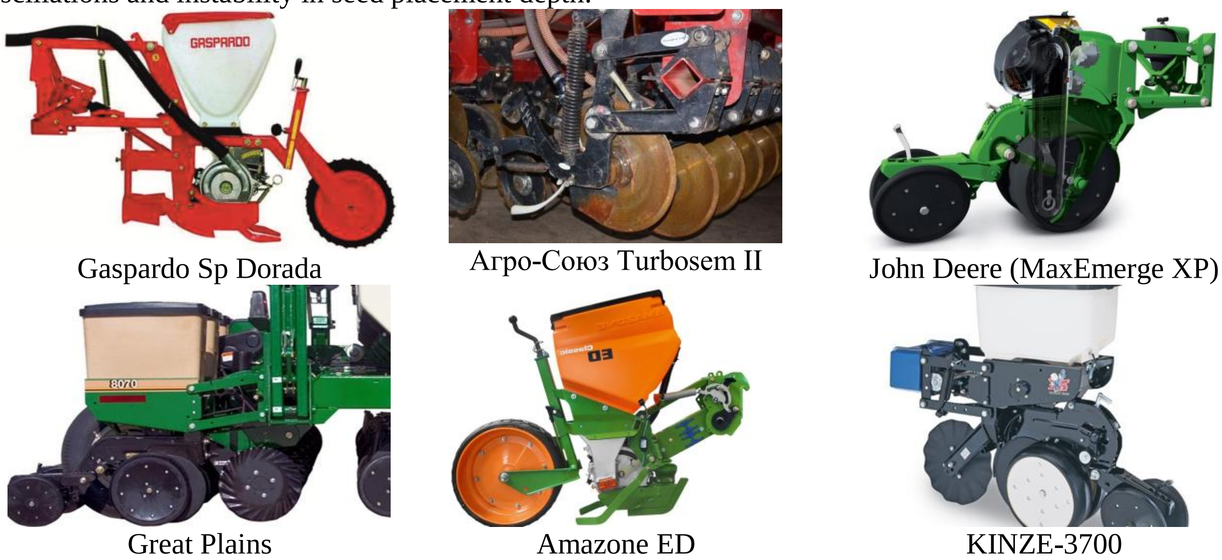
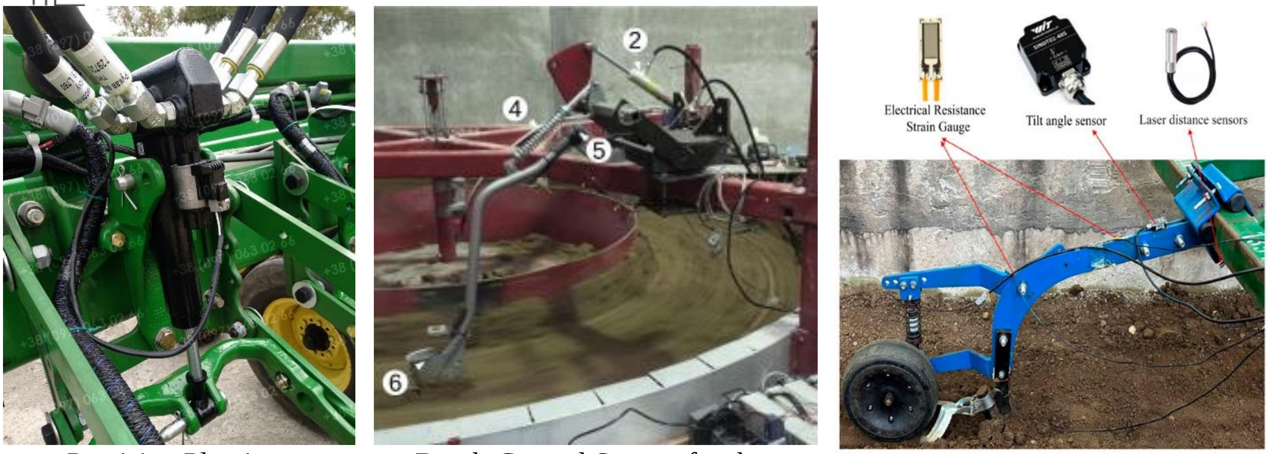


Fig. 1. General view of row units with parallelogram linkages

Active ground-following systems operate on the basis of automatic adjustment of the working tools using hydraulic or electromechanical actuators (Fig. 2). These systems employ pressure, position, and acceleration sensors that respond to changes in the vertical load acting on the opener and transmit corresponding signals to the control unit. Based on these inputs, the actuator promptly adjusts the position of the row unit, providing an adaptive response to variations in field topography and soil properties in real time.

Such technical solutions are typical for high-capacity, premium-class seeding systems, where it is particularly important to minimize the influence of travel speed, soil heterogeneity, and vibration disturbances on seeding accuracy. Active systems are characterized by high precision in maintaining the working depth–within ±5–7%, significantly reduced vertical oscillation amplitude, and the ability to ensure stable operation at speeds exceeding 15 km/h.

The main disadvantages of active systems include structural complexity, high component cost, and increased maintenance requirements, which may limit their widespread adoption in farms with medium-level technical capabilities.



Precision Planting Delta Force [3] | Depth-Control System for the Opener [4] | MR-damper-based System [5]

Fig. 2. General view of row units with active ground-following systems

Damping systems in seeding complexes perform a specific yet equally important function–reducing vibrations and impact loads transmitted from the soil to the frame and opener during machine operation. Modern seed drill designs incorporate various types of damping elements, including mechanical spring dampers, elastomer inserts, pneumatic components, and hydraulic dampers [6]. Spring-based systems can effectively compensate for medium-intensity oscillations; however, they show reduced efficiency under high-frequency vibrations and sudden impact loads. Elastomer elements provide mechanical energy absorption over a wider range of loads, though their performance deteriorates over time due to material aging.

Hydraulic dampers are the most effective means for smooth vibration attenuation and stabilization of the row unit position under conditions of rapidly changing terrain or high operating speed. At the same time, such systems increase the mass of the row unit and require greater maintenance precision, which may complicate their use on farms with moderate technological capacity.

Overall, the combined operation of ground-following and damping mechanisms determines the ability of a seed drill to ensure uniform seed placement across a wide variety of field conditions. Analysis of current trends in seeding technology demonstrates a gradual transition from simple passive mechanisms to intelligent adaptive systems operating in real time. The use of such solutions significantly increases the precision of maintaining seeding depth, reduces energy consumption, improves furrow formation quality, and ensures more uniform crop emergence regardless of terrain complexity and variations in soil physical and mechanical properties.

3. The purpose of the article

The aim of the study is to substantiate and determine effective directions for improving the design of a seed drill row unit through the application of DEM simulation to analyze the interaction between the working tools and the soil, evaluate the dynamic performance of the unit, and optimize the parameters that ensure stable seeding depth and improved sowing quality.

4. Results and discussion

A comprehensive analysis of the performance of modern seed drill row units for sowing agricultural crops was carried out in accordance with the requirements of SOU NAN 73.1-001:2011 «Organization and Conduct of Research and Development Activities». Compliance with this regulatory document ensured proper structuring of the study, clarity of its stages, correct formulation of tasks, planning of the experimental component, and consistency in the procedures for processing and interpreting results. Applying the provisions of this standard made it possible to organize the research in line with established scientific and methodological approaches and to guarantee the representativeness of the obtained data.

Additionally, the requirements of DSTU 3575-97 «Patent Research. Basic Provisions and Procedure» were taken into account. This standard regulates the conduct of patent-information analysis and specifies a clear sequence of actions for searching protective documents, examining the state of the art, identifying trends in design development, and assessing the innovativeness of technical solutions. Its application enabled the formation of a complete overview of modern patented developments, characterization of the most common row-unit designs, and identification of promising directions for their improvement.

Beyond regulatory requirements, the informational support of the study included the use of widely adopted methods for targeted scientific and technical information retrieval: analysis of relevant scientific publications, monographs, review papers, analytical reports, technical catalogs of leading seeder manufacturers, as well as electronic libraries and patent databases. This approach made it possible to form a broad and representative information base, systematize modern design solutions, and compare the results of fundamental and applied research in the field of row units.

Altogether, the application of regulatory and technical documents combined with modern information-retrieval methodologies ensured a comprehensive, objective, and methodologically sound analysis of contemporary row-unit designs, forming the basis for further theoretical generalization and determination of directions for their structural improvement.

The development of opener designs for seed drills, their wear characteristics, energy efficiency, and their influence on seeding quality remain active research topics among both domestic and foreign scientists. In particular, studies [7, 8] examined a modernized double-disk opener equipped with a fixed "heel" positioned in the inter-disk space. Theoretical analyses and experimental tests showed that such a design improves seed distribution in terms of depth and row width. At the same time, one limitation of these studies is that tests were conducted under restricted soil and field conditions, which do not fully reflect the diversity of real-world production scenarios.

The analysis of opener designs presented in [16, 17, 18] covers various types–passive and active, single-disk, double-disk, and shovel-type-highlighting their advantages and disadvantages. The authors emphasize that despite the large number of available design solutions, some of them are not adapted to the requirements of modern minimum-till and no-till technologies, which necessitates further research aimed at increasing the versatility of opener configurations.

Regarding wear rate and service life, studies [9, 10] are particularly important. These works measured the mass, thickness, and diameter of disk openers before and after operation (e.g., after ≈80 ha). Based on the obtained data, statistical distributions (Gaussian, log-normal) were constructed, revealing characteristic patterns of abrasive wear. This approach enables predicting disk lifespan and planning timely replacement. However, the limitation of these studies is that the experiments were conducted for a specific disk type (diameter, steel grade), meaning the results cannot always be extrapolated to other models or soil conditions.

Another research direction involves improving the energy efficiency of double-disk openers. Studies [19, 20] proposed an analytical model that accounts for furrow geometry, disk opening angles, depth, and diameter, demonstrating how parameter variations affect energy consumption. These investigations were carried out not only experimentally but also using numerical simulations (Fig. 3). Nevertheless, the model has certain limitations, as actual field conditions–variability in soil hardness, presence of residues, moisture fluctuations–may differ significantly from the idealized assumptions adopted in theoretical analyses.

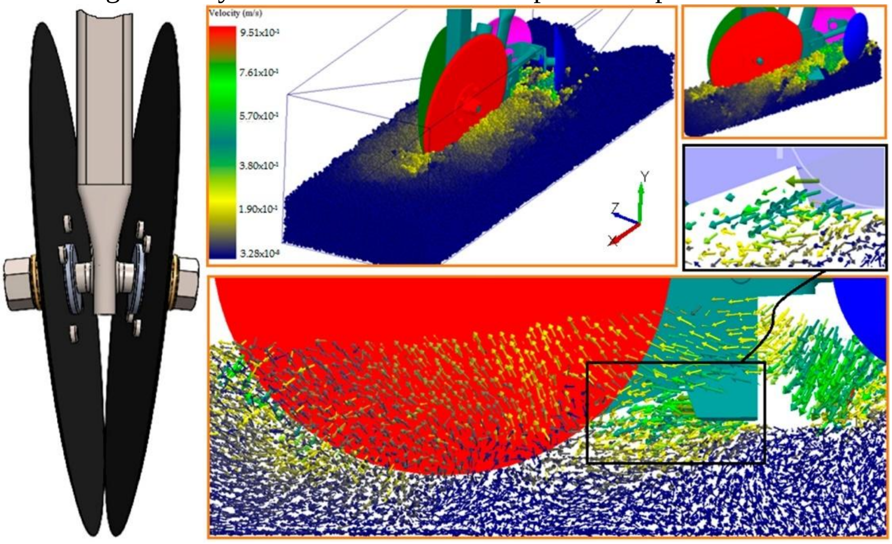


Fig. 3. Soil–Soil and Soil–Enhanced Double-Disk Opener Interaction in DEM [20]

Metallurgical aspects of opener design also constitute an area of significant scientific interest. Studies of the steel structure of disk openers, their hardness, and microstructure indicate that proper material selection can substantially improve their wear resistance [9, 21]. A limitation of such research is that most experiments are conducted under laboratory conditions, which complicates the scaling of results to real production processes in large agricultural enterprises.

Experimental and analytical studies have also focused on determining the influence of opener design and disk type on seeding performance. For example, works [22] assessed the efficiency of different disk types–smooth, notched, and serrated–in terms of their ability to cut through crop residues during seeding, which is critically important for No-Till technologies where the field surface contains significant amounts of stubble. However, the drawback of these studies is that the tests were conducted mainly on model stands or test tracks rather than full-scale commercial seed drills, which may lead to underestimation of large-scale effects.

Study [23] conducted parameter calibration for soil–tool interaction based on experimental design methods, which was further confirmed in [24]. The use of DEM–MBD simulation made it possible to evaluate the influence of soil coverage and compaction on seed placement under various row-unit travel speeds (Fig. 4). The obtained results can be applied to further optimization of opener designs and improvement of soil-covering and compaction systems used during seeding.

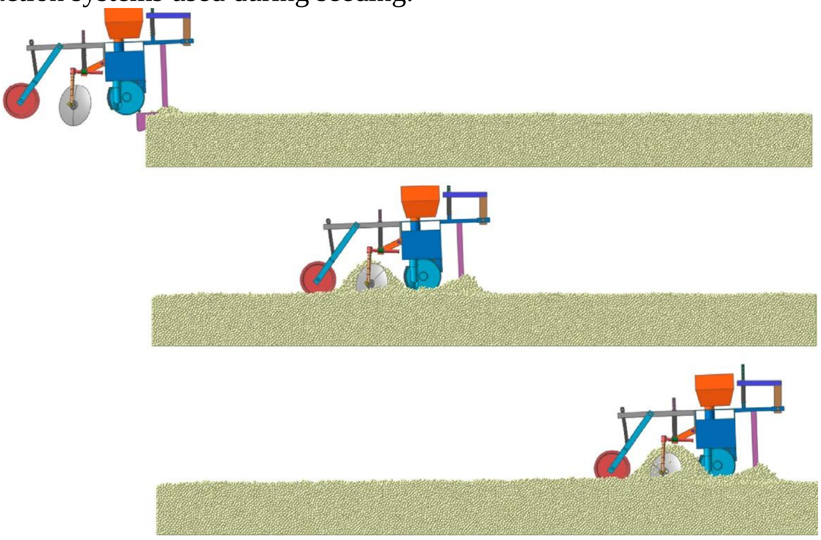


Fig. 4. Interface for Simulating Opener–Soil Interaction [23]

Another practical direction in improving seeding systems is the instrumentation of seed drills for real-time monitoring of opener operating depth (Fig. 5). In studies [25], a sensor-based system was developed and tested, providing continuous tracking of seed placement depth and enabling automatic adjustment during machine operation. Such technical solutions have the potential to significantly enhance seeding accuracy and depth-stability; however, their widespread implementation is limited by structural complexity and the high cost of integrating these systems into large seed drills.

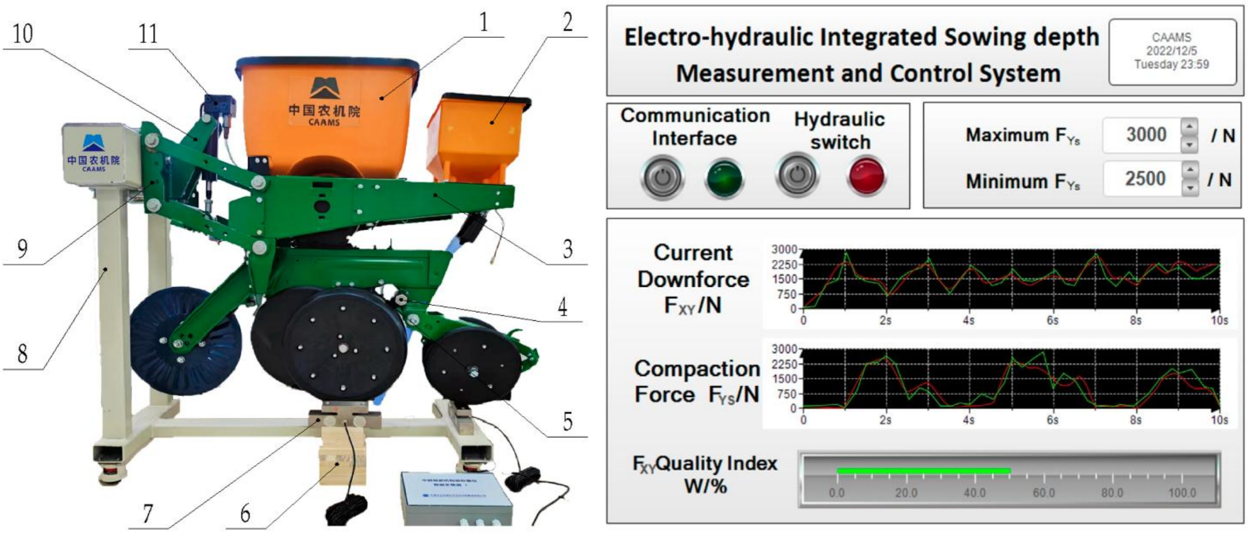
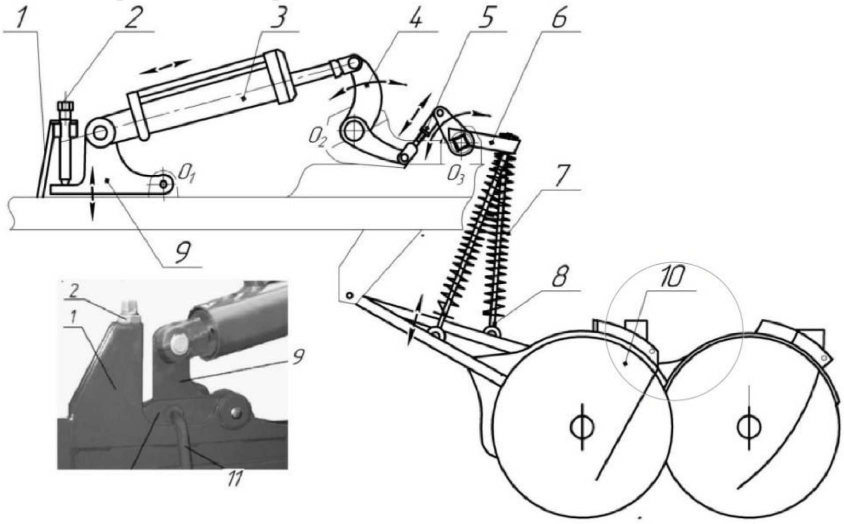


Fig. 5. General view of the developed row unit and the software used to record its oscillations [25]: 1 – seed box; 2 – fertilizer box; 3 – frame; 4 – load cell; 5 – angle sensor; 6 – gauge-wheel pads; 7 – weighing device; 8 – test bench; 9 – four-bar linkage; 10 – cylinder bracket; 11 – IPRC.

Machines in which seed placement depth is regulated at the level of the entire frame include universal grain drills such as ASTRA-6 (Fig. 6), SZD-U 25V, ASTRA 3.6, and SZD-360 [26]. In such designs, changes in seeding depth are carried out synchronously for the entire row-unit assembly, which simplifies the adjustment process and ensures uniform operation of all working tools. Under conventional tillage conditions and with a sufficiently leveled field surface, this regulation principle makes it possible to effectively maintain the required and stable seed placement depth [27, 28].



a b

Fig. 6. Seed Drill Depth-Adjustment Device [26]: a – seeding-depth adjustment screw; b – depth-control system diagram; 1 – bracket; 2 – screw; 3 – lifting hydraulic cylinder; 4 and 9 – hydraulic-cylinder mounting levers; 5 – screw drive; 6 – opener lift/lower levers; 7 – spring; 8 – downforce rod; 10 – opener; 11 – lock (latch).

Study [29] examined the design of a direct-seeding corn planter equipped with a disk-type metering device, the performance of which is determined by the inclination angle of the cells, their number, and the rotational speed of the disk (Fig. 7). This design ensures seed transport through the cells and delivery into the furrow, while the efficiency of the seeding process depends on the degree of seed mixing, disk rotation stability, and the uniformity of individual seed release. Simulation results showed that an optimal combination of these parameters provides a high percentage of acceptable seed placement; however, the design is sensitive to vibrations and operating modes, which may reduce seeding accuracy under actual field conditions.

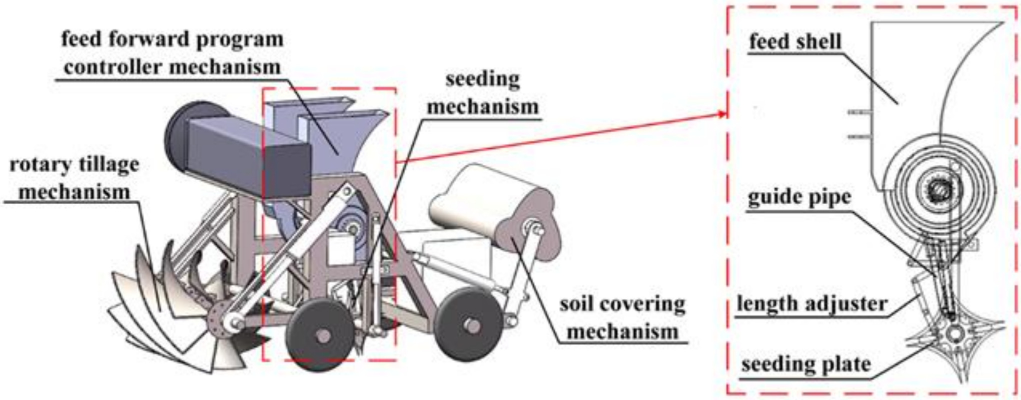


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Fig. 7. Design of a Zero-Tillage Precision Corn Planter [28]: a – 3D model of a direct-seeding corn planter; b – 2D diagram of the seed dispensing mechanism and metering system

The review studies [13, 30] provide a detailed analysis of various aspects of applying the Discrete Element Method (DEM) to model soil tillage processes and furrow formation for optimizing working-tool designs (Fig. 8). The authors examined different models of contact interaction, particle shapes and sizes, as well as calibration techniques required for accurately reproducing soil environments. Special emphasis is placed on DEM’s capabilities to predict furrow profiles, disturbed-surface topography, soil fracture and displacement patterns, and the reactive forces generated during opener operation. The studies also describe the specific features of modelling various soil types represented as discrete particles.

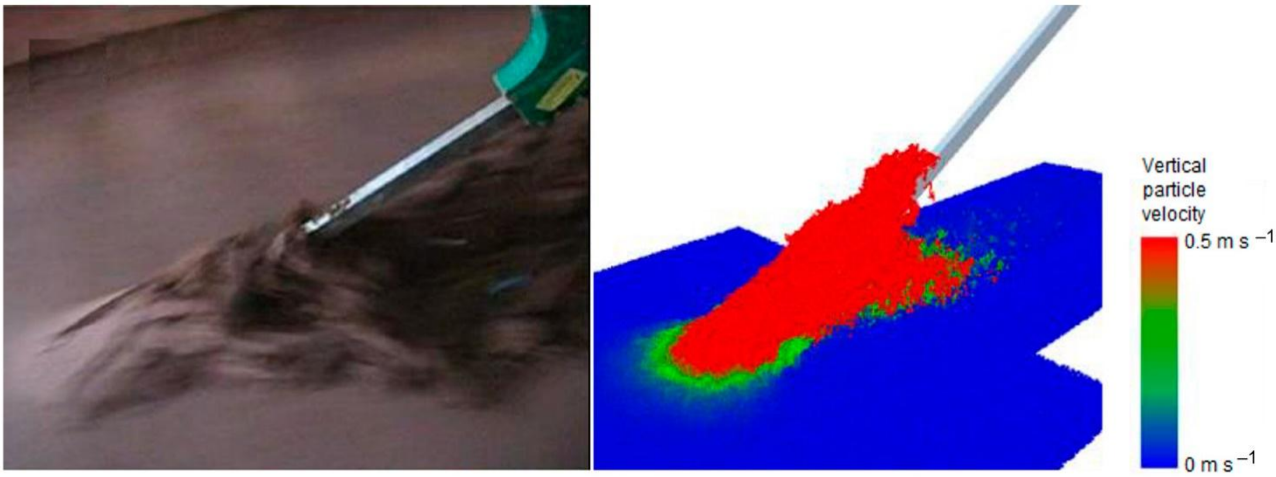

Fig. 8. Discrete Element Method Simulation of a Narrow-Opening Opener Operating in Moist Sandy Loam–Loam Soil Conditions [13, 30]

Research on alternative and combined opener designs continues to develop actively. In particular, study [31] tested a seed drill equipped with combined working tools–such as shovel–disk openers–under NO-TILL conditions. The results showed that this configuration may be more effective than traditional shovel-type units. However, a limitation is that the tests were conducted under restricted conditions, so the results cannot yet be fully generalized to different soil types and crops.

Another important direction in domestic research is the evaluation of the performance of runner-type openers used in grain drills [32]. Study [33] examined the behavior of such openers with reinforced runners under field conditions, focusing on the influence of reinforcement on wear resistance, operational stability, and productivity. However, the limitation of these studies is a narrow set of testing scenarios–mainly within a single soil type or specific region.

An analysis of the existing literature shows that despite the substantial number of experimental, analytical, and design-related studies, most works share common constraints. Research is typically conducted under a limited set of soil characteristics and field parameters, making it difficult to extrapolate results to real production conditions, where external variability is significantly higher. Frequently, studies focus on individual opener types, specific structural configurations, or particular material grades, which restricts the generalization of obtained data. Many studies are performed in laboratory conditions or on test stands that do not reproduce the real dynamics of field processes or account for the influence of crop residues, soil hardness variations, terrain irregularities, frame oscillations, and other factors.

A further limitation of many analytical models is the use of idealized assumptions regarding furrow geometry, soil compaction levels, particle behavior, or the nature of tool–soil interaction. Such models are not always capable of reproducing the complex dynamics of the process, reducing the accuracy of their application in real conditions.

Research on new or combined opener designs also fails to fully reveal their performance across a broad spectrum of operating scenarios. An additional challenge is that many experimental studies do not allow real-time monitoring of the working tool's behavior. Instrumented systems with depth and load sensors show significant potential, but their use is limited by high cost, technological complexity, and low scalability.

In this context, the Discrete Element Method (DEM) [14, 15] offers clear advantages, as it enables simulation of soil, seed, and tool behavior without the need to create numerous physical prototypes. DEM allows analysis of opener performance across a wide range of soil conditions, moisture levels, travel speeds, and design parameters, significantly expanding research capability compared with traditional experimental methods.

DEM also enables the study of processes that are difficult or nearly impossible to measure in field conditions: soil particle distribution, furrow formation, soil fracture and displacement patterns, particle–particle and particle–tool interactions, and reactive forces. This reduces the required number of physical tests, accelerates design optimization, and provides higher accuracy in predicting tool performance under varying conditions.

Thus, considering the numerous limitations and fragmented results of previous experimental and analytical studies, DEM-based numerical modelling is currently one of the most promising and effective approaches for improving opener design and predicting tool–soil interaction under variable field conditions.

Based on the conducted analysis, it was established that the row unit of a seed drill is a complex spatial structure composed of a support, damping device, link arm, knife opener, frame, and depth-control mechanism (Fig. 9). One end of the support is rigidly attached to the drill frame, providing basic fixation of the entire unit. At the opposite end, the link arm and damping device are pivot-mounted, and their spatial configuration is designed to enable parallel operation and synchronized movement of the opener under vertical loads.

The second end of the damping device is connected to the link arm, forming a kinematic pair that ensures coordinated relative motion between the two components. This kinematic interaction plays a crucial role in stabilizing the position of the row unit as it passes over soil irregularities, as it partially compensates for vertical oscillations and reduces the amplitude of impact loads transmitted to the knife opener. As a result, the damping device provides not only vibration attenuation but also smoother response of the unit to changes in terrain conditions, which is essential for maintaining a stable trajectory of the working tool.

A knife opener is rigidly attached to the lower part of the link arm; it directly forms the seed furrow and ensures seed placement at the required depth. The rigid connection provides precise force transmission and eliminates parasitic movements that could lead to deviations in seeding depth. At the rear of the link arm, a pivot-mounted wheel frame is installed, enabling free movement within the design constraints and coordinated interaction with other elements of the unit.

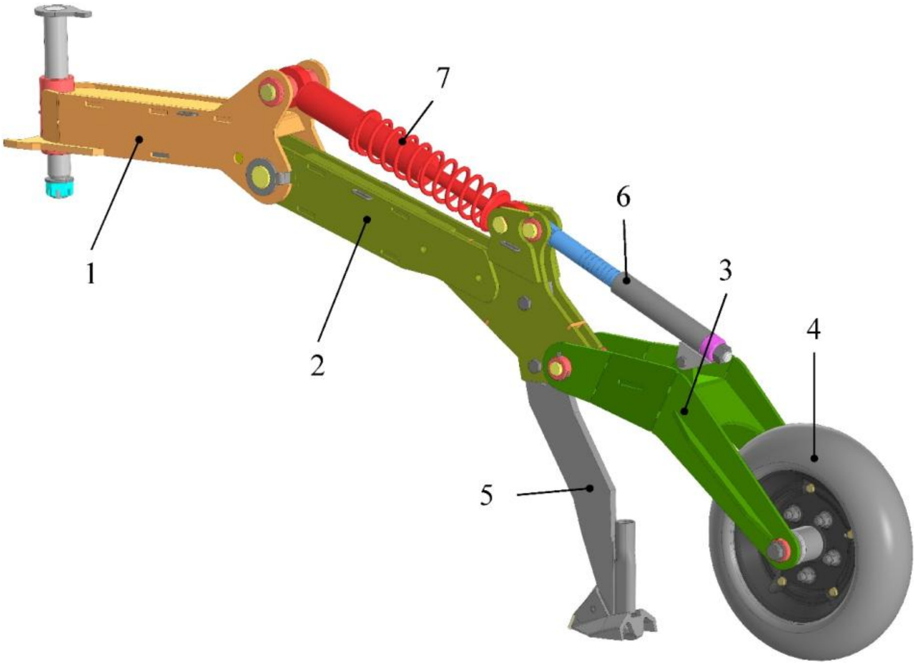

Fig. 9. Structural and Technological Diagram of the Row Unit: 1 – support; 2 – link arm; 3 – frame; 4 – wheel; 5 – knife opener; 6 – depth-control mechanism; 7 – damping device

A press wheel is mounted on this frame to stabilize the row unit's operation in the longitudinal plane. The wheel performs a dual function: first, it maintains the required seeding depth by limiting the vertical movement of the opener; second, it stabilizes the soil in the furrow zone, contributing to the formation of a uniform seedbed. To precisely adjust the working depth, the wheel frame is equipped with a depth-control mechanism that allows altering the wheel position and, accordingly, adjusting the operating depth of the knife opener. Adjustment is carried out with consideration of agronomic requirements, soil physical and mechanical properties, and the operating speed of the machine.

The proposed structural and technological scheme ensures coordinated operation of all row-unit components and effectively compensates for dynamic loads arising during machine movement. The use of a damping device facilitates a significant reduction in vertical oscillations, ensures smoother opener movement, and improves the quality of furrow formation. In turn, this is critically important for achieving uniform seeding depth and obtaining even, vigorous crop emergence, which determines the effectiveness of subsequent plant development and the overall productivity of the seeding process.

5. Conclusion

Ensuring stable seeding depth and high-quality furrow formation remains one of the most critical challenges in the design of row units. Traditional passive ground-following systems, although simple and reliable, show insufficient effectiveness under increased travel speeds and uneven terrain. Active systems with hydraulic and electromechanical actuators provide high precision, but they are complex, costly, and difficult to scale for most farms. Likewise, various damping systems partially mitigate vibrations but do not offer a comprehensive solution for stabilizing opener motion.

The review of opener designs demonstrated that existing types–from double-disk to combined configurations–have clearly defined functional limitations. Most studies are conducted under laboratory or modelled conditions, which do not account for the full variability of real soil environments, the presence of crop residues, or field irregularities. Similarly, the potential of sensor-based depth-monitoring systems remains limited: although accurate, they require expensive equipment and complex integration.

The application of DEM simulation plays a particularly important role in addressing these issues. The method enables the assessment of soil particle behavior, reactive forces, and the dynamics of tool–soil interaction, making it possible to optimize opener and row-unit designs without producing numerous physical prototypes. DEM provides the foundation for justifying new technical solutions.

Against this backdrop, the proposed structural and technological scheme of the row unit is distinguished by its comprehensive approach and elimination of the key shortcomings of existing designs. It integrates the coordinated operation of the link arm and damping device, forming a synchronized kinematic system for stabilizing the motion of the knife opener. The rigid attachment of the opener to the link arm improves force transmission accuracy and eliminates parasitic movements, while the adjustable press-wheel frame ensures stable seed placement depth across a wide range of soil conditions.

Compared to traditional systems, the proposed scheme effectively absorbs impact loads, minimizes vertical oscillations, and ensures coordinated interaction of all row-unit elements. This creates the prerequisites for improved seeding uniformity and crop emergence, confirming the relevance of further refinement using DEM simulation.

Thus, the literature analysis not only outlined existing problems and limitations but also provided objective grounds for developing a new row-unit design capable of delivering greater stability and seeding quality under variable terrain and dynamic loading conditions.

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ШЛЯХИ УДОСКОНАЛЕННЯ КОНСТРУКЦІЇ ВИСІВНОЇ СЕКЦІЇ СІВАЛКИ НА ОСНОВІ DEM-МОДЕЛЮВАННЯ

У статті розглянуто актуальну науково-технічну проблему підвищення стабільності роботи висівних секцій сівалок за умов змінного рельєфу та неоднорідних фізико-механічних властивостей ґрунту. Проаналізовано сучасні конструкції механізмів копіювання рельєфу та амортизації, їхні обмеження у забезпеченні сталої глибини загортання насіння, а також проєктні рішення для різних типів сошників. Особливу увагу приділено недолікам традиційних експериментальних досліджень, які не дозволяють повною мірою відтворити реальні динамічні процеси взаємодії сошника з ґрунтом.

Показано, що значна частина існуючих конструкцій втрачає ефективність за підвищених швидкостей руху або на пересічених ділянках поля, що призводить до нестабільності глибини висіву та зниження рівномірності сходів. Наведено результати аналізу сучасних досліджень, зокрема щодо зношування сошників, впливу типу дисків на якість висіву, розробки комбінованих робочих органів та застосування сенсорних систем контролю глибини.

Визначено перспективність використання методу дискретних елементів (DEM) для моделювання динаміки роботи висівних секцій, оскільки він дозволяє оцінювати процеси формування борозни, поведінку частинок ґрунту, реактивні сили та стабільність руху сошника без потреби у створенні численних фізичних прототипів.

На основі проведеного аналізу запропоновано нову конструктивно-технологічну схему висівної секції, що включає узгоджену роботу поводка, демпфувального пристрою та механізму регулювання глибини. Така конфігурація забезпечує ефективне гасіння коливань, зменшення ударних навантажень і підвищення стабільності глибини загортання насіння. Розроблена конструкція є обґрунтованою для подальшої оптимізації та верифікації на основі DEM-моделювання.

Ключові слова: *висівна секція, сошник, DEM-моделювання, сівалка, копіювання рельєфу, амортизація, динаміка взаємодії, глибина загортання насіння, анкерний сошник, вібрації, конструктивна оптимізація, посівний комплекс.*

Рис. 9. Літ. 33.

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