Application of the new structural solutions in the seeders for precision sowing as a resource saving direction

Article · September 2018

DOI: 10.15587/1729-4061.2018.142023

Nataliia Gerasymchuk
Rzeszów University of Technology

Проведеними дослідженнями представлена можливість підвищення надійності виконання технологічного процесу дозування насіння, що впливає на результативність – витрати посівного матеріалу, шляхом введення в конструкцію висівного апарата дозатора направленої дії. Для проведення досліджень розроблено пневмомеханічний апарат з дозатором направленої дії. Присмоктуючі активні комірки дозатора, провертаючись змінюють своє положення з метою кращої орієнтації щодо дозованого насіння. Експериментальними дослідженнями підтверджено, що дозатор направленої дії за рахунок активних присмоктуючих комірок покращує умови дозування при висіві насіння. В результаті використання нового конструктивного рішення дозатора на 12 % підвищена точність виконання технологічного процесу формування регулярного однозернового потоку насіння. Розроблено методику експериментальних досліджень для встановлення і обчислень параметрів надійності виконання апаратом технологічного процесу висіву.

Встановлено закономірності появи пропусків і двійників в залежності від основних технологічних параметрів роботи висівного апарата: швидкості руху дозуючого елемента і ступеня розрідження у вакуумній камері. Дослідженнями виявлено, що насіння сої практично не утворюють двійників і ймовірність їх виникнення близька до нуля. Визначено значення стохастичних показників точності виконання технологічного процесу висіву, якими підтверджено переваги апарата з дозатором направленої дії в порівнянні з серійним.

Для оцінки ефективності роботи висівних апаратів доцільно використовувати комплексний показник ймовірності точності висіву, який включає ймовірність появи пропусків, ймовірність утворення двійників і ймовірність відхилення насіння від заданої точки висіву при практично відсутньої інверсії.

В результаті використання нового конструктивного рішення дозатора, підвищена точність виконання технологічного процесу формування регулярного однозернового потоку. Ймовірність точності висіву дослідного апарата, як комплексний показник підвищення ефективності його використання, на 0,11 більше ніж у серійного

Ключові слова: пневмомеханічний висівний апарат, дозатор направленої дії, насіння, точний висів, ймовірність пропусків, ймовірність двійників, ймовірність точності висіву

UDC 631.331: 330.34
DOI: 10.15587/1729-4061.2018.142023

APPLICATION OF THE NEW STRUCTURAL SOLUTIONS IN THE SEEDERS FOR PRECISION SOWING AS A RESOURCE SAVING DIRECTION

A. Boyko
Doctor of Technical Science, Professor*
P. Popyk
PhD, Senior Lecturer*
E-mail: GTP2005@i.ua
I. Gerasymchuk
PhD
E-mail: m407@ukr.net
O. Bannyi
PhD, Senior Lecturer*
E-mail: bannyy@nubip.edu.ua
N. Gerasymchuk
Doctor of Economical Sciences, Professor
E-mail: 90999nag@gmail.com
*Department of Engineering Reliability
National University of Life and Environmental Sciences of Ukraine
Heroiv Oborony str., 15, Kyiv, Ukraine, 03041

1. Introduction

Up to now, development of the national economy has been predominantly extensive. Consequently, enhancing the resource potential and ensuring the stable growth of production volumes have required the ever-increasing amount of additional raw materials. Under the new economic conditions, there is a significantly increased shortage of raw materials, which is why the economical use of resources should become a major priority for development of the economic complex. Given the complexity of industrial processes and the increased cost of resources used in the process of production, it becomes a relevant task to stimulate careful use. The specific conditions of functioning of sectors in the agroindustrial complex (AIC) restrict in a certain way the dynamics, volumes of resource flows, organization and regulation. These flows could be activated through saving the resources at all stages of the production process in the agricultural sector based on constructing the resource-saving logistics systems, which can be considered a promising field of scientific research.

To improve technologies in agriculture, four main areas were identified. The first one is the application of rational schemes for placing plants in order to make the best use of land and equipment, which makes it possible, by exploiting the biological features of plants, to save resources of fertilizers and chemicals. The second area is to reduce the number of farming techniques based on combining them in combined units, for example, sowing and fertilizing, which requires the renovation of agricultural machinery, but, in the long run, could save resources and improve environmental parameters. The third area, close to the second one, is the flow execution of operations within separate technological operations, such as harvesting crops, clearing the field from straw, disking, etc.

The fourth area is the application of new technologies related to equipment and processes, specifically a precision seeding technology.

Improving the precision seeding was addressed in many studies; several promising units have been designed. The obtained results meet the agricultural requirements for sowing technical crops to a certain extent, however at present it is not possible to argue about the issue having been completely resolved. Further studies in this field remain relevant; their positive results open up the prospects to save not only the seeding material, but to increase the overall crop yield as well.

2. Literature review and problem statement

The result of the recent trends in the development of sowing technologies and, accordingly, machinery for their implementation was the need for new structural solutions of seeding units, aimed at improving the precision of their operation. Scientific solutions and design improvements of the pneumomechanical device were directed at improving the precision of operation of pneumomechanical seeding units, specifically to change the shape of the suction cell of a sowing disk and to change the profile of discharge of extra seeds [1, 2]. The proposed structural solutions have almost reached their limits, thereby making it a relevant issue to substantially improve the design of the pneumomechanical unit in order to enhance its technological reliability.

Paper [3] analyzed the designs and special features of the structure of seeding units intended for the formation of a regular one-seed sowing with the aim of creating a machine that would meet modern requirements to the precision of sowing [3]. Special attention was paid to machines whose designs include elements of universality when capturing seeds of different shapes.

Several studies [4–6] have addressed improving the precision of sowing. In recent years, the process of sowing has increasingly employed seeders for precision sowing that satisfy modern agricultural requirements and make it possible to implement intensive and resource-saving technologies when growing agricultural crops [7–9].

The impact of the seeder's motion speed on quality (precision) of sowing has been examined comprehensively in studies by different authors [10–12]. It can be considered an established fact that increasing the speed above 2 m/s significantly reduces the accuracy of sowing. It is possible to resolve the specified pattern by improving the system of dosage in a sowing machine. This is especially important for modern conditions of land practices under which there is a general tendency for increasing the productivity of operations and reducing their duration.

In order to reveal the maximum potential of a crop, it is necessary to apply the seeder that would evenly distribute seeds.

The pneumomechanical units that were initiated in the 1930s have satisfactorily handled the sowing of non-calibrated seeds and the seeds with a rough surface. The advantages of pneumomechanical units include their high versatility, a rather simple design, and operational reliability [13]. Note, however, that these units fail to uniformly distribute seeds along the length of the row. A significant scientific contribution to the development of agricultural machinery was made by authors who considered the probability and the patterns of seeding in papers [14, 15]. The main shortcomings in the work of dosing systems in the pneumomechanical seeding machines are the gaps and the formation of double items, which, from the perspective of reliability of performing a technological process for dispensing the seeds, could be categorized as failures.

3. The aim and objectives of the study

The aim of this research is to improve the precision of sowing the seeds of row crops using the example of a sowing unit with a dispenser of targeted action.

To accomplish the aim, the following tasks have been set:

– to identify ways to improve the pneumomechanical seeding units in order to enhance the precision of sowing;

– to determine basic stochastic indicators for the operation of pneumomechanical seeding units: the probability of forming the double items, the probability of the occurrence of gaps, the probability of sowing precision.

4. Materials and methods to study the work of pneumomechanical seeding units

4. 1. The subject of research used in the experiment

The base of a precision sowing seeder is the seeding unit that should ensure an uninterrupted, one-grain flow of seeds into a furrow under different conditions of use.

A hypothesis for the development of a sowing machine with a dispenser of targeted action implies designing a pneumomechanical unit with a cell that changes its position to fit best its orientation relative to the dispensed seeds. The concept of developing such a device implies the improvement of sowing precision.

The seeding unit is composed of vacuum chamber (Fig. 1, 2), to which seed chamber 2 is connected. Between the chambers, there is sowing disc 3.

Sowing disc 1 (Fig. 3) is a plate with the through drills in a circle of diameter D, which hold swivel cells 5 with levers 3 whose ends are pressed by springs 4 against the working surface of copier 2.

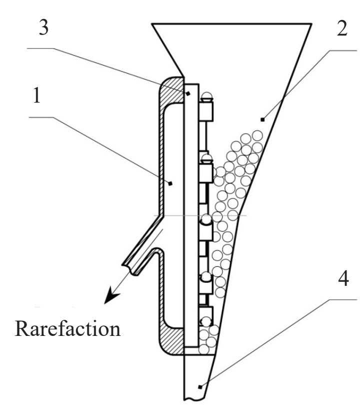

Fig. 1. Schematic of sowing pneumomechanical unit with a dispenser of targeted action: 1 — vacuum chamber; 2 — seed chamber; 3 — sowing disk; 4 — seed pipeline

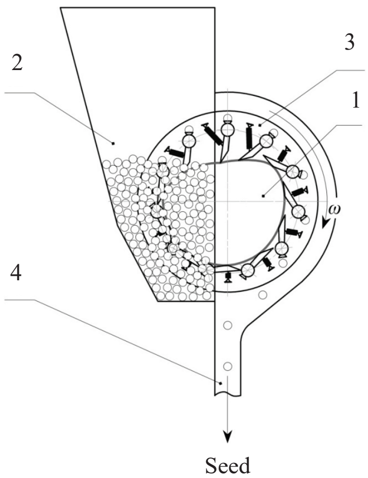

Fig. 2. Schematic of sowing pneumomechanical unit with a dispenser of targeted action (side view): 1 – fixed copier; 2 – seed chamber; 3 – sowing disk; 4 – seed pipeline

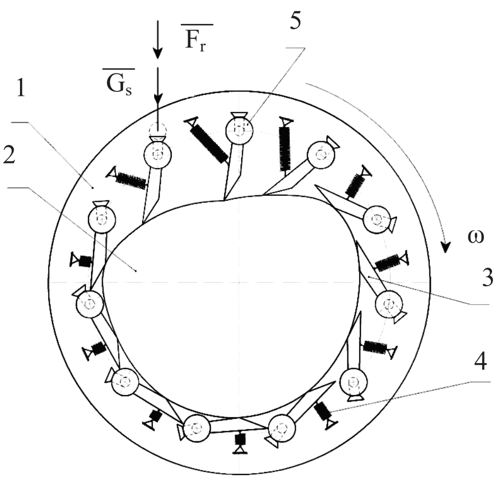

Fig. 3. Schematic of dispensing disk with a dispenser of targeted action: 1 – sowing disk; 2 – fixed copier; 3 – lever; 4 – spring; 5 – rotating cell

The ends of axial drilling *A* (Fig. 4) and radial drilling *B* of rotating cell 1 coincide. Drillings *B* have conical nozzles 2. The rotating cell is mounted into sowing disc 4 and is locked by locking ring 3.

The pneumomechanical sowing unit operates in the following way. During work of the sowing unit, under the action of an external source, there occurs the rarefaction in the vacuum chamber within 4.0...5.0 kPa. The rarefaction is passed along the drillings to the rotating cell.

Due to the rarefaction, a seed from the seed chamber is sucked into the nozzle of the rotating cell where it rotates along with the sowing disk. In this case, the rotating cell with a seed copies, through levers, the working surface of the fixed copier. The radial drilling of the rotating cell will remain in the upright position until the axial drilling of the rotating cell leaves the plane of the vacuum chamber.

Owing to the presence of the immovable copier and levers of the rotating cell, the radial drilling acquires a vertical position from the moment of capturing a seed from the seed chamber until the rarefaction stops acting on it.

A seed due to its own weight enters the seed pipeline and, next, the coulter.

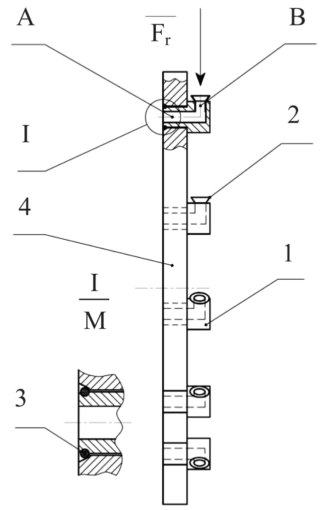

Fig. 4. Schematic of dispensing disk with rotating cells (side view): 1 – rotating cell; 2 – nozzle of the cell; 3 – blocking ring; 4 – sowing disk

It is assumed that the changes introduced to the design of the unit would ensure the best conditions for capturing, keeping, and removing from the bulk of seeds, a single seed to enable its transportation to the seed pipeline even at a slight rarefaction in the vacuum chamber [16, 17].

An analysis of the structures of units made by leading global manufacturers allowed us to select the most rational design of the device to be investigated experimentally.

The special feature of the sowing unit of the seeder Kleine Multicorn SK-8 (Germany) is the existence of the rotor that moves in the same direction and at the same speed as the entire sowing machine. Thus, a seed enters soil from the blade of the rotor at almost zero speed relative to the ground. That prevents the inertial rolling of seeds along the seed bed along the row.

Carrying out experimental field study of the sowing section, equipped with a dispenser of targeted action, requires that it should be modified.

The adjustment implies the introduction of the dispenser with a targeted vector of action to the design of the sowing unit of the seeder Kleine Multicorn SK-8. To this end, it would suffice to replace a standard sowing disk with peripheral cells (Fig. 5) in the form of holes with the required diameter and shape with the dispenser with active cells of targeted action (Fig. 6). Replacing a standard sowing disk with the experimental one does not require any significant changes to the design of the sowing machine.

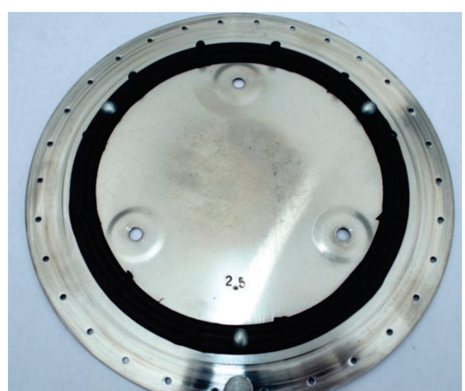

Fig. 5. Standard sowing disk

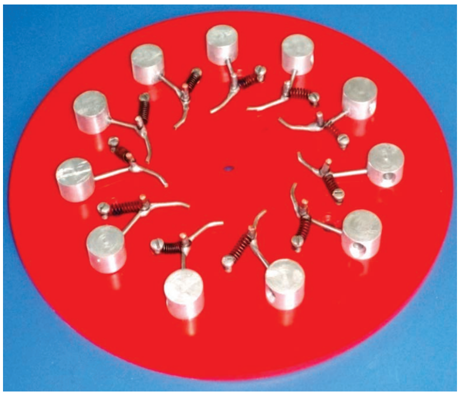

Fig. 6. Sowing disk with active cells for targeted action

The dispenser of targeted action is mounted onto the blade rotor located in the body of the vacuum chamber.

The copier is rigidly set in the seed chamber so that its axis coincides with the axis of rotation of the dispenser with targeted action.

The main constituent elements of the dispenser with active cells of targeted action are a rotating suction cell with a lever (Fig. 7) and a copier (Fig. 8).

Fig. 7. Suction cell with a lever

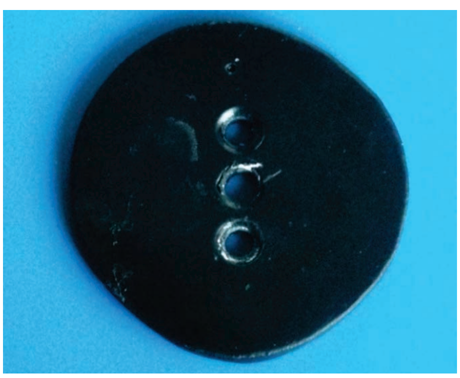

Fig. 8. Copier

The rotating cell has an axial and radial drilling that make up the L-shaped channel with rarefaction that creates the suction force. A beginning of the radial drilling has a recess of conical shape, which forms a cell. The rotating cell is fixed at the disk using a corkscrew ring. The suction cell copies the working surface of the fixed copier with the help of the sprung lever.

The copier's profile is based on the rational values for the cell orientation angle θ regardless of the change in the angle of rotation of sowing disk φ for all phases of operation of the pneumomechanical sowing machine. Of practical importance is the correct orientation of the cell, which is required to reliably capture a seed, its transportation, the possibility to dispose of excessive seeds by centrifugal force and to discharge the bulk of seeds into a coulter.

Distributing the seed flow that arrives from the bunker to the seed chamber is contributed to by the blade rotor, specifically installed in a given standard sowing unit, to which the sowing dispenser is attached with screws (Fig. 9).

Installing the dispenser of targeted action does not require changes to the shape and volume of the vacuum chamber. Only the seed chamber is to be modified; a fixed copier is installed inside it (Fig. 10).

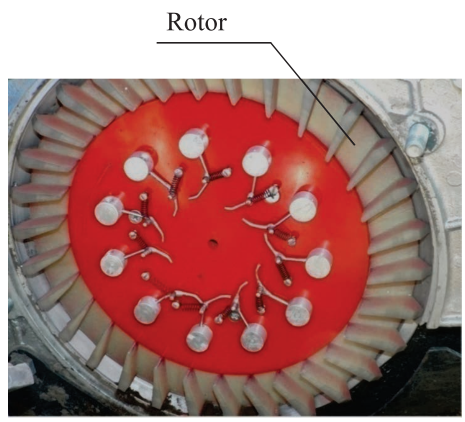

Fig. 9. Rotor of the sowing unit of the seeder Kleine Multicorn SK-8 seeder with the dispenser of targeted action

Fig. 10. Seed chamber of the seeder Kleine Multicorn SK-8 with a fixed copier

General view of the modified sowing section with a dispenser of targeted action is shown in Fig. 11.

Fig. 11. General view of the examined sowing section

The proposed design of the sowing unit with the dispenser of targeted action is patented in Ukraine [18]. The complication of the design of the dispensing unit is compensated for by its versatility when used for sowing the seeds of different cultures and fractions.

4. 2. Procedure for conducting field experiments

Experimental study is conducted according to the existing standards for quality assessment of sowing operations [19].

The field study is conducted during sowing under actual operating conditions of the seeder Kleine Multicorn SK-8, which is connected to tractors of class 1.4 and 2 kN.

To conduct the study, one of the standard sowing sections in the seeder is replaced with the specially prepared experimental one. Such a replacement makes it possible to run a comparative evaluation of operation of the standard and experimental sowing sections under identical conditions [20].

Sowing is performed at the plot of the field prepared in advance. The working speed of the unit is chosen based on the agrotechnical requirements for sowing in the range of 5...9 km/h. The working rarefaction, required for sowing the seeds of different crops and fractions, is set to range from 2.5 to 5.5 kPa. The depth of burying the seeds is selected at the level of 40...120 mm.

We measured spacing between seeds using a measuring instruments (roulette, liner). After sowing, the distance between the seeds is measured with an accuracy of up to 5 mm; the data are then entered in special tables for further statistical processing.

The quality of the technological process of sowing is estimated based on the precision of sowing along a row [21]. Parameters of quality are accepted to be the indicators of reliability with respect to possible gaps and the emergence of double items when feeding the seeds to the furrow.

5. Results of studying the pneumomechanical sowing unit with a dispenser of targeted action

The shape of a seed and the state of its surface largely affect the density of contact between it and the surface of the suction hole in a cell of the dispensing disk. Since we selected the conical shape of the cell, the tightest coupling that ensures the maximum magnitude of the suction force is the soybean seed. Similar to most granular seeds, its shape is the closest to spherical, which produces, in a combination with the conical shape of the hole of the cell, the coupling almost in a circle.

The results of experimental study into the pneumomechanical machine with a dispenser of targeted action for the precision of sowing have revealed the relationship between the speed of displacement of the dispensing element and the degree of rarefaction in the vacuum chamber.

The sowing was performed under a standard operational mode of the seeder at the speed of its motion $V_s = 9$ km/h and at the rarefaction in the vacuum chamber $P = 4$ kPa. When the motion speed of the seeder is converted into the displacement speed of the dispensing disk, we obtain $V_d = 0.4$ m/s.

Fig. 12 shows dependences of the emergence of spaces and double items when sowing the seeds of soybeans.

One of the important parameters that significantly affect the quality of dispensing when separating seeds from the bulk is the degree of rarefaction in the vacuum chamber. Investigating the impact of this parameter on probability of spaces has shown that an increase in rarefaction in the vacuum chamber leads to a decrease in the probability of spaces. At the same time, there is a non-linear relationship between these magnitudes and a gradual decrease in the influence of rarefaction.

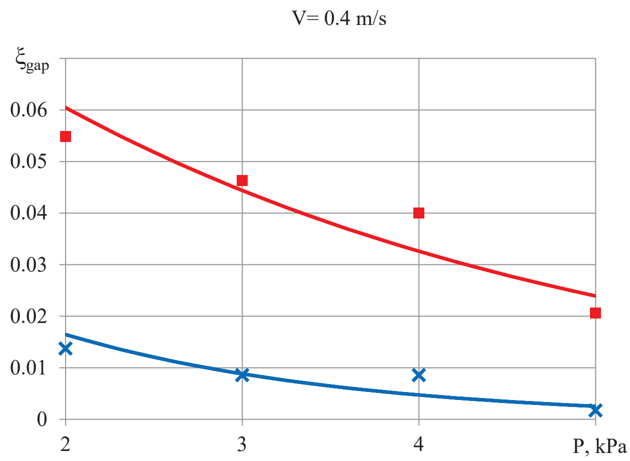

Fig. 12. Dependence of probability of spaces on the degree of rarefaction in the vacuum chamber: ■ – standard sowing unit; × – experimental sowing unit

The dependence of the probability of double items on the degree of rarefaction in the vacuum chamber is shown in Fig. 13.

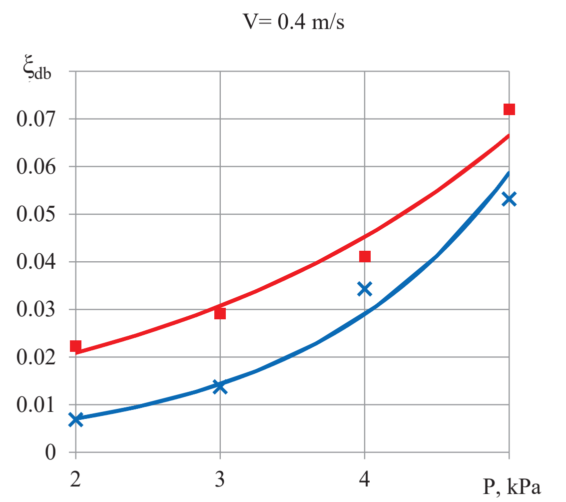

Fig. 13. Dependence of probability of double items on the degree of rarefaction in the vacuum chamber: ■ – standard sowing unit; × – experimental sowing unit

The charts show that they have opposite dependence in comparison with the probabilities of spaces (Fig. 13). That is, an increase in rarefaction leads to an increase in the probability of emergence of double items. Moreover, a given pattern is characteristic of the standard and the experimental units. Dependences demonstrate a non-linear character with a gradual increase in the probability of double items with an increase in rarefaction.

The results of research are shown in Fig. 14 in the form of graphical dependences of change in the probability of spaces ξ_{db} on the speed of displacement of the dispensing element V relative to the weight of seeds in the loading chamber.

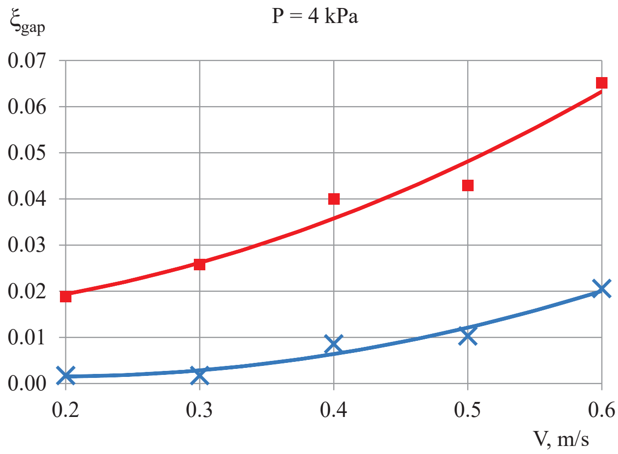

Fig. 14. Dependence of formation of spaces on the displacement speed of the dispensing element: ■ – serial sowing unit; × – experimental sowing unit

The Figure above shows that all charts are nonlinear in character. Typical for them is an increase in the probability of spaces with an increase in the relative motion speed of the dispensing element.

The second kind of failures in the pneumomechanical unit is the emergence of double items – a simultaneous suction of several seeds. At a stable magnitude of rarefaction ($P=4$ kPa) we established the non-linear dependences of change in the probability of the occurrence of double items on the speed of relative displacement of the dispensing cell (Fig. 15).

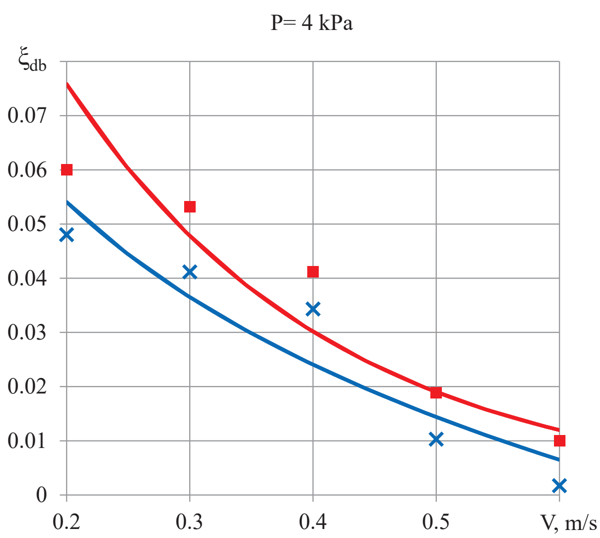

Fig. 15. Dependence of the formation of double items on displacement speed of the dispensing element: ■ – serial sowing unit; × – experimental sowing unit

The chart shows that dependences descend non-linearly. An increase in speed leads to a decrease in the probability of double items. Given this, the larger the motion speed of a dispensing element, the greater the probability to dispose of the excessive seeds.

Based on these results, we can state that the effectiveness of operation of the experimental sowing unit with a dispenser of targeted action is predetermined, above all, by a significant decrease in the probability of emergence of spaces and double items, by 1.2 to 3.6 times.

6. Discussion of results of studying the pneumomechanical sowing unit with a dispenser of targeted action

The practical significance of the obtained results emphasizes that the proposed pneumomechanical precision sowing unit with a dispenser of targeted action demonstrates not only the greater performance and the higher quality, compared with the sowing machine-analog, but ensures saving the seed material as well.

The examination of functioning of sowing units made by leading manufacturers of seeders allows us to assert that the obtained results have strengths and weaknesses in the technological process of sowing. That means that taking this fact into consideration opens up a possibility for the further improvement of designs of precision sowing seeders. Based on this, we have proposed a rational structural solution for the pneumomechanical unit of precision sowing with a dispenser of targeted action.

It should be noted that the common notion of precision, based on statistical data processing, requires a refinement to characterize the quality of sowing. It is known that assessing the sowing produces large values for the coefficient of variation, which describes the inaccuracy due to the inversion of seeds distribution relative to the predefined places of their location. In order to account for this circumstance, which introduces inaccuracies to the estimation when applying the standard statistical approach, our study justifiably introduces a constraint in the form of a probability of the seed taking the precalculated place with a limited regulated deviation. The sowing precision could then be characterized by the product of three probabilities: ξ_{gap} is the probability of emergence of gaps, ξ_{db} is the likelihood of emergence of double items, $\xi_{\{\eta\leq\pm h\}}$ is the probability of deviation in the seed position.

With respect to the notation adopted in the present study, the formula for determining the probability of sowing precision is recorded as follows:

$$\xi_{pr}=(1-\xi_{gap})\cdot(1-\xi_{db})\cdot\xi_{\{\eta\leq\pm h\}}, \qquad (1)$$

where $\xi_{\{\eta\leq\pm h\}}$ is the probability that the deviation of the actual position of the sown seed η from the desired position is not larger the sowing step h.

The sowing step h is assigned according to agronomic conditions for sowing, or can be calculated based on the established norm of sowing. Anyhow, the desired points of sowing (location of seeds) could be defined as the places of their theoretical ideal position in a furrow. Deviation from this position produces the scattering of points of the actual sowing around the desired one. Stochastic characteristics of such a spread, and, therefore, the likelihood $\xi_{\{\eta\leq\pm h\}\}}$, are determined in the course of experiment.

Probabilities ξ_{gap} and ξ_{db} are the characteristics of operation of the sowing machine, which is why data on them are taken from the results of laboratory research and are given in Table 1. The probability of deviation in a seed position from the required $\xi_{\{\eta\leq\pm h\}}$ is determined based on the results of measurements carried out directly during experiment. Statistical processing of these data allowed us to calculate probabilities $\xi_{\{\eta\leq\pm h\}}$ for the standard and experimental units, which are given in Table 1.

The result obtained for the precision of sowing, derived from formula (1), matches the desired data for the best samples of pneumomechanical seeding machines. This confirms the appropriateness of recommending the developed unit for production.

Table 1

Basic stochastic indicators for operation of pneumomechanical seeding units

Seeding unit	Operational indicators			
	Probability of gaps	Probability of double items	Probability of deviation in a seed position	Probability of sowing precision
	ξ_{gap}	ξ_{db}	$\xi_{\{\eta\leq\pm h\}}$	ξ_{pr}
Standard seeder Kleine Multicorn SK-8	0.04	0.041	0.88	0.81
Experimental with a dispenser of targeted action	0.008	0.034	0.96	0.92

7. Conclusions

1. A commonly accepted trend in the development of agricultural equipment for cultivating row crops is the design of seeders that implement a more precise sowing as a driver for saving seed material and improving yields. Promising for the further enhancement of sowing precision is the use of the pneumomechanical unit with a dispenser of targeted action.

2. The probability of sowing precision for the experimental unit, as a comprehensive indicator of the improved efficiency of its application, is larger by 0.11 than that for the standard Kleine Multicorn SK-8, which allows us to argue about the effectiveness of using the proposed design of the pneumomechanical sowing machine. This testifies to the possibility of improving the technology of agricultural production based on resource-saving.

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UDC 3326. 01
DOI: 10.15587/1729-4061.2018.143133

INFLUENCE OF ELASTIC CHARACTERISTICS OF RAW COTTON ON THE MECHANICS OF FEED ROLLERS IN THE CLEANERS FROM LARGE IMPURITIES

F. Veliev
Doctor of Technical Sciences, Professor*
E-mail: fazil-uzbek@mail.ru
R. Sailov
PhD, Associate Professor*
E-mail: rahib.sailov@yandex.com
*Department of technological machines and equipment of the branch
Azerbaijan State University of Economics (UNEC)
Istiglyaliyat str., 6, Baku, Azerbaijan, AZ 1001

Вплив строку збирання на якості бавовни-сирцю, а також на фізико-механічні властивості волокна, має величезне значення, так як від зрілості і засміченості бавовни залежить ефект очищення бавовни від сміття. Експериментальні дослідження проводилися в реальних польових умовах. Результати досліджень підтвердили, що час збирання істотно впливає на зрілість і якість бавовни-сирцю. Встановлено, що понад 60 % бавовни-сирцю зібраного при розкритті від 50 % до 60 % коробочок відповідає вимогам першого промислового сорту, тобто розривне навантаження волокна вище 4,5 гр. с. З огляду на той факт, що зрілий бавовна-сирець добре деформується, це призводить до підвищення очисного ефекту.

В результаті теоретичних досліджень визначені розпірні зусилля при деформації шару бавовни лопатями очищувача і проаналізовані форми деформованого шару бавовни-сирцю. Проведено оцінку пружних характеристик бавовни-сирцю і розрахунок розпірних зусиль. Для визначення чисельних значень сил тиску лопаті на потік бавовни-сирцю в коефіцієнті узагальнених властивостей матеріалу K величина V для бавовни-сирцю була прийнята в діапазоні 0,25–0,3.

Експерименти показали, що шар бавовни-сирцю товщиною від 170 до 380 мм і шириною 700 мм навантажувався зосередженої по лінії силою 3–10 кгс. Згідно з наведеними розрахунками встановлено, що 38,89 % часу в очищенні бавовни-сирцю бере участь одна лопать валика.

В результаті експериментальних і теоретичних досліджень отримані дані, які дозволяють організувати ефективну роботу очисних машин в бавовноочисній промисловості

Ключові слова: бавовна-сирець, розривне навантаження, очищувач великого сміття, бавовнозавод, зрілість бавовни сирцю, потік бавовни-сирцю, летучка бавовни-сирцю

1. Introduction

Development of a system for estimating the uniformity of feeding the cleaners, as well as requirements to the characteristics of feeding devices, is of practical importance in order to prepare raw cotton for the principal technological process. Studying the mechanics of interaction process between the working elements of feeding devices and a layer of transported material, as well as searching for feed systems with a targeted change in the technological properties of raw cotton, requires particular attention. It is a relevant task to investigate the interrelation between the physical-mechanical properties of raw cotton, the elastic characteristics of raw cotton, and efforts in the feed rollers. Addressing these issues would make it possible to find the optimal variant of raw cotton harvesting, which could lead to the improvement of harvested cotton, as well as strengthen the effect of cleaning the raw cotton from weedy impurities.

2. Literature review and problem statement

Paper [1] explored issues on cleaning the thin-fiber raw cotton, with focus on the strength of keeping the «fly» particles