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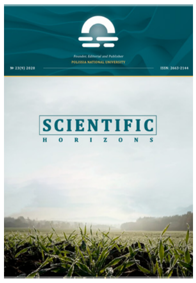


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# Prerequisites for the Creation of a Mechatronic System of Indented Cylinders for the Separation of Fine Seeds

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**Abstract**. Nowadays, an important aspect for achieving a high level of seed production is the expansion of the range of high-quality seed material, which disrupts the technological process of separation and increases its costs. The purpose of the study is to analyse indented separator cylinders for cleaning small-seed crops and develop an appropriate mechatronic system for their control, the use of which would allow performing the technological process of separation with lower specific operating costs and higher productivity. The presented analysis of the technical support of the process of separation of seed material of small-seeded crops indicates the need to improve indented separator cylinders based on automated control of their parameters using photo or video recording of the seed separation with subsequent processing. It has been established that the determination of formal performance indicators of an indented separator cylinder is not trivial. Based on the results of the analysis, a design and technological scheme of the mechatronic system of an indented separator cylinder has been developed. The difference between the proposed system and the conventional one is that the camera captures the trajectory of seeds. This information is processed in the control unit, which in turn changes the speed of rotation of the gear motor and, as a result, the drum with cells, the angle of inclination of the tray, the angle of rotation of the flap with the stepper motor of the hopper dispenser. These manipulations with the operating parameters of the indented separator allow adjusting it to changes in the seed mixture composition, thereby improving the quality and productivity of separation. In addition, due to the automatic adjustment of the operating parameters of the indented separator, the participation of the operator in the separation process is practically not required, which reduces labour costs

**Keywords**: seed, grain separator, control, automation, parameters, modes



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## INTRODUCTION

An important task of agro-industrial production remains to increase the range of seed material to meet the growing needs of farms of various forms of ownership. When the level of seed production is reached, the load on seed cleaning equipment increases, which leads to a violation of the technology of its in-line post-harvest processing [1].

The quality of seed material after processing is largely determined by the compliance of technical means of volume and rational technology of post-harvest seed treatment [2]. Therefore, seed treatment in existing production lines does not allow selecting high-quality seeds without cost and ensure the efficiency of their cleaning from impurities in length. In Ukrainian institutions engaged in selection and seed work, grain separators made more than 20 years ago are used as basic machines for cleaning seeds of various agricultural crops collected from research sites. Physically, the machines are worn out and need to be upgraded.

There are a large number of technologies and technical means of post-harvest seed processing and preparation of seed material of small-seeded crops. The most famous manufacturers of seed cleaning equipment are Bühler Schmidt-Seeger, Denis Prive, NEUERO Farm- und Fördertechnik GmbH, PETKUS Technologie GmbH (Germany), Zanin F.lli s.r.l. (Spain), Westrup (Denmark), Akyurek (Turkey). However, even the proposed integrated approach, including the use of universal cleaning machines, does not allow systematising and developing the technological basis for the processes of cleaning and separating seeds of a number of oilseed varieties, such as flax, mustard, rapeseed, ginger, sage, amaranth, etc. [3]. One of the options for solving this problem is to improve existing technical means for separation by creating mechatronic systems for automated control of their design and operating parameters.

Therefore, *the purpose of the study* is to analyse seed separators for small-seeded crops and to develop an appropriate mechatronic system for their control, the use of which would allow performing the technological process of separation with lower specific operating costs and higher productivity.

## THEORETICAL FOUNDATIONS OF THE SORTING PROCESS

Seed sorting is an important step in the overall seed processing. In the seed mixture collected from the fields, there are such impurities as stems, leaves, mineral impurities, etc. In addition, the seed material contains: low-quality seeds of other crops, broken and damaged seeds of the main crop, weed seeds [4-6]. The quality of seed material increases due to its processing by removing impurities and excess moisture. Separation machines are based on physical differences in characteristics that may exist between seeds of cultivated plants and other undesirable particles. Seed sorting can be considered as a subtask of separation and improving the quality of seed material.

The result of separation depends on various individual physical properties of seeds [7]. Examples of such physical characteristics are: size, length, weight, shape, colour, etc. [8]. Conducting an overview of the physical characteristics of various types of seeds is important for the further customisation of modern seed cleaning machines [9; 10] and for the development of new types of machines [11; 12]. Several such reviews were published [13-15], the generalisation of which allowed forming a modern technological line of processes for separating seed material of small-seeded crops according to their physical and mechanical characteristics (Fig. 1). New methods for determining these characteristics continue to be developed [16].

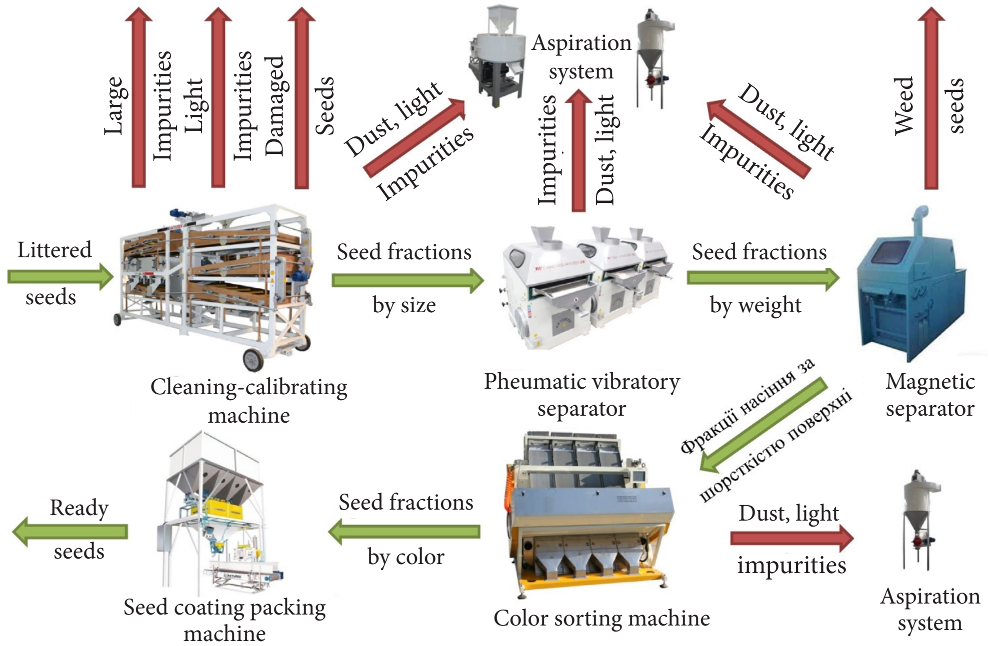


***Figure 1**. Modern technological line of oilseed separation*

***Source**: [3]*

All methods of seed material separation can be divided according to the corresponding physical and mechanical properties of seeds [17-19]: according to aerodynamic properties (in pneumatic columns and other air channels); according to dimensional characteristics (width and thickness – on sieves with round and rectangular holes, length – on indented separators); according to density or bulk volume (on pneumatic tables, pneumatic vibratory separators) [20-22]; according to surface properties and shape (on slides, friction separators); according to elasticity (on reflective sorting tables); according to electrophysical properties (in dielectric separators, separators in the corona discharge field); by colour (colour sorting machines) [23-25].

There are some preliminary studies in the field of mechanical seed separation and optimisation. For example, [26] investigated the improvement of the winnower and rice cleaning machine to reduce the amount of impurities and the loss of viable seeds. A prototype winnower and regression models were developed, through which the researchers drew conclusions about the choice of basic parameters such as air velocity, humidity, and feed rate. Other researchers [27] developed a mathematical model of cleaning efficiency in a stationary thresher. The model applies the principles of dimensional analysis as a theoretical basis. Dimensional analysis was also used in [28] for mathematical modelling of the cleaning process on flat sieves.

In [29], a hybrid intelligent approach was used to control pneumatic separators to obtain the most optimal result, including the use of an artificial neural network and genetic algorithms. A pneumatic separator was developed [30] and analysed using crushed mixtures of three lupine varieties. The researchers identified correlations between the parameters of the separation process and its efficiency. Automated modelling and control of post-harvest aspects have also been studied for seed drying and sorting systems [31]. Recently, there has been interest in the use of artificial intelligence methods to control such processes.

A cylinder with cells is used to sort or improve the quality of seeds using length as the main distinguishing feature. The cellular cylinder divides the seed mass into 2 fractions: "long" seeds and "short" seeds. There are also other seed sorting machines. The next machine used after the cylindrical separator is the gravity separator. This device separates seeds based on their weight. It is necessary that the seeds are relatively uniform in physical characteristics or length – any that a cylinder with cells can capture. The researchers [32] modelled the granular flow on the gravity separator table. Particle motion was modelled as a stochastic process [33]. In further analysis, the researchers [32] used digital imaging technologies and computer scanning (or image analysis) techniques as a mechanism for the empirical sampling of some of the corresponding initial cellular cylinder variables.

Work in related fields such as artificial intelligence and object recognition has been carried out for at least 60 years, starting with the invention of the first digital computers. Since then, these areas have developed and a large number of studies are being conducted in these areas. Over time, they gave rise to the field of computer scanning – an area of research aimed at developing methods for extracting visual information encoded by pixels of a digital image. The goal is to obtain digital or symbolic information necessary for decision-making [34; 35]. Both the main and applied discipline of computer science, this branch relies heavily on methods of geometry, statistics, physics, learning theory, etc., to obtain visual information from data stored in pixels [36; 37].

Automation and optimisation of seed validation and classification using computer scanning/image analysis remain important, especially for non-invasive seed germination testing [38]. Recently, the line of equipment for seed sorting has been supplemented with the use of a simple form of image analysis – colour division. Such a machine classifies certain types of seeds based on their colour using various sensors. Seed sorting machines are used at the end of the machining process [39; 40].

Classifying non-moving seeds is usually seen as a simple object recognition task. Researchers [41] addressed the problem of seed crops classification, focusing on various characteristics and categorisers. The artificial neural network (ANN) was one of the categorisers used. Discriminant analysis and k-nearest neighbour (k-NN) were used in the control (controlled) classification. A fairly popular and generally successful approach with controlled ANN was used to assess wheat quality [42]. Studies [43] have taken a very careful approach to the assessment of the quality and classification of barley seeds. The method used estimates of placement, orientation, direction, and surface structure of individual barley grains.

The studies mentioned so far are united by the fact that they do not deal with the actual physical separation of seeds. Instead, the studies were focused on the task of analysing images to classify seeds that were statically placed in front of the camera. The main focus was on developing new sorting machines – usually based on colour separation as a reference. An automatic seed sorting system based on machine scanning for automated classification of red and white wheat seeds was developed in [44]. The system was capable of processing 15 seeds per second with a classification coefficient of more than 92%. A similar system was developed [45] for testing wheat and other grain crops. The system was capable of processing 30 seeds per second with an accuracy of 95 to 99%. The experiment was conducted using red and white wheat grains.

The study [46] developed another low-cost image-based sorting device capable of processing 75 seeds per second. Minor colour deviations and small defects in the seed surface were the main criteria for classification.

An interesting innovation in seed sorting was a device patented in [47]. The idea that became the basis of this invention is a pellet sorting machine, which is based on the performance characteristics of an indented cylinder separator.

The presented analysis indicates the need to improve indented separators based on automated control of its parameters using photo or video recording of the seed separation process with subsequent processing.

## SEPARATION OF SEEDS ON INDENTED SEPARATORS

The length of the seed is used as an excellent physical characteristic in the cellular cylinder. As a rule, the seed material sent to the machine is divided into 2 groups: long seeds and short seeds. Cellular cylindrical machines are known as an indented separators. They sort seeds by length.

Figure 2 is a graphical representation of the perfect separation process in a cellular cylinder along the length. At the top is a graph of two normal distributions with different mean and standard deviations. These are examples of possible distribution of seeds by length in the input mixture. A circle in the centre represents a cellular cylinder. The cleaning process depends on several parameters: seed mix, machine settings, and interference that can and cannot be measured (controlled and uncontrolled). The input mixture is two-component – long (1) and short (2) seeds. The last 2 graphs show two separate divisions of long and short seeds into separate components. The scenario shown in Figure 2 is very simplified and can be considered unrealistic. The separation of input material by length in most cases cannot be statistically modelled as an ideal two-component mixture of long and short seeds. A more realistic way to statistically model the separation of the source material by length is to use the separation of a mixture of normal random variables with the corresponding mixture density.

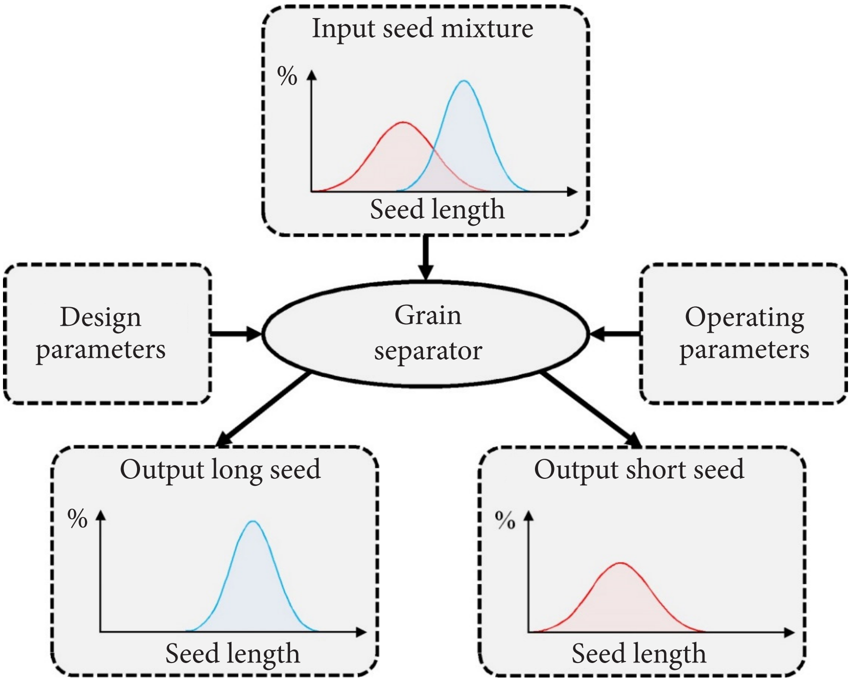


***Figure 2**. Conceptual model of the operation of indented grain separator*
***Source**: compiled by the authors based on [18]*

The working body of a cylindrical cellular separator is an inclined steel cylinder with cells of a certain shape and size. These cells are tightly located on the inner surface of the cylinder. Such a cylinder is usually made of a steel sheet that has indentations on the surface.

The cylinders have recesses with identical geometric dimensions or close to those shown in Figure 3. An overview of the principle of operation of an indented cylinder separator is shown in Figure 4. While the cylinder rotates at a constant speed, the seed enters the cylinder continuously from the raised end (for example, using a vibrating feeder). The seed falls to the bottom of the cylinder, where a layer of seeds is subsequently formed. The input material consists of seeds and other large components that do not fit in cells. In this case, they are affected by friction with the surface of the cylinder between the cells. Alternatively, they can fit, but due to their longer length, the centre of gravity will not be in the cells. These two scenarios usually result in a low level of rest during rotation. Other seeds and other small fractions (dust, broken seeds) are quite small and do not fit in cells (where they will remain dormant for some time before falling out of the cells). This is especially relevant for seeds with a length equal to or less than the depth of the cell. The centre of gravity of such seeds is usually located inside the cells, which means that the seed is securely fixed in the cell during rotation.

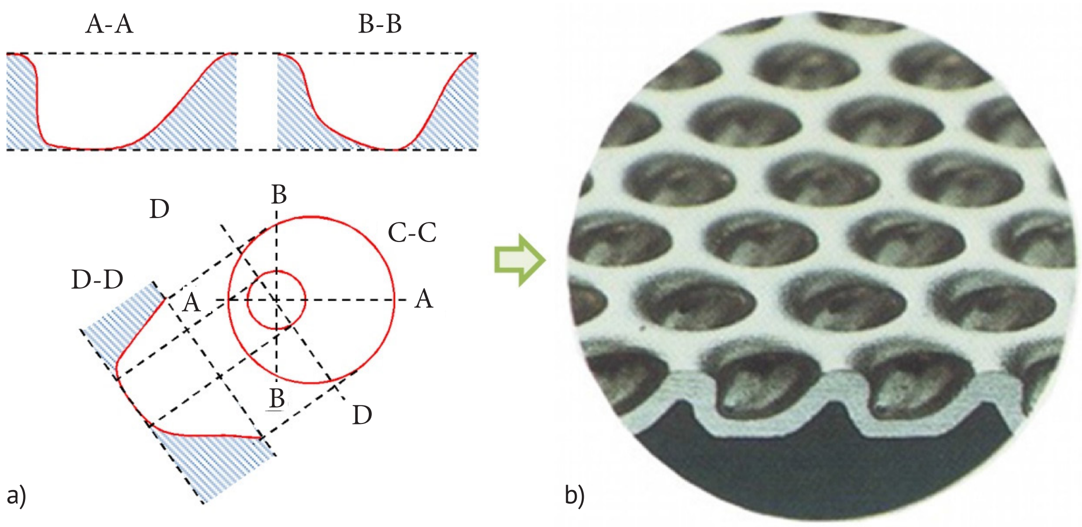


***Figure 3**. Geometry and photos of stamped drop-shaped cells on the inner surface of the cylinder: a – geometry of stamped drop-shaped cells on the inner surface of the cylinder; b – photo of drop-shaped cells*
***Source**: [48]*

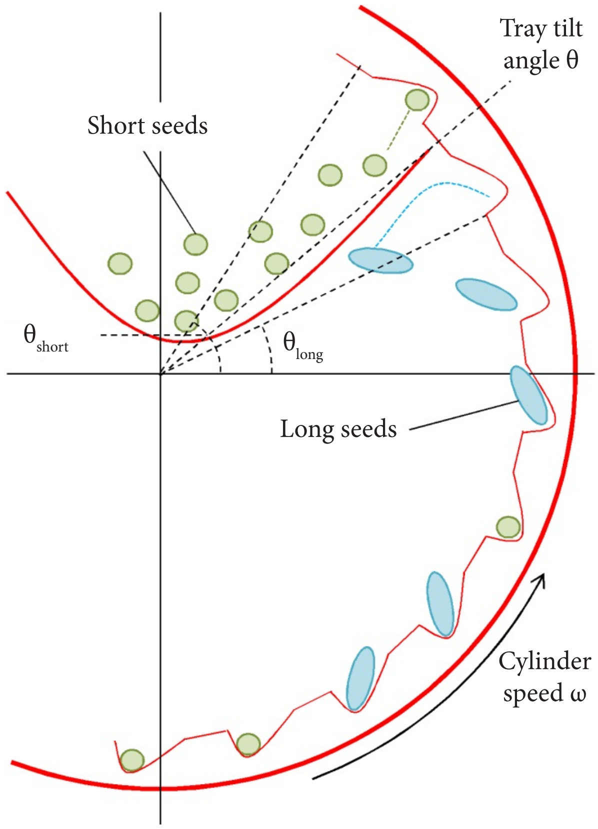


***Figure 4**. Cylinder with cells, front view (the superimposed graph shows the angles of long and short seeds at which seeds fall out of the cylinder cells along a parabolic trajectory)*
***Source**: [48]*

The next two fractions of material are formed during continuous rotation of the cylinder. "Unreclaimed" fraction – a fraction of a material with low support at rest in a cell during rotation. Seeds in this fraction are transferred in the direction of rotation of the cylinder and fall out of the cell at a certain angle. This part of the source data is called the unselected fraction. "Raised" fraction – a fraction of a material with high support at rest during rotation. During rotation, the seeds are in the cells up to a certain departure angle, after reaching which the seeds fall out of the cells. This fraction is called raised. Usually, due to the difference in support at rest $\Theta_{long}$ less than $\Theta_{short}$. Hence the name "raised" and "not raised". This expected physical phenomenon is referred to as the "lifting phenomenon".

The cellular cylinder is also equipped with a collection hopper mounted on the axial support of the cylinder. This prefab hopper is adjustable and has a horizontal working angle. Particles of the "raised" fraction from the inner surface of the cylinder fall out and enter the collection hopper, provided that its working angle has been correctly adjusted for this purpose. These trapped particles, classified as "short" seeds, are transferred and removed from the total mass. Particles of the "unoccupied" fraction do not enter the collection hopper. These particles, classified as "long" seeds, fall to the bottom of the cylinder and exit the inclined cylinder through the lower end.

An important point is the difference between partitioning and sorting processes. Separation process – separation by length performed by rotating a cell cylinder. The sorting process is the result of the collection hopper capturing the raised fraction and passing the unoccupied fraction. The inner surface of the cell cylinder is an important part of the machine, and this part is responsible for the actual separation of the "raised" and "not raised" fractions. Thus, the separation efficiency does not depend on the existing collection hopper, which acts as a form of adjustable memory of the inner surface of the cylinder. The ability to sort, on the other hand, depends on the collection hopper, because without it, the efficiency of separation quickly "disappears".

To make a conclusion about the correct separation of "long" and "short" seeds, it is necessary to know the actual data of the source material. In other words, the equipment operator needs to know what the sorting result should be. For example, if the source material consisted of a mixture of whole and broken barley grains, the operator expects the broken grain in the short fraction, and the whole grain in the long fraction. Determining the formal performance indicators of a cylindrical cellular separator is not trivial. The optimal sorting result can be one that has a minimum "overlap" of the seed distribution between the two initial subgroups in the source material. This can be considered as a form of "optimality criterion" for a cell cylinder. "Overlap" can be defined as the number of short seeds that fall into the long ones, plus the number of long seeds that fall into the short ones.

## INDUSTRIAL SEED CLEANING EQUIPMENT

The cell cylinder is available in two different scales: (1) industrial scale and (2) laboratory scale. Among industrial cylinder separators, the most famous are the BTS, BTHM brands and modern separators of the Westrup A/S, TR series (Fig. 5, 6).

***Figure 5***. *Industrial cellular cylinder separator (Westrup A/S, TR series) with or without doors*

***Source***: *[48]*

***Figure 6***. *Laboratory cellular cylinder separator (Westrup La-T model)*

***Source***: *[48]*

The disadvantages of cylindrical separators are low efficiency because they require special settings for the optimal mode of its operation for cleaning seeds of various crops, the frequency of vibrations of the separator chute, and when the frequency of oscillation of the chute decreases, its transport capacity decreases or is completely suspended. Therefore, such a separator cannot be used for cleaning complex seed mixtures, which must be separated using small revolutions of the cylinder. Another disadvantage is the short service life of the drive and support rollers assembled in the form of packages of flat rubberised disks. As a result of the wear of the contact surfaces of the rollers, the smoothness of the separators is disrupted, which causes vibration and reduces the separation efficiency. Another significant disadvantage of indented cylinder separators is the high power and, as a result, high energy consumption.

To eliminate the shortcomings of indented cylinder separators, researchers from different countries conducted a large number of studies. In [49], relatively simple models of seed movement in a cell cylinder are presented. In these models, the seed is modelled as a dimensionless body. In addition, the simulation is performed only in two dimensions – provided that the movement of the seed is limited by a plane perpendicular to the axis of rotation of the cylinder. Two main options are usually used: diagrams of the forces acting on the seed between the cells and inside the cell. The active element of the cells is simplified to a small area of a more inclined surface. The event when the seed leaves the surface or cell is expressed by trivial equivalents of forces, including frictional forces and normal pressure forces (depending on the speed of rotation of the cylinder W and the acceleration of gravity g).

In [49] a more complex model is also presented for long and short seeds inside the cell. This model takes into account the fulcrum points in the cell, which would be different for each seed type. These models give definitions for $\Theta_{long}$ and $\Theta_{short}$. Moreover, given that they depend on specific biological parameters (seed length, coefficient of friction, humidity, etc.), it is likely that the ranges $\theta_{long}$ and $\theta_{short}$ intersect, which makes it difficult to completely separate. Observation, identification of the system, and modelling of existing seed sorting devices, such as the cellular cylinder separator, using state-of-the-art technologies such as computer scanning and other computer technologies, received some attention in later years, although to a limited extent.

The basics of modern literature on the analysis of indented cylinder separators are presented in the following papers: in [50], the author contributed to an early and important analysis of perhaps the most complex and least understood parameter of a cylinder cell – the analysis of cylindrical cells (described as cells in the work). H. Fouad provided recommendations on the most optimal ranges of cell shape parameters.

In [51], the researcher continued to improve the cellular cylinder separator. A new cellular device (on a laboratory scale) equipped with perforated metal with round cells has been developed. The new model was equipped with a self-cleaning device in the form of a brush that rotated together with the cylinder and removed seeds that remained in the cells. The conclusions mention that the separation was mainly affected by the speed of rotation of the cylinder W, the tilt of the cylinder, and the working angle of the collection hopper.

In [52], the researchers made some interesting and early attempts to achieve a reproducible set of rules ("decision support system") for length separation using a cylindrical cellular separator (scalable in the laboratory). Three different rotation speeds W, three different working diameters of cells d (here called "pockets" instead of "cells"), and three different working angles of the collection hopper A (Alpha) were used. As a result, 27 experiments were conducted. Stevens' early computer analysis system was used to measure the length of pre-peeled wheat. The authors concluded that all three parameters had a significant effect on seed length separation in the raised fraction ("short" seed) and did not significantly affect seed length separation in the unoccupied ("long" seed) fraction.

In [53], a cellular cylinder separator (scaled in the laboratory) was used to find optimal working conditions for removing broken rice. 41 different rice grades, three different indentation diameters r, and three different settings for the working angle of the collection hopper A (Alpha) were used (the rotation speed W did not change). The study was summarised by providing recommendations on the working cell diameter for different rice varieties. An overview of important mechanical laws regulating the movement of long and short seeds in a cylinder with cells is presented in [54].

The study [55] is extremely relevant and contains several important conclusions. A high-speed camera was installed in front of a laboratory-scaled cylinder with cells. The use of variables from the cells themselves is applied to construct a physical model used to simulate the angle of incidence and parabolic trajectories of short seeds (impurities). A good correlation between the model and reality is shown, and this is despite simplifying assumptions in the mathematical model, such as using point masses and neglecting any seed resistance forces.

Since researchers delved upon universal cleaning machines, and the studies in the field of cleaning various varieties of seeds of small-seeded crops were not conducted, the urgent task remains to improve existing technical means for separation by creating mechatronic systems for automated control of their design and regime parameters.

To solve this problem, a design and technological scheme of the mechatronic system of an indented separator is proposed (Fig. 7), which consists of a frame (1) in which supporting rollers (2) are installed. A drum with cells (3) is installed in the middle of the frame on rollers. On the frame (1) on the rear part, a gear motor (4) is installed, the shaft of which touches the drum with cells (3) through the drive roller (5). In the middle of the drum with cells (3), a tray (6) is installed, which is fixed to the frame (1) at a horizontal angle with the ability to rotate around its axis. The rear part of the tray (6) is attached to the shaft of the stepper motor (7), which is rigidly mounted on the frame (1). On the frame (1) on the rear part there is a hopper dispenser (8), which dispenses the seed mixture using a flap with a stepper motor (9). On the frame (1) on the front part, a larger seed intake (10) is installed under the drum with cells (3), and a smaller seed intake (11) is installed under the tray (6). A camera (12) is installed on the front of the tray (6), the lens of which is directed to the middle of the drum with cells (3). The control unit (13) is attached to the frame (1). A gear motor (4), a stepper motor (7), a damper stepper motor (9) and a camera (12) are connected to the control unit (13) by means of electrical wires (14).

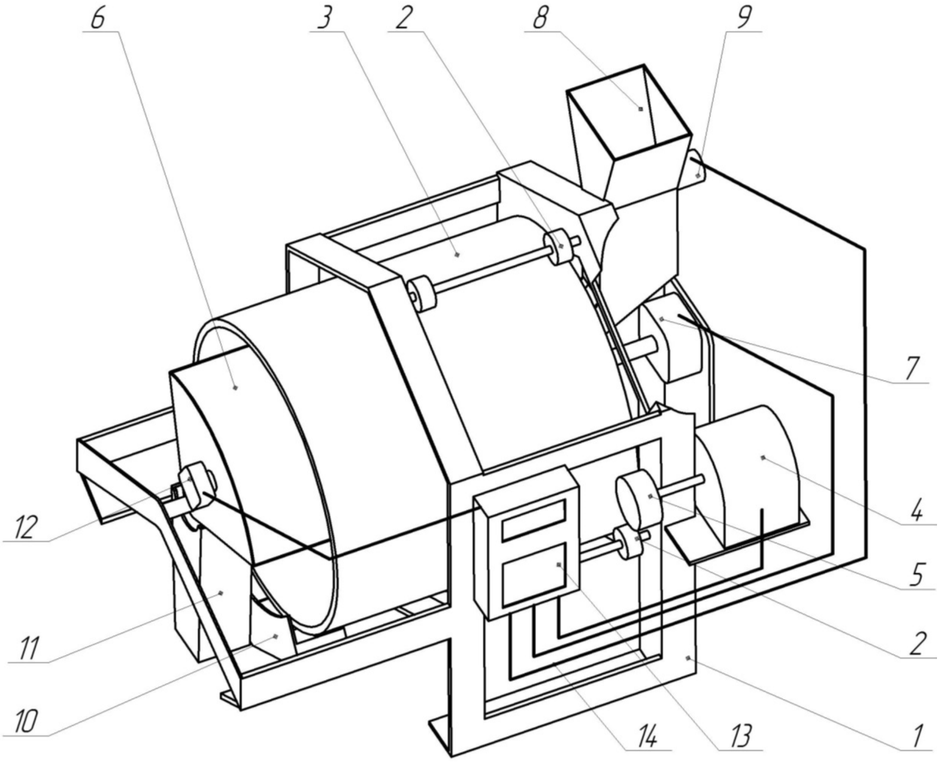


***Figure 7***. *Design and technological scheme of the mechatronic system of an indented cylinder separator: 1 – frame; 2 – supporting rollers; 3 – drum with cells; 4 – gear motor; 5 – drive roller; 6 – tray; 7 – stepper motor; 8 – hopper dispenser; 9 – flap with stepper motor; 10 – larger seed intake; 11 – smaller seed intake; 12 – camera; 13 – control unit; 14 – electrical wires*

***Source***: *[2]*

The difference between the proposed mechatronic indented separator system and the conventional one is that the camera (12) captures the trajectory of seeds (Fig. 8). This information is processed in the control unit, which in turn changes the speed of rotation of the gear motor (4) and, as a result, the drum with cells (3), the angle of inclination of the tray (6), the angle of rotation of the flap with the stepper motor (9) of the hopper dispenser (8). These manipulations with the operating parameters of an indented separator allow adjusting it to changes in the composition of the seed mixture, thereby improving the quality of separation. In addition, due to the automatic adjustment of the operating parameters of the indented separator, the participation of the operator in the separation process is practically not required, which reduces labour costs.

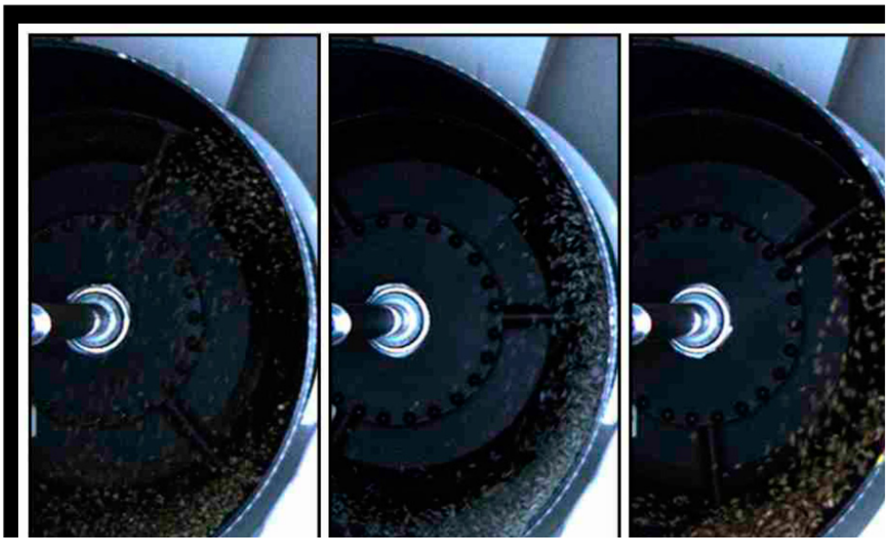

***Figure 8**. Photo recording of the seed trajectory of mechatronic indented separator system*

***Source**: [48]*

## CONCLUSIONS

The presented analysis of the technical support of the process of separation of seed material of small-seeded crops indicates the need to improve indented separators based on automated control of its parameters using photo or video recording of the separation of seed material with subsequent processing. It has been established that the determination of formal performance indicators of an indented separator cylinder is not trivial. The optimal sorting result can be one that has a minimum "overlap" of the seed distribution between the two initial subgroups in the source material. This can be considered as a form of "optimality criterion" for a cell cylinder. "Overlap" can be defined as the number of short seeds that fall into the long cells, plus the number of long seeds that fall into the short cells.

Based on the results of the analysis, a design and technological scheme of the mechatronic system of an indented separator has been developed. The difference between the proposed system and the conventional one is that the camera captures the trajectory of seeds. This information is processed in the control unit, which in turn changes the speed of rotation of the gear motor and, as a result, the drum with cells, the angle of inclination of the tray, the angle of rotation of the flap with the stepper motor of the hopper dispenser. These manipulations with the operating parameters of an indented separator allow adjusting it to changes in the composition of the seed mixture, thereby improving the quality of separation. In addition, due to the automatic adjustment of the operating parameters of the indented separator, the participation of the operator in the separation process is practically not required, which reduces labour costs.

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## Передумови створення мехатронної системи трієрних сепараторів насіннєвого матеріалу дрібнонасіннєвих культур

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**Анотація**. В умовах сьогодення важливим аспектом для досягнення високого рівня виробництва насіння залишається розширення асортименту якісного насіннєвого матеріалу, завдяки чому порушується технологічний процес сепарації, зростають витрати. Метою досліджень є аналіз насіннєочисних трієрних сепараторів для очищення дрібнонасіннєвих культур і розробка відповідної мехатронної системи їх керування, завдяки застосуванню якої технологічний процес сепарації буде характеризуватися зниженими питомими експлуатаційними витратами і більш високою продуктивністю. Представлений аналіз технічного забезпечення процесу сепарації насіннєвого матеріалу дрібнонасіннєвих культур дає змогу стверджувати про необхідність удосконалення трієрних сепараторів базуючись на автоматизованому керуванні їх параметрами з використанням фото- або відеофіксації процесу сепарації насіннєвого матеріалу із подальшою обробкою. Встановлено, що визначення формальних показників продуктивності циліндричного чарункового трієра не є тривіальним. За результатами аналізу розроблено конструктивно-технологічну схему мехатронної системи трієрного сепаратора. Відмінність запропонованої системи від традиційної полягає в тому, що фотокамера фіксує траєкторію польоту насінин. Ця інформація обробляється в блоці керування, який у свою чергу змінює частоту обертання мотор-редуктора і як наслідок барабана із чарунками, кут нахилу лотка, кут повороту заслінки із кроковим двигуном бункера-дозатора. Дані маніпуляції із режимними параметрами трієрного сепаратора дозволяють підлаштовувати його до зміни складу насіннєвої суміші, тим самим підвищуючи якість і продуктивність сепарації. Окрім цього, через автоматичне підлаштування режимних параметрів трієрного сепаратора, участь оператора установки в процесі сепарації практично нівелюється, що зменшує трудові витрати

**Ключові слова**: насіння, трієр, керування, автоматизація, параметри, режими