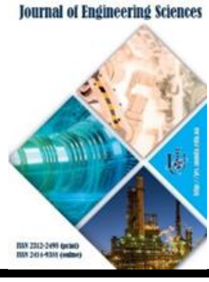
JOURNAL OF ENGINEERING SCIENCES

Volume 10, Issue 1 (2023)

Spirin A., Borysiuk D., Tsurkan O., Tverdokhlib I., Veselovska N., Edl M. (2023). Ways of intensification of grass seed production. Journal of Engineering Sciences, Vol. 10(1), pp. F11-F19, doi: 10.21272/jes.2023.10(1).f3



Ways of Intensification of Grass Seed Production

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Article info:

Submitted:	March 6, 2023
Received in revised form:	May 19, 2023
Accepted for publication:	May 30, 2023
Available online:	June 2, 2023

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Abstract. The main reason that restrains the development of seed production of perennial grasses is losses during harvesting, which depend on the agrotechnical properties of plants and the imperfection of existing means. There are no special grass seeds yet. Therefore, serial equipment with special devices is recommended for their collection. There are enough options for technologies for collecting grass seeds. In the article, six main options of technologies used in production were analyzed and compared according to the main indicators. The best results of a comprehensive comparison are those technologies that process the collected seed mass into a stationary one. The design of a device for wiping the seed mass was proposed to develop this direction of grass seed collection technologies. The article presents theoretical and experimental research results that allowed improving these devices based on rational design and operating parameters. Another way to intensify the production process of leguminous grass seeds is to combine the technological processes of wiping and separation in one machine. The analysis of various separating devices showed that machines with a rotating screen of cylindrical or conical shape are best suited for this purpose. The conducted theoretical studies confirmed the hypothesis that extending the time the material stays on the sieve by using a conical surface increases the yield of clean seeds and contributes to uniform loading of the sieve surface, improving the quality of the initial material. According to the research results, the design of the grating-separating block was proposed for the implementation of this scientific hypothesis. The theoretical and experimental studies presented in the article will allow for significantly intensifying the process of collecting grass seeds and outlining the further development of scientific research in this field.

Keywords: process technology, product innovation, grating device, wiping, separation.

1 Introduction

An indisputable axiom is that developed animal husbandry requires an appropriate production level of fodder crop seeds, especially alfalfa, and clover. This was stated repeatedly by various sources, including the authors [1], but judging by the unsatisfactory state of livestock breeding in Ukraine, the problem remains unresolved. It should be noted that, unlike other problems of agricultural production, several objective reasons restrain the development of the production of grass seeds.

The main reason restraining the development of seed production is the agrotechnical and physical-technical features of plants and, in fact, seeds. A characteristic feature of grass for seeds is their increased clogging (up to 60 %) by weeds of high humidity. During the collection of grass seeds, there is a significant difference in the humidity of individual parts of the plants. So, for example, the moisture content of clover seeds is within 12-35 %.

2 Literature Review

Some plants tend to lie down. Another feature of a physical and mechanical nature is the insignificant mass share of seeds in the total crop yield. So, for example, in [2], the use of rotary threshing-separating devices for collecting clover seeds is considered. At the same time, the instability of the flow of the technological process is observed, primarily due to the intensive formation of bundles from plant stems and, as a result, a rapid increase in energy consumption. It was concluded that the main way to overcome these problems is the improvement of grating surfaces, minimization of gaps, as well as the search for solutions to normalize stem mass.

Observing the rational parameters of the engine and main working organs is essential when collecting grass seeds with combined harvesters. Thus, in work [3], it is noted that when the engine speed is reduced by 10 %, the loss of the straw shaker and other working parts of the combine increases by 5 times. Therefore, during assembly, the engine speed should be maximum. At the same time, a significant conclusion is made that collecting grass seeds is the most complex labor- and energy-consuming operation in the technology of works on their production. It is noted that special harvesters for harvesting grass seeds do not yet exist. Therefore it is recommended to use serial harvesters equipped with special devices for their collection.

The works [3, 4] are devoted to the search for new solutions for the intensification of herb seed collection in Ukraine. They concluded that the main directions for improving the process of processing the seed mixture at the stationary plant are the intensification of the process of primary cleaning of the seed and its wiping from the beans, which provides an opportunity to increase the productivity of the technological line and reduce the labor intensity of the process.

All these features significantly complicate the performance of the most challenging and responsible operation in seed production – harvesting.

According to various estimates, under favorable weather conditions, the loss of biological harvest can reach 20 %, and it can even exceed 50 % in rainy weather.

All these noted facts, unfortunately, lead to the conclusion that the problem of collecting grass seeds remains unsolved. Despite several decades of work by many collectives, the issue of providing the fodder industry with high-quality forage seeds, especially legumes, remains relevant.

Collecting grass seeds is the most complicated part of their production. If the main issues with the cultivation of seed crops of alfalfa, clover, and other grasses have already been resolved [5, 6], then the issue of harvesting remains open [7]. That is, it can be said that the primary way of intensifying the production of grass seeds is, even, not to increase the yield of crops on the root but to reduce losses during their harvesting. Harvesters with special attachments are usually used to collect grass seeds. It should be noted that these tools do not always meet modern requirements. However, it should be noted that this article is rather an exception from a number of quite normal studies. After all, most works, as a rule, are devoted to studying someone's constructive element.

In many cases, it is necessary to carry out repeated threshing of chaff. The characteristics of these plants again explain this.

This especially applies to alfalfa and clover. When harvesting, some beans are not threshed and fall into the chaff after cleaning the combine. Therefore, even using modern grain harvesters with appropriate devices requires including stationary elements. The authors have already considered the possible options for combining combined and stationary elements [8]. After summarizing the results of the analysis of the latest research on the cultivation and collection of grass seeds, it can be noted that there are many modernizations of harvesters, particular adaptations for them, stationary machines and equipment, and, accordingly, a significant number of possible combinations of them into actual technologies. The purpose of the work can be formulated based on the conducted analysis.

The research aims to increase the production of leguminous grass seeds by analyzing possible alternative technologies for collecting seeds and choosing rational options for specific agro-climatic conditions and technical capabilities of the farm.

3 Research Methodology

It was already noted above that in most cases, the harvesting of leguminous grass seeds by combine harvesters (even with special devices) exceeds agrotechnical requirements, so technologies are being developed in which the processing of the entire crop or part of it is transferred to a stationary plant. We refer to these technologies as stationary because mobile units, the main source of losses in combined technologies, are here replaced by stationary units.

Work on the improvement of stationary technologies has been carried out for a considerable time [9] in three main directions: harvesting the entire biological crop in the field and processing it at the stationary; harvesting part of the crop in the field (harvesting option) and processing it at the stationary; harvesting the non-threshed mixture in the field (an option is harvesting beans by threshing on soft modes) and processing it at the stationary.

The first technology ensures a minimum loss of seeds. However, in practice, it is hardly used due to high transport costs and difficulties with dosing the mass when feeding to the threshing floor. The low productivity of drying equipment and threshing devices necessitates transshipment operations. Long-term storage of wet mass can lead to its self-heating and loss of sowing qualities.

Storage of chopped biological harvest (or even better – combed seed part [10]) allows much better use of vehicles. Shredded or combed mass can be fed to the threshing floor more evenly and dosed. When collecting crushed mass with a field machine, even with the correct adjustment of the grinding device, there is increased seed damage.

Combing machines are free of these disadvantages, but the losses of the seed part slightly exceed agrotechnical requirements. Of course, after them, machines can be run for picking beans (for example [9]), but introducing an additional operation into the technology reduces its economic efficiency. However, this reduction in efficiency is offset by additional seed collection.

The third stationary technology provides significantly smaller volumes of transportation, drying, and threshing (or wiping) of material of uniform size and moisture content. This technology involves mainly using serial machines, devices, and equipment.

Processing beans, separated from the mixture, combed in the field, or collected in a hopper after "soft" threshing, is complicated with combined and stationary technologies. Their processing at the hospital is carried out either with a special grating device or a suitably prepared grain harvester. The use of combine harvesters is less efficient due to problems with loading them with the mixture and the need to pass the material through the combine twice to wipe the seeds entirely.

When analyzing technologies and technical means for their implementation, many indicators are considered: operational and energy costs, the productivity of units, their metal consumption, and the quality of execution of the technological process. According to the technology options, they differ significantly in terms of individual indicators, which makes it difficult to make the optimal decision when comparing them. For a better understanding of the advantages and disadvantages of technology, their comparison should be carried out according to complex indicators. The authors have already made a similar comparison for other technologies and machines [1]. In these works, the method of determining complex indicators is described in detail, so we will only give the result of technology evaluation.

Six of the most widespread technologies for collecting alfalfa seeds were compared according to the following individual indicators: operating costs (monetary units/ha), energy intensity (MJ/ha), metal intensity (kg/ha), and crop losses (kg/ha). The results of comparing technologies according to two comprehensive indicators are shown in the Table. 1 (where I_1 and I_2 are generalized indexes of the first and second kinds, respectively, defined in scientific work [1]).

Table 1 – Comparison of alfalfa seed harvesting technologies

Assembly technology	I_1	I_2
Direct combining	0.40	3.39
Separate combining	0.45	3.64
Threshing at the stationary biomass	0.47	3.82
Stationary threshing of unthreshed piles	0.51	4.01
Stationary processing of the combed seed pile	0.57	4.32
Stationary processing of the seed pile after "soft" threshing	0.61	4.51

From Table 1, the best results of a comprehensive comparison are those technologies that process the entire collected seed mass on a stationary basis. Of course, these results cannot and should not be taken as an absolute verdict on the issue of the final choice of the best technologies, but they show the main direction of development of the ways of intensification of grass seed production.

The most "bottlenecks" in stationary technologies are wiping beans and separating the obtained material. With harvester technologies, the largest share of seeds is lost precisely because of unsatisfactory drying of beans because its degree does not exceed 70-75 %, even under favorable working conditions. This is the main reason for transferring part of the operations to the stationary.

Few modern serial machines for wiping the pile do not provide the necessary quality of work and have increased requirements for the composition of the pile, which causes a decrease in the efficiency of the entire technology.

The question of creating a universal grating device that would meet all the requirements has been around for a long time. Such a grating device should work in a wide range of changes in the fractional composition and moisture content of the seed mixture, be reliable in operation, provide the required quality of work, and not be very expensive and difficult to manufacture. It is also necessary to consider a particular farm's seed production volume. Therefore, the universality of the grater device can only be talked about relatively, bearing in mind a certain range of their productivity. Over the past decades, a significant amount of work has been carried out on creating various structures of grating devices. Only according to the type of working body, they are divided into the following: hammer, drum hammer, drum pin, rotary hammer, rotary blade, screw, disk, screw disk, and roller. However, scientific research in this field continues.

The authors developed a design of a grating device with horizontal grating disks [1]. The scheme of the grating device is presented in Figure 1. The grating device includes a housing 6, in which a hopper 1 is installed with a loading neck 2 and a loading hole 3. In the space of the hopper, a finger activator 4 is installed, which has bars 5. The activator is mounted on the upper part of shaft 9, and the movable part is mounted on the lower part of the shaft grater disk 8. A fixed disk 7 is installed in the housing, which has a cup, the opening of which is a continuation of the loading neck.

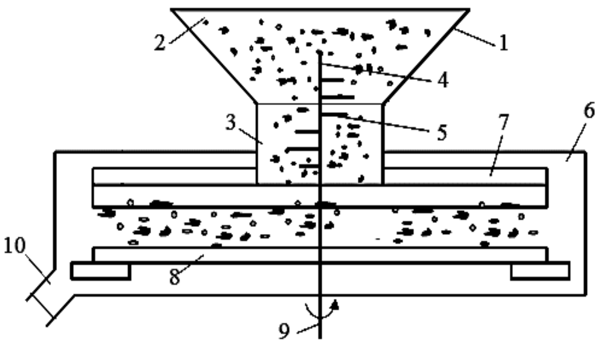
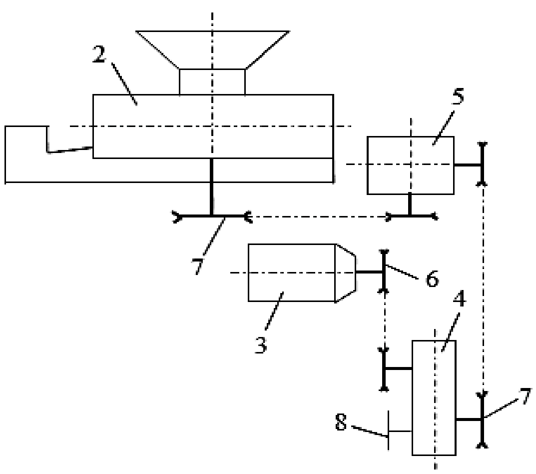


Figure 1 – Scheme of the grating device: 1 – hopper; 2 – loading neck; 3 – loading hole; 4 – activator; 5 – bar; 6 – body; 7, 8 – fixed and moving disk; 9 – drive shaft; 10 – output channel

The glass is made in the form of a hollow cylinder, on the outer side of which a threaded sleeve is wound. Beams are fixed to the lower surface of the fixed disk, installed radially on the disk in the form of rays. It was made in the form of reefs that have a notch. Ring protrusions are placed concentrically to the disk's axis in the spaces between the blades. The output channel 10 is placed in the lower part of the case.

In order to obtain new scientific data about the physical process of wiping seeds from beans and to study the patterns that occur in this process, theoretical and experimental studies were conducted on a laboratory installation, the structural scheme and general appearance of which is presented in Figure 2.



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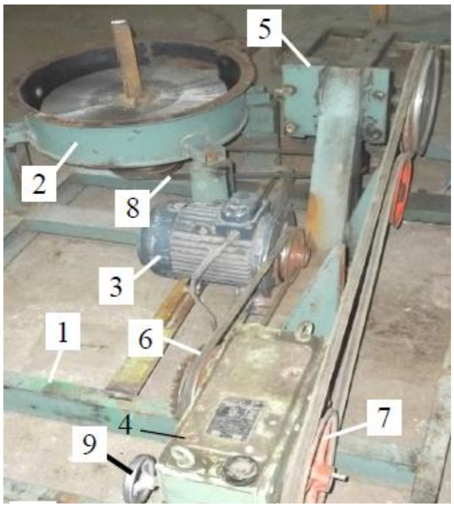

b

Figure 2 – Structural diagram (a) and general view (b) of the laboratory installation: 1 – frame; 2 – grating device; 3 – electric motor; 4 – speed variator; 5 – conical reducer; 6-8 – V-belt transmission; 9 – handle

The transportation of loose material in the space of the working channel of the grater device can take place in the form of movement of single particles of the rubbed seeds of the alfalfa mixture or their separate group under the influence of the forces of the carrier airflow in the form of an aeromix [11]. In contrast, two main types of particle movement modes are possible: particles of loose material are carried by the airflow with the help of "jumps" and continuous flow [12].

Modes of movement of the flow of particles of bulk material are regulated, as a rule, by its main physical and mechanical properties, the main of which are density, particle size, coefficients of internal and external friction, and the uniformity of supply of bulk materials into the space of the working channel [13].

The energy consumption of the transportation process during the pneumatic method of moving the bulk medium primarily depends on the movement modes of the flow of particles of the bulk material. The flow speed is the dominant factor in the energy consumption of the transportation process, which is minimal during the wave and batch movement of the material in a quasi-liquid state [14].

The analysis of the modes of movement of flows of particles of loose materials shows that they are accompanied by their mutual movement, which is very complex [15, 16]. In order to formalize the process of movement of loose material, it is necessary to accept the restriction that its transportation takes place in the form of a continuous flow, and the particles of loose material in the process of movement retain their shape and mass.

In the grating device, due to the different speeds of the translational movement of the particles by mass m_n in the space of the working bed of the grating device, they have a relative shear speed of V_c. Due to the mutual contacts (collisions) of the particles, they acquire additional components of the translational speed V_n of chaotic movement, while the mass m_n participates in the portable rotational move together with the moving disk and at the same time relative to it - along the groove beat.

Consider the process of collision of two elements with mass m_n, which are located in the radial interaxial groove of the ball at a distance R_n from the axis of rotation of the disk, which rotates with an angular velocity ω_n, while we consider that the material of the particles is elastic. The calculation scheme of the elastic collision process of two formalized spherical particles 1 and 2, by mass m_n is shown in (Figure 3).

The phenomenon of collision of two particles 1 and 2 by mass m_n occurs mainly in an oblique collision due to the mutual exchange of shock mass pulses (Figure 3). In contrast, shear flows of material occur, and the direction of the vectors $\vec{u}_1$ and $\vec{u}_2$ velocities of the colliding bodies is directed at the collision angle β_c to the horizontal axis of the Cartesian coordinate system.

We apply the kinetic theory of solid gases to solve the problem of shear flows that occur during the collision of two particles 1 and 2 by mass m_n [17]. In contrast, according to the theory of the movement of a granular medium [18], it is known that when the flow is sheared, the instantaneous speed of the particles is the sum of three related speed components: fluctuation speed, translational (averaged) and rotational speed.

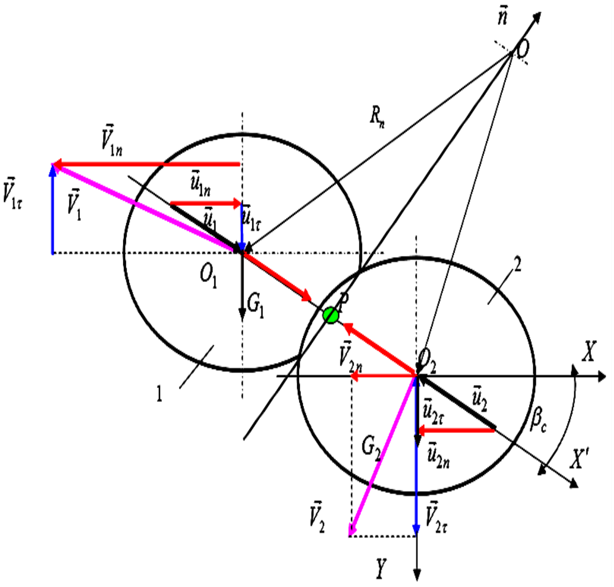

Figure 3 – Scheme for calculation of the collision of material particles by mass m_n

According to the provisions of [19], the equation of state of the loose medium during its movement is written in the form:

$$p(x)\bar{\varepsilon}(x)=\chi\left(\frac{du}{dx}\right)^2. \qquad (1)$$

The analysis of equation (1) shows that the product of the square of the speed of movement of the loose granular medium $(du/dx)^2$ by the coefficient of the physical constant χ, which is written in the right part, is identical to the specific value of the work spent on moving the layer of particles 1 and 2 by mass m_n based on 1 m^2. The left part of the product of the analog of hydrostatic pressure $p(x)$ on the porosity of the granular medium $\bar{\varepsilon}(x)$ is identical in the physical sense to the kinetic energy of the mutual chaotic movements of particles 1 and 2 by mass m_n due to the movement of the loose granular medium.

For the contact (collision) between particles 1 and 2 mass mn to occur, the angle of collimation β_c (Figure 3) must be within the range from 0 to $\pi/2$ rad.

Taking into account the fact that the movement of particles in the flow of the working bed of the grating device has a complex functional nature [9, 10], the total kinetic energy $\sum K_m$ of the mutual movements of particles 1 and 2 by mass m_n is written as the sum of the kinetic energies of particles by mass m_n:

– in their relative translational displacement during shearing K_V, J;

– for their chaotic movement K_C, J;

– in transverse mass transfer K_T, J, namely

$$\sum K_m = K_V + K_C + K_T. \qquad (2)$$

The kinetic energy of particles in their relative translational displacement in the direction of shear K_V, chaotic movement or fluctuation K_C, and transverse mass transfer K_T of particles 1 and 2 by the mass m_n of the loose medium according to [20] is determined from the following expressions

$$\begin{cases} K_V=\dfrac{1}{2}m_n(\Delta X)^2\left(\dfrac{du}{dx}\right)^2; \\ K_C=\dfrac{1}{2}m_n(u')^2; \\ K_T=\dfrac{1}{4}m_n l_c u'\dfrac{du}{dx}, \end{cases} \qquad (3)$$

where m_n is the mass of a particle of alfalfa seeds, kg; ΔX – a difference of coordinates of the centers of particles of adjacent layers of bulk environment, m; u' – particle fluctuation rate (m/s).

Taking into account that:

$$m_n=V_n\rho_v=\rho_v\pi d_n^3/6,$$

where $V_n=\pi d_n^3/6$ – the volume of the i-th particle, m^3; d_n – diameter of the n particle, m; ρ_v – the density of the seed particle, kg/m^3.

$$\Delta X = b_1 - b_2,$$

where b_1 and b_2 are the corresponding coordinate of the center of adjacent layers (particles) colliding with each other, m;

$$u'=2l_c\gamma_n,$$

where l_c is the average distance between particles relative to their reduced mass, m; γ_n – average collision frequency of particles of a loose medium (1/s) and according to (3) can be written:

$$\begin{cases} K_V=\dfrac{1}{12}\pi d_n^3\rho_v(b_1-b_2)^2\left(\dfrac{du}{dx}\right)^2; \\ K_C=\dfrac{1}{2}\dfrac{\pi d_n^3}{6}\rho_v(u')^2=\dfrac{2\pi d_n^3}{3}\rho_v\gamma_n^2 l_c^2; \\ K_T=\dfrac{1}{4}\dfrac{\pi d_n^3}{6}\rho_v l_c u'\dfrac{dV}{dx}=\dfrac{1}{12}\pi d_n^3\rho_v\gamma_n l_c^2\dfrac{du}{dx}. \end{cases} \qquad (4)$$

According to [21], the average collision frequency γ_n of the particles of the material of the loose medium is determined by the Ackerman-Shen method, while

$$\gamma_n=\frac{\tau}{E_k Z_n}\cdot\frac{du}{dx}, \qquad (5)$$

where τ is the shear stress, Pa; E_k – dissipation of the kinetic energy of a particle collision with one contact, J; Z_n – the number of particles per unit volume of the layer, 1/m^3.

The dissipation of the kinetic energy E_k of the co-impact of one particle of the alfalfa seed mixture during its single contact is determined according to [22] by the Ackerman-Shen formula, namely

$$E_k=\frac{1}{12}\pi d_n^3\rho_v\left(\frac{1-k^2}{4}+\frac{f(1+k)}{\pi}-\frac{f^2(1+k)^2}{4}\right)(u')^2, \qquad (6)$$

where k is the recovery factor during impact; f – the coefficient of friction between particles.

At the same time, it is known that according to the Gauss hypothesis [22], the relationship between the magnitudes of tangential and normal impulses during impact is formed, similar to Coulomb's law for friction

$$\Delta u = -u' f(1+k), \tag{7}$$

where Δu is the change in the relative tangential velocity due to the impact, m/s.

The fluctuation rate u' of alfalfa mixture particles weighing m_n according to [2] characterizes the transverse quasi-diffusion coefficient D_{kd}

$$D_{kd} = 0{,}5 u' l_c. \tag{8}$$

At the same time, the coefficient of transverse quasi-diffusion D_{kd}, in turn, regulates the intensity of mutual movement of particles of a loose medium. In contrast, the intensity of the movement of particles increases in proportion to the coefficient of transverse quasi-diffusion D_{kd} and the gradient of the speed of translational movement of seeds in the direction of the shear speed du/dx.

From dependence (7), we determine the particle fluctuation rate, namely

$$u' = -\Delta u / f(1+k), \tag{9}$$

By substituting the value (9) into the dependence (6), we obtain the formula for determining the dissipation of the kinetic energy E_k of the collision of one alfalfa seed particle during its single contact

$$E_k = \frac{(\Delta u)^2}{12} \cdot \pi d_n^3 \rho_v \cdot \left(\frac{1-k}{4 f^2 (1+k)} + \frac{1}{\pi f (1+k)} - \frac{1}{4} \right). \tag{10}$$

According to (5) and (9), the average collision frequency γ_n of the particles of the loose medium will be determined

$$\gamma_n = \frac{48 f^2 \tau (1+k)}{(\Delta u)^2 d_c^3 \rho_v \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right] Z_n} \frac{du}{dx}. \tag{11}$$

By substituting the value of the average collision frequency γ_n of alfalfa seed particles or particles of a loose granular medium from equation (11) into dependence (4), we obtain:

$$K_C = \frac{2\pi l_c^2}{3 d_n^3 \rho_v Z_n^2} \cdot \left(\frac{48 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right)^2 \cdot \left(\frac{du}{dx} \right)^2; \tag{12}$$

$$K_T = \frac{4\pi l_c^2 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right] Z_n} \cdot \left(\frac{du}{dx} \right)^2. \tag{13}$$

Thus, the total kinetic energy $\sum K_m$ of mutual movements of particles of a loose granular medium or alfalfa seed particles after substituting the first equation from the system of equations (2) and equations (12) and (13) into dependence (2) and after the corresponding transformation and simplification of the expression, is defined by dependence

$$\begin{aligned}
\sum K_m &= \frac{1}{12} \pi d_n^3 \rho_v (b_1 - b_2)^2 \left(\frac{du}{dx} \right)^2 + \\
&+ \frac{2\pi l_c^2}{3 d_n^3 \rho_v Z_n^2} \left(\frac{48 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right)^2 \left(\frac{du}{dx} \right)^2 + \\
&+ \frac{4\pi l_c^2 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right] Z_n} \left(\frac{du}{dx} \right)^2 = \\
&= \frac{\pi}{12} \left(\frac{du}{dx} \right)^2 \left\{ \begin{aligned} &\left[d_n^3 \rho_v (b_1 - b_2)^2 \right] + 8 \frac{l_c^2}{d_n^3 \rho_v Z_n^2} \left(\frac{48 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right)^2 + \\ &+ \frac{48 l_c^2 f^2 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right] Z_n} \end{aligned} \right\} = \\
&= \frac{\pi}{12} \left(\frac{du}{dx} \right)^2 \left\{ \begin{aligned} &\left[d_n^3 \rho_v (b_1 - b_2)^2 \right] + \frac{48 l_c^2 f^2 \tau (1+k)}{Z_n (\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \times \\ &\times \left[\frac{8}{d_n^3 \rho_v Z_n} \left(\frac{48 f^4 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right) + 1 \right] \end{aligned} \right\}
\end{aligned} \tag{14}$$

or

$$\sum K_m = \frac{\pi}{12} \left(\frac{du}{dx} \right)^2 \left\{ \begin{aligned} &\left[d_n^3 \rho_v (b_1 - b_2)^2 \right] + \frac{48 l_c^2 f^2 \tau (1+k)}{Z_n (\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \times \\ &\times \left[\frac{8}{d_n^3 \rho_v Z_n} \left(\frac{48 f^4 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right) + 1 \right] \end{aligned} \right\}. \tag{15}$$

The obtained dependence (15) is a mathematical model that characterizes the total kinetic energy $\sum K_m$ of the mutual movements of the particles of the loose granular medium, which is lost during a single collision of two spherical particles of the alfalfa seed mixture in the process of their movement to the periphery of the moving disk (or the output channel of the grating device). Depending on the speed components of the co-impact process, the physical and mechanical properties of alfalfa seeds and the conditions of the impact environment.

The mathematical model can be used for the analysis and analytical-empirical description of the state of the loose granular medium during the movement of alfalfa bean particles in the internal volumetric space of the working channel of the grating device.

Then, taking into account dependence (1), the known equation of the state of the loose granular medium $p(x)\bar{\varepsilon}(x) = \chi (du/dx)^2$ during the movement of alfalfa seed particles can be written in the following form:

$$p\bar{\varepsilon} = \chi' \frac{\pi}{12} \left(\frac{du}{dx} \right)^2 \left\{ \begin{aligned} &\left[d_n^3 \rho_v (b_1 - b_2)^2 \right] + \frac{48 l_c^2 f^2 \tau (1+k)}{Z_n (\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \times \\ &\times \left[\frac{8}{d_n^3 \rho_v Z_n} \left(\frac{48 f^4 \tau (1+k)}{(\Delta u)^2 \left[\pi(1-k) + 4f - \pi f^2 (1+k) \right]} \right) + 1 \right] \end{aligned} \right\} \tag{16}$$

where χ' is the coefficient of the physical constant, which is identical to the specific value of the work spent on moving the layer of particles per 1 m^2; $\bar{\varepsilon}$ – the average porosity of the granular medium.

The obtained dependences of the state of the loose medium (16) and (15) can be used for further analysis and justification of the parameters of the technological process of the grating device.

The program of experiments provided for, among other things, obtaining regression dependencies that characterize the change in the mass of the rubbed seeds, the degree of wiping of the seeds from the mixture, and the performance of the grating device depending on the technological parameters of the process and the structural and kinematic parameters of the working bodies and the design of the fixed disk of the grating device. Laboratory experimental studies were carried out with stationary discs of four types. Variants of immovable discs are presented in Figure 4.

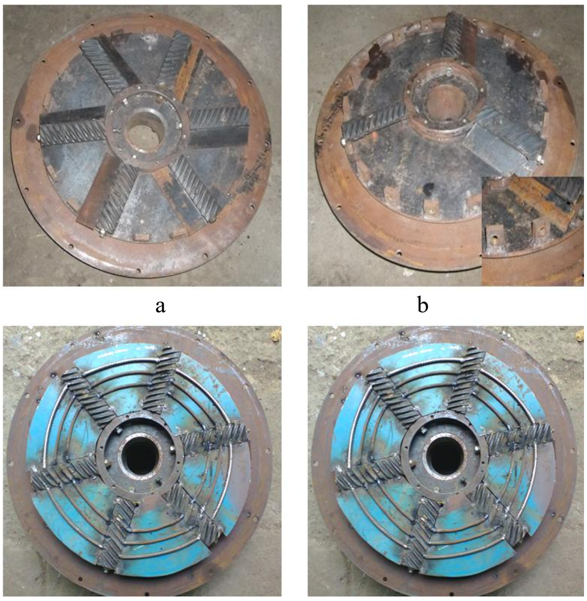

Figure 4 – Variants of execution of the stationary disk of the grating device: a – a disk with six balls fixed on it and flat plates installed in the space between the balls; b – a disk with three balls fixed on it and flat plates that, installed in the space between the balls; c – a disk with six fixed on it rings between which circular inserts with a diameter of 200, 250, and 300 mm, fixed from a rod with a diameter of 8 mm; d – a disk with 6 balls fixed on it, between which ring inserts made of a rod with a diameter of 6 mm, fixed in a circle with a diameter of 200, 250, and 300 mm

4 Results and Discussion

The conducted studies showed that the best results of the wiping process (the maximum degree of wiping of the seeds) were obtained with option “d” of performing a stationary disk. This conclusion was made after analyzing the response surfaces of the change in the degree of wiping from the design of the fixed disk and the number of passes of the technological mass, which are presented in Figure 5. The approximating function, that is, the nature of the change in the degree of seed wiping from the alfalfa pile, is presented in the form of a mathematical model of a complete quadratic polynomial:

$$P_{4v}^{(21)} = 0.74 + 0.006 \cdot n + 4.9 \cdot k_n - 0.02 \cdot n \cdot k_n + 1.4 \cdot 10^{-5} \cdot n^2 - 0.28 k_n^2, \quad (17)$$

where n is the rotation frequency of the moving disk, rpm; k_n – multiplicity of the wiping process [2]. Index “21” means the moisture content of the technological mass (21 %), and index “4” is the version of the fixed disk (option “d” in Figure 4).

Figure 5 presents the response surfaces for seed wiping.

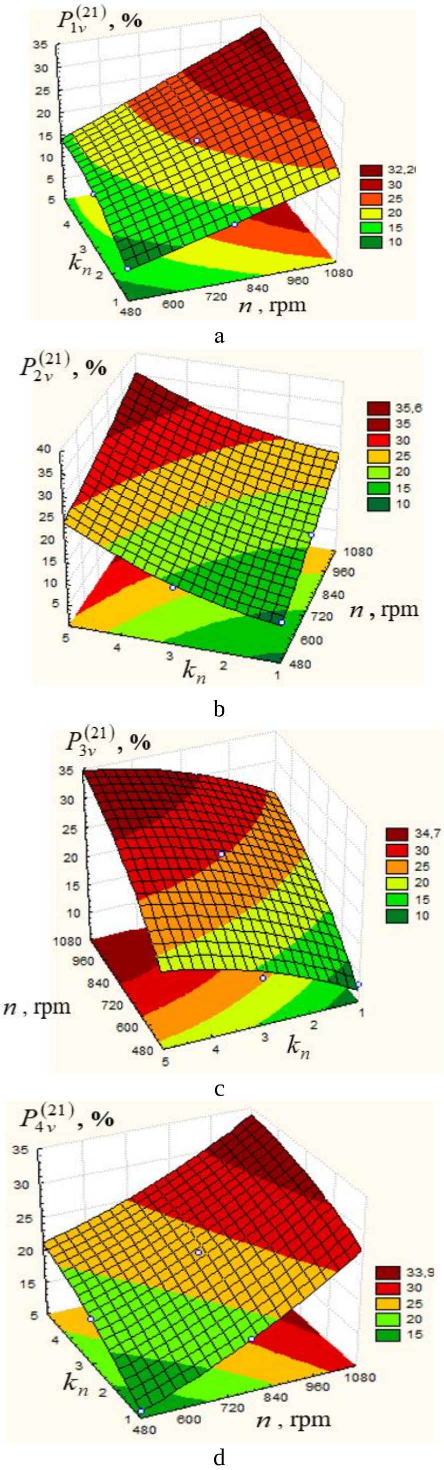

Figure 5 – Response surfaces of changes in the degree of seed wiping from the number of passes of the technological mass with a moisture content of 21 % and the frequency of rotation of the moving disk for various versions of the stationary disk: a – a disk with six balls fixed on it and flat plates, installed in the space between the balls; b – a disk with three balls fixed on it and flat plates installed in the space between the balls; c – a disk with six fixed on it rings between which circular inserts with a diameter of 200, 250, and 300 mm, fixed from a rod with a diameter of 8 mm; d – a disk with six balls fixed on it, between which ring inserts made of a rod with a diameter of 6 mm, fixed in a circle with a diameter of 200, 250, and 300 mm

The conducted experimental studies made it possible to determine the rational parameters of the wiping process: for the productivity of the grating device 0.8-6.6 kg/min, the diameter of the disks should be within 0.5-0.6 m, the rotation frequency of the moving disk 700-900 rpm, the diameter of the opening of the loading channel of the bunker is 0.11-0.15 m, the filling factor of the internal space of the working channel is 0.5-0.7.

One way to intensify the production process of leguminous grass seeds is to combine the technological processes of wiping and separation in one machine. The analysis of various separating devices showed that machines with a rotating screen of cylindrical or conical shape are best suited for this purpose. Such a combination was implemented in a grating-separating device [2], the technological scheme presented in Figure 6.

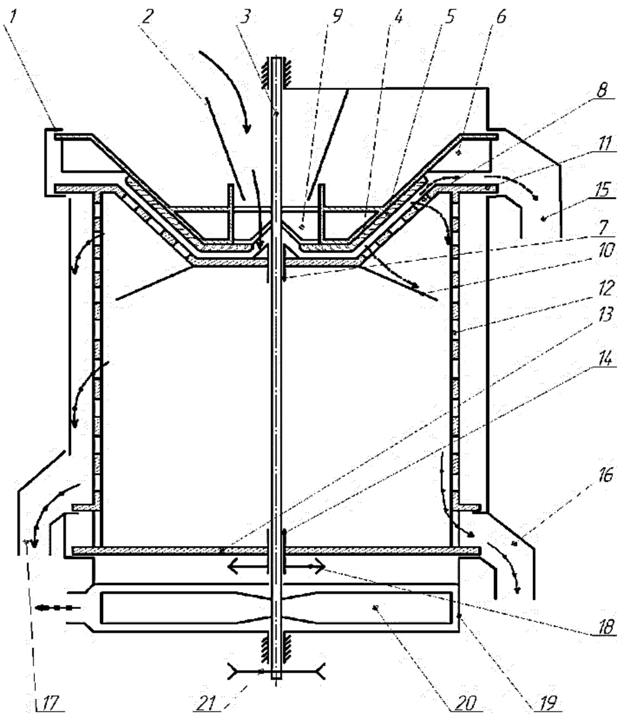

Figure 6 – Technological scheme of the grating-separating device: ⟶ heap; ⟶ coarse impurities; ⟶ grain part; ⟶ wiped grain; ⟶ unwiped grain; ⟶ air; 1 – casing; 2 – loading funnel; 3 – shaft; 4 – conical drum; 5 – beat; 6 – shoulder blades; 7 – bearing; 8 – tray; 9 – scrapers; 10 – scattering cone; 11 – ring; 12 – rotary sieve; 13 – disc; 14 – bearing support; 15 – a channel for removing the straw part of the pile; 16 – channel for removal of unwiped grain from beans; 17 – channel for removal of cleaned seeds; 18 – autonomous drive; 19 – fan; 20 – blades; 21 – drive

Laboratory studies of the grating-separation device of this design have shown one of its main shortcomings - insufficiently efficient use of the sieve surface. With this design, most seeds are removed from the upper part of the sieve, leaving the lower part empty. It is possible to increase the uniformity of the load on the separating surface by replacing the cylindrical sieve with a conical one with a decrease in the radius of the cone in the direction of movement of the material [12].

Based on the results of the research, an expression was used to determine the speed V, m/s, of the seed supply depending on the time t, s, of the particle staying on the cone sieve and the length x (m) of the cone of the lattice-separation device: $V = dx/dt$.

The experiment results at the seed feeding speed for $V = 0.1$ m/s, and $V = 0.5$ m/s are presented in Figure 7 and Figure 8, respectively.

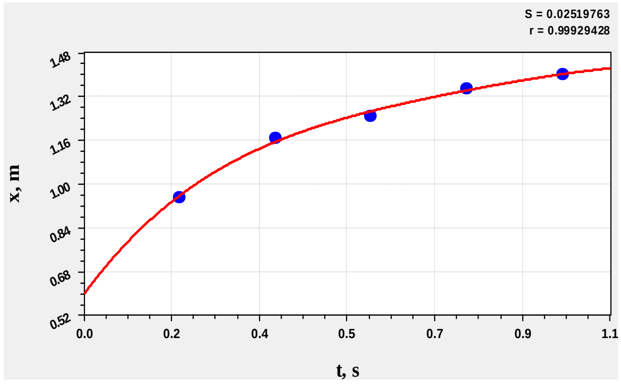

Figure 7 – Dependence of the seed residence time on the conical sieve on the length of the generating cone of the grating-separating device at $V = 0.1$ m/s

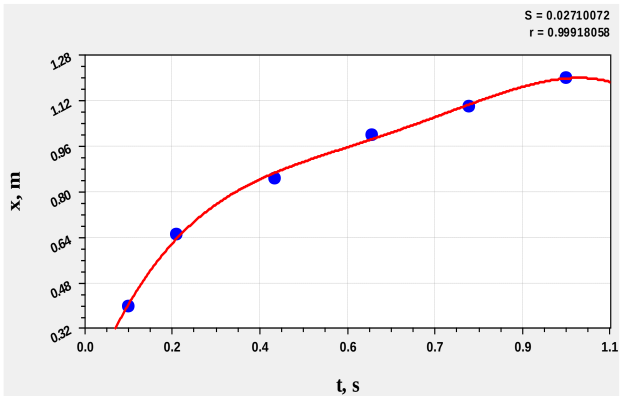

Figure 8 – Dependence of the seed residence time on the conical sieve on the length of the generating cone of the grating-separating device at $V = 0.5$ m/s

The equations obtained based on the regression analysis of experimental data have the following form:

- at the seed feeding speed for $V = 0.1$ m/s (Figure 7)

$$x = 0.5984127 + 2.3749339 \cdot t - 3.3715278 \cdot t^2 + 2.5810185 \cdot t^3 - 0.78125 \cdot t^4; \qquad (18)$$

- at the seed feeding speed for $V = 0.5$ m/s (Figure 8)

$$x = 0.034670173 + 4.5729655 \cdot t - 9.6638261 \cdot t^2 + 10.12661 \cdot t^3 - 3.8718052 \cdot t^4. \qquad (19)$$

Therefore, extending the time the material stays on the sieve by using a conical surface increases the yield of clean seeds and contributes to the uniform loading of the sieve surface, improving the quality of the initial material.

5 Conclusions

The intensification of forage seed production, especially leguminous grasses, is held back by the imperfection of modern means of seed collection. All efforts in the field of harvesting should be focused on reducing losses during seed harvesting.

The analysis of literary sources and the authors' experience allows us to state that the main way to reduce seed losses during harvesting is the processing of the seed part of the crop at the hospital. According to the authors, the most promising technologies are harvesting the seed part by combing and threshing the mass in the "soft" mode to obtain a pile with unthreshed beans in the combine hopper.

The most responsible operations in treating the seed pile at the hospital are wiping and separation. To implement the wiping process, we can recommend grating units of the original design similar to the one described in this article.

The obtained mathematical model for the total kinematic energy of mutual movements of particles of a loose granular medium during their movement with collisions in the working space of the grating device. The research results can be used to determine the device's rational parameters for wiping the alfalfa seed mixture.

The combination of wiping and separation operations in one machine appears to the authors to be a significant effect of intensification during the processing of grass seed piles at the stationary plant. The conducted theoretical and experimental studies show the prospects of such a direction.

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