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Theoretical Justification of the Efficient Operation of the Seed Sorting Device

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Abstract

In this article, the results of researches on the sorting of seeds in the cotton ginning enterprises were described. The main goal of the research work is to theoretically study the technology of separating various impurities and immature seeds from the composition of seeds. As a result, the theoretical basis for increasing the efficiency of the sorting process is created.

Keywords

Cotton, Ginning, Seed Seeds, Construction, Parameter, Seed Sorting, Forces, Aerodynamic Resistance, Air, Motion

1. Introduction

A peculiar aspect of cotton vegetation in agriculture is that even seeds of the same type differ in their development depending on their location in the bolls. In addition, their location in the groin has a specific effect. We know that seeds are the basis of quality and quantity of future harvest. Therefore, the creation of material intended for planting during the processing of raw cotton seeds is subject to objective existing laws, that is, the seeds have different effects on the growth of cotton and the level of future productivity due to the fact that the physiological maturity level, density and weight are not the same. These characteristics of the seeds have a negative effect on the total energy index of the germinating seeds and the rate of germination, as a result of which the ripening period of the cotton is delayed or the uneven development has a negative effect on the productivity.

The parameters representing the physical properties of cotton seed include its geometric dimensions, weight, degree of hairiness, strength, condition of the husk, coefficient of friction and other properties.

When planting cotton seeds, the requirements for them can be divided into 3 different groups:

1) Quality indicators directly related to the seed itself (yield, product quality, vegetation period).

2) Requirements for mechanical sowing (level of hairiness, contamination).

3) The requirement for storage of seeds intended for future planting (moisture, damage by warehouse pests).

There are many quality indicators of seeds intended for planting, instrumental evaluation and normative limitation possibilities (level of hairiness, moisture, mechanical damage, etc.). But until now, attempts have beeen made to determine the quality indicators of seeds using direct and indirect indicators. Most of the experiments show that these parameters affect the yield, the quality of the obtained product, etc. They can include the energy of germination in the laboratory, the fullness of the nuclear part of the seed, density, geometric parameters, etc. In addition, cotton ginning enterprises have special requirements for quality in the initial processing conditions. Factors that determine seed mass and quality include seed size, scattering rate, coefficient of internal friction, and others.

Lintered seeds should be cleaned and sorted according to the technological process in cotton ginning enterprises.

Pneumomechanical sorting units for seed cleaning and sorting have been introduced into modernized seed processing plants [1]. Seed sorters clean and sort seeds using horizontal or vertical air flow. This requires a great deal of precision in adjusting the airspeed.

2. Research Method

As a result of many scientific researches, improved constructions of sorting devices have been developed [2]. The productivity of these devices reached 3 t/h and the mass of 1000 seeds of sorted seeds increased by 2 - 4 grams compared to the mass of 1000 seeds of the original seed.

Today, seed sorting and calibration works are carried out by mechanical and pneumatic methods in enterprises. The seeds have such parameters as density, volatility, nuclear completeness, geometric dimensions, dielectric index. These parameters are interrelated and are of great importance in the efficiency of sorting.

Based on the study of seed sorting methods and machines, their complete classification was developed [3]. On the basis of this classification, the working principles, advantages and disadvantages of each sorting method and machine are based, and the superiority of air sorting of hairy seeds according to specific mass is shown.

As a result of scientific research on the improvement of some air-assisted sorting devices [4], the height of the sorters was reduced by 1 m and was designed to allow the mechanical weeder to be turned right and left. This has been proven by research to increase the ease of deployment of technology in seed preparation workshops.

In order to solve the above-mentioned tasks and prevent existing shortcomings in the technological process, several working bodies have been improved and developed, and one of the main directions of scientific work is to clarify the parameters of the work in the sorting and cleaning of seeds based on experience, and to improve the quality of the seed receiving part.

Another unit used in seed shops of cotton ginning enterprises is USM-A pneumomechanical cleaning and sorting unit [2]. The principle of operation of the pneumomechanical seed cleaning device is based on the separation of seeds into waste and other fractions by suction with air flow generated by centrifugal fans (**Figure 1**).

Depending on the initial state of the cotton seeds, the waste mass separated by this device is 0.1% - 0.2% of the initial mass of the seeds. The amount of seeds (whole, broken) and fibrous material in waste is 18.5 - 19.6 and 11.8% - 55.4%, respectively. The main disadvantage of the pneumomechanical seed cleaner is the low cleaning efficiency of small debris—only 20% - 25%, and the need for relatively large power (12.85 kW) and the need to regularly adjust the aerodynamic working order of the device. Such shortcomings do not satisfy the requirements of the cotton ginning industry at all.

The device is easy to prepare, reliable in operation, but when used together with the USM-A seed cleaning process line, it leads to excessive energy and metal costs.

As seen above, today's technique and technology for fractionation of cotton seed intended for seed has one or another shortcoming, and the absence of efficient machines requires thorough research. In addition, it is necessary to take into account the reduction of the total cost by focusing the direction of research and development on the improvement of local machines and aggregates.

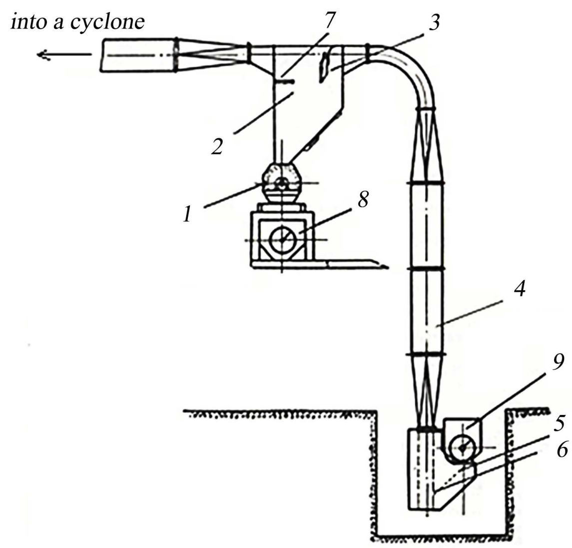

Figure 1. USM-A weeding device. 1-vacuum-valve; 2-separating chamber; 3-adjustable plate; 4th pipe; 5-receiving service provider; 6-receiver hole slot; 7-non-adjustable plate; 8-distributing screw conveyor; 9-screw assembly conveyor.

3. Studying the Movement of Seeds in the Sorting Chamber

One of the main requirements for cotton ginning enterprises to increase the efficiency of the technology of seed preparation is to prepare the seed while preserving the natural physical and mechanical properties of the seed. In the technological process of sorting seeds of the cotton ginning enterprise, it is observed that various impurities and foreign compounds, immature seeds are added to the incoming seed mass. As a result, quality indicators of seed preparation are decreasing [5].

In the dissertation, it was proposed to improve the USM-A seed sorting device operating at the enterprise by analyzing the results of previous researches and observing the seed preparation technologies at the operating enterprise.

In the improved seed sorting device, special hoppers are installed for separating the impurities, empty seeds and technical seeds into fractions by sucking the seed by the air, and the sorting of the seeds is controlled with the help of a moving auger. The newly proposed improved seed sorting device increases the efficiency of trapping fines, loose and broken seeds and prevents fines, loose and broken seeds from mixing with the dusty air.

The new device works by horizontal air flow. Due to the change in air speed in the sorting chamber, sorting is carried out according to aerodynamic parameters [6] [7] [8] [9].

In the proposed horizontal air flow seed sorter:

1) Maximum cleaning of various impurities in seeds;

2) Separation of seeds into optimal fractions due to selection of air speeds;

3) To create opportunities for the separation of selected seeds depending on the mass;

4) The following simplifications were adopted in the mathematical equation representing the law of movement of seeds in the working chamber under the influence of air flow:

- Seeds moving in the air flow do not affect each other;
- Seeds of mass m_1 and m_2 moving under the influence of air flow have a certain elastic connection with each other;
- In both cases, seeds are taken as material points with known flight coefficient—K_{ch} and aerodynamic resistance coefficients—K_{chk}.

We check the movement of the seed in the sorting chamber with respect to the XOY—Cartesian coordinate system (**Figure 2**). Let the velocity of the air flow entering the chamber be V_0, the velocity inside the chamber be V_x, and let the laws of movement of seeds inside the chamber be $x(t)$, $y(t)$.

Masses of seeds differ from each other in the degree of completeness, choice, immature and hairiness. In the process of movement, seeds are affected by Pix, Pi—air resistance forces and G-gravity forces in the corresponding directions.

We formulate the equations of motion of seeds based on the Lagrange principle, taking into account the above forces;

Unlike seeds, they do not have an elastic bond between them. In this case, the

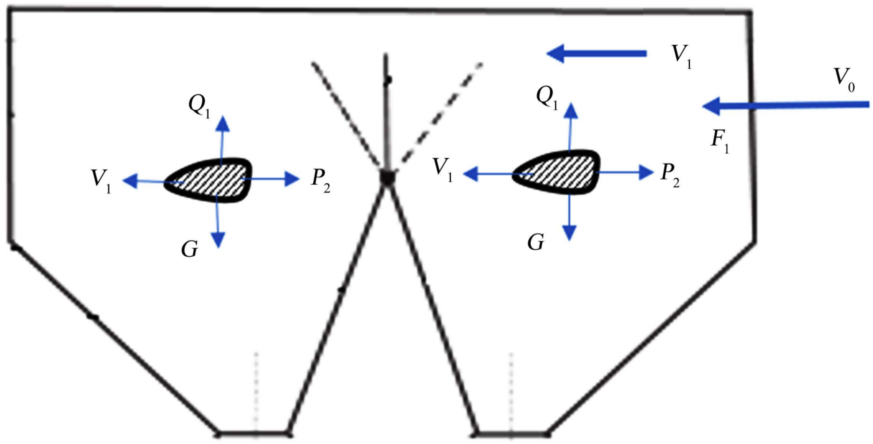

Figure 2. Scheme of the movement of seeds in the sorting chamber and the forces affecting it.

laws of movement of seeds are expressed by the following system of differential equations:

$$\begin{cases} m_i \ddot{x}_i = c_i \left(V_x - \dot{x}_i \right) \\ m_i \ddot{y}_i = -\left(c_{ki} y_i + c_{pi} \dot{y} \right) - m_i g \end{cases} \quad i = 1, 2, 3 \tag{1}$$

Here: c_i -seed flight resistance coefficients

Let the seeds of masses m_1 and m_2 be mutually elastically connected.

We look at the vertical and -horizontal states of two-component, interconnected seeds.

For these cases, the laws of movement of seeds are expressed using the following system of differential equations:

$$\left.\begin{aligned} m_1 \ddot{x}_1 &= v_{x0} - c_{k1} \dot{x}_1 + c_{x0} \left(x_2 - x_1 \right) \\ m_2 \ddot{x}_2 &= v_{x0} - c_{k2} \dot{x}_2 + c_{x0} \left(x_1 - x_2 \right) \\ m_1 \ddot{y}_1 &= -m_1 g + c_p \dot{y}_1 + c_k \left(y_1 - y_2 \right) \\ m_2 \ddot{y}_2 &= -m_2 g + c_p \dot{y}_2 + c_k \left(y_2 - y_1 \right) \end{aligned}\right\} \tag{2}$$

For both cases, the system of differential equations is solved numerically in special computer programs with appropriate initial conditions and values taking into account the coefficients of elasticity and aerodynamic resistance.

Case 1. The graphs of the patterns of movement of the seeds in the sorting chamber were obtained when they were considered as discrete material points without any interconnection (Figure 2). The graphs are obtained in different variations, and some of the results are presented in the first table (Figure 3). From the results, it was observed that the change of the elasticity coefficient S_k (C_p = const) has little effect on the distance of flight (landing) along the length of the seed sorting chamber. Because the mass of seeds is small, during the movement, the effect of elastic forces will not be sufficient. However, increasing or decreasing the resistance coefficient of the seed—S_r (C_k = const) is one of the main factors affecting the distance of seed flight.

It was determined that the seeds, depending on their mass, fall into the distance of $0.46 < x < 0.82$ m intervals along the length of the sorting chamber. In fact, when seeds have a certain degree of fertilization, their flight coefficient increases. This is important in the selection process. Table 1 shows the relationship between the values of the seed masses and the values of the take-off distances depending on the change in air speed.

Case 2. Since the seeds are not completely hairy, it is somewhat difficult to sort them. Because they can be in a certain relationship (Figure 4). Table 2 and Table 3 show the results of a part of graphs representing the laws of motion when two seeds with different masses are in mutual elastic connection.

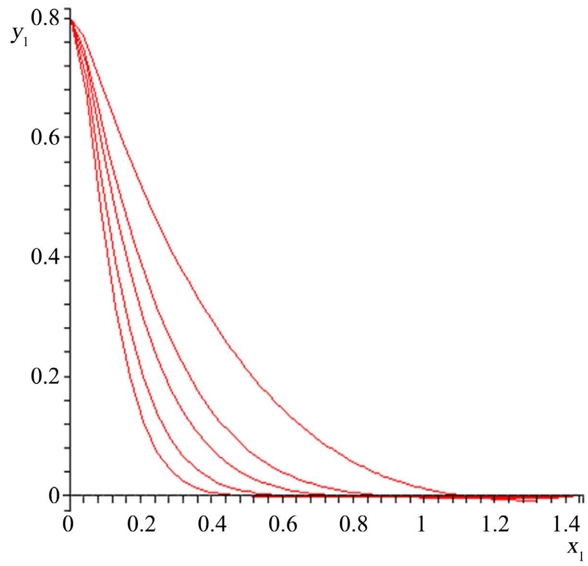

Figure 3. A graph representing the dependence of the take-off distance with the decrease of the elasticity resistance coefficient.

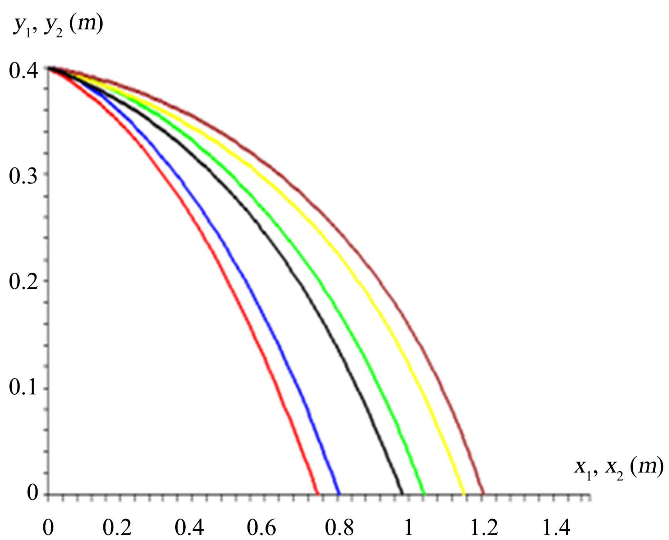

Figure 4. A graph representing the patterns of movement of seeds with and without cross-linking.

Table 1. Dependence of the take-off distance on seed mass and air speed.

m (kg)	$v_0 = 8$ m/s	$v_0 = 12$ m/s	$v_0 = 16$ m/s	$v_0 = 20$ m/s
	$x(m)$	$x(m)$	$x(m)$	$x(m)$
0.001	0.46	0.48	0.60	0.71
0.002	0.31	0.44	0.56	0.66
0.003	0.28	0.42	0.51	0.62
0.004	0.24	0.34	0.45	0.54

Table 2. Dependence of the mass of the flying distance of the bound seeds when the speed is constant. ($V_0 = 8$ m/s)

m (kg) / $x(m)$	$m_1 = 0.001$ $m_2 = 0.002$	$m_1 = 0.001$ $m_2 = 0.003$	$m_1 = 0.002$ $m_2 = 0.003$	$m_1 = 0.002$ $m_2 = 0.003$
x_1	0.98	0.80	0.90	0.76
x_2	0.88	0.75	0.77	0.68

Table 3. The variation in flight distance when the speed of the connected seeds is constant, and their mass and drag coefficient are variable. ($V_0 = 8$ m/s)

m (kg) / $x(m)$	$m_1 = 0.001$. $m_2 = 0.002$. $C_\kappa = 0.02$		
	$C_p = 0.01$	$C_p = 0.02$	$C_p = 0.03$
X_1	1	1.2	1.36
X_2	0.92	1.16	1.28
x (m)	$C_p = 0.005$	$C_p = 0.007$	$C_p = 0.009$
X_1	0.84	0.92	1.00
X_2	0.76	0.88	0.88
$x(m)$	$C_p = 0.2$ $C_\kappa = 0.01$	$C_p = 0.2$ $C_\kappa = 0.02$	$C_p = 0.2$ $C_\kappa = 0.03$
X_1	1.20	1.20	1.21
X_2	1.15	1.16	1.16

In both cases, the laws of movement are basically the same, and the distance of seed flight is highly dependent on the change of the coefficient C_p, and less dependent on the change of C_k. That is, in the selection process, the level of hairiness of seeds is one of the important factors. In addition, the speed of the air entering the sorting chamber has a special place in the fractionation of seeds. The above results provide an opportunity to choose the fractionation distances of seeds under the influence of horizontal air flow. On this basis, it is possible to place fractionated seed receiving sections in the structure of the sorting chamber.

4. Result

Depending on the initial state of the cotton seeds, the waste mass separated by this device is 0.1% - 0.2% of the initial mass of the seeds. The amount of seeds (whole, broken) and fibrous material in waste is 18.5 - 19.6 and 11.8% - 55.4%, respectively. The main drawback of the pneumomechanical seed cleaner is the low cleaning efficiency of small debris—only 20% - 25%, and it requires a relatively large power (12.85 kW) and it is necessary to regularly adjust the aerodynamic working order of the device. Such shortcomings do not satisfy the requirements of the cotton ginning industry at all.

The results of the scientific work on the improvement of seed sorting and cleaning aggregates were studied, and the results of the analysis showed the feasibility of conducting research on improving the sorting efficiency of the aggregate. In this direction, the goals and tasks of scientific research work were determined.

In the analyzes conducted on the performance of sorting aggregates it was seen that when the productivity of the unit reaches 2600 kg/h, the probability of seed seed passing into technical seed increases, and when the productivity reaches 2800 - 3200 kg/h, the output of technical seed fraction increases to 25% - 30%. Based on this, it was determined that the existing sorting device operating at the enterprise should be improved in order to use it with high efficiency.

By conducting scientific research and experiments, it was determined the need to improve the existing USM unit at the enterprise, develop a scheme that ensures its high-quality operation, and conduct tests to compare the improved USM unit with the actual working unit.

5. Conclusions

A mathematical model representing the movement of seeds in a two-section sorting chamber with non-interconnection and partial connection was created and numerically solved in the MARLE program.

Fractionation distances were determined in the two-section sorting chamber according to the mass of the seeds.

The graphs of the laws of motion are obtained when the seeds are considered as discrete material points with no interconnections. According to the amount of seed mass, the flying distances along the length of the sorting chamber were determined.

The distance of seeds flying along the length of the sorting chamber was determined by taking the laws of movement of the seeds at different air velocities.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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