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MODELING OF A VIBRATORY CLEANING DEVICE WITH COSINOSOIDAL AND SINUSOIDAL SHAPES IN MATCHING THE LONGITUDINAL AND TRANSVERSE CUTTING SURFACE

MAMAKHONOV AZAM

Professor, Namangan State Technical University, Namangan, Uzbekistan
Phone.: (0598) 772-7160, e-mail.: mamahonovazam@gmail.com

KHIKMATILLAEV ISMOILKHON

PhD student, Namangan State Technical University, Namangan, Uzbekistan
Phone.: (0590) 555-9614, e-mail.: ismoilkhonkhikmatillaev@gmail.com
Corresponding author

Abstract: This article analyzes scientific research conducted on vibratory cleaning devices. Based on the analysis, a new vibratory cleaning machine with longitudinal and transverse cross-sections of cosinusoidal and sinusoidal shape, respectively, is proposed. The motion law of cottonseeds on the screen surface was determined. Graphs were obtained showing the relationship between the longitudinal vibration amplitude and period of the screen surface and the cleaning efficiency.

Keywords: Vibratory screen, spherical, banana screen, sinusoidal and cosinusoidal, chaotic motion, optimal parameters, amplitude, frequency, length, hole diameter, hole pitch, hole density.

Introduction. Vibrating screens are widely used in food processing, mining, agriculture, construction, pharmaceuticals, and almost all industrial sectors. The problem of improving their productivity and cleaning efficiency has always been a pressing issue for researchers [11-17].

Most existing studies focus on optimizing the perforated screen dimensions or increasing vibration intensity. However, as current approaches mainly aim to reduce production costs and extend service life, they no longer meet the growing industrial demand. Therefore, many studies have shifted toward developing more efficient screen designs.

The proposed screen structure aims to achieve high efficiency in cleaning fuzzy cottonseeds with complex physical–mechanical properties [11–21]. In linear vibrating screens, the transportation velocity of cottonseeds and their distribution along the working surface remain uniform, which leads to the ineffective separation of impurities and thus poorer cleaning quality.

A number of studies have focused on increasing the efficiency of vibratory screens [8–21]. To optimize vibration parameters (e.g., frequency and amplitude), a deeper analysis of the cleaning and screening process is necessary. Several studies [9, 10] investigated the influence of vibration parameters on cleaning and screening efficiency. For instance, Xiao and Tong [11] studied particle stratification and screen penetration during cleaning, developing mathematical models that describe how vibration parameters affect these processes. Zhao et al. [12] proposed adjusting the desired vibration amplitude of a screen by incorporating two eccentric blocks into the drive system. Gary et al. [13] emphasized the importance of considering particle shape in simulation and experimental analyses of vibratory screen performance. Their results showed that assuming spherical particles can significantly distort predictions of real industrial screening systems.

One innovative design, the “banana” screen, includes several inclined surfaces that maintain a constant particle bed thickness during screening [14]. Studies have shown that banana screens can double processing capacity by improving material flow control. However, when particle size is about 0.5 mm, their screening efficiency decreases sharply [15]. Further in-depth investigation is required to optimize banana screen performance. For example, Dong et al. [16] simulated particle motion on a multi-deck banana screen using the discrete element method (DEM), analyzing ways to improve screen efficiency.

Some researchers have proposed new vibration modes for traditional vibratory cleaning devices. Xiao and Tong [17], for example, developed a novel vibrating screen with a swing motion based on manual sieving principles. Compared with simple unidirectional vibration, the swing mode combines oscillatory and shaking movements with varying amplitude and direction, which significantly improves cleaning and screening efficiency. However, this complexity increases energy consumption and design difficulty.

Experimental studies in production facilities revealed that fuzzy cottonseeds tend to accumulate in the central part of the screen surface, blocking the perforations and preventing effective removal of impurities [18]. Therefore, such swing screens are ineffective for cleaning fuzzy cottonseeds.

New technological approaches have also been proposed regarding vibration amplitude [19]. Jiang et al. [20] developed a dual-axis variable-amplitude vibrating screen characterized by high productivity and cleaning efficiency. Later, Jiang and co-authors [21] investigated a variable-amplitude equal-thickness screen, demonstrating that adjusting vibration amplitude can significantly enhance screening efficiency.

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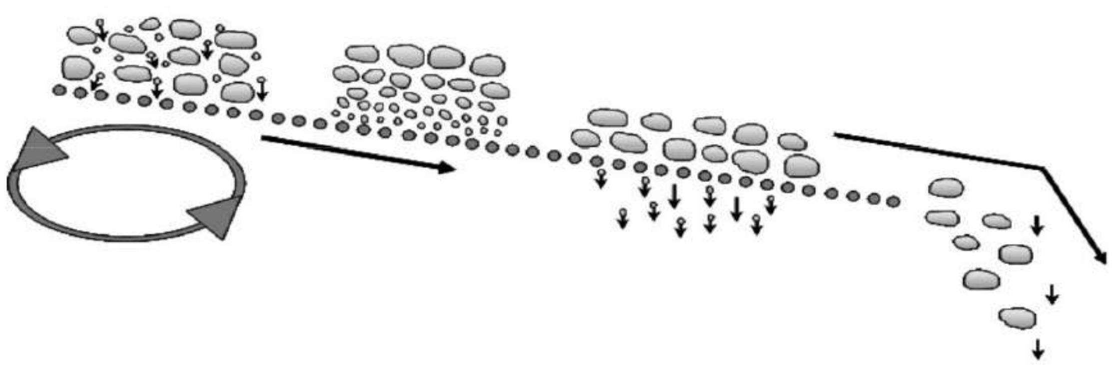


Figure 1. Scheme of the cleaning process in vibrating screens

A screen with holes of a predetermined size is used to separate the raw material of hairy seeds into two fractions, i.e. according to their size. It is usually used to classify or clean the impurities contained in the dispersed products. Hairy seeds larger than the minimum size are retained on the screen surface, while small particles (impurities) pass through the holes. The cleaning process mainly includes three main stages. Figure 2 depicts the cleaning process along the length of the screen, corresponding to the size of the seed pile.

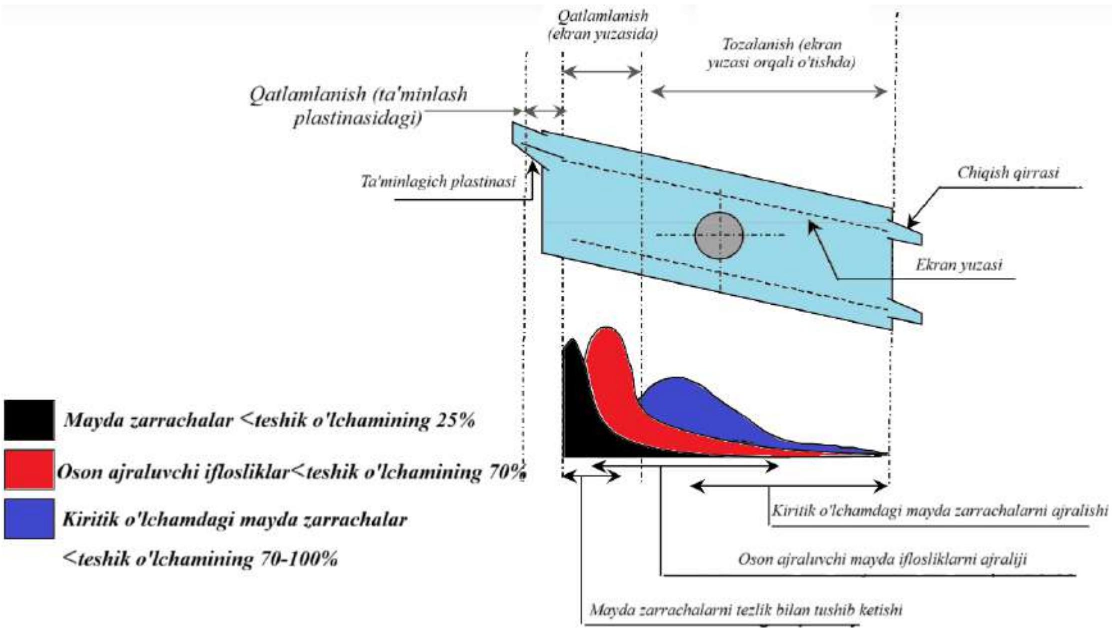


Figure 2. Stages of grain flow cleaning

Layering on the inlet plate - when the grain enters the screen, small particles settle on the bottom, and the grain settles on the top layer. The vibration of the screen repeatedly layers the impurities according to their size, the small particles approach the holes. As the grain passes through the screen surface, the smallest impurities (small particles) quickly pass through the holes, while larger impurities pass slowly or remain until the exit.

Categories of impurities in the grain pile:

• Fine impurities < 25% pore size - particles in this category pass through the screen holes very quickly;

• Easily separated impurities < 70% pore size - pass through the screen holes at a moderate speed;

• Critical size impurities < 70– 100% pore size - the most difficult to separate impurities, they often remain on the screen for a long time.

The efficiency of screening depends on the correct layering of the material and the continuous flow movement. Fine impurities are separated quickly, while larger ones can continue to separate until the outlet. The efficiency of a grain cleaning screen depends on five main parameters:

Type of movement:

Sloping (rotary) movement: Depends on the screen's rotation (oscillation) speed (rpm), oscillation amplitude, and direction of rotation.

Horizontal (elliptical or rectilinear) movement: Determined by speed, oscillation amplitude, angle of attack (e.g., 45°), and direction of rotation.

Screen installation angle. The inclined position of the screen directly affects the material flow rate and separation efficiency.

Screen material and surface area of the holes. The type of screen (mesh, perforated plate, polyurethane, etc.) and the smallness of the surface area of the holes determine the ease of passage of impurities.

Screen carrying capacity. Indicates the amount of grain that the screen can effectively handle for a certain period of time without overloading.

Physical and mechanical properties of the grain. The condition of the seed pile—whether it is dry, moist, wet, or sticky—directly affects stratification and separation efficiency.

All of the above factors are interrelated and affect the overall efficiency of the screen [1-23]. The efficiency of the cleaning process depends on the combination of the type of movement, angle, screen material, loading, and the physical and mechanical properties of the grain.

Layering. This is a traditional screening process, which is based on the principle of layering. During the process, the grain pile is naturally layered according to its size and density under the influence of vibration: depending on its size, the grains rise to the top, while the finer impurities fall down to the screen holes (Figure 3).

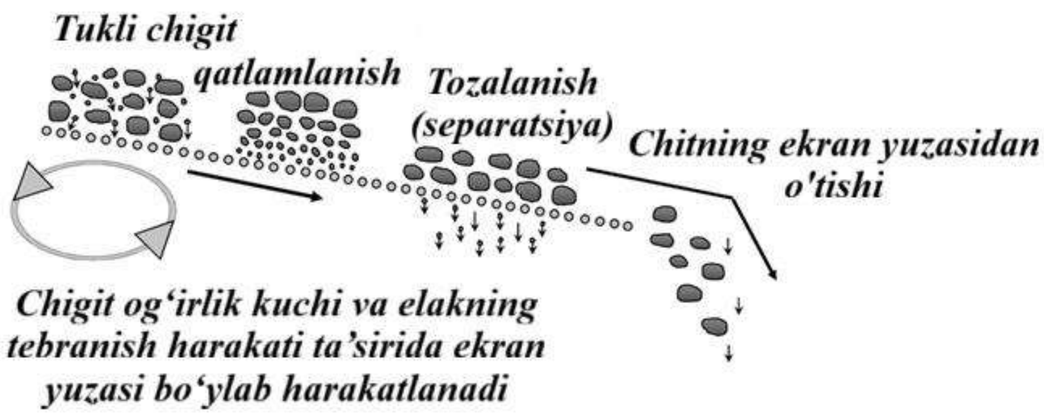


Figure 3. Seed cleaning process

Free-fall cleaning is a process based on the principle of gravitational separation, in which material particles freely pass through or slide over the holes of a screen, without accumulating on the surface. In this method, each particle moves independently. Small particles quickly pass through the holes. Large particles move along the screen surface and are directed to the outlet. The main feature of this type of cleaning is the free-fall property, which makes it very effective for dry, low-moisture materials and provides high productivity. For free-fall cleaning to be effective, at least 70 percent of the incoming material must pass freely through the screen holes.

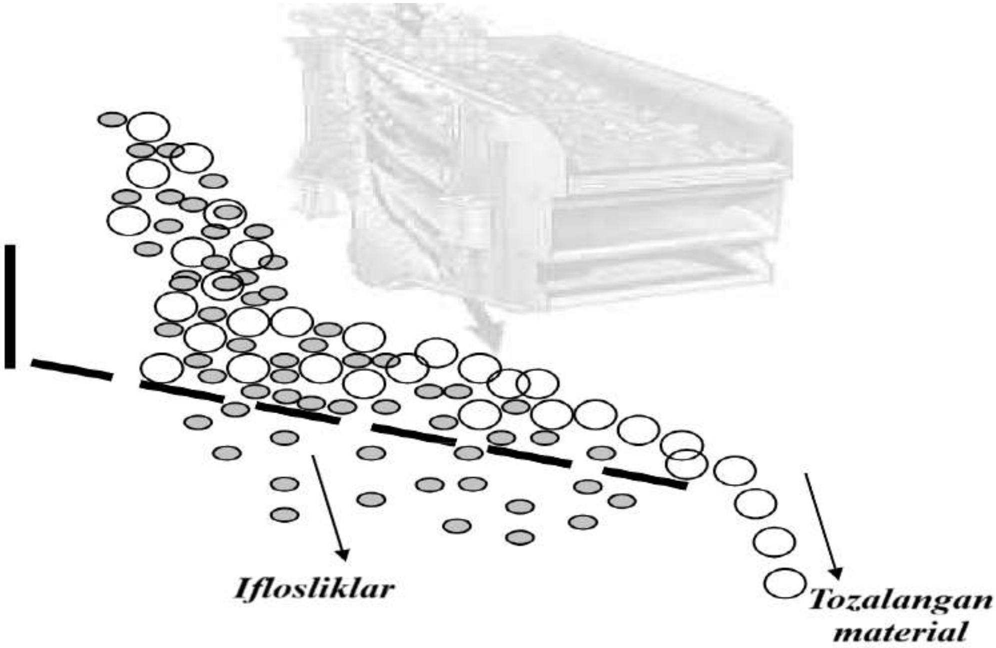


Figure 4. Free-fall cleaning scheme

In other words, if the material contains a lot of fine fractions, this provides high productivity and effective separation. The main features of vibrating screens are as follows:

Inclined vibrating screen. The screen surface is located at an angle of 15–30°. The material is moved by a circular vibrating motion. Used to clean large and medium impurities.

High-frequency vibrating screen. Operates at a high vibration frequency, with a small amplitude. Very useful for separating fine impurities. Often used in mineral processing and sand production. High accuracy and low probability of clogging of screen holes.

Horizontal vibrating screen. The screen surface is located horizontally (0– 5°). The vibration is elliptical or linear, which increases control and efficiency. Used for precise separation of fine and medium particles. Creates good stratification with low energy consumption.

Scalper screen. Used for pre-separation of large impurities, i.e. before the secondary or fine impurities cleaning stage. Removes large particles and waste from the raw material. Widely used in mining, gravel and processing plants.

Differential layer screens. Consists of several layers of screens, the frequency or amplitude of which is slightly different. Due to this, the material is separated into small, medium and large fractions at the same time.

Roller screen. Works using rollers in a circular motion instead of vibration. Very convenient for cleaning sticky, wet or muddy materials - highly effective for cleaning materials that clog in ordinary vibrating screens. Each roller acts as a sieve element: small particles pass between the rollers, while large ones move forward.

High-efficiency cleaning of hairy seeds directly affects the efficiency, productivity and maintenance costs of the enterprise. If cleaning is effective, the seeds move through the processing system without obstacles, which increases production efficiency. Impurities are separated before they reach the next stage, which improves product quality and reduces wear on the saw blades of the screening device. As a result, the service life of the equipment is increased and repair costs are reduced. The seeds that pass through the screen are sent to the next stage accordingly.

Vibrating screens use various types of vibrational movements to effectively stratify and clean the scattering products. The type of vibration determines the material flow, the rate of stratification and the efficiency of dusting. The types of vibrational screen movements are presented in Figure 1.10. The vibrational movement of the screen is based on the laws of: circular motion; elliptical motion; oval motion; rectilinear motion. The efficiency of a vibrating screen is determined by its ability to effectively separate the material and move it smoothly along the screen surface. The following factors determine the quality of screen performance in cleaning hairy seeds:

Layering of the material. As a result of vibration, particles of different sizes are separated into layers: small particles fall to the bottom, and large ones rise to the top. This increases the accuracy of separation.

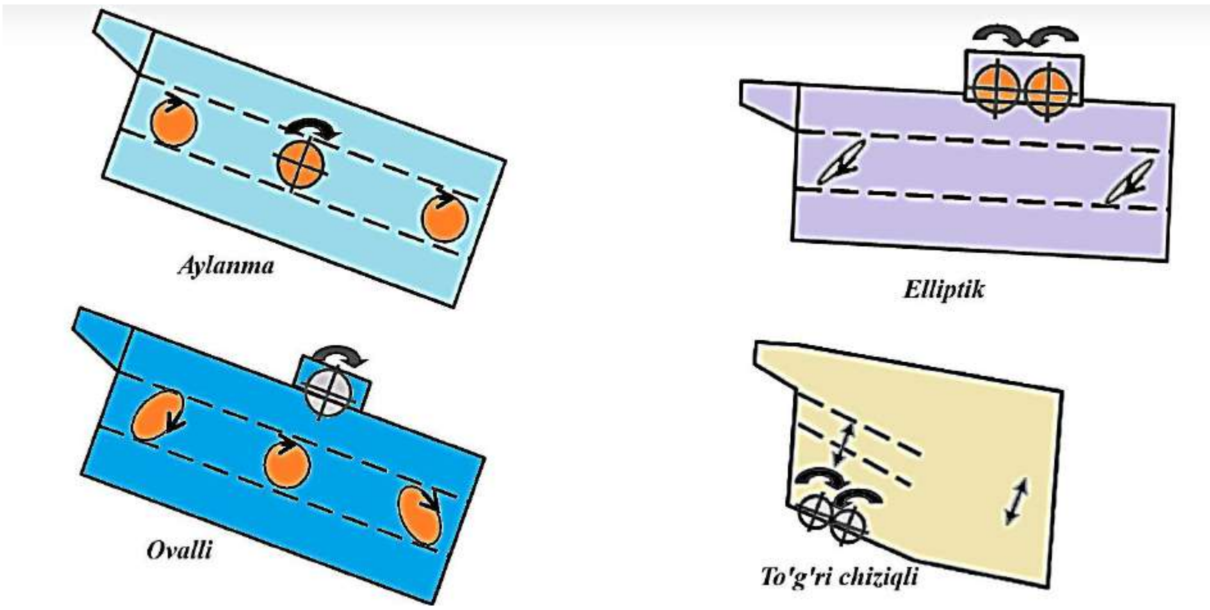


Figure 5. Types of Vibrating Screen Action

Preventing hole clogging. This is the condition where large particles become trapped in the screen holes. Controlling the vibration amplitude, screen pitch, and seed moisture content can reduce this problem.

Preventing hole clogging. This occurs when small particles block the holes. Using self-cleaning screens or varying the vibration frequency can reduce this condition.

Fraction of the seed mass. The main purpose of cleaning is to separate the incoming seed mass into two or more size fractions.

Movement of the fuzzy cottonseed. The screen should move the seed continuously across its surface.

The carrying capacity is the maximum amount of seed that the screen can carry before the weight of the seed balances the impulse of the screen. If too much seed mass is fed to the screen, stratification will slow down and the accuracy of separation of impurities will decrease.

Type of screen material. Wire mesh, polyurethane, or rubber screens have different effects on friction. A smooth screen increases material velocity, while a coarse or thick screen slows it down.

Obstructions and material buildup. The buildup of grain on the screen reduces flow rate. A constant and uniform feed ensures a stable velocity.

Gravity and free fall. The screen must move the grain with sufficient vibration energy against the force of gravity.

Main Section: At the Namangan Textile Plant, the structure, operation, and technological conditions of the fuzzy cottonseed cleaning device were systematically analyzed to improve its performance. To enhance cleaning quality and final product purity, the screen design was modified while maintaining structural simplicity: the longitudinal and transverse cross-sections were made cosinusoidal and sinusoidal, respectively.

It was determined that the spatially chaotic motion of cottonseeds on such a surface is advantageous for cleaning. In addition, by developing an adaptive chain transmission compatible with the vibrations, the overall stability of the machine was improved, providing a comprehensive solution to the problem.

During experimental studies, a new screen design was proposed and tested using a specially developed laboratory prototype. Tests were conducted by varying only one parameter—the surface curvature amplitude—under different rotational speeds. The influence of vibration parameters on cleaning efficiency was quantitatively studied through sequentially controlled digital experiments.

Results showed that, compared to the existing flat-screen cleaning device, the proposed screen achieved significantly higher cleaning efficiency. This approach provides a scientific foundation for developing industrial-scale vibratory screens with sinusoidal and cosinusoidal surface profiles and for determining their optimal parameters.

In the proposed screen, the sinusoidal–cosinusoidal surface induces a three-dimensional chaotic motion of cottonseeds compared to linear motion on a flat screen. This occurs because the surface is curved in both longitudinal and transverse directions. When vibrating, the cottonseeds move along the x- and y-axes and, due to amplitude effects, also oscillate along the z-axis. As a result, their motion becomes complex, consisting of rolling, sliding, and jumping in multiple directions, highly sensitive to small parameter changes, producing chaotic trajectories [24-25].

In contrast, on a flat screen, vertical vibrations mainly cause the material to bounce up and down with minimal lateral displacement.

The transverse cross-section of the proposed screen has a cosinusoidal wave shape. During vibration, the normal reaction force decomposes into components, creating impulses that act along the y-axis. The longitudinal cross-section is sinusoidal, generating impulses along the x-axis. Together, these components produce combined horizontal (x) and vertical (z) movements, causing cottonseeds to follow chaotic 3D trajectories [25].

The analytical representation of the proposed surface as a two-dimensional wave is expressed as follows:

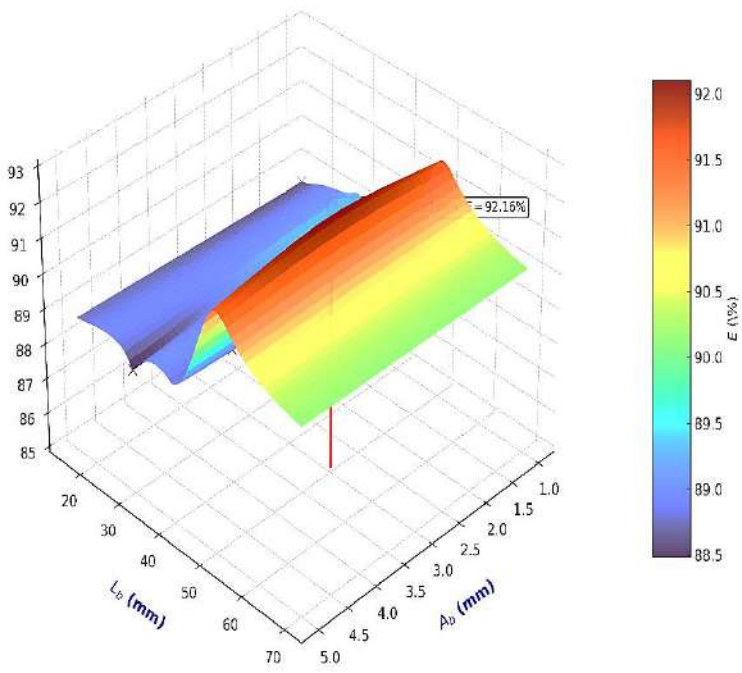
$$z(x,y) = Acos\left(\frac{2\pi x}{L_A}\right) + Bsin(\frac{2\pi}{L_B}) \tag{1}$$

where, A is the transverse (x −direction) amplitude (vertical part of the screen edge line), L_A −is the transverse wavelength (period), B is the longitudinal (y-direction) amplitude, and L_B −is the longitudinal wavelength.

The optimal parameters for the proposed sinusoidal and cosinusoidal screens are values chosen to maximize the efficiency of such a shape. They often depend on the properties of the material being cleaned and the physical and mechanical properties of the seed. Cosine amplitude A: if the seed diameter is $4-6$ mm, it is desirable that $A \approx 3$ mm. If the amplitude is chosen too small, the horizontal impulse will not be sufficient; if it is too large, there is a risk that the seed will jump off the screen. Sinus amplitude B: often the equality or closeness between A and B is preferable: $B \approx A$, since a similar deflection is created in both directions. For example, $B \approx 4$ mm. Transverse wavelength L_A −: one wave period across the width of the screen. It is desirable that the optimal L_A −is several times larger than the size of the seed or particle. For example, if the seed diameter is 5 mm, $L_A = 50$ mm, and the longitudinal wavelength $L_B = L_A = 50mm$ are selected. Although the screen is wavy, its overall vibration amplitude is also important. It is known that the amplitude of most vibrating screens is around 1– 10 mm. Optimally, making it 10 mm will both bounce the seed sufficiently and prevent it from falling off the screen. Vibration frequency: If the standard screen operates at a frequency of about 12– 20 Hz, the movement of the seed will be effective. The main goal in choosing these parameters is to enhance chaotic motion and help the seeds roll on the screen. For example, increasing the amplitude gives the seed a greater impulse and increases its bounce; decreasing the wavelength increases the number of bends. Typically, experiments show that when the screen wave amplitudes are close to the size of the seed and the vibration parameters are around 1– 10 mm amplitude and 12– 20 Hz, the seed movement is maximally disrupted and cleaned.Most vibrating screens operate at amplitudes of 1– 10 mm and frequencies of 12– 20 Hz, which are effective for chaotic motion and efficient cleaning.

Based on experimental results, the dependence of cleaning efficiency η\etaη on the longitudinal amplitude A and period T was determined as follows:

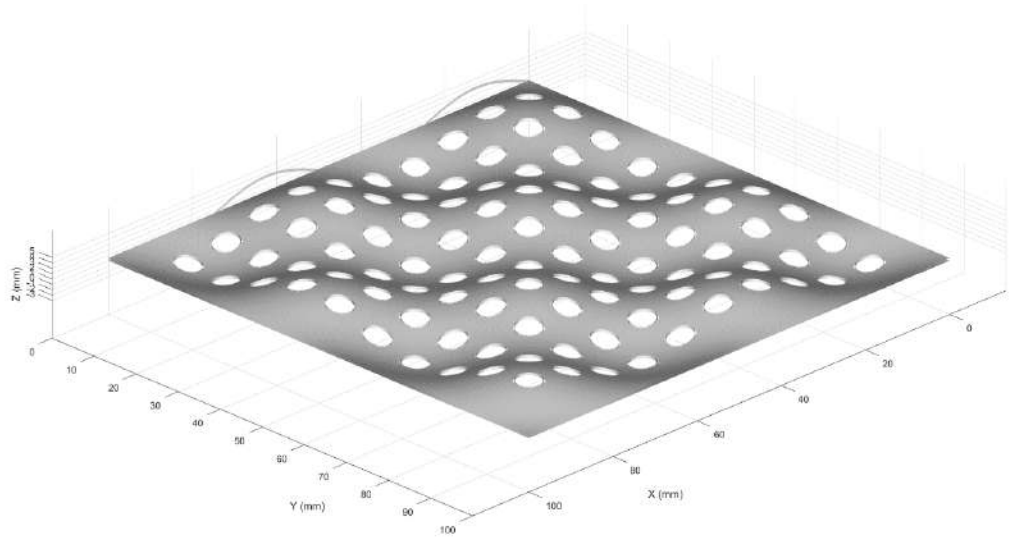
$$E = f(A_b, L_b) \tag{2}$$

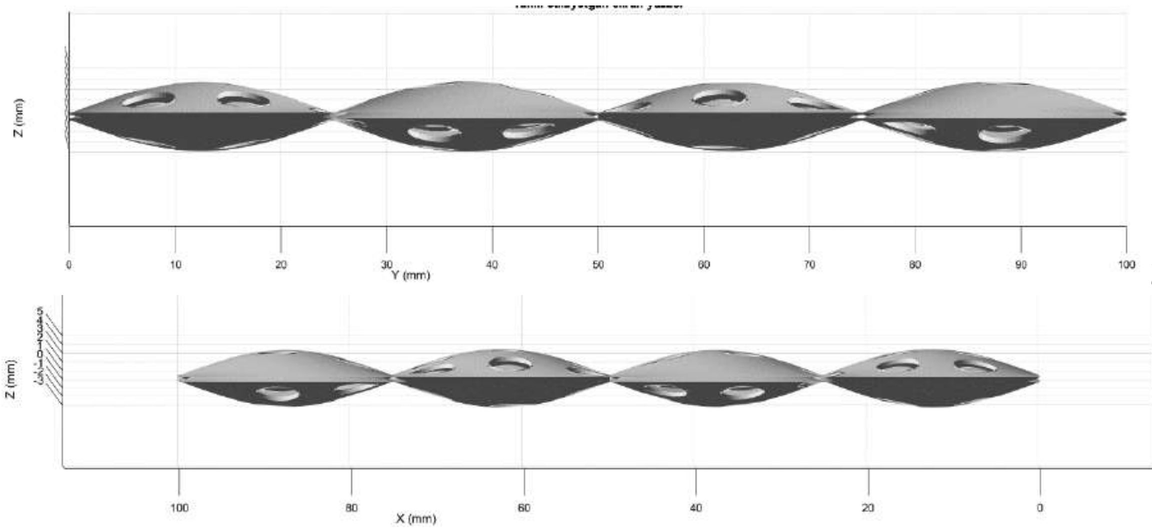


According to the results of experimental research, the dependence of the longitudinal surface shape of the screen on the efficiency of chitin removal was studied (Fig. 6). It was determined in terms of amplitude and as a 3D spatial model. In the graph, A_b-section vibration amplitude (mm), L_b—vibration period (mm), E-esa represents the cleaning efficiency of the screen (%).

Figure 6. Graph showing the relationship between longitudinal vibration amplitude, period, and cleaning efficiency

The results of the experiments show that the ratio of the parameters A_b and L_b has a significant effect on the effective separation of the screen. The maximum point of the spatial surface constructed on the basis of numerical analysis was observed at the values A_b =3mm and L_b = 50 mm. At this point, the cleaning efficiency was E = 92,16%. The graph depicts the optimal indicator (peak) of the screen efficiency, which allows you to choose the physically optimal parameters. This parameter is the factor that has the greatest impact on the screen efficiency; around the value of 3 mm, a resonance state is formed, and the cleaning process achieves maximum results.





b)

c)

Figure 7. Structural diagram of the proposed screen. a) 3D view, b) y-axis section, c) x-axis section

A section (0,001 m^2 section) of the structural model of the proposed screen with a cosinusoidal and sinusoidal shape of the transverse and longitudinal cross-sections, respectively, is shown in Figure 5.

The geometric parameters of the proposed screen, based on numerous experimental studies, are presented in Table 1.

№	Screen parameter name	Recommended size
1.	Width	$1m$
2.	Length	$2\ m$
3.	Hole diameter	$5mm$
4.	Hole pitch	$9\ mm$
4.	Hole shape	Doirasimon
5.	Hole density	$12345\frac{dona}{m^2}$
6.	Screen thickness	0,002m
7.	Longitudinal wave (cosinusoidal)	$A = 3mm, L_A = 50\ mm$
8.	Transverse wave (sinusoidal)	$A = 4mm, L_B = 40\ mm$

Conclusion: According to analytical and experimental studies, at a longitudinal vibration amplitude of approximately 3 mm, resonance occurs, achieving the maximum cleaning efficiency of 97%. This parameter has the greatest influence on the screen's overall performance. The proposed screen design with cosinusoidal and sinusoidal surfaces ensures stable operation, enhanced cleaning quality, and potential industrial application.

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