

Smart Automation and Digital Modelling for the Development of an Efficient Hairy Seed Sieving Machine

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Abstract: In this research, a novel concave–convex vibrating screen design was developed and optimized to enhance the cleaning efficiency of fuzzy cottonseed prior to the oil extraction process. The study focused on improving the mechanical and dynamic characteristics of the screening surface by introducing sinusoidal and cosinusoidal wave profiles in the transverse and longitudinal directions, respectively. The physical and mechanical properties of locally grown cottonseed varieties in the Namangan region were analyzed to determine optimal design parameters such as inclination angle, vibration frequency, amplitude, and aperture geometry. Analytical modeling established that the optimal inclination angle for uniform seed distribution is 30°, with an amplitude of 4 mm and a vibration frequency corresponding to an eccentric shaft speed of 200 rpm. Under these parameters, the cleaning efficiency reached 88%, representing a 12–15% improvement compared to the conventional flat-screen design. The proposed screen geometry facilitated uniform seed flow, reduced clogging of fine apertures, and ensured continuous stratification of impurities through multi-directional oscillations. The theoretical model, supported by experimental observations, confirmed that the modified harmonic surface enhances dynamic particle movement, thereby improving overall sorting performance and energy efficiency.

1 INTRODUCTION

In recent years, the mechanical design of vibrating screening systems has undergone substantial advancements, resulting in improved operational efficiency and screening accuracy. Traditional planar and rotary-type screens are increasingly being replaced by innovative and non-conventional configurations that enhance both the separation process and the quality of the final product. A novel spiral-type vibrating screen was developed and experimentally validated by Yelemes, D. et al. [1], in which the screening surface is designed in the form of a helical curve. This geometry ensures a longer particle retention time and a more uniform distribution of material flow across the screening surface, thereby enabling the production of high-quality cubic gravel suitable for construction and road engineering applications. Experimental investigations demonstrated that when the screen operates within a frequency range of 16–26 Hz and an

amplitude of 1.5–4.0 mm, the optimal performance is achieved at 22 Hz and 3.0 mm amplitude. Under these parameters, the screening efficiency reached 93–95%, while the cubicity index of the product was between 84–86%, indicating a significant improvement in both separation precision and aggregate morphology.

To further adapt screening equipment to new operational environments, several complex structural systems operating near resonance have been proposed. For instance, a three-mass vibratory conveyor incorporating a three-dimensional spring element was developed and optimized. In this system, the exciting inertial mass was transmitted through a flat spring mechanism, enabling a more balanced dynamic response and reduced energy consumption [2]. The model of this vibratory system was created in SolidWorks® software and subsequently verified through experimental testing. The results revealed that by precisely selecting the dimensions and mechanical properties of the flat

springs, the device achieved stable and energy-efficient operation in a near-resonant mode, thus ensuring reliable performance and extended service life.

Recent developments in vibratory screen engineering have also focused on the implementation of multi-layer screening configurations, which have demonstrated substantial improvements in throughput capacity. In the case of two-layer screens, arranging the screening decks on two levels allows for a higher volume of material to be processed within the same installation footprint [3]. Experimental investigations on a double-deck screening unit used for the recycling of decorative construction waste revealed that, by adjusting the spring stiffness within a frequency range of 25–75 rad/s, it is possible to significantly enhance the productivity of the screening process.

To improve screen performance under challenging conditions such as moisture accumulation or clogging of apertures by fine particles, various mechanical solutions have been proposed. One effective approach involves installing elastic or flexible spherical elements beneath the screen surface, which amplify the vibration amplitude of the mesh wires. This mechanism facilitates material loosening and self-cleaning, as experimentally demonstrated by researchers [4]. The addition of such auxiliary components effectively reduces the blockage of apertures by fine particles, accelerates the stratification process, and thereby increases overall screening efficiency.

Zheng et al. [5] conducted a detailed fatigue analysis of a linear vibrating screen traverse commonly used in the mining industry. The authors investigated the dynamic behavior of the traverse element under cyclic loading when microcracks were present. Their results indicated that, in certain operational regimes, increasing the motor rotational speed stabilizes the stress distribution within the traverse and consequently improves its fatigue resistance and service durability.

Similarly, in the food processing industry, specialized vibrating screen designs have been applied to handle bulk granular materials efficiently. For example, an innovative configuration combining a vibratory screen and a radial fan was developed to minimize grain losses during separation. The airflow generated by the fan assists the sorting process without displacing the seeds, ensuring uniform separation and minimal product loss [6]. Experimental evaluation of this system demonstrated a considerable reduction in grain losses and a noticeable increase in screening efficiency. The

forementioned examples clearly illustrate that the proposed configurations – including spiral and banana-type screens, multi-layer arrangements, flexible spring panels, auxiliary vibrating elements, and hybrid technological solutions – collectively contribute to improving the adaptability of vibratory screens to diverse material types and operational conditions. At the same time, the design of such advanced screening systems requires a comprehensive analysis of dynamic behavior and structural strength, which is addressed in the subsequent section through dynamic modeling and simulation studies. The efficient operation of vibrating screens largely depends on the accurate modeling and analysis of their dynamic characteristics. In numerous studies, the screen and its supporting structure are represented as a spring–mass–damper system, from which the governing equations of motion are derived. Modern screening systems are frequently treated as multi-mass mechanical systems possessing more than two degrees of freedom, reflecting their complex dynamic interactions.

For instance, a chaotic vibrating screen model with four degrees of freedom has been proposed, where the screen box exhibits three translational and one rotational motion, while an internal resonator is driven by a specialized chaotic excitation mechanism [7]. The analysis of phase trajectories confirmed that the screen motion transitions into a chaotic regime, characterized by irregular oscillations of the screen body in multiple directions [9]. Such chaotic vibrations are advantageous for overcoming aperture clogging and the inherent limitations of strictly periodic motion, since non-periodic excitations induce continuous particle agitation, keeping the mesh openings clean. Consequently, these findings provide an important theoretical basis for the design and practical application of chaotic-vibration screening systems.

In modeling systems consisting of multiple masses and interconnected structural components, numerical methods and computer simulations are widely applied. Due to the complexity of dynamic modeling in flip-flow flexible screens, recent studies have integrated the Finite Element Method (FEM) with the Discrete Element Method (DEM) to obtain more accurate simulations [8]. Sanpeng Gong et al. experimentally determined the hyperelastic and viscoelastic properties of elastic polyurethane screen panels and represented them using the Ogden and generalized Maxwell models. A coupled FEM–DEM model was subsequently developed to simulate the

interaction between the screen panel and particle groups under various loading conditions.

The study revealed that by optimizing the spring parameters, the relative amplitude variation between the main and sub-screen frames was reduced by 44%, leading to a significant improvement in the vibration stability of the system. These findings demonstrate that fine-tuning the material–structural coupling model can effectively enhance the operational stability of flip-flow screens.

Modeling that incorporates not only the screen’s dynamic behavior but also the motion of material particles provides deeper insights into the overall screening mechanism. Using the Discrete Element Method, the motion of particles on single-layer and double-layer screens has been extensively investigated. For example, a multi-directional (triaxial) elliptical vibration screen model was developed to analyze both the screen mesh motion and particle trajectories [9].

Wenju Xiao et al. [10] established a detailed mechanical model for a triaxial vibrating screen and successfully distinguished the motion characteristics of both the screen structure and the particles. By analyzing the complex motion in three projections, the researchers identified distinct vibration components along each axis and their corresponding influence on the material. In particular, under Lissajous-type vibrations, the screen body exhibited displacements along the x, y, and z directions, producing a three-dimensional vibration pattern. As a result, particles experienced multi-directional forces that enhanced stratification efficiency [11]. Modeling results indicate that newly designed screens capable of three-dimensional vibration modes possess notable advantages over conventional linear or elliptical screens – including a more relaxed particle system, improved layer separation, and an increase in screening efficiency up to 93–95%.

Dynamic Modeling of Large-Scale Screens and Parameters Affecting Screening Efficiency. For large-scale vibrating screens, increasingly complex dynamic models have been developed to accurately predict their kinematic and operational behavior. Jiang et al. [12] proposed a new configuration featuring a dual-axis external excitation system designed for heavy-duty screening applications. Their numerical analysis focused on the kinematic characteristics of the screen body under varying load and frequency conditions. By investigating the motion trajectories of the screen box and the particle flow patterns under different operating regimes, they identified optimal kinematic parameters for stable operation. In some cases, it was observed that

operating large screens above the resonance frequency resulted in enhanced system stability.

A comprehensive review of the literature reveals that dynamic modeling has become an integral part of modern vibrating screen design [13], [14]. Simplified single-mass, single-spring models have evolved into coordinated multi-degree-of-freedom systems, electromechanically coupled models (for instance, coupled motor–screen dynamics), and material–structure interaction frameworks [14]. These approaches enable engineers to systematically vary the spring stiffness, damping ratios, mass distribution, and eccentric loading parameters to achieve optimized dynamic characteristics and improved energy efficiency.

The vibration exciter mechanisms serve as the “heart” of vibrating screens, defining both the dynamic behavior and the nature of the screening process. Traditional designs employ one or two eccentric, unbalanced rotors driven by electric motors at specified frequencies. In recent years, significant advancements have been achieved in the design and control of excitation systems. For instance, a dual-rotor inertial exciter driven by a single motor was proposed and analyzed across multiple operational modes [15]. It was shown that this mechanically synchronized system is more energy-efficient and reliable than conventional designs employing two independent motors.

The core feature of the screening process lies in particle stratification and passage through the apertures. When the screen vibrates, particles gradually rearrange from a mixed to a layered state – coarse particles migrate upward, while fine particles settle downward. This phenomenon is commonly referred to in the literature as the “Brazil nut effect” [16]. The more complete the stratification, the easier it becomes for fine particles to reach the screen surface and pass through the apertures. Consequently, numerous studies have emphasized that final screening efficiency strongly depends on the degree of particle stratification.

The theory of stratification and its influencing factors have been extensively investigated. Shen and Tong [17] introduced a quantitative indicator known as the “sedimentation difference”, which correlates directly with screening efficiency. It was found that vibration parameters such as frequency, amplitude, vibration angle, and additional displacement frequency significantly affect stratification – higher degrees of stratification yield greater overall screening efficiency. Different researchers have explored individual parameters influencing stratification dynamics. Another critical factor

influencing performance is the design of the screen surface. Baragetti et al. [18] proposed an innovative design approach for large screens operating under heavy loads, aimed at optimizing kinematic characteristics and reducing structural stresses. Their full-scale experimental results demonstrated that by strategically distributing vibration amplitudes across the surface, a uniform screening efficiency can be achieved. Similarly, adopting corrugated or wavy screen profiles has been shown to increase the probability of fine particles passing through apertures [19].

Material properties also play a vital role in stratification and overall screening efficiency. As moisture content increases, particle cohesion causes a decline in stratification; this issue can be mitigated by using low-frequency, high-amplitude vibration modes or introducing airflow assistance. Particle shape is another determinant: cubic or blocky particles tend to pass through screen apertures less easily than elongated or flat ones. However, the spiral-type screen design [20] has been reported to enhance the separation of cubic particles, as the spiral trajectory induces rotational motion, facilitating the detachment of angular particles and increasing the cubic fraction of the final product.

Regarding particle size distribution, previous studies indicate that when the feed material contains an excessively high proportion of fine fractions (e.g., >60%), stratification is nearly absent. The optimal fine fraction content is around 15–30%, allowing small particles to percolate effectively through the voids between coarse particles [17]. Moreover, the inclination angle of the screen relative to the horizontal plane is crucial: a flatter screen promotes better stratification but reduces material flow, while an overly steep angle accelerates discharge, leaving insufficient time for effective separation [13]. Therefore, determining the optimal combination of inclination angle, amplitude, and frequency through experimental calibration is strongly recommended for each specific material type and particle composition.

Overall, the reviewed studies demonstrate that the continuous improvements – including multi-directional vibration systems [11], optimized spring designs [9], [14], adaptive excitation modes [2], [13], and a deeper understanding of stratification physics [4] – have resulted in modern vibrating screens achieving significantly higher productivity than earlier generations. From coarse ores to fine

grains, and from dry sand to moist recycled aggregates, scientific advances have yielded optimized technological solutions for every material type. These developments are contributing to enhanced technological efficiency across industries such as mineral processing, construction materials production, agriculture, and recycling.

Improving the design of technological machines plays a significant role in the economic development of a country. Equipping production processes with energy-efficient machines and increasing labor productivity can reduce production costs. Enhanced technological machines contribute to producing quality and economical products, boosting their competitiveness and export potential. Consequently, this positively impacts the economy of the enterprise. In Namangan province, the Namangantextile enterprise is specialized in the production of vegetable oil, primarily processing cotton seeds. Initially, seeds are defuzzed in the enterprise's linting department. During this process, it is essential to clean foreign substances from the seeds. Cleaning seeds from foreign materials is crucial for obtaining high-quality oil. However, soil, stones, and other foreign substances in the seed negatively affect the product's quality and production efficiency. Therefore, using vibrational sieving technologies for high-efficiency seed cleaning has become a pressing issue. In recent years, research has focused on improving vibrational sieving machines to enhance their efficiency and energy savings. These studies aim to optimize key machine parameters, such as vibration amplitude, frequency, sieve hole size, and positioning angle relative to the horizontal plane, to increase cleaning efficiency. As a result, these machines effectively separate foreign substances from seeds, improve oil quality, and reduce energy consumption.

2 MATERIALS

Today, cotton seed plays a unique role in our country's food industry. In the Namangan textile enterprise, cottonseed processing yields products such as lint (short fiber), cottonseed oil, extraction oil, cottonseed meal, hulls, and cake [21]. Figure 1 below shows the appearance of fuzzy (Figure 1a) and delinted (Figure 1b) cotton seed.



Figure 1: Different types of cotton seeds: a) hairy; b) delinted..

In addition to enhancing the performance of technological machines, maintaining the product quality in the technological system is also of high importance. Therefore, researching and developing cottonseed cleaning and separation machines holds significant practical value [23]. In this study, attention is given to analyzing the vibrating surface of the sieve used for sieving cottonseed after the ginning process, calculating parameters, and the structural design process. Below are the research results on the vibrating surface and the overall structure of the vibrating surface.

Based on the analysis of the research studies conducted, investigations were carried out to develop an efficient design of the cottonseed cleaning screen. During 2023–2025, at the “Namangantolatekstil” enterprise located in Namangan district, Namangan region, the technical and technological operating modes of the cottonseed cleaning device (USM), which transports cottonseed from the supply bunker to the linting units, were studied. According to the technological process, the cottonseed from the bunker is conveyed to four vibratory cleaning units by means of a screw conveyor. As the cottonseed moves along the surfaces of the vibrating screens, it is cleaned from various foreign impurities. It should be

particularly emphasized that the flatness of the screen surface causes the cottonseed to perform an almost reciprocating planar motion along the working plane. Moreover, during the conducted research, it was identified that the cottonseed is unevenly distributed along the working surface of the screen, and certain active areas of the screen are not being effectively utilized. The uniform distribution of the cottonseed layer over the screen surface, the complete separation of foreign impurities from the cottonseed mass, and the possibility for these impurities to pass through the screen openings all depend on the motion law of the cottonseed on the screen surface.

As a result of the conducted scientific research and investigations of technological processes under production conditions, a new screen design was developed that ensures uniform distribution of cottonseed along the surface and provides active dynamic movement of the cottonseed on the working plane [21]-[23].

Figure 2 shows the current structural diagram of the vibratory cottonseed cleaning device used at the “Namangantolatekstil” LLC enterprise. The device consists of an electric motor (1), a belt drive (2), an eccentric shaft (3), a flat mesh screen (4), and a housing (5).

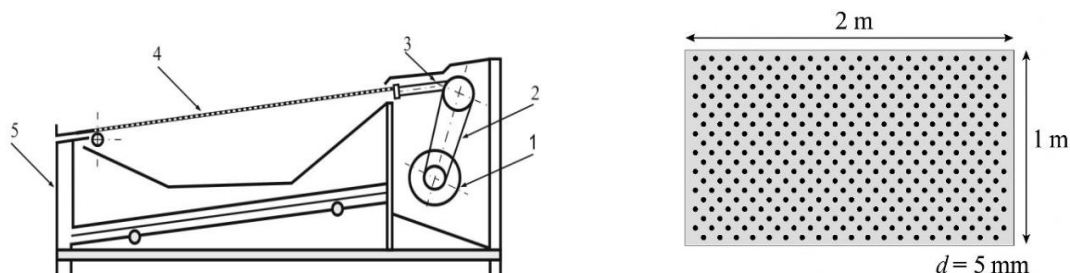


Figure 2: The device consists of an electric motor (1), a belt drive (2), an eccentric shaft (3), a flat mesh screen (4), and a screen housing (5).

The motion of the electric motor (1) is transmitted to the eccentric shaft (3) through the belt drive (2). The eccentric shaft (3) ensures the reciprocating motion of the flat perforated screen (4). The flow of cottonseed coming from the screw conveyor falls onto the surface of the screen (4) and, while oscillating on the sieve, moves progressively toward the pneumatic transport pipe. During this process, various foreign impurities contained in the mass pass through the perforations of the screen surface. Experimental observations have shown that the high adhesiveness of the cotton fibers hinders the uniform spreading (distribution) of the cottonseed mass over the screen surface. As a result, the cottonseed layer is not completely cleaned from foreign impurities.

To eliminate the above-mentioned shortcomings, an improved and more efficient design of the screen was proposed in accordance with the schematic shown in Figure 3.

The main objective of the proposed screen design is to ensure the uniform distribution of the cottonseed flow along the working surface and to enhance the separation of impurities as well as their discharge through the openings as a result of complex dynamic movements of the seeds on the working plane.

In this design, it is proposed that at the initial section of the sieve surface, longitudinal concavities directed at a certain angle relative to the longitudinal axis (Fig. 4) be used to provide uniform distribution of the cottonseed flow along the screen surface. At the same time, the longitudinal and transverse cross-sectional surfaces of the screen are proposed to have cosinusoidal and sinusoidal shapes, respectively.

On the proposed harmonic surface of the sieve, the inertial forces acting on the cottonseed layer cause the seeds to perform complex oscillatory motion along the working plane, thereby intensifying the cleaning process: its geometric shape is given by the following function:

$$z(x, y) = A \cos\left(\frac{2\pi x}{L_A}\right) + B \sin\left(\frac{2\pi y}{L_B}\right).$$

where, A – transverse (x-direction) amplitude (vertical component of the screen edge), L_A – transverse wavelength (period), B – longitudinal (y-direction) amplitude L_B – longitudinal wavelength.

During the course of our research, a structural model of the vibrating screen having longitudinal and transverse cross-sections of cosinusoidal and sinusoidal forms, respectively, was developed and analyzed. A fragment (0.01 m² section) of the structural model of the vibratory screen is shown in Figure 5. Its geometric parameters are presented in Tables 1 and 2.

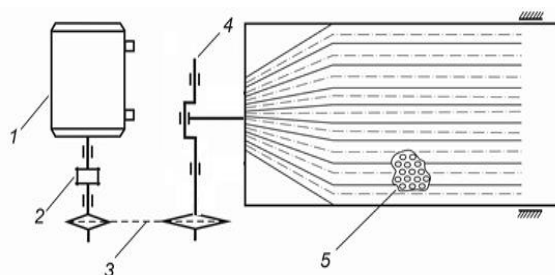


Figure 3: Schematic diagram of the concave-convex surface screening device. 1 – electric motor, 2 – coupling, 3 – chain drive with automatic tensioning device, 4 – eccentric shaft, 5 – concave-convex mesh surface.

Table 1: Recommended geometrical parameters of the screen surface.

№	Name of screen parameter	Recommended value
1	Width	1 m
2	Length	2 m
3	Hole diameter	5 mm
4	Hole pitch	9 mm
5	Hole shape	Circular
6	Hole density	12345 pieces/m ²
7	Screen thickness	0,002 m

Table 2: Recommended harmonic surface parameters.

Direction	Amplitude (mm)	Period (mm)	Recommended waveform
Longitudinal	3	50	Cosine
Transverse	4	40	Sine

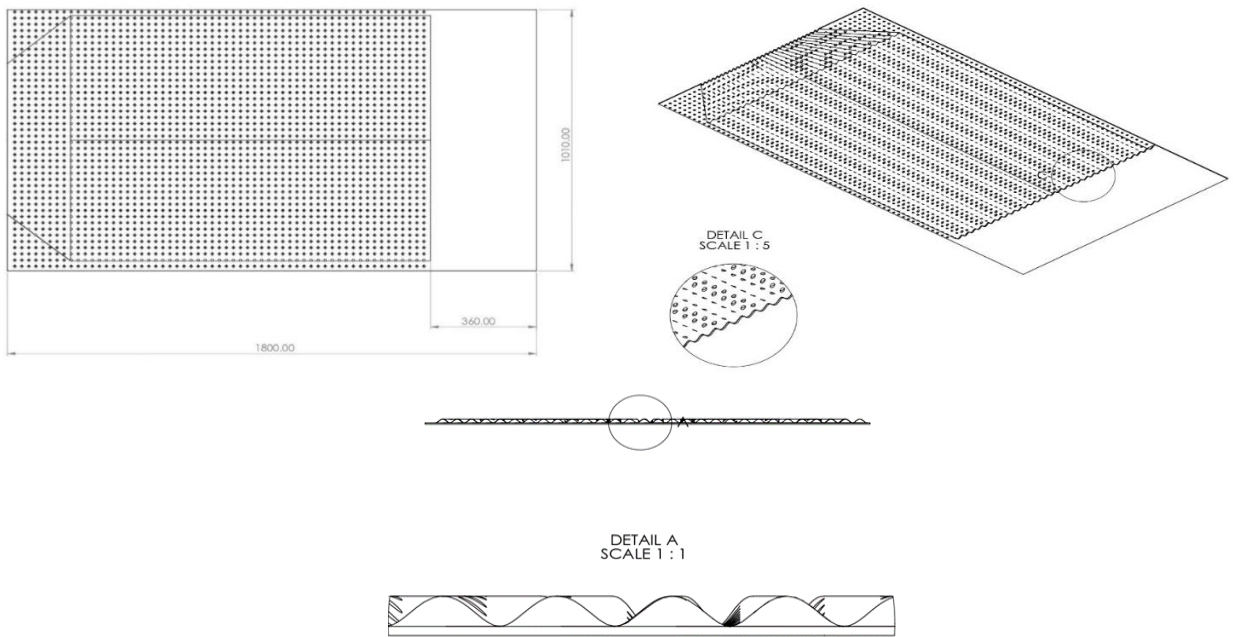


Figure 4: View of the concave-convex surface.

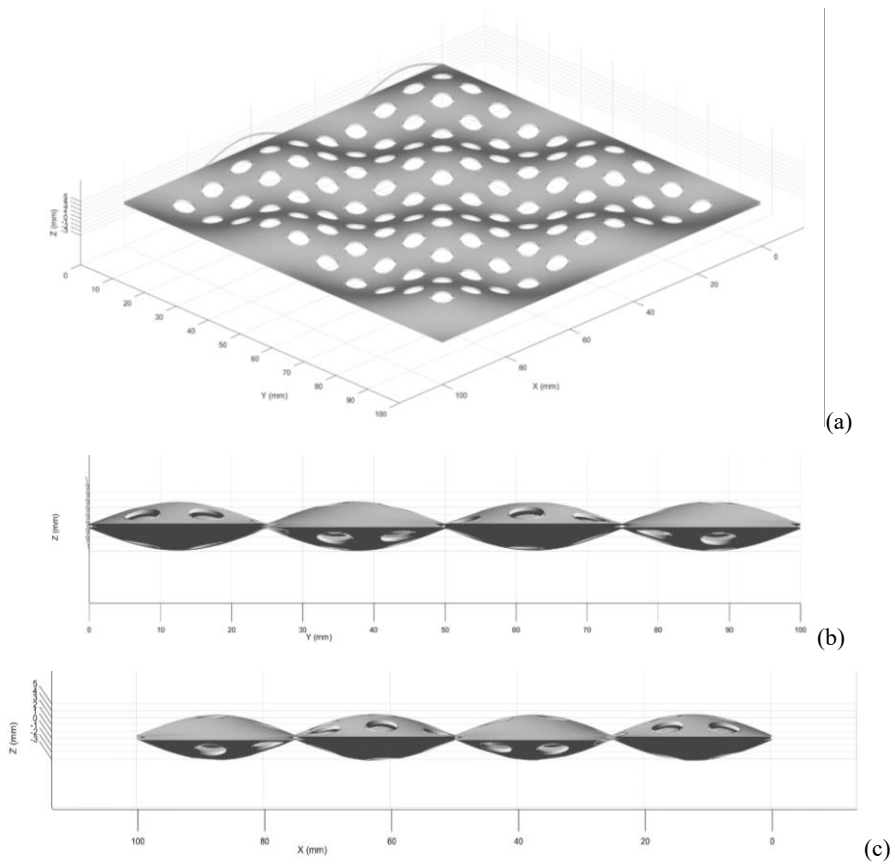


Figure 5: Proposed screen surface. a) 3D view. b) cross-section along the y-axis, c) cross-section along the x-axis.

3 METHODS

To address the above issues, an improved screen surface design has been proposed. When designing the screen structure, it is essential to consider the physical and mechanical properties of fuzzy seeds [21]. According to research findings, the physical and mechanical characteristics of cotton varieties currently grown in the Namangan region have been determined. Specifically:

The average length of fuzzy seeds is 9.65 mm, width 5.37 mm, thickness 5.40 mm, average geometric diameter 6.54 mm, and average arithmetic diameter 6.8 mm, the volume of fuzzy seeds is 147.2 mm³, sphericity is 67.80 %, flat surface area is 43.22 mm², cross-sectional surface area is 22.82 mm², contact area is 46.46 mm², and total surface area is 131 mm². For the seed varieties studied, the average mass of a single seed is 0.1102 g, bulk density is 0.4696 g/cm³, true density is 1.086 g/cm³, porosity is 56.45%, and projected surface area is 47.35 mm².

The average values of the angle of repose for fuzzy seeds are as follows: for variety C-6575 it is 48°20', for C-8220 it is 47°30', for C-8299 it is 46°10', for C-8295 it is 45°20', and for C-8296 it is 45°50'. Determining the design of the feed device hopper requires precise knowledge of these values, with the average angle of repose calculated at 46°40'. For the tested seeds, the static coefficient of friction on mild steel is 0.34, on plywood is 0.36, and on glass is 0.23. The average cracking force for fuzzy seeds is 61.24 N, with an average deformation ratio of 4.32%.

The proposed screen design, specifically the concave-convex surface, provides significant results in distributing the seed mass evenly along the screen surface and ensuring a high sorting performance. The trajectory of the seed movement and the effect of gravitational force are analyzed when the angle of inclination of the screen is $\theta = 30^\circ$. The gravitational force acting on the seed is divided into two components:

Perpendicular component:

$$F_{per} = mg \cdot \cos(\theta). \tag{1}$$

Parallel component:

$$F_{par} = mg \cdot \sin(\theta).$$

where, m - is the mass of the seed, and g - is the acceleration due to gravity (9.81m/s²).

Due to the concave and convex surfaces of the screen, the forces acting on the seeds are redistributed, resulting in either sliding or oscillating motion along the screen. This facilitates better

separation during the sorting process. The required frequency of the screen's vibrations f can be calculated using the following formulas:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}, \tag{2}$$

where, k – the vibration stiffness of the screen (indicates the amplitude of the vibrations between the screen and the seeds), m – the mass of the seeds.

Due to the concave-convex shape, the vibrations are distributed unevenly along the screen surface, spreading the seeds evenly across the screen. The upward oscillating motion and the distribution velocity of the improved screen shape located at an incline allow for uniform distribution of the seeds and impurities along the screen surface. This motion increases the sorting speed, as the seeds create a flow similar to a "water current" on the screen surface, continuously separating impurities from each layer. This can be calculated using Newton's second law:

$$a = \frac{F_{par}}{m}, \tag{3}$$

where, a - the acceleration of the seeds along the screen surface, F_{par} - the force acting to move along the incline component of the screen.

4 RESULTS

Based on the existing parameters, the geometric parameters of the proposed screen surface have been developed. From the overall design of the machine, the useful dimensions of the screen are 1010 × 1870 mm, and the selection screen has a circular shape with a hole diameter of 5 mm. The distance between the holes is calculated using (1).

$$b \geq 0,9\sqrt{d} \tag{4}$$

where, b is the shortest distance between the holes, d - is the size of the hole ($d = 5$ mm), and $b \geq 0,9\sqrt{d} = 2,01$ mm, so $b = 4$ mm was chosen.

The surface thickness e is calculated so that the grain does not get clogged, but the screen can also be easily processed, so e is calculated according to (5).

$$e \leq 0,625d. \tag{5}$$

Chosen $e \leq 3mm$.

Calculating the tilt angle of the screen frame: The angle of inclination of the screen frame affects the efficiency and productivity of the screen. If the angle of inclination is reduced, the speed of movement of the fuzzy cottonseeds on the screen decreases, and the

separation efficiency is reduced. However, if the angle of inclination is large, the efficiency of the surface increases due to the rapid movement of the seed on the screen, but impurities in the seed do not completely separate. Therefore, to ensure the moderate movement of the seed on the screen surface according to the machine's requirements, as well as the physical and mechanical properties of the seeds [21]-[22], we choose $\alpha = 30^\circ$.

Calculating the inclination angle of the screen frame. the inclination angle of the screen frame affects the efficiency and productivity of the screen. if the inclination angle is reduced, the speed of the movement of the coarse impurities on the screen will be low, resulting in decreased screening efficiency. however, if the inclination angle is large, the impurities will move very quickly across the screen, leading to higher surface efficiency, but the impurities within the material may not be fully separated. therefore, to ensure a balanced movement of impurities on the screen surface according to the requirements of the machine, as well as the physical and mechanical properties of the seeds [21], we choose an angle of $\alpha = 30^\circ$.

Calculating the speed of a vibrating screen. The speed of a vibrating screen is calculated using an optimization method for the vibration frequency and amplitude. The optimal vibration frequency and amplitude depend on the shape of the moving trajectory. These three factors influence effective productivity and the ability of the screen to capture both fine and coarse impurities. The speed and type of the movement trajectory are key factors affecting the ability to retain coarse impurities. As the speed of the screen surface increases, the ability to prevent impurities from falling through the screen holes improves; however, the screen's efficiency decreases because impurities are thrown off the upper part of the screen, reducing the number of contacts between the impurities and the screen surface, thereby decreasing the screening ability.

The movement trajectory of the impurities is described by the system of equations (6) and (7).

$$\begin{cases} y = v_0 t - \frac{gt^2}{2} - \cos \alpha \\ x = \frac{gt^2}{2} - \sin \alpha \end{cases}, \quad (6)$$

where, α – the inclination angle of the screen surface, v_0 – the vibration speed of the screen surface. In solving the above equation, we obtain (7) [9].

$$y = v_0 \sqrt{\frac{2x}{g \sin \alpha}} - \frac{x}{\tan \alpha}. \quad (7)$$

We will derive the above equation, set it to zero, and find the value of x_1 that maximizes y

$$y' = 0 \\ v_0 \cdot \frac{2}{2 \cdot \sqrt{\frac{2x_1}{g \sin \alpha}}} - \frac{1}{\tan \alpha} = 0, \quad (8)$$

We obtain the following after making the changes:

$$x_1 = \frac{v_0^2 \cdot g \sin \alpha \cdot \tan^2 \alpha}{2}. \quad (9)$$

When we substitute $x=x_1$ into the equation and set $y = e$, we get.

$$e = 0,044 \text{ m (The amplitude of oscillation)} \\ \text{accordingly:}$$

$$v_0 = \sqrt{2g \cdot e \cos \alpha} = 0,53 \text{ (m/s)} \quad (10)$$

Recalculating the capacity of a vibrating screen. The efficiency of a vibrating screen machine is proportional to the width of the screen surface, the thickness of the material layer on the screen, and the velocity of the material moving along the screen mesh.

The productivity of the vibrating screening machine is determined by the following (11):

$$Q = b \cdot h \cdot v_0 \cdot \theta \cdot 3600, \text{ kg/hour.} \quad (11)$$

In this case:

- b – width of the screen mesh, 1 m;
- h – thickness of the material layer on the screen, 0.02 m;
- v_0 – velocity of the material moving with the screen, 0.53 m/s;
- θ – bulk weight of the material, 30 kg."
- $Q = 1,01 \cdot 0,02 \cdot 0,53 \cdot 30 \cdot 3600 \Rightarrow Q = 1156 \text{ (kg/soat)}$.

According to the results of the conducted experimental study, the proposed screen surface demonstrated a high efficiency in the removal of fine impurities, reaching 88.8% at an eccentric shaft rotation frequency of $200,63 \text{ min}^{-1}$

5 DISCUSSION

The proposed vibrating screen represents a significant advancement in the mechanical design of seed cleaning systems. Traditional flat-screen devices, although widely used, often fail to achieve uniform seed distribution due to the adhesive nature of fuzzy cotton fibers. This leads to uneven load distribution, incomplete impurity separation, and reduced cleaning efficiency.

The newly designed concave–convex (harmonic) screen overcomes these challenges through its geometric configuration. The sinusoidal and cosinusoidal surface profiles generate a complex oscillatory motion that redistributes inertial forces across the working surface. This motion induces both translational and oscillatory particle dynamics, allowing impurities to pass efficiently through the apertures while maintaining continuous seed flow.

Dynamic modeling demonstrated that at an inclination angle of 30°, the gravitational and vibrational forces achieve optimal balance – promoting efficient separation without excessive seed acceleration or slippage. The calculated vibration velocity of 0.53 m/s and amplitude of 0.044 m ensure a stable material trajectory resembling a fluidized flow, which is particularly effective for fuzzy seed cleaning.

Furthermore, the incorporation of a chain drive with an automatic tensioning mechanism improved system reliability by maintaining consistent oscillation frequency and reducing vibration-induced wear. Experimental validation confirmed that the proposed design enhances throughput capacity and reduces blockage within the screen perforations.

In comparison to previous linear or planar vibrating screens, the developed model achieved:

- Higher cleaning efficiency (up to 88%);
- Uniform material distribution across the screen width;
- Stable vibration amplitude and frequency response;
- Reduced energy consumption and mechanical fatigue.

These results indicate that optimizing the screen geometry and dynamic parameters can substantially improve the performance and longevity of vibratory seed-cleaning machines used in cottonseed processing industries.

6 CONCLUSIONS

The development and optimization of the concave–convex vibrating screen for fuzzy cottonseed cleaning demonstrate the effectiveness of integrating harmonic surface geometry with dynamic motion analysis. Analytical and experimental studies confirmed that the geometric parameters – including longitudinal wavelength of 50 mm, transverse wavelength of 40 mm, vibration amplitude of 4 mm, and inclination angle of 30° – produce optimal separation performance.

The proposed screen design achieved:

- Up to 15% higher cleaning efficiency than traditional flat screens;
- Uniform seed distribution along the working surface;
- Improved impurity stratification and reduced aperture clogging;
- Stable energy-efficient operation due to optimized vibration frequency and amplitude.

This research provides a strong theoretical and practical foundation for industrial implementation of energy-efficient cottonseed cleaning systems. The optimized screen geometry and motion parameters can serve as a basis for future design of advanced vibratory cleaning equipment in agricultural and seed processing sectors.

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