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Simulation of Screening Performance of Linear Vibrating Screen for Sand Sorting Based on Discrete Element Method

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Screening technology has been widely used in the grading of granular materials, in order to improve the screening efficiency and screening quality of sand particles, a linear vibrating screening device was designed. Analyzing the motion state of the vibrating screen, it is found that the factors affecting the screening efficiency and screening quality, mainly include: vibration frequency, amplitude and screen surface inclination angle. Taking sand grains as the research object, the Hertz-Mindlin with JKR contact model was chosen to analyze the influence of individual factors on the screening performance, and the discrete element method was applied to simulate and analyze the screening process of the material, and the screening efficiency of the material was used as a measure to obtain the vibration parameter set of the optimal screening performance. It is found that the best vibration parameter set of linear vibrating screen is: vibration frequency f=25Hz, amplitude A=4mm, screen surface inclination angle φ=4^°, at this time the screening efficiency can reach

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95.77%. This study proves that the discrete element method has good reliability for the screening of particles, and it can be used to carry out efficiency analysis in the pre-production stage of the screening device, and provide corresponding reference for the design and parameter optimization of the vibrating screen.

Keywords: Linear vibrating screen; discrete element method; screening efficiency; vibration parameters.

1. INTRODUCTION

With the development of China's economy, river sand plays many roles in various industries in society. If the impurities are filtered after mining and sorted according to the particle size, it is not only used for construction, road building materials, artificial marble, cementitious materials, breeding and beautification, but also used for farmland irrigation and land improvement and the construction of artificial beaches, sand sculpture and other leisure projects. River sand has a high economic value and has an irreplaceable role in the field of construction and life, and the mining of river sand is conducive to the dredging of river channels to a certain extent [1]. In the process of sorting sand and gravel, how to carry out fast, efficient and accurate sorting has become a problem faced nowadays.

Screening is by far the most effective method of material size classification, vibrating screen is an important material screening device, the use of screen holes on the screen surface will be dispersed particles of the mixture according to the size of the classification. Material screening generally includes four processes: stationary, loose, stratification, and permeability [2]. Linear vibrating screen has the advantages of easy to achieve different vibration mode, screening efficiency and so on, not only plays an important role in mineral processing, but also in metallurgical manufacturing, building materials construction, food processing, chemical production and other fields are widely used.

In the early 1970s, Dr Cundall first proposed a discrete element method (DEM), which is a method for calculating the mechanics of bulk media systems, and the research state of the whole research object is obtained through statistical calculation of a single motion state [3], and it is obtained in the fields of mining engineering, material sorting, geotechnical engineering, etc. widely used, and has gradually received extensive attention in the research field of multidisciplinary intersection. Wang Guifeng et al. [4] carried out simulation based on discrete element method and analysed the screening process of sand grains in the process, and studied the possible influence of screening efficiency when the screening parameters are different. Wang Bing et al. [5] carried out simulation based on discrete element method and analysed the movement of corn on the vibrating screen, and optimised the structure of the vibrating screen according to the screening situation. Zhou Jianping et al. [6] performed simulation based on discrete element method to simulate the sieving process of wet particles, and the preferred constitutive parameters of sieving were obtained in the simulation results.

In this study, simulation based on discrete element method can visualise the movement and sieving process of sand particles under different parameters of linear vibrating screen, and analyse the various factors that have an impact on the sieving performance, which mainly covers the number of particles sieving through the sieve and the sieving efficiency, which will provide a reference for the working parameters of the particle group on the linear vibrating screen and the structural design of the linear vibrating screen in the future.

2. OVERALL DESIGN AND WORKING PRINCIPLE OF LINEAR VIBRATING SCREEN

2.1 Overall Design

On the basis of the traditional sand screening vibrating screen, continuous optimisation has been carried out to design a portable device for solving the problem of screening impurities in construction sand, and the three-dimensional model of the vibrating screen is shown in Fig. 1. The composition of this screening device mainly includes the following aspects: screen box, screen frame, rubber spring, excitation system, screen mesh, inlet and outlet device, bracket and so on. The linear vibrating screen makes use of the downward sloping screen surface, coupled with the excitation force generated by the two exciters to effectively alleviate the accumulation of materials on the screen surface, and has a good screening performance [7], when the vibrating screen is working, the two vibration motors do the relative operation, the eccentric block will produce the excitation force in two directions, the transverse excitation force is due to the relative operation of the motors and therefore cancel each other, the longitudinal excitation force is due to the motor's homogeneous operation and therefore superimposed on each other, and finally make the motor to be the most powerful vibrating screen. The longitudinal excitation force is superimposed on each other due to the same direction of motor operation, and finally the material will be vibrated reciprocatingly on the screen mesh.

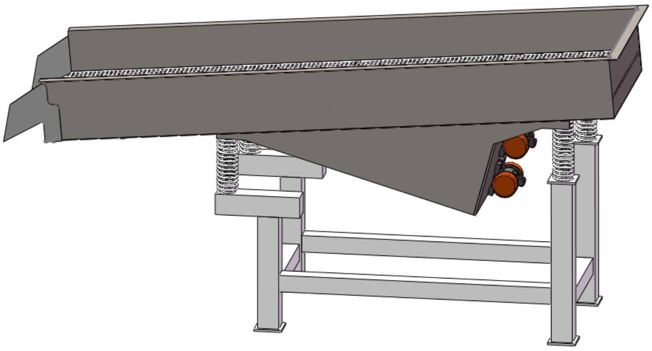


Fig. 1. Linear vibrating screen model

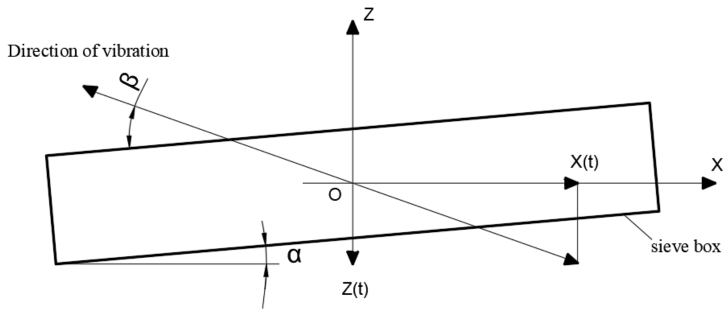


Fig. 2. Simplified model of vibrating screen motion

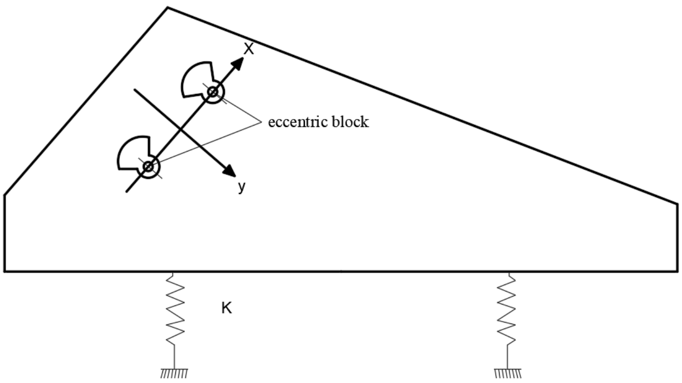


Fig. 3. Linear vibrating screen working principle diagram

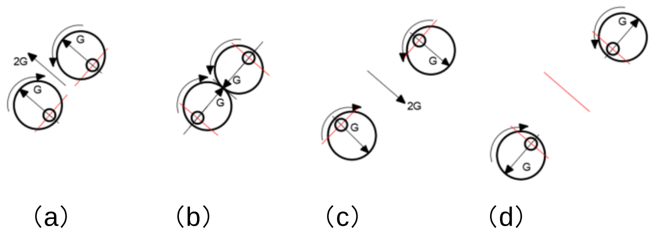


Fig. 4. Shaker working principle diagram

2.2 Model Simplification and Parametric Analysis

Fig. 2 is a simplified model of the movement of the device, O point for the device of the centre of mass of the screen box, over the 0 point to establish the coordinate system XOZ, X axis along the horizontal direction, Z axis along the vertical direction, the direction of the vibration force on the device of the vibration motor and the direction of vibration of the sieve box over the centre of mass of the sieve box O; sieve frame and the angle of the X-axis for the inclination of the sieve surface α, the vibration of the sieve box with the sieve surface of the sieve surface of the angle of the vibration direction of the vibrating screen angle β.

Generally speaking, the motion of each point on the screen box of the linear vibrating screen is a simple harmonic motion along the vibration direction, so the displacement can be expressed as:

$$S = Asin\varpi t, \omega t = \varphi \quad (1)$$

Where, S represents the displacement, A is the amplitude , ω is the vibration frequency, t is the time, φ is the vibration phase angle.

2.3 Working Principle

The working principle of the linear vibrating screen is shown in Fig. 3, the same specifications of the two exciter together constitute the excitation system of the screening device, the eccentric mass of the exciter eccentric block on the two axes to equal speed reverse rotation [8], in the installation, the position of the two axes of the exciter and the y-y axis is symmetrically distributed, and the y-y axis is not only over the centre of gravity of the linear vibrating screen screen box but also with the x-axis of the horizontal direction of the formation of a 45 ° angle. Machine in the process of rotary motion, the centrifugal force generated by the eccentric wheel at this time to decompose, respectively, to the x-axis, y-axis direction, due to the rotation of the eccentric wheel is synchronous but reverse movement, so the two exciter centrifugal force along the x-x and y-y direction is also different, along the x-x direction to offset each other, along the y-y direction superimposed on each other [9], thus the vibrating screen in the movement of the process by the The excitation force is along the y-y direction, which is ultimately the power source to drive the linear true vibrating screen to make reciprocating linear motion. In Fig. 4, when the eccentric wheel turns to the (a) and (c) positions in Fig. 4, the centrifugal forces generated are superimposed as a combined force, and the excitation force reaches the peak state at this time, and the centrifugal forces generated cancel each other out when the eccentric wheel turns to the (b) and (d) positions in Fig. 4, and the excitation force is zero at this time

3. VIBRATING SCREEN SIEVING DISCRETE ELEMENT MODEL AND SIMULATION PARAMETERS

3.1 Discrete Element Model for Vibrating Screen Sieving

EDEM can be used to simulate and analyse the generation process of particle handling and its manufacturing equipment in agriculture, industry and mining, etc., which is divided into three main modules: Creator, Simulator and Analyst [10]. In the Creator module, the particles are modelled with spherical particles instead of sand particles, with average particle sizes of 0.5 mm and 1.0 mm and a standard deviation of 0.5 mm. the Hertz-Mindlin with JKR contact model is chosen, and the particles are generated at a velocity of 0.1 Kg/s, and the other test conditions are shown in Tables 1 and 2. In the Simulator module, the time of simulation is defined as 10s, and the Riley time step and grid size are adjusted. In the Analyst module, the corresponding simulation data are extracted, like the number of particles passing through the sieve, and the size of particle size can be seen when different colours are given to the particles.

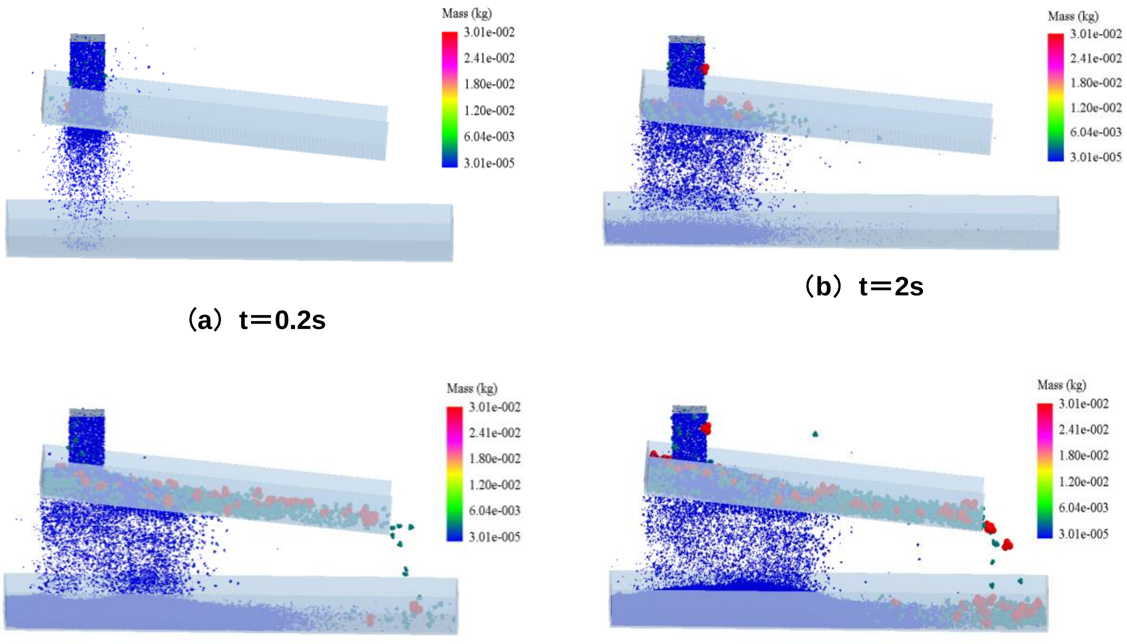
In this paper, three vibration parameters (vibration frequency, amplitude, screen inclination) are used to simulate the sieving process using the discrete element software EDEM. The selected data for each parameter are: vibration frequency 25, 30, 40, 50, 60Hz, amplitude 2, 4, 5, 6, 7mm, screen surface inclination 2°, 3°, 4°, 5°, 6°.

Table 1. Material property parameters

Material	Poisson's ratio	Density /（kg/m³）	Shear Modulus（/pa）
Sand	0.25	2650	2.2*10e^8
Impurities (stones)	0.2	2500	3.5*10e^8
Sieve box (stainless steel)	0.3	7850	8.0*10e^10

Table 2. Collision coefficients between materials

contact coefficient	coefficient of restitution	coefficient of static friction	coefficient of rolling friction
Sand-sand	0.40	0.5	0.05
Sand-impurities	0.35	2500	0.015
Sand-sieve box	0.30	0.3	0.01
Impurities - sieve box	0.35	0.2	0.01
Impurity-impurity	0.35	0.2	0.02



(a) t=0.2s **(b) t=2s**

(c) t=8s **(d) t=10s**

Fig. 5. Vibrating screen screening process

3.2 Discrete Element Numerical Simulation of Screening Process

The vibrating screen starts to move from 0s, and then adopts the "rainfall method" to generate a variety of particles with different sizes, and the linear vibrating screen starts to vibrate linearly with a frequency of 15Hz, an amplitude of 5mm, and an inclination angle of the screen surface of 5°. The movement and screening of particles on the screen surface is mainly divided into four processes, namely, stationary, loose, stratification and permeability. At the beginning, the particles are discharged from the inlet, the vibrating screen throws the particles out of the screen surface so that they fall back and move down along the screen mesh, during the vibration process, the vibration of the exciter causes the feed particles to be stratified so that the fine particles will settle through the layer of material to the surface of the screen mesh and the large particles will rise to the top, the fine particles after stratification will have the opportunity to pass through the screen mesh opening to the undersize material stream, the large particles and the impermeable Large particles and part of the particles that do not pass through the screen will be sent to the end of the screen and become oversized particles. With more and more particles will eventually cover the entire screen surface, when the particle quality of the particles on the screen and the particles under the screen to achieve relative stability, the screening process has also reached a dynamic and stable state.

As shown in Fig. 5 for the sand sieving process, according to the different diameters of the sand particles will be set to different colours, the darker the colour represents the larger the sand particle size, and vice versa, the lighter represents the smaller the sand particle size. At the beginning of the sieving process, sand particles of different sizes fall on the screen surface in sequence as if it were "raining", at this time, the part of the particles in contact with the screen surface and the sieve holes are compared, the sand particles smaller than the sieve holes will penetrate the screen surface, and the particles that do not penetrate the sieve surface will be vibrated with the direction of vibration to the middle of the sieve surface movement as shown in Figs. 5(a) and 5(b). With the increase of the incoming particles and the movement of the vibrating screen, the particles under the screen continue to increase, and the particles that do not penetrate the screen follow the vibration of the screen surface to move towards the discharge end continuously, as shown in Fig. 5(c). With the screening process, the particles can not be screened together to form a material flow, and due to the vibration of the screen surface, the material layer is relatively loose, the particles of different sizes appeared in the stratification, part of the small particles encountered the screen surface through the sieve holes, not screened impurities to the discharge end of the run, this time, the screening effect of the vibrating screen gradually tends to stabilise, as shown in Fig. 5 (d).

4. PROCESS PARAMETERS ON THE SCREENING EFFECT

4.1 Linear Vibrating Screen Screening Material Performance Indicators

In screening, due to the vibrating screen by the movement parameters, the shape of the screen holes and the screen opening rate, feeding mode, particle viscosity and other factors, so the material is not in accordance with the ideal state in screening, the actual screening, not as long as the particles are smaller than the size of the screen can be passed through the screen, there are also a portion of small particles can not pass through the screen and become the screened material. In order to evaluate the actual effect of the sieving process, the concept of sieving efficiency is introduced to provide an intuitive and objective evaluation of the sieving results [11]. The sieving process is mainly divided into four steps: feeding, penetrating sieve, conveying and discharging, so the sieving is a continuous dynamic process, and in this process, the sieving efficiency will also change with the change of time, and the traditional method of sieving efficiency calculation has not been able to measure the dynamic screening process, for this reason, this paper adopts the formula (2) as a measure of the dynamic sieving effect.

$$\eta_{dt} = \frac{B_t}{A_t} \times 100\% \tag{2}$$

Where, η_{dt} is the dynamic sieving efficiency at the moment t; B_t is the weight of the sieve product produced at the moment t; A_t the total weight of the fine particles contained in the material at the moment.

4.2 The Influence of Vibration Frequency on the Screening Effect

The vibration frequency is the power source that makes the screen produce reciprocating cyclic motion, which affects the motion energy of particles on the screen, making the particle groups in the cycle collide and scatter again, and the larger amplitude can make the particles bounce more violently, and the position and motion mode of the material on the screen is redistributed, so the effect of amplitude on the screening effect is very intuitive, and it is an important parameter that affects the structural strength of the vibrating screen. According to the screening material and the commonly used amplitude range, five sets of data were selected for simulation by controlling the frequency, screen surface angle and screen hole shape unchanged during the simulation.

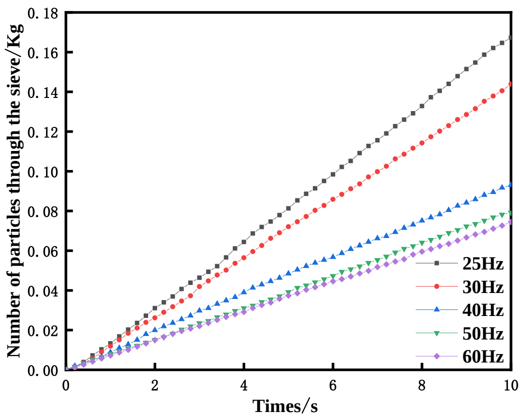


Fig. 6. Number of particles passing through the sieve at different frequencies

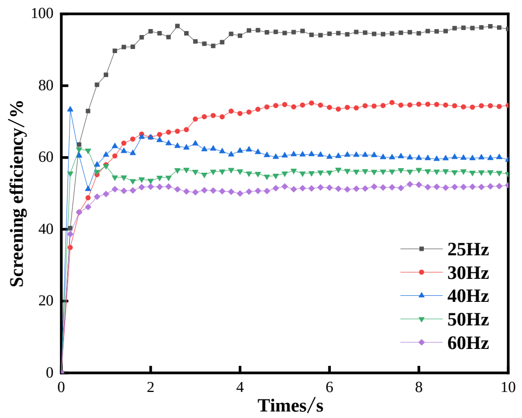


Fig. 7. Dynamic screening efficiency curves at different frequencies

In the simulation test, the control amplitude and screen angle is unchanged, the vibration frequency is taken as 25Hz, 30Hz, 40Hz, 50Hz, 60Hz, and the rest of the parameters are baseline parameters remain unchanged, and the number of particles through the screen, the screening efficiency is calculated and plotted in a graph, as shown in Fig. 6. As can be seen from the figure, the number of particles through the sieve mesh with the change of time is an increasing trend, according to the number of particles through the sieve mesh and the total number of particles can be derived from the sieving efficiency, as shown in Fig. 7, in the vibration motor was just started, due to the lack of power supply voltage and current, the operation is still unstable, so the particles in the boot of the first 2s appeared in the back and forth rebound situation, 2s after the machine to reach a stable state, the dynamic sieve efficiency curve of the The trend is stable, and with the increase of frequency, the slope of the curve gradually becomes smaller, and each frequency corresponds to a large difference in screening efficiency, when the frequency is 25Hz, the screening efficiency of the vibrating screen is the largest, the best performance.

4.3 The Impact of Vibration Amplitude on the Screening Effect

Amplitude refers to the displacement of the sieve along the vibration direction, affecting the movement speed of the material particles on the screen surface, therefore, in the operation of the amplitude of the appropriate value should be selected, the amplitude is too large, the particles in the sieve surface jumping the more violent, the particles transported when the amount of the larger but the more likely to be layered, the amplitude is too small, the particles do not collide on the screen surface, is not conducive to the particles layered.

In the simulation test, the control frequency and sieve surface angle is unchanged, the amplitude of 2mm, 4mm, 5mm, 6mm, 7mm, the rest of the parameters are benchmark parameters remain unchanged, the use of EDEM's sensor module to detect the number of particles on the sieve, under the sieve and the size of the particles can be derived from the number of particles can pass through the sieve, the sieve can be obtained after the later analysis of the calculation of the particles can be derived from the sieve efficiency, based on these data and Draw a curve graph, as shown in Fig. 9. It can be seen from the figure, when the amplitude of 4mm sieving efficiency can reach the peak, and after 4mm sieving efficiency with the increase of amplitude and reduce. This is because, when the amplitude is low, it will make the particles in the X direction of the sieve surface throwing distance becomes small, the particles on the sieve surface is easy to form a pile up, at this time the particles with the sieve surface contact is reduced, resulting in a reduction in screening efficiency; with the increase in amplitude, the particles in the X direction of the sieve surface throwing distance becomes large, so that the particles piled up to the sieve surface is easy to the sieve box in all directions of the dispersal, then the particles with the sieve surface contact is increased, increase the screening rate, improve the screening efficiency. Penetration rate, improve the screening efficiency; in addition, the amplitude is too large, the particles in the screen surface movement is more violent, the number of particles were thrown into the air and the time increased, when this time more than the vibration cycle of the screen surface, the number of particles in contact with the screen surface will be reduced, the screening efficiency is greatly reduced.

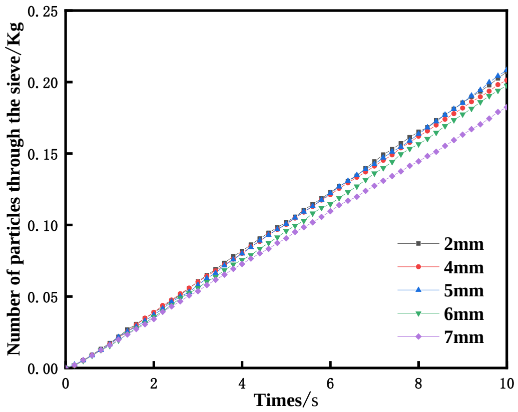


Fig. 8. Number of particles passing through the sieve at different amplitudes

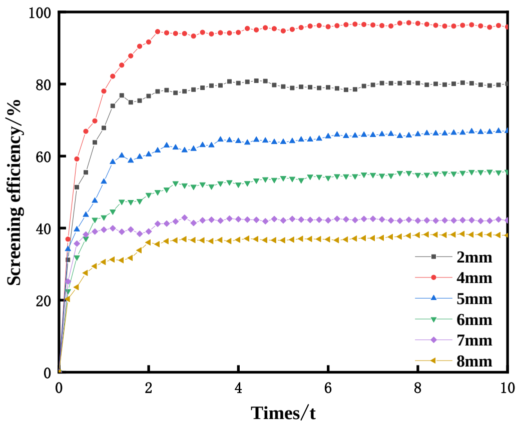


Fig. 9. Dynamic screening efficiency curves at different amplitudes

4.4 The Influence of Sieve Surface Inclination Angle on Screening Effect

Sieve surface inclination angle mainly affects two aspects: the speed of displacement of particles along the direction of the screen surface, the distance of particles being ejected during vibration, when the larger the sieve surface inclination angle, the greater the speed of displacement of materials on the screen surface, the short time can be screened, but a larger moving speed will lead to particles are easy to slip through the screen surface, and can not be completed screening, this time, the screening efficiency is lowered, and vice versa, when the sieve surface angle of inclination the smaller, the material is screened on the screen surface On the contrary, when the smaller the inclination of the screen surface, the smaller the speed of displacement of the material on the screen surface, that is, the particles move slowly, and the longer the particles stay on the screen surface, the easier it is to cause the accumulation of materials, which is not conducive to the automatic classification, and the permeability and screening performance are reduced.

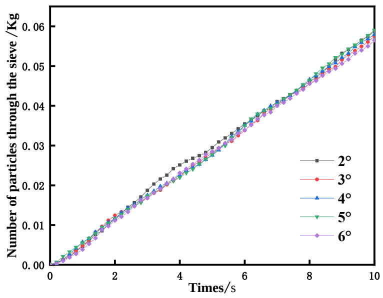


Fig. 10. Number of particles passing through the sieve at different inclinations

In the simulation test, the control frequency and amplitude unchanged, the sieve surface inclination angle of 2 °, 3 °, 4 °, 5 °, 6 °, the rest of the parameters are benchmark parameters remain unchanged, the number of particles through the sieve detected at this point in time, after the later analysis of the calculations can also be derived from the particles of the sieve efficiency, according to the data and plotting the curve, as shown in Fig. 11. It can be concluded from the figure, the screening efficiency in the sieve surface inclination angle of 4 ° and 5 ° before and after the best screening effect, with the screening process in an orderly manner, the screening efficiency of the particles in the machine when the machine just started to increase rapidly, after 2s into a stable state.

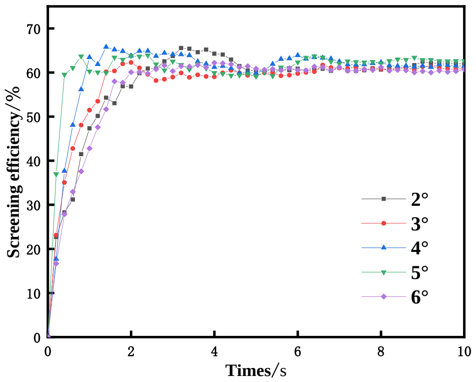


Fig. 11. Number of particles passing through the sieve at different inclinations

5. CONCLUSION

(1) This paper designs a linear vibrating screen for sand and gravel, which is mainly used for grading sand grains, providing help for its different use occasions, using vibration motors as the power source of linear vibrating screen, so that the sand grains jump forward on the screen surface in order to complete the screening.

(2) Use EDEM software to simulate the movement state of sand particles on the vibrating screen, according to the simulation results of the influence curve of each process parameter on the screening efficiency, the optimal parameter group of the linear vibrating screen: vibration frequency f = 25Hz, amplitude A = 4mm, the screen surface inclination angle φ = 4 °, this time, the screening effect is relatively good.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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