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Study on the effect of deck inclination angle on the screening efficiency of banana-shaped vibrating screens applying discrete element method (DEM)

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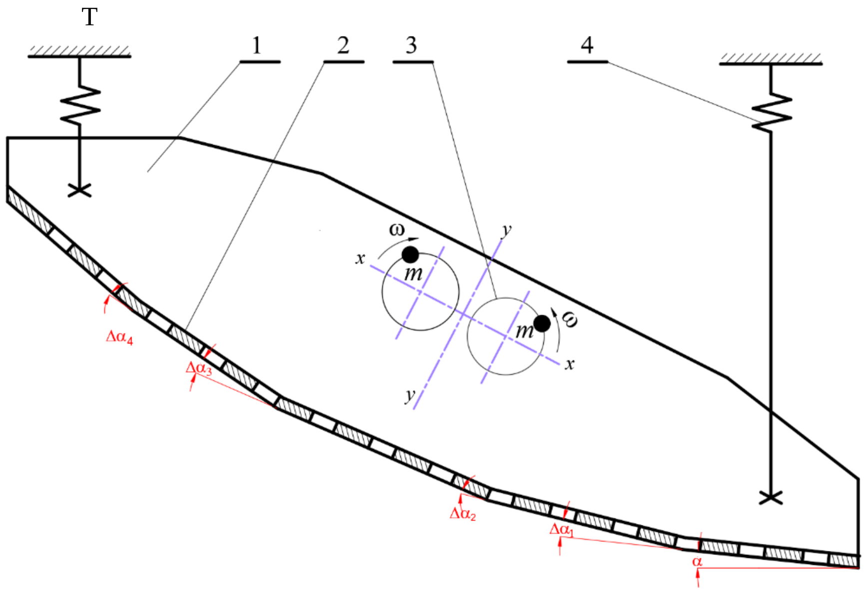
Abstract: - A banana-shaped vibrating screen (also called banana screen) is a device for the separation of bulk materials into granules according to different sizes. It is a combination of multi-decks having different inclined angles, which is widely used in screening plants [1-3]. The screening efficiency is one of the most important criteria to evaluate the machine performance, and it depends on various factors, such as the deck inclination angle (screening surface angle), vibration frequency, vibration amplitude, material properties, etc [4-9]. The banana-shaped vibrating screen is a specially designed vibrating screen, in which the screening efficiency greatly relies on the inclination angle of decks. Traditional measures applied to identify and evaluate the efficiency were proved to take a lot of time, effort, and not feasible. In this work, based on the soft-particle contact model [10], and the equation of motion of material [11-13], the authors applied the Discrete Element Method (DEM) to simulate and analyze the effect of deck inclination angle on the screening efficiency. The findings of this study may be practicable for designing geometric parameters to improve the efficiency of banana screens.
Keywords: - Banana-shaped vibrating screen; DEM; screening efficiency; deck inclination angle.

I. INTRODUCTION



1 - Screen box (Screen body);
2- Multi-slope screen;
3 – Vibrator motor (geared exciter drives);
4 - Springs.

Figure 1: Operating principle of a banana-shaped vibrating screen

A banana screen is a sorting machine to split bulk materials into several different kinds of particles passing through the apertures. The operating principle of a typical banana screen is given in Figure 1. When the vibrator motor (3) is working, two eccentric shafts that have counterweights will rotate simultaneously in opposite directions, creating centrifugal forces. The force components acting along the x-x axis will be opposite and cancel out. In contrast, the force components acting along the y-y axis will combine to produce oscillating forces. This force is transferred to the screen box (1) which linked to springs (4), generating vibrations and associated with screening surface (2) carrying out the sieving process to classify materials [9].

The screening efficiency is a vital indicator that fully reflects the screening quality of the machine, and it is derived from multiple parameters. In reality, the sieving process is a continuous one, including feeding, sieving, conveying, and discharging materials. Therefore, the screening efficiency also flexibly varies over time, so it is impossible to determine precisely by the formula for the calculation of efficiency in the stationary state.

In order to solve this problem, the authors used the dynamic screening efficiency (η_{dt}) to investigate the efficiency of the screen (formula 1). Also, the method of discrete elements (DEM) was employed to model and analyze the effects of screen inclination on the screening efficiency.

$$\eta_{dt} = \frac{B_t}{A_t} \quad (1)$$

Where,

η_{dt} = Dynamic screening efficiency at time t;

B_t = The mass of fine-grained material becoming the product under the sieve at time t,

A_t = The total mass of fine-grained material in the material at time t, (kg).

II. MOTION EQUATIONS OF THE MATERIAL

According to Iwashita K and Oda M [10], the contact model of material particles is shown in Figure 2.

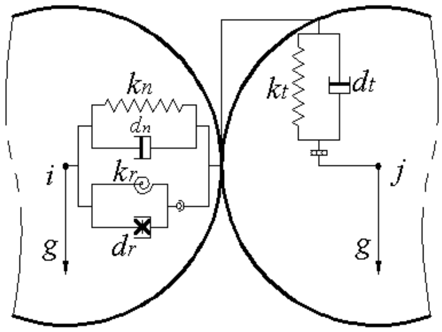


Figure 2: Contact model of material particles

Where,

k_n = Hardness in the normal direction,

d_n = Damping force in the normal direction,

k_t = Hardness in the tangent direction,

d_t = Tangential damping,

k_r = Rolling hardness,

d_r = Rolling dampers,

g = Gravitational acceleration.

In the course of working, the material is mainly affected by the following forces: The material mass itself, the contact force of material particles in the normal direction and tangent direction, the tangential torque, the torque of rolling friction. Based on the motion theorem of objects in a plane, we have the motion equations of material particles as follows [11-13]:

$$m_i \frac{dV_i}{dt} = m_i g + \sum_{j=1}^{n_i} (F_{n,ij} + F_{t,ij}) \quad (2)$$

$$I_i \frac{d\omega_i}{dt} = \sum_{j=1}^{n_i} (T_{t,ij} + T_{r,ij}) \quad (3)$$

Where,

m_i, I_i = Mass and moment of inertia of the i^{th} particle,

n_i = Number of material particles in contact with the i^{th} particle,

V_i = Velocity of the i^{th} particle,

ω_i = Angular velocity of the i^{th} particle,

t = Time;

$\mathbf{F}_{n,ij}$, $\mathbf{F}_{t,ij}$ = The forces acting upon in the normal and tangent direction of material particles,

$\mathbf{T}_{t,ij}$, $\mathbf{T}_{r,ij}$ = Tangential moment and rolling friction moment of material particles.

III. Applications of Discrete Element Method (DEM) to simulate the influence of deck inclination angle on the screening efficiency of banana-shaped vibrating screens

The discrete element method (DEM) is a numerical method developed in the 1970s and used in a variety of fields, including geological engineering, mining techniques, mineral sorting, etc. The application of DEM is capable of assisting us in solving the problems of discrete materials, such as the position of space, the velocity, the force and energy change of particles, and so forth [14-16]. In this article, the authors utilized DEM to model the influence of angle of deck slopes on the screening efficiency, with the following given parameters: The size of screening surface 1200 mm x 640 mm; the size of apertures a = 10 mm; the diameter of material particles d = (2 ÷15) mm, in which ready materials (d/a = 0,2 ÷ 0,7) accounting for 80%; difficult materials (d/a = 0.7 ÷ 1) comprising of 15%; non-ready materials (d/a = 1 ÷ 1.5) occupying 5%. The physical parameters of the model are listed in Table 1. Plus, there are four types of screening surface with different slope angles as follows: Each screening surface is divided into five equal segments with different inclined angles, and the inclined angle of the original segment is $\alpha_1 = 10^0$. The consecutive segments are increased in quantity by $\Delta\alpha$ = 3^0, 4^0, 5^0, 6^0. From that point, we yield models as seen in figures 3 a, b, c d.

Table 1: Physical parameters of the contact model

Parameter	Density (kg.m^{-3})	Elastic coefficient	Static friction coefficient	Rolling friction coefficient	Poisson ratio	Shear modulus (Gpa)
Coal particle	1300	0.5	0.6	0.05	0.3	1.0
Screening surface	7861	0.5	0.4	0.05	0.29	79.92

The paper outlined the influence of the inclination angle of screening surface on screening efficiency, thereby, and chose the vibrating intensity of screen D = 2.5, the vibration angle of the screen δ = 45^0. After the simulation, the results can be exported in Fig. 4 and Fig. 5.

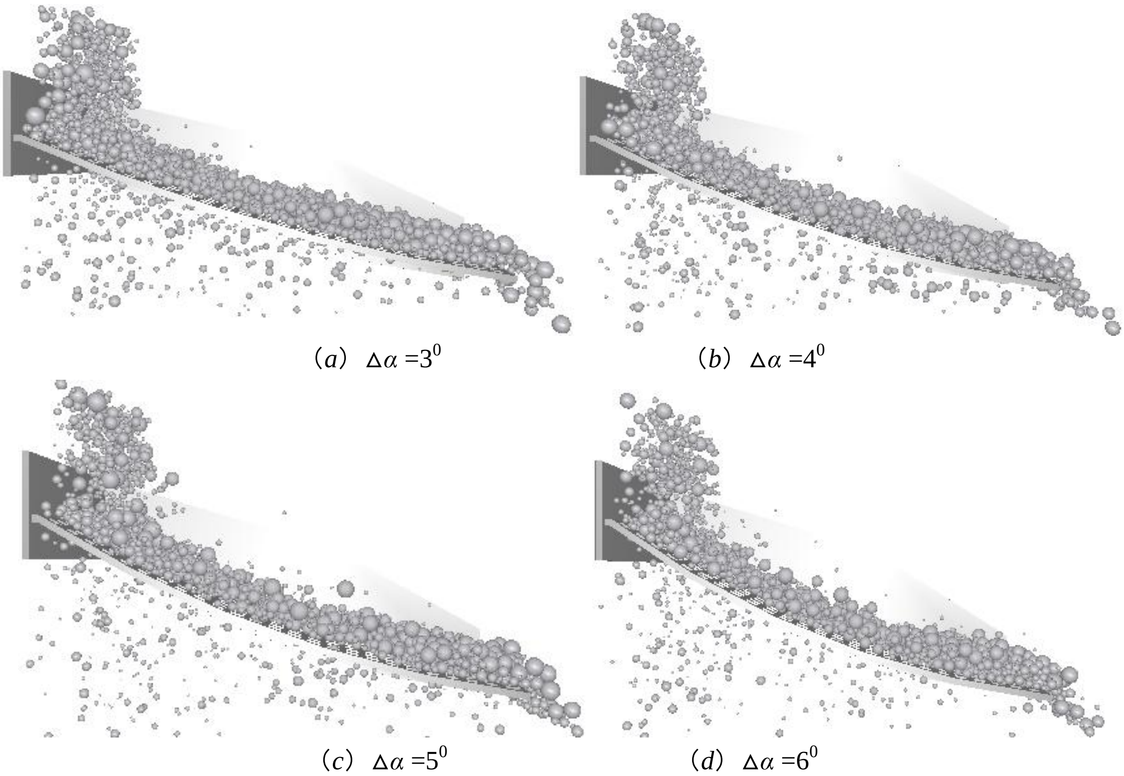


Figure 3: Screen model with various inclination degrees of deck

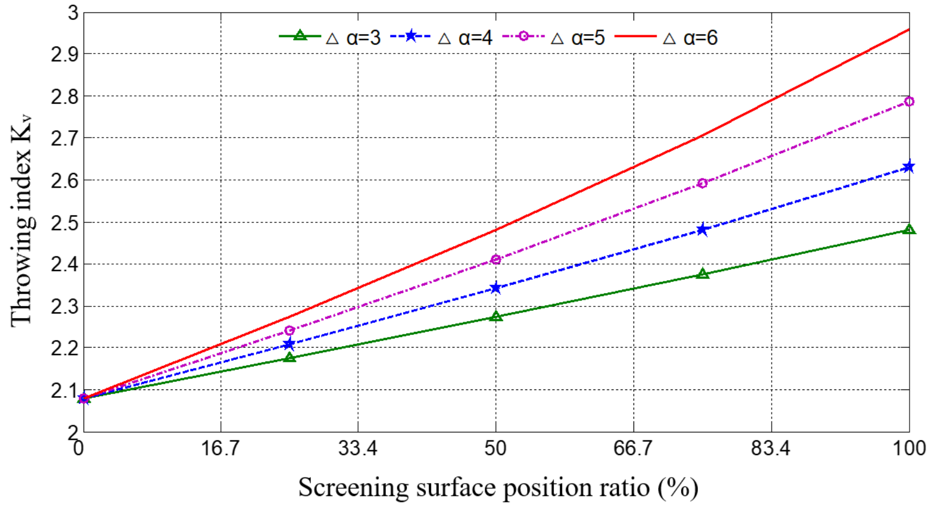


Figure 4: Distribution of throwing index along the screening surface

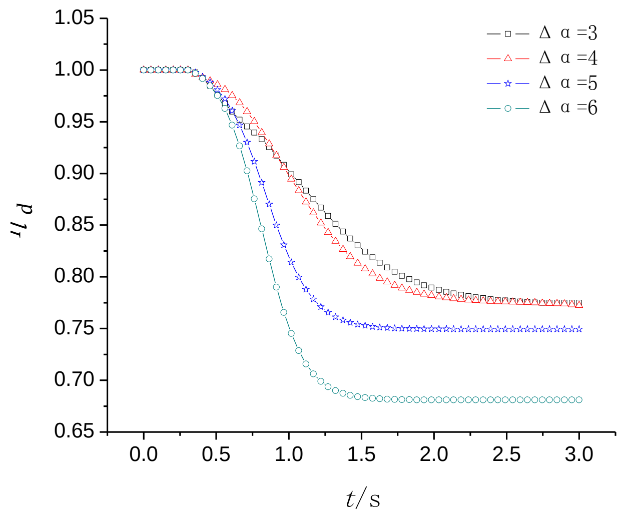


Figure 5: Dynamic screening efficiency corresponds to different inclination degrees of deck

IV. RESULTS AND DISCUSSION

- For a banana screen having the parameters selected as above, in all four cases, the screening surface has different slopes, the throwing index $K_v > 2.08$. This is proof that the material will always bounce on the screening surface when the screen is working;

- When the inclination angle of deck increases, the throwing index K_v is going up as well, meaning the work capacity of the equipment will also climb;

- At the beginning of the sieving process, the screening efficiency is huge, due to the material does not spread along the screening surface but splits on it. Thus, there is very little fine material on the screening surface, After that, the screening efficiency decreases and gradually stabilizes (for screening surface Δα = 3, Δα = 4, after 2.4s, the screening efficiency will be stable; for screening surface $\Delta\alpha = 3$, $\Delta\alpha = 4$ after 1.6s, the screening efficiency will be reliable).

- In case of screening surface Δα = 6, the screening efficiency will reach the minimum value since the throwing index (K_v) is relatively large (the largest in four cases), driving material on screening surface jump up sharply. The velocity of particles will also increase as the inclination angle of deck climbs. Eventually, the material particles cannot be stratified and will be discharged, resulting in low screening efficiency.

- In the case of screening surface Δα = 5, then the throwing index (K_v) is smaller than the above scenario where Δα = 6. The particle velocity is also lower than that in the above case. Hence, the material cannot be stratified and will be discharged. Conversely, by dint of the slower speed, the screening efficiency, in this case, is also higher than in the case of Δα = 6;

- In case of the screening surface $\Delta\alpha = 3$; $\Delta\alpha = 4$, although the throwing index (K_v) fluctuates, the variation of screening efficiency is almost the same. As a result, it can be stated that the screening efficiency has reached the limit state, and in this situation, the machine will obtain the maximum screening efficiency.

V. CONCLUSION

Sieving is a relatively complicated process due to throughout the operational period the screening efficiency depends on numerous parameters (such as the movement of material on the screen deck, inclination angles of deck, properties of the material, etc.). Thanks to the establishment of the motion equations of the material and employing the discrete element method, the problem of this paper has been addressed. Accordingly, providing the analyses and evaluation of the effect of the angle of deck slopes on screening efficiency. The results indicated that at the beginning of the sieving, the screening efficiency was large but unstable, and it took time to be stable, which depends on the inclination angle of screening surface. When this angle gets bigger then the throwing index also gets bigger, but screening efficiency is smaller, the screening efficiency reaches the bound state when $\Delta\alpha = 3$; $\Delta\alpha = 4$. Finally, the outcomes of this work may be favorable for scientists in their field of banana screen design and calculations.

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