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Simulation of the screening process on a circularly vibrating screen using 3D-DEM

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ABSTRACT

A numerical study of the motion particulates follow along a circularly vibrating screen deck was done using the three dimensional Discrete Element Method (DEM). The motion of the particles was analyzed. The effects of vibration amplitude, throwing index, and screen deck inclination angle on the screening process are discussed. The results show that the average velocity of the particles increases along the longitudinal direction of the deck. The screening efficiency is highest when the vibration amplitude, throwing index, and screen deck inclination angle are 3–3.5 mm, 2.7 and 15°, respectively. This work is helpful for developing a deep understanding of particle motion and for optimizing screen separator designs.

1. Introduction

Screening is an important means of size classification used on granular or particulate materials [1,2]. But obtaining reasonable operation and optimized performance of a screen to meet different conditions has been an important practical problem in the screening industry because the fundamental motion of the particles, and their screen penetration, is poorly understood [3,4].

The Discrete Element Method (DEM), which has been developed since the 1970s, is a numerical method suitable for calculating the mechanical behavior of a granular medium. Successful applications of DEM in granular media engineering fields include work in geotechnical engineering, mining engineering, mineral processing, and material separation [5,6].

There have been few reports in the literature to date concerning DEM simulation of the screening process: and the existing reports are limited to simple processes [7–10]. In this work, we present a 3D-DEM simulation of a circularly vibrating screen classification process. The particle motion on the screen-deck and the effects of various vibration parameters on screening performance are studied by conducting a series of numerical simulations. These studies present a better understanding of the circularly vibrating screen helpful for the optimal design of a vibrating screen process.

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2. Mathematical model

An improved DEM dry contact soft-sphere model was used in our studies [11,12]. As Fig. 1 shows, k_n and d_n are the normal stiffness and normal damping, k_t and d_t are the tangential stiffness and tangential damping, and k_r and d_r are the rolling stiffness and rolling damping.

The contact model considers the force of gravity and the normal and tangential forces acting on a particle during the screening process. In addition, two torques that are produced by a tangential force and a rolling friction force also are considered to act on the particles. The equation of motion for the *i*'th particle is expressed by [13–16]:

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

$$I_i \frac{d\omega_i}{dt} = \sum_{j=1}^{n_i} (T_{t,ij} + T_{r,ij}) \tag{2}$$

where m and I are the mass and moment of inertia of the *i*'th particle; n_i the total number of particles in contact with the *i*'th particle; V velocity; ω angular velocity; t time; and g the acceleration of gravity. The forces and torques mentioned above cause the particles to develop moving and rolling movements during the screening process.

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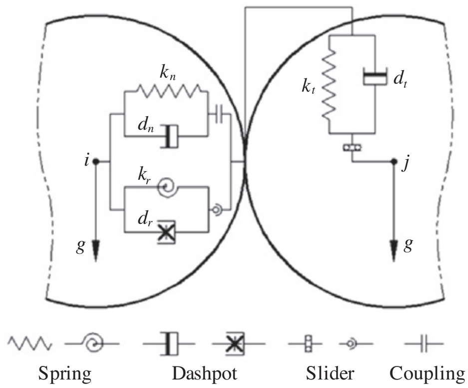

Fig. 1. Soft-particle contact model.

3. Simulation of a circularly vibrating screen classification process

The circularly vibrating screen classification processes was simulated for coal particles using the physical parameters shown in Table 1. The geometrical and technical parameters of the circularly vibrating screen model used in the simulations are presented in Table 2.

Simulation results using these parameters are shown in Fig. 2. During the screening process particles move continuously along the longitudinal direction of the screen deck because of the effect of the vibratory force and the inclination angle of the screen. Some smaller sized particles pass through the apertures upon contact with the deck while oversized particles and some of the smaller sized particles continue toward the discharge end. The size distribution of particles on the screen shows that oversized particles gradually move into the upper layer of the media while smaller ones are principally located in the lower layers as shown in Fig. 2a.

The velocity distribution of the particles on the deck is illustrated in Fig. 2b. The circularly vibrating screen generates a rotating acceleration vector and the screen has a very steep throwing angle, which is not conducive to transportation along the screen deck. Therefore, the screen deck should be constructed with an angle greater than 10° to develop adequate particle transportation. The layer thickness gradually thins from the feed end toward the discharge end and the material has an increasing velocity along the same path.

The numerical computations predict the time dependent particle behavior shown in Fig. 3.

Fig. 3a shows that the average velocity has significant periodic variations induced by the vibrating screen deck. At a time of about 1.5 s particulates cover the entire screen and the screening process is in a stable state. The overall average velocity of the particles is stable at 0.373 m/s.

In this work, the screen-deck was divided into six equal sections along the longitudinal axis. The average velocity of the particles on each of these sections can be calculated independently. The distribution of the average particle velocity along the longitudinal axis of the screen deck is shown in Fig. 3b. The rotary acceleration has a loosening effect on the particles on the screen deck. This, plus the gravitational component acting along the screen deck, promotes particle transportation toward the discharge end of the screen. The average particle velocity increases along the screen-deck increasing from 0.315 m/s at the feed end to 0.424 m/s at the discharge end.

Fig. 3c shows the predicted screening efficiency as a function of time. The screening process reaches a stable state after about 1.5 s. At this time the feeding, transportation, screening, and delivery processes are in a dynamic balance. After curve fitting the dynamic screening efficiency using a non-linear least square method the stable screening efficiency is found to be about 0.70.

4. Results and discussion

The effect of vibration parameters on a circularly vibrating classifier is shown in Fig. 4. Fig. 4a shows that the steady state screening efficiency increases significantly (from 0.661 to 0.702) with an increase (from 2.5 to 3.0 mm) in vibration amplitude. The value stabilizes around 0.701 at a vibration amplitude of 3.5 mm and decreases to 0.665 when the amplitude is 4.0 mm. So, the screening efficiency is predicted to increase with an increase in vibration amplitude but then decrease with further amplitude increases. The model suggests good screening performance will occur when the vibration amplitude is 3–3.5 mm.

The analysis shows that particle velocity increases linearly with an increase in vibration amplitude. The time that particles stay on the screen deck is shorter when the velocity is larger than the critical value of 0.373–0.389 m/s. Segregation of particles is then incomplete and the chance for smaller particles to pass through the aperture is reduced. This causes the screening efficiency to be reduced.

The effect of throwing index on the screening efficiency is shown in Fig. 4b. Screening efficiency in the steady state is 0.699 with a throwing index of 2.4. The efficiency increases to a maximum of 0.702 at the higher throwing index of 2.7 but then decreases to 0.674 as the throwing index is increased to 3.0. This predicts that the screening efficiency cannot be increased by using large values of the throwing index. A throwing index of 2.7 has the time particles are up off the deck equal to the time on the screen deck. The particles then have a high probability of going through the screen deck as it vibrates. However, as the throwing index is further increased the throwing height and the speed of the particles is also increased. As a result the collision frequency between the particles and the screen deck decreases and the screening efficiency is reduced.

Particles develop a sharp throwing angle from the rotary acceleration of the screen deck during the vibrating screen separation process. This motion acts against transport and segregation of the particles. Consequently the screen deck should have a larger inclination angle. Fig. 4c shows that a circularly vibrating screen has a lower screening efficiency when the screen deck angle is 12°. The screening efficiency increases to 0.702 for a screen deck angle of 15°. However, the screening efficiency reduces to 0.647 when the deck angle is increased above this value. The decrease in efficiency results from a decrease in the effective area of the mesh and an increase in the particle velocity along the deck. This

Table 1
Physical parameters of the model.

Physical parameter	Density (kg/m^3)	Coefficient of resilient restitution	Static friction coefficient	Coefficient of rolling friction	Poisson ratio	Shear modulus (GPa)
Coal particle	1300	0.500	0.600	0.050	0.300	1.000
Screen deck	7861	0.500	0.400	0.050	0.290	79.920