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DEM simulation of particle flow on single deck banana screen

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Abstract: This paper presents a mathematical study of particle flow on a banana screen deck using the discrete element method (DEM). The motion characteristics and penetrating mechanisms of particles on the screen deck are studied. Effects of geometric parameters of screen deck on banana screening process are investigated. The results show that when the values of inclination of discharge and

- increment of screen deck inclination are 10° and 5° respectively, the banana screening process get a good screening performance in the simulation. The relationship between screen deck length and screening efficiency is further confirmed. The conclusion that the screening efficiency will not significantly increase when the deck length $L \ge 430$ mm ($L/B \ge 3.5$) is obtained, which can provide 15 theoretical basis for the optimization of banana screen.
- Keywords: mineral processing engineering; banana screen; particle flow; discrete element method; numerical simulation

0 Introduction

Screening is an important means of size classification for granular or particulate materials^[1,2]. Banana screen has been wildly used in mineral industry in recent years because of its high efficiency and capacity. But for lacking deeply understanding the fundamental mechanisms of particle motion and penetration behavior in the screening process, reasonable operation and optimization of banana screen to meet different conditions have been important practical problems in screening industry^[3-5].

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Most of the mathematical models of screening processes currently in use are phenomenological models and concern the establishment of factors that influence the screening efficiency^[6]. In principle, the bulk behavior of particles on banana screen depends on the collected outcome of the interactions between individual particles and between particles and screen deck. So

30 it is useful to understand the screening phenomena on a particle scale, but this is difficult to realize with the existing experimental techniques.

The discrete element method (DEM) which has been developed since 1970s is a numerical method which is suitable for calculating mechanical behavior of granular medium system. DEM has got successful applications in granular media engineering fields, such as geotechnical engineering, mining engineering, mineral processing and material separation and so on. DEM has become a multi-disciplinary research filed rapidly, which core is to help people investigate the relationship between microscopic and macroscopic characteristic of the discrete particles ^[7,8].

However, to date there has been little report in the literature about DEM simulation of the screening process most of which are limited to simple process ^[9-12]. Furthermore, few numerical

40 studies on the complex banana screen have been reported, which mainly concentrate on the influence laws of vibration parameters on banana screening process [3-5,13-15]. The study on the influence of geometric parameters, which are the main characteristics of banana screen, is rather preliminary.

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In this work we present a three-dimensional DEM simulation research of banana screening process. The effects of geometrical parameters on screening performance are studied by a serial of controlled numerical experiments. Such study presents a better understanding on multi-deck banana screen, which is helpful to optimal design of banana screen.

1 The mathematical model

1.1 The discrete element method

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The motion of vibrating screen can be defined as three types: linear, circle and elliptical modes according to the trajectory. As Fig. 1 shows, λ is the amplitude and β is the vibration direction angle. In the simulations, an improved DEM dry contact soft-sphere model was used [16,17]. As Fig. 2 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. So, the *i*'th particle motion can be calculated by the basic principles of DEM which equations are expressed by [18,19].



60 **1.2 Simulation of banana screening process**

In this work, banana screen with five decks is considered, as schematically shown in Fig.2. Deck numbers are counted from the feed end to the discharge end. The detailed geometrical conditions are listed in Table 1. The size distribution of feeding particles is based on practical condition which includes small undersized, near-mesh sized and over-sized particles. Table 1 gives the material properties used in the simulation, which are based on the properties of coal particles and steel screen deck.



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Tab.1 Simulation parameters				
Parameters	Values			
Screen total length $L(mm)$	360			
Screen total width $B(mm)$	150			
Aperture size(mm)	10×10			
Particle shape	Sphere			
Particle size(mm)	-7 to +2	-10 to +7	-15 to +10	
Feed rata(num/s)	3200	600	200	
Vibration frequency(Hz)	16.15			
Vibration amplitude(mm)	2.0			
Vibration motion	Linear,45° with horizontal line			
Density (kg/m^3)	1300(particle)	786	1(screen deck)	
Young's modulus (GPa)	1.0(particle) 79.92(screen de		2(screen deck)	
Poisson's ratio	0.3(particle) 0.29(screen deck)		9(screen deck)	
Coefficient of restitution	0.5(inter-particle)	0.5	0.5(particle-deck)	
Coefficient of static friction	0.6(inter-particle)	icle) 0.4(particle-deck)		
Coefficient of rolling friction(inter-particle)	0.05(inter-particle)	05(inter-particle) 0.05(particle-deck)		

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At the beginning of a simulation, mixtures of different sized particles are generated continuously above the deck at the feed end and fall freely under the gravity force. The particles will then pass through the apertures of the deck or rebound when approaching the screen deck. Information about the particle flow is recorded in the simulation. Fig.3 shows a snapshot of the simulation of a 5-deck banana screen at the steady state.



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1) Distributions of different sizes particles (b) Distributions of particles vel Fig.3 Snapshot of DEM simulations of banana screening process

The changes of material layer and distributions of each sized particles in steady screening status are shown in Fig.3 (a). Particles are colored by their sizes: smaller ones are light grey and larger ones are dark grey. In the screening process, the bed thickness is thinner and constant along the screen deck. Fig.3 (b) shows the distributions of particles average velocity along screen deck, which show a decreasing trend from the feed end to the discharge end. So, the particles near the feeding region flow quickly along the screen surface to avoid accumulation. Under the effect of vibrating screen deck, segregation between different size particles occurs continuously, in which over-sized particles will rise to the top of layer and be delivered to the discharge end, while small size particles will sink to the bottom of layer and pass through the apertures becoming undersize. Over-sized particles tend to travel along the screen surface together with the remaining smaller particles to become oversize at the discharge end.

95 2 Results and discussions

2.1 Effect of inclination of discharge end

The DEM simulation results of banana screening process are shown in Fig.4, in which the inclination of discharge end $\alpha 0$ increases from 0° to 10° with the increments of each deck

inclination of 5°.



Fig.4 DEM simulations of banana screening process with different screen deck inclinations of discharge end

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Fig.5(a) shows that when the inclination of discharge end is less than 5°, the particle average velocities on each screen deck change slowly and show the decreasing distribution characteristics. However, the too small velocity amplitudes will cause poor material transportation and accumulation on screen deck, both of which will reduce the screening performance, as shown in Fig.4 (a), (b) and Fig.5 (b).



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As α_0 increased to 10°, the particles velocity amplitudes are higher and show significant gradient feature. The screening performance is improved for good material transportation, thinner 115 and approximately constant thickness material layer, as shown in Fig.4 (c). And the screening efficiency reached about 0.83 in steady screening state. As α_0 increased to 15°, the velocity amplitudes further increased. The fine particles screening performance is affected by the high velocity of particles on the front 3 screen decks. In addition, the particles segregation and screening performance of near-mesh sized particles are also affected by the high velocity. So, 120 material layer is thin, but the steady-state screening efficiency is only 0.68, as shown in Fig.4 (d) and Fig.5 (b).

2.2 Effect of increment of screen deck inclination

Taking the inclination of discharge end α_0 as 10°, when the increment of each deck inclination $\Delta \alpha$ increases from 3° to 6°, the DEM simulation results of banana screening process 125 are as Fig.6 shown.

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Fig.6 DEM simulations of banana screening process with different increment of screen deck inclination

130 Fig.7 (a) shows that when the increment of screen deck inclination is small ($\Delta \alpha \leq 4^{\circ}$), the velocity amplitudes of particles are small and change slowly. The velocity of particles on the connection point of the first and the second deck reaches the maximum. From the middle of the third deck, the velocity amplitudes of particles are small and change slowly which affect the transportation and segregation effect of particles on the screen deck. So, the material layer is 135 uniformly distributed getting thick thickness and poor segregation effect. The time required to reach the steady screening state increases, which has seriously affected the screening performance, shown in Fig.6 (a), (b) and Fig.7 (b). When $\Delta \alpha$ increases to 5°, the velocity amplitude gets a significant increase and gradient distribution characteristic. The velocities of particles on deck-1 and deck-2 are higher, which are conductive to rapid transportation of materials and penetrating of 140 fine particles. Meanwhile, the velocities of particles on deck-4 and deck-5 are lower, which are conductive to further segregation and penetrating of near-mesh particles and fine particles remaining in the layer. So, the material layer gets good distribution and segregation effect, as Fig. 6(c) and Fig. 7(b) shown. Screening efficiency of steady state is high which value reaches to 0.83. When $\Delta \alpha$ further increases to 6°, particle velocity increases due to the large incline angles of

145 screen decks, but particle residence time on the screen deck deceases which causes the screening efficiency to be reduced to about 0.77.



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2.3 Effect of screen deck length

Changes of banana screening efficiency with different screen deck length are shown in Fig.8. When the screen deck length L is 290 mm (the ratio of screen deck length and width L/B is about 2.5), the efficiency is only 0.72. The screening efficiency increases to 0.83 when the screen deck

155 length is 360 mm (L/B is about 3). When the screen deck length further increases to 430 mm (L/B is about 3.5), screening efficiency increases to 0.92. But the efficiency will not obviously increase which value is state at around 0.94 when the length of screen deck continuously increases.



Fig.8 Effect of screen deck length on sieving efficiency

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It is found that by further analysis when the changes of banana screening efficiency is fitted using Boltzmann equation, the determination coefficient of curve fitting R2 is 1. So, the relationship between screen deck length and screening efficiency obeys the Boltzmann distribution law in 0.95 confidence level and can be approximately expressed as the follows:

$$\eta_{\rm d} = \frac{0.70424 - 0.94345}{1 - e^{(L - 361.74)/27.055}} + 0.94345.$$

3 Conclusions

(1) Inclinations of screen deck (including the inclination of discharge end and the increment of screen deck inclination) are the key parameters to decide whether banana screening can be achieved. When the inclination of discharge end is too small, the screening process will be difficult to proceed for the too small particle velocity amplitude. But when it is too big, the screening efficiency will be seriously affected by the too fast particle velocity on the screen deck. The increment of screen deck has a same effect on banana screening process as inclination of discharge end. And when the values of inclination of discharge and increment of screen deck inclination are 10° and 5° respectively, the banana screening process get a good screening performance in the simulation.

(2) The relationship between screen deck length and screening efficiency can be approximately expressed by Boltzmann equation. The steady state screening efficiency increases as screen deck length increases. But when the deck length $L \ge 430 \text{mm} (L/B \ge 3.5)$, the screening efficiency will no longer significant increase.

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References

- [1] LIU C S, LU J X. Study on nonlinear characteristic of particle motion during the process of coal screening[J]. Journal of China Coal Society,2009,34(4):556-559. [in Chinese]
- [2] ZHAO Y M, LIU C S. Study on screening mechanism of moist fine coal on elastic screen surface[J]. Journal of China Coal Society,2000,25:206-208. [in Chinese]
- [3] DONG J K, YU A B, BRAKE I. DEM simulation of particle flow on a multi-deck banana screen[J]. Minerals Engrneering,2009,22:910-920.

[4] LI J, WEBB C, PANDIELLA S S, CAMPBELL G M. Discrete particle motion on sieves-a numerical study using the DEM simulation[J]. Powder Technology,2003,133:190-202.

- 190 [5] LIU K S. Some factors affecting sieving performance and efficiency[J]. Powder Technology,2009,193(2): 208-213.
 - [6] CLEARY P W. DEM prediction of industrial and geophysical particle

flows[J].Particuology,2010,8(2):106-118.

- [7] ZHU H P, ZHOU Z Y, YANG R Y, YU A B. Discrete particle simulation of particulate systems: A review of major applications and findings[J]. Chemical Engineering Science,2008,63:5728-5770.
 - [8] ZHAO L L, LIU C S, YAN J X, XU Z P. Numerical simulation on segregation process of particle using 3D Discrete Element Method[J]. Acta Physica Sinica,2010,59(3):1870-1876. [in Chinese]

[9] ZHAO Y M, ZHANG S G, JIAO H G, TIE Z X. Simulation of discrete element of particles motion on the vibration plane[J]. Journal of China University of Mining & Technology,2006,35(5):586-590. [in Chinese]

- [10] JIAO H G, ZHAO Y M. Screen simulation using a particle discrete element methodp[J].Journal of China University of Mining & Technology,2007,36(2):232-236.[in Chinese]
 [11] JIAO H G, ZHAO Y M, WWANG Q Q. Numerical study of collision and penetration behavior between particles and screen plate[J]. Journal of China University of Mining & Technology,2006,16(2):137-146.
 [12] CHEN Y H, TONG X. Application of the DEM to screening process: a 3D simulation[J]. Minining Science
- and Technology,2009,19(4):493-497.
 [13] CLEARY P W, SINNOTT M D, MORRISON R D. Separation performance of double deck banana screens Part 1: Flow and separation for different accelerations[J].Minerals Engineering,2009,22(14):1218-1229.
 [14] CLEARY P W, SINNOTT M D, MORRISON R D. Separation performance of double deck banana screens-Part 2: Quantitative predictions[J]. Minerals Engineering,2009,22(14):1230-1244.
- [15] CLEARY P W. Industrial particle flow modeling using discrete element method[J].Engineering Computation,2009,26(6):698-743.
 [16] IWASHITA K, ODA M. Rolling resistance at contacts in simulation of shear band development by DEM[J]. Journal of Engineering Mechanics,1998,124(3):285-292.
 [17] CUNDALL P A, STRACK O D L. A distinct element model for granular assemblies[J].
- Geotechnique,1979,29(1):47-65.
 [18] ZHAO L L, LIU C S, YAN J X, JIANG X W, ZHU Y. Numerical simulation of particle segregation behavior in different vibration modes[J]. Acta Physica Sinica,2010,59(4):2582-2588. [in Chinese]
 [19] ZHAO Y Z, CHENG Y. Numerical simulation of radial segregation patterns of binary granular systems in a rotating horizontal drum[J]. Acta Physica Sinica,2008,57(1):322-327. [in Chinese]

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单层香蕉筛筛面上颗粒流的离散元法模拟

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- 摘要:本文基于离散元法对香蕉筛筛面颗粒流进行了数值模拟研究。对筛面颗粒群的运动特 225 征及透筛机理进行了研究,讨论了筛面几何参数对等厚筛分过程影响作用,结果表明:当排 料端倾角和筛面倾角增量分别为10°和5°时,等厚筛分过程具有较高的筛分效率。筛面长 度与筛分效率之间的关进得到了进一步确定,当筛面长度大于430mm(筛面长度与宽度之比 大于3.5)时,筛分效率不再有明显地增加。研究成果能够为香蕉筛的优化设计提供理论依 据。
- 230 关键词: 矿物加工工程; 香蕉筛; 颗粒流; 离散元法; 数值模拟 中图分类号: TD921.3

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