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Kinematics of variable-amplitude screen and analysis of particle behavior during the process of coal screening

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ABSTRACT

Screening is an indispensable unit process for separation of particulate materials in various industrial processes. The variable-amplitude screen (VAS) has been widely used for particle classification because of its large production capacity and good screening performance. In this paper, a novel VAS driven externally by an unbalanced two-axle excitation was proposed. Kinematics characteristics of the VAS and particle behavior under different operational conditions were investigated using vibration test and dynamic image analysis system. The results show that the displacement amplitude of the VAS decreased gradually along the direction of material flow. Consequently, the migration velocity of particles was larger and the screening time of particles was long, due to the larger and smaller displacement amplitudes at the feed and discharge ends, respectively. Both of these effects are conducive to improved screening performance. The operational factors unbalanced excitation force coefficient (k_f), relative beam span (l_{reb}) and feed rate (Q) all showed significant influences on the kinematics of the VAS, particle behavior and screening efficiency. The difference between the amplitudes of the feed end and the discharge end increased with increasing k_f and l_{reb}, thus resulting in the increase of particle velocity; however, these variables showed an inverse relationship with Q. The screening efficiency showed a maximum with the increase of all three of the test parameters. It was found that the screening efficiency was higher than 94% when $k_f = 1.22$, $l_{reb} = 45\%$, and $Q \leq 4.80$ t/h. This indicated that the VAS has excellent performance for coal screening.
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1. Introduction

Screening is an indispensable unit process and is often used extensively in the separation of coal, mineral ores, aggregates and food powders into different size fractions [1–3]. In many applications, vibrating screens are widely used due to their efficient screening performance and large capacity [4–7], which can result in reduced costs of production, increased economic benefits, and improved energy efficiency [6–10]. The variable-amplitude screen (VAS) is a kind of vibrating screen, whose amplitude changes gradually from feed end to discharge end. The VAS has the advantage of strengthening the loose layers of materials, thereby improving the utilization rate of the sieve surface. The VAS has therefore been extensively used in large-scale coal preparation and mineral processing plants in recent years because of its high capacity and reliable performance [11,12].

Many scholars have studied the kinematics of vibrating screens and analyzed particle behavior, due of the importance of these phenomena in elucidating the mechanisms of particle stratification, migration and penetration [12–16]. Zhang et al. [17] established a dynamic model for a three-axis vibrating screen with a variable trajectory, as well as reported that the motion of the centroid and the surface of the vibration screen are consistent with characteristics of the banana vibration screen. Fernandez et al. [18] reported that the slurry motion is controlled by a balance of the hydrodynamic forces and the inter-phase drag, whose strength is determined by the solid fraction distribution of the particulates and the fluid viscosity. Dong et al. [19–21] reported that particle accumulation is affected by the motion of particles on a multi-stage banana vibrating screen; specifically, a certain particle velocity contributes to a percentage passing, and a low velocity generally causes accumulation.

For vibrating screens with variable amplitude, an insight into the dynamic characteristics, particle behavior and the screening performance under different conditions can help mineral engineers to design, develop and optimize such systems [22,23]. Ma et al. [11] reported that the VAS caused particles at the front of the screen to be rapidly thrown up and moved back; their study provided insight into solving the retention problem of materials at the screen front. Liu et al. [12] investigated the dynamic characteristics and classification performance of a four-axle banana vibration screen with a variable trajectory, and reported an

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excellent screening efficiency of 94.01% using this method. In the current study, a novel VAS is proposed, which is driven externally by an unbalanced two-axle excitation with a large span, a configuration that should be advantageous to screening performance. The kinematic characteristics of the different positions of the VAS along the material flow were studied using a vibration test and analysis system. In addition, particle behavior in the process of screening coal was investigated using a high-speed dynamic image acquisition and analysis system. Finally, the optimum operating conditions were identified through analysis of the screening performance of the coal in the VAS under different operating conditions.

2. Experimental

2.1. Experimental apparatus

A schematic diagram of the VAS system is illustrated in Fig. 1; the system consists of a silo, feeder, variable-amplitude screen, receiver, frequency converter, vibration test and analysis system, and dynamic image acquisition and analysis system. The VAS is 0.6 m wide and 1.2 m long, has a sieve pore diameter of 15 mm. The silo is used to store the material used for screening, and the speed of the feeder is adjusted using a frequency converter to control the feed rate to the VAS. The receiver is used to collect over- and undersized products. The vibration test and analysis system consists of several acceleration transducers, a data acquisition device, and a computer and DASP software. The dynamic image acquisition and analysis system consists of a high-speed camera and a computer and i-SPEED software.

2.2. Experimental procedure

The acceleration transducers were set on the vibrating screen using magnets at the points to be measured. The sensors, acquisition instrument and the computer were connected using shielded cables after installation of the sensors. The vibration test equipment was started and test parameters were set. The vibration signal was collected and recorded by the data acquisition device and computer, once material was fed and the running state of the VAS was stable. The sampling time was set to 30 s. The kinematic parameters and variance of the measured points were analyzed using the DASP software.

The lens of the high-speed dynamic camera was adjusted to focus on the observation window in the side plate of the vibrating screen and the test parameters of the camera were set before recording. The shutter button on the camera was pressed to start recording and material was fed into the system after ensuring that the VAS was running smoothly. Once the material was completely discharged from the screen, filming was stopped. A number of particles were labeled and selected for analysis to determine the patterns of the stratification and migration of material particles, using the i-SPEED software.

2.3. Materials used

The size distribution and moisture content of the coal sample (obtained from Xuzhou, China) is given in Table 1. The yields of the 50.00–19.50 mm, 19.50–13.00 mm, 13.00–9.75 mm and 9.75–0.00 mm were 10.70%, 25.20%, 23.90% and 40.20%, respectively, and the designated particle size was 13 mm. The near-aperture (13.00–9.75 mm) and hindered particles (19.50–13.00 mm) accounted for 49.10% of the total; this makes the material difficult to screen. The moisture content of the coal was low, and thus did not greatly affect the screening performance.

2.4. Evaluation of screening performance

During the screening process, particles that are smaller than the designated size exist in the oversized product and particles that are larger than the designated size exist in the undersized product. In the current study, oversized and undersized products were sieved and weighed in order to analyze and evaluate the screening performance of the vibrating screen. The screening performance was evaluated using the screening efficiency, which was calculated as in Eq. (1):

$$\eta = \frac{(\alpha - \theta)(\beta - \alpha) \times 100}{\alpha(\beta - \theta)(100 - \alpha)} \times 100\% \tag{1}$$

where η is the screening efficiency (%), α is the content of fine particles in the feed (%), β is the content of fine particles in the undersized product (%), and θ is the content of fine particles in the oversized product (%).

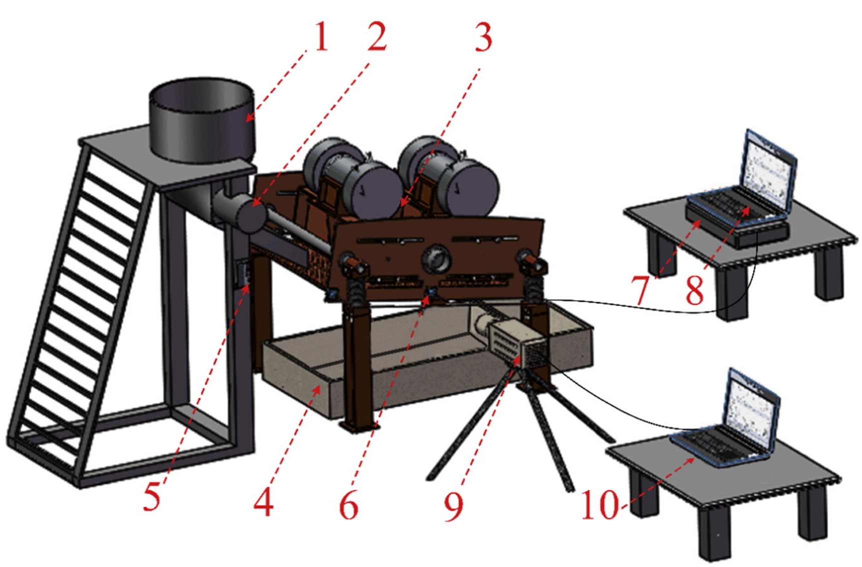

Fig. 1. Schematic diagram of the VAS system: 1. silo; 2. feeder; 3. VAS; 4. receiver; 5. frequency converter; 6. acceleration transducer; 7. data acquisition device; 8. computer and DASP software; 9. high-speed camera; 10. computer and i-SPEED software.

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