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Discrete-element method simulation of agricultural particles' motion in variable-amplitude screen box

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ABSTRACT

Cleaning and screening of agricultural materials is an important process in agricultural production. Many researchers have carried out important works in this area based on mechanism, parameter optimization, and particles' motion. In this paper, both advantages and disadvantages of the traditional reciprocating screen widely used in combine harvester were analyzed. Furthermore, a variable-amplitude screening mechanism developed from classical swing bar type reciprocating screens in Adams software was studied, and the trajectories of 11 marker points on the screen under different conditions were obtained. After transforming the motion of a variable-amplitude screen to 3 DOF (degree-of-freedom) motions (two translations and one rotation, 2T–1R), DEM (discrete-element method) simulations of agricultural particles (grain and stalk) in a variable-amplitude screen box were performed based on the Hertz–Mindlin contact model in an EDEM software environment. The results show that the variable-amplitude screen could make the agricultural particles at the front of the screen be quickly thrown up and moved back but could not favor their segregation and separation at the screen front. This variable-amplitude screening method can provide reference for solving the retention problem of agricultural materials at the screen front.

1. Introduction

Cleaning and screening of agricultural materials is an important process in agricultural production. To improve the sieving efficiency and quality and to reduce cleaning loss, many researchers have carried out important works in this area. Some of them studied from the mechanism perspective. Liu et al. (2008) studied the kinematics modeling method of a 2T–2R (two-translation and two-rotation) type parallel mechanism screen using conversion matrix and presented the kinematic positive and inverse solutions of this mechanism. Wang et al. (2012) designed a multi-dimensional vibration test bench [three translations and one rotation (1R)] using a fully decoupled main exciting mechanism and a short driving chain based on parallel mechanism and performed an experiment for typical agricultural materials. Deng et al. (2013) designed a parallel kinematic vibration sieve based on one degree of freedom (DOF) and a two-loop spatial mechanism with non-planar screen and analyzed the topology structure of its main mechanism. In these studies, all researchers claimed that the multi-dimensional vibration screen could increase screening efficiency.

Some researchers studied the screening technology by optimizing certain parameters. For example, Shen (1984) optimized the amplitude and direction of acceleration, vibrating frequency, and airflow velocity of a given cleaning structure for cleaning quality using a regression orthogonal design method. Cheng and Wang (1998) investigated the effect of structure and motion parameters of a given air-and-screen cleaning mechanism and optimized its main parameters based on a mathematical model, which was adopted in the current paper. To investigate the complex cleaning process of a combine harvester, Craessaerts et al. (2007a,b, 2008, 2010) first presented an input selection methodology based on the principle of natural selection to rank the candidate input variables as possible regression variables for cleaning loss prediction. Thereafter, they used a nonlinear genetic polynomial regression technique to rank the pool of potential sensors as possible regression variables for a prediction model of the MOG (material other than grain) content. Finally, they identified the optimum and non-optimum working conditions based on experimental data and fuzzy modeling techniques and evaluated the performance and robustness of the fuzzy control system by field tests during wheat harvesting.

Some researchers also studied the screening technology by investigating the particles' motion. Hao et al. (1992) theoretically analyzed the agricultural particles' motion and developed a computational method for computing particles' motion using BASIC

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language. Jianping and Yun (1997) simulated the tossing motion of agricultural materials on a cleaning screen based on a mathematical model and compared the test and simulation values. To obtain the target particle's motion of an air-and-screen cleaning mechanism, Li et al. (2009) stained the particle and tracked its position based on mean shift algorithm using a high-speed camera system. Li et al. (2012a,b) simulated the agricultural material motion on an air-and-screen cleaning device and studied the effects of air speed on the cleaning loss.

All the above mentioned research works promoted the development of screening technology of agricultural materials. Furthermore, in our view, particles' motion should be the starting point and final objective of these investigations. In recent years, with the rapid development in computers and computational technology, the discrete-element method (DEM) (Cundall and Strack, 1979) has been used by an increasing number of researchers for simulation and investigation of the particles' motion characteristics, and it has proven to be feasible and effective. Such DEM simulation technology is not only used in industrial processes (Jiao et al., 2008; Kawaguchi et al., 1998) but also applied in agriculture processes such as fertilizer spreading (Tijskens et al., 2003; Van Liedekerke et al., 2009), grain flow in silos (González-Montellano et al., 2011), or manure handling and land application equipment (Landry et al., 2006). Furthermore, Li et al. (2012a,b) coupled the DEM and the CFD (computational fluid dynamic) simulation technology to study the agricultural particles' motion in the cleaning unit of a combine harvester. Kattenstroth et al. (2011) developed a discrete-element model for straw particles constructed using connected spheres and studied the alignment of straw particles and cutting blades in the chopper section of a combine. Lenaerts et al. (2014) introduced changes into the DEM to construct the segmented bendable straw particles in a DEMeter++ software environment and simulated the separation process of grain and straw particles.

With regard to the screening types of agricultural materials, some researchers claimed that multi-dimensional screens based on a parallel mechanism have higher screen efficiency than common screens (Liu et al., 2008; Wang et al., 2012) because they have higher freedom, higher loading capacity, and more controlling. However, as shown earlier, many research works have yet to be performed on traditional screens (Li et al., 2009; Craessaerts et al., 2010; Li et al., 2012a,b). Specifically with regard to the cleaning equipment used in combine harvesters, we can observe that the traditional screen, namely, reciprocating screen, remains the most widely used screen in combine harvester. In our view, we should pay sufficient attention to such traditional but widely used screen. In fact, the structure of a multi-dimensional screen based on a parallel mechanism is more complex than that of the traditional reciprocating screen. Therefore, its application in the limited space of a combine harvester is difficult.

However, people hope that agriculture production will increasingly become efficient and precise. In particular, the traditional reciprocating screen indeed suffers from some drawbacks. First, the materials constantly move in and out during the screening process. Therefore, the quality and composition of materials at the screen front are different from those at the screen tail, i.e., the materials at the screen front are heavier and contain more grains than those at the screen tail. Thus, the materials at the screen front require more screening intensity than those at the screen tail. However, the traditional reciprocating screen works in a single manner to address the different screening requirements. Second, because of complex landform and uneven growth of crops or some other artificial operating factors, the feeding quantity of agricultural materials in the field varies. When the fluctuation in the feeding quantity of agricultural materials becomes too significant to be neglected, some adjustments must be made to compensate for such fluctuation or to prevent material retention. With regard to the cleaning section, we naturally hope to increase the screening intensity at the screen front to make the materials quickly move back and forth when the feeding quantity significantly increases.

The conventional idea of varying the screening intensity is to change the frequency and/or the amplitude of vibrations; however, only the amplitude change can likely increase the local screen strength. In terms of the two abovementioned drawbacks, what we need is an unequal-amplitude screen and a variable-amplitude screen. Accordingly, we need to understand the effect of variable amplitude on the particles' motion. In this study, a variable-amplitude screen mechanism was first constructed, and the effect on the particles' motion was later investigated. In particular, the research presented in this paper was not carried out for any specific machine but as a general and basic research to provide reference for subsequent and some other research activities.

2. Variable-amplitude screen

From the viewpoint of basic research, the swing bar type reciprocating screen is one of the classical screening mechanisms. This kind of screen mechanism serves as the basis of many theoretical investigations because it reflects the concept of a reciprocating screen. In our research of classical screening mechanism, the dip angle and amplitude of the screen are kept constant because the front and back swing bars (similarly as shown in Fig. 1) are parallel and have equal length. The variable-amplitude screen that we constructed in this study is developed from the classical swing bar type reciprocating screen.

2.1. Construction of variable-amplitude screen

From the above description and expectation, the following requirements must be first met:

(a) The front and back swing bars are in a vertical state at the initial moment.
(b) The front swing bar is shorter than the latter.
(c) Only the front swing bar can be adjusted.
(d) The screen front is lower than the screen tail at the initial setup.
(e) Irrespective of how the front swing bar is adjusted, the position of the screen at the initial setup must be the lowest position during the whole cycle.

After several preliminary analyses, we built a variable-amplitude screen mechanism according to the abovementioned concepts and requirements from the classical swing bar type reciprocating screen, as shown in Fig. 1. In this figure, the line AC repre-

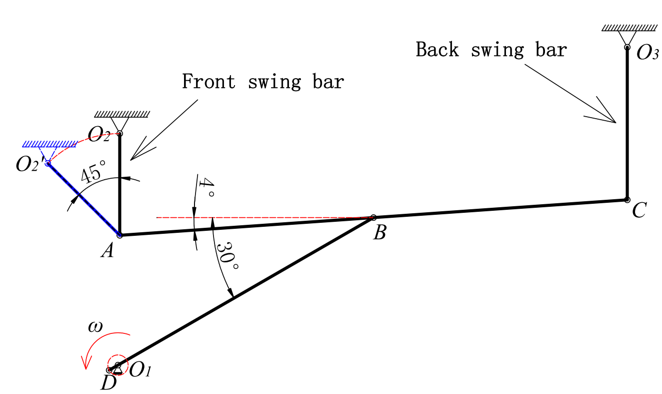

Fig. 1. Scheme of the variable-amplitude screen.