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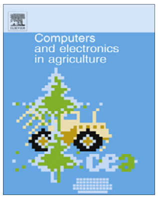

Monitoring method of rice seeds mass in vibrating tray for vacuum-panel precision seeder

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ABSTRACT

According to the physical properties of rice seeds, triaxial ellipsoidal particle models were established based on the multi-sphere approach, and simulations of seeds motion in a vibrating tray were performed using the discrete element method (DEM). It was shown that the normal impact force F_n of seeds action on the tray was mainly composed of transient impact and accumulation force sections. The value of transient impact force was not stable because it was influenced comprehensively by shape of seed, vibration parameter and seeds-mass-per-unit-area (SMA). The variation of accumulation force determined by impulse change of seeds was relatively stable. Simulation results indicated that its value was almost linearly varied with SMA under a certain vibration parameter, and a real-time monitoring method of seeds mass in a vibrating tray is presented in this paper.

Two cantilever force sensors were back-to-back fixed at the bottom of seed tray. Due to a phasic difference ψ existed between the vibration inertia force and the seeds normal impact force F_n, a differential operation was performed between the output signals of two sensors to eliminate the influence of inertia force and extract F_n effectively. Then, a signal processing circuit mainly composed of differential amplifier, active low-pass filter, bias voltage circuit, envelope detector, and passive low-pass filter in series was designed to detect seeds mass. Calibration tests were carried out in laboratory with vibration frequency f and amplitude A of tray in the ranges of 9–13 Hz and 3–5 mm, the results showed that the comprehensive measurement errors were <3.5% with SMA κ in the range of 0.2–1.8 g/cm^2.

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1. Introduction

China is the largest producer and consumer of rice in the world. The annual production is over 200 million tons from 30 million ha, which accounts for about 31% of total world rice production (Zhao et al., 2011). Nursery-transplanting is the mainly used planting pattern. With the improvement of rice varieties and the increasing of planting area of hybrid-rice, there is a need to improve the seeding precision (from 3–5 to 1–2 seeds in a desired spacing) in the nursery process. Precision seeding provides a better growing area per seed, increases the tillering capacity and has been demonstrated to be a significant factor in affecting rice yield production (Yuan et al., 2007; He et al., 2008).

To date, a large number of precision seeding machines have been developed by researchers all over the world for different crops (Nørremark et al., 2007; Gaikwad and Sirohi, 2008; Zhao et al., 2010). The most common types are using belt and vacuum principles. The physical properties of seeds are essential for the design of seeders (Guarella et al., 1996; Karayel et al., 2004). Rice seed has the properties of irregular shape, rough surface and large friction coefficient. So, vacuum seeders are used mainly for the advantages of better working quality, more precise seed rates with lower rate of seed damage, better control and adjustment, and broader spectrum of applicability. Among various vacuum precision seeders, those utilizing rotational discs were researched most widely (Singh et al., 2005; Karayel, 2009). Many experiments have been carried out in laboratory or field in order to improve the working performance of seeders (Barut and Özmerzi, 2004; Yazgi and Degirmencioglu, 2007). This type of seeder is successfully applied in direct seeding of crops in field. To meet the requirements of rice seeding for nursery, a seeder was designed which was primary composed of a vacuum panel and a seed tray (Liu and Song, 2004). The seed tray was vibrated at high frequency and low amplitude, so that the seeds in the tray could be separated to reduce interaction forces and easily precision picked up. Seeds motion state plays an important role in improvement the seeding performance. It is mainly determined by the physical properties of seeds, vibration parameter of tray and layer thickness of seeds in the tray (Li et al., 2009; Chen et al., 2011). When the layer

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thickness is greater, it becomes difficulty for seeds to be separated each other. This will lead to a higher multiple-index because of the complex interaction forces between seeds. When the layer thickness is smaller, it usually leads to a higher miss-index because of a sparser spatial distribution density of seeds. It has been proved that, to improve the seeding performance, the seeds layer thickness in a vibrating tray should be maintained in a reasonable range (15–25 mm for rice seeds in general). Problem occurs in this case. Under the excitation of vibration, the flowability of seeds is enhanced. It is easy to cause an uneven distribution of seeds in the tray. The seeds thickness is greater in some areas and is smaller in other areas, which seriously restricts the improvement of continuous operating performance (Gong et al., 2012). One possible solution is to monitor seeds mass in different areas of tray real-time, and adjust the operation parameters such as vibration direction vector correspondingly to promote the flow of seeds orderly. In addition, with the proceeding of the seeding operation, seeds mass in the tray is continuously decreasing, and need to be added timely. So, it is necessary to propose a monitoring method of seeds mass in a vibrating tray.

Understanding of seeds motion characteristics and interaction between seeds and vibrating tray is important. The DEM as introduced by Cundall and Strack has evolved to an important method for modelling and understanding the behaviour of granular materials (Tijskens et al., 2003; Zhu et al., 2008) Particles were usually modelled as discs and spheres in the early DEM simulations. In order to obtain more realistic particle behaviour, other shape models have been introduced into the DEM. Single-particle and clustered-particles are two widely used approaches. In a single-particle approach, non-spherical shapes mainly include the ellipsoid, cylinder, glued-sphere and polyhedral (Landry et al., 2006; Boon et al., 2012). It has a disadvantage that the contact criterion is generally developed by solving sets of non-linear equations, which is time consuming and makes DEM simulations extremely slow. In a clustered-particle approach, small body elements such as spheres are allowed to overlap in order to form a complex shape (Markauskas et al., 2010; Keppler et al., 2012). The best advantage is that contact detection and force calculation can be determined using simple algorithms valid for spheres and is therefore very efficient and robust. This method has been successfully applied in various fields and is furthermore implemented in the commercial DEM-packages, although it has certain limitations in microscopic properties (Kruggel-Emden et al., 2008; Lenaerts et al., 2014).

The objective of this paper was to simulate the rice seeds motion in a vibrating tray using DEM and triaxial ellipsoidal particle models. Through the analysis of normal impact force of seeds action on tray under different vibration parameters and SMA, a real-time monitoring method and device of seeds mass were proposed. Finally, calibration tests were conducted in laboratory to evaluate the measurement accuracy.

2. Materials and methods

2.1. Material properties

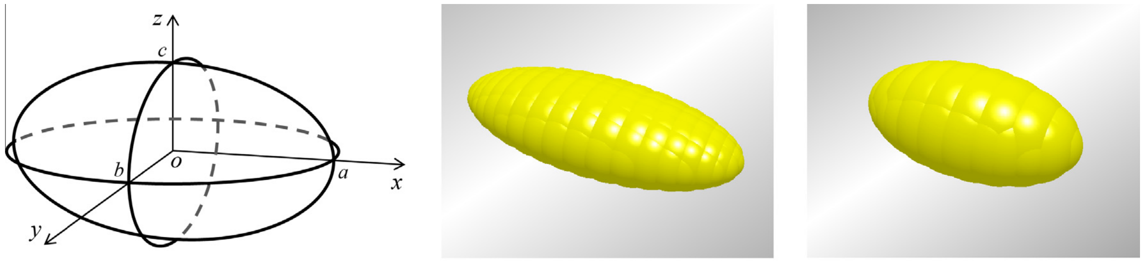
Rice seed is usually a triaxial ellipsoidal particle. The difference of seed physical properties between varieties is mainly reflected in the mass and the length of three axes (Fig. 1(a)). The multi-sphere model is a realistic and relatively simple particle model applicable to DEM simulations of the behaviour of the real ellipsoidal particles. The model exhibits a clear tendency of convergence with increasing number of sub-spheres. Here, two typical rice seeds with different shapes were established by using a varying number of spheres (Fig. 1). The material of seed tray was aluminium alloy #7075. Table 1 summarises the values of the material properties required in the DEM.

2.2. DEM simulations

In the DEM, the motion of the particle as a rigid body described in the framework of classical mechanics naturally consists of translational and rotational motions. As the particles move, they impact each other and undergo deformations. Contact forces are computed as a function of the particle deformations. A commercial three-dimensional DEM code (EDEM® 2.5, DEM Solutions) has been used in this work. The process is a cycle with repeated calculation the equation of motion for all the particles individually using the forces evaluated by using contact models to obtain the acceleration, velocity and displacement. The Hertz–Mindlin no slip contact model uses spring–dashpot model of interacting particles. This model has been successfully applied to the dynamic analysis of agricultural materials. The material and interaction parameters have their effect on the normal and tangential forces, and moment acting between the interacting particles in the form of the following equations.

Table 1
Values of material properties used in the DEM.

Parameter	Rice seed #1	Rice seed #2	Tray
Semi-axes (mm)	$3.75 \times 1.60 \times 1.05$	$2.85 \times 1.55 \times 1.35$	/
Mass (g)	28.2×10^{-3}	26.5×10^{-3}	/
Density (kg/m^3)	1080		2800
Young's modulus (MPa)	375		72,000
Poisson's ratio	0.25		0.33
Coefficient of friction			
Seed–seed	0.48		/
Seed–tray	/		0.32
Coefficient of restitution			
Seed–seed	0.42		/
Seed–tray	/		0.48
Time step (s)	1×10^{-6}		



(a) (b) (c)

Fig. 1. Multi-sphere model of rice seeds: (a) geometry, (b) seed model #1, (c) seed model #2.

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