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ORIGINAL RESEARCH ARTICLE

Application of discrete element method in agricultural engineering

Lintao Chen, Xiangwei Mou*, Zhujing Peng

Teachers College for Vocational and Technical Education, Guangxi Normal University, Guangxi 541004, Guilin Province, China

*** Corresponding authors:** Xiangwei Mou, xwmou@126.com

ABSTRACT

The basic principles of the discrete element method were summarized, and commonly used software and its characteristics were introduced. The application of the discrete element method in tillage, planting, harvesting, and other agricultural machinery R&D was reviewed. Typical examples of the application of the discrete element method in agricultural machinery research and design at home and abroad were discussed and analyzed. Application prospect and trend of discrete element method in the field of agricultural engineering were prospected in order to provide reference for further development of modern agricultural equipment digital design.

Keywords: agricultural engineering; discrete element method; digital design

1. Introduction

The application of a series of numerical simulation software in China's agricultural engineering technology is becoming more and more prominent[1]. The Discrete Element Method (DEM) is a numerical calculation method that has the advantages of saving time and labor, low cost, and high visualization of results[2,3]. The early discrete element method is mainly used to analyze the collision and accumulation characteristics of granular materials and study slope stability[2]. With the continuous development of modern agricultural machinery in China, the optimization design technology and method of key components of agricultural machinery based on the discrete element method has become one of the hot spots in this field. In this paper, the application of the discrete element method (DEM) in agricultural mechanization engineering is reviewed, especially various mechanical equipment and devices in agricultural production activities and agricultural product processing. Then, the application prospect and trend of DEM in agricultural engineering are projected in order to provide reference for the further development of modern agricultural equipment design.

2. Basic principle and software of discrete element method

2.1. Basic principles

The Discrete Element Method (DEM) is a numerical method used to simulate and analyze the dynamic behavior of granular media systems. The research object is divided into independent elements. According to the interaction between elements and Newton's law of motion, iterative methods such as the dynamic relaxation method or the static relaxation method are adopted for cyclic iterative calculation, and the forces

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and displacements of all elements at each time step are determined and the positions of all elements are updated. Each divided unit has its own independent movement, and the overall law can be obtained by studying each individual[2]. Discrete element method (BEM) system as the main idea is to simulate the media has a certain shape and quality of the particle set, and the boundary wall said mechanical working parts, by giving a specific contact between particles and particle and the boundary between mechanical model and parameters, to consider analog medium and working parts of different physical properties and their interactions, and then offer certain initial boundary conditions, by tracking the motion of each single particle, the energy exchange generated by the collision between particles and between particles and boundaries is used to predict the detailed motion process of particle groups, and the corresponding media-component interaction law is revealed[4,5]. Discrete element numerical calculation, mainly by way of tracking loop to calculate the material particles moving status, discrete element is given priority to with grain contact, according to the amount of overlap between particles to calculate contact force, in accordance with this update each particle's speed and position, and then determine the movement of the whole system, its internal relations computation is shown in **Figure 1**.

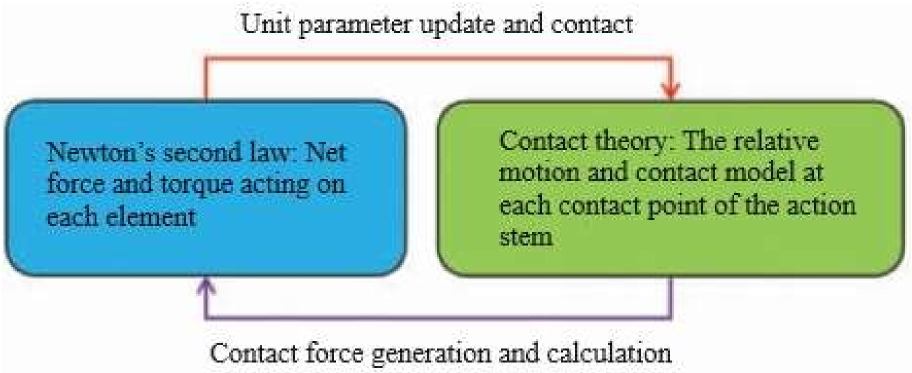


Figure 1. Internal calculation relationship.

2.2. Common software

As shown in **Figure 2**, discrete element numerical simulation software mainly includes PFC and EDEM[2]. PFC (Particle Flow Code) from the simulation provides a reference for the development of compound ground preparation machinery. Yuan et al.[6] used the DEM-MBD coupling algorithm to simulate the operation process of a deep loosening machine. The ITASCA Engineering Consulting Company, founded by Cundall, who proposed the scatter-element method, was first launched in 1994. It supports C++ interface programming. Users can compile the DLL (Dynamic Link Library) dynamic link library, construct a custom particle contact model, and use a custom FISH function. PFC supports a self-input command stream to create models, and its overall architecture design has high universality, which provides the possibility to simulate the system with a relatively complex structure and relatively diverse media components. EDEM was developed by DEM Solutions Ltd. in the UK. In 2006, the company developed and launched comprehensive computer-aided design engineering software. Mechanical geometry can be imported from CAD or CAE in the form of a solid model or grid model into EDEM. EDEM can be combined with the mainstream CAE tool software to simulate the coupling of particle systems with fluid, mechanical structure, and electromagnetic field.

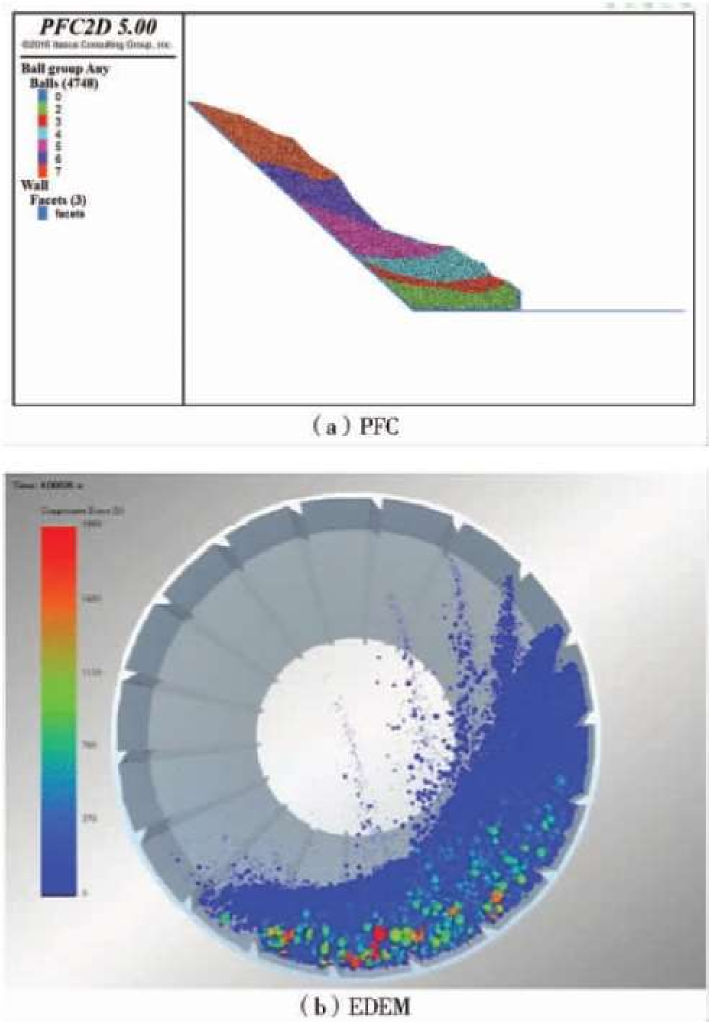


Figure 2. Discrete element software.

3. Application status

3.1. Tillage and land preparation machinery

Zhu et al.[7] of Huazhong Agricultural University built a power consumption prediction model for rotary tillage in rice-plate field based on the discrete element method, so as to facilitate the power consumption detection of rotary embedded knife rolls. Xiong et al.[8] of South China Agricultural University built a simulation model of rotary tilling-soil interaction adapted to the soil environment in South China based on the discrete element method. Qin et al.[9], Nanjing Agricultural University, applied EDEM software to carry out field operation simulation, providing reference for the development of compound land preparation machinery. Yuan et al.[10] used DEM-MBD coupling algorithm to simulate and analyze the operation process of deep loosening machine. Fang et al.[6] of Nanjing Agricultural University carried out a study on the micro-interaction technology of straw, soil and rotary tillers (**Figure 3**).

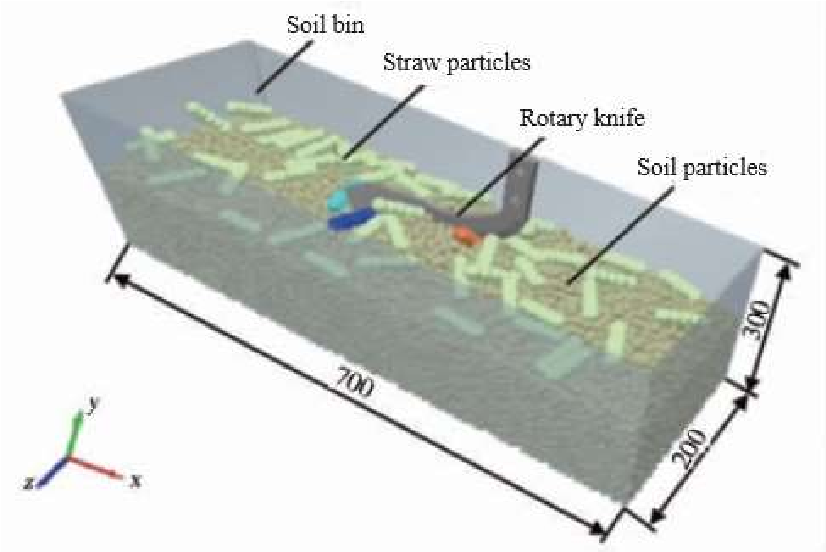


Figure 3. Optimization design of tillage machinery and equipment based on discrete element method.

3.2. Planting machinery

According to the structural principles of different seed arrangers (**Table 1**), simulation analysis and optimization were carried out. Simulation research[11–17] was conducted for different operating objects (**Table 2**). Such as China Agricultural University Wang et al.[18] used EDEM software to examine the device inside the wheat seeds in terms of seed motion, rotation speed of 1000 r/min, seed breakage rate of 1.1%, and sowing depth variation coefficient of 8.9%. Based on the discrete element method, Lu et al.[19] of South China Agricultural University carried out simulation analysis on the precision sowing device of the rice seedling raising line, and the sowing qualified index increased to 92%, and the hole index was controlled below 2%. Li et al.[20] of China Agricultural University designed a mechanical precision seed arrangement device for mung bean and used the discrete element software EDEM simulation optimization method to determine the optimal parameter combination of seed-carrying holes (**Figure 4**).

Table 1. An example of optimal design of sowing agricultural machinery and equipment based on discrete element method.

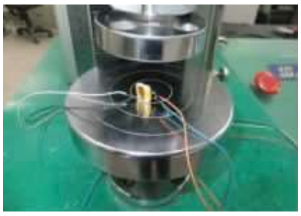
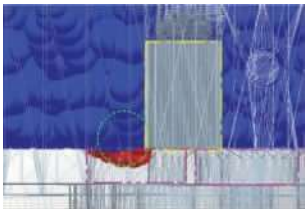
Type	A design or object	Simulation and optimization process	The results of
Disc type			The speed of the seed plate is 17 r/min, the radius of the top fillet of the type of hole is 1 mm, the conformity index is 97. 05%, and the replay index is 1. 83%
Nest eye wheel			The qualified rate of seed filling was 98. 01%

Table 1. (*Continued*).

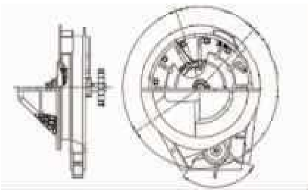
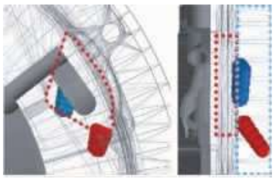
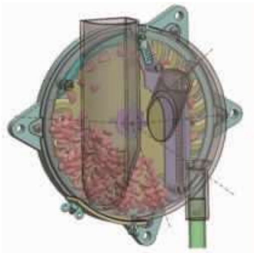
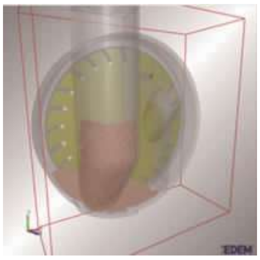
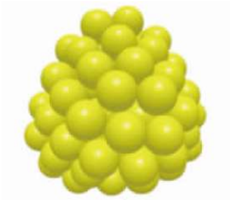
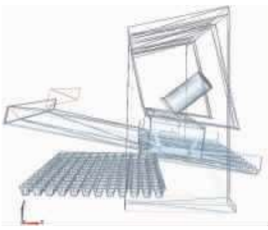
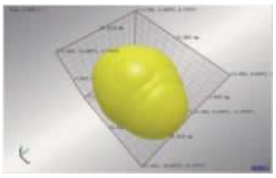
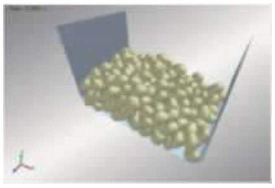
Type	A design or object	Simulation and optimization process	The results of
Refers to the clip-on			When the working speed ranged from 15 to 45 r/min, the seed arrangement performance of medium size grain was the best, and the qualification index was more than 84%
Air pressure type			The increase of population disturbance intensity could not significantly reduce the total amount of seed normal stress, but it would reduce the transient normal stress of seed, namely the instantaneous friction force inside seed

Table 2. The second example of sowing agricultural machinery optimization design based on discrete element method.

Object	Particle model	The simulation process	The results of
Notoginseng			The optimal inclination angle is 50°
Rice			Through the simulation experiment, the influence law of different seed slots on the seed flow rate and the sowing performance of the device was explored
The potato			When the operating speed is 2.4 km/h, the suction negative pressure is 6 kpa, the seed layer height is 70 mm, and the vibration amplitude is 20–21 mm, the qualification index is >95%

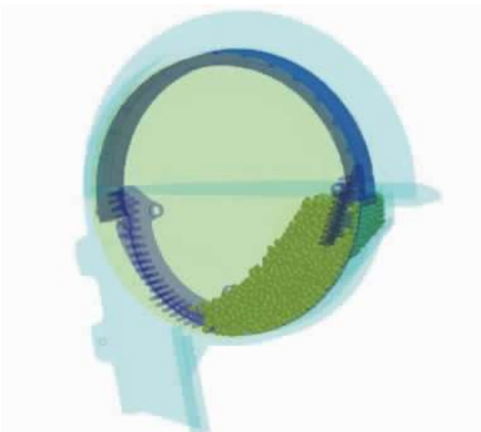


Figure 4. Optimal design of planting machinery and equipment based on discrete element method.

3.3. Harvesting machinery

Wang et al.[21] of Henan Agricultural University used EDEM software to analyze the migration rule, axial velocity, and changes in the local material mass flow rate of wheat in the process of continuous transportation. Wei et al.[22] of Shandong University of Technology optimized the structure of the latter half of the separation screen, which adopts an undulating screen surface to reduce the loss and separation of potato soil. Dai et al.[23] of Gansu Agricultural University improved the design of the 4GX-100 wheat seed harvester in the plot, established the grain model of threshing material by using discrete element software EDEM, and analyzed and studied the variation law of the average speed and displacement of wheat grain in threshing material with the removal time (**Figure 5**).

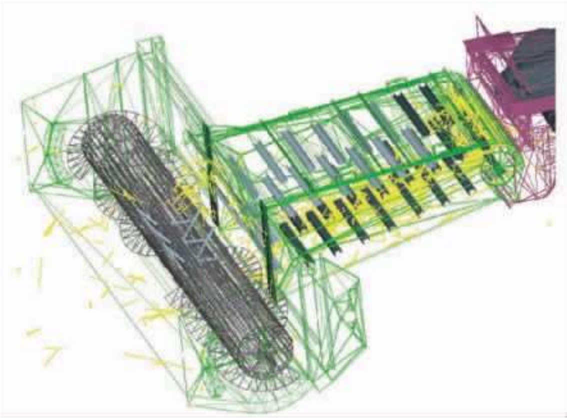


Figure 5. Motion simulation of threshing material in conical threshing device.

Mou et al.[24] of Shandong Institute of Technology designed a disk-type crushing test console for silage corn grain crushing based on DEM method to analyze the motion and mechanics of grain crushing process and optimize the device (**Figure 6**) in view of the poor effect and low crushing rate of corn grains in silage corn harvester.

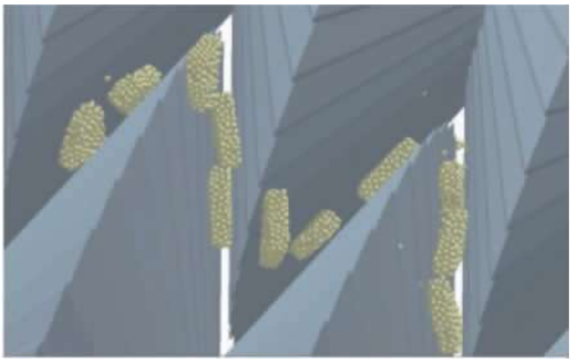


Figure 6. Optimal design of harvesting machinery and equipment based on discrete element method.

3.4. Other agricultural machinery

Liu et al.[25] of Huazhong Agricultural University used EDEM discrete element software to conduct simulation and comparative analysis on the fertilizer discharging process of the fertilizer drainer. Yuan et al.[26] adopted the discrete element method to model the soil and fertilizer mixing operation link of the designed combined operation machine and analyzed the influence of bit speed and mixing time on the uniformity of bacterial fertilizer and soil mixing. Shi et al.[27] of Nanjing Agricultural University used the discrete element method and EDEM software to conduct performance analysis and numerical simulation of the fertilizer discharge process of the fertilizer applicator (**Figure 7**). Zhang et al.[28] of China Agricultural University used the discrete element software EDEM to determine the significant influencing factors of the residence time of materials in the middle cylinder through orthogonal experiment design and establish a matching mathematical model. Liu et al.[29] established a coupling simulation model of fry and mechanical components by using discrete element software.

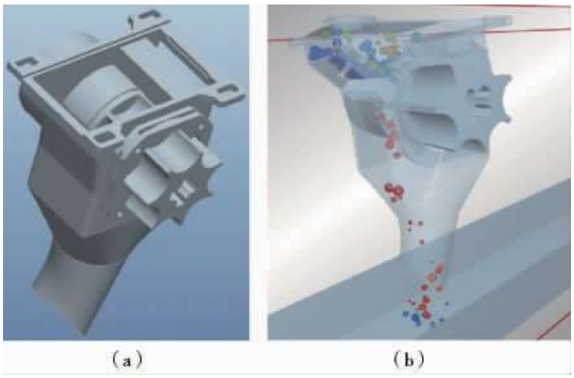


Figure 7. Discrete element simulation model of variable rate fertilizer applicator with external groove wheel.

4. Conclusion

The discrete element method can accurately simulate the schottky contact state of separation between bodies, fast computing speed, acceleration, and displacement between particles, and solving the previous shot of body particles obtained by a physical test is more difficult because of the mutual relationship between mechanical parts. For the research of agricultural material internal movement of rice grain broken disc crushing test the console, important means are provided based on DEM law[30–32]. The basic theory, particle modeling, contact algorithm, and contact detection method of discrete elements need to be further improved, which will also be an important direction of the development of discrete elements in the future.

- The development of special discrete element software and multi-software coupling has become an important direction of the application and development of discrete element methods in agricultural engineering. At present, there is no discrete-element software dedicated to the field of agricultural engineering. The reason is that it is difficult to develop the special discrete element software in the field of agricultural engineering, and the coupling development cycle with other software is long. Therefore, it is an important direction for the development of the discrete element method to expand its application range and solution accuracy by coupling the discrete element method with the finite element method, the boundary element method, and other numerical methods for solving continuous media.
- The development of efficient discrete element computing methods is another important direction for the development of discrete element methods for expanding the scientific research and engineering application fields of discrete elements and saving computing resources. The discrete element method is more and more widely used in dealing with the continuum problem. This kind of method divides the continuum into several particles and obtains the macroscopic response characteristics through the movement of the particles. Discrete elements are gradually used to describe the mechanical properties of continuum materials. This is because when dealing with the dynamic fracture of a continuum and a large number of crack propagation problems, grid calculation methods such as finite element will encounter many challenges. Meshing is a complicated work, and the whole process cannot be simulated as easily as the discrete element method. The discrete element is mainly based on particle contact, and the contact force is calculated according to the overlap between particles, and then the motion law of the entire system is determined. The discrete element method has some difficult problems, such as a large amount of

computation and low computational efficiency, so the development of an efficient discrete element computation method is one of its important development directions.

Conflict of interest

The authors declare no conflict of interest.

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