SIMULATION OF AGRICULTURAL PROCESSES USING THE DISCRETE ELEMENT METHOD

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Abstract: The simulation of agricultural and forestry processes provides a huge potential in terms of process understanding. At the Institute of Mobile Machines and Commercial Vehicles of Technische Universität Braunschweig agricultural materials like grass, straw and wood are simulated by using the Discrete Element Method (DEM). The DEM offers the possibility to define different structural models which consist of discrete elements connected by flexible bonds. By parameterising the flexible bonds of the stalks different physical properties can be considered. In order to model the natural behaviour of stalks the physical properties have to be measured in advance. Therefore different test rigs are used. Additionally at the Institute different cutting, conveying and compacting processes of agricultural machinery are regarded. An overview of the key results, the potential of the DEM and future research activities is given.

Keywords: DISCRETE ELEMENT METHOD (DEM), PROCESS SIMULATION, PROCESS ANALYSIS

1. Introduction

Normally newly designed or modified agricultural machinery can only be tested during a short period of time as a dependency on the growing season is given. In order to widen this period of time manufactures evade to other continents, leading to a cost-intensive test schedule. Especially during an early stage of the development process, new ideas can be investigated by simulations with acceptable effort. Furthermore processes can be investigated by eliminating external determining factors. One suitable solution to model agricultural processes in simulations is the Discrete Element Method (DEM). The DEM is a numerical, time based and mesh free method to describe particle movements and their interactions. The method was developed during the 1970th and it was used to investigate the flow of soil particles under dynamic loads [1, 2].

At the Institute of Mobile Machines and Commercial Vehicles the focus is set on cutting, conveying and compacting processes of stalk materials. The DEM offers the possibility to realize different structures as single particles can be joined by flexible bonds. The physical properties are defined by adaptable parameters. Furthermore digging processes and the soil-tool-interaction of a cultivator tine have been investigated, which are exclude here. Additionally the chipping of wood by helical chippers has been modeled.

In order to set up significant simulation models, material models have to be implemented. In this context the complexity of the simulation models has to be limited in order to limit the computing time.

At first this article explains of the functionality of the DEM. Based on this theoretical background an overview of research results is given. In detail different stalk structures will be explained. Necessary parameter tests are focused, before simulations of real agricultural and forestry processes are highlighted. Focusing on these processes the opportunities and limitations of the Discrete Element Method will be presented.

2. Functionality of the DEM

In the DEM two element types can be distinguished: particles and wall elements representing the geometry. After the simulation has been initialized, the calculation cycle starts. Each particle is affected by forces and torques which are calculated by solving Newton’s laws of motion. In order to calculate these reaction forces contact models are used. The interaction of particles and the interaction between particles and wall elements are described by contact models. A contact is detected if the two radii of the particles overlap. Mechanical analogous models are used in order to describe the contact behavior of the particles. One possible contact model is shown in Fig. 1. The requirement of two overlapping contact radii is given. The contact model gives a mathematical description of forces in normal and tangential direction.

In the mechanical analogous model a combination of spring, damper and friction elements is considered.

A special case of the contact model is the bond model (see Fig. 2). For the creation of a bond an additional contact radius is defined. If the contact radii of two particles overlap during a defined time step, a bond is created. A physical contact of the two particles is not given, so a defined distance between the particles can be implemented.

Fig. 1 Contact model in a DEM simulation [3].
Fig. 2 Bond model in a DEM simulation according to [4].

The properties of the bond are characterized by the stiffness and the strength in tangential and normal direction. In general the bonds are flexible and dividable. With the utilized simulation tool EDEM, by DEM Solutions Ltd., user-defined bond models can be implemented with the application programming interface. By default a cylindrical bond between the particles is considered (see Fig. 2).
3. Simulated processes using the DEM

At the Institute three major structures representing different types of stalks have been defined. The easiest approach to model a stalk is realized by a particle chain. Furthermore a hollow structure and a full structure have been researched (see Fig. 3). The hollow structure represents grain or maize stalks with their hollow core. Other biological goods like wood can be modeled by using the full structure.

![Particle chain, Hollow structure, Full structure](image)

**Fig. 3 Different types of stalk structures.**

In the following sub-chapters significant simulations are presented.

3.1 Wood chipping with a helical chipper

Wood chipping with a helical chipper is less in common for example compared to the usage of drum chippers. A scientific investigation of helical chippers is worthwhile as they have several advantages. The achievable size variation of the wood chips is quite low, that means that the wood chips are of high quality. Due to the continuous self-closing a powered feeder is not needed, leading to a low specific power requirement.

The researched helical chipper is shown in Fig. 4. Wood is an anisotropy material. As a simplification isotropy material behavior has been considered in the simulation, leading to a first approximation.

![Helical wood chipper](image)

**Fig. 4 Helical wood chipper [5].**

In order to replicate a 12 mm poplar rod a full structure consisting of four particle layers was implemented. The diameter of each particle was 1.6 mm, leading to a closest particle distance of 1.8 mm. The rotational speed of the rotor was constantly 1055 min⁻¹ [5].

Next to the torque the feeding speed of the rotor was evaluated and compared with results from test rigs. The feeding speed of the rotor is shown in Fig. 5. The feeding speed slowly increases until the rod was caught by the cutting rotor and reaches an average level of about 1.5 m/s. Fig. 5 shows the curve of the feeding speed. The measured, average feeding speed was about 1.38 m/s. The simulations show an average feeding speed of 1.49 m/s. High-speed camera recordings confirm these results [5].

![Feeding speed curve](image)

**Fig. 5 Simulation result - curve of the feeding speed [5].**

In addition the feeding angle of the helical chipper was varied in order to compare experimental and simulativ results. The self-closing of the poplar rod can be proven too. Due to the smaller angle between the blade and the rod the length of chips changed. If feeding speeds are regarded (see Fig. 6), simulations show a decrease of the feeding speeds reaching a minimum at an angle of 30°. Qualitatively the same effects can be monitored in experimental studies [5].

![Feeding angle comparison](image)

**Fig. 6 Comparison of the feeding speeds depending on the feeding angle.**

Referring to wood chipping with a helical chipper, the results of the simulations qualitatively confirm the results from test rig testing. In future research activities the DEM model will be adapted in order to model more details of the wood chipping process. Experiments show that the wood chips normally fan out between the different blades. This characteristic was not considered in the first step with the assumption of an isotropy material behavior [5].

3.2 Cascade straw walker

The cutting of threshed straw and its equal distribution is of high importance. In general, for stochastically aligned stalks the more power is required the shorter the straw is chopped, as more cuts are needed. Therefore the systematic alignment of straw to optimize the cutting process in a combine’s straw chopper was investigated. In order to evaluate the cutting quality a cascade straw walker was used. The cascade straw walker consists of an oscillating screen with different screen diameters, dividing the straw samples into different categories according to the realized cutting
length. Fig. 7 shows the cascade straw walker with a representative sample of chopped straw [see 6].

Fig. 7 Cascade straw walker.
As shown above the used straw walker consists of six screens of different diameters, leading to the size distribution shown in Fig. 8. More than 80% of the straw stalks have a length between four and sixteen millimeters.

Fig. 8 Cutting length distribution according to the alignment angle [6].
In order to validate the simulation model and to evaluate the cutting quality the cascade straw walker can be implemented into the simulation environment which is shown in Fig. 9.

Fig. 9 Cascade straw walker simulation.
In the simulation a straw sample of 1.5 kg with a density of 37.13 kg/m³ was used. In further research activity the equal distribution of the chopped straw will be regarded. Especially the high energetic distribution process is analyzed.

4. Results and discussion
For reliable simulation results the parametrization of the simulation model is determining. At the Institute of mobile Machines and Commercial Vehicles different approaches to model stalks have been researched. In order to point out and discuss the influence of the stalk structure types on the mechanical properties, the results of a tension test are compared with results from simulation. A “simple” and a “complex” structure are regarded in detail. The simple structure consists of a particle chain, surrounded by one particle layer [see Fig. 10]. A particle chain surrounded by three particle layers is chosen for the complex structure [see Fig. 11]. The results of simulativ tension tests are shown below.

Areas colored in red represent areas of high tension whereas areas colored in blue/green represent areas of low tension.

Fig. 10 Tension test of the simple structure [7].
Fig. 10 shows that the normal tension is constant across the cross section of the stalk. The tension increases linearly. When the maximum tension is reached all bonds fail simultaneously. The complex structure shows different characteristics. Fig. 11 shows the breakage of the bonds. The bonds fail successively so an absolute and a local maximum of normal tension occur.

Fig. 11 Tension test of the complex structure [7].
The number of bonds considered within the complex structure is much higher than those considered within in simple structure, leading to different physical characteristics. In the future the focus is set on the systematically build-up of different stalk structures according to the agricultural process and on the parametrization. One of the main points is the determination of the required complexity with regard to parametrization and computing time.

5. Conclusion
The Discrete Element Method is a suitable tool, in order to visualize agricultural processes. Details can be researched in an early stage of the developing process. Determining for significant results is the validation of the simulation model. Different parameter tests (e.g. tension tests etc.) will be done in order to validate the simulation results.

The bottle neck of the DEM is the needed computing time. For example the computing time of a parameter test (e.g. tension test) can rise up to more than 200 hours, depending on the complexity and the details considered in the simulation. As modifications of the machinery design should be analyzed, numerous stalks have to be considered. Therefore the number of particles needs to be minimized. Actually different approaches are researched at the Institute of mobile Machines and Commercial Vehicles in order to model the mechanical behavior of a full and a hollow structure by using just single particle chains.
6. References


