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Simulation of stalks in agricultural processes – Applications of the Discrete Element Method

The Discrete Element Method (DEM) is a suitable method for simulating agricultural processes. At the Institute of Mobile Machines and Commercial Vehicles agricultural materials like grass or straw stalks are simulated by different structural models. The stalks consist of discrete elements which are connected with flexible configurable bonds. To analyze the conveying process on a straw walker and the cutting process in a disc mower different structural stalk models are used.

Keywords
Discrete Element Method (DEM), process simulation, straw stalks, structural models

Abstract
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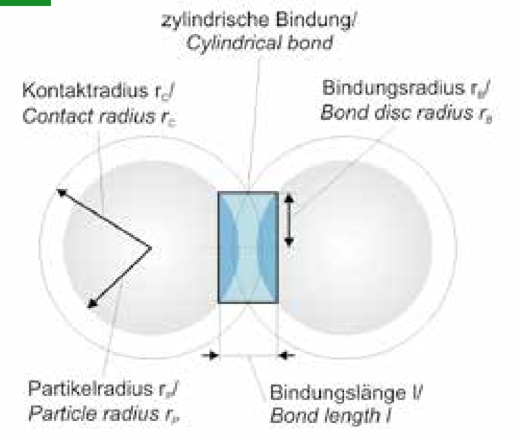
The simulation of agricultural processes provides a huge potential in terms of process understanding and the development of agricultural machines. Newly designed or modified processes can be investigated in an early stage of the development process by using simulations, without cost-intensive and complex test rigs. This approach enables the investigation of new or unconventional ideas with acceptable effort. 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. It was developed in the early 1970th and used to investigate the behaviour of soil particles under dynamic loads [1, 2]. Single particles can be joined by flexible bonds with adaptable parameters to build up different structures consisting of several particle clusters. These particle models interact with each other and with wall elements, whereby the DEM simulation offers a huge potential of modelling agricultural processes in detail. Modelling of stalk structures in the DEM simulation is very important. The focus of the activities in the field of process simulation at the Institute of Mobile Machines and Commercial Vehicles is on cutting, conveying and compacting of stalks. By mapping stalks in the DEM simulation special challenges have to be taken into account. The main task consists in the build-up of material structures, in the determination of the model complexity and in the standardized parameterisation of such models.

Functionality of the DEM bond model

The DEM is based on the use of Newton´s laws of motion. Translatory and rotatory movements of every single particle in the simulation can be computed. In addition to Newton´s laws forces on particles and structure elements are described by contact models and bond models. Contact models for calculating forces in normal and tangential direction are mechanical analogous models based on spring, damper and friction elements. The contact models can be supplemented with bond models which are activated if a bond condition between two particles is defined. An overlapping of the contact radii r_C (**Figure 1**) is required.

With the utilised simulation tool EDEM®, by DEM Solutions Ltd., user-defined bond models can be implemented with the application programming interface [4]. For the calculation of bond forces a cylindrical bond between the particles is considered (**Figure 1**). This cylindrical bond is defined by the bond

Fig. 1



Cylindrical bond according to [4]

radius r_B and the length of the bond l. The material properties of the bond are parameterised by strength and stiffness in normal and tangential direction.

For the calculation of bond forces and torques in normal and tangential direction a linear relationship is assumed, taking into account the Young´s modulus (E) and the shear modulus. The input parameters are the particular particle velocities v at the beginning of each time step. With these velocities the relative velocity between two flexible bonded particles can be determined and with the time step Δt the virtual movement δ of the bonded particles within a time step can be calculated. The following equations show exemplary the calculation of the resultant normal bond force ΔF_{normal} for a cylindrical bond with its cross section area.

$$\delta_{normal} = \left(v_{normal,\,Partikel\,1} - v_{normal,\,Partikel\,2}\right) \cdot \Delta t \quad \text{(Eq. 1)}$$

$$\Delta F_{normal} = \delta_{normal} \cdot \frac{EA}{l} \quad \text{(Eq. 2)}$$

with $A = \pi r_B^2$

Modelling of stalks

The described bond model is used for the simulation of stalks in the DEM. According to the application and the level of detail different structural stalk models are considered (**Figure 2**). In their simplest form the stalks consist of aligned single particles (sphere chain). Each sphere is connected with the next by parameterised bonds. For example this structure can be used for conveying processes or for simplified cutting processes. It is not possible to consider the buckling of stalks with this structure model, because flexible bonds cannot be disconnected and connected. Therefore an advanced sphere chain is recommended, consisting of several joins with a defined direction of the kink. With this model also compaction processes could be simulated. The hollow structure is composed of several sphere chains, arranged around a circle. With this model cutting processes can be simulated more realistic because the structure is similar to grain or grass. The complex structure requires increasing computing times as for each particle the motion and force equations for a contact or bond have to be solved. An advanced form of the hollow structure is the solid body. An additional sphere chain is arranged in the centre of the structure to model the pith of the plants.

Parameterisation and validation

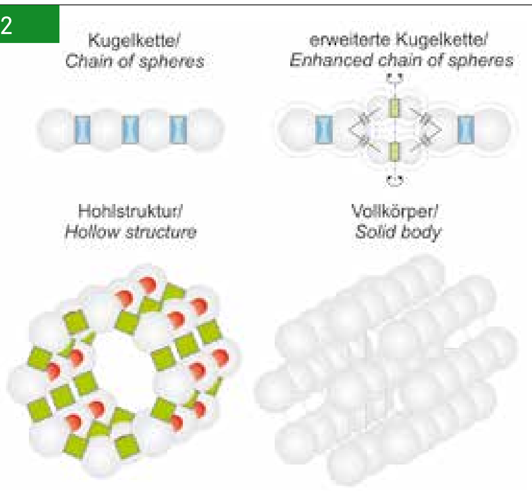
For the parameterisation of the stalk models material and geometry properties of the particles and strength properties of the bonds are to define. Material properties are material density, shear modulus, Poisson ratio and the coefficients of restitution and friction. Different particle types and clusters with different materials can be implemented within one simulation. The bond properties are defined by the stiffness and strength in normal and tangential direction. As an additional factor the bond radius of the cylindrical bond has to be specified. Since this parameter only exists in the model, a method is required to determine the parameter and to transfer the parameter to the bonds of the different stalk structures.

To determine the real plant parameters tensile and bending tests are suitable. Single stalks are fixated and loaded in test rigs. For setting up the parameters the tests have to be modelled in the DEM. The focus of the parameterisation depends on the level of detail and process type (conveying, cutting and compacting). For the conveying process the outer behaviour of the stalks like friction, bending and damping is important. For the investigation of a cutting process the focus is on the material properties like stiffness and strength to get realistic cutting forces.

Application examples

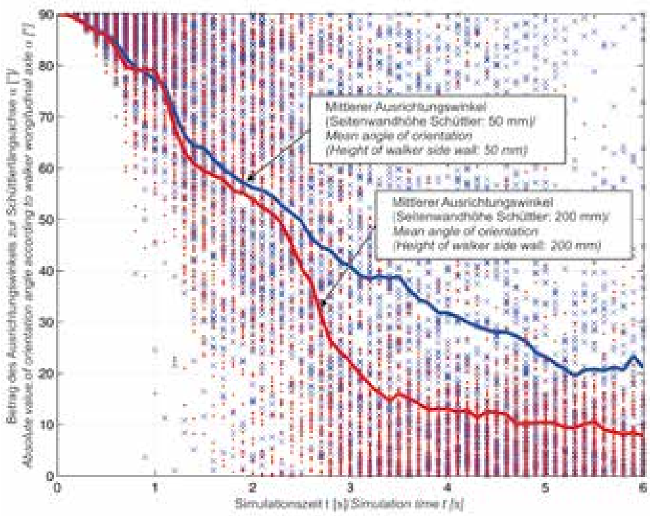
The area of application of the Discrete Element Method to investigate stalk processes is manifold. In a research project the

Fig. 2



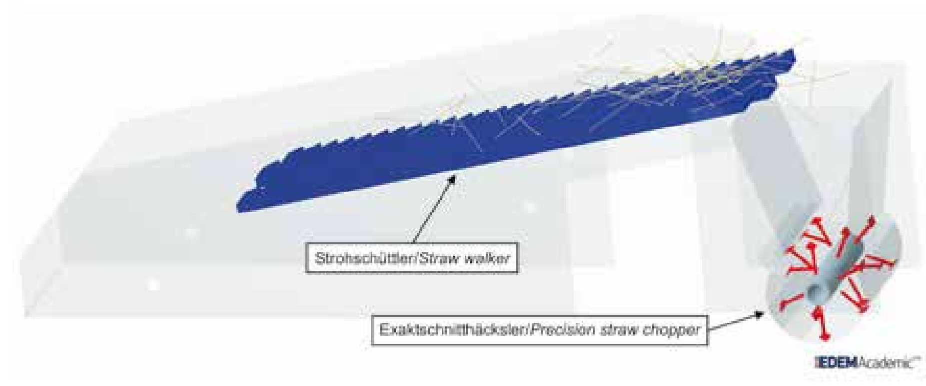
Structural stalk models

Fig. 3



Influence of straw walker design on stalk orientation

Fig. 4



DEM model of a straw walker with precision straw chopper

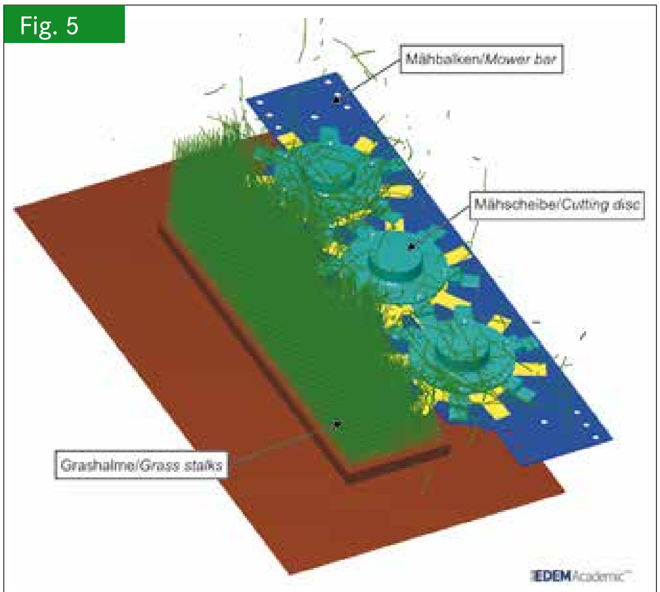
alignment of straw on a combines straw walker is investigated with the DEM. Stalks are built up of several clustered sphere chains. Each five spheres are rigid coupled without flexibility. The sphere clusters are connected cluster by cluster with flexible bonds.

The simulation model contains three straw walkers with a realistic movement profile. At the beginning of the simulation 100 straw stalks are applied on the straw walker in cross direction. Caused by the conveying effect of the straw walkers the stalks are conveyed in longitudinal direction of the walkers. The adjustment of the stalks varies in the process. The results of two simulations in which the side panel height of the walkers is varied are exemplarily shown in **Figure 3**. An adjustment angle of 0° is in accordance with the longitudinal direction of the walkers. The blue line in the chart of **Figure 3** shows the stalk adjustment for a side panel height of the walkers of 50 mm and the red line corresponds to a side panel height of 200 mm. It is visible that the use of a higher side panel leads to a decrease of the adjustment angel. That means an increased adjustment in longitudinal direction can be reached. This longitudinal stalk adjustment is advantageous for the process quality using a precision straw chopper as specified in [5].

Currently the influence of the stalk adjustment on cutting length distribution will be examined within the simulation. For this purpose a precision straw chopper model according to [5] will be added to the DEM straw walker model (**Figure 4**). Rigid and unbreakable bonded particle cluster lead to falsified simulation results of the particle size distribution because these clustered particles cannot be divided in the cutting process. So the stalk model structure has to be modified to stalks consisting of single spheres which are connected with breakable bonds. Due to adjusted stalks in combination with the precise straw chopper an optimised cutting length distribution is expected. The effect of the stalk adjustment on the cutting length distribution could be investigated in real experiments [5; 6].

Another application area of the DEM at the IMN is the investigation of rotary mowers. The aim is to analyse different mower configurations in simulations to determine the required power for the process. Therefore a ‘grass field’ is modelled, consisting of several grass stalks with single spheres. For the cutting process the geometries of the mower discs and the mower bar are implemented in the model. Different motions and velocities of these components can be simulated. **Figure 5** shows the simplified model of a rotary mower.

Fig. 5



DEM simulation of a disc mower

During cutting one or more bonds between particles are separated, because the maximum bond properties are exceeded. This indicates that the bond parameterisation is very significant. In this simulation a simplified stalk model was used and the influence of wind turbulences is neglected to decrease the computing time.

Conclusions

This article describes possibilities to model stalks in agricultural processes with the DEM simulation. Various stalk structures for different plants and processes are shown. These structures have significant influence on accuracy of the simulation results and on computing time. Beyond that two application examples are presented, in which agricultural processes are optimised and developed with the DEM. The previous investigations show that relative comparisons in design changes for example on the tools can be analysed with the DEM simulation at the current state. If detailed examinations with absolute values are needed complex stalk models with substantial parameterisation effort is required. In the future the focus of the work at the IMN is on the systematically build-up of different stalk structures according to the agricultural process and on the parameterisation. One of the main points is the determination of the required complexity with regard to parameterisation and computing time.

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