Modelling of maize plant by the discrete element method

The experiments of this thesis were carried out to explore the physical characteristic and mechanical behaviour of harvest-ready maize by using methods relating harvesting with a combine harvester. The conclusions drawn from the experimental work was used to form and calibrate a DEM model about the plant and advance the capability of DEM to reproduce the mechanical and breakage behaviour of fibrous agricultural materials. Finally, a simulation on maize harvesting was carried out to present a possible way for utilization of the model.

Experimental Work

A measurement method to determine the physical, morphological and mechanical properties of maize was established. The relationship among the physical and morphological properties and traits of maize were analysed based on in-situ and laboratorial measurements and observations. The typical mechanical behaviour, damage and breaking phenomena of maize parts were determined through sectional and local transversal compression, three-point bending, dynamic cutting, ear-detachment and ear-drop experiments.

The results of the experiments and observations prove that the natural structure of the plant is developed for growing an ear because the significance of the physical, morphological and mechanical properties and traits of maize parts below the maize ear is higher than the significance of its upper parts from the point of view of harvesting with a combine harvester. The presented results could be exploited advantageously to develop maize heads for combine harvesters.

DEM Simulations

Based on the measured and the observed characteristics, the DEM model of the 4th internodal section was formed to simulate the transversely isotropic mechanical behaviour and breaking phenomena of the real material under scrutiny. An extensive parametric study was carried out to analyse the influence of the bonded input properties, moreover, based on a series of calibration experiments an optimization loop was established to obtain the most accurate mechanical behaviour of the model in each loading case simultaneously.

The DEM results agree well with the experimental results from the compression and the bending tests, moreover, the required work for each experiment obtained from the DEM model was also close to the experimental results. The DEM simulated cutting process presents the typical stages of the real cutting process, while, the breaking phenomenon of the virtual samples was similar to the observed phenomenon of the experiments in case of the compression and bending tests. Therefore, the results clearly show that the accuracy of the presented DEM model with the determined bonded parameter set is satisfactory to analyse the interactions among the maize stalk and the maize header during harvesting.

Recommendations for Future Work

Based on the results and the collected knowledge during the research, the following recommendations could be drawn for future work.

Experimental Work

The described measurement method was only tested on one maize variety from one experimental plot in the growing season of 2016. Thanks to the high diversity of maize varieties, it is not declared that the same physical or mechanical characteristics of maize can be obtained during the same experiments. Thus, the applied method should be extended to more samples, more maize species and different cultivating conditions to form a database on the physical, morphological and mechanical properties of maize when harvesting.

Several other physical (e.g. dynamic coefficient of friction), mechanical (e.g. soil-root relationship) and environmental (e.g. detailed fertilizing condition) properties can have an in- fluence on maize harvesting, but our study only focuses on a few crucial properties. Thus, it is suggested to consider more properties that have a possible influence on the mechanical behaviour of the plant during harvesting.

The special apparatuses (plunger for local transversal compression, blade of dynamic cut- ting, apparatus for ear detachment force experiments, surfaces for drop test) were selected or designed based on the general parts of a combine harvester maize head. Thus, the applied apparatuses should be standardize.

The majority of the applied methods was quasi-static, however, the interaction among maize and machine parts takes place in milliseconds due to the operational parameters of a maize header. Thus, it is recommended to involve further experiments (e.g. field tests) to explore the mechanical behaviour of maize during rapid processes.

The mechanical behaviour of maize as related to the harvesting of shelled maize kernels were measured, observed and analysed. Accordingly, it is not justified that the measurement method is adaptable for other agricultural process without consideration of major modifications.

DEM Simulations

The poly-disperse core of the first five internodes provides the majority of the computational costs. Thus, it is suggested to consider and analyse other geometrical structures to replace it.

The bonded structure between the poly-disperse core and the well-structured skin was proved to be the weakness of the bonded structure. Thus, it is recommended to consider a new bonded structure or method that ensures a better bond distribution here.

The results of the three-point bending, cantilever bending and local transversal compression simulations highlight the need for the development of the Timoshenko Beam Bonded Model (TBBM) to enable elastic-plastic (hardening) deformation of the virtual beam.

During the parametric study only a set of parameters were analysed in details. Thus, it is suggested to involve more numerical parameters, especially regarding the dynamical behaviour of the DEM model, into the parametric study.

The results of the harvesting simulation could not be compared with experimental results. Again, it is highly recommended to involve further experiments (e.g. field tests) to improve the accuracy of the DEM model.

To keep the number of the variables under control, several assumptions and considerations were used during the model formation, parametric study and calibration through the optimization process. Thus, the presented results can be justified by using the same assumptions and considerations.