Simulation of Granular Product Flows in SIMPACK using the PCM Contact Method

Multi-body simulation (MBS) is suitable for a precise kinematic and dynamic behavior analysis of mechanical systems. If externally applied forces have a significant impact on overall system behavior, consideration of the mechanical system alone is not sufficient. The goal of MBS is to create a system model of a machine, taking into account all relevant forces.

The agricultural machinery company Grimme develops and manufactures machinery for potato and sugar beet cultivation. For this study, the behavior and loads acting on the granular flow of potatoes inside the machine are of interest. A common approach for this scenario would be to perform a co-simulation with a commercial "Discrete Element Method" (DEM) software and SIMPACK. In order to avoid additional software licensing costs and interface development, the possibility to simulate the entire model exclusively in SIMPACK is examined within the scope of this study. The "Polygonal Contact Model" (PCM) is used for the definition of the contact characteristics between all bodies.

INTRODUCTION

This feasibility study was conceived using a potato planter as an example. To create this model, it was necessary to replicate a rubber-elastic belt strap interacting with a potato product flow. The belt strap is additionally agitated by an electrically driven vibrating unit. The belt vibration causes the seed potatoes to be separated into individual scoop cups.

The modeling of machine parts can be easily realized using a powerful MBS (multi-body system) software such as SIMPACK. A more interesting question is whether or not the contact force elements, which are implemented into SIMPACK, are capable of adequately representing the contact between numerous particle-like bodies, some of which have a complex geometry. Another challenge is to keep the computing time within an acceptable range despite the high number of degrees of freedom, by using appropriate parameter selections and favorable solver settings.

GENERAL MODEL SET-UP

The modeling of a highly elastic belt strap poses one of the more difficult challenges. This is achieved through a discretization of the belt strap into single rigid body segments [Fig. 2]. A larger number of segments better replicates the characteristics of the belt strap and reduces the vibrational excitation of the deflection pulleys caused by polygon effects. A suitable compromise must be found between the number of segments and computation time. The individual segments are coupled by bushing force elements (FE). For the subsequent definition of the contact forces between the belt strap segments and the deflection pulleys, as well as between the belt strap segments and the seed potatoes, it is necessary to model these segments using cuboid and cylinder primitives.

All machinery parts that are in contact with the product flow must also be incorporated into the model. In this example, these are the pick up chamber and down pipe along the downward strand. The assembly part geometry is extracted from the CAD-file and converted to an obj-file. By doing so, the contact forces between the machine parts and the particle bodies can be accurately modeled using PCM.

CONTACT DEFINITION

Two different contact types are used in this model. One of them is the curve/curve contact which is used for defining the contact between the belt strap segments and the deflection pulleys. This contact type has a significantly shorter processing time than other geometry contacts. Since the curve/

curve contact can only be implemented between contact partners with curved surfaces, each belt strap segment must be extended with the afore-mentioned small cylindrical surface part.

Additionally, contact between the particles themselves and between each particle and the components of the machine must be defined. This is achieved using SIMPACK's PCM. Any form can be used for defining the contact surface. The only constraint is that the contact surfaces must be composed of a triangular mesh in obj-file format. The PCM contact allows multiple contacts between the contact surfaces, which is a prerequisite for the calculation of particle contacts. An additional advantage of this contact model is the highly efficient collision detection, since surfaces which are not touching only have a minimal effect upon computation time.

The total number of contact elements in the model of the planter depends on the number of particles and the discretization degree of the belt strap. The model design of a planter with 108 belt strap segments and 24 potatoes requires a total of 4309 force elements.

GENERATING MODEL DATA WITH MATLAB®

Due to the high number of required force elements, this model generation would be very time consuming if the standard GUI were to be used. A MATLAB® script has therefore been developed in order to automatically generate the model files for SIMPACK. All model parameters such as belt speed and number of potatoes are predetermined in

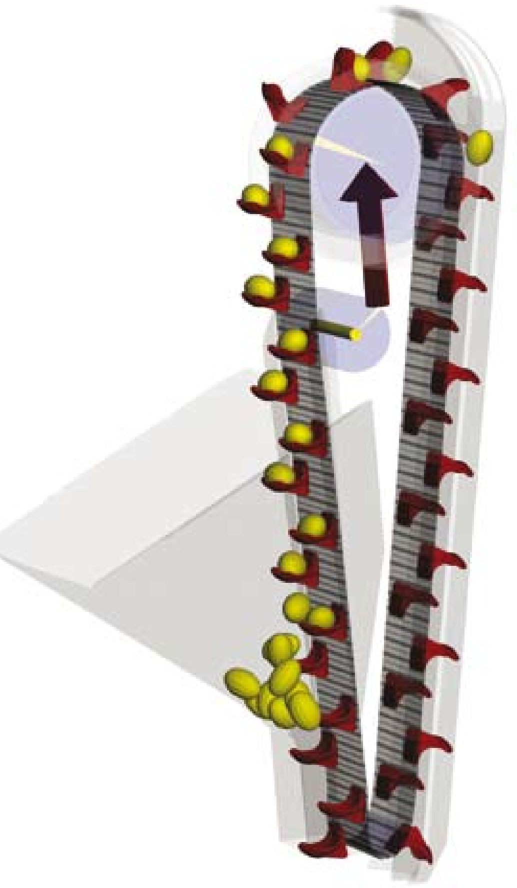

Fig. 1: Multi-body simulation model of a potato planting element

MATLAB. Subsequently the script execution generates the necessary data files for the simulation which can then be started directly afterwards. Fundamental changes to the model always require modification of the MATLAB script. Different sections of the script can often be adopted during the creation of new simulation models, which significantly decreases the time required for the modeling.

SIMULATION SCENARIO

The SODASRT 2 integrator is used for all simulation processes. It has proven useful to limit the maximum integrator stepsize to 10^{-4} seconds. This enables a reliable detection of all contact events and avoids major alterations of the integrator stepsize.
The first simulation runs were used to adjust the contact parameters in the model. The actual contact properties between potatoes and various component materials have been identified through various practical drop impact experiments. These experiments determine the course of the impact force and the restitution coefficient which are dependent on the mass of the potato, the drop height and the contact material.

The primary objective of future simulation studies is to optimize the computing time for the highest possible number of particles. In the second step, the product flow should be optimized and the stress on the seed crops reduced by analyzing variations of the machine parameters and part geometries.

RESULTS

The comparison of the simulated and measured impact force or shock acceleration curves during a simple drop test show a good correlation. Fig. 3 shows the curves of the subsequent impact when a 100 gram potato is dropped onto a steel surface from a height of 50 cm.

"...results showed a high degree of correlation with measured values from tests."

The impact force acting on the tuber is of great importance to Grimme with regard to subsequent model analysis in the context of product development. A key goal of all new developments is to achieve the maximum degree of protection for the product.

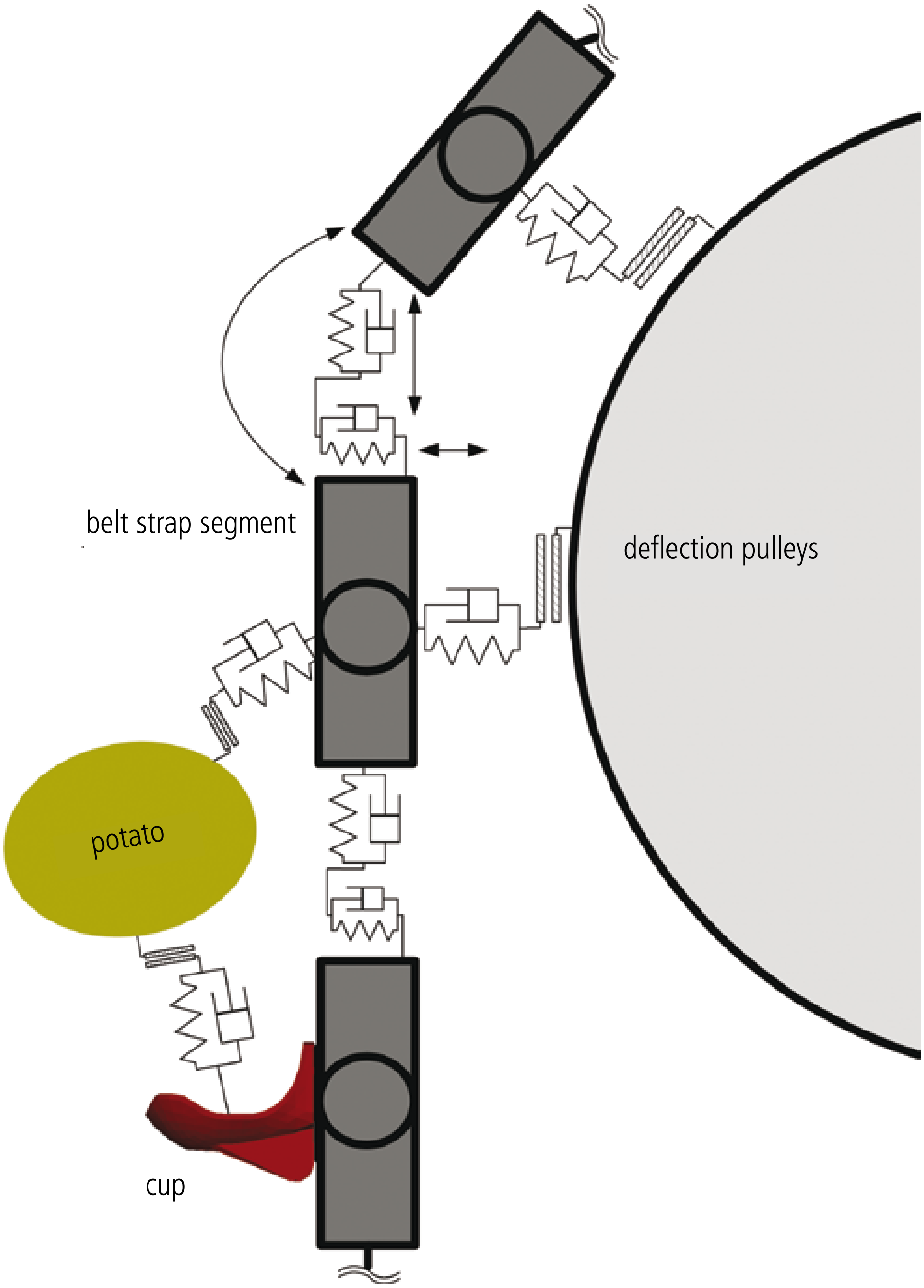

Fig. 2: Schematical diagram of the belt strap

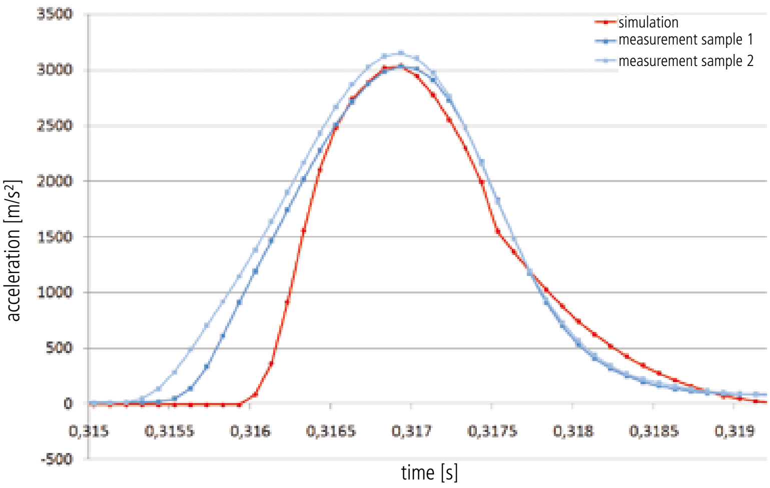

Fig. 3: Comparison of measurements (blue) and simulation (red) of impact acceleration

A further evaluation criterion for the quality of the simulation model is the direct visual comparison of product flow movement behavior. In the experimental and simulation runs, golf balls were used in addition to the potatoes because of their better comparability and homogeneous particle properties. High-speed imagery acquired through bench tests with a planting element served as a reference. Figure 4 shows a snapshot from the high-speed imaging on the bench and on the left a comparable state from the simulation. Because of this and other video comparisons, it is possible to determine a very realistic movement behavior of the particles in the simulation model. It was noted that even the slightest changes in contact parameters have a dramatic effect on product flow.

FUTURE WORK

For future product development, it is necessary to essentially optimize two points.

First of all, a simple and fast contact model is required which enables the implementation of much higher particle counts with accordingly shorter processing times.

Additionally, the ability to design the models easier and faster must be made available. This problem could be solved with a tool that allows the modeling of material-transporting belt straps with a GUI. The implementation of the particles should occur accordingly without the need to manually define the contact elements between each individual particle and every single part of the machine. In so doing, it would be possible to achieve a faster model creation with the SIMPACK GUI. Determination of the mathematical contact parameters is also a very complex task for PCM. A direct input capability of the physical parameter values, such as the restitution coefficient, would significantly ease the model design process.

Fig. 4: Visual comparison, virtual and real

CONCLUSION

The fundamental suitability of SIMPACK for modeling and simulation of particle models was demonstrated using the planter as an example. There are, however, limitations regarding the model structure, number of particles and the computation time.

The attained results showed a high degree of correlation with measured values from tests. Both the temporal course of the impact forces acting on the particles as well as the movement behavior of the entire product flow was taken into account. For some simulation models, especially those with fewer particles, a co-simulation can be omitted and the entire model can be calculated in SIMPACK.