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Simulation of agricultural cutting and transport processes

Application of modern simulation procedures in agricultural machinery is generally limited to technologies that are known and used in the automotive industry. Looking at the harvesting process itself these simulation procedures may also contribute to a large extent to designing and dimensioning of harvesting machinery with respect to sustainability and conservation of nature and natural resources. The following paper presents an approach to simulating cutting processes in harvesting technology using Multi Body Simulation (MBS). Beyond that a chaff cutter serves to demonstrate the application of Computational Fluid Dynamics (CFD).

Keywords

Computational Fluid Dynamics (CFD), Multi Body Simulation (MBS), combine harvester straw chopper, cutting process

Abstract

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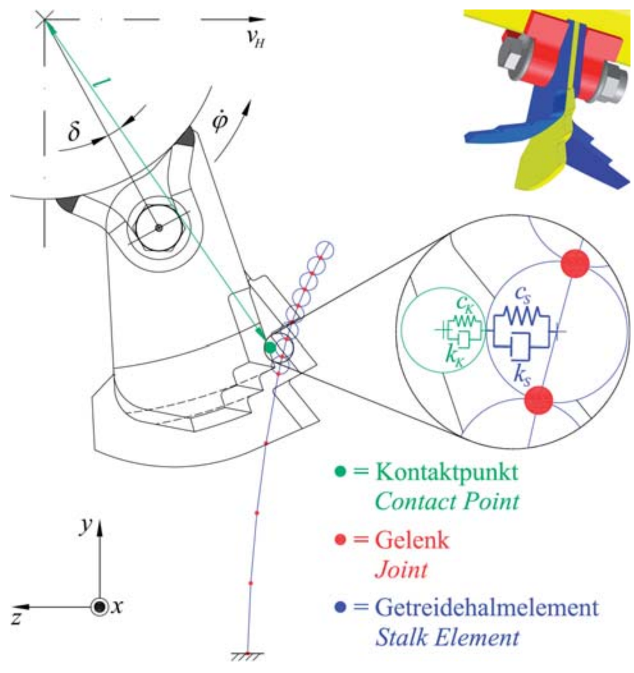
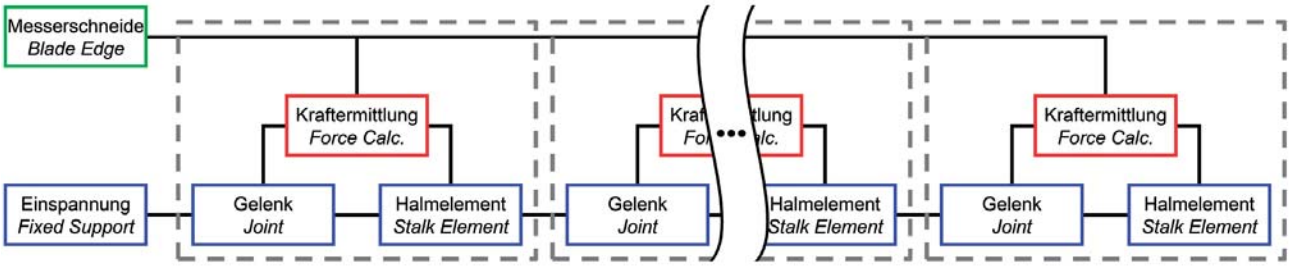
Before beginning Multi Body Simulation (MBS) of a cutting process the chopper and the cut crop material have to be defined in an MBS programme. Hereby the individual objects are defined without movement. They are comprehensively defined through their individual mass, their moment of inertia as well as their centre of gravity and are connected to one another via joints and force elements. In order to represent the elastic properties of the straw it is first of all discretised in the MBS (**figure 1**).

Fig. 1



Cutting Process (Cutting Blade of the Company ESM) [1]

Fig. 2



SimMechanics-Model for the simulation of a cutting process (schematically) [1]

Fixed-position straw elements are attached to each other with pivot joints featuring angular springs and angular shock absorbers. **Figure 2** shows the design of the SimMechanics model used for simulating the cutting process.

During the simulation the positions and the velocities of a predetermined contact point positioned on the knife blade, as well as the mid-point of the spherical stalk elements, are defined (**figure 1**). These values are input parameters for the subsystems for determining forces (**figure 2**). Calculating the contact force is through **equation 1**, once the distance between the contact point on the blade and the mid-point of a stalk element is smaller than its radius (**figure 1**).

$$\underline{F} = \underline{F}_F + \underline{F}_D = \underbrace{F_F \cdot \underline{e}_S}_{=\underline{F}_F} + \underbrace{F_D \cdot \underline{e}_v}_{=\underline{F}_D} = \underbrace{\frac{c_K \cdot c_S}{c_K + c_S}}_{=c} \cdot \begin{bmatrix} ds_x \\ ds_y \\ ds_z \end{bmatrix} + \underbrace{\frac{k_K \cdot k_S}{k_K + k_S}}_{=k} \cdot \begin{bmatrix} dv_x \\ dv_y \\ dv_z \end{bmatrix} \quad \text{(eq. 1)}$$

The thus calculated contact force is the output value of the subsystem force calculation and acts upon the blade-side contact point as well as upon the mid-point of the affected stalk element (**figure 2**).

Should this force exceed the value required for the cut, the two stalk elements involved must be separated from one another. In general, however, the MBS does not offer the possibility of dividing rigid bodies. Because of this the cut takes place through the releasing of the joint positioned between the two affected stalk elements (**figure 1**). So that this is possible and able to offer observation of a level plane model, every joint features a degree of rotary freedom as well as two translational freedom degrees. As long as the contact force is smaller than the cutting force a spring acts on each of these freedom degrees with a large spring constant (stalk elasticity module). The movement of the body in the direction of both these degrees of freedom is very small and represents the flexing of the stalk. Angular springs and dampers act on the rotational degree of freedom so that the stalk can flex when under load. Should the contact force now be greater than the cutting force all spring and damping constants of the joint below the stalk elements in contact with the blade are set to zero. **Figure 3** shows the result of a simulation with two consecutive cuts.

Because two in-series activated Kelvin-Voigt two-parameter damping models were applied (**figure 1**) the contact force, as well as the driving power sequences at the beginning of a cut, rapidly reached their respective local extreme value (**figure 3**). This can be explained through the relative velocity between the blade and the immobile straw stalk being greatest at this moment. The damping force achieved its maximum value while the spring force is low because the flexing of the straw stalk has hardly begun. Whether the adoption of a Kelvin-Voigt damping model is realistic must be investigated with the help of measurements. Because of the rapid rise of the characteristic values it can, however, be assumed that another damping model (e.g. Maxwell) might be more suitable.

The driving power required for the cut is approximately proportional to the calculated cutting force (**equation 2**).

$$P = M \cdot \Omega = F_{Schnitt/Cut} \cdot l \cdot 2 \cdot \pi \cdot n \quad \text{(eq. 2)}$$

The average value required for assessing energy requirement can be calculated with **equation 3**.

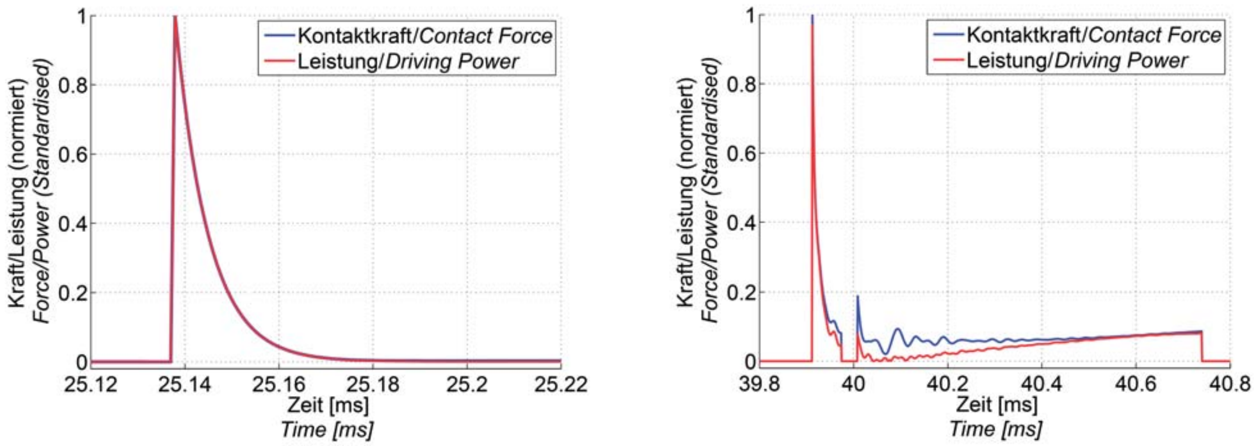
$$\overline{P} = \frac{1}{T} \cdot \int_0^T P \cdot dt \quad \text{(eq. 3)}$$

Flow simulation of the transport process

To optimise the machine with regard to its energy requirement, account has to be taken of the power needed for the cutting operation as well as that needed for transport of the chopped straw. For this a flow simulation is indispensable.

In general, simulation of particle flows involves that a difference is made between unidirectional and bi-directional interaction. With the former, only the influence of the flow on the particle movement is taken into account. The presence of the particles that have mass has, however, no influence on the flow field. This assumption is valid for flows with low particle

Fig. 3



Simulation results for two cuts; left: first cut, right: second cut

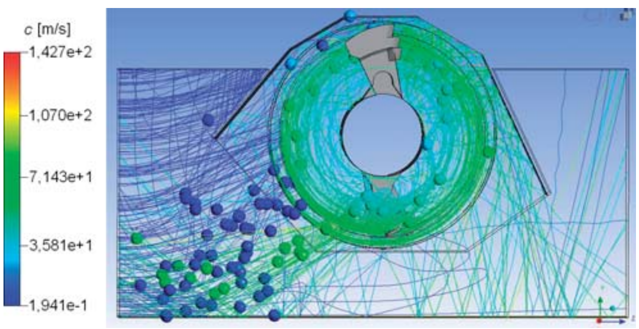
content. With bi-directional interaction the reciprocal influencing of the flow field and the particle is taken account of. In this case a simulation is conducted with the help of the bi-directional interaction. The straw stalk elements not bound to one another are represented as spherical particles with mass. **Figure 4** shows the results of the simulation.

Angular momentum and particle collisions can, among other methods, be accounted for through applying stochastics and statistics. The same applies to numerous further effects such as clump formation. Requirement for the validity of such a method is a high particle content flow. Because the modelling is not based on physical laws the algorithms for different types of particles must be validated. Therefore observation of individual particle movement is not possible.

Figure 5 shows flow simulation results which allow to explain many effects observed in field trials such as the sticking of cut material to the underside of the Y-blade. The reason for this is clearly seen in **figure 5a** where a forward flow moving from under the blade to a large extent neutralises the flow from the holder. Hereby this very flow would be the one with the ability to keep the underside of the Y-blade clean. Additionally it can be seen that the forward flow produced in part blows out from the cutting circle radius, thus obstructing particle inflow.

Because of the large projection area, and therefore resistance area, of the knives in flow direction, high-pressure loads occur in numerous areas (**figure 5b**). A reduction of the projection area as part of an optimisation of the blade geometry would thus reduce the required driving power requirement. Here, however, it must be ensured that sufficient flow continues around the knives.

Fig. 4



Simulation of the particle glow (c = flow velocity) [1]

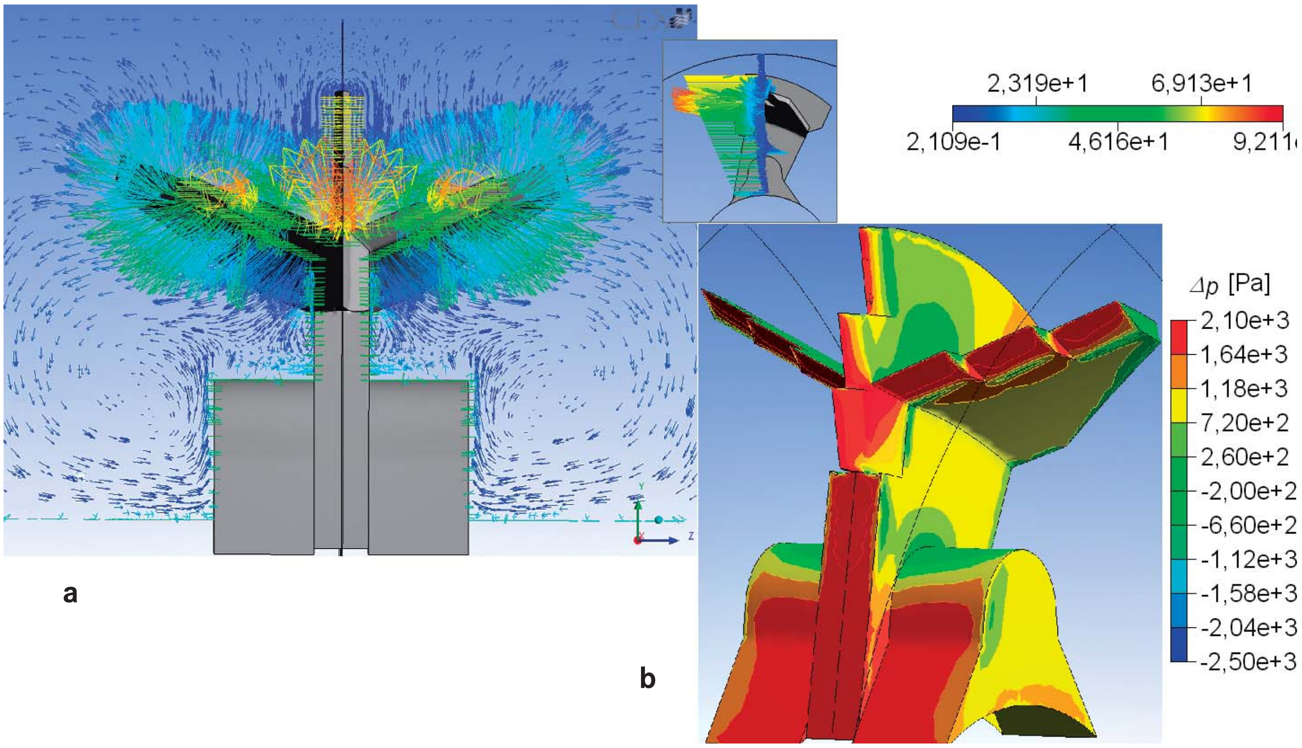
Conclusions

The application of modern simulation processes can make an important contribution to optimisation of choppers with regard to reducing drive power requirements. Additionally the degree of smallness in chopped material can be increased and blockages, e.g. at the chopper knives, avoided. The simulation results also delivered scientific explanations for phenomena observed in field trials. The comparison of recorded values with flow simulation results already indicates a good agreement.

The cutting process simulation must, on the other hand, be further optimised. Among other points, through measurement of material characteristic values of cut material and their implementation in the simulation results can be further improved. Measurements can also help in the assessment of whether application of another damping model might deliver better results.

In order to achieve in future more precise statements about the effects occurring in choppers and similar machinery, work

Fig. 5



Results of the CFD Simulations (c = Flow Velocity) [1]
a: front view, b: pressure difference Δp on the blades (absolute pressure 101325 Pa)

is continuing at the moment on the development of a method linking the MBS or the discrete element Method (DEM) with flow simulation. The DEM is an efficient method for taking account of contacts between individual particles. Further information on simulation of agricultural engineering cut and flow processes can be found in [3], [4] und [5].

Literature

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Notations

The program SimMechanics is an add-on tool for the Matlab/Simulink program packet produced and distributed by MathWorks (www.mathworks.com).

The program CFX is an ANSYS product. Among other companies, it is distributed by CADFEM (www.cadfem.de) and ANSYS Germany (www.ansys.com).