Prüfer, Andreas; Englisch, Jörg; Schultze, Marten and Meinel, Till

ADALS – Contribution to DEM particle simulation in agricultural machinery

The Discrete Element Method (DEM) is the tool of choice for simulation of agricultural material's processing. For this are needed granular matter models, whose generation and parametrization is costly. That fact prohibits the use of DEM within small and medium sized companies. ADALS (user friendly Discrete Element Method database for agricultural materials) fills this gap and provides these models via a simple database, for which has been designed a range of experiments for the determination of material properties and simulation verification.

received 23 April 2014
accepted 30 June 2014

Keywords
DEM, Young's Modulus, compression, rotating drum

Abstract
Landtechnik 69(4), 2014, pp. 180–184, 5 figures, 10 references

The Discrete Element Method (DEM) proves to be usable within the fields of simulation of bulk material and granular matter. Research institutions and companies in agricultural machinery show keen interest in this kind of simulation. The DEM was intensively discussed within the 70th International Conference LAND.TECHNIK in Karlsruhe, where a whole plenary session was dedicated to this topic [1].

Foundations of the Discrete Element Method

Basis of the DEM is the modelling of the investigated object by means of spheres, which possess properties like weight and volume, and walls within a virtual physical environment. This physics defines via appropriate contact formulation – such as impact, friction and force fields – the interaction possibilities between these elements. Finally a construct is created, which reproduces the occurring real world phenomena in their studied aspects.

For every single one of the spheres within the simulation model the numeric solving algorithm – often: „Central Difference Time Integration Scheme" [2] – sets up the Newtonian equation of motion with all the acting forces and moments and the resulting acceleration, using the initial parameters the solver calculates the velocity and the new location of the sphere. So the DEM shows characteristics of mesh free time discrete simulation methods. By extending this approach via superposition of spheres, now describing clumps, and with the introduction of binding forces far more complex particle shapes and material behavior up to tissues can be modeled.

The Future Application

Current research topics are mainly focused on visual phenomena and their representation. In long term perspective coupling DEM together with multi body simulation and continuous flow simulation has high potential to simulate the processing of granular materials. This comprises for example, separation, mixing and transport processes, which can be simulated, including the retroactive effects on the mechanical systems. So the circle between machine, material and process simulation is closed, enabling a holistic simulation.

This enables the simulation of complete sowing and harvesting machines or fertilizer spreaders, their complex mechanics included. In future an engineer will be able to test his design in virtual reality for functionality, impact, efficiency and generate load assumptions for his design. In addition, the DEM allows a deeper insight into the occurring processes within the granular material and on the particles up to damage mechanisms and comminution.

The Challenge

The main requirement for such a simulation is the mechanical accuracy of particle models. That is, in addition to the ensemble behavior of the particles, both the impulse and the energy balances must be right on a macroscopic scale so that the experimentally determined resulting forces and moments lead to verifiable load assumptions. Therefore it is necessary to aid the prospective simulation creator through a handy tool, which offers him suitable material models for the imaged process. The project ADALS is aiming to fill this currently existing gap. The work objectives are structured into the following four modules:

- (A) Providing general purpose measurement methods to determine the relevant model parameters
- (B) Providing evaluation methods of model quality
- (C) Transfer of real particle mixtures in 3D models
- (D) Compression and verification of these models

The Project's Objective

ADALS has set itself the goal to determine, collect and process material properties of agricultural granules such as crop, seed and fertilizer for the DEM simulation. Therefore the form of any respective individual particle of the granular material needs to be captured, measured and characterized, further the mechanical properties have to be determined and verified through multiple usable application related experiments and simulations. Finally a knowledge and literature database, parallel maintained, documents the results and helps with the anchoring of the expertise in the field of granular media at the Institute.

Methods

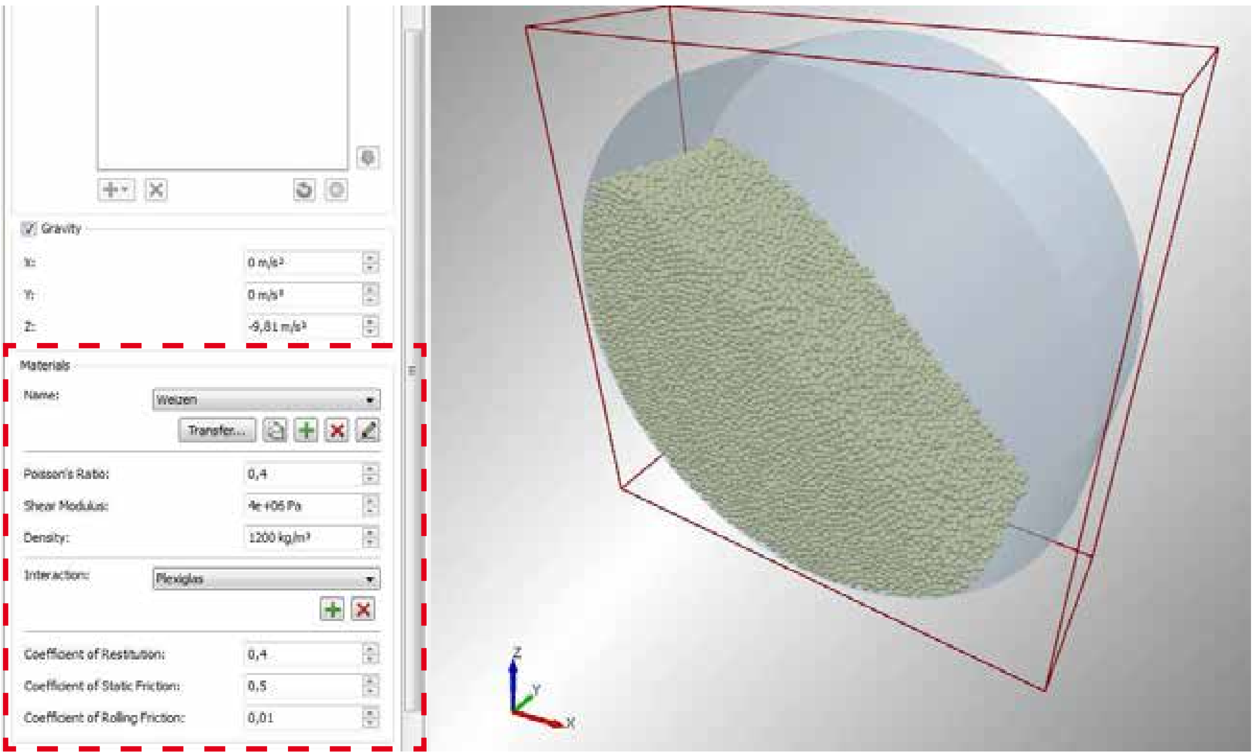
The software EDEM (Sales: DEM Solutions GmbH, Eschborn, Germany) is used for simulation within the project ADALS, the approaches and solutions developed can however be transferred to other common DEM simulation tools.

Even if EDEM is basically open to contact models of any kind, the standard contact model according to Hertz Mindlin was chosen deliberately. For this purpose the input values of Poisson's ratio, shear modulus, density, coefficient of restitution, coefficient of static friction, coefficient of rolling friction and the geometry of the particle are required. In **Figure 1** this is shown by example; the input form for the material and contact properties is highlighted by a dashed border.

This does not necessarily mean that these simulation parameters and their values do correspond to reality, considered from systems theory's perspective, DEM is a functional depiction with a certain analogy in the inner microstructure [3]. For example the real mechanisms in the particle contacts of real solids are much more complex and more diverse than what could be modeled accurately by employing DEM [4]. A complete identity between the construct in the simulation and the investigated object in the real world should, apart from some special cases, be out of the question. This must be taken into account in the application of the DEM.

Consequently ADALS searches for a formalism, based on the solution of inverse problems, which makes it possible to provide appropriate values for the simulation parameters for the studied process in accordance with the forecast quality and the technical simulation effort. The main goal is an identical outcome in simulation and reality in the studied aspects of the

Fig. 1



Screenshot EDEM, entry for material parameters in dashed red rectangle, dynamic angle of repose within a rotating drum simulation occurring macroscopic phenomena within the prescribed tolerance range.

Therefore it is necessary to determine the mechanical parameters within experiments and to verify the system behavior in simulation and reality. Main experiments within ADALS are the compression test for the evaluation of the effective elastic modulus and the coefficient of restitution and the rotating drum experiment to verify the simulation. Both experiments are well known and have been studied in depth and discussed in peer review literature already.

The Compression Test

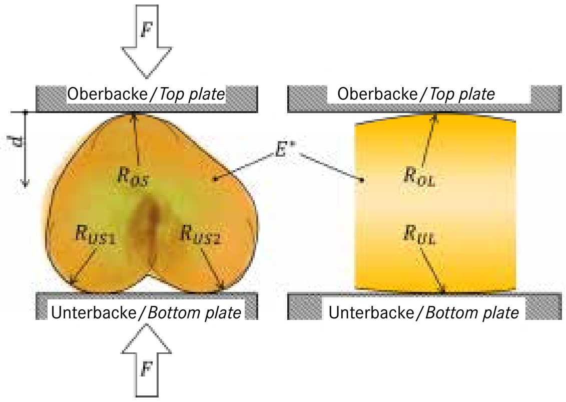
One of the input parameters in EDEM is called the coefficient of restitution, a measure for the fraction of kinetic energy, which has been dissipated during the impact process. However, this is not a material property, but a phenomenon and it is – which has been described by Schäfer et al. in [5] – depending on the material, on the shape of the contact partner of an impact and also on the initial mechanical conditions (start impulse). A complete and coherent explanation of the complex microscopic processes for this purpose does not exist up to now, there are only descriptions of phenomena to be found in literature.

It shows further that in compression experiments with wheat kernels between plane-parallel plates after Omarov [6] the loading rate has a significant influence on the mechanical behavior of a single grain. Accordingly a contact model, consisting of spring-damping elements with friction, should be used to model the contact forces after his proposal. With the known material parameters, which are determined by the compression test in interpretation of the standard ASAE S368.4 DEC2000 „Compression Test of Food Materials of Convex Shape“ [7] in a universal testing machine, and the appropriate model for the collision process, the coefficient of restitution should be sufficiently predictable for slow speeds [6].

Starting point of the approach according to ASAE S368.4, on which Omarov also based his theory, is the theory of elastic contact between the sphere and plate according to Hertz, which can be expanded via the introduction of a geometric mean radius of curvature on ellipsoidal shaped contacts. Thus the grain of wheat, shown as an example in **Figure 2**, has three contact points to the two parallel compression plates, each of which can be approximately described by an ellipsoidal curved surface. This allows the modelling of the general mechanical behavior of these three contact points as a series circuit of a single contact with two parallel contacts and in the end, the determination of the elastic modulus according to the Hertzian theory.

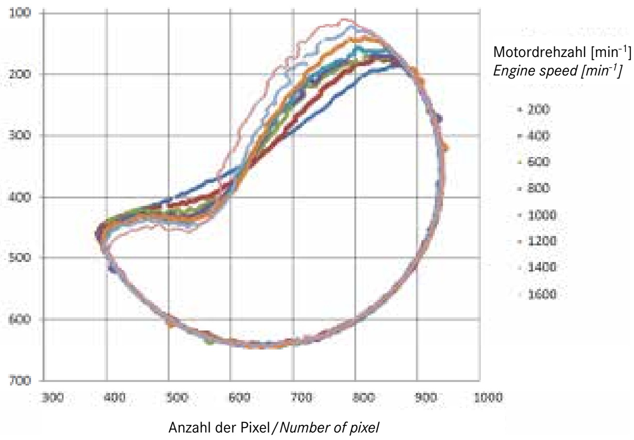
The two main problems in the compression test of natural substances are the diversity of the contact surfaces and the influence of surface roughness and thus the onsetting smoothing in the forming of the initial contact. In order to overcome the first one, a compression system was designed with replaceable plates, which allows the testing of in epoxy embedded samples, this now enables the examination of the isolated contacts. For solving the second problem, adaptation of the analysis of

Fig. 2



Example for the compression of a wheat-kernel, left in section, right in side view, F forces, R contact radii, d deflection, E apparent Young's Modulus*

Fig. 3



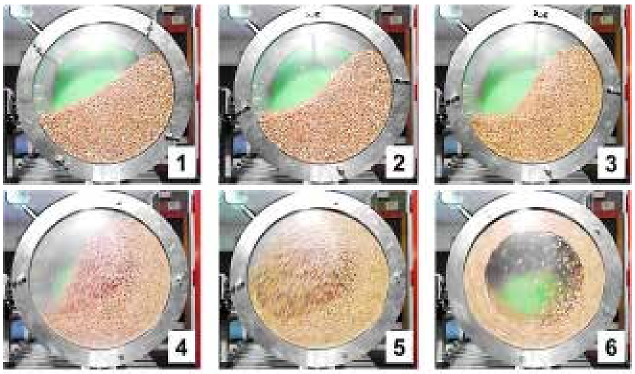
Rotating drum experiment, evolution of the surface with increasing rotational speed

the compression curve according to ASAE S368.4 is needed. In order to do this, the compression curve is segmented in a preliminary step, and each segment is checked in terms of its curvature and the applicability of the Hertzian contact, which is chracterized by the curve exponent. Thus the disturbing influence of the initial contact with its much stronger curvature is filtered out. The subsequent regression analysis to determine the nonlinear spring stiffness is limited onto this analysis window. Finally, based on this parameter the modulus of elasticity is calculated according to ASAE S368.4.

The Rotating Drum Experiment

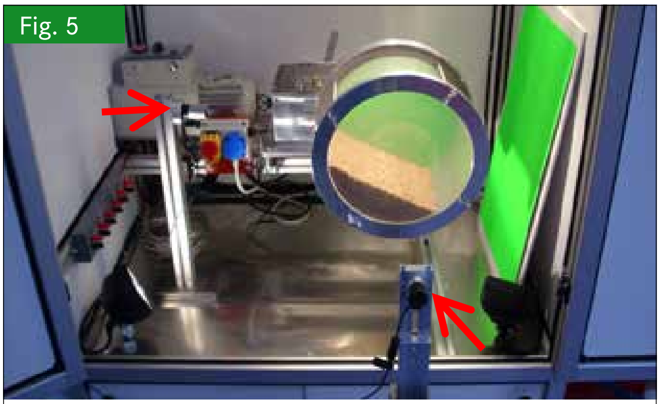
The rotating drum experiment, where granules are studied with respect to their characteristic movement of material at different fill levels and rotational speeds in a closed cylinder, that spins around its longitudinal axis, has been selected as the main experiment for the verification of simulation prognosis quality. The analyzable phenomena here are manifold, depending on the rotational speed different distinctive material flow

Fig. 4



Rotating drum experiment, evolution of the surface with increasing rotational speed: (1) avalanching, (2, 3) cascading, (4, 5) cataracting, (6) centrifuging (Photos: A. Prüfer)

Fig. 5



Rotating drum experiment, dynamic angle of repose is clearly seen, arrows marking the webcams (Photo: J. Englisch)

phenomena can be observed [8] (**Figures 3** and **4**). For image processing and comparison with the simulation, especially quasi-stationary phases of material movement are interesting, which show well defined distinctive patterns. The most important characteristic phenomenon and measured variable is here in the slow rotational speed range the occurring dynamic angle of repose [9].

Based on Johnstone's [10] studies his experimental setup was analyzed in depth, significantly expanded and supplemented with a robust image analysis (**Figure 5**). Here experiments showed a significant influence of the geometry of the drum on the studied phenomena, therefore a completely new experimental setup has been designed. The newly designed drum adapter allows the use of different diameters and lengths of drum cylinders. This makes it possible to examine influences of the drum's cylinder and side plates on the movement of material separated from each other. As a result experiment and simulation can be compared together visually by simple means. **Figure 3** shows an example for a degree of filling of around 50 % the evolution in the surface shape with increasing rotational speed. It begins in the low rotational speed range with an almost flat surface and develops with the increase of speed towards an increasingly curved shape. **Figure 4** shows individual still frames of the related video recordings.

Conclusions

Within the project ADALS a variety of tests for determining mechanical and geometrical parameters were designed and implemented both in the experiment and in the simulation. Currently the finalisation and the evaluation of test series, which were carried out with rapeseed, wheat and airsoft bullets, are conducted. Meanwhile the experiments are expanded to a range of other granular materials and the influence of moisture, for the granular material behaviour in addition to the shape of the particles the influence of the surface texture is relevant. Further research work within this project will focus on the data analysis and evaluation with the objective to create a material database.

References

[1] Max-Eyth-Gesellschaft Agrartechnik im VDI (2012): Land.Technik 2012. Mit Erfahrung und Innovationskraft zu mehr Effizienz. Conference: Agricultural Engineering, Karlsruhe 6. und 7. November 2012; Tagungsband, VDI-Verlag

[2] Rougier, E.; Munjiza, A.; John, N. (2004): Numerical comparison of some explicit time integration schemes used in DEM, FEM/DEM and molecular dynamics. Int. J. Numer. Meth. Engng. 61, pp. 856–879

[3] Ropohl, G. (2009): Allgemeine Technologie. Eine Systemtheorie der Technik, KIT Scientific Publishing, S. 75 ff.

[4] Popov, V.L. (2010): Kontaktmechanik und Reibung. Von der Nanotribologie bis zur Erdbebendynamik. Berlin, Heidelberg, Springer-Verlag

[5] Schäfer, J.; Dippel, S.; Wolf, D. (1996): Force Schemes in Simulations of Granular Materials. Journal de Physique 6(1), pp. 5–20

[6] Omarov, A.; Aman, S.; Müller, P.; Tomas, J. (2012): Mikromechanische Eigenschaften von Weizenkörnern. Chemie Ingenieur Technik 84(4), S. 535–539

[7] ASAE S368.4 DEC2000 (2008): Compression Test of Food Materials of Convex Shape

[8] Mellmann, J. (2001): The transverse motion of solids in rotating cylinders – forms of motion and transition behavior. Powder Technology 118(3), pp. 251–270

[9] Schulze, D. (2006): Pulver und Schüttgüter. Springer Verlag, S. 176 ff.

[10] Johnstone, M. (2010): Calibration of DEM models for granular material using bulk physical tests, Dissertation, The University of Edinburg

Authors

Dipl.-Ing. Andreas Prüfer is project coordinator for the project ADALS and a research associate at the Institute of Agricultural Machinery Engineering and Renewable Energies (Head: **Prof. Dr.-Ing. Till Meinel**) at the Cologne University of Applied Sciences (CUAS), Betzdorfer Strasse 2, 50679 Cologne, e-mail: andreas.pruefer@fh-koeln.de.

M. Eng. Jörg Englisch was a research assistant in the project ADALS and works as a test engineer at the company AGCO Marktoberdorf.

B. Eng. Marten Schultze was a research assistant in the project ADALS and is currently a Master student in mechanical engineering at the Cologne University of Applied Sciences (CUAS).

Acknowledgements

The project is funded by the Federal Ministry of Education and Research BMBF (Grant Number 17N0811) and supported by the companies Amazonen-Werke H. Dreyer GmbH & Co. KG, Claas Selbstfahrende Erntemaschinen GmbH, Kverneland Group Soest GmbH, Lemken GmbH & Co. KG and Rauch Landmaschinenfabrik GmbH.
The authors wish to thank Ms. Annika Schneider for editing and reviewing the English version of this article.