USAGE OF THE DISCRETE ELEMENT METHOD IN CONVEYOR TECHNOLOGIES

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ABSTRACT The calculation models for the most mechanical conveyors are based on continuum mechanical entries. Unfortunately, the results of these models are often deficient and intensive tests are necessary to determine adjustment factors. Due to this fact the design of mechanical conveyors demands a lot of experience and practise. So far no numerical method is used in industry to support, verify and improve this design process. This paper tries to show the possibilities of the usage of one of the most auspicious numerical methods: the **D**iscrete **E**lement **M**ethod (DEM). The project aim is to verify the simulation results on real sized test rigs and to utilise the major advantages of this method for the industry by the development of an easy to use software tool.

1 INTRODUCTION

The behaviour of bulk solids inside mechanical conveyors, like trough chain conveyors and screw conveyors, is very complex. The analytical models for the calculation of such conveyors do not work without adjustment factors, which must be determined by expensive and extensive tests under close to reality conditions. But not only is it difficult to analyse the transportation process of bulk solids. It is also hard to find equations for the loading and discharge or the transfer of bulk solids especially in the field of belt conveyors and elevators. Due to these facts a lot of practical experience is necessary to design bulk solid handling equipment. These experiences are highly valuable for all companies in this field.

But in a time where the globalisation of markets will force companies to work more and more time and cost effectively, the design and development process is often characterized by assorting parameterised module-assemblies without the consideration of the special properties of the bulk solid. This design technology provides a fast construction phase, but it risks that the conveyor does not meet the requirements. In the field of large conveyor plants, whose design process can not be standardized, a design mistake would be very expensive. An optimisation of the transport process is often only in operating conditions possible.

Nevertheless until now in the field of conveyor technology no numerical method has been established to control the function of the conveyor *before* it has been built. This would be a very useful tool to check the interaction between bulk solids and standardized or non standardized conveyors.

2 BASICS OF THE DISCRETE ELEMENT METHOD

One of the most auspicious numerical method to simulate the transport process of bulk solids is the **D**iscrete **E**lement **M**ethod (DEM). Developed by Cundall [1,2] in the 1970s this method today is extensively used for simulations in the field of geo- and rock-mechanics, particle characterisation and process engineering, unfortunately not in the field of conveyor technologies. In the above-named fields the DEM provides close to reality simulations and a look inside particle systems like shown in [7]. In the field of conveyor technology the first work about the usage of the DEM analysing the function of pipe conveyors was done by Gröger 1998 [4].

The DEM allows the calculation and simulation of discrete and discontinuous processes. That means the DEM is the opposite of the classical continuum mechanical approach. According to [9] the calculations performed in the DEM alternate between the application of Newton's second law to the particles and a force-displacement law at the contacts. Newton's second law is used to determine the motion of each particle for a very small timestep arising from the contact and body forces acting upon it, while the force-displacement law is used to update the contact forces arising from the relative motion at each contact (see fig. 1). The force-displacement law relates the relative displacement between two entities at a contact to the contact force acting on the entities. The interpenetration of the particles is interpreted by the elastic deformation in the contact process without any influence on the particle shape. The calculated overlap value is used for the calculation of the contact forces using a constitutive law given by the contact model (see fig. 2). This contact model characterises together with the particle shape (mostly spherical) and the particle density the bulk solid properties.

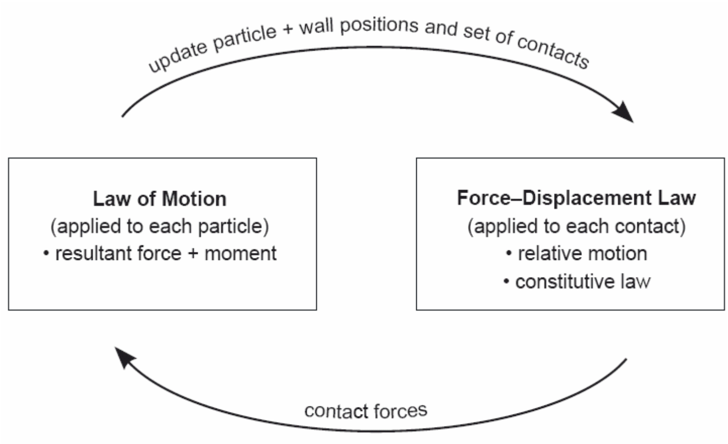

Figure 1: General calculation cycle of the DEM [9]

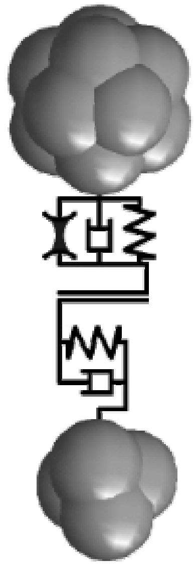

Figure 2: Visualisation of a contact model characterised by spring, dash-pot, coulomb-friction, liquid bridge [4,5]

3 ECONOMICAL IMPORTANCE OF THE PROJECT RESULTS

The complex mathematical background of the bulk solid mechanics are also a problem for the most experienced designers of conveyor technology. For the producers and users of such equipment, the usage of the DEM provides:

- a cost-effective possibility to simulate the function of conveyor technology.
- the control of exactly defined problem zones e.g. transfer chutes, redirection stations, wear regions…,
- the integration of processes e.g. mixing and segregation in the transport process due to the simulation of the physical effects with DEM,
- market advantages due to the usage of innovative techniques and the integration of the customer in the design process by visualisation of the mass flow and the function check in advance,
- marketing advantages due to attractive video-sequences and pictures of the simulation.

The simulation of the transport processes will prevent damages and increase the conveyor efficiency extensively.

4 EXAMPLES FOR THE USAGE OF THE DEM AND PROJECT AIMS

The project aims are to show the application possibilities of the DEM in the field of the bulk solids handling technology and to provide a simulation tool which can be used for a wide range of applications due to the universally valid method. New design solutions and calculation models should be developed by means of distinct problems from any part of the branch. Furthermore, the performance and the reality degree of the DEM-simulations regarding the complex bulk solid behaviour should be controlled. The verification of the computer simulation is one major project part. Therefore our institute and partners provide many different real sized and model test rigs as well as the equipment to accomplish extensive measurements. The adaptation of the software to real problems is also centred in the project. For an easy usage of the software it is necessary to integrate user friendly graphical interfaces which allow the fast modelling of the problem due to pre-defined assemblies based on the product catalogue.

The following collection of problems defining the project tasks should illustrate the comprehensive possibilities of the DEM.

❖ Simulation of the transport process in:

- Screw and spiral conveyor: The calculation models are based mostly on extensive empirical test due to the complex geometry of such conveyors

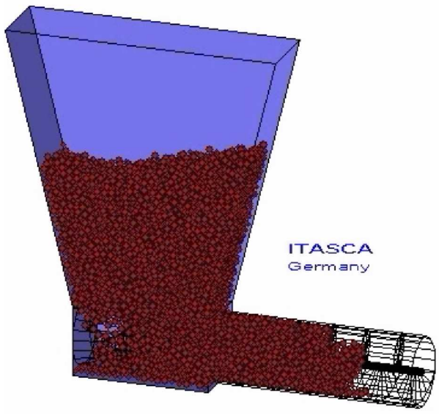

Figure 3: DEM - simulation of a bin screw feeder [6]

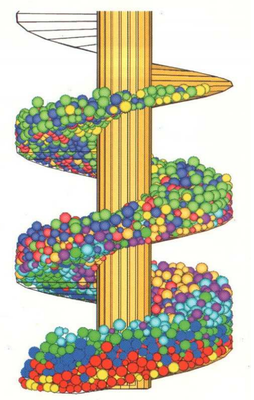

Figure 4: DEM – simulation of a vertical screw conveyor [6]

- Through chain and tube chain conveyor: These conveyors can manage difficult conveyor routes in 2 or 3 dimensions. The behaviour inside the necessary redirection stations are not completely understood.

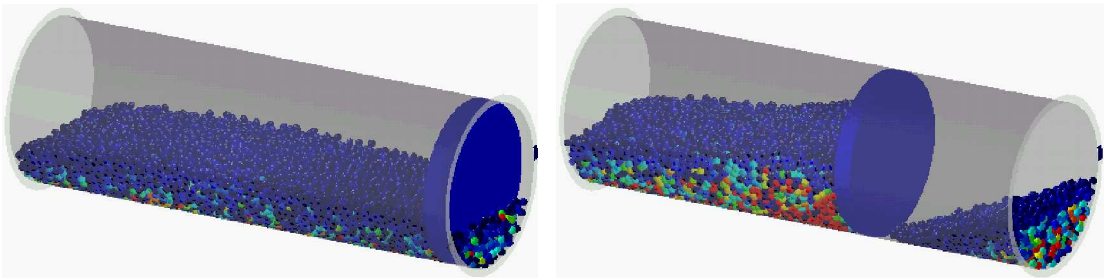

Figure 5: DEM - simulation of a tube chain conveyor [6]

- Pipe conveyor: The experimental test on high inclined test rigs showed a pulsing discharge behaviour although material loading was homogenous and continuous. Until now this effect can not be explained in a satisfying way.

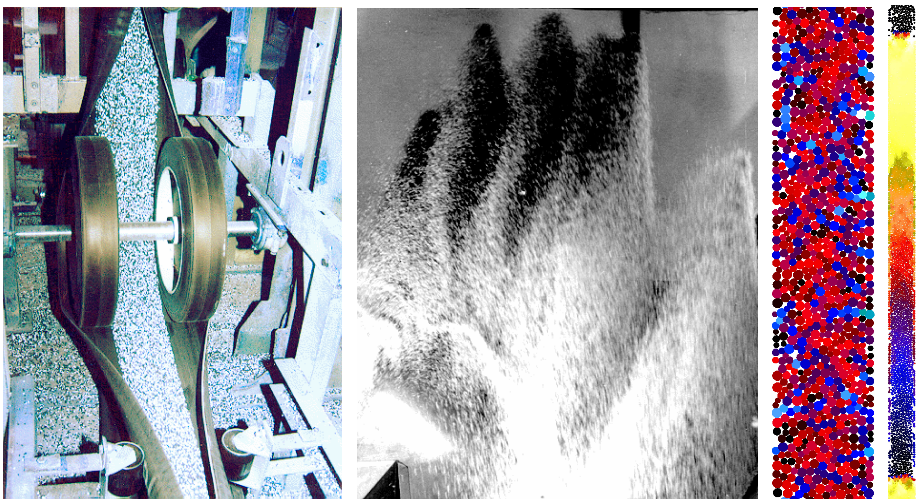

Figure 6: Pulsing pipe conveyor (center) although continuous loading (left) and DEM-Simulation: Particle Colour code: bright = high velocity, dark = low velocity [4]

❖ Simulation of silo and bunker feeding with different conveyor technologies:
The modelling of the complex stress distributions of the bulk solid dependent of the chosen feeding technology is hard to analyse. Therefore an optimal design of such feeder equipment can only be found empirically.

- Simulation of transfer chutes (especially in the field of belt conveyors with a high mass flow): The design of a wear less transfer chute is centred in this task, which can today only be solved by experience.

A b c d

Figure 7: Major problems on poorly designed transfer chutes: a) Spillage, b) Plugging, c) Belt wear, d) Chute wear. [3]

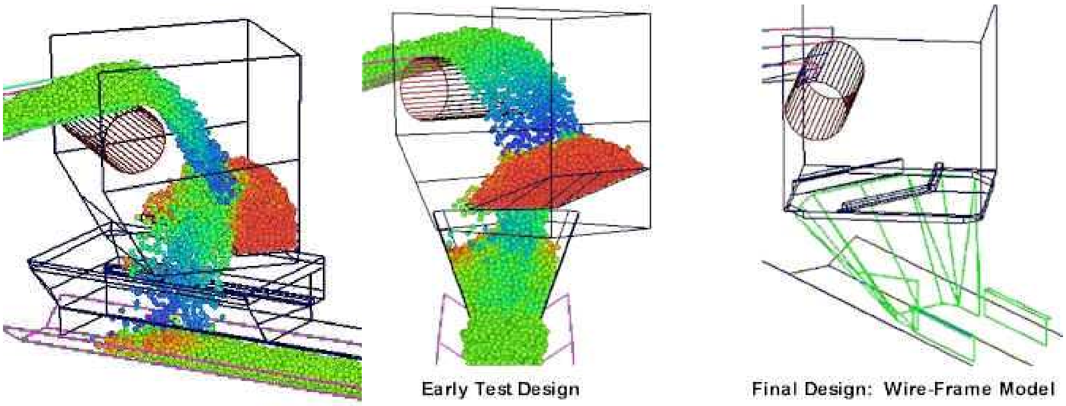

Figure 8: DEM - simulation of a transfer chute of belt conveyors (left, center) and the interactive design optimisation (right). The velocity of the particles is characterised by the colour. [3]

- Simulation of the scoop and discharge behaviour of bucket elevators (see fig. 9): Due to the complex process in the whole scoop and discharge process only empirical research works were done. Using the DEM it should be possible to analyse the whole transport process. That would be the base of an optimised bucket design (especially designed for so called gravity-, mixed- or centrifugal-discharge [6]) and of the operating parameters.

The commercial software "**P**article **F**low **C**ode 3D" (PFC 3D) by the ITASCA Consulting Group Ltd., Minneapolis, USA provides a universally usable program. It allows the modelling of many conveyor problems without comprehensive programming knowledge and provides efficient simulation due to the sophisticated and powerful algorithms. Therefore the usage of the DEM comes into reach of the praxis. This work should show the potentials of this method as well as support and document the introduction in the practical usage.

5 DISADVANTAGES

Nowadays only the computer performance will limit the usage of the DEM. Large reality closed particle systems with millions of particles with irregular shapes can not be simulated efficiently. Nevertheless the increasing computer performance will solve that problem in the future. It can be expected that in the near future the DEM will become as important as the FEM in the field of continuum mechanics.

6 PROJECT COURSE

The PFC 3D software allows the modelling and the customization of comprehensive tasks. Add-ons can be integrated by self-programmed C++-modules. Due to this fact and the above-named project aims, the project concept includes five parts:

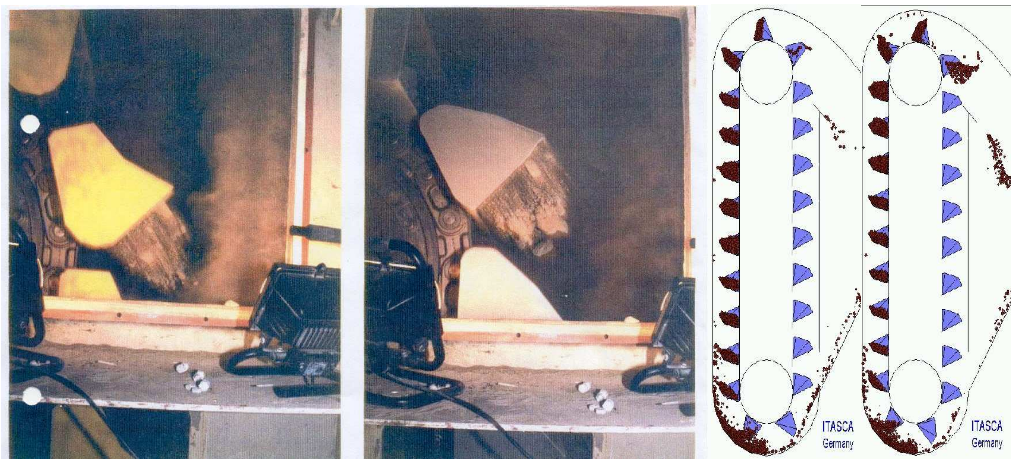

Figure 9: Discharge process of two differently designed buckets (2 pictures left) and a DEM - simulation of a bucket elevator (2 pictures right). The discharge behaviour can be seen clearly: so called mixed discharge is prevailing [6].

1. Programming of the necessary modules to simulate a concrete problem: including of new flexible and parameterised “wall objects” e.g. the spiral geometry of a spiral- or screw conveyor. Furthermore it will be worked on a software interface to common 3D-CAD – system files e.g. IGS or STEP;
2. DEM – simulation including the variation of test and simulation parameters: the simulations will be done using a powerful standard PC (dual processor technology). The ratio between simulation performance and level of detail will be focused on especially. The degree of reality should be controlled in the next step;
3. Measurements and observation of real sized and model test rigs with the same operation conditions and parameters as in the computer simulation: the character of mass flow, bulk solid motion and motion resistance has to be determined by the above-named tasks.
4. Comprehension of simulated and measured results and adjustment of the simulation parameters.
5. Programming of an easy to use graphical user interface for the given task customized for the project partners.

7 ACKNOWLEGMENTS

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