

## FEEDER TYPE OPTIMISATION FOR THE PLAIN FLOW DISCHARGE PROCESS OF AN UNDERGROUND HOPPER BY DISCRETE ELEMENT MODELLING

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### ABSTRACT

This paper describes optimisation of a conveyor from an underground hopper intended for a coal transfer station. The original solution was designed with a chain conveyor encountered operational problems that have limited its continuous operation. The Discrete Element Modeling (DEM) was chosen to optimise the transport. DEM simulations allow device design modifications directly in the 3D CAD model, and then the simulation makes it possible to evaluate whether the adjustment was successful. By simulating the initial state of coal extraction using a chain conveyor, trouble spots were identified that caused operational failures. The main problem has been the increased resistance during removal of material from the underground hopper. Revealed resistances against material movement were not considered in the original design at all. In the next step, structural modifications of problematic nodes were made. For example, the following changes have been made: reduction of storage space or installation of passive elements into the interior of the underground hopper. These modifications made were not effective enough, so the type of the conveyor was changed from a drag chain conveyor to a belt conveyor. The simulation of the material extraction using a belt conveyor showed a significant reduction in resistance parameters while maintaining the required transport performance.

**Keywords:** Drag Chain Conveyor, Discrete Element Method, Simulation.

### INTRODUCTION

Underground hoppers are mostly used for short-term storage of bulk material. A great advantage of these storage facilities is the easy and quick unloading of the input material e.g. by truck or rail. Almost every underground hopper is equipped with a dispenser that conveys the bulk material to the related technology. The optimal design of underground hoppers and dispensing devices depends on many factors, operating conditions and properties of the stored material [1, 2]. The initial design of transport and storage devices begins almost always with a theoretical calculation of the dimensional and performance parameters of individual parts. The calculations should

take into account the dynamic effects arising from the storage and transport of bulk materials. When designing transport and storage facilities, it is appropriate to use studies and knowledge from various areas of transport and handling equipment designed not only for bulk materials [3, 4, 5, 6, 7, 8, 9]. In this case, the problem of optimisation of the existing underground hopper and the drag chain conveyor is being solved. The existing drag chain conveyor system is designed for the processing of black coal. During operation, there are operating problems that limit continuous transport. The Discrete Element Method (DEM) was used to optimise the current unsatisfactory state. The advantage of optimising transport and storage processes using DEM simulations is the computer-based

verification of planned design changes [10]. This replaces the step of experimental design changes that do not guarantee removal of the original problems. These direct structural modifications are always costly both in time and money. The DEM simulation modelling significantly reduces the development time of new devices as well as of optimising existing devices [11, 12]. At the beginning, it is very important to define the mechanical and physical properties of the bulk material to be processed. These properties include grain size and shape, material density, shear modulus and the Poisson constant. In our case, it is black coal. The mechanical and physical properties of the material together with the transport system model are the input parameters for the creation of the actual DEM simulation. During the simulation process of the material transport, it is possible to detect different physical quantities at different time points, such as the vector velocity field, the force and torque effects of the particles on the structure in any direction, etc. [13, 14, 15].

## DESCRIPTION OF THE CURRENT PROBLEM

The current problematic situation concerns the underground hopper with a capacity of  $V = 30 \text{ m}^3$  and the drag chain conveyor. The drag chain conveyor is dimensioned for the amount of transported material  $Q = 100 \text{ t} \cdot \text{h}^{-1}$  with the installed drive power  $P = 11 \text{ kW}$ . The length of the transport channel  $L = 16 \text{ m}$  and speed of the drag chain conveyor is  $v = 0.74 \text{ m} \cdot \text{s}^{-1}$ . The combination of the underground hopper and the drag chain conveyor is used to process the black coal, which is delivered to the underground hopper by truck at regular intervals.

Black coal has a wide range of particle size distributions, approximately from 0 mm to 100 mm. Other parameters are bulk density  $\rho_s = 1100 \text{ kg/m}^3$  and maximum material humidity  $\theta = 15\%$ . A 3D model of a cross-cut of the underground hopper and drag chain conveyor is in Fig. 1.

In real-time operation, there were problems with the occurrence of bridging in the underground hopper in the spaces above the drag chain conveyor channel. The bridging was causing blockages of material above the conveyor, and the drag chain conveyor transported only a minimal amount of material. The second major problem occurred with the drag chain conveyor. When the underground hopper was filled with more material (approximately 1/3 of the total volume of the underground hopper) and after a certain period of time had elapsed, the movement of the conveyor was stopped. The reason was overloading of the drive, which could not overcome the emerging drag resistance. Other undesirable effects during operation were manifested by deformations of the drive elements and the shredding of the material at the point of material extraction from the hopper.

Based on the above facts, which stem from real operation and available technical parameters, a 3D CAD model of the current state was created, see Fig. 1. The 3D CAD model was imported into EDEM Academic, which is used to create DEM simulations. The model of the underground hopper and drag chain conveyor has been assigned physical properties and kinematic parameters. In the second step, a bulk material resembling black coal was created (Contact Material + Material Definition). The individual particles were assigned the measured mechanical and physical properties. Then the calibration

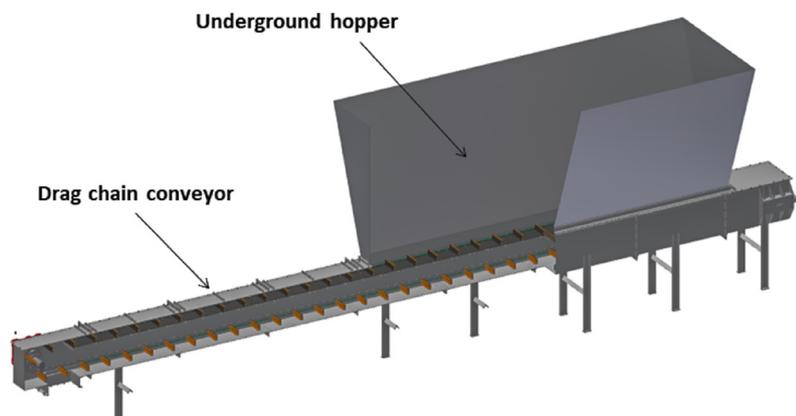


Fig. 1. Cross-cut of an underground hopper and a chain conveyor

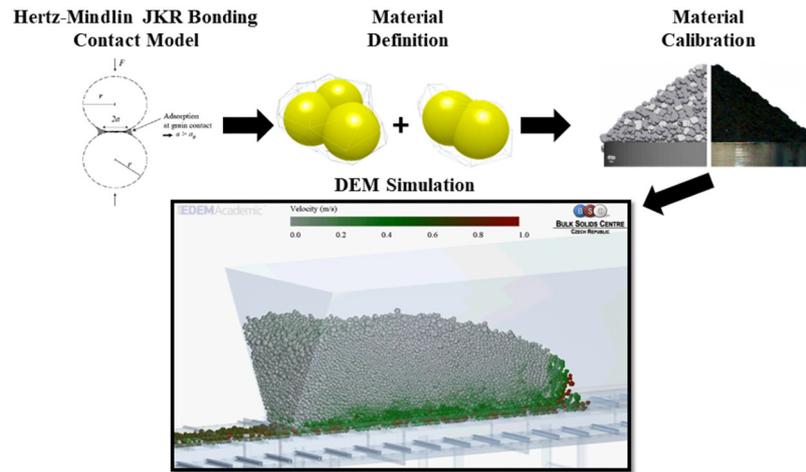


Fig. 2. Illustration of preparation of the DEM simulation

simulation was performed (Material Calibration). The basic material calibration was performed on a comparative experiment where the angle of repose of real material with DEM simulation was compared. After the necessary calibration has been done, the material was generated in a prepared underground hopper model. The whole process of preparing the DEM simulation is visually represented in Figure 2.

The DEM simulation of the current state has confirmed the large compressive forces occurring in the material while movement of the drag chain conveyor. Large compressive forces occurred especially in the area where the material from the underground hopper was extracted. The size of the compressive force in the material was approximately 1000 N. The critical areas of the compressive forces in the underground hopper are shown in Fig. 3.

Furthermore, DEM simulation discovered increased values of the total force which affects the drive elements during the movement of the drag chain conveyor. Total force effect on the drive elements expresses the total drag resistance. From the 36-second time period of the DEM simulation, the average value of  $F_T = 40000$  N has been read. The course of  $F_T$  in time and the distribution of forces on the drive elements of the drag chain conveyor are illustrated on Fig. 4. Total drag resistance is the main parameter when calculating and dimensioning the performance of the drag chain conveyor. Following the established total force from the DEM simulation, a control calculation of the required power of the drag chain conveyor was carried out according to equation (1). The control calculation showed that the proposed drive is seriously underpowered. The drive power for this application should be at least 45 kW.

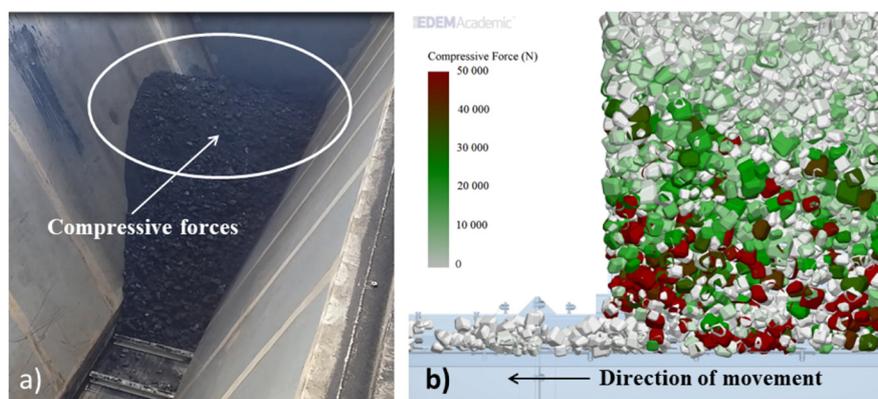


Fig. 3. Displaying areas of compression forces in a underground hopper: a) real situation, b) DEM simulation

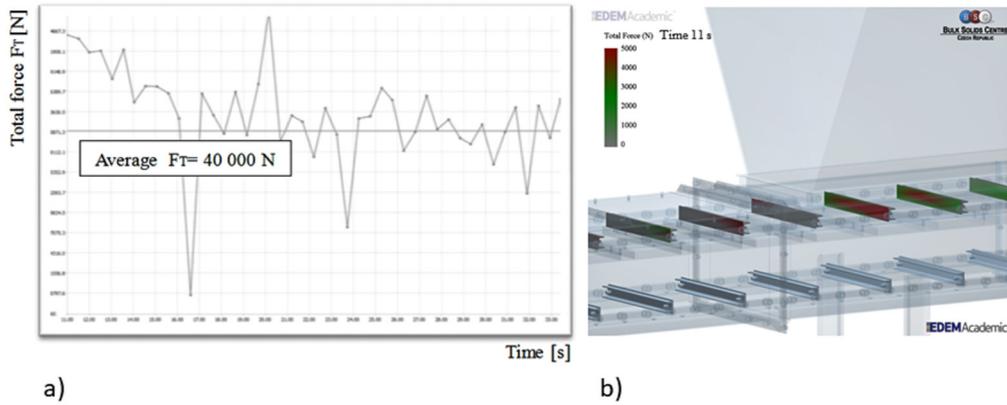


Fig. 4. a) Dependence of total force  $F_T$  on time; b) Loadings on the drag elements of the chain conveyor

$$P = 1.3 \cdot \frac{F_T \cdot v}{\eta \cdot 10^3} \text{ [kW]} \quad (1)$$

- P ... required power of the drive unit [kW]
- $F_T$  ... total drag resistance [N]
- v ... speed of the drag chain conveyor [m.s<sup>-1</sup>]
- $\eta$  ... overall efficiency of mechanical drive transmission [-]

### OPTIMISATION OF THE FEEDER PROCESS

The reasons for these consequences were identified based on the compression forces found in the material and the total drag resistance. High drag resistances of the conveyor are generated from a large amount of material lying directly on the bottom of the conveyor channel. When moving the drive elements, the drag chain conveyor must overcome big dynamic shocks when picking up the material from the underground hopper. As a result of this, design modifications have been pro-

posed, which should reduce the resistance parameters during the movement. To reduce the loading area of the material to the bottom of the channel, a passive element was applied which was placed in the underground hopper space. A further modification consisted in limiting the length of the drive portion of the conveyor located in the underground hopper space. Structural modifications were made only in a virtual 3D model. Subsequently, a new DEM simulation was performed, see Fig. 5.

Evaluated results from the DEM simulation have shown that the proposed solution reduces the performance of the drag chain conveyor. However, the effectiveness of reducing the drag resistance parameters was not sufficient. The passive element was placed very close to the transport channel. This positioning of the passive element has resulted in a limitation of the continuous flow of material. During the DEM simulation, air bridges were formed between the passive element and the underground hopper walls.

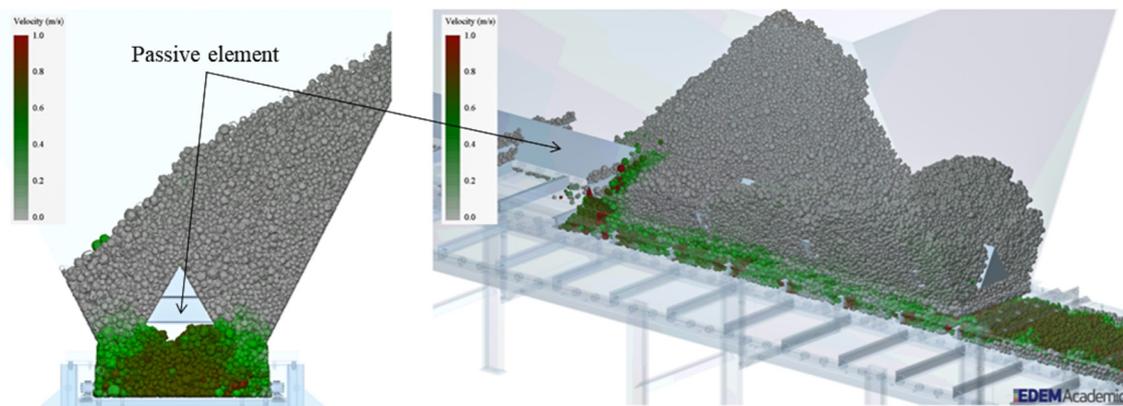


Fig. 5. DEM simulation of material discharge process with a passive element



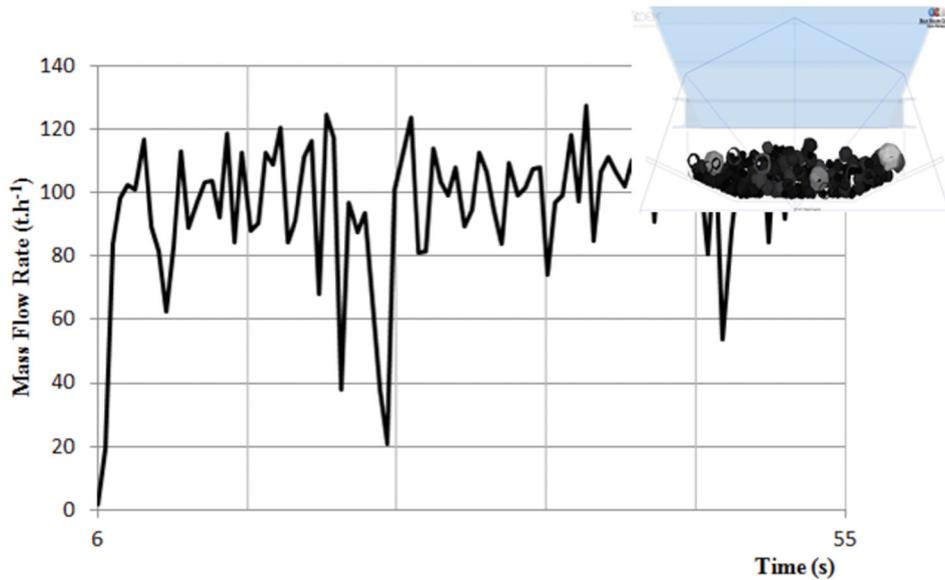


Fig. 8. The course of mass flow rate based on DEM simulation

shows a DEM simulation of the transport of material from an underground hopper using a belt conveyor where the particle speed can be read at each instant of the transport process.

During the DEM simulation, other parameters can be monitored to allow us to better understand specific transport or storage processes. In our case, the mass flow rate that the belt conveyor is able to transport is monitored. Fig. 8 shows the mass flow rate dependency on time. The figure shows the average value of the mass flow rate, which ranges from  $95 \text{ t}\cdot\text{h}^{-1}$  to  $100 \text{ t}\cdot\text{h}^{-1}$ . This range fulfils the set mass flow rate condition of  $Q = 100 \text{ t}\cdot\text{h}^{-1}$ .

## CONCLUSIONS

This paper describes verifying the possible use of computer DEM simulations for designing completely new or optimising existing conveyor and storage devices for bulk materials. Using discrete modelling, it has been possible to identify problematic areas in transporting coal from an underground hopper using the drag chain conveyor. It was found that the original drag chain conveyor was heavily underpowered. The DEM simulation showed very high drag resistances, on average around  $F_T = 40000 \text{ N}$ . In the first phase of optimisation, the effort to reduce the magnitude of the resistive resistances was only a minor design change. A passive element was placed in the underground hopper above the conveyor transport channel, which only slightly reduced the drag resistances. In the second phase, the drag chain

conveyor was replaced by a classic belt conveyor. This radical change has brought very positive results. The average total force in the conveyor belt during the simulation was only  $F_T = 12000 \text{ N}$ . It should be noted that all design modifications were made on a virtual 3D CAD model. DEM simulation allows us to apply different design solutions and verify process functionality. This verification method prevents the production of non-functional prototype devices. Based on the results obtained in this paper, it is possible to assume that DEM simulations represent a very effective tool in the design of conveying and handling equipment in the field of bulk materials.

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## REFERENCES

1. Ekmann J. M. and Le P. H. Coal Storage and Transportation. Reference Module in Earth Systems and Environmental Sciences, from Encyclopedia of Energy, 2004, 551-58.
2. Cloete F.L.D. A drag chain feeder/conveyor based on standard engineering components. Powder Technology, 20(1), 1978, 21-27.
3. Molnar V., Fedorko G., Stehlikova B., Michalik P. and Weisz M. A regression model for prediction of pipe conveyor belt contact forces on idler rolls. Measurement, 46(10), 2013, 3910–3917.

4. Molnar V., Fedorko G., Stehlikova B., Tomaskova M. and Hulinova Z. Analysis of asymmetrical effect of tension forces in conveyor belt on the idler roll contact forces in the idler housing. *Measurement*, 52, 2014, 22-32.
5. Debski H., Teter A., Kubiak T. and Samborski S. Local buckling, post-buckling and collapse of thin-walled channel section composite columns subjected to quasi-static compression. *Composite Structures*, 136, 2016, 593-601.
6. Jachowicz T., Garbacz T., Tor-Świątek A., Gajdoš I., Czulak A. Investigation of selected properties of injection-molded parts subjected to natural aging. *International Journal Of Polymer Analysis And Characterization*, 20 (4), 2015, 07-315..
7. Molnar V., Fedorko G., Stehlikova B., Kudelas L. and Husakova N. Statistical approach for evaluation of pipe conveyor's belt contact forces on guide idlers. *Measurement*, 46(9), 2013, 3127-3135.
8. Kral J. and Kral J. Verification of a three axis milling machine accuracy in the process of complex shaped part production. *Applied Mechanics and Materials*, 474, 2014, 261-266.
9. Bigos P., Kulka J., Kubin K., Mantic M. and Kopas M. Necessity of experiment for technical state verification of supporting structure of foundry crane before its reconstruction. *Experimental Stress Analysis-TU Liberec*, 2009, 1-7.
10. Cleary P.W. Large scale industrial DEM modelling. *Engineering Computations*, 21(2/3/4), 2004, 169-204.
11. Guo Y.C., Wang S., Hu K. and Li D. Optimization and experimental study of transport section lateral pressure of pipe belt conveyor. *Advanced Powder Technology*, 27(4), 2016, 1318-1324.
12. Grima A.P., Fraser T, Hastie D.B and Wypych P.W. Discrete element modelling: trouble-shooting and optimisation tool for chute design, 2011, 1-26.
13. Coetzee C. J. and Els D. N. J. Calibration of discrete element parameters and the modelling of silo discharge and bucket filling. *Computers and Electronics in Agriculture*, 65(2), 2009, 198-212.
14. Coetzee C. J. Review: Calibration of the Discrete Element Method. *Powder Technology*, 310, 2017, 104-142.
15. Grima A. and Wypych P. Discrete element simulation of a conveyor impact-plate transfer: calibration, validation and scale-up. *Australian Bulk Handling Review*, 3, 2010, 64-72.