Inclined Screw Conveyors – DEM Analysis of the Impact of Intermediate Bearings

W.A. Günthner and S. Rakitsch, Germany

The design and sizing of high inclination screw conveyors for bulk materials is still often based on experience from the equipment manufacturers. To assure an efficient sizing based on trusted calculation methods the Institute of Materials Handling Material Flow Logistics (fml), Munich, Germany, is working on a research project, funded by the Deutsche Forschungsgemeinschaft (DFG), which is aimed at analyzing inclined screw conveyors. By the use of simulations by the discrete element method the influence of intermediate bearings on the conveying process, which is very hard to constitute analytically and experimentally, can be analysed.

Key Words: *screw conveyor, DEM-analysis, bearings*

1 Introduction

The requirements regarding reliability, performance and economic efficiency of conveyors, as well as energy efficiency and environmental protection, have increased significantly in recent years. The advantages, such as the simple and robust assembly, low equipment and maintenance costs, low susceptance to failure, and in particular the dust-proof design, therefore, often lead to the use of screw conveyors. In ship unloaders, for example, they are used for the vertical transport of bulk material from the hold as well as for the inclined transport along the boom.

As the length of the boom conveyor – according to the dimensions of the ship unloader – is in the area around 30 m, intermediate bearings are necessary to avoid impermissible distortion of the screw. Other applications for inclined screw conveyors, which require an intermediate bearing due to their length, can be found in the silo discharge in cement plants.

2 State of Research

If an intermediate bearing is necessary, the screw helix has to be divided into sections and an undisturbed conveying can no longer take place. In this area the bulk material transport condition can be described as 'slug phase', because the axial transport of the material in bearing area is caused by the pressure exerted by the subsequent bulk material. Another problem in the bearing area is a reduction in cross section due to the struts that connect the intermediate bearing with the tube. These two effects, slug phase and cross-sectional constriction, lead to choking of bulk material and thus conveying problems and an increased power requirement [1].

While the influence of intermediate bearings for screw conveyor with a maximum inclination of 20° and for vertical screw conveyors is already analysed, such investigations do not exist for the existing inclination of some well over 20° today. In the earlier works entirely different methods have been applied to achieve the respective aims. A model to consider the impact of intermediate bearings on the vertical conveyor was developed by Greinwald [2].

By the use of approaches from continuum mechanics the state of stress inside the bulk material while being conveyed through an intermediate bearing was determined. Based on this analytically determined state of stress the volume flow and the power requirement can be calculated. As the entire conveying process according to this model can not be described by a closed solvable set of equations, numerical methods for solving each specific problem are needed.

The influence of intermediate bearings at horizontal or lightly inclined screw conveyors was also investigated in the past at the Institute for Materials Handling Material Flow Logistics (fml) [3]. By a purely empirical approach, data of screw conveyors, once each with and without intermediate bearing, but otherwise identical, were compared and evaluated. As the main factor influencing the increasing power requirement the filling level φ was identified, which affects the power requirement at values of $\varphi \geq 0.2$.

By the use of a regression analysis, a simple formula for calculating a coefficient of intermediate bearing λ_{ZWL} was determined as a function of the filling level for each intermediate bearing. The coefficient of intermediate bearing is taken into account as a multiplier of the friction loss in the calculation of the power requirement. The result of the regression analysis for the coefficient of intermediate bearing is listed in Table 1 (filling levels greater than 0.5 were not examined).

3 Approach

The key parameters that need to be determined in the sizing of screw conveyors, are the achievable volume flow respectively the required geometry and operating conditions to achieve the re-

Fig. 1: Bulk handling by the means of screw conveyors.

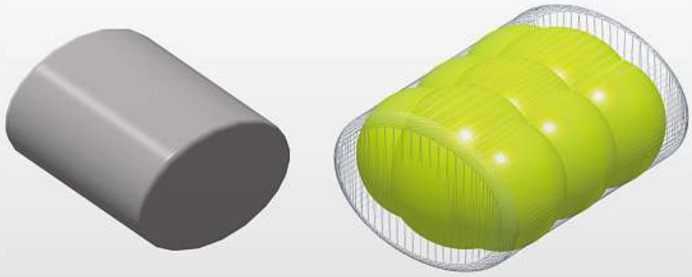

Fig. 2: CAD-Model and simulated model of the particle.

quired flow rate and the necessary power requirement. These targets must be determinable for the user as simple and practical, yet safe and reliable, as possible. To determine the influence of an intermediate bearing to the target sizes for screw conveyors with an inclination between 20° and 60° is therefore the objective of this investigation.

As a tool to achieve this goal, the simulation by discrete element method was chosen. This approach has certain advantages against the above-mentioned approaches. Thus in the evaluation of the simulated data also effects are taken into account, which cannot be considered in an analytical model. It also eliminates the time-consuming numerical solution of equations, which are usually the result of analytical considerations.

Compared to the standard empirical approach with experiments on real test rigs, this opens the advantage of being able to do without a real test rig with intermediate bearings, which reduces the cost and complexity of the investigation significantly. The obtained data are in turn subjected to a regression analysis and presented in a formula as simple as possible.

Simulations by the Discrete Element Method (DEM) are in principle numerical experiments in which besides the geometry of the conveyor the individual particles of the bulk material are depicted as discrete elements. In each calculation step for all particles, the Newtonian equations of motion are solved and thus it permits the calculation and simulation of discrete, discontinuous processes. This simulation method is basically very simple, but it reaches its limits due to the very large number of particles to be considered.

Only by the use of modern computers with multi-core technology and high processing speed, it is possible to calculate even complex simulations with tens of thousands of particles and high resolution with high accuracy in reasonable time [4]. In the present investigation, the simulation program EDEM by the company DEM Solutions is used.

4 Simulated Particles

The simulations are performed with PET-pellets as bulk material. These pellets are also used on a real test rig of the institute and are thus known in the properties and behaviour. The particles are cylindrical with an elliptical basic shape and a volume of about 25 mm³. The CAD-Model and the model of the particle used in the simulation are shown in Fig. 2. The simulation model of the particle consists of the shell of the CAD-model, on those properties such as volume, weight, inertia, etc., are based and nine ball-spheres, which represent the boundary of the particle in contacts.

As the mass of the particle is proportional to the numerical time step, the simulation time would not be practical if using full-scale particles. The first step in the abstraction of the simulation is therefore to increase the particles so that the realism of the simulation is not significantly reduced. Therefore the particle properties of the simulation model must however be adjusted so that the behaviour of particles is still consistent with the real bulk behaviour.

For material handling problems the inner and outer friction is of particular importance [5] and is therefore calibrated together with the bulk density. In preliminary simulations a particle model with a similar geometry, whose volume is increased by a factor of 20, was carried out in acceptable computing times. To cali-

Table 1: Influence of intermediate Bearings at the horizontal and lightly inclined Screw Conveyor [3].

Without intermediate bearing	With intermediate bearing	
	$\varphi < 0,2$	$0.2 \le \varphi \le 0.5$
$\lambda_{ZWL} = 1$	$\lambda_{ZWL} = 1$	$\lambda_{ZWL} = 8.5 \cdot (\varphi - 0.2) + 1$

Table 2: Bulk material parameters of PET-pellets and in simulation.

	PET-pellets	Simulation
Bulk density [kg/m³]	790	793
Angle of repose [°]	35.8	35.7
Angle of slip [°]	21.0	20.9

Table 3: Simulated values of the screw parameters.

Rotating speed n [1/s]	1	3	5	7	9
Inclination β [°]	30	45	60		
Filling level φ [-]	0,2	0,4	0,6		

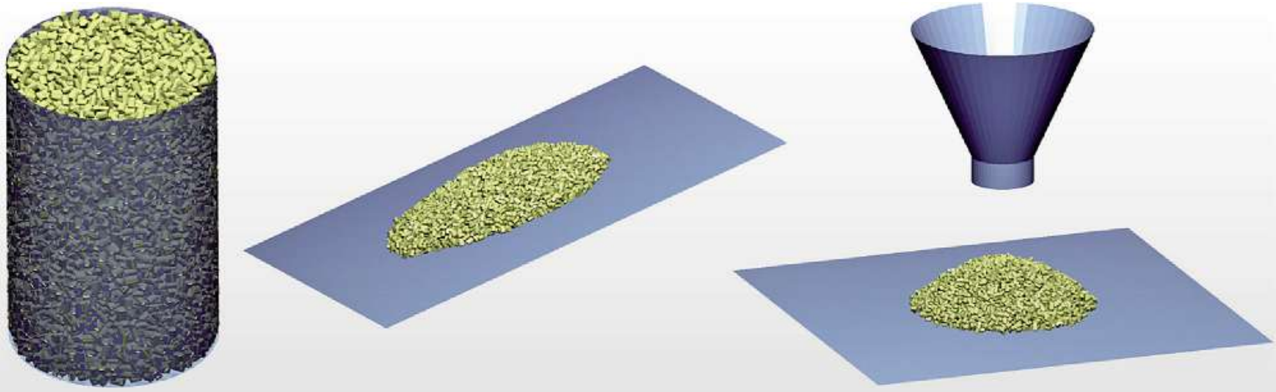

Fig. 3: Simulation models for calibration: bulk density, angle of slip, angle of repose (left to right).

brate the particles, tests to determine bulk properties are reproduced in the simulation. The simulated parameters are modified iteratively until the behaviour of the simulation model is equivalent to the real bulk behaviour with sufficient accuracy. To test the model, the determination of the bulk density, angle of repose and wall friction are performed.

The experimental setup and the simulation models for the calibration are based on the recommendations given in FEM 2481 [6]. The resulting values for the PET-pellets used in the this work shown in Table 2. The simulation models to realise the calibration are shown in Fig. 3. In each case, the simulation results are shown together with the final results, see also Table 2.

5 Simulation Model

In addition to the simulated bulk material the simulated model of the conveyor is of fundamental importance. In a second step of abstraction, therefore, the geometry of the screw conveyor is reduced to the necessary geometric and functional components [4]. In the case of the investigated screw conveyor the interaction of the bulk material with the screw, the inner wall of the tube and the intermediate bearing is primarily of interest.

To reduce the number of particles, therefore the function of periodic boundaries of the simulation program is used. That means that only a short section of the conveyor is really simulated (in this case 4 pitches). If a particle reaches the end of the conveyor, it is removed and relocated at the beginning of the conveyor with the same characteristics (position in the cross section, speed, stresses, ...) again. In this way a quasi-infinitely long conveyor is built.

As in the current investigation, the influence of an intermediate bearing on the conveying process is to be tested, both a conveyor with intermediate bearing and a conveyor without intermediate bearing is modelled. The dimensions of the conveyor and the intermediate bearing are chosen similar to the existing test rig. This allows the simulation model to be verified with data from the test rig. This was done for the screw conveyor without intermediate bearing in advance and is not subject to this investigation.

The screw diameter amounts to 0.260 m, shaft diameter of 0.076 m and the pitch of 0.230 m. The interruption of the screw helix for the intermediate bearing is at a length of 35 mm. The intermediate bearing itself has an outer diameter of 100 mm and a length of 153 mm, it is fixed in the tube with four struts. The CAD models of the tube with intermediate bearing and the associated screw are shown in Fig. 4. All geometry models can be loaded into the simulation model directly over the CAD data interface.

Finally the operating parameters of the screw conveyor, which are simulated, have to be defined. The rotation speed n, the inclination β and the filling level φ are to be varied. The different rotation speeds can thereby directly be defined as dynamic properties of the screw. To set the different inclinations of the screw conveyor to the horizontal the vector of gravity is varied accordingly. This has the advantage that the rest of the simulation model can be maintained unchanged.

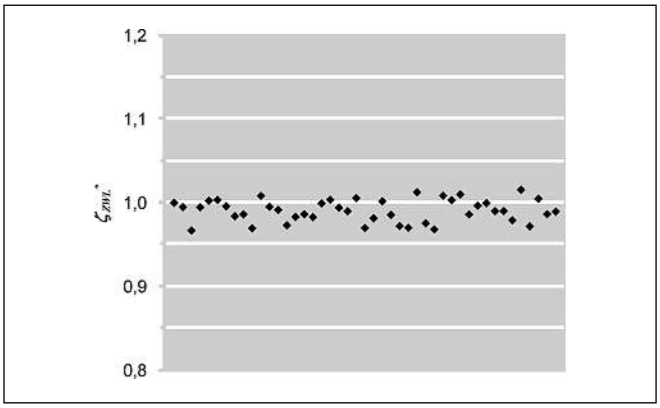

Fig. 6: Detected coefficient of velocity with intermediate bearing.

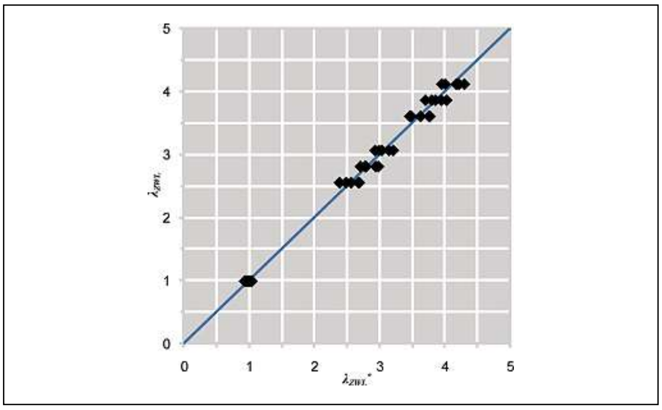

Fig. 8: Model accuracy of the coefficient of intermediate bearing.

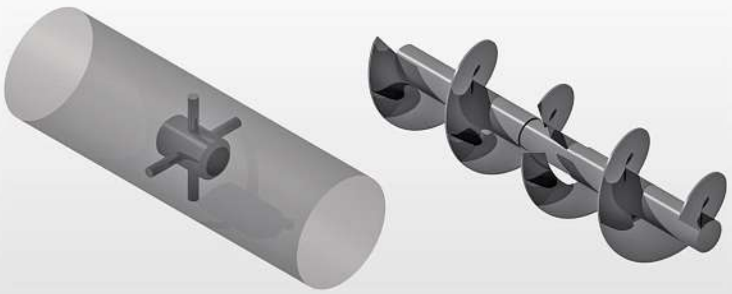

Fig. 4: Tube with intermediate bearing and screw.

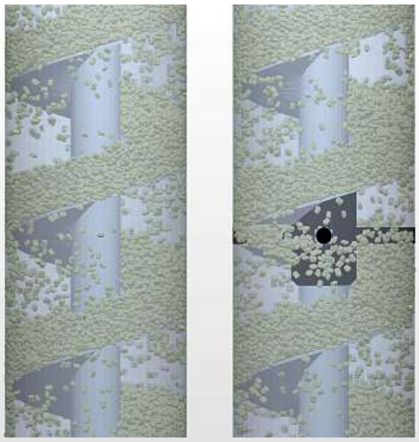

Fig. 5: Comparison of screw conveyor without (left) and with (right) intermediate bearing.

To set the respective filling level, first the theoretical filling level of the conveyor with static screw is calculated. After filling the conveyor with much more particles as needed and let the particles come to rest, the particles above the calculated level are cut away. The simulated values of the described operating parameters are listed in Table 3.

As targets, the average axial velocity of the bulk material v_{ax} and the torque M measured on the screw are evaluated. The evaluation is done with the evaluation algorithms of the simulation program. From the axial velocity of the bulk material the volume flow I_V can be calculated using the continuum mechanics approach that the volume flow is equal to the product of the carrying surface and velocity component in flow direction. To assess the impact of an intermediate bearing on the volume flow the ratio of the achieved volume flow of screw conveyors with and without intermediate bearings is considered. As apart from that identical conditions are given this ratio, called the detected coefficient of velocity with intermediate bearing ζ^*_{ZWL}, can be calculated by the following formula as only a function of the axial velocities of the bulk material:

$$\zeta^*_{ZWL}, = \frac{v_{ax,ZWL}}{v_{ax}} \qquad (1)$$

The read-out torque of the shaft is the basis for calculating the power requirement P, which is necessary for conveying. Again, the ratio of power consumption with intermediate bearing to the power consumption without intermediate bearing is used to evaluate the influence of an intermediate bearing. As the power requirement is calculated as the product of torque and the same angular velocity of each screw, the determined coefficient of intermediate bearing λ^*_{ZWL} can be calculated according to the following formula.

$$\lambda^*_{ZWL} = \frac{M_{ZWL}}{M} \qquad (2)$$

6 Results

After evaluation of the simulation runs a first, pure quality, visual comparison of the conveyor with intermediate bearing and without intermediate bearing can be taken. Therefore a top view on both conveyors is given in Fig. 5 with the same conditions at the moment of recording. Although back-flowing bulk material can be seen in the vicinity of the intermediate bearing, a great influence on the conveying process can not be identified in the previous or following subsequent pitches.

This also becomes clear in the second step, the analysis of the obtained data. The aim there firstly is to identify those parameters that have significant influence on the conveyance. As first important result it can be stated that the intermediate bearing has no significant influence on the achievable volume flow. The determined values for the coefficient of velocity with intermediate bearing ζ^*_{ZWL}, scatter only slightly and not systematically by 1, as shown in Fig. 6.

The analysis of the determined values of the coefficient of intermediate bearing λ^*_{ZWL} however confirms a clear influence of

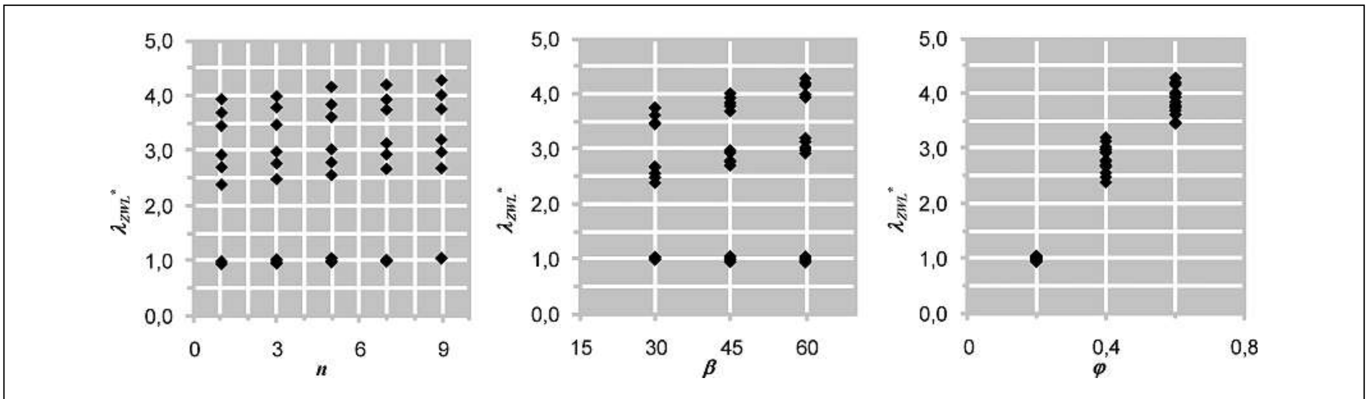

Fig. 7: Detected coefficient of intermediate bearing lZWL* against the analysed influencing factors.

the intermediate bearing to the power requirement. As shown in Fig. 7 the filling level φ has the most considerable influence previous to the inclination β. The influence of the rotation speed of the screw *n* on the coefficient of intermediate bearing is lowest and is no longer considered in the following in favour of a simple calculation rule.

Other findings are that there is an apparently linear effect of the inclination and the filling level. Also the coefficient of intermediate bearing is, regardless of the inclination, approximately equal to 1 for filling levels of $\varphi = 0.2$. The influence of a intermediate bearing must therefore only be considered for filling levels $\varphi > 0.2$. This observation is consistent with the results of previous studies on horizontal or lightly inclined screw conveyors [3].

With these findings from a regression analysis the following relationship results to calculate the influence of a intermediate bearing on the coefficient of intermediate bearing λ^*_{ZWL} and thus to the power requirements of a strongly inclined screw conveyor:

$$\lambda^*_{ZWL} = 1 + 5.253 \cdot (\varphi - 0.2) + 0.017 \cdot \beta \quad \text{for } \varphi > 0.2$$
$$\lambda^*_{ZWL} = 1 \quad \text{for } \varphi \le 0.2 \qquad (3)$$

Finally follows the assessment of whether the found regression model reproduces the observed data with sufficient accuracy. A first step is to calculate the root of the mean square error, thus the average deviation of the determined from the calculated value. This is $\sqrt{MSE} = 0.097$ and thus only about 4 per cent for the calculated values of filling levels $\varphi > 0.2$. Another way to assess the quality of the model descriptively is the direct comparison of observed with calculated values.

Therefore in Fig. 8 the calculated values are plotted over the observed values. The closer the points are to the bisecting line, the better the match is. It shows again that the calculation model is sufficiently accurate and there are no large outliers. The respective horizontal spread of the points is due to the non-consideration of the rotation speed, but also shows the legitimacy of this measure, since the spread is low.

7 Summary

As part of the described analysis the influence of an intermediate bearing on the conveying process of strongly inclined screw conveyors is examined. Tool for realisation are simulations by the discrete element method. By the simulation of screw conveyors, which differ only by the presence of an intermediate bearing, dimensionless parameters are obtained for the influence.

While no relationship between the intermediate bearing and the achievable volume flow can be detected, a clear influence on the necessary power requirement is shown. As significant influencing factors the inclination and the filling level, each with linear relationships, can be identified. These relationships lead to the calculation of a regression model, whose model accuracy is also be able to be demonstrated.

Nomenclature

I_V	Volume flow	[m³/s]
M	Torque	[Nm]
M_{ZWL}	Torque with intermediate bearing	[Nm]
MSE	Mean square error	[-]
P	Power requirement	[W]
n	Rotation speed of screw	[1/s]
v_{ax}	Axial material velocity	[m/s]
$v_{ax,ZWL}$	Axial material velocity with intermediate bearing	[m/s]
β	Inclination of screw	[°]
λ_{ZWL}	Coefficient of intermediate bearing	[-]
λ^*_{ZWL}	Detected coefficient of intermediate bearing	[-]
ζ^*_{ZWL}	Detected velocity coefficient with interm. bearing	[-]
φ	Filling level	[-]

References

[1] Rong, O.: *Auslegungsverfahren für Hochleistungs-Schneckenförderer*. Dissertation, Technische Universität München, München 2004.

[2] Greinwald, K.: *Untersuchung der Förderung leicht fließender Schüttgüter im senkrechten Schnecken-förderer unter Berücksichtigung der Zwischenlager*. Dissertation, Technische Universität München, München 1994.

[3] Günthner, W. A., Blomeyer, N., Rong, O.: *Entwicklung von praxistauglichen Auslegungsverfahren für Schüttgut-Hochleistungs-Schneckenförderer*. Research report, Lehrstuhl für Fördertechnik Materialfluss Logistik, Technische Universität München, München, 2006.

[4] Katterfeld, A., Krause, F.: *Funktionsanalyse eines Rohrkettenförderers mit Hilfe der Diskrete Elemente Methode (DEM)*. In: Tagungsband Fachtagung Schüttgutfördertechnik 2004, Technische Universität München, München, 2004.

[5] Gröger, T.; Katterfeld, A.: *Kalibrierung von DEM-Simulationsmodellen für die Schüttgutfördertechnik*. In: Tagungsband Fachtagung Schüttgutfördertechnik 2005, Otto-von-Guericke-Universität Magdeburg, Magdeburg, 2005.

[6] FEM 2.481:1997-07: Spezifische *Schüttguteigenschaften bei der pneumatischen Förderung*. Fédération Européenne de la Manutention.

About the Author

Prof. Dr.-Ing. Willibald A. Günthner

Technische Universität München
fml – Lehrstuhl für Fördertechnik Materialfluss Logistik
Boltzmannstraße 15, 85748 Garching, Germany
Tel.: +49 (0)89 289 15921
Fax: +49 (0)89 289 15922
E-Mail: kontakt@fml.mw.tum.de

About the Author

Dipl.-Ing. Stefan Rakitsch

Technische Universität München
fml – Lehrstuhl für Fördertechnik Materialfluss Logistik
Boltzmannstraße 15, 85748 Garching, Germany
Tel.: +49 (0)89 289 15923
Fax: +49 (0)89 289 15922
E-Mail: rakitsch@fml.mw.tum.de