

Bulk Material Handling and Processing – Numerical Techniques and Simulation of Granular Material

1. Introduction

When we drop a pebble into the sand on a beach, the pebble does not bounce very much, but sticks in the hole it has made. When we pluck the pebble out, some sand may flow back into the hole, but the indentation largely remains. This simple observation illustrates two unique properties of granular materials.

The first property is that the contact between the grains is dissipative. The thousands of grain-to-grain contacts dissipate kinetic energy rapidly. While the material of each grain is relatively elastic, the relative motions between the grains dissipate the energy so that the overall behavior is inelastic. The fact that the sand does not flow back to fill the hole completely illustrates the common occurrence in nature of granular arrangements which are local minima but which are far from the global minimum energy state. The dent in the sand remains, although lower energy states are available, because thermal vibrations are insufficient to drive the particles to the lowest Energy State. These two properties make the behavior of granular systems unique. While they exhibit some of the properties associated with the gaseous, liquid and solid states of matter, the granular state cannot be characterized by any one of them alone.

Here we discuss the research in discrete element methods (DEM) that capture the contacts between individual particles in an explicit manner. In contrast to continuum methods that smear out the individual particles into a smooth plenum, the discrete element method captures the individual geometry and dynamics of each particle, including the dissipative effects of contact friction.

2. Discrete Element Modeling

Discrete element method are a family of numerical modeling techniques designed to solve problems in engineering and applied science that exhibit gross discontinuous behavior, see [3,4]. It should be noted that problems dominated by discontinuum behavior can not be simulated with conventional continuum based computer modeling methods such as finite element or finite difference procedures. There are a large number of examples, such as geo-engineering problems dominated by discontinuum behavior, including stability of underground mine openings, stability of rock slopes, micro-mechanical behavior of particular media, mineral processing and the flow of bulk solids (as in hoppers, feeders, chutes, screens, crushers, ball mills,

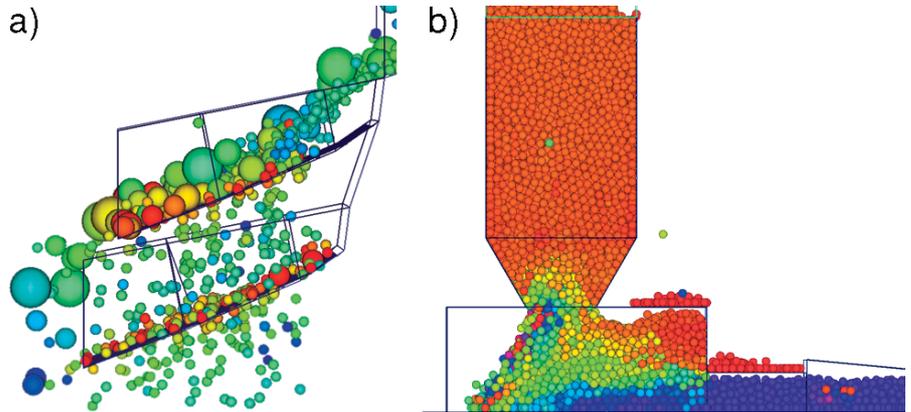


Fig. 1: Examples of granular material analysis: a) screening/separation; b) feeders, hoppers, storage facilities

mixers, all types of conveyor systems and many more). In addition, the discontinuum and continuum can be coupled together to come up with new analysis tools that provide us with better understand of the behavior of material handled and the processing of it.

In simple terms, DEM explicitly models the dynamic motion and mechanical interactions of each body or particle in the physical problem throughout a simulation or time, and provides a detailed description of the velocities, positions, and force acting on each body or particle at a discrete point in time during the analysis. The fundamental unit of a discrete element scheme is the single body or grain. In contrast to the finite element approach, which often assembles a global, functional for the total system, the discrete element method views the individual grain or body as the fundamental unit. Interaction with neighboring grains is achieved by replacing the contact conditions between bodies by external forces. All communication between bodies occurs through a boundary forces and not through a global stiffness matrix.

3. Discrete Element Modeling of Conveyor Transfers

The discrete element method has been shown as an excellent computational tool for simulating the material flow in transfer stations. One engineering design tool which now leads the way in bulk material handling analysis of transfers and chutes is Chute Analyst™, a software application which integrates the Discrete Element Method (DEM) and Computer Aided Design (CAD). Note that the 3-D DEM modules are a further development of the research performed by MUSTOE and co-workers [1,2].

The results from a DEM model provide a detailed evolution of the particles motion, interaction forces and stresses over the duration of the analysis. These features make the DEM a very powerful tool for analyzing bulk material handling problems as it explicitly models bulk material flow and its effects on the transfer and chute structural elements. One practical use of this new

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integrated DEM/CAD technology in the field of bulk material handling is in the analysis and design of belt conveyor transfers. 3-D visualizations of the modeling results provide an overall feel of the flow behavior in the chute. Wear profile, moment arm, and lateral force diagrams provide the engineer with a definable means of improving transfer station design. Bulk material transfer modeling is used to:

- 1) optimizes material flow,
- 2) minimizes abrasion to the belt and chute, and
- 3) minimizes dust and material degradation.

In the transfer point DEM model the pieces of material are modeled with a system of spherical shaped bodies that are representative of the overall behavior of the material. The material bodies can interact with other material bodies, with steel transfer point surfaces, and with moving rubber conveyor belt surfaces. The contact/impact phenomena between the interacting bodies are modeled with a contact force law, which has components defined in the normal and shear directions.

The normal contact force component is generated with linear elastic restoring component and a viscous damping term to simulate the energy loss in a normal collision. The linear elastic component is modeled with a spring whose coefficient is based upon the normal stiffness of the contact bodies and the normal viscous damper coefficient is defined in terms of an equivalent coefficient of restitution.

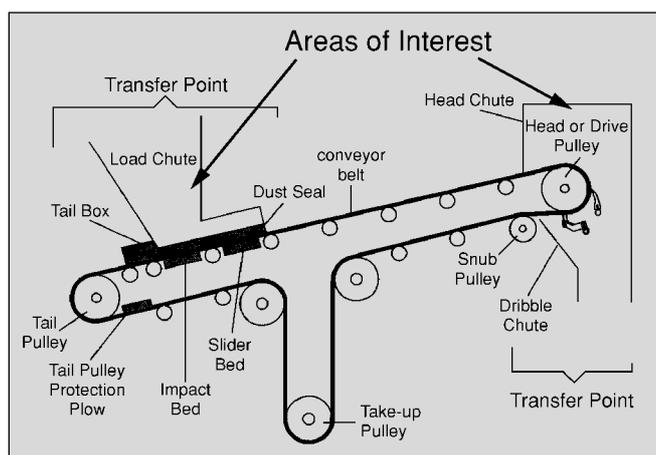
Here we will describe briefly the problems associated with belt-conveyor transfer points and new design techniques using Chute Analyst™ (see Figs. 2 and 3 for typical transfer point examples).

3.1 Characteristics of Belt Conveyor Transfer Points

A transfer point is the location on a conveyor where the material is loaded or unloaded. A typical transfer point is composed of metal chutes that guide the flow of material. In most applications, problematic material flow conditions occur because the design of transfer points often rely on rule-of-thumb techniques, engineering and years of experience. This often lacks one basic component of analysis and simulation, which leads to arcane solutions that require field modification and costly maintenance.

The design of a transfer point will greatly affect the life of its components, maintenance costs and safety and yet it is always left to the end and considered as an after thought. Chute and

Fig. 2: Typical conveyor system components and chutes



other loading equipment is heavily influence by conditions such as the capacity, size, vertical drop, characteristics of the material handled, speed and inclination of the belt and whether it is loaded at one or several locations. An ideal transfer point would be designed to take into account the following:

- center loading of the material,
- loading of material at a uniform rate,
- loading of material in the direction of belt travel (receiving conveyor),
- loading of material at the same speed as the belt is moving (receiving conveyor),
- loading after the belt is fully troughed, and
- loading of material with minimum impact.

At the same time, the transfer point has to prevent:

- plugging,
- chute wear and belt wear,
- the creation of dust, and
- material spillage.

Ideal transfer point chutes are very difficult to achieve by rule-of-thumb engineering and techniques, as most chute geometry and conditions are unique and cannot be tested at full-scale or optimized in a laboratory or workshop. As such, most users live with unfortunate problems which lead to high maintenance costs and retrofits. This is where Chute Analyst™, and computer simulation of bulk material flow has become an important technical advancement providing the solutions to and simulation of the problems.

3.2 Major Problems Associated with Belt Conveyor Transfer Points

To better understand the major problems with transfer points lets take a look at what they are. Most of the major problems with bulk material belt conveyor transfer points can be attributed to problems with the original design, field retrofits and the low priority given during the design process. It is common for the transfer point to be the last part of a belt conveyor system designed almost as an afterthought. Although the transfer point is a vital part in the control of bulk material flow. Some of the major problems that mines/plants have with transfer points are:

- Plugging: stops the entire operations see Fig. 4.

Fig. 3: Typical transfer point, everyday solution by past engineering practices

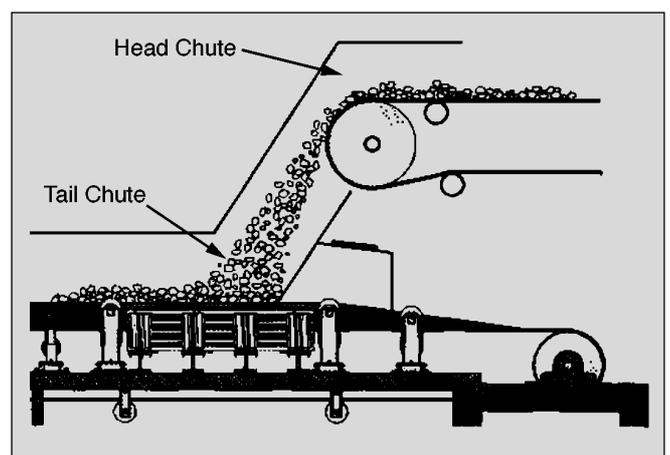




Fig. 4: Plugging and spillage



Fig. 5: Belt wear



Fig. 6: Impact damage



Fig. 7: Spillage



Fig. 8: Dust generation and material degradation



Fig. 9: Chute wear on the sides

- Spillage: corrosion, extra cost of maintenance and most importantly safety (one-half of all the accidents that occur around belt conveyors in mines are attributable to cleanup and repairs required by spillage and buildup per MSHA statistics), see Figs. 4 and 7.
- Belt wear: poor chute design can reduce belt life by as much as 75% and belting is the largest cost of the conveyor system, see Figs. 5 and 6.
- Material degradation: leads to dust generation, reduction in the quality of the material and in some extremes the cause of a fire or an explosion, see Fig. 8.
- Chute wear: as conveyor throughputs become larger, the down time to fix and repair a chute will not only be a direct maintenance cost but a lost of production, directly impacting the output of the facility, see Fig. 9.
- High cost of maintenance and/or operation: this is probably the most forgotten aspect of the chute. It is something that is a bad by product of a poor design that most operators live with and just tend to write it off on the bottom line.

3.3 Design and Creation of an “Accurate Virtual World Model” with DEM

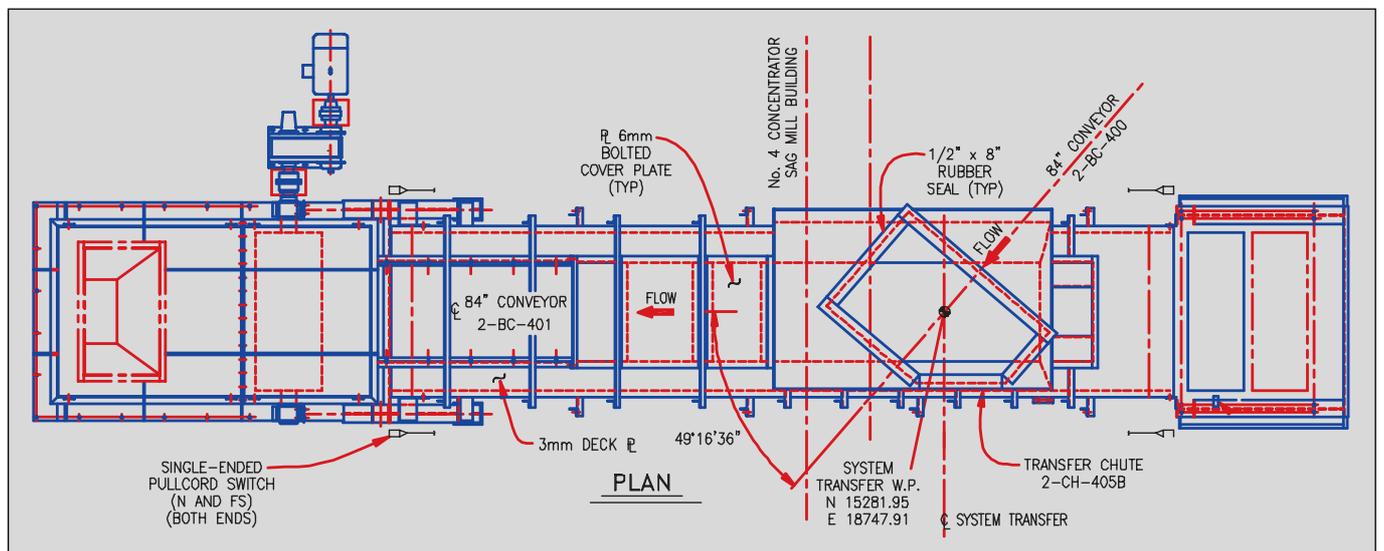
Chute Analyst™ is a design tool utilizing DEM/CAD technology that provides computer simulations of material flow in actual industrial transfer points. It enables the engineer to design a chute, simulate the material flow through it and optimize chute geometry. It has been used by Overland Conveyor Company since 1997 to model an extensive number of new and existing transfer points. These analyses have simulated different geometry, conditions (like dry, wet) and various materials, including run-of-mine and clean coal, copper/gold ore, sulfur, coke, aggregate materials (like gravel, marble, rock), waste products and many more.

The typical process that a designer and/or engineer performs to retrofit an old or design a new transfer points are as follows [5].

Transfer Chute New and/or Retrofit Design Steps:

1. Render accurate 3-D CAD representation of old transfer or new transfer

Fig. 10: Original geometry and overall chute layout



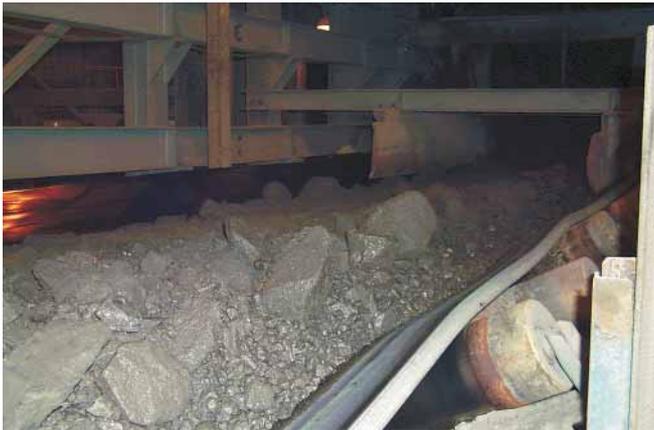


Fig. 11: Material on BC 401 conveyor belt from the new BC 400 chute

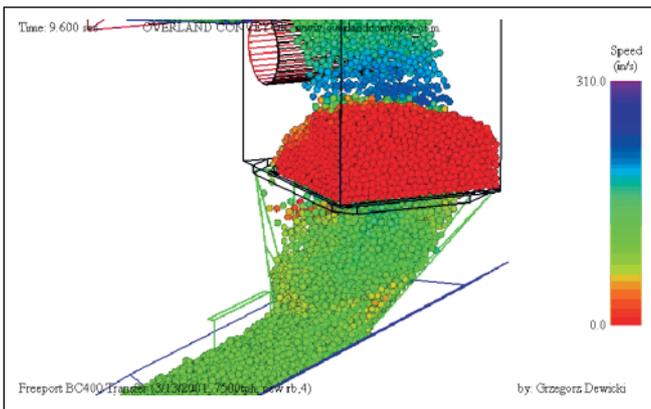
2. Identify chute geometry restrictions and manufacturing limitations
3. Identify project goals (i.e. dust emissions, flow restrictions, etc.)
4. Identify material properties and develop representative particle description
5. Make design changes to chute geometry with CAD
6. Simulate performance using Chute Analyst™
7. Evaluate simulation results
8. Detail Design
9. Manufacture
10. Installation

A good example of a transfer chute retrofit project is conveyor BC400, at Freeport/McMoRan's Grasberg Mine in Indonesia (one of the world's largest copper and gold mines). This existing chute had been in place and operating for several years. This application seemed to be a very simple chute that could have been successfully designed using rule's-of-thumb techniques and engineering. However, this transfer chute had a very poor operational performance history with high maintenance expenses.

The original geometry and overall chute layout is shown in Fig. 10.

The original chute was made up of two sections, upper chute (head chute) and lower chute (receiving chute). The upper chute had a rock box in it that was used to protect the sides and front of the chute from material wear and at the same time redirect the material flow down into the lower chute. The lower chute had a slanted side and a rock box as to protect the sides of the chute, with vertical sections that would mate with the skirting of

Fig. 12: Final geometry, BC 400 Chute with material, 7500 t/h



the chute to help to center load the receiving belt-conveyor. It looks like a very straightforward chute with the angle between the incoming and outgoing conveyor of 130.72°. The major problems that were reported by the mine site were as follows:

- The material position on the receiving belt-conveyor was not center loaded, causing belt miss-alignment and excessive skirt wear.
- The receiving conveyor belt was wearing out prematurely (three to four months at an extreme replacement cost to the mine).
- Extreme build-up of material in the chute, in some cases leading to plugging causing unplanned down time in production.

Using the nine step criteria mentioned previously, chute geometry was developed that met the mine site design criteria. Fig. 11 shows a brief look at the chute and the material as it flows out of the new chute in current operation.

A new engineering analysis software system based on Chute Analyst™ is an effective engineering design tool. The original transfer point had problematic material flow characteristics which lead to poor operational performance and high maintenance costs because of wear problems. The DEM/CAD re-designed transfer point (see Fig. 12) has been operating very efficiently in terms of material flow with minimal wear and low maintenance costs for over a last year now.

4. Conclusion

With the increase in complexity of conveyor systems, the ability to accurately predict performance is becoming increasingly important. One method of quantifying performance and simulate real life applications with out building and running them is to construct a numerical models. This can be done quickly and economically and the influence of various parameters can be determined prior to installation. Perhaps the greatest benefit that can be derived from the use of these tools, is the feeling an experienced engineer can develop by visualizing performance prior to the need for high availability and reliability. From this, the design can be started with the transfer station components arranged in a way as to minimize and even eliminate the unwanted behavior. In other words, eliminate as much of maintenance and retrofit costs as possible while increasing the over all reliability and availability.

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