

Computer Simulation Solves Conveyor Problems

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The ability to simulate conveyors and the dynamics of high-volume bulk material handling problems on a computer helps engineers design better transfers and chutes. As computer hardware continues to advance, simulators will only become more common in the design process.

Just as important as hardware, mathematical methods such as Discrete Element Modeling (DEM) help solve real-world problems. DEM is a relatively new finite difference mathematical scheme perfectly suited to bulk material handling problems as it explicitly models the dynamic motion and mechanical interactions of particles in a physical system. By monitoring this interaction, the behavior of the bulk material can

be better understood. The first use of this new technology in the field of bulk material handling has been in the analysis and design of belt-conveyor transfers.

ADVANCES IN DISCRETE ELEMENT MODELING ALLOW DESIGNERS TO MORE ACCURATELY MODEL CHUTES AND TRANSFERS

One of the most important benefits of conveyor haulage is its continuous operation and high reliability/availability. If a

conveyor system is working well, it is almost invisible to the mine. A single conveyor can run at close to 100% availability, but as the number of conveyor flights increases, the availability of the conveyor system decreases. Mine engineers always strive to handle material with the least number of conveyors possible.

A number of technological advances allow mines to run longer, continuous flights.

Better belting and modern drive technology contributes to the lengthy designs. In one application, 11 individual drive locations and 17 horizontal curves were incorporated into a design of a single 9-mile conveyor.

But, no matter how good conveyor technology becomes, material will never be conveyed throughout a mine or plant on a single conveyor. Therefore, conveyor transfers will always be necessary to move material to and from multiple conveyors and processing equipment. As the number of flights increase, so does the number of transfer chutes.

BUILDING A BETTER TRANSFER

Most mine operators would agree that conveyor transfers (or chutes), particularly between two belt conveyors, are a major source of maintenance headaches and downtime. Several problems normally develop with high-volume transfers, including:

- **Plugging-** Stops the entire mining operation;
- **Spillage-** Roughly one-half the accidents around belt conveyors are attributable to cleanup and repairs due to spillage;
- **Belt Wear-** Poor chute design can reduce belt life by 75%;
- **Belt Damage-** A sharp object that penetrates a belt can destroy it in a matter of minutes;
- **Chute Wear-** Conveyors now carry as much as 10,000 tons per hour and mines produce 10 million tons per year, therefore conveyor wear points must be kept to a minimum or constant attention will be required; and
- **Material Degradation-** Leads to heavy coal dust generation.

Although transfers are problematic, transfer design has historically received little attention. This is because transfer design has been more of an art than a science. Designers often resort to rule-of-thumb approaches where one chooses arcane solutions that often lead to fixes in the field. Computer simulation can stop the problems before conveyor crews turn the first wrench.

Almost all mining conveyors are unique and a conveyor's physical size and complexity renders prototypes or small-scale models impractical. Computer simulation, however, allows engineers to observe dynamic interactions. In other words, computer sim-



To solve transfer plugging problems, West Elk employed a computer simulator that used discrete element modeling.

ulation is the discipline of designing a model of a physical system, executing the model on a computer, and analyzing the results.

PRACTICAL APPLICATIONS

Arch Coal's West Elk mine, a high-production longwall mine located near Somerset, Colo., uses conveyors to move coal from the face to the plant. West Elk has diligently sought and implemented advanced technology over the years to

improve its belt-conveyor system. Consequently, they now operate some of the most advanced conveyor equipment available on the market.

Most high-volume mines are faced with transfer problems and West Elk was no exception. West Elk engineers were one of the first to use DEM technology in the mid-1990s, so when the company identified a transfer problem in the summer of 2000, they again turned to the technology.

The first transfer after coal exits the portal was identified as a bottleneck. If coal volume exceeded a certain amount, the chute would plug, shutting down the entire mine. Operators became so aware of the capacity limitation, they could predict plugging by watching the belt scale.

A 3-D model of the transfer problem was created in AutoCAD using existing drawings and field measurements. The coal was studied to understand the critical parameters such as density, moisture content, and lump size distribution and these characteristics were used to develop a mathematical representation of these coal particles. All of this data was then entered into the Chute Analyst program developed by Overland Conveyor Co. to simulate the flow of coal through the existing structure.

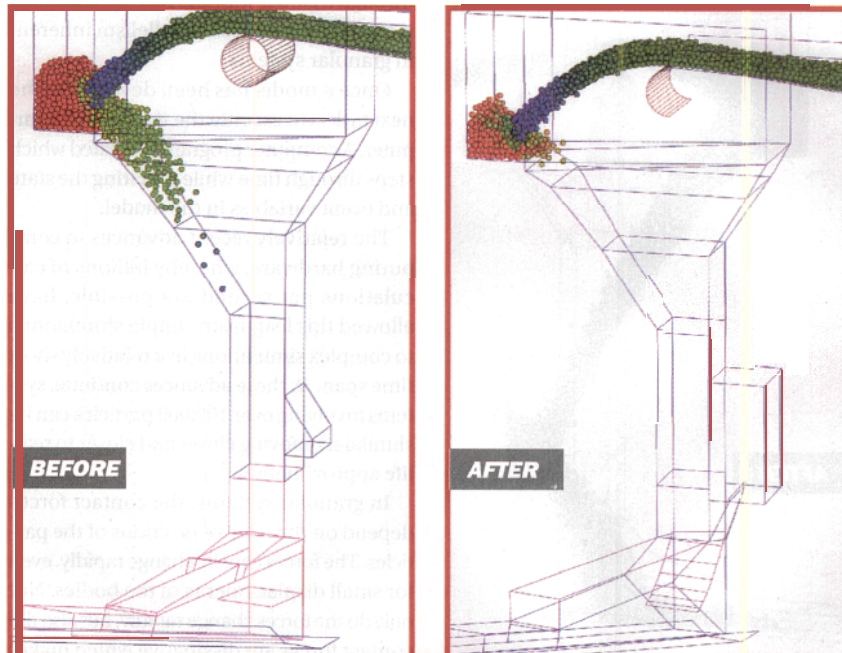
A set of 3-D computer-generated animations were recorded that showed over 50,000 particles of coal flowing from the discharge conveyor to the receiving conveyer (See Figure 1). In these animations, the velocity of each particle is color coded, allowing the engineer to visualize where the material is flowing properly vs where it is impeded. Red indicates zero velocity; therefore, all particles approaching the color red are slowing down. The tonnage known by the mine to cause a plug was entered into the computer and the condition was simulated exactly as it occurred in real life (See Figure 4A).

Knowing that the problem could be properly modeled gave the engineers confidence a solution could be achieved. Although the chute is more than 70-feet high, only three specific areas were identified as problems. These three areas of the chute were modified one at a time starting with the highest area [first to see the coal flow] and the simulation was rerun to ascertain the results of each individual change. After four iterations of structural changes and simulation, an optimum solution was found. The coal flowed through the entire transfer without any inappropriate disruption (See Figure 4B). The drawings were completed, fabrication and installation of the changes were made, and the transfer performed as the computer predicted. This bottleneck was eliminated on the first try.

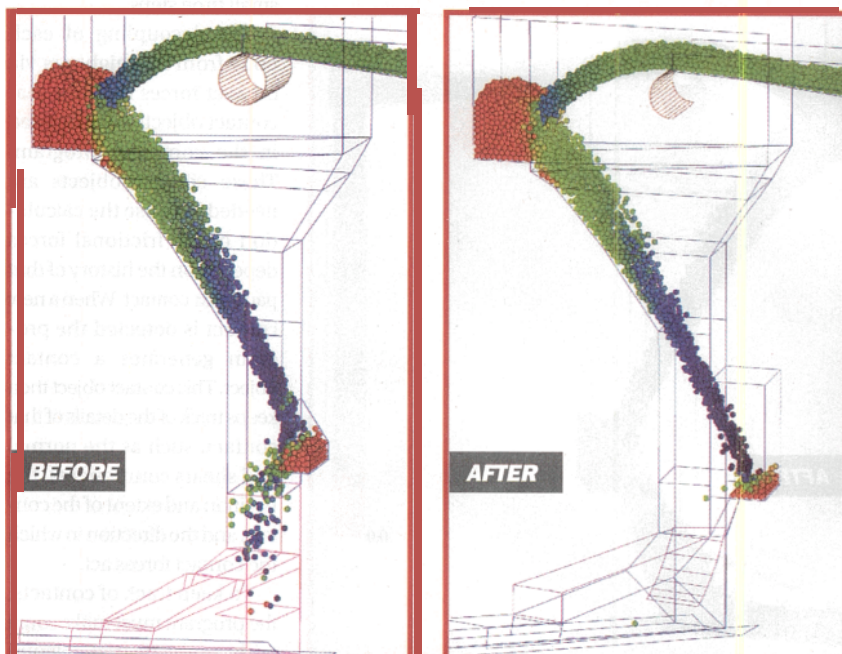
HOW THE DISCRETE ELEMENT METHOD WORKS

To simulate something physical, a mathematical model is created which represents the physical object. This may sound simple, but it's usually the most difficult task. The accuracy of the simulation effort starts here as the artificial world and its rules are defined.

The research in DEM captures the contact forces between individual particles in



Figures 1A and 1B—Coal enters the top of the transfer chute work.



Figures 2A and 2B—As the coal makes its way toward the bottom it strikes the wear box.

an explicit manner. In contrast, continuum methods spread out the individual particles into a smooth surface. The discrete element method captures the individual geometry and dynamics of each particle, including the dissipative effects of contact friction.

As a simple example, when a rock is dropped onto the sand at a beach, the rock does not bounce, but sticks in the hole it has made. While the material of each particle is relatively elastic, the relative motions

between the particles dissipates the energy so that the overall behavior is inelastic. When the rock is picked up, the hole basically remains intact. Although lower energy states are possible, contact forces between particles are sufficient to keep the particles in place. These two simple actions demonstrate the unique properties of particulate systems. They exhibit some of the properties associated with both liquids and solids but cannot be characterized by either of them alone.

The fundamental unit of a discrete element scheme is the single particle. In contrast to the finite element method, which often assembles a global, functional matrix for the total system, the discrete element method views the individual particles as the fundamental unit. Interaction with neighboring particles is achieved by replacing the contact conditions between bodies by external forces. All communication between bodies occurs through boundary forces and not through a global stiffness matrix. The effect is to make the explicit parallelism inherent in granular systems.

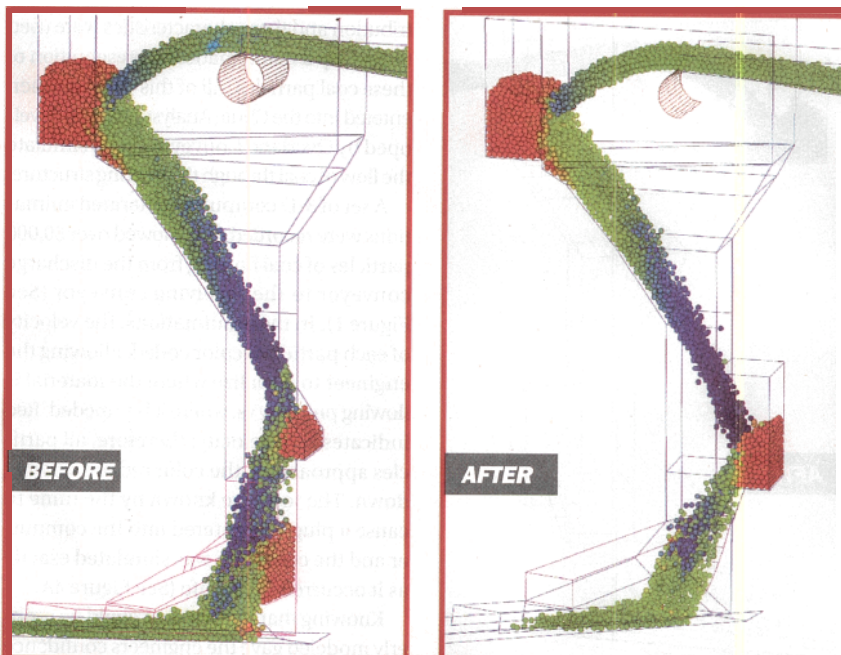
Once a model has been developed, the next task is to execute the model on a computer. A computer program is created which steps through time while updating the state and event variables in the model.

The relatively recent advances in computing hardware, whereby billions of calculations per second are possible, have allowed this leap from simple simulations to complex simulations in a relatively short time span. As these advances continue, systems involving over 100,000 particles can be simulated, moving closer and closer to real-life approximation.

In granular systems, the contact forces depend on the relative positions of the particles. The forces usually change rapidly, even for small displacements of the bodies. Not only do the forces change rapidly, but also the contact forces are dissipative which makes the system highly non-linear. The only way to achieve an accurate solution is to take very small time steps.

The decoupling of each body from its neighbors via contact forces requires that contact objects be generated in the computer program. These contact objects are needed because the calculation of the frictional forces depends on the history of that particular contact. When a new contact is detected the program generates a contact object. This contact object then keeps track of the details of that contact, such as the normal and shears components, the position and extent of the contact, and the direction in which the contact forces act.

To keep track of contacts, the program must make some fairly sophisticated calculations. The difficulty arises because of the finite time step



Figures 3A and 3B—The redesigned chute geometry allows material to flow more smoothly.



Figures 4A and 4B—The newly remodeled chute work demonstrated a free-flowing transfer.

and the finite motion that particles undergo between time steps. For example, consider that the computer has detected a contact between two bodies at a given time step. Consider now that the bodies translate and rotate a finite amount by the next time step. The program now detects a contact at a different physical location on each body and must make the decision whether or not this is a new contact or just the old contact that has moved. If it is the old contact then the contact forces must be translated and rotated to their new location. Even if there is no relative motion at the contact point itself, and the magnitudes of the contact forces do not change, the computer program must still rotate the old contact forces to their new orientations. For this and other reasons contact detection and resolution of contact forces is one of the most computationally demanding parts of any discrete element code.

Once all the external forces acting on the body are known, the acceleration, velocity, and displacement of the body can be calculated. For rigid bodies this is a straightforward application of Newton's laws of conservation of linear and rotational momentum. In the case of deformable bodies there are several choices available,

Execution of these models generates extremely large amounts of data. Data, how-

ever, is of no value unless it is turned into knowledge. To accomplish this, a whole field called "scientific visualization" has developed. This task is just as important if not more important than the first two as this is where the simulation provides its answers.

DEM MODELING OF BELT CONVEYOR TRANSFERS

Dr. Andrew Hustrulid, director of marketing and applications engineering for Scandura, was the first to apply DEM to conveyor transfers while working on his Ph.D. from the Colorado School of Mines in 1995-97. Since then, Overland Conveyor has continued the research and development of DEM and has proven that it's an excellent computational tool for simulating the material flow in transfer stations many times over.

The 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. Today, bulk material transfer modeling is used to: optimize material flow, minimize abrasion to the belt and chute, and minimize dust and material degradation.

In the transfer point DEM model, the particles of material are modeled with a system

of spherical-shaped bodies. The material bodies can interact with other material bodies, with steel chute 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 a 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.

There is no doubt computer simulation using DEM technology has become the state-of-the-art in conveyor transfer design. As it continues to develop along with computer hardware advances, this tool will become even more powerful and efficient and will find its way into many other areas of bulk material handling. CA

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