CHAPTER 2

ENGINEERING ANALYSIS OF TRANSFER POINTS USING DISCRETE ELEMENT ANALYSIS

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An advanced numerical model based upon the Discrete Element Method (DEM) has been developed to provide the engineer with unique detailed information to assist in the design of transfer points in large industrial conveyor systems in mining operations. This modeling technique provides a quantitative description of the bulk solids movement through the transfer point. This information consists of the velocity distribution of the bulk solids and the stresses within the bulk solids. The DEM model also gives detailed information concerning the impact forces acting on the transfer structure and the conveyor belts from the bulk solids flow.

INTRODUCTION

In this paper an application of a DEM model to the analysis of a transfer point in an underground coal mine is presented. The results of the model clearly illustrate the flow of the coal through the transfer point. The simulation also shows the transition region on the lower belt where the coal is being accelerated up to the belt speed. The impact force distribution in this region of the belt can be used to provide belt wear information. Although belt wear is not an issue with this transfer point, for other mining operations where very abrasive materials are being transported this will be an important design constraint. Predicted impact forces on the transfer point structure are also shown.

Within the DEM model many design parameters can be changed so that the effect of each design parameter on the overall performance of the transfer point can be assessed. These parameters include; (i) the conveyor belts orientation, geometry and speed, (ii) the size and geometry of the transfer point structure, and (iii) friction, restitution coefficients and the size distribution of the bulk solids bodies.

HISTORICAL REVIEW

Traditionally, in the design of a conveyor belt system, the majority of the time and money is spent on the belting, supporting structure and control. Minimal effort has been made in the design and analysis of the transfer points. With the continued increase in tonnages needed today more effort needs to be spent at the transfer points. A properly designed transfer point should minimize belt wear, control dust, and efficiently transfer the material from one belt to the next. Three levels of transfer point design; drafted, specified, and engineered are common (Swinderman 1994). Swinderman defines an engineered transfer point as;

> "The engineered transfer point design method requires analyzing the conveyed material's flow properties. The method then uses fluid mechanics to engineer custom transfer point chutework to minimize disruption of the material's trajectory and place material on the receiving belt in the right direction and at the receiving belt's speed."

The engineering method that Swinderman eludes to is a fluid mechanics model. This method has been implemented by (Nordell 1994) in two dimensions to aid in the design of a curved transfer chute. This fluid mechanics model represents a significant step toward a engineered transfer point design method. However, there are significant drawbacks in using a fluid mechanics or Eulerian type model; (i) the flow regime must be specified apriori, (ii) material size distribution can not be readily included and (iii) the material is assumed to behave in a continuous manner. The Discrete Element Method (DEM) overcomes these limitations by modeling the physical discontinuous material flow by considering each individual particle, its interactions, and its motion within the system. It is therefore, proposed that a rationally based engineering designed transfer point method utilizes a DEM model rather than a fluid mechanics model.

OVERVIEW OF THE DISCRETE ELEMENT METHOD

In this section we give an overview of the discrete element method (DEM) in general terms, and then provide a description of the DEM transfer point model developed and used in this study.

DEMs are a family of numerical modeling techniques specifically designed to solve problems in engineering and applied science that exhibit gross discontinuous mechanical behavior. It should be noted that problems dominated by discontinuum behavior cannot be simulated with conventional continuum based computer modeling methods such as finite element or finite difference procedures. Some examples of geo-engineering problems dominated by discontinuum behavior include: stability of rock slopes comprised of a blocky rock mass, stability of underground coal mine openings, micromechanical behavior of particular media such as soils, and the flow of bulk solids in hoppers, chutes and conveyor systems. For further details of DEMs the interested reader should refer to (Mustoe 1989 and Williams 1993).

The DEM explicitly models the dynamic motion and mechanical interactions of each body or particle in the physical problem throughout a simulation, and provides a detailed description of the positions, velocities and forces acting on each body or particle at discrete points in time, called time steps, during the analysis.

In a typical DEM algorithm the following tasks are performed:

- Solution of the dynamic equations of motion for each body in the system
- An automatic collision detection module that continuously determines which pairs of bodies are in contact.
- A contact force algorithm that uses Newton's third law to compute the forces acting on pairs of contacting bodies.
- Computer graphics modules for pre- and post-processing tasks such as DEM model data generation and visualization of the DEM computed results.

In the transfer point DEM model the pieces of coal are modeled with a system of spherical shaped bodies of varying sizes. The contact/impact phenomena between the interacting coal bodies, the coal bodies interacting with either the transfer point surfaces, or the conveyor belt surfaces are modeled with a contact force law which has components defined in the normal and shear contact 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 contacting bodies, and the normal viscous damper coefficient is defined in terms of an equivalent coefficient of restitution. The shear contact force component is governed with a Coulomb friction model, and defined with a simple friction coefficient. The springs and dashpots modeling the contact law is illustrated in Figure 1.

The geometry of the transfer point structure and the conveyor belt surfaces are described with a discretization of user defined planar surfaces. Motion of the conveyor belt surfaces is specified with a user defined tangential velocity profile. Contact checking between the bodies and the surfaces is performed in an efficient manner, by using an algorithm that subdivides the three-dimension workspace into a cubic grid. The task of contact checking is then done with a 'divide and conquer' type computational strategy to minimize the computational effort.

SOUTH MAINS TO WEST MAINS TRANSFER POINT

The conveyor belt transfer point from the South Mains belt to the West Mains belt at Cyrpus AMAX Twentymile Coal Company has been modeled using the Discrete Element Method (DEM). This is the first time the DEM has been used to model the material flow at a transfer point and this project shows the applicability and possibilities available with this method. The results show that the DEM is capable of modeling the material flow at a transfer point in significant detail that was previously unavailable to engineers.

During a site visit several photographs of the transfer point were taken. Figures 2 and 3 show several views of the transfer point.

The belting and transfer point are designed for 3629 t/h (4000 tph). The transfer point is more commonly operated at 2903 t/h (3200 tph) so this tonnage is used in the analysis. Both the incoming and exiting belts have the same troughing geometry and speed. The belts are both traveling at a speed of 3.81 m/s (750 *fpm*), are 1.524 m

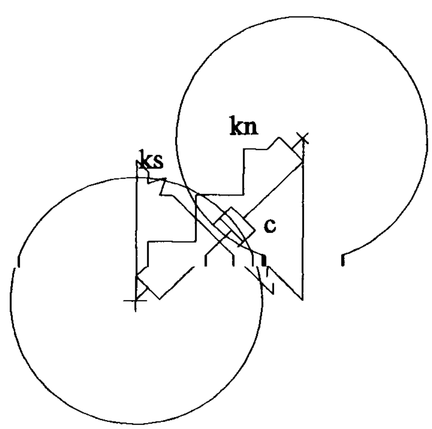

Figure 1. Contact Model

Figure 2. Transfer Point Geometry — Front View

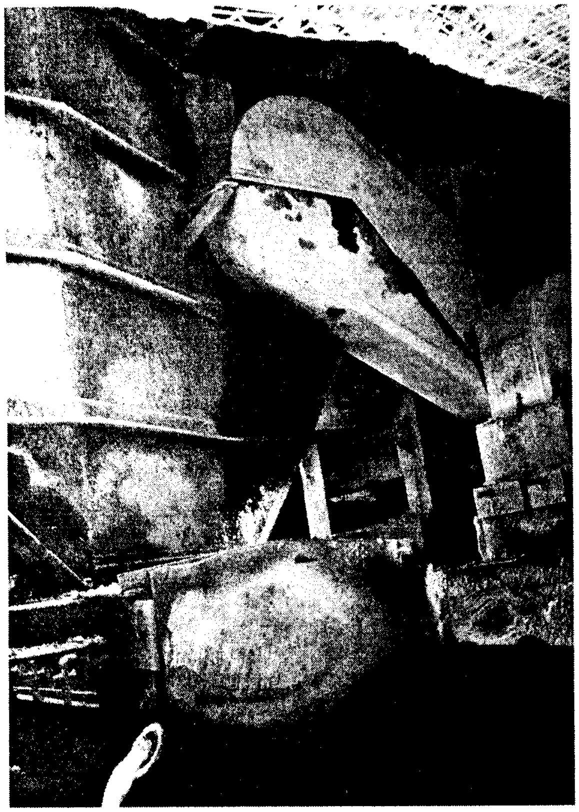

Figure 3. Transfer Point Geometry — Rear View

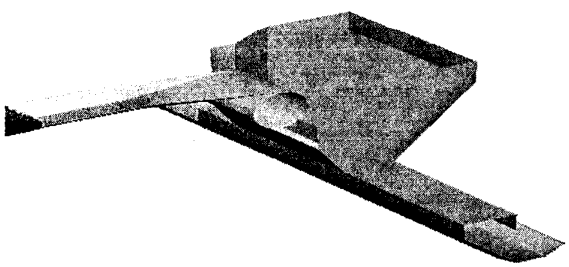

Figure 4. Transfer Point Geometry — Front View

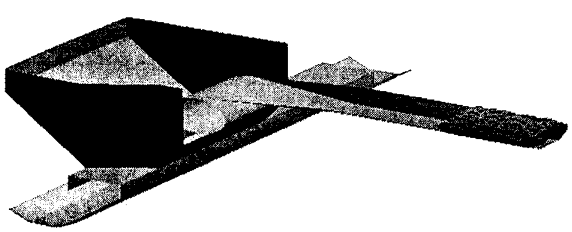

Figure 5. Transfer Point Geometry — Rear View

(60 in) wide, and are supported on 35 degree troughing idlers. The transition distance of the incoming belt has been modeled as 3.175 m (125 in) with the head pulley at full trough depth.

DISCRETE ELEMENT TRANSFER POINT ANALYSIS

The transfer point between the South Main to West Main belts at Cyrpus AMAX Twentymile Coal Co. has been modeled with the three dimensional DEM model. The transfer point geometry modeled is shown in Figures 4 and 5.

Material Properties

Run of Mine (ROM) coal is being handled at this transfer point. The density of the coal is $913\ {}^{kg}/_{m^3}$ ($57\ {}^{lb}/_{ft^3}$) with a surcharge angle of 20 degrees. At the actual transfer point there is an approximate size distribution of the particles ranging from approximately 203 mm (8 in) to 25 mm (1 in) diameter as summarized in Table 1.

Size	Percentage
-203 mm (-8")	10%
-152 mm (-6")	15%
-102 mm (-4")	25%
-59 mm (-2")	35%
-25 mm (-1")	15%

Table 1. Material Size Distribution

The coefficients of friction used in the model are determined by modeling piles of the material and measuring the angle of repose. The coefficients of friction used in this simulation are summarized in Table 2.

Interaction	μ
Coal - Coal	0.3
Coal - Rubber (Belting)	0.7
Coal - Steel (Transfer Structure)	0.2

Table 2. Coefficients of Friction

The amount of energy loss occurring during a collision is specified with a coefficient of restitution, e. The coefficient of restitution is proportional to the ratio of the energy remaining after a collision compared to the energy before the collision occurred. In this simulation a coefficient of restitution of 20% is used which corresponds to a ratio of 4% energy loss.

Modeling the Incoming Material

Several methods were attempted to load the material on the incoming belt at the specified flow rate. The method that works most efficiently is to randomly generate the material and allow it to fall on to and be accelerated by the upper belt. The material sizes are also randomly generated to give the specified material size distribution.

Measuring the Exiting Material Flow Rate

The flow rate of the material on the lower belt is measured at the "end" of the lower belt. As the particles move beyond the end of the belt modeled in the simulation their masses are recorded and they are removed from the simulation. The removed mass is summed over a period of time and then divided by the length of time summed over, resulting in the material flow rate. Figure 6 shows that the steady mass flow rate for this simulation is approximately 2903 t/h (3200 tph) which is in agreement with the specified injection flow rate.

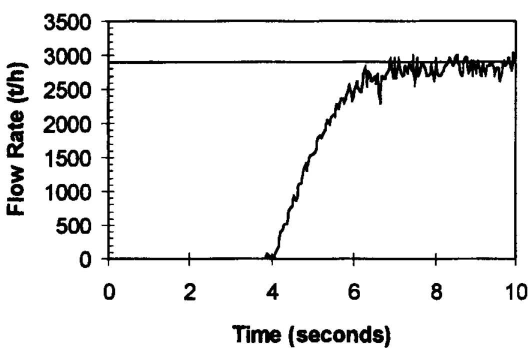

Figure 6. Mass Flow Rate

Tension Increases Along the Lower Belt

One measurement that is used to compare this method with current material handling guidelines is the tension increase in the transfer point area of the lower belt. This measurement can be directly compared to what CEMA (1988) predicts. The tension increase in the lower belt can be extracted from the model by looking at the total force acting in the direction of motion on the lower belt. According to CEMA this force results from two components, (i) the acceleration of the material up to the speed of the belt, and (ii) the friction between the material and the skirt boards.

The force required to accelerate the material is calculated exactly as

$$T_{am} = Q \cdot V = 2903\,{}^{t}/_{h} \cdot 3.81\,{}^{m}/_{s} = 3.072kN$$

The force resulting from the drag force between the skirt board and the material is calculated as

$$T_{sb} = C_s L_b h^2_s$$

where

Cs = Skirt board friction factor $\left(\frac{kN}{m^3}\right)$

L_b = Skirt board length (m)

h_s = depth of material touching the skirtboard (m)

For bituminous mined coal a value of $C_s = 1.706 \frac{kN}{m^3}$ ($0.0754 \frac{lb}{in^2 ft}$) is used. The length of the skirt boards is approximately $L_b = 6.757\ m$ ($22.17\ ft$) and the depth of the material touching the skirtboards at a flow rate of $Q = 2903 \frac{t}{h}$ is $h_s = 0.068m$. The drag force from the friction between the material and the skirt boards is

$$T_{sb} = C_s L_b h^2_s = 1.706 \frac{kN}{m^3} \cdot 6.757m \cdot (0.068m)^2 = 53.4N$$

Figure 7 shows the comparison between the forces calculated with the DEM simulation and the CEMA predictions.

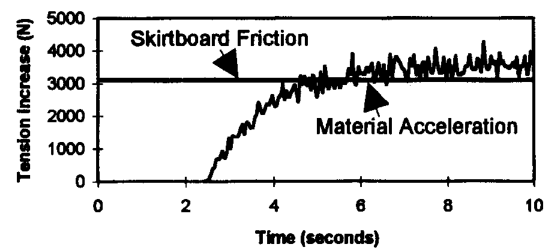

Figure 7. Forces Acting on the Exiting Belt

The forces acting on the skirt boards were also calculated in the simulation. The comparison with CEMA predictions are shown in Figure 8.

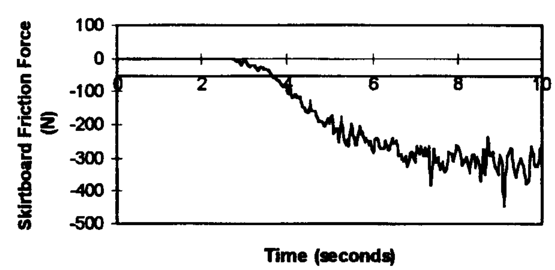

Figure 8. Forces Acting on the Skirt Boards

Material Velocity and Shear Force Profiles

The following computed data at a specified time is illustrated as an example of the detailed information that was determined from the DEM model.

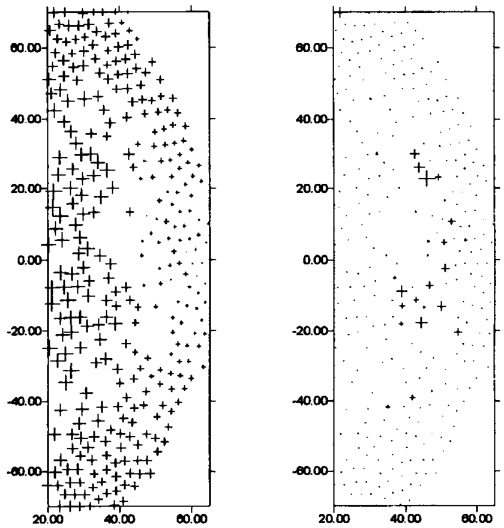

Figure 9. a) Relative Velocity of Contacts BetweenCoal and the Inclined Ttransfer Point Back Plate. b) Shear Forces Acting on the Inclined Transfer Point Back Plate.

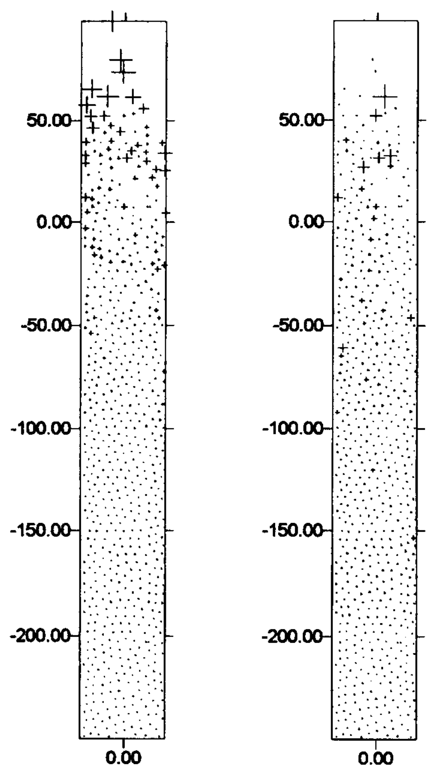

Figure 10. a) Relative Velocity of Contacts Between Coal and the Exiting Belt. b) Shear Forces Acting on the Exiting Belt.

Figures 9a and 9b show typical spatial profiles of the relative velocity and shear forces acting on the inclined transfer point back plate.

Figures 10a and 10b show typical spatial profiled of the relative velocity and shear forces acting on the exiting conveyor belt in the transfer region.

The actual determination of wear requires the data from a series of spatial data at various times during the steady state phase of the simulation. Wear can then be predicted by using a combined spatial and temporal averaging process. The development of this averaging process in currently in progress and will be reports in a subsequent article.

CONCLUSIONS

This initial study of a transfer point using a DEM simulation has been successfully completed. The DEM procedure has provided the following preliminary information: (i) the material flow regime as it passes through the transfer point, (ii) forces acting on the transfer point structure, and (iii) forces acting on the lower conveyor belt at the load point region. Much of this information could not have been obtained by existing engineering analysis technology.

The major advantage of the DEM is that several different proposed transfer point designs can be evaluated with respect to; (i) the flow regime of bulk solid, (ii) the location and amount of wear within the transfer point, and (iii) the profile and amount of wear on the conveyor belt receiving the bulk solid.

Further work could now be undertaken to predict specific data on; chute flow vs. material tonnage flow rates, material buildup within the transfer point due to moisture and belt wear, sizing the transfer point bin and optimizing geometry.

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