Discrete Element Modeling of Sag Energy Losses in a Conveyor Belt System

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Energy losses are important factors in a conveyor's performance and design. A significant energy loss due to belt sag within a conveyor system occurs when shearing motion between the bulk material particles occurs as the material moves along the belt.

An initial analysis of these phenomena was performed using the discrete element method, which is a general-purpose numerical modeling technique for analyzing the mechanical behavior of particulate materials. The software used in this work was Overland Conveyor Company's, Chute Analyst Professional, a discrete element computer code designed specifically for analyzing bulk materials transportation and handling problems.

INTRODUCTION

This sag energy loss has been studied previously using analytical mechanical methods that employ several simplifying approximations such as: (a) dry bulk material, (b) assumed pressure distributions between the bulk material and belt, and (c) inertial effects within the bulk material and belt, etc. For further details of these studies see Spaans 1999, Brands 2001, and Wheeler 2003, 2005.

The current work employs a discrete element method (DEM) modeling approach eliminating the need for many of the simplifying assumptions required in previous analyses. See the DEM conference proceedings Mustoe et al. 1989, and Williams and Mustoe 1993 for a detailed description of the discrete element method. Furthermore, a DEM algorithm specifically designed for bulk solids analysis is described in Hustrulid, and Mustoe, 1996.

The DEM method models: (a) the bulk material as a discrete system of particles with a specified size distribution, and interaction laws for dry and wet materials, and (b) the belt geometry shape with a detailed 3D CAD description. In this paper the effects of belt sag are studied for a dry bulk material.

TECHNICAL APPROACH

In the work described here the discrete element method is used to analyze the conveyor belt sag problem. This type of analysis provides a detailed prediction of the motion of the bulk material and its interaction with the conveyor belt.

The DEM model of the conveyor system employed simulates the mechanical behavior of a region between two sets of adjacent idlers on the belt. The configuration for this study and is a three-roll system with a 60 in. wide belt, a 20 in. center flat region, with two inclined rolls at 35° to the horizontal direction. The belt is loaded to approximately 80% of its capacity with coal material and the belt speed is defined as 120 in/s. The coal material is modeled as a system of 2 in. diameter particles, with a mass density of 1.064×10^{-4} lb-s^2/in, a coefficient of friction of 0.3, and a coefficient of restitution of 0.2.

The geometry of the conveyor belt surface has a deformed shape defined by equations developed from a semi-analytical approach described in Spaans 1999. The longitudinal vertical sag displacement function is defined by:

$$u_z(x) = C_1\left[x^2 + C_2\frac{x}{\sinh(C_3x)}(1 - \cosh(C_3x))\right] \quad \textbf{EQ. 1}$$

where

$C_1 = 3.54 \times 10^{-4}$

$C_2 = 57.9$

$C_3 = 0.184$

Note, these parameter values were determined for the specific DEM conveyor model described above.

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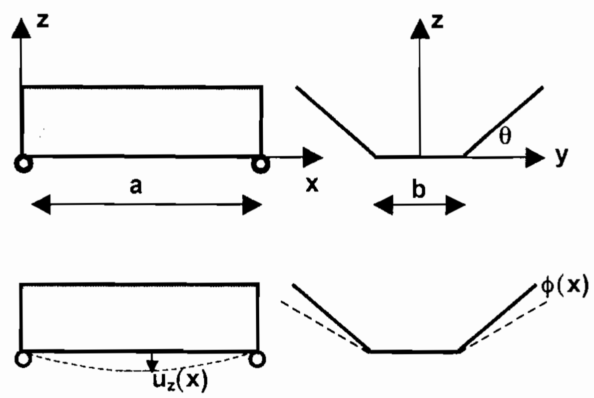

FIGURE 1 Geometry definition of the conveyor belt model, and the vertical sag displacement and bulge angle

The bulging of the belt between the idlers is approximated by assuming the maximum belt opening at the belt edge is equal to the maximum vertical sag displacement. The corresponding bulging angle function is defined by:

$$\phi(x) = \phi_{max} u_z(x)/u_{max} \qquad \text{EQ. 2}$$

where $u_{max} = u_z(a/2)$ and $\phi_{max} = u_{max}/R$ are the maximum values of vertical sag displacement and bulging angle respectively. Figure 1 shows the model geometry and the definitions of $u_z(x)$ and $\phi(x)$ respectively.

The DEM model consist of the following components:

1. A three-dimensional CAD model of the conveyor belt surface between sets of adjacent idlers, discretized with 3-noded and 4-noded planar boundaries.
2. The bulk material is modeled as a system of spherical particles.

DEM SIMULATIONS AND RESULTS

Figure 2 shows the DEM model geometries with different sags. Figure 2A shows the belt shape defined by the sag deformation and bulge angle equation defined with the values of C_1, C_2 and C_3 specified above. Figure 2B shows the belt shape defined by increasing C_1 by a factor of 2, and Figure 2C shows the belt shape defined by increasing C_1 by a factor of 3.

Figure 3 illustrates the average stress acting on the coal particles for each of the three DEM Models with different sag deformations. Note that red particles have low stresses and blue particle have maximum compressive values. These figures clearly show the increase in compressive stresses acting on the coal particles that are near the downstream idler set adjacent to the belt surface. Note animation of the material flow in these DEM models, shows the reversal of the active and passive stress states in the coal material particles as the belt opens and closes between idler sets.

Figure 3C also shows that the DEM model with the largest mid-span bulging and vertical sag, compresses the coal particles near the downstream idler set to a much higher degree than predicted in other two DEM models with smaller sag deformations (see Figures 3A and 3B).

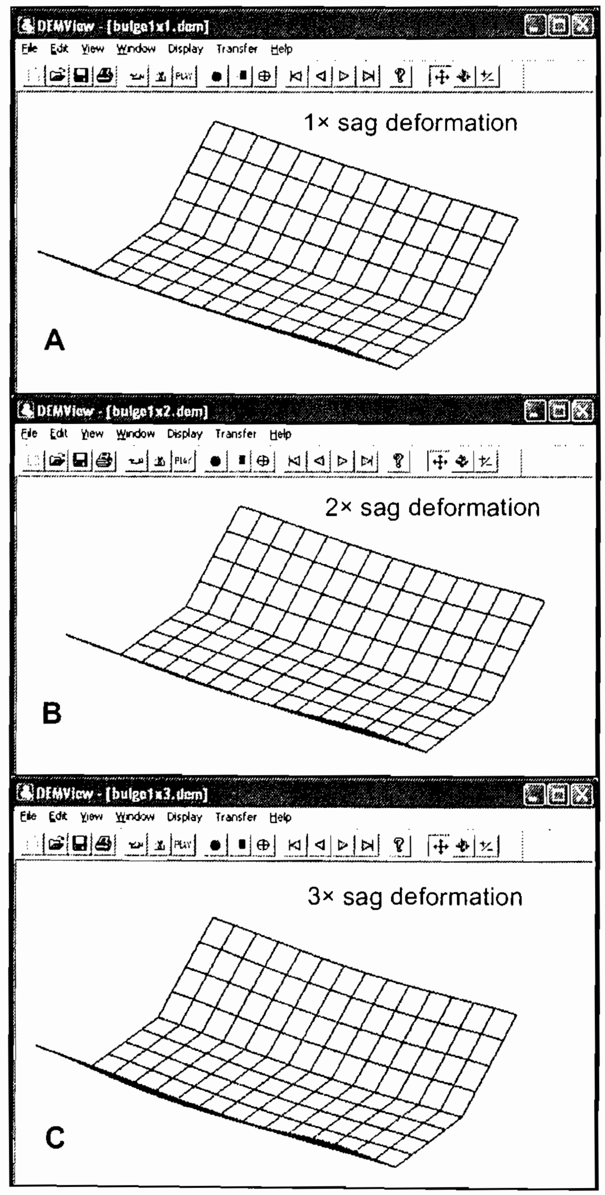

FIGURE 2 3D belt geometry of the DEM models with different sag

The average power requirements computed from the DEM models are reported in a non-dimensional format in Table 1. Note the power values in Table 1 are normalized with respect to the power requirements of the conveyor belt model (1 × sag) with the sag defined by the original values of C_1, C_2 and C_3.

CONCLUDING REMARKS

The initial DEM calculations reported show its applicability to the analysis of energy losses because of sag deformations in conveyor belts. The DEM results agree with previous studies and show that power requirements increase significantly as the magnitude of sag deformations increases. Further results using this DEM model will be presented at the conference.

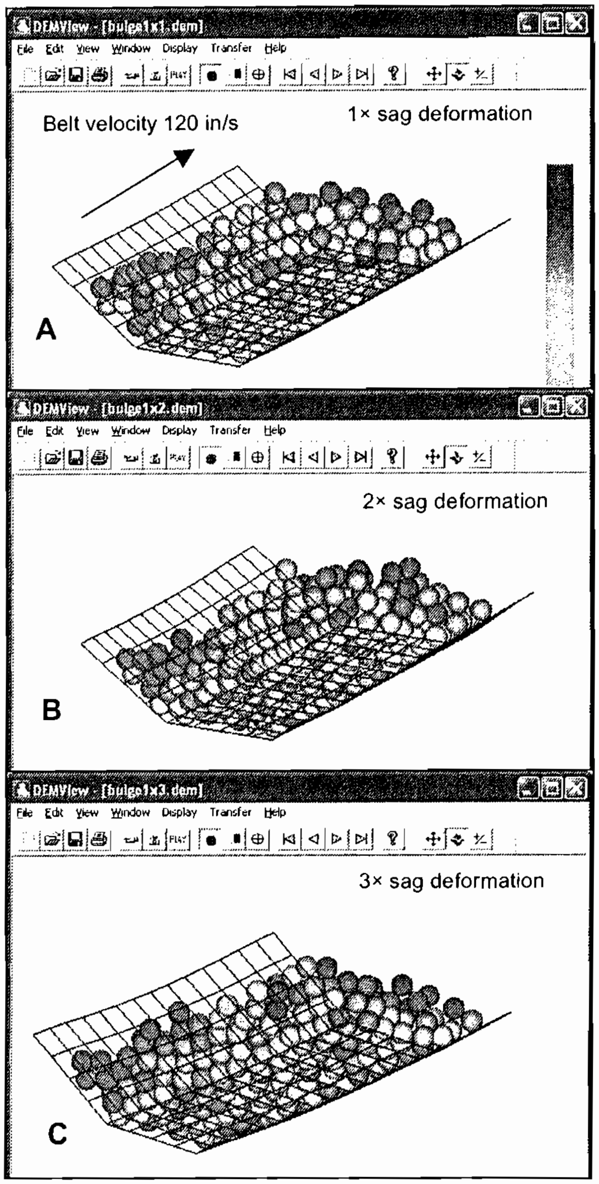

FIGURE 3 Average particle stresses in DEM models with different sag

TABLE 1 Normal power for DEM models with different sag deformations

DEM Model	Normalized Power
(1× sag)	1.00
(2× sag)	2.45
(3× sag)	3.92

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