SIMULATION OF TRANSFER CHUTE OPERATION USING THE DISCRETE ELEMENT METHOD

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Abstract. Transfer chutes are widely used in mining plants, mainly in the mineral product transfer between belt conveyors. However it is not rare to find chutes with problems like spillage, excessive dust generation, blocking, as well as problem in the belt conveyor such as poor belt alignment, higher impacts on idlers and belt failures (rip or damage). Therefore, it is necessary an accurate chute design before the manufacture where some steps need to be performed: accurate calculation of the trajectory of the material, the control of the material flow and material speed through the transfer, and ensuring the material is presented appropriately to the receiving belt. Therefore, this paper presents a study case of chute design to replace an existing problematic transfer chute of alumina (bauxite processed). The new chute consists of utilization of curve deflector plates inside the transfer (hood and spoon chute) and it is used the Discrete Element Method to assist the design and simulate the material flow through the transfer.

Keywords: Discrete Element Method, Transfer chute, Hood and spoon, Bulk flow.
1 INTRODUCTION

The mineral sector in Brazil plays a key role in economy of the Country. The Mining Industry is responsible for the positive balance of Brazil’s trade. From 2000, the increased demand for minerals, especially the high global growth rate, boosted the value of the Brazil’s mineral production (BMP). During 2001/2011, the value of the BMP had an increase of 550%, from US$7.7 billion to US$53 billion (IBRAM, 2012) as we can see in Fig. 1.

![Figure 1. Growth of Brazil’s mineral production In US$ billions (IBRAM, 2012).](image)

The private mining sector invests in the Country an average of over US$ 13 billion per year (IBRAM, 2012). Therefore all technological areas in mineral processing sector, such as comminution, dewatering, concentration, conveyor, etc. have been improved.

Equipment used in mining have also been undergoing an evolution in their design. Transfer chutes are one of them. Transfer chutes are a key component used for transferring bulk material from one conveyor to another (Fig.2). Among other uses it can also be used under hoppers or silos to transfer material to conveyors, trains, trucks or ships. In the past, the design of conveyor transfer chutes was traditionally based on trial and error or previous experience. Nowadays the design of transfer chutes has been improved since the advent of discrete element modeling (DEM) as well as increases in computer processing power.

![Figure 2. Transfer chute (CEMA, 2007).](image)
In this context, this work presents a study case of chute design to replace an existing problematic transfer chute of alumina (bauxite processed) which presents problems of blockage. The redesign is performed using the discrete element Method (DEM) through the software EDEM (DEM Solutions, 2013). Before the description of the case study, some issues about chutes and a briefly theory of DEM are presented.

2 TRANSFER CHUTES

Chutes used in bulk handling operations perform a variety of operations. For instance, Transfer chutes are employed for transferring bulk material from one conveyor to another. In other cases, they can be also be used under hoppers or silos to transfer material to conveyors, trains, trucks or ships. The correct chute design is to ensure efficient transfer of bulk solids without spillage and blockages and with minimum belt wear (Roberts, 2003).

Various chute configurations are used in the bulk materials handling industry. These configurations depend on the specific requirements of the system layout or material properties. There are basically three basic transfer configurations: chutes using impact plates, the rock box (or dead box) chutes and dynamic chutes (or hood and spoon chutes).

The impact plate in chutes (Fig. 3) is a surface introduced into the flow stream of material to cause it to impact and flow in a different direction. It is the crudest and earliest form of transfer causing direction change. The advantages of this type of transfer are: they are cheap and easy to design and inexpensive to build and install. However, the disadvantages are numerous and include higher dust and noise generation, spillage, blockage, poor belt life (receiving belt) and high maintenance (Benjamin et al, 2010). Due to these factors, it's only justified the use of this form of transfer for systems with low height and small capacity.

![Figure 3. Chutes with impact plates (Benjamin et al., 2010; Chaves et al., 2011).](image-url)

The rock box (Fig.4) was developed to absorb the high energy impact associated with handling large rocks that would otherwise severely damaged or cause the receiving belt to be ripped. It is designed as a rock ledge in the form of an open box such that the particle can flow into the box and as fills, overflow onto the receiving belt. As this kind of transfer slows the material flow the capacity is a limiting factor.
The dynamic chute or ‘hood and spoon’ is shown in Fig. 5. The name ‘hood and spoon’ is because the concept incorporated a parabolic shaped dished hood deflector at the top of the chute and a similar spoon deflector at the bottom to deliver the material onto the receiving belt (Benjamin et al., 2010). This type of transfer improves the material flow control and it has been widely used in mineral industries. However, it has some constraints, such as: (i) more than any other type of transfer it relies on accurate calculation of the trajectory; (ii) if the drop height is excessive (over 5 meters) controlling the material speed can become a significant issue (Benjamin et al., 2010).

This kind of chute was design in this work. The calculation of the curvatures ratios of the hood and spoon in the study case was performed initially using the methodology proposed by Roberts (2003). The author presents mathematical models for calculation of the velocity in superior deflector (hood) and in inferior deflector (spoon) as shown in Fig. 6 and Fig. 7. Actually, the Roberts model gave a first idea of the geometry of the chute used in this work. The final dimension was obtained after the simulations in DEM software.
DISCRETE ELEMENT METHOD

The Discrete Element Method (DEM) is a reliable and powerful tool to study and predict the flow of particles. This methodology is being widely used in research in the area of mining, which can optimize mineral equipment design, such as ball mills, conveyors, chutes and vibrating screens (Cleary, 2010). The DEM captures 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 (Dewicki, 2003).

Historically, the Discrete Element Method (DEM) had as pioneers Cundall and Strack (1979). The DEM method takes in account the translational and rotational motion equations of the particles. The mathematical model includes the interaction between particles and between particle and wall, as well as the van der Waals forces, electrostatic forces, liquid bridges, particle-fluids interaction force, etc. (Fig. 8). A description of the governing equations is made by Zhou et al. (2007), as follow:

\[ m \frac{dV_i}{dt} = \sum_j F_{i,j}^c + \sum_k F_{i,k}^{nc} + F_i^f + F_i^e \]  \hspace{1cm} (1)

\[ I_i \frac{d\omega_i}{dt} = \sum_j M_{i,j} \]  \hspace{1cm} (2)
where $m_i$ and $I_i$ are, respectively, the mass and moment of inertia of particle $i$; $V_i$ and $\omega_i$ are, respectively, translational and rotational velocities of particle $i$; $F_{ij}^C$ and $M_{ij}$ are the contact force and the torque acting on particle $i$ by particle $j$ or wall; $F_{nck}$ is the non-contact force acting on particle $i$ by particle $k$ or other sources; $F_{if}$ is the particle-fluid interaction force on particle $i$ and $F_{ig}$ is the gravitational force.

![Figure 8. Schematic illustration of the forces acting on a particle (Zhou et al, 2007).](image)

Various models have been proposed to calculate these forces and torques (Zhu et al., 2007). Once the forces and torques are known, Eqs. (1) and (2) can be readily solved numerically. Thus, the trajectories, velocities and the transient forces of all particles in a system considered can be determined.

### 4 CASE STUDY

In this work it is redesign a problematic chute using DEM discrete element. The current chute (problematic chute) has impact plates in its interior and the proposed chute was designed using the superior and inferior curve deflector, i.e. the hood and spoon chute. In this section it is presented details of the geometry of the new chute, its DEM model and the simulations results.

#### 4.1 Description of the current chute and proposed chute

The current chute is located in a plant of mineral transformation in Brazil and presents some problems of spillage, blocking and consequently stoppages of the receiving belt. Therefore, these problems result in production delays and increased maintenance costs. These problems reflect the lack of control the direction and speed of flow of material due to inappropriate design of the transfer chute. This chute is presented in Fig. 9a. Therefore, it is proposed a new configuration: a chute with upper and lower curve deflector ("hood and spoon" type) (Fig. 9b). This kind of choice is due to better driving the material within the transfer chute, with better control of the velocity, avoiding the commonplace problems of
noise, dust generation, wear, spillage and blocking the material in the chute, and also wear and misalignment of the receiving belt conveyor. The chute was design based on mathematical model by Roberts (2003) and then it drawn in SolidWorks and exported to EDEM (DEM software) to visualize the simulation and check out if the design is correct.

4.2 Validation of the particle model

It is very time demanding the DEM simulation with the real size of the particles. Therefore, in order to overcome this problem, the mean diameter of the particles was increased and some of their parameter was changed in order to angle of repose of the material remain constant ($40^\circ$ for alumina). Figure 10 shows the material in a virtual experiment of measurement the angle of repose. Table 1 shows the parameters obtained after the calibration procedure.
Table 1. Coefficients of the materials used in simulations.

<table>
<thead>
<tr>
<th>Material Combination</th>
<th>Restitution Coefficient</th>
<th>Static Friction Coefficient</th>
<th>Rolling Friction Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alumina/Alumina</td>
<td>0.5</td>
<td>0.95</td>
<td>0.095</td>
</tr>
<tr>
<td>Alumina/Steel</td>
<td>0.5</td>
<td>1.425</td>
<td>0.19</td>
</tr>
<tr>
<td>Alumina/Rubber</td>
<td>0.5</td>
<td>1.425</td>
<td>0.19</td>
</tr>
</tbody>
</table>

The other required input parameters for numerical simulations are listed above and in Table 2. The model used for particle-particle interaction and particle-geometry interaction was the Hertz-Mindlin model because there are not significant cohesion forces (Zhou et al, 2007).

- Model of particle-particle interaction: Hertz-Mindlin
- Model of particle-geometry interaction: Hertz-Mindlin
- Particle size (diameter) in the simulation: 15mm
- Total mass in the simulation: 1250 kg
- Mass flow: 125 kg/s (450 t/h)

Table 2. Material data.

<table>
<thead>
<tr>
<th>Material</th>
<th>Poisson Ratio</th>
<th>Shear Modulus</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrated alumina</td>
<td>0.25</td>
<td>1e+08 Pa</td>
<td>1150 kg/m³</td>
</tr>
<tr>
<td>Steel</td>
<td>0.3</td>
<td>7e+10 Pa</td>
<td>7800 kg/m³</td>
</tr>
<tr>
<td>Rubber</td>
<td>0.5</td>
<td>1e+06 Pa</td>
<td>1100 kg/m³</td>
</tr>
</tbody>
</table>

4.3 Simulation of the current situation and the proposed solution

At first the simulation in the current chute was performed using only 50% of the required capacity of the project (62.5 kg/s). The result shows the belt receives material at speed over 7m/s (Fig. 11). In this situation small spillage is noticed but without blocking. Another point to be noticed is that over 70% of the material arrives at the receiving belt on one side, which dramatically increasing the possibility of belt misalignment.

Figure 12 shows the simulation for the current chute using 75% of the required capacity of the project (93.75 kg/s). The result was the belt receiving material at speed over 7m / s. Considerable spillage is perceived, and already beginning to blocking the chute. More than 70% of the material arrives at the receiving belt on one side, therefore, dramatically increasing the possibility of misalignment. The last scenario for the current chute was the simulation with 100% of the capacity (125 kg/s). In this case we can see the blockage problem in the chute (Fig. 13).
Figure 11. Different views of the simulation for chute with 50% of the current capacity of the belt.

Figure 12. Numerical simulation for chute with 75% of the current capacity of the belt.
Numerical simulations have shown satisfactory and consistent with reality and with reasonable computational time, generally 24 hours of processing time for simulations of 10 seconds. The problems of spillage, blocking and belt misalignment that appeared in the current chute are the main problems to be solved using another chute transfer (the hood and spoon configuration).

The results of the numerical simulation of the hydrated alumina into the hood and spoon (dynamic) chute have shown no problems related to spillage, blocking and belt misalignment. The material average speed on the receiving belt is approximately 2.5 m/s. These results show this new configuration is adequate for this conveyor process. Figure 14 presents the numerical simulation for chute with 100% of the current capacity of the belt.
5 CONCLUDING REMARKS

This work presents a case study of design of a chute for replacement of a transfer which uses impact plates in its configuration. This chute presents some problems in some operation conditions, such as spillage, blocking and misalignment of the receiving belt conveyor. The new transfer chute uses the hood and spoon configuration (utilization of curve deflectors on top and bottom of the transfer). The proposed chute was design based on mathematical model by Roberts (2003), drawn in SolidWorks and exported to EDEM (DEM software) in order to visualize the simulation. This new chute in the simulations (in all operation conditions) doesn’t show the problems faced by the current configuration.

REFERENCES


IBRAM, Information and Analysis on the Brazilian Mineral Economy, Brazilian Mining Association, December, 2012.

