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# Efficiency Improvement Of Ball Mill Liners By Simulation Of Balls And Ore Trajectory In Sarcheshmeh_copper Complex

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***Abstract:*** Tumbling mill liners transfer the energy to the mill charge and have a significant effect on the load behavior. A plant audit at the Sarcheshmeh copper complex indicted that due to the inappropriate design of ball mills liners, the liners wear and tear increased and the grinding efficiency decreased. With the objective of investigating the design of initial, current and proposed liners, charge trajectory was simulated by the GMT and KMPCDEM software packages. It was observed that the charge impact point for the current liners design was above the toe and on the shell liners. By simulation it was found that increasing the liner lifter face angle from 0 to 15° and the lifter height from 18 to 21cm could decrease the difference between the impact point and the toe and direct ball impacts to liners. Given the promising results, the new liners were designed, constructed and installed in ball mill 4. The result of sampling for a period of one liner life indicated that the amount of particles smaller than 75 microns in ball mill 4 product (with proposed design) compared with ball mill 3 (with current design) increased by 2.5% and the liners life of the first half and second half increased by 18% and 20%, respectively.

***Keywords:*** Ball mill, Liner, Lifter angle, Sarcheshmeh.

## INTRODUCTION

The mining industry is a significant consumer of energy and 6% to 7% of the total world's energy is devoted to the industry. Comminution is the major consumer with a share of 40-50%. The grinding process accounts for 90% of the energy required, crushing uses 5-7% and explosives 3-5% [1]. The final stages of


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primary comminution are performed in tumbling mills using steel balls as the grinding medium, and so are designated “ball mills”. The internal working faces of mills consist of renewable liners, which must withstand impact, be wear-resistant, and promote the most favorable motion to the charge. The structural characteristics of liners, lifter shape and mill speed substantially influence particle motion in tumbling mills and dramatically influence the grinding process and power draw of the mills [2, 3].

It has been well established that a change in the lifter face angle on tumbling mill shell lifters results in a change in the motion of the charge. With the development of trajectory-generating computer programs, the effects of operational conditions, face angle, packing and lifter height have been incorporated in the shell lifter design. Increasing shell liner face angle does reduce the impact point of thrown balls and can reduce shell liner damage [4-7].

In recent years, DEM (Discrete Element Method) has been used successfully for modelling and analyzing the internal dynamics of grinding mills motion. With this computational technique, the motion and interactions of individual bodies are calculated using a set of equations referred to as Newton’s laws and contact models. DEM helps to understand charge motion in tumbling mills for given liner designs and lifters, ball size and rock properties and mill operating conditions. Based on the success of the 2-D model of the tumbling mill the 3-D model in DEM was developed. These types of models could help study charge motion, power draw, liners wear and energy draft more accurately [6-13].

The charge trajectory is the main concern in liner design because the direct impact of balls to the shell liners could result in liner damage and breakage. The charge trajectory can be optimized by the modification of the liner design [5]. Yahyaei and Banisi (2010) designed a spreadsheet-based software (GMT; Grinding Media Trajectory) to model charge trajectory in tumbling mills [14]. Charge shape and charge motion predicted by the GMT program was based only on a single ball trajectory. Maleki-Moghaddam et al., (2013) proposed new relationships to modify the GMT results to take into consideration the effect of charge. By applying the corrections to the charge shape and motion, the GMT software outputs became more realistic [5].

### The sarcheshmeh copper complex primary ball mills

This study was carried out at the Sarcheshmeh copper complex located southeast of Iran. Primary grinding circuit consists of eight single stage primary ball mills. The grinding plant has two sections, each consisting of four single-stage grinding ball mill operating in closed-circuit with ten cyclones. The mill discharge goes into a sump and is pumped to the cyclone cluster for size classification. Cyclone underflow recycles by gravity to the mill. Cyclone overflows from four grinding units (one of the two mill sections), at 28% solids, are combined and delivered to the corresponding rougher distributor [15].

The internal working faces of these mills consist of renewable liners. According to the preliminary design, they were made of manganese or chrome molybdenum steels [15]. The high noise levels of steel liners, their long replacement time, low lifetime and high costs have led to change the steel liners to rubber. Investigations showed that due to the inappropriate design of the existing liners, a direct collision of the balls load with the liners occurred. This research was then conducted to improve the grinding efficiency and extend the life of the liners.

## METHODS

In this research, the process of designing a new liner starts with analytical and numerical simulation of the charge trajectory and modification of the liner geometry to arrive at the desired trajectory. The results of using the GMT software and 3D simulation of the Sarcheshmeh SAG mill by the $KMPC_{DEM}$ software package to predict the charge motion are presented in detail. The comparison of the initial steel liner, current and proposed liner shape on the charge trajectory was the key step in arriving at the final liner shape. After final refinements of the liner design, engineering drawings were prepared and sent to the liner manufacturer.

### The GMT software

In order to simulate the charge shape and motion, a new version of GMT [14] was used. In the new



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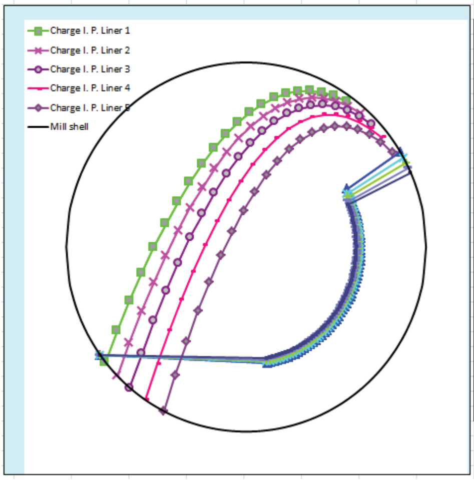
version of GMT, Maleki-Moghaddam et al. (2013) corrected the charge shape. The main feature of GMT is the ability to show the crescent-like shape of the charge along with the charge trajectory, which has not been incorporated in the previous version and similar software packages [5]. A typical result page of the GMT software is shown in Figure 1.




| | Liner 1 | Liner 2 | Liner 3 | Liner 4 | Liner 5 |
|---|---|---|---|---|---|
| Face Angle (deg) | 14.00 | 20.00 | 25.00 | 30.00 | 35.00 |
| Lifter Height (mm) | 152.00 | 152.00 | 152.00 | 152.00 | 152.00 |
| Distance from Angle (mm) | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Speed (% of C. S. ) | 76.00 | 76.00 | 76.00 | 76.00 | 0.76 |
| Point of Equilibrium | | | | | |
| Xe (m) | 4.03 | 4.29 | 4.48 | 4.63 | 4.74 |
| Ye (m) | 2.63 | 2.18 | 1.76 | 1.31 | 0.82 |
| Angle (deg) | 33.09 | 26.91 | 21.47 | 15.78 | 9.85 |
| Point of Free Flight | | | | | |
| Media Speed (m/s) | 4.96 | 4.87 | 4.79 | 4.70 | 4.60 |
| Release Angle (deg) | 54.60 | 48.63 | 43.37 | 37.89 | 32.23 |
| Point of Impact (Single Ball) | | | | | |
| Xi (m) | -3.65 | -3.08 | -2.48 | -1.77 | -0.96 |
| Yi (m) | -3.14 | -3.70 | -4.12 | -4.47 | -4.71 |
| Angle (deg) | 220.68 | 230.21 | 238.94 | 248.36 | 258.44 |
| Vi (m/s) | 12.71 | 12.87 | 12.93 | 12.90 | 12.76 |
| Kinetic Energy (kj) | 0.64 | 0.66 | 0.67 | 0.66 | 0.65 |
| Point of Impact (Charge) | | | | | |
| Xi (m) | -3.81 | -3.49 | -3.15 | -2.73 | -2.23 |
| Yi (m) | -3.04 | -3.40 | -3.72 | -4.04 | -4.34 |
| Angle (deg) | 218.60 | 224.26 | 229.76 | 235.96 | 242.82 |
| Charge Shape | | | | | |
| Toe (deg) | 216.05 | 216.05 | 216.05 | 216.05 | 216.05 |
| Shoulder (deg) | 31.01 | 28.89 | 27.13 | 25.36 | 23.60 |
| Toe Departure (deg) | 282.60 | 282.60 | 282.60 | 282.60 | 282.60 |
| ri (m) | 3.13 | 3.09 | 3.06 | 3.03 | 2.99 |

**Figure 1.** A typical result page of the GMT software

### Charge motion simulation by discrete element method (DEM)

Discrete element method (DEM) modelling is a powerful tool to allow comparative analysis of various liner designs within the mill and has been widely used for liner design in the recent years. In this research, three-dimensional DEM simulations were performed by the $KMPC_{DEM}$ software at the same operating conditions for old and proposed liners in order to predict the charge shape and impact point. The development of the software started in 2013 at the Kashigar Mineral Processing Research Center (KMPC). Full access to the software source codes enabled us to add or modify the algorithms and related relationships. Further details can be found elsewhere [13].

## FINDINGS AND ARGUMENT

With the objective of investigating the effect of the initial, current and proposed liners on the charge trajectory simulations were performed by the GMT and $KMPC_{DEM}$ software packages. Since the lifter face angle has the main impact on the load trajectory and, it was decided to increase the lifter face angle of liners. Increasing the shell lifter face angle (for the same mill speed) reduces the impact point of thrown balls, increases the distance between ball impact points and liners which results in reduction of the shell liner damage. As the angle of the lifter increases, the wear of the liners increases and its lifetime decreases. To overcome this problem and to increase the liner life, the height of the liners was increased in the proposed design. A typical snapshot of load trajectory simulation using the $KMPC_{DEM}$ software for steel liners, current and proposed design is shown in Figure 2.

By simulation it was found that increasing the liner lifter face angle from 0 to 15° and the lifter height from 18 to 21cm could decrease the difference between the impact point and the toe and direct balls impact to liners. Finally, considering the operating conditions and constraints on the installation of liners, the industrial liners were designed and sent to the manufacturer for construction. After installing the new liners, the performance of the liners was monitored. The result of sampling for a period of one liner life indicated that the amount of particles smaller than 75 microns in the product of ball mill 4 (proposed design) in comparison with ball mill 3 (current design) increased by 2.5% and the liners life of the first half and second half increased by 18% and 20%, respectively.



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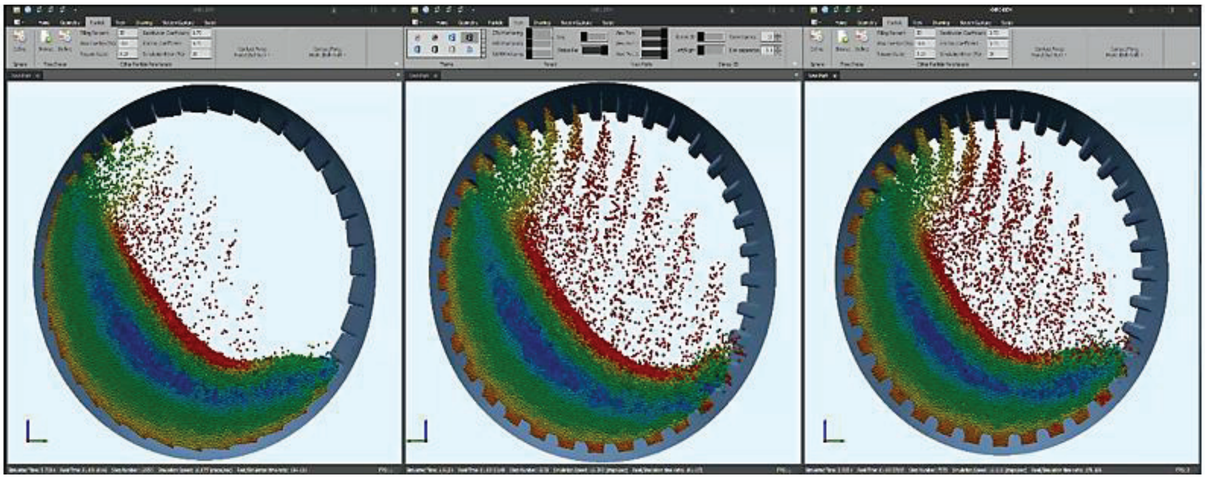

(A) (B) (C)

**Figure 2.** A typical snapshot of load trajectory simulation using the $KMPC_{DEM}$ software for A: steel liners, B: current and C: proposed design

## CONCLUSIONS

Investigations showed that at the Sarcheshmeh grinding circuit due to the inappropriate design of ball mills liners, the liners wear and tear increased and the grinding efficiency decreased.

With the objective of investigating the effect of initial steel liners, current and proposed liners, the charge trajectory was determined through simulation by the GMT and $KMPC_{DEM}$ software packages.

The simulation of the charge trajectory indicated that the charge impact point for the current liners design was above the toe and on the shell liners. The results indicated that increasing the liner lifter face angle from 0 to 15° and the lifter height from 18 to 21cm could decrease the difference between the impact point and the toe and direct balls impact to liners.

Given the promising results, the new liners were designed, constructed and installed in ball mill 4. The result of sampling for a period of one liner life indicated that the amount of particles smaller than 75 microns in the product of ball mill 4 (proposed design) in comparison with ball mill 3 (current design) increased by 2.5% and the liners life of the first half and second half increased by 18% and 20%, respectively.

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