

INCREASING THE GRINDING EFFICIENCY OF GOL-E-GOHAR IRON ORE AND SARCHESHMEH COPPER COMPLEX SAG MILLS WITH CHANGING LINER DESIGN BY DISCRETE ELEMENT METHOD (DEM)

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Abstract: At Gol-E-Gohar iron ore concentration plant and Sarcheshmeh copper complex, SAG mills are used with the diameter of 9 and 10 meters and length of 2 and 4.9 meters, respectively. Monitoring the operation in these two plants indicated that the tonnage of the mill at Gol-E-Gohar was lower than the nominal value with large variations and the Sarcheshmeh mill experienced liner breakages which in turn increased the non-scheduled shutdowns. In order to overcome these difficulties and to increase the performance, the charge trajectory, which is an important parameter, was studied in these two mills. To simulate the charge trajectory KMPC_{DEM} software was used, which has been developed based on discrete element method (DEM). The results of simulations using two different liner designs were verified with a model mill of 1-m diameter and 22-cm length. The comparison indicated that in the worst case the difference between the shoulder and toe positions of the simulated and measured charges was found to be less than 4 degrees which was not considered significant given the experimental error of the test. Once the accuracy of the simulation was verified, it was used to simulate the charge trajectory in the two industrial SAG mills. The simulations showed that unlike the expectation, cataracting particles do not impact toe, they rather they hit shell liners. In order to solve this problem, various liner designs at the plant operating conditions were simulated with the objective of reaching a state where the falling charge impacts the toe region. To achieve such a goal, for Gol-E-Gohar SAG mill the release angle was increased from 7 to 30 degrees and for the mill at Sarcheshmeh, the number of lifters was decreased from 60 to 40 and the release angle increased from 15 to 30 degrees. The proposed liner designs were constructed and installed in the industrial SAG mills where their performances were monitored during a period of twenty months. At Gole-E-Gohar, the feed rate increased by 17% and its variation reduced by 31% which indicates more stable operation. At Sarcheshmeh, the average number of broken liners decreased from 4.2 to 1 and the variation of feed rate decreased by 30%. The promising results of liner change in the last few years resulted in replacement of old liners in the SAG mills of the two plants with the proposed liners.

Keywords: Terajjectory, SAG mill, Discrete Element Method (DEM), Model mill, KMPC_{DEM}

INTRODUCTION

Comminution is the most energy intensive operation which constitutes the major portion of operating and capital costs of the mineral processing plants (Morrell 1993). The use of large AG (autogenous)/SAG (semi autogenous) mills in the mineral industry has been on rise due to a significant reduction in capital and operating costs and increase in the plants throughputs. The availability of these mills plays an important role in the economics of the operation (Maleki-Moghaddam, Yahyaei, and Banisi 2012).

At Gol-E-Gohar iron ore concentration plant and Sarcheshmeh copper complex, SAG mills with the diameter of 9 and 10 meters, and length of 2 and 4.9 meters are used, respectively. Monitoring the operation in these two plants indicated that the tonnage of the mill at Gol-E-Gohar was lower than the nominal value with large variations and the Sarcheshmeh mill experienced liner breakages which in turn increased the non-scheduled shutdowns.

Charge motion plays a major role in the efficiency of comminution in mills. It has been known for many years that a change in a mill lifters face angle results in a change in the charge shape (Yahyaei and Banisi 2010, Rajamani 2006). Since direct observation of charge shape and its motion in industrial mills is not possible, an alternative methods is used to determine charge trajectory (Maleki-Moghaddam, Yahyaei, and Banisi 2013). The charge shape is usually defined through the

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position of toe and shoulder. These parameters, therefore, are of prime importance in evaluating the mill efficiency. There have been many attempts to quantify the effect of various parameters on the mill charge (Morrell 1993, Powell 1991a, Vermeulen and Howat 1986, Cleary 2009, Makokha and Moys 2006).

The first method was to use a software called GMT (Grinding Media Trajectory) (Yahyaie and Banisi 2010). The approach first introduced by Powell (Powell 1991b) which can be used to determine charge trajectory. In comparison with other software packages, GMT has the advantage of using all MS Excel© readily available functions and capabilities. However, the low accuracy in determining the charge shape is one of its limitations. As a result, in cases where high precision is required, physical modeling methods such as model (laboratory) mills are sometimes used along with this method (Maleki-Moghaddam et al. 2015). In the model mills, where one end of the mills is transparent, charge shape parameters are precisely measured by image analysis (taking photographs). Despite the precision of this method, the use of laboratory mills is time-consuming and expensive.

In recent years, the availability of large-scale cost-effective computing power has allowed the development of Discrete Element Method (DEM) computer programs that model charge flow in mills (Maleki-Moghaddam, Yahyaie, and Banisi 2012). DEM is gaining more ground to partly replace the costly approach of physical modeling of particulate systems. DEM was first introduced by Cundall (1979) to model the behavior of soil particles under dynamic load. In 1992, Mishra and Rajamani simulated the laboratory ball mill charge motion in two dimensions which could be considered as the first reported work using DEM in the mineral processing field (Mishra and Rajamani 1992).

In this research, the charge trajectory was studied in these two industrial mills by DEM in order to overcome the difficulties and to increase their performances.

METHODS

In order to simulate the particles movement within the mills, a 3D DEM-based software called KMPCDEM© was used. The development of the software started in 2013 at the Kashigar Mineral Processing Research Center (KMPC) in Mining Engineering Group, Shahid Bahonar University of Kerman, Iran. Full access to the software source codes made it possible to add or modify the algorithms, related equations and also extract the desired simulation data from particles and/or geometries.

To determine the accuracy of the KMPCDEM© simulation results at various operating condition, the KMPC model mill with the diameter of 100 cm was used. In this way, two different liner designs each at two different operating conditions were simulated with a diameter of 1 meter and length of 22-cmand then compared with the KMPC model mill.

Once the accuracy of the simulation was verified, it was used to simulate the charge trajectory in the two industrial SAG mills. The mills along with the detailed features were drawn in SolidWorks© (2016 version) and the geometries were imported to the KMPCDEM© software. In order to resolve the mills related issues, various liner designs at the plant operating conditions were simulated with the objective of reaching an optimum charge shape.

FINDINGS AND ARGUMENT

The difference between the results of simulations and the model mill using two different liner designs each at two different operating conditions indicated that the overall shape of the charge and the ball impact points were in good agreement with the experiment, in all simulations with

different liners and operating condition. In order to compare the simulation results and the experiment in detail, the toe and shoulder positions were measured. Each measurement was repeated ten times, then the average and standard deviation (STD) were reported. The comparison indicated that in the worst case the difference between the shoulder and toe positions of the simulated and measured charges was found to be less than 4 degrees, which was not significant given the experimental error of the test (Table 1).

Table 1 - The difference between the results of simulations and the model mill using

Comparison No.	Method	Average Toe(degree)		STD (degree)	
1	The model mill	14.6	248.6	2.1	2.6
	KMPC _{DEM}	14.8	245.6	2.0	2.2
2	The model mill	35.9	226.8	2.3	2.6
	KMPC _{DEM}	34.1	224.9	2.4	2.3
3	The model mill	45.4	220.8	2.9	3.5
	KMPC _{DEM}	47.7	223.5	2.8	3.1
4	The model mill	61.5	225.4	3.7	3.9
	KMPC _{DEM}	60.1	229.2	3.6	3.8

Once the accuracy of the simulation was verified, it was used to simulate the charge trajectory in the two industrial SAG mills. The simulations showed that unlike the expectation, cataracting particles in Gol-E-Gohar SAG mill, do not impact toe and they rather hit shell liners (Fig. 1-a). In order to solve this problem, various liner designs at the plant operating conditions were simulated with the objective of reaching a condition where the falling charge impacts the toe region. To arrive at such a condition, the release angle was increased from 7 to 30 degrees (Fig. 1-b). The simulations showed similar trends for the Sarcheshmeh case (Fig. 2-a). In this case, the number of lifters was decreased from 60 to 40 and the release angle increased from 15 to 30 degrees (Fig. 1-b).

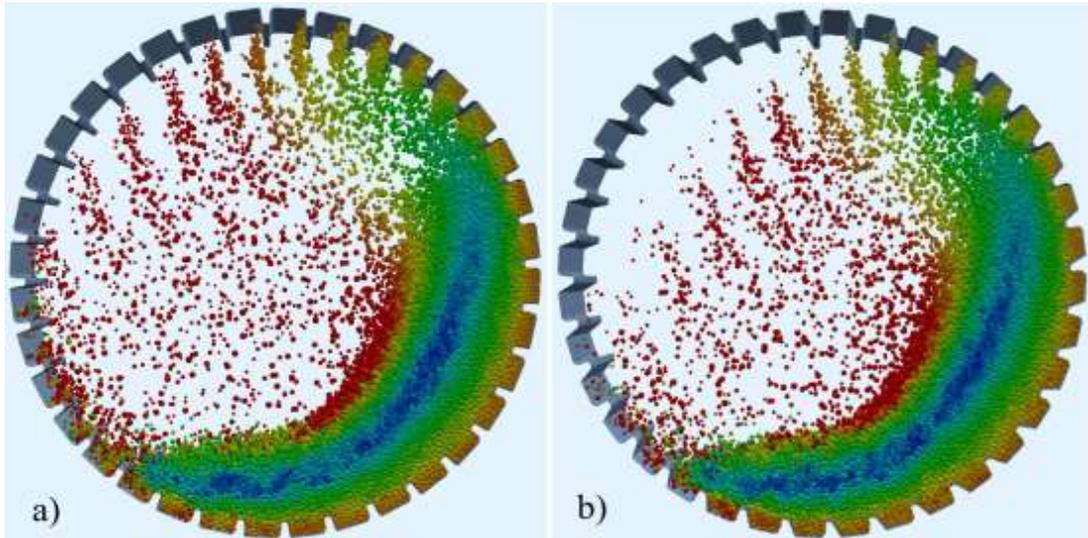


Fig.1 Gol-E-Gohar SAG mill charge shape a) original and b) new liners

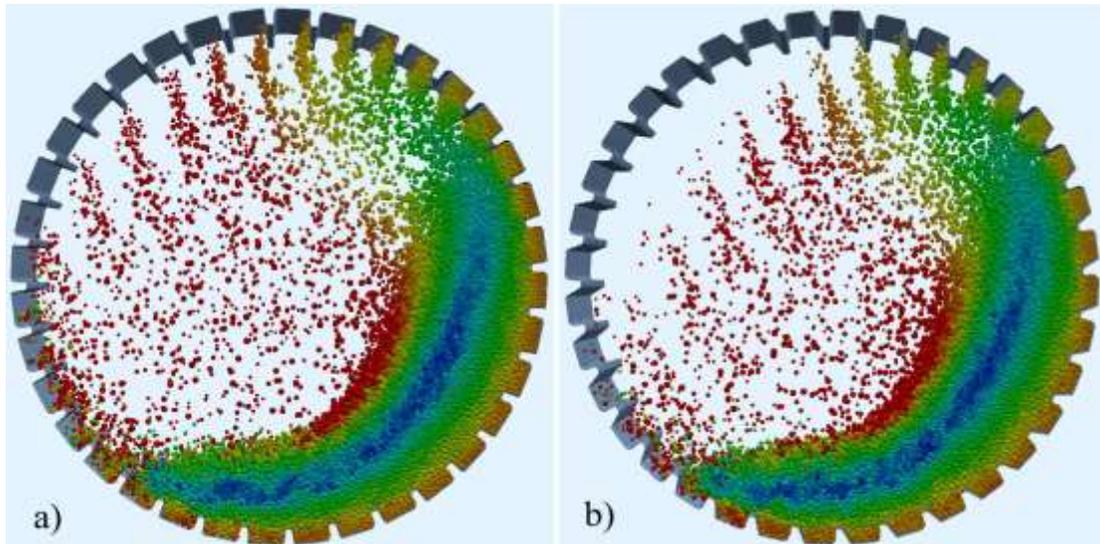


Fig. 2 Sarcheshmeh SAG mill charge shape a) original and b) new liners

The proposed liner designs were constructed and installed in the industrial SAG mills where their performances were monitored during a period of twenty months. At Gole-E-Gohar, the feed rate increased by 17% and its variation reduced by 31% which indicated more stable operation (Table 2).

Table 2 - Throughputs and product sizes of Gole-E-Gohar mill before and after liner change

	Averagin g period (months)	Throughput (t/h)	P80 (μm)
Before change	18	67 \pm 419	44 \pm 516
After change	2	46 \pm 489	36 \pm 513

At Sarcheshmeh, the average number of broken liners decreased from 4.2 to 1 and the variation of feed rate decreased by 30%. The promising results of liner change in the last few years resulted in the replacement of old liners in the SAG mills of the two plants with the proposed liners.

CONCLUSIONS

- The comparison between the results of KMPC_{DEM} and the model mill indicated that in the worst case the difference between the shoulder and toe positions of the simulated and measured charges was found to be less than 4 degrees, not significant considering the experimental error of the test.
- The simulations by KMPC_{DEM} showed that unlike the expectation, cataracting particles do not impact toe; they rather hit shell liners.
- To arrive at optimum charge shape for the Gol-E-Gohar SAG mill, the release angle was increased from 7 to 30 degrees, and for the Sarcheshmeh case, the number of lifters was decreased from 60 to 40 and the release angle increased from 15 to 30 degrees.
- The proposed liner designs were constructed and installed in the industrial SAG mills where their performances were monitored for a period of twenty months.
- At Gole-E-Gohar, the feed rate increased by 17% and its variation reduced by 31% which indicated more stable operation.

- At Sarcheshmeh, the average number of broken liners decreased from 4.2 to 1, and the variation of feed rate decreased by 30%.

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