Effect of Lifter Shapes on the Mill Power in a Ball Mill

Zixin Yin¹, Tongqing Li²,*  Yuxing Peng¹ and Guiyi Wu¹

¹School of Mechatronic Engineering, China University of Mining & Technology, Xuzhou 221116, China
²School of Mechanical and Ocean Engineering, Huaihai Institute of Technology, Lianyungang 222005, China

*Corresponding author e-mail: litongqing@cumt.edu.cn

Abstract. To investigate the power of ball mill with differing lifter shapes, a series of Discrete Element Method (DEM) simulations were performed on a ball mill. The research results shown as follows: the charge position density limit is an effective method to investigate the charge behavior; Mill power increases to the maximum with increasing mill speed for all lifter shapes and then decreases, the maximum power occurs at 90% of critical speed. Moreover, the trapezium lifter having the maximum power comparison with waveform and rectangle lifter.

1. Introduction

Comminution in mineral processing is a complex phenomenon, especially in tumbling ball mill. Because there are complicated dynamic systems and dependent on multiple factors.

The supplied energy only small fraction is directed towards comminution processes, and remaining energy is wasted [1-4]. Therefore, a greater understanding of comminution processes could lead to an increased efficiency.

Lifters are an essential element in the tumbling action of a grinding mill, having the function to prevent slippage of the charge. Researchers have performed a significant amount of works and obtained interesting and important results. Powell et al. [5] used DEM software to predict the rate of wear of lifter geometry. Cleary [2] described the effects of changes to the properties of the lifter shape and rock size. He indicated that reducing the number of lifters can be increases the specific power draw. Djordjevic [6] used PFC3D code shows that the lifter condition have a significant influence on the power draw and the mode of energy consumption in the mill. Bian [7] investigated the effect of lifters and mill speed on particle behaviour, the changes in the torque and power consumption of a ball mill can be effectively explained using two important factors: lifter and particle area ratio. Generally, optimization of power consumption will have a significant impact on the overall economic performance of mineral processes. Lameck [8] investigated the effect of grinding media shapes on load behaviour and mill power, the power increases to a maximum with increasing mill speed for all media shapes. Kiangi et al. [9] used experimental method to study the effect of particle filling on the power, there is a notable difference in the variation of net power with increasing particle filling for both coarse and fine particles.

The following work is a further assessment of DEM prediction of lifter performance and mill power. A method of charge position density limit was used in this paper to investigate the effect of lifter shapes on mill power.
2. Method
To study the effect of lifter shapes on mill power, a DEM model (Ø520×40 mm) with 24 pieces of lifter was established. As shown in Figure 1, the lifter was designed with three different profiles in cross section, rectangle, waveform and trapezium, the grinding media with three different sizes (Ø6, 8, 11 mm) and filled mass ratio with 1:1:1. The simulations were operated at 30% ball filling for six levels of mill speed (N=50%, 60%, 70%, 80%, 90%, 100% of critical speed).

Figure 1. DEM model

A method of charge position density limit was used to predict the charge behaviour. In the cross section of ball mill, it was meshed into 100×100 cells, which represents the number of particles. Main characteristics of the simulation parameters are listed in Table 1.

Table 1. Simulation parameters

| Parameters                              | Values                           |
|-----------------------------------------|----------------------------------|
| Steel ball size /mm                     | Ø6,8,10                          |
| Steel ball density /kg·m⁻³              | 7800                             |
| Steel ball filling                      | 30%                              |
| Steel ball shear modulus/Pa             | 7×10¹⁰                           |
| Steel ball-steel ball static friction coefficient | 0.15                            |
| Steel ball-steel ball rolling friction coefficient | 0.01                            |
| Steel ball-wall static friction coefficient | 0.2                             |
| Steel ball-wall rolling friction coefficient | 0.01                            |
| Mill speed /of critical speed           | 50%,60%,70%,80%,90%,100%        |
| Lifter shape                            | rectangle, trapezium, waveform    |
3. Results and discussions

3.1. Charge behaviour

The lifter wear occurs most strongly on the protruding lifter bars, reducing the lifter heights and shape over time. In order to evaluate the effect of the lifter life cycle on mill performance, a series of DEM simulations were run for lifter shapes and mill speeds. Figure 2 shows the charge shapes predicted for ball mill and charge filled to 30% (by volume) for three rotation rates. The three kinds of lifter approximately represents the worn periods of lifter profile. The charges are shaded according to their number with light blue being lower charge number and dark red being higher. For \(N=50\%\), the charge moves with the mill rotation and then flows down the steep free surface to the toe region, most of the charge leads to the ore particles size reduction by abrasion and attrition. For \(N=70\%\), the shoulder position moves higher and the bulk toe lower, an amount of cataracting charge impacts the mill shell and bulk toe, the charge shape in cascading region increasingly rise up. For \(N=90\%\), the amount of cataracting charge increases and cascading charge reduces.

![Figure 2. Charge shape predicted for a ball mill at 30% ball filling with differing lifter shapes and mill speeds](image-url)
It was further observed that charge toe and shoulder regions were affected by lifter shapes and mill speeds. The rectangle and waveform lifter are only subtle changes to the charge behaviour, the shoulder and toe regions are lower than other lifter shapes. Above all, the mill performance are affected by mill speed and lifter shape, and the photographs of charge position density limit are noticeably described the charge behaviour.

3.2. Mill power

Figure 3 compares the mill power among the three lifter shapes at various speeds for 30% ball filling. It was observed that trapezium lifter have higher power than waveform and rectangle lifter. Mill power increases to the maximum with increasing mill speed for all lifter shapes, the maximum power occurs at 90% of critical speed. The amount of cataracting charge increased with mill speeds, the balance of charge improves and the torque required maintaining the asymmetric charge position declines steadily.

It was found that mill power sensitive to the lifter shapes and the charge load behaviour inside tumbling mills also affected mill power. As the mill speed continuous increases, increasing the number of charge in flight and impacting the mill shell. Energy is imparted back to the mill by the flight charge, leading to a loss in power as the mount of centrifuging charge increases. Thus, effective control of lifter shapes can improve energy utilization and lifter life cycle.

Figure 3. Variation of power with mill speed

4. Conclusion

In this paper, a DEM model ball mill is employed in investigating the effect of lifter shape on mill power, the main research conclusions are summarized as follows.

(a) The charge position density limit is an effective method to investigate the charge behaviour.
(b) The mill power increases first and then decreases as the mill speed increases. Mill power increases to the maximum with increasing mill speed for all lifter shapes, the maximum power occurs at 90% of critical speed. Moreover, the trapezium lifter having the maximum power comparison with waveform and rectangle lifter.

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