A Review on Current Mill Liner Design and Performance

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Abstract. Milling management in Mining and Mineral Industries should keep on improving liner design based on operating experience, ore types, good design practice, and also additional data from ball trajectory and DEM simulations. The small-scale trials for evaluating different liner shapes would rather provide important basic information to industrial mills. The lifters with the same face angle, but different configurations could provide improvements in energy efficiency and performance. Integrating the wear rates of liners from the actual measurement of the changes in liner profile over milling time and also using laser-based thickness gauging technology would assist in establishing a more efficient liner profile.

1. Introduction

As semi-autogenous (SAG) mills become increasingly larger in size, the design of SAG mill liners has been more and more important, and the appropriate liners would enhance mill efficiency and performance. The replaceable liners are mounted inside the mill and exposed to media and/or the material being ground. The liners have to resist impact, be wear-resistant, and provide the most favorable motion of the charge. The primary purposes of the liners are to transfer energy to the charge (ore/rock + grinding media), to hold grinding media, and to protect the mill shell from the wear, as well as to prevent liners/lifters and balls from damage.

The early sets of liners that are normally selected at the milling-plant design stage almost never perform very well in tumbling mills and only limited number of liners work optimally in new installation [1]. Thus, in order to determine proper liner design, it is necessary for the milling management to keep improving the design by relying on useful information from practical operating experience.

Both the liner design and selection of liner materials are particularly crucial in the design and operating stages. They are mainly affected by the physical characteristics of ores (such as abrasiveness, hardness), corrosion environment, and size of balls. The other factors, such as mill speed and filling, also have significant impacts. From a practical experience point of view, the design usually plays the most important role in affecting the mill efficiency and liner life.

The discrete element method (DEM) has provided significant contributions to the design and operation of grinding mills [2]. Because DEM capability to take account of changes in lifter geometry, ball/rock size distribution, and density in predicting mill power draft is better than well-established mill power models, DEM has successfully been used for predicting SAG and
ball mill power in large-scale operations. DEM has become increasingly interesting as a tool in establishing the basis for shell lifter designs. However, the leap from the DEM simulation to plant practice is big, particularly for predicting mill power draw with respect to lifter shapes and rock/ore variability. Therefore, the DEM utilized for optimizing the lifter shapes should be validated with small-scale trials rather than plant trials in which the risk, cost and time appear enormous.

The small-scale mill would allow for better evaluating the effect of changes in lifter design, grinding media, and operating parameters, which could then provide important basic information to the design and operation engineers in industrial mills [3,4]. The optimal mill liner is expected to improve the mill efficiency and to promote effective grinding as well, to promote more efficient grinding media trajectories, maximize mill throughput with the correct spacing and height of lifter bars, and to minimize liner/lifter and ball damage by avoiding impact onto the mill shell.

This paper presents a short review of mill liner design and its effects on mill performance. Firstly, considerations associated with liner design are briefly described. Then, the effects of mill liner design and operating parameters on mill performance are discussed. The review ends with current trends in establishing appropriate liner design at the operating stage.

2. Considerations in Liner Design

This section begins with a short description of the interaction between mill liner and charge that is a key factor in providing appropriate liner design. Then, liner spacing and shapes that contribute to the improvements in mill performance are discussed.

Mill Liner and Charge Interaction. The effects of the different lifters with the same lifter number/spacing on steady-state charge motion have been predicted using the DEM Millsoft [5]. Figure 1 shows snapshots of the charge motion at a steady state in the 4-m mill for the different lifters. The charge motion of rectangular lifters is almost similar to that of high-low (Hi-Lo) lifters, and a number of free-flying balls are observed for both rectangular and Hi-Lo lifters. Compared with both rectangular and Hi-Lo lifters, trapezoidal lifters with release angles of 20° allow balls to leave from shoulder position earlier and would minimize balls from hitting the mill shell, thereby reducing lifter wear. It is also seen in the mill that triangular lifters with higher leading face angle lower shoulder position of the ball charge, and therefore, it may decrease impact action.
Figure 1. Charge motion of the 4-m mill with different lifter shapes and at the same operating conditions: 70% critical speed, 35% mill load.

Liner Spacing and Shapes. Liner designs depend mainly on various combinations of lifter angles, spacing, height, and mill speed as well. Making changes in lifter spacing and height would modify the charge lifting rate, and thus they affect mill performance. It was found that the different ratios of spacing-to-height of lifter bars in an autogenous mill significantly affect the specific power and mill capacity. Therefore, using the spacing-to-height (S/H) ratio of 4-4.5 could give the optimum specific power and capacity [6].

Furthermore, the Skega A/B (lifter spacing/height) formula, which is an empirical equation for a rubber-lined mill, was formulated and shows that the S/H ratio considerably depends on mill speed [7]. Therefore, the mill could attain a maximum capacity and grinding efficiency at the different S/H ratio. If the lifter spacing is made too widely, it will generate slippage over the shell plate, leading to severe wear. On the other hand, if the lifter distance is spaced too shortly, it would produce material pocket between lifters, resulting in a very high rate of wear on the top of the lifter bars.

Most mill operators have not determined lifter angles at the beginning, and mill suppliers usually decide the angles based on their own experience. The operators consider changing lifter angles to fit their operating conditions just when the liners/lifters underperform or get broken. Powell et al. [1] mentioned some case studies of using good liner designs. For example, the initial SAG mill liner was installed using Hi-Hi with a 6° contact angle. Mill throughput increased by 11% after the face angle had been altered to a 17° angle and then to a 30° angle.

Currently, the large face angle (typically 20° up to 30°) with adequate spacing between lifters is used in the lifter design [8]. The suitable lifter angles could prevent the liner from premature failure and production loss. For mills without packing, computer-program trajectory tools together with DEM have been used for simulating the effects of liner spacing and angles on charge behavior; the outputs showed that mill performance in some cases significantly increases as the results of using wider-spacing and larger lifter-face angles. However, it would decrease as lifter wear becomes larger, and finally the benefits of the initial lifter end as a function of time.

Since the lifter height decreases and the face angle becomes larger because of wear, increasing mill speed for variable-speed mills may lead the ball impacts to directly go down on the toe of the charge and, therefore, compensate for initially wearing lifter to preserve mill performance. Liner wear life, in general, can be increased by increasing lifter height.

3. Effects of Liner Design and Operating Parameters.

The power draw of the mill, which was measured in the wet batch AG mill with different lifter types, decreases exponentially over the milling time [9]. In other words, the power draw of a mill changes significantly with respect to the mass of rock/grinding media remaining in the mill. Optimal liner shapes depend on mill speed, and a lower lifter with a lower face angle is appropriate for mills with higher
speeds. The linings leading to the lowest power draw would produce the finest grind and the coarsest grind for those with the highest power draw.

Jonsen et al. [10] also measured torque distribution in detail over one mill revolution at 77% critical speed and found there are obvious peaks in the torque readings when the lifters make a contact with the charge. This indicates that lifter shapes installed in the mill also have an effect on the power draw profiles.

Moreover, mill testing was carried out to measure load cell force of the 1-meter mill installed with the three lifter configurations at the operating conditions: 31% charge (13% ball & 18% rock), 70% critical speed [5]. Figure 2 shows the average power draw of the mill with the different lifters. It appears that the mill power differs slightly for the different lifter shapes with the same face angles of 20°. The mill with rail lifter would relatively require higher power, and with the high-low (Hi-Lo) lifter it does lower power. Even the high (Hi) lifter has the same lifting angles as the Hi-Lo lifter, the use of alternate high and low lifters would markedly affect the internal dynamic of charge in the mill, resulting in a slight change in the mill power draw.

The breakage rate in the laboratory mill with different lifters at the operating conditions: 25% mill charge and 70% critical speed was also determined using a single size of -19+12.7 mm (-3/4+1/2 inch) aggregate. For simplification, the mass fraction, mi(t)/mi(0), of the single size feed remaining in the top size interval versus grinding time is assumed to follow the first order rate. As shown in Figure 3, the breakage rate of the Hi-Lo lifter is highly faster than the first order rate for 4 minutes. Then, it goes down in the range of 4 to 11 minutes and rises at the end. Figure 4 shows that the corresponding size distributions of the mill product is also different with time and at longer grinding times, the rate of production of finer sizes decreases after 8 minutes.

![Figure 2](image_url)

**Figure 2.** Power draw of the mill with the different lifters, 31% charge: 13% ball & 18% rock, 70% critical speed.
Figure 3. First order plot for the -19+12.7 mm ground in the mill with Hi-Lo lifter at 25% charge, and 70% critical speed.

Figure 4. Cumulative size distributions versus time for the -19+12.7 mm ground in the mill with Hi-Lo lifter at 25% charge and 70% critical speed.

4. Establishing Liner Design at Operation
Some mill operators have noticed that mill throughput will systematically change as the liners wear. The wear would lead to significant changes in the shape of lifters, resulting in a significant impact on the grinding efficiency. There is a trade-off between the dual function of liners; designing linier profile to maximize liner life would, on the other hand, decrease the mill power draw, and as a result, the overall grinding rate also decreases. Therefore, it is a good practice for liner development to balance liner life and milling performance.
The relative wear rates of the different liner components resulting from the measurement of the changes in liner profile over milling time could be used for making a decision to change the liner design [1,11]. For instance, the base section of the liner was found to have a much lower wear rate than the lifter bar. This would be meaningful for the next liners, which should be designed with a little thinner base section. Furthermore, if the wear pattern of the mill liner has been determined, the original design may be made better by redistributing metal from the low wear rate areas to the high wear rate areas. Liner design in the future will be custom-built and not only driven by mill manufacturers but also mill operators. The appropriate design is developed and optimized based on practical experience, operating conditions, and ore types [12,13]. Because of advances achieved in laser-based thickness gauging technology, the tool has been used for measuring the liner wear pattern and rate during service. Combining the data from these scans with the power of DEM simulations and realistic wear testing techniques could provide a more effective way for liner optimization. Therefore, a more efficient liner profile during the liner lifecycle can be determined accordingly.

5. Summary

To establish favorable design, milling management should continue to improve liner design based on useful information from operating experience, ore types, previous good design practice, and supported by sophisticated ball trajectory and DEM tools as well. Due to higher cost and various drawbacks observed from plant trials in industrial mills, the small-scale trials would rather provide important basic information to the design and operation engineers in industrial mills.

The current lifter design utilizes a large face angle with sufficient spacing between lifters. The spacing-to-height (S/H) ratio of 4 at 75% critical speed would work best, and the optimal ratio would change at different mill speeds. The lifters with the same face angles but different configurations would generate different power draw and breakage rates.

Liner design also integrates the wear rates of liners derived from the actual measurement of the changes in liner profile over milling time. Laser-based thickness gauging technology, such as mill mapper, can provide the in-service measurement of the liner wear pattern and rate for determining a more efficient liner profile throughout the liner lifecycle.

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