Improving Autogenous/Semi-Autogenous Grinding Performance and Energy Efficiency with Optimised Pulp Lifter Design

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ABSTRACT

The comminution process indicates that the most energy-efficient comminution system would be one where the particles leave the breakage field as soon as they reach product size. Contrary to the free falling gravitational (vertical) flow in crushers, the grinding mill’s energy efficiency essentially depends on ore characteristics and the discharge rate of broken particles, which in turn depends on how efficiently the discharge pump (grate and pulp lifters) operates.

The essential function of a pulp lifter is to transport the broken material and slurry from the discharge grate out of the mill. Hence, the design optimisation of pulp lifters affects not only the energy efficiency and throughput of autogenous grinding/semi-autogenous (AG/SAG) grinding mills, but also contributes other process benefits such as improved wear life and operator-friendly steady and smooth mill operation.

Following its introduction in 2006, Outotec’s patented Turbo Pulp Lifter (TPL™) design has been retrofitted at existing sites and also installed in some new ones around the world. This paper will provide operational experience and data on how the TPL™ design has allowed AG and SAG mills to operate efficiently.

INTRODUCTION

The emphasis in mineral processing has always been on improving the energy efficiency of grinding mills as they consume significant amount of the total energy used in the mining industry. However, the question, ‘how energy efficient are the existing mills?’ needs to be answered.

The comminution process is typically a combination of breakage and classification aspects (Figure 1) as typically illustrated in comminution modelling. What Figure 1 indicates is that ‘the most energy efficient breakage system would be the one where the particles leave the energy field as soon as they become smaller than the required product and size’ – a classic example of which is the crushers where free falling gravitational (vertical) material transport exists (Figure 2).

Contrary to the crushers, the material transport in grinding mills is horizontal and therefore requires a suitable arrangement to remove the product, where the particles are forced for multiple breakage events even after they reach product size due to an inefficient material transportation system (Figure 3).

Fig 1 - Comminution process.

Fig 2 - Material transport in crushers and grinding mills.

Fig 3 - Material transport with conventional pulp lifters.

Realising this in the early 1900s, different designs of grate-discharge mechanisms have been tried to rapidly discharge the product size particles and significantly increase capacity and energy efficiency. However, the relentless increase in mill size has put mechanical restrictions on building energy efficient discharge systems and we were left with the existing grate-pulp lifter discharge and overflow-discharge grinding mills.

Outotec has carried out extensive studies to ensure an efficient material transport system, therefore enhancing the energy efficiency and maximising the capacity of the horizontal grinding mills. As a result of these studies, Outotec has developed a new technology – Turbo Pulp Lifter (TPL™). TPL™ enhances the grinding efficiency of AG/SAG and ball mills and therefore saves significant amount of electrical energy while maximising the mill capacity.

The objective of the TPL™ is to ensure energy efficient grinding by pushing the breakage/classification process in AG/SAG mills towards that of crushers by creating ideal material transportation as shown in Figure 4.

ENERGY EFFICIENCY ISSUES IN GRINDING MILLS

The research carried out in the past few years has explained the principal factors that cause inefficient grinding in AG/SAG mills, which are summarised in Table 1. The effects of each of these factors on energy efficiency in grinding mills are discussed here.

Flow-back and energy efficiency

Flow-back is the inevitable phenomena associated with the conventional pulp lifter designs – radial and curved, applicable to...
both slurry and solids/pebbles phase. Slurry flow-back is predominantly in single stage AG/SAG mills, as they handle large volumes of slurry due to the higher circulating loads up to 400 - 500 per cent. The geometry of radial and curved pulp lifters allow the slurry to be always in contact with the grate until it is completely discharged, which makes the ‘flow-back’ process inevitable.

As illustrated in Figure 5, while the gradient across the grate is from the grinding chamber in to the pulp lifter between the toe and shoulder of mill load, the gradient reverses from the pulp lifter into the grinding chamber, once the pulp lifter crosses the shoulder position. When slurry and pebbles flow down across the grate slots, they get an equal chance to go back into the mill as illustrated in discrete element method (DEM) simulation of 36 ft SAG mill pulp lifters shown in Figure 5.

Solid particles and coarse pebbles also flow-back through the grate apertures along with the slurry. While flow-back of slurry leads to pool formation, flow-back of pebbles increases the quantity of critical size material in the mill. The amount of pebbles passing through the grate increases with the angle of the grate. A DEM simulation of this scenario for a 36 ft diameter SAG mill is shown in Figure 5.

The inefficient usage of energy due to the flow back phenomena are summarised below:

- the amount of energy spent on the product size particles that flow back, after they passed through the grate, contributes to wasteful energy, as well as over grinding and generation of unwanted fine particles;
- the excess mill power draw due to the higher mill loads caused by the pebbles flow back contributes to wasteful energy;
- the flow back of coarse pebbles also increases the quantity of critical size particles and affects the energy levels available for breakage of coarse particles; and
- the mill capacity can be curtailed to the extent of flow-back, which has been noted to be anywhere from ten to 40 per cent based on pilot scale and industrial data.

The TPL™ discharge system completely stops the flow-back process and hence saves all the wasteful energy and uses it efficiently in breaking the new particles.

### Slurry pool and energy efficiency

The fraction of slurry that is flown back into the grinding chamber ultimately leads to slurry pool formation near the toe of the charge as depicted in Figure 6. The presence of the slurry pool absorbs a significant fraction of impact energy causing poor coarse particle breakage. The presence of the slurry pool also leads to poor attrition action, as the probability of particles draining into the slurry pool increases due to drag force, thus causing poor fine particle breakage. Both poor impact and poor attrition leads to overall lower breakage rates and therefore limits the mill capacity.

### Inefficient discharge

When a grinding mill rotates in the clock-wise direction, the pulp lifter essentially has the possibility to discharge its contents (slurry and solids) starting from nine o’clock and complete by
the three o’clock position. If the contents are not emptied by the three o’clock position, then the leftover slurry/solids gets carried over inside the pulp lifter.

The discharge of water from pulp lifter in pilot scale mill is shown in Figure 5 and the discharge of slurry from single stage SAG mill operating at 13 rpm (78 per cent critical speed) is shown in Figure 7. It can be seen from Figure 7 that the discharge is occurring in a narrow space between the 1.30 and three o’clock positions. Compared to Figure 5, where a fraction of water is left inside the pulp lifter, it is quite reasonable to assume in Figure 7 that a significant fraction of slurry (74 per cent solids) must be left inside the radial pulp lifter (RPL), as 0.58 seconds is not enough for complete discharge. The leftover slurry ultimately flows back through the grate into the grinding chamber and becomes part of the slurry pool.

However, with the TPL™ discharge system, the available time for discharge of pulp lifter contents could increase four fold (2.31 seconds) as indicated in Figure 7, providing ample time for complete discharge without carry over.

**Effect of carry-over on grinding efficiency**

With the advent of simulation techniques such as discrete element modelling (DEM), appropriate shell lifters can be designed to operate mills at higher speeds to attain higher throughputs. In contrast, the discharge efficiency of conventional pulp lifters decreases with increasing mill speed and hence a compromise is often made around 75 per cent critical speed.

Carry-over is a strong function of mill speed and slurry viscosity. Similar to the differential flow behaviour of water and sand in open channel river streams, the slurry fraction and solids follow different flow patterns inside pulp lifter. The fraction of slurry that is carried-over in a pulp lifter ultimately flows back into the grinding chamber and leads to slurry pool formation. However, only part of the solid particles flow back through the grate and majority of them stay inside the pulp lifter chamber as shown in Figure 8, where both DEM simulation and an actual picture are shown.

By the time a pulp lifter reaches the six o’clock position, the pebbles remaining in the pulp lifter reach the bottom and exert resistance to flow through the outer few rows of grate slots. However, to maintain the overall discharge rate using the remaining slots, the load level automatically raises to a level sufficient enough to exert the required pressure head. The increased mill load draws extra power as well as decreasing the grinding efficiency. It may be noted here that there is no direct way to measure this variation in mill load, but the difference in the mill load measured before and after the TPL™ installation does give an indication. In the present instance only the pre-TPL™ and post-TPL™ mill loads were measured while treating the same ore type, and the results obtained are shown in Table 2. The reduction in mill load from 27.59 (pre-TPL™) to 14.46 (post-TPL™) includes the change due to elimination of both flow-back and pebble pooling.

| TABLE 2 |
|---|---|---|
| Measured mill load before and after TPL™ installation. |
| | Pre-TPL | Post-TPL |
| Throughput (st/h) | 340 | 365 |
| Gross power (kW) | 2921 | 1928 |
| Specific energy (kWh/st) | 8.59 | 5.28 |
| Mill speed (rpm) | 11.14 | 10.18 |
| Total load (%vol) | 27.59 | 14.46 |
| Ball load (%vol) | 9.08 | 9.08 |
| % reduction in total load | 47.59 |

**Wear in pulp lifters**

The left-over pebbles inside the pulp lifter simply rattle across the pulp lifter length in each revolution and cause severe impact wear and excessive sliding wear. The resultant effect of repeated impact of these pebbles can be seen predominantly in rubber pulp lifter, as large holes in corner filler rings as shown in Figure 9. If unnoticed, they can make their impression on to the mill shell also. In steel pulp lifters these impact wear spots can be seen as shallow dishes.

In the TPL™ design, the impact forces that cause excessive wear are eliminated while providing a smooth laminar flow of slurry and solids, which increases the life of pulp lifters, possibly up to two fold.
EFFECT OF TURBO PULP LIFTER ON DOWNSTREAM PROCESSES

In ABC/SABC circuits, the mill discharge consists of slurry and coarse pebbles/rocks, which passes over a vibrating screen. The slurry phase typically enters the ball mill circuit for further grinding and the coarse pebbles are crushed and sent back to the mill as shown in Figure 10. Typically the aperture size of these vibrating screen ranges from eight to 15 mm, which also happened to be the typical closing screen size of tertiary crushers in traditional grinding circuits to generate the typical feed size (F80 = 7 - 10 mm) to ball mills. However, when modern AG/SAG mills entered the grinding circuit, the transfer size (vibrating screen U/S or T80) generated has decreased to the range 1000 to 3000 microns, accompanied by an excessive proportion of fines, generated due to internal circulation of product size particles.

But the top ball size that is fed to the ball mills remained around 60 mm to 75 mm, which do not match the recommended ball size for the present F80 sizes generated by AG/SAG mills. McIvor (1997) has reviewed the work related to the effect of media size on ball milling efficiency, and it was concluded that media size has a significant effect on grinding rates. To illustrate the impact of correct media size, the top ball size has been estimated for various feed particle sizes (F80) using the classic bond top ball size equation (given below) and the results are shown in Figure 11.

\[ B = \left[ \left( \frac{F}{K \sqrt{Wi}} \right)^{\frac{1}{3}} \right] \times 25.4 \]

where:
- \( B \) = ball diameter (mm)
- \( F \) = F80 (μm)
- \( Wi \) = work index (kWh/t)

It is often thought that producing fines in AG/SAG mills (by sacrificing their energy efficiency as explained in earlier section) could reduce the burden on ball mills. But, with a mismatch of particle size and ball size, it becomes questionable.

However, with TPL™ installed in AG/SAG mills, with the objective simply to make grinding mills energy-efficient by stopping internal recirculation (shown in Figure 3) and ensuring ideal material transport (shown in Figure 4), the production of an abnormal amount of fines is eliminated to produce appropriate transfer size (T80) similar to a typical ball mill feed. The T80 for post TPL™ operation has been estimated to be 8.1 mm, compared to pre TPL™ T80 of 1 - 2 mm, based on historical data as a complete grinding survey could not be undertaken for pre TPL™ operation. By doing so, a good match of required top ball size and particles size gets established, and therefore increases the performance of the ball mill circuit as indicated in Figure 12.

TURBO PULP LIFTER (TPL™)

Taking the above facts into consideration, it is imperative to efficiently remove both slurry and coarse solids to optimise the energy efficiency of AG/SAG mills.

The TPL™ ensures the best grinding conditions by allowing the product size particles to migrate faster through the discharge grate. The TPL™ does not require redrilling of the mill head when retrofitting. From the outside, the TPL™ appears exactly like the conventional radial pulp lifter (Figure 13a) with the internal design as shown in Figure 13b. Whilst maintaining this concept, the internal TPL™ design is varied to suit the existing mill configuration to ensure the ideal material transportation.

Elimination of material transport problems using TPL™ will bring the following process benefits:

- maximises the classification and breakage rates by improving the material transport,
- significantly increases energy efficiency by reducing the energy consumption (proven up to +20 per cent),
- allows the mill to operate at its maximum possible capacity (proven up to +20 per cent),
- ensures the mill gives true response for any changes in ore characteristics or process parameters,
- operator friendly – allows the mill to operate smooth and steady,
**CONCLUSION**

The optimal performance of grinding mills (AG/SAG/ball) is the key to a successful plant operation. Grinding mills with conventional pulp lifter designs suffer from inherent material transport problems, reducing energy efficiency and limiting mill capacity. The Turbo Pulp Lifter (TPL™) ensures the best grinding conditions by stopping internal recirculation of product size particles in AG/SAG mills, leading to significant electrical energy savings and capacity improvements. The application of TPL™ in AG/SAG mills automatically improves the energy efficiency of ball mills.

**REFERENCES**

Latchireddi, S, 2005. World patent, Apparatus for discharging a material from a mill, Patent pending, Outokumpu OY.


