SUSTAINABLE OPTIMISATION OF THE BELL CREEK SAG MILL

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ABSTRACT

Lake Shore Gold is engaged in commercial gold production at both the Timmins West and Bell Creek mines, located in Timmins, Ontario. Run of mine ore is processed at the Bell Creek mill which consists of a conventional gold mill flow sheet involving crushing, grinding, gravity concentration and carbon-in-leach (CIL) for gold recovery. Since 2009, the operating capacity of the mill has been upgraded from 2000 tpd tonnes per day (tpd) to over 3,000 tpd. The most recent expansion involved the installation of a low aspect ratio SAG mill to replace the secondary crusher. Without operational data on the low aspect mill, combined with a site team that was new to SAG milling, there were many challenges in achieving the target throughput from the circuit. Through the implementation of AwaRE advanced controllers, running in closed loop with PRC fragmentation cameras as well as embedded PARC modules within the Allen Bradley PLC, the site was able to rapidly develop a best operating practise and has been successful in creating a stable and consistent operational environment. The process, lessons learned and eventual solution will be reviewed in this paper.

KEYWORDS

Comminution, SAG Mill, Process Instrumentation, Process Control, Process Optimisation
INTRODUCTION

Lake Shore Gold is engaged in commercial gold production at both the Timmins West and Bell Creek mines, located in Timmins, Ontario. Run of mine ore is processed at the Bell Creek mill which consists of a conventional gold mill flow sheet involving crushing, grinding, gravity concentration and carbon-in-leach (CIL) for gold recovery. Since 2009, the operating capacity of the mill has been upgraded from 2,000 tpd tonnes per day (tpd) to 3,150 tpd. The most recent expansion involved the installation of a low aspect ratio SAG mill to replace the secondary crusher. This endeavor was split into two phases: the expansion of the back-end (Phase 1) and the front-end (Phase 2) of the mill. Phase 1 of the expansion was completed at the end of 2012 and involved enhancements and capacity addition to the leaching and adsorption circuits, which increased the mill’s capacity to 2,500 tpd. Phase 2 of the expansion commenced at the end of July 2013 and involved the expansion of the crushing and grinding circuits. The expanded front-end of the mill now has a capacity of 5,500 tpd, and processes ore from both Bell Creek and Timmins West mines. The updated flow-sheet, as shown in Figure 1, illustrates the replacement of the two-stage crushing and ball milling circuit with a single stage crusher and a low aspect ratio SAG mill.

To ensure a smooth and successful start-up following the expansion, Lake Shore Gold and Portage Technologies combined their expertise to build a robust system comprised of AwaRE advanced controllers, running in closed loop with PRC fragmentation cameras, as well as embedded PARC modules within the Allen Bradley PLC.

The steps taken in accomplishing this included:

1. Development of a ‘site best operating practice’ as per the updated flow-sheet, with the primary focus on the newly installed SAG mill.
2. Installation and commissioning of Portage Rock Characterization (PRC®) fragmentation cameras for the comparison of feed size on each apron feeder.
3. Integration of Portage Rock Characterization (PRC), Portage Advanced Regularly Control (PARC) modules, and AwaRE advanced controllers to provide a progressive control solution tailored for the Bell Creek operation.

Figure 1 – Simplified process flow sheet for Lake Shore Gold
SAG MILL: OPERATING PHILOSOPHY

Prior to the expansion, Bell Creek was a two-stage crushing and ball milling operation. The fact that the operational team was new to SAG milling, accentuated the need for the development of a ‘site best operating practice’. The fundamentals of SAG and ball milling make the operation and control of the respective mills notably different. In ball mills, grinding media accounts for approximately 80% of the total mass of the mill charge and dominates both power draw and grinding performance. In SAG mills, however, the feed ore is used as a significant portion of grinding media. Therefore, a change in feed size distribution or hardness can result in a noticeable difference in breakage characteristics, which impacts the charge level and mill power draw. Hence, SAG mills tend to have a much wider range of variability in power draw than ball mills, the latter of which are relatively stable. Ore variability was a significant challenge at Bell Creek, given that the mill was processing ore mined from both Bell Creek (soft) and Timmins West (hard) mines. The variability in ore hardness (work index), as determined during SAGDesign grinding test work by Starkey & Associates, ranges from 10 kWh/t to 17 kWh/t.

Another challenge encountered while transitioning from ball-milling to SAG milling was that the heuristics for SAG and ball mill operations are the opposite. Power draw can be used to detect mill load in both SAG and ball mills. When a ball mill starts to load up, the power draw gradually decreases. In SAG mills, this trend is reversed. Typically, as a SAG mill loads-up, the power draw increases. However, if a SAG mill is severely overloaded, its center of gravity shifts and the mill power draw starts decreasing. This is referred to as a ‘classical overload’ or ‘freewheeling’. A ‘freewheeling’ mill can be identified when the hydrostatic bearing pressure is increasing (due to increased holdup of material), but the power draw is decreasing.

![Figure 2 Behavior of Power Draw - Ball Milling vs. SAG milling](image)

The complexity of the interaction between bearing pressure and mill power draw in SAG mills is explained in Table 1.

<table>
<thead>
<tr>
<th>Bearing Pressure</th>
<th>Increasing</th>
<th>Stable</th>
<th>Decreasing</th>
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<tr>
<td>Power Increasing</td>
<td>LOADING</td>
<td>UNLOADING or LOADING</td>
<td>UNLOADING</td>
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<tr>
<td>Stable</td>
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As long as the bearing pressure and power track one another, characterizing the mill load is simple. However when power and pressure stop tracking one another, load characterization becomes tricky. This is explained further in the figures below.
Figure 3 and Figure 4 show real-life examples of the Bell Creek SAG mill being ground-out following mill overloads. In Figure 3, both bearing pressure and mill power can be seen to be increasing up until the mill feed is stopped. As the mill is ground-out, both bearing pressure and power draw decreases. This relationship is inversed in Figure 4, where the bearing pressure is increasing while the mill power draw decreases due to the onset of a classical overload. In the case of Figure 4, as the mill is ground-out, the bearing pressure drops significantly, however the power draw increases (this is a typical response for a SAG mill coming out of a classical overload). These examples highlight a fundamental difference between ball mill and SAG mill control. While monitoring power draw alone is sufficient for ball mills, in SAG mills, both bearing pressure and power draw need to be considered for proper operation and control.

MILL: BEST OPERATING PRACTICE

In planning for the mill expansion, the team was proactive in identifying a number of challenges associated with the project. These are most notably:

1. The operating crew was new to SAG milling.
2. There was no dedicated control room that would provide continuous oversight of the plant. Operators at Bell Creek relied on field-mounted screens to observe process conditions and make set point changes.

Given that the crew was new to SAG milling, combined with the fact that there were no systems in place to provide continuous oversight of the process to protect against sudden process changes, there was a gap that needed to be bridged. Lake Shore Gold and Portage Technologies combined their expertise to develop a ‘site best operating practice’, where the overall control philosophy focused on maximizing tonnage while maintaining stability.
The modes of control were divided into three regimes:

1. Overload prevention mode for avoiding critical situations such as mill overloads,
2. Optimisation mode for throughput maximization while preserving stability,
3. Liner Protection mode to avoid steel-on-steel collision from running the mill empty.

As discussed earlier, feed size and ore hardness have a noticeable impact on SAG mill load and performance. To stabilise the load in the SAG mill, ‘degrees of freedom’ must be adjusted, sometimes significantly. In manually controlled SAG mill operations, the most commonly adjusted parameter for load stabilisation is tonnage. However, there are other degrees of freedom that can be leveraged to stabilise mill load without impacting throughput. This includes feed size (if appropriate instrumentation is available), mill feed density, mill speed, and cyclone feed density. The ‘site best operating practice’ prioritised individual ‘degrees of freedom’ in order to maximize throughput while maintaining stability.

Figure 6 and Figure 7 show the prioritisation of the ‘degrees of freedom’. In ‘high’ SAG load situations, feed size, SAG feed density and SAG discharge pump-box water are manipulated in parallel to unload the SAG mill. Tonnage is the last parameter to be adjusted and is manipulated only after all other ‘degrees of freedom’ have been exhausted. The only exception is in the event of a severe overload, where all ‘degrees of freedom’ are leveraged simultaneously to unload the SAG mill.

During ‘low’ and ‘acceptable’ mill loading situations tonnage is prioritised first. If mill load continues to be classified as ‘low’, even after tonnage has reached its maximum allowable set point, then feed size, mill feed density and the SAG discharge pump-box water addition are adjusted to load up the mill. A secondary benefit of this control strategy is that once tonnage targets have been met, the system naturally starts to optimise grind size. This occurs because the combination of a heavier mill density and a lighter cyclone feed density both contribute to producing a finer cyclone overflow.
Figure 6 – Overload prevention mode, degrees-of-freedom prioritisation

Figure 7 – Liner protection and optimisation mode, degrees of freedom prioritisation
This ‘site best operating practice’ was implemented at Bell Creek using Portage Technologies’ AwaRE expert system. AwaRE combines a heuristic model with a fuzzy logic core and inference engine to evaluate a situation. Fuzzy logic is the concept that few things can be defined as true or false when considering control and optimisation. Process conditions are often best defined using degrees of truth, which are analogous to how sure one is that something is a certain way. This ability to think in shades of grey enables a system to better emulate a human being's thought process. AwaRE evaluates the current state of the process, but this evaluation is not black and white. Using fuzzy logic, AwaRE determines how certain it is that a particular situation exists and it makes changes based on that level of certainty. AwaRE is designed to identify changes in operational regimes (i.e. hardness, mineralogy) and modify the operating parameters based on the process conditions. By using the ability to reason, the system is uniquely suited to guide the control strategy. This is especially valuable when considering unmeasured disturbances, such as ore variability, experienced by the SAG mill at Bell Creek.

**PRC® - FEED CHARACTERIZATION**

SAG feed size is a powerful ‘degree of freedom’ for loading or unloading a SAG mill. However, in order to leverage feed size as a ‘degree of freedom’, appropriate instrumentation must be installed to characterize the feed. In most SAG milling operations, it is common for mill Operators to run the middle apron feeder noticeably faster than the outer feeders. More feed is drawn from the middle feeder because it typically contains the finest material, which is favourable for throughput.

![Figure 8 – Stockpile Drawdown Dynamics](image)

The fact that the middle feeder contains the finest material can be attributed to the natural segregation in a stock-pile, where the larger, coarser rocks tumble down the side of the stockpile towards the outer edge, whereas finer material is able to move through the voids and report to the middle. However, running the middle feeder disproportionately faster than the outer feeders ultimately results in the formation of an ‘inverted cone’ (colloquially referred to as ‘rat holing’). When this occurs, coarse particles start reporting to the middle feeder. Further to this, when the stockpile gets drawn down low enough, it is typical for operations to send a dozer in and push the remaining stock-pile in to the feeders. In such situations, the middle feeder can often contain the coarsest material (relative to the other two feeders), however, without any instrumentation, the Operator is unaware of the size distribution on each feeder and hence must rely on visual verification in the field in order to set the feeder ratio set points. In the case of Bell Creek, after a dozer was sent in to clean up the stock-pile, it was common for the middle feeder to have substantially coarser material than at least one of the outer feeders. In order to have the feeder ratio set-points adjust dynamically based on changing feed size, PRC fragmentation cameras were installed on each apron feeder. By installing a fragmentation camera on each feeder, feeders can be ranked in terms of coarseness. This allows the system to take action on the appropriate apron feeder for SAG mill load stabilisation.
The PRC system installed at Bell Creek consists of an enclosure overlooking the process. There are two inspection doors installed on the front and side of each enclosure. This facilitates inspection and maintenance of the PRC system, even while the plant is running. The enclosure is fitted with 4 LED lights that provide sufficient illumination required for image processing and the PRC camera installed at the top. Camera data is transmitted from the stockpile dome to an Image Processing server in the engineering station server room. The Image Processing Server is used to perform fragmentation analysis on-line. Raw images captured by the PRC camera are processed using Portage’s proprietary fragmentation algorithms. The results from the fragmentation analysis allows the PRC system to determine what fraction of the feed on each belt can be classified as ‘coarse’, ‘mixed’, or ‘fines’. Based on this information, AwaRE ranks each feeder according to relative coarseness. This information can then be leveraged as a degree-of-freedom for SAG load stabilisation. Fragmentation data is displayed to the Operators using the ‘PRC Operator View’ application which is continuously running in the Server Room. The Operator View also provides a video stream of each apron feeder along with key process parameters such as the particle size distribution, percent coarse, percent mixed, and percent fines on each feeder.
INTEGRATION: DEVELOPING A PROGRESSIVE CONTROL SOLUTION

Progressive control is a disciplined approach that begins with the instrumentation and builds towards optimisation. Developing a progressive control solution for Bell Creek was accomplished through the integration of instrumentation, foundation controllers, PARC modules, and AwaRE. The progressive control hierarchy at Bell Creek is illustrated in Figure 12.

Prior to integration, the Operator was responsible for evaluating process conditions for the SAG mill and downstream processes. Based on this evaluation, a set point was set on six foundation controllers on the SAG mill and remaining foundation controllers downstream were adjusted. All of this needed to be done from the plant floor while shuttling back and forth between the primary and secondary grinding buildings. The progressive control solution, as illustrated in Figure 13, integrated process information obtained from the field and adjusted set points on all six foundation controllers in order to meet the metallurgical targets set by Operations. The mill was consistently being run by a ‘seasoned’ SAG mill Operator.
Figure 13 - Progressive control implementation for SAG mill operation (after integration)

Being a green-field operation, the lack of operational data was one of the challenges facing the start-up team. Also, due to the fact that this was a low aspect ratio SAG mill, the process dynamics were considerably different from the typical North American high aspect ratio mills (pancake mills).

High aspect ratio mills exhibit faster dynamics. As a result, the rates of change for high aspect mills must be calculated over shorter periods of time as the mill can go from stable to an over-loaded state in less than a minute. Lower aspect SAG mills, such as the one at Bell Creek, have longer residence times and hence exhibit slower and more gradual dynamics, there is more inertia. Thus, when analysed over a short period of time, the mill may appear to be stable, however, it would continue to gradually load up to the point where the mill becomes over loaded. Accounting for the differences in mill dynamics was an important step in deploying the progressive control solution. However, the lack of operational data made it challenging to provide suitable operational targets to the system. Establishing suitable parameters that would ensure that the system was pushed to full capacity without compromising on stability was one of the key challenges experienced during fine-tuning the AwaRE system. To overcome this challenge, the Lake Shore and Portage start-up team worked together, monitoring mill power draw, bearing pressures, grind size and overall mill stability to converge upon well-defined operating parameters for SAG mill control. As a result, the team successfully built a system that would continuously apply the ‘site best operating practice’ and created a stable and consistent operational environment.

A notable example of this is shown in Figure 14, where there was a noticeable change in ore hardness, which led to a rapid increase in mill power draw. During this incident, mill power draw increased from 5,500 kW to 6,100 kW in 15 minutes, with an initial rate of change of approximately 10% per minute. Such a rapid change in power consumption would have likely resulted in a tonnage cut if an Operator was running the SAG mill manually. However, as shown in the figure below, AwaRE was able to leverage feed size and mill feed density to stabilise the SAG mill without making any tonnage cuts. As a response to the rapid increase in mill power draw, the system sped up the feeder with the finest material while
proportionally slowing down the feeder with the coarsest material. In addition, the system increased the mill feed-end water addition. The combination of these actions resulted in the stabilisation of mill power, without necessitating any adjustments to throughput.

Figure 14 - SAG mill stabilisation using feed size and mill feed density

Another example is shown in Figure 15, where mill load was stabilised by adjusting SAG feed size and cyclone feed density. As shown in the figure below, the ratio set point to the coarsest apron feeder was decreased, which consequently sped up the finest apron feeder proportionally. In addition, the cyclone feed density was increased to allow for a coarser split, which consequently reduced the recirculating load around the SAG mill and helped stabilise mill load.

Figure 15 – SAG mill stabilisation using mill feed size and cyclone feed density
CONCLUSION

The objective of the progressive control solution was to help the site achieve target throughput by developing a 'site best operating practice'. To ensure continuity in system ownership, training the Operators was an important step in the journey. Portage engineers worked closely with the Operators at Bell Creek to familiarize them with the concepts of SAG milling. In addition, Portage worked with the team to ensure that they understood the fundamental operating philosophy of the progressive control solution developed for site. Operators were also trained on how to interact with AwaRE and set targets using the AwaRE parameters page that was custom built for the Human-Machine-Interface (HMI) at Bell Creek.

At the time of sign-off and hand over to Lake Shore Gold, the overall system utilisation rate was in excess of 90%. With the layers of progressive control working together, grind-outs were effectively eliminated and the mill was never run empty. The system had been well accepted, Lake Shore gold achieved design tonnage within three weeks, and the value added from progressive control was clear.

ACKNOWLEDGEMENTS

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Starkey & Associates Inc. (2011). SAGDesign Comminution Analysis and Mill Sizing Report on Bell Creek and Timmins West Drill Core Samples