Leinster Nickel Mine—Comminution Circuit Optimisation

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Abstract

Over the course of 2021, the Leinster Nickel mine focussed on continual improvement of the comminution circuit to reach production targets aided by the MillROC service provided by Orway IQ. The comminution circuit operating at a nominal throughput of 3 Mt/a comprises a primary crusher followed by a closed circuit SAG mill (7 MW) with an adjacent ball mill (1.6 MW) receiving a bleed of the SAG mill cyclone underflow, closed with its own cluster of cyclones. The aim of the circuit optimisation was to identify the main impediments to grinding circuit throughput and to implement changes to alleviate bottlenecks where possible.

Efforts began in early 2021 with circuit stabilisation through implementation of process control initiatives. The objective of this phase was to stabilise key operating variables like SAG mill weight, density and circulating load. Once implemented, the stabilised circuit allowed for clearer diagnosis of circuit constraints and better prioritisation of critical optimisation steps.

The key opportunities identified following the circuit stabilisation were slurry pooling in the SAG mill; underutilisation of the ball mill due to volumetric constraints and the inability to independently control SAG mill and flash flotation density.

Changes to the grinding circuit control philosophy, SAG mill grate configuration and operator training resulted in significant improvements is circuit throughput, efficiency, and stability. Improvement in SAG throughput of 15% was realised as was a 20% improvement in grinding efficiency, achieving a finer grind at increased throughput. Significant improvements in circuit stability and consistency of performance were also achieved, benefiting downstream processing.

This paper outlines the optimisation steps taken and the critical learnings along the journey.

Keywords

SAG, comminution, optimisation, process control, stabilise, grate, slurry pool

Introduction

The Leinster Nickel Mine is located in Western Australia and is owned and operated by BHP Nickel West. Ore for the processing plant is sourced from various open pit and underground sources and is blended by alternating loader buckets fed into the primary crusher from stockpiles on the ROM pad. Nickel is recovered through milling to a target cyclone overflow product P_{80} size of <120 µm, followed by downstream sulphide flotation. Additional flash flotation capacity is installed within the SAG mill circulating load, treating cyclone underflow to target recovery of coarse liberating sulphide nickel and reduce downstream losses due to over grinding.

The grinding circuit was originally commissioned in 1976 as a ball mill circuit processing circa 0.5 Mt/a. A circuit upgrade in 1991 added a 7 MW AG mill to the circuit with the existing primary ball mill used to treat a portion of AG mill cyclone underflow. In the late 1990s the AG mill was converted to a SAG mill.

A summary of the circuit design criteria is outlined in Table 1.

Table 1—Leinster Nickel Mine Comminution Circuit Design Criteria

Parameter	Unit	Value		
Annual Plant Throughput	Mt/a		3.0	
Primary Crushing				
Throughput	t/h		450	
Milling				
Throughput	t/h		375	
Cyclone Overflow P_{80}	µm		80 - 120	
Typical Ore Characteristics		**UG**	**Camelot**	**Rocky's**
Typical Blend Proportions	%	35–55	20–30	20–40
BWi	kWh/t	22–28	22–26	16–18
Ai	g	0.005	0.007	0.075
Axb		30–40	60–70	50–70
SG		3.3	2.54	2.61

Circuit Description

The Leinster comminution circuit consists of a primary jaw crusher (Jaques Terex 6048H, 160 kW), operated without a scalping grizzly. The primary crusher product reports to a coarse ore stockpile with a live capacity of 40,000 tonnes.

Feed to the SAG mill is drawn from four vibrating feeders located beneath the coarse ore stockpile. The milling circuit comprises a closed circuit SAG mill (ø 9.6 m x 4.86 m EGL, 7 MW, 75% Nc) which discharges onto a horizontal vibrating screen (2.4 x 4.8 m) with 4 mm slotted apertures. SAG mill discharge screen oversize is conveyed back to the feed of the SAG mill without pebble crushing.

Screen undersize is pumped to two clusters (east and west) of Cavex (250CVX) cyclones which typically operate at 90–120 kPa with 8–12 online per cluster. The underflow from each cluster feeds dedicated flash flotation cells (SkimAir SK500) with flash feed water added to optimise flotation performance. Flash flotation tails are combined in a splitter box with the majority returning to the SAG mill feed.

The ball mill (ø 4.56 m x 4.75 m EGL, 1.65 MW, 71% Nc) which is installed alongside the SAG circuit receives feed from a portion of the flash flotation tails which is bled across to the ball mill discharge hopper. The ball mill operates in closed circuit with a dedicated cluster of Cavex (250CVX) cyclones at a pressure of 90–120 kPa with 5–7 cyclones typically operating at a time. In addition to new feed from the SAG circuit, the ball mill can at times, also treat additional recycle streams from the flotation circuit in a regrind capacity.

A summary flowsheet for the crushing and grinding circuit is presented in Figure 1.

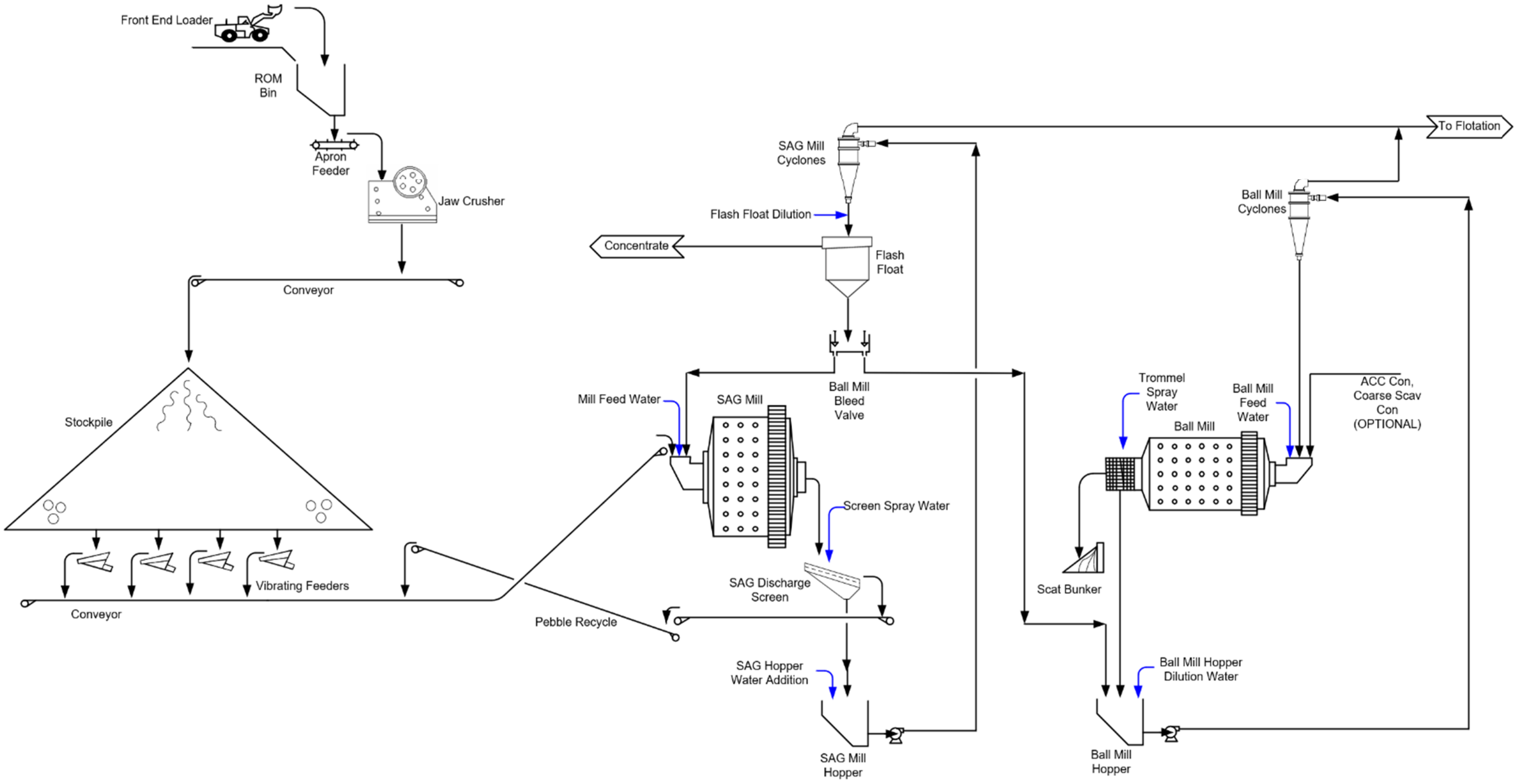


Figure 1—Leinster Comminution Circuit Flowsheet

Circuit Stabilisation

A site visit was conducted by Orway Mineral Consultants (OMC) in February 2020 to provide an initial review of the grinding circuit performance and existing control system. During the visit opportunities for improvement of overall circuit stability were identified. To assist with the implementation of the initial recommendations and ongoing grinding circuit optimisation, Orway IQ (OIQ) were engaged by BHP Nickel West to implement MillROC in late March 2020. MillROC provides a live cloud server link to the plant control system which allows for remote data collection and analysis of the plant operating data in real time. The real time data allows for KPI dashboards to be implemented on the web-based interface and remote consultation and with site teams on an ongoing basis. This consultation model allows ongoing contact and re-evaluation through the implementation phase rather than the traditional consultation engagement where implementation is usually left to the site or project team.

The first stage of the circuit optimisation was to stabilise key operating variables through the implementation of updated process control loops to reduce variability in the SAG mill load and cyclone operating pressure. Once key operating variables are stabilised, root cause analysis is significantly simplified and systematic testing of hypothesis is possible.

HISTORICAL CONTROL

The circuit control philosophy in use prior to the optimisation effort is summarised below.

SAG Mill Feed Rate

The SAG mill feed rate was a manually input set point (fixed feed rate) with SAG mill operated between acceptable weight and power draw limits (variable load). Operators adjusted the amount of material feeding the ball mill by changing the ball mill circuit feed valve position (% open) on the flash flotation tails to manage the SAG mill weight and circulating load. When circulating loads increased, the bleed valve was opened to allow more material to feed across to the ball mill. If the SAG mill was overloaded, it was ground out.

SAG Milling Density

The SAG mill feed water addition was controlled by manual operator set points. The SAG feed water was added at the Flash flotation feed to control the flotation, milling and overflow density. Anecdotally, it seemed that the Flash cells had problems with discharge flow if operated at densities (above 55% solids). This density was probably lower than optimal and was operated in that way to cater for changes in circulating load and cyclone underflow density. This resulted in very low SAG milling densities of less than 60% solids at times as the flash performance was prioritised over SAG milling density. Whilst it was noted that some ore types exhibited higher slurry viscosity and lower milling densities were required to ensure slurry could flow through the SAG mill grates and the SAG discharge screen, other ores would have benefited from higher densities, particularly with new liners.

SAG and Ball Mill Cyclones

The number of cyclones operating was adjusted to achieve a pressure setpoint between 80 and 120 kPa. Typically, 8 to 10 SAG cyclones and 5–7 Ball mill cyclones were operated. The cyclone feed pump speed was modulated to maintain a constant hopper level. Typically, no water was added to the discharge hoppers (apart from screen sprays) and operating density of the flash flotation and SAG mill was controlled by adding water at the flash flotation feed. Water was added in the bleed stream to the ball mill to help maintain flow. Cyclone feed density was measured but not controlled.

Ball Mill Feed

The feed rate to the ball mill was controlled through adjusting a pinch valve on the flash tails splitter box which allowed material to gravitate to the ball mill discharge hopper. The ball mill feed valve was opened to help relieve SAG overloading. When the SAG weight increased, the ball mill bleed valve was opened to remove material from the SAG circulating load.

UPDATED CONTROL PHILOSOPHY

Following the commencement of MillROC, a revised control philosophy was proposed for implementation. The control philosophy hinged around stabilisation of key operating variables: SAG mill load, milling density and circulating load. The key process control loops implemented in the SAG mill circuit were:

1. Control of SAG mill weight by adjusting new feed rate
2. Control of SAG cyclone pressure using SAG discharge water addition and cyclone feed pump speed
3. Control of SAG mill density by adjusting SAG (flash) feed water addition

And in the ball milling circuit:

1. Control of ball mill cyclone feed pressure by adjusting ball mill discharge hopper water addition
2. Control of bleed to ball mill to cyclone feed density/cyclone overflow grind size

SAG Weight

The SAG mill feed rate is automatically adjusted to maintain a target SAG mill weight. The SAG mill weight set point is provided by the operators. When the SAG weight is below set point, the controller increases feed rate to raise the weight and vice versa.

SAG Milling Density

SAG (flash flotation) feed water addition is controlled in ratio with the new feed rate. A feed water ratio set point is provided by the operators with the feed water automatically adjusting with fluctuations in new feed rate to maintain stable operating density in the SAG mill. This possible with a more consistent recycle back to the mill resulting from constant pressure operation and no cyclone switching.

SAG and Ball Mill Cyclones

A cyclone feed pressure set point is provided by the operators. The cyclone feed pump speed is adjusted to maintain hopper level, with discharge hopper water addition used to control pressure. In this control loop, if the cyclone pressure is above/below set point, discharge water addition is reduced/increased resulting in a slower/faster pump speed to maintain the hopper level (and a reduction/increase in cyclone pressure results). The number of cyclones online is selected to achieve a circulating load of around 250% and not changed unless there is a significant shift in throughput. Cyclone feed density is not controlled but allowed to drift with natural changes in ore characteristics and milling conditions within an acceptable P_{80} range as measured by the online PSA.

Ball Mill Feed

The feed to the ball mill circuit is controlled by adjusting the valve position on the flash flotation tails splitter-box. Once constant pressure control is setup on the ball mill cyclones, the cyclone feed density corresponds to a cut point (and therefore COF P_{80}). The ball mill cyclone overflow P_{80} then indicates whether the ball mill power is fully utilised with a P_{80} below target indicating additional material could be bled across to the ball mill and a P_{80} above target indicating that less material should be bled across to the ball mill.

A summary of the control changes implemented is presented in Table 2.

Table 2—Grinding Circuit Control Philosophy Comparison

Parameter	Unit	Existing	Proposed
SAG Weight	t	Range 150–330 t	Operator Set Point
SAG Power Draw	kW	Range with max for safety	Range with max for safety
SAG Feed Rate	t/h	Operator Set Point	Varies to control SAG mill weight
SAG Feed Water	m^3/h	Operator Set Point	Varies in ratio with new feed rate. Operator provides ratio SP based on measured SAG discharge density
SAG Discharge Water*	m^3/h	Fixed. Discharge screen sprays only	Varies to control hopper level
Cyclone Pressure*	kPa	Range 80–120 kPa	Operator Set Point
Cyclone Feed Pump Speed*	%	Varies to control hopper level	Varies to control cyclone pressure
Cyclones Online*	#	Varies to control cyclone pressure	Operator Set Point
Bleed to Ball Mill, Valve Position	%	Operator Set Point	Adjusts to target ball mill COF P_{80}

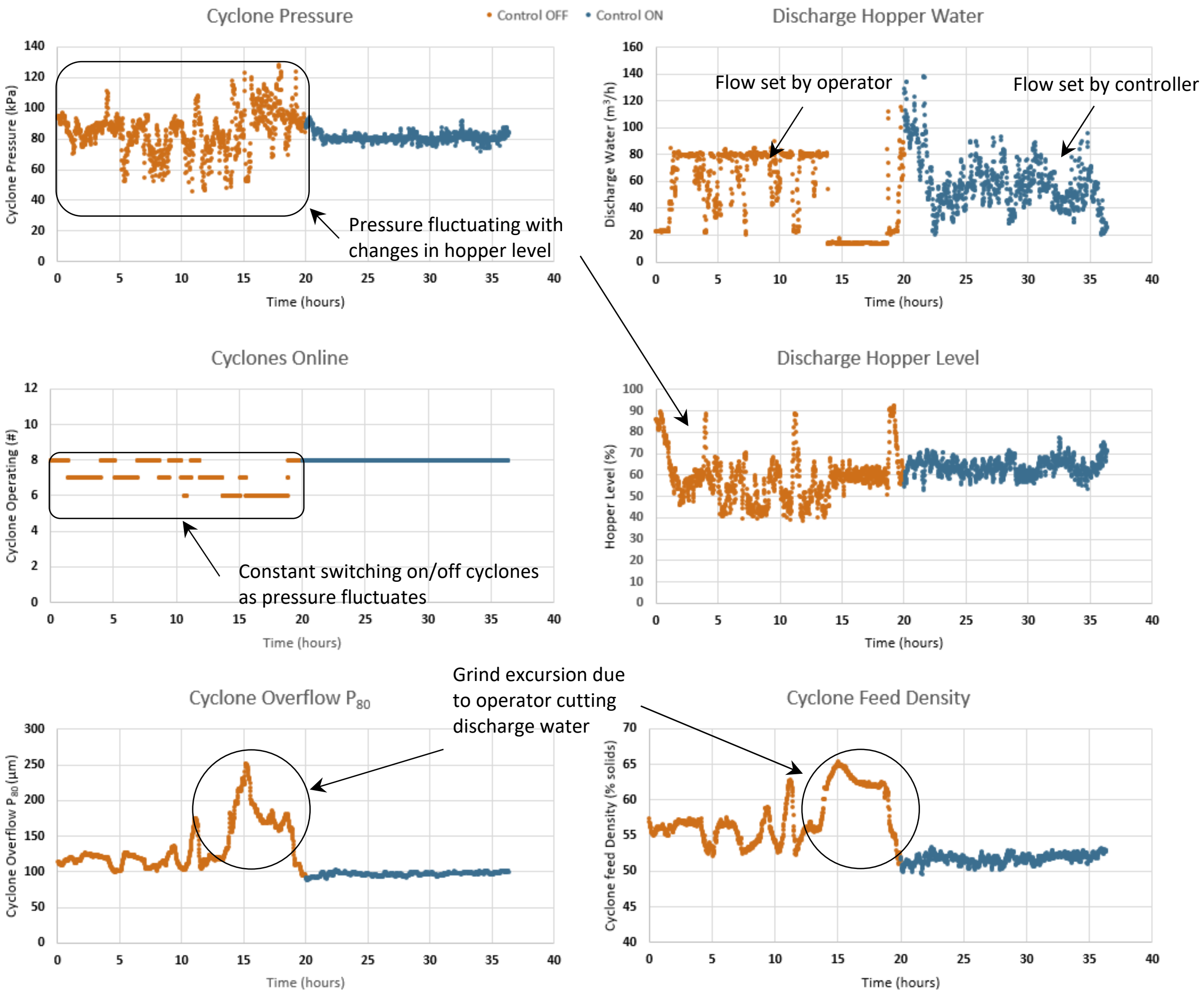
* Applies to both SAG and ball mill circuit

Through the implementation of the proposed control loops, the flows through the circuit and the operating conditions in the SAG mill were stabilised enough to allow trials of different operating conditions to be undertaken.

IMPACT OF CONTROL CHANGES

Cyclone Pressure

An example of the impact of the implemented control system on cyclone stability is shown in Figure 2.



Pressure fluctuating with changes in hopper level

Flow set by operator

Flow set by controller

Constant switching on/off cyclones as pressure fluctuates

Grind excursion due to operator cutting discharge water

Figure 2—Cyclone Pressure Control Stabilisation

Figure 2 illustrates the cause-and-effect driving circuit instability. The fluctuating cyclone pressure causes changes in the cut size which effects the amount of material returning to the mills as well as the density of the slurry in the mill. As the flows returning to the mills are unstable, this instability effectively recycles back through the mills to the feed of the cyclones and makes stabilisation even more difficult. As soon as the pressure is stabilised, the whole circuit steadies out and fluctuations due to changes in recycle flows are removed from the system. Stabilising the pressure is achieved by using discharge water addition to maintain a stable flow into (and out of) the discharge hopper. Once implemented, the controller only needs to manage instability from changes in fresh feed flows rather than fluctuations in both new feed and recycles. With typical circulating loads of 200%–400% of new feed, recycle flows have a much larger influence on overall stability.

As a result of the pressure control, the cyclone feed flow and density operate in a much narrower band and the correlation between cyclone feed density and overflow product size is very strong, allowing the cyclone feed density to be used as a reliable proxy for overflow P_{80} size.

The relationship between overflow P_{80}, as measure by the particle size analyser (PSA), and cyclone feed density is illustrated in Figure 3 with differentiation of pressure control on and off.

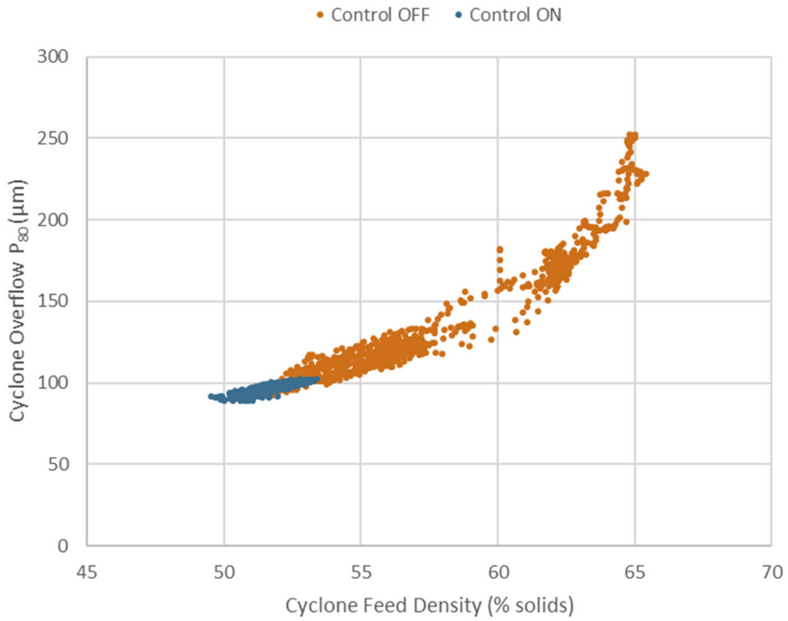


Figure 3—Cyclone Feed Density and Overflow P_{80} with Pressure Control ON and OFF

The pressure control ON data not only has a tighter spread of P_{80} for a given feed density but also illustrates how much more stable the cyclone feed density becomes with pressure control operating. This is a natural side effect of stabilising the recycle flows which is often under emphasised. Pressure control does not imply wide fluctuations in feed density and generally stability of both pressure and density improve when using this philosophy as is illustrated in Figure 3.

SAG Weight

Implementation of SAG weight control was undertaken using the existing Knowledge Scape (KSX) model predictive controller (MPC) which had been previously decommissioned. The controller allows the SAG feed rate to operate in a band (ranges provided by the operators) with the new feed rate to the SAG mill adjusted through manipulation of the feeders beneath the coarse ore stockpile. A comparison of the variability of the SAG weight from set point with and without the KSX control is shown in Figure 4.

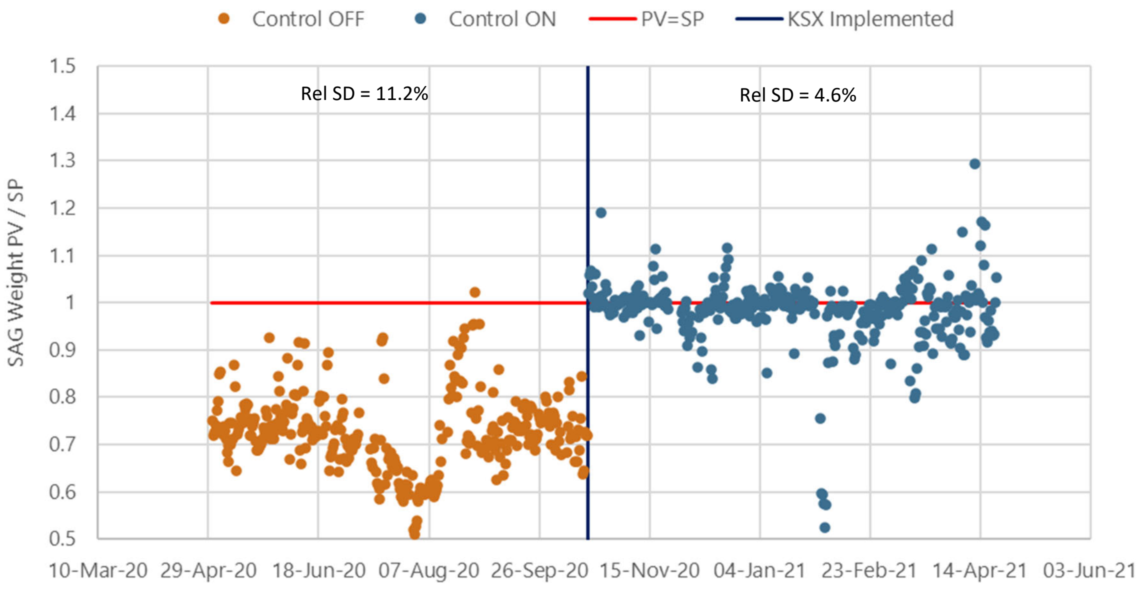


Figure 4—SAG Weight Control with and Without KSX

Without the KSX MPC, the SAG weight setpoint was used as an upper limit for operating weight (together with SAG power). The operating weight (PV) never approached the SP value unless the weight increased to maximum at which point the SAG mill would be ground out. When the KSX control was reinstated, the controller managed the SAG weight to below 5% relative standard deviation of the set point provided by the operators. This was a significant step towards stabilising the SAG mill operating load. If the load can be controlled, intentional manipulation of the breakage mechanisms in the SAG mill becomes possible and provides the metallurgists and operators with the power to choose and test different operating conditions.

IMPLEMENTATION CHALLENGES

One of the most difficult aspects of the implementation of SAG weight control was changing the mindset of operators who were used to having direct control of the SAG feed rate. Manipulating the weight set point and milling density often proved to be frustrating with the circuit responses slower than operators were expecting (hours required to observe the circuit response rather than minutes). To circumvent the slower response of new control system, it became common practice for the operators to manually increase the weight set point to allow temporary (1–2 h) increases in feed rate whilst slowly overloading the SAG mill again. Whilst this did increase the feed rate for a couple of hours, the feed had to be stopped while the mill was ground out before restarting again. Constraining the KSX controller high and low throughput limits was also a technique used to try and hold throughput rate at the budgeted target even when the mill load was escalating. The effectiveness of the control also deteriorated over the life of the liners.

Being under constant production pressure is commonplace across most operations and with implementation of new control philosophies, operators can understandably feel as though they have lost hold of the steering wheel. Intensive, live coaching and constant discussion with the metallurgists and production team is required during the implementation of these kinds of control changes. Preferably done on site in the control room. Support from management to weather potential short term production losses while the control is properly implemented is also invaluable to encourage adoption as it reduces the immediate pressure to perform while learning to operate in a new way.

In the longer term, this approach was a fundamental improvement in the way the SAG mill is operated and yielded improved and more consistent production. Perhaps as important, however, is that it will allow a sound justification of plant performance to upper management in the future. It is the metallurgist and operator's role to ensure the SAG mill operating conditions are optimal in terms of milling density, operating speed, ball charge, total load and power utilisation. The throughput that results is then mainly a function of the ore properties and feed size, parameters generally not in the control of the metallurgists and operators. If the SAG mill parameters are stable and at close to optimal conditions consistently, there is a much stronger justification for capital allocation to help overcome future throughput limitations when management set targets are beyond the capability of the installed equipment.

When implementing cyclone pressure control, strong resistance was initially received from the operators mostly around the addition of water to the discharge hopper. There were many misconceptions around addition of water to the discharge hopper causing SAG mill overload events. While in reality there is no direct causal relationship between controlled amounts of SAG discharge water and retention of material in the SAG mill if cyclone pressure is maintained (balancing water added to the feed and discharge of the mill), scepticism due to past experience was hard to overcome initially. As with the KSX control, operators found methods to circumvent or constrain the controller so that its intended functionality was diminished or entirely compromised. For example: constantly adjusting pressure setpoints and changing the number of cyclones online when no action was required; and reducing the number of cyclones online to ensure that the discharge water stayed below a certain threshold which was historically considered to be the main driver of SAG overload events.

Usually, the driving reasons for changes to cyclone operation stemmed from the need to respond to fluctuations in SAG feed rate to maintain the SAG weight set point. While the correct response to increased SAG weight (and lower throughput) would have been step trial manipulation of the SAG milling density, weight set point and perhaps operating ball charge, these actions are slow to deliver a change (typically requiring multiple hours), whilst removing a cyclone could result in a temporary increase in throughput within half an hour. The fact that the increase in throughput disappeared half an hour later only reinforced the perceived need to take more cyclones offline until pressure control was completely compromised and the circulating loads in the circuit were destabilised to the point that no meaningful testing could be undertaken. In essence, what the operators perceived was justified in the short term, but their responses tackled the symptoms rather than the root causes and therefore no long term benefits were realised.

Ultimately, a significant amount of time in the field, coaching and interaction was required to successfully implement wholesale control changes like those discussed. Training of theory and holistic control needs to be implemented so that the causes of instability, rather than symptoms is understood an accepted. Management buy in and a good relationship between the metallurgists and production team are also key ingredients for a successful outcome. Strong top-down management is required to push through the early implementation phase.

Optimisation

Diagnosis of key circuit bottlenecks was the next phase of the optimisation effort. Analysis of long-term trend analysis, historical surveys, power modelling and mass balancing indicated a few key opportunities for improvement.

- Observed inverse relationship between SAG power draw and weight from time to time with wide fluctuations in SAG mill operating weight and power indicative of slurry build up in the SAG mill.

- Limitations on operating ranges for the SAG milling density imposed by the flash flotation requirements was driving the milling circuit water balance.
- The water balance in the ball mill circuit was limited by unmetered water addition making pressure control to stabilise the ball mill circulating load and overflow product size difficult.
- No control of the flow of material to the ball mill to ensure the ball mill power was properly utilised.

The ability to bypass a portion of the cyclone underflow around flash flotation was implemented and separate water addition at the SAG mill feed proposed to alleviate restrictions around SAG density control.

It was found that large amounts of unmetered water was added to the ball mill to deal with cyclone instability. This was systematically reduced with the operating team as the process control was added to address cyclone stability.

Automated control of the ball mill bleed valve position (% open) to target a grind size on the ball mill cyclone overflow was proposed to address ball mill power utilisation.

Whilst all these opportunities are worth detailed discussion, for brevity, this paper focusses on the actions taken to address inverse power/weight relationship and alleviate the impact of slurry pooling in the SAG mill.

SLURRY POOLING

It was identified early in the engagement that there appeared to be periods of operation where SAG mill weight and power draw were positively correlated and periods when the correlation reversed (mill weight up, power draw down). It was hypothesised that the root cause was a build up of slurry inside the mill resulting in a negative weight/power correlation. Possible causes for the slurry pool development were identified as:

- Viscosity of the ore preventing free flow of slurry through the grates causing slurry to hold up inside the SAG mill
- An obstruction/blockage of the SAG mill discharge grates preventing slurry from flowing through.

An example of a two-week trend of the SAG mill weight, power and feed rate at the time is shown in Figure 5.

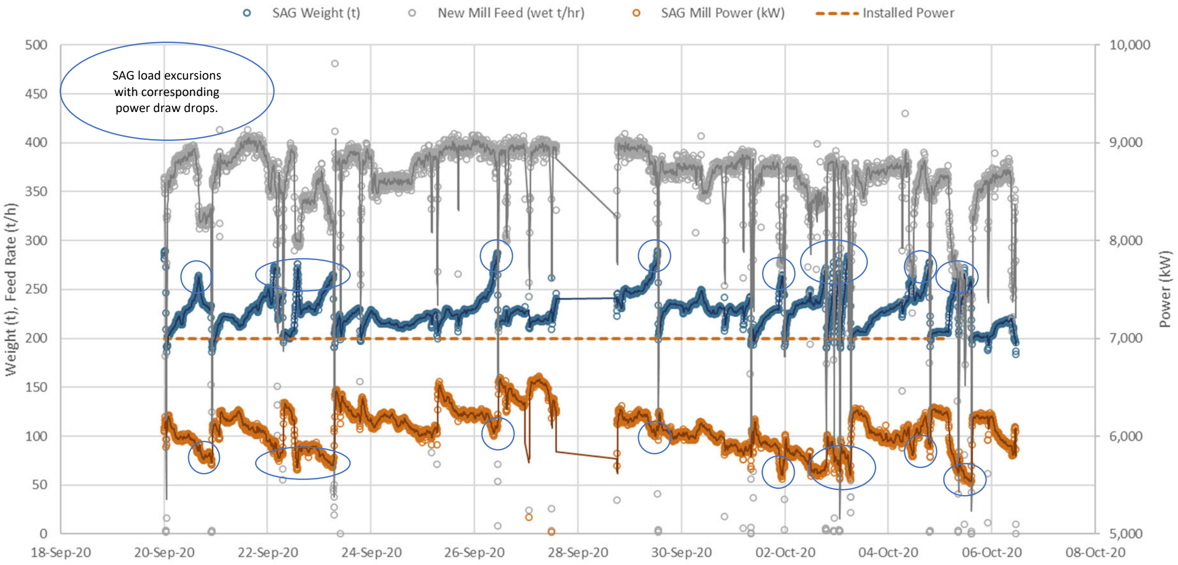


Figure 5—SAG Mill Trends Indicating Slurry Pooling

The trend illustrates the typical mode of operation at the time as operators tried to manage SAG load excursions by grinding the mill out to reduce the SAG weight before starting to feed the SAG mill again. The frequency of the load excursions can be seen to increase over the period with the divergent SAG weight and power trend (weight up, power down) clearly visible. The negative correlation of weight and power was noted to revert to the expected positive correlation following grind outs, but only for a short period of time. Increasing the SAG feed water to reduce milling density had little to no impact on preventing the observed trends. This supported the view that blockages of the grate apertures were likely causing a flow restriction.

Physical inspection of the SAG grates had historically indicated some pegging was occurring, particularly towards the end of the grate life as the rubber grates developed a reverse taper making them more prone to pegging with near size material. An example of the observed pegging is shown in Figure 6.

Figure 6 SAG Grate Inspections

Physical inspections of the grates were however often undertaken following grind outs and so the extent of pegging observed was likely underrepresented with the grates being cleared by the grind out process as grinding media knocked pegged scats and pebbles through the grates. This observation would also explain the temporary reversal of the power/weight correlations immediately following grind outs. The grind out provided temporary clearance of the grates which slowly re-pegged, resulting in blockages and load excursions as the flow capacity of the grates reduced.

GRATE DESIGN

The SAG discharge grate in use at the time were rubber grates including 15x30mm "slotted" grates as well as some "ported" grate segments with larger 25 x 40 mm apertures. Drawings of the SAG discharge grates in use at the time are shown in Figure 7.

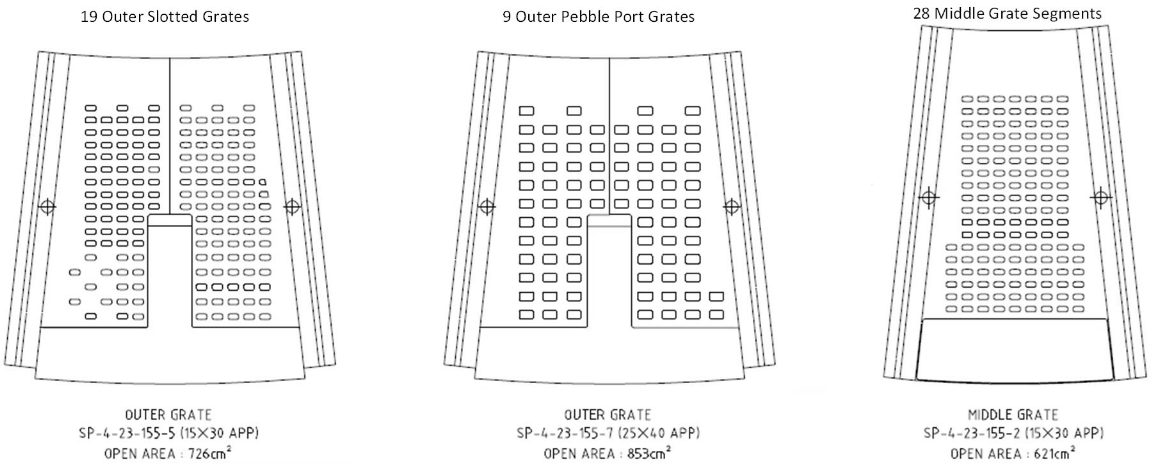


Figure 7—SAG Mill Grate Specifications September 2020

Since the Leinster SAG mill is operated without pebble crushing and mostly in single stage, the grate apertures are smaller than typically seen on open circuit SABC designs and so the term "ported" is site specific terminology to reference the slightly larger aperture grates.

It is worth noting that the thickness of the rubber grates had slowly been increased over time in an attempt to extend the reline intervals. The thicker grates may well have exacerbated the pegging issues as the path for near size material to be cleared was increased and relieving tapers tend to decrease as thickness is increased in order to maintain open area and mechanical integrity.

The mechanism for grate pegging is typically cyclic once started. The movement of pebbles slow through the grate decreasing grate open area, increasing the size of the slurry pool. The increased slurry pool reduces coarse rock breakage, increasing the number of pebbles, which further blocks the grates and so on, which results in the observed deteriorating conditions.

Following discussions around grate options to assist with alleviating the pegging issues which became increasingly severe as the grates wore, an alternative hardox grate with longer slots and a steeper 8 degree relieving taper were proposed for a trial. OMC had recent experience with the use of Hardox grates on other project and suggested the use. The reasoning was that the use of two grate material types would reduce the likelihood of extreme pegging as it was unlikely that both materials would be prone to pegging at the same time and furthermore, it was likely that the Hardox grates may not peg at all.

The site team collaborated with Metso:Outotec to conceptualise and develop two potential Hardox options (20 mm slot and 30 mm slot) which could be installed alongside the existing rubber grates. A conceptual drawing of the proposed hardox grate design is shown in Figure 8.

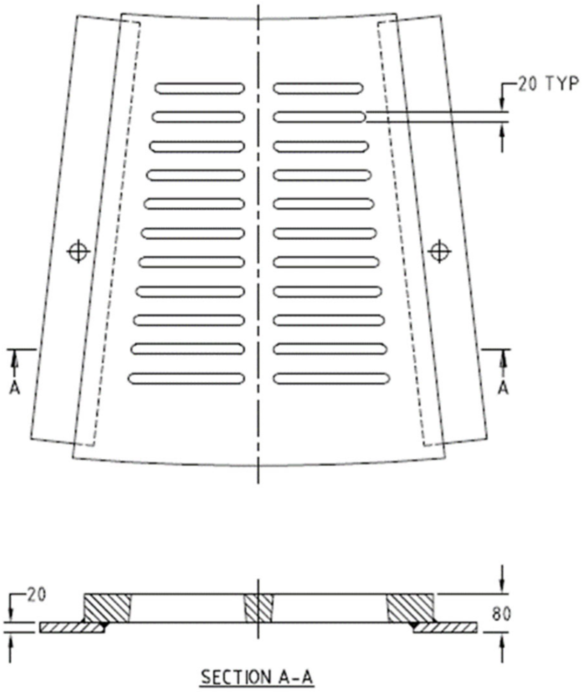


Figure 8—Hardox Outer Grate Design

A change in grate configuration was installed as a trial during the April 2021 shutdown. A comparison of the grate configuration before and after the changes are presented in Table 3.

Table 3—Grate Configuration Changes

Grate Description	Apertures (mm x mm)	Open Area per Grate (cm^2)	Number of Grates	
			Original	**Trial**
Middle—Rubber Slots	15 x 30	621	28	28
Outer—Rubber Slots	15 x 30	726	19	13
Outer—Rubber Pebble "Ports"	25 x 40	853	9	7
Outer—Hardox 30 mm "Ports"	30 x ~120	1,298		4
Outer—Hardox 20 mm Slots	20 x ~120	1,282		4
Total Open Area	**cm^2**		**38,859**	**43,117**
	%		5.8	6.4
Percentage "Ported"	%		19.8	25.9

The addition of 8 Hardox grates out of 28 segments (4x 20mm slotted outer grates and 4x 30mm slotted outer grates) was trialled with an increase in the total open area from 5.8% to 6.4%. The increase in the percentage of open area considered “ported” went from around 20% to 26%.

After implementation, the SAG load stability and circuit performance were significantly improved. A time trend of the circuit throughput for the full liner cycle is shown in Figure 9.

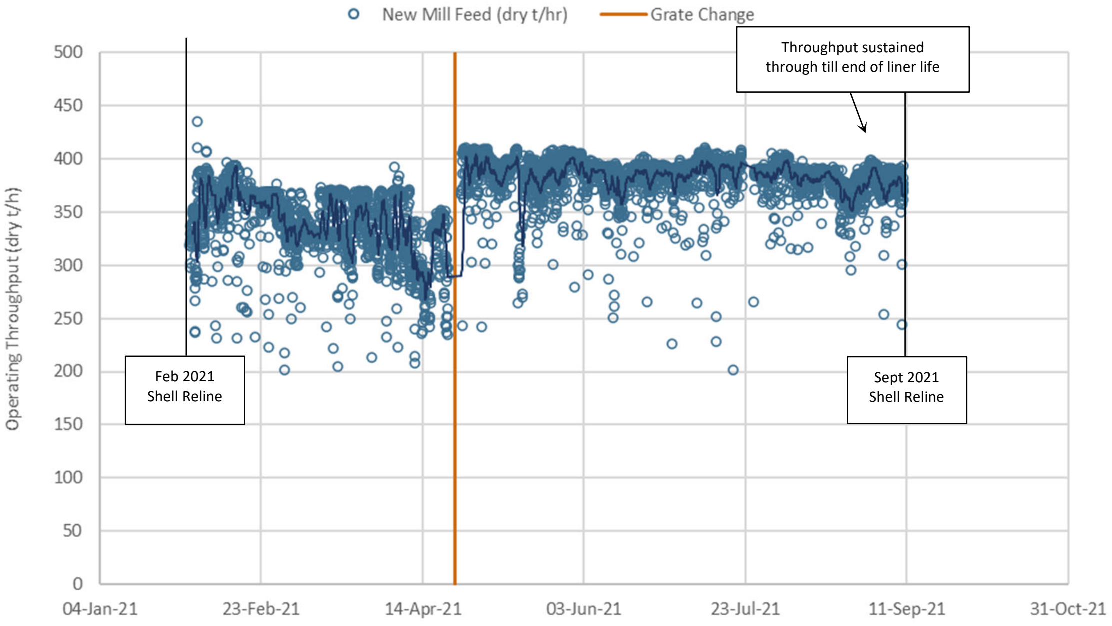


Figure 9—SAG Throughput Feb–Sep 2021 Liner Cycle

The improvement in circuit throughput was drastic and immediate. SAG feed rates had to be increased to over 400t/h to hold SAG weight at a reasonable level (to manage liner impacts).

Critically, the improved performance was sustained for the entire life of the grates. Where the full rubber grate design showed significant decreases in performance after 1.5–2 months in operation, the mixed rubber/hardox combination performed consistently throughout the life of the grates. A comparison of the throughput profiles for the re-line cycle prior to the grate change and the reline cycle after the grate change are shown in Figure 10.

Improvements in mill performance were common immediately following relines but what was most encouraging with this change was that the improved performance remained for the full life of the liners with no reductions in throughput seen all the way through to the shell reline.

It was suspected at the time that the combination of rubber and hardox materials were complimentary to one another. With the hardox apertures typically widening as the grates wear, effectively increasing the open area of these segments. While the rubber grates start to develop reverse taper and become more prone to pegging, slowly reducing the open area of these segments.

Inspections of the grates towards the end of the life showed less pegging of the rubber grates than historically noted. This was also attributed to the more consistent operation of the SAG mill at a stable load rather than the large weight fluctuations and grind outs seen when managing the grates previously which would have accelerated the grate wear as well as produce chipped balls (scats) which easily wedged into the grates.

With a large increase in throughput, an increase in grind size typical results. In this case, the overall circuit grind size reduced, resulting in a significantly lower operating work index for the circuit. A time trend showing the operating work index and combined overflow product size for the grinding circuit is shown in Figure 11.

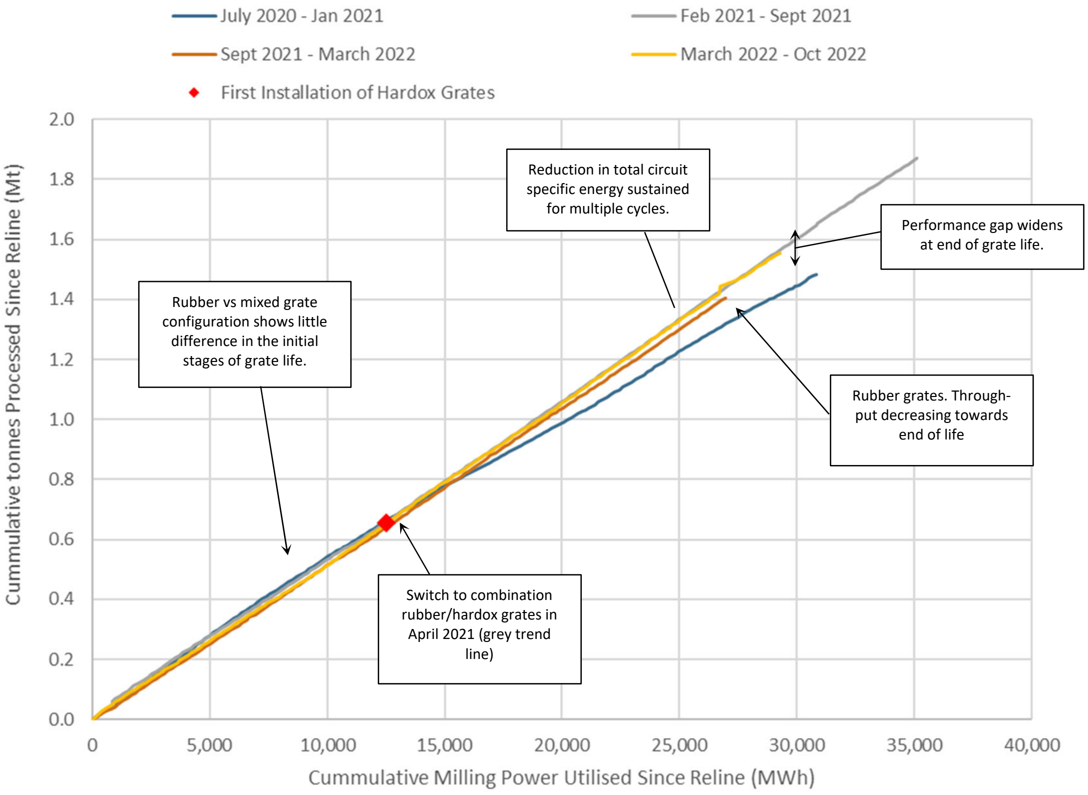


Figure 10—Cumulative Throughput vs. Power Utilisation for Multiple SAG Liner Cycles

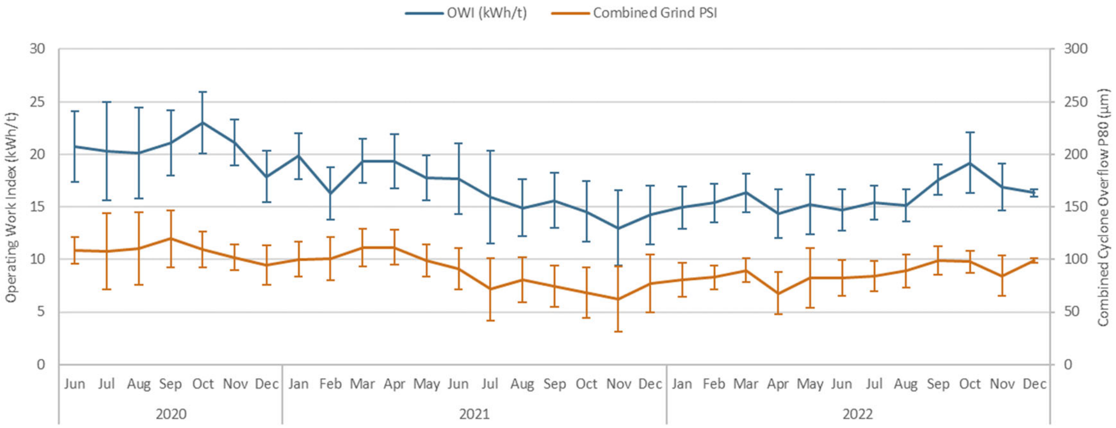


Figure 11—Combined Grinding Circuit Product Size and Operating Work Index

The operating work index reduced from 20.2 kWh/t to 16.0 kWh/t. No significant change in the feed blend had occurred and this change is attributed to improved grinding efficiency, determined to be around 20% based on the change in the operating work index. A summary of the SAG and ball mill motor power draws, throughput and grind sizes from the ball mill and SAG mill cyclone overflows are shown in Figure 12.

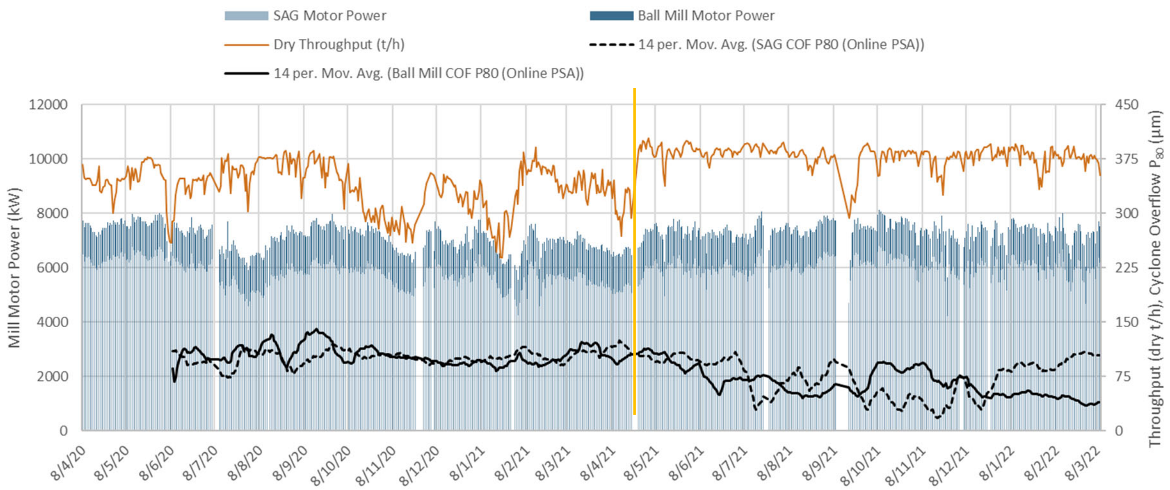


Figure 12—Overall Circuit Performance Summary

The circuit operated for over a year (April 2021–April 2022) at sustained throughputs of around 400t/h whilst maintaining final product size. During this time, the circuit throughput was constrained by factors outside of the grinding circuit. Conveyor limitations and downstream thickener constraints were the main constraints to increased throughput. There was consistently unutilised capacity in the ball mill as demonstrated by the consistently finer cyclone overflow product (blue trend in Figure 12).

Conclusions

Changes to the grinding circuit control philosophy, SAG mill grate configuration and operator training resulted in significant improvements in circuit throughput, efficiency, and stability. An improvement in SAG mill throughput of 15% was realised, with a 20% improvement in grinding efficiency and a finer grind. Significant improvements in circuit stability and consistency of performance were also achieved (grinding circuit grind outs eliminated), benefiting downstream processing.

These benefits had not been achieved through historical optimisations using traditional surveys, analysis and reporting of results. A continuous improvement/optimisation approach was required.

Changes in process control to stabilise performance was required and this needed ongoing involvement to drive the change in operation, culture, and education of the team. Continual analysis of the day-to-day operating data was required to optimise the process control. Additional analysis of long-term data, over multiple reline cycles, was required to identify the impact of grate pegging. Once identified additional consulting was required to identify solutions and assist site in implementation. MillROC provided a single source of knowledge for identifying constraints and analysing the impact of changes.

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References

Ed. Note: The authors have elected not to provide a bibliography or citations.