Optimisation of the Damang Comminution Circuit

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Abstract

Gold Field Ghana's Damang Operations team recently embarked on a continuous optimization project. The crux of the work was focused on the comminution circuit; however, decisions for change were driven by the overall economic impact. While this sounds like a relatively conventional approach, optimization of operating plants often happens in silos, devoid of any consideration of the current market conditions, including technology, and how these have changed since the original project design. Establishing the ability to effectively control and vary the circuit throughput and product grind within a comminution circuit to match the optimum economic contribution from the processing circuit is a worthy goal for any comminution optimization initiative.

Optimization occurred in three phases—stabilization control, optimization control, and long-lead improvement items. A total contribution change of 4% was achieved to date with a further 8% expected once implementation is complete. This optimization is an example of what can still be achieved in well-established operations with little to no capital investment by returning to first principles and ensuring all process decisions are driven by the overall economic impact on the project. Key to the ongoing success of the Damang project has been the operational team's growth mindset approach to challenges and unwavering dedication to operational excellence.

Keywords

SAG milling, process control, remote optimization consulting, improvement and change management, MillROC

Introduction

Gold Fields Ghana holds a 90% interest in the Damang Project, with the remaining 10% held by the Ghanaian Government. The comminution circuit comprising tertiary crushing followed by a semi-autogenous grinding (SAG), ball milling, and crushing (SABC) circuit. The SAG mill receives 100% tertiary crushed feed and operates in closed circuit with a pebble crusher. The SAG discharge screen undersize reports to the ball mill discharge hopper in closed circuit with cyclones, with partial cyclone underflow (U/F) treated via a gravity circuit. The cyclone overflow (O/F) reports to a pre-leach thickener prior to the carbon-in-leach (CIL) circuit. The circuit achieves 4.75 million tonnes per annum (Mt/a).

Feed to the circuit is now relatively consistent in competency; however, it can have a variable grind-recovery relationship (Brittan, 2010). Issues had been experienced with cyclone stability including high U/F density, roping with coarse grit reporting to the trash screens, and high recirculating load with power draw losses in the ball mill. The client's primary objective was to explore if increased throughput and gold recovery is achievable by producing a finer and more consistent grind, without compromising the circuit throughput.

To manage the optimization effort, the Mill Remote Optimization Consulting and Coaching (MillROC) solution was implemented. MillROC is a collaborative solution that enables clients to benefit from regular direct engagement with subject-matter experts on real-time process data utilising a cloud-based platform (Oblokulov et al., 2021).

Project Background

The Damang Project comminution circuit was originally commissioned as a primary crusher–SAG–ball circuit in 1997 on soft oxides from the original Damang pit, with a capacity of 3 Mt/a. Gold Fields Limited acquired 71.1% ownership of the project in 2002, with mining of the main Damang pit ceasing in 2004 when ore supply was replaced by Amoanda, Tomento, and Lima South pits shortly after. The circuit throughput of 5 Mt/a was achieved due to the soft feed ore blend. A cutback to the Damang Pit occurred in 2005, with the weathered ore largely exhausted over the next five years. 2010 saw the construction of the secondary crushing circuit in response to an increase in competent ore to 95% of the blend (Amoah et al., 2011). Over the next decade, numerous crushing-circuit upgrades occurred to further the reduce the mill feed size. The current milling circuit received a full tertiary crushed feed (−32 mm) and achieves 4.75 Mt/a. As such, the SAG mill operates with a low autogenous load (Figure 1), performing a SAG mill and primary ball mill hybrid duty.

The primary crusher, a 54–75 gyratory, receives feed from either front-end loader or direct truck tip. A parallel jaw crusher is used during gyratory downtime to crush directly to the stockpile. Crushed ore is drawn from the surge chamber by an apron feeder and is conveyed to an inclined double deck screen (SN-28), which has an 80-millimetre (mm) x 55 mm top deck and a 32 mm x 32 mm bottom deck aperture. SN-28 screen oversize reports to the secondary crushers or can be diverted directly to the SAG feed stockpile. SN-28 screen bottom deck oversize reports to the tertiary crushers. SC-28 undersize reports to the stockpile. The secondary crushers are operated in open circuit, and the tertiary crushers in closed circuit with a single-deck product screen (SC-29) fitted with 30 mm x 30 mm aperture panels.

The secondary and tertiary products combine and report to SC-29. SC-29 oversize stream reports back as the tertiary crusher feed, while SC-29 screen undersize combines with SC-28 undersize, both reporting to the SAG mill feed stockpile. The main equipment details are shown in Table 1.

Figure 1—SAG mill crash stop charge

Table 1—Major comminution equipment—crushing

Description	Unit	Primary	Secondary	Tertiary	Pebble
Make	-	Krupp Gyratory	Sandvik Cone	Sandvik Cone	Metso Cone
Model		54 / 75	CS660	CH440 / CH660	HP500
Quantity	no.	1	2	3 / 2	2
Open/Closed Side Set	mm	150 OSS	38-80	18 - 48	12
Motor	kW	600	315	220 / 315	375

Note: kW = kilowatt.

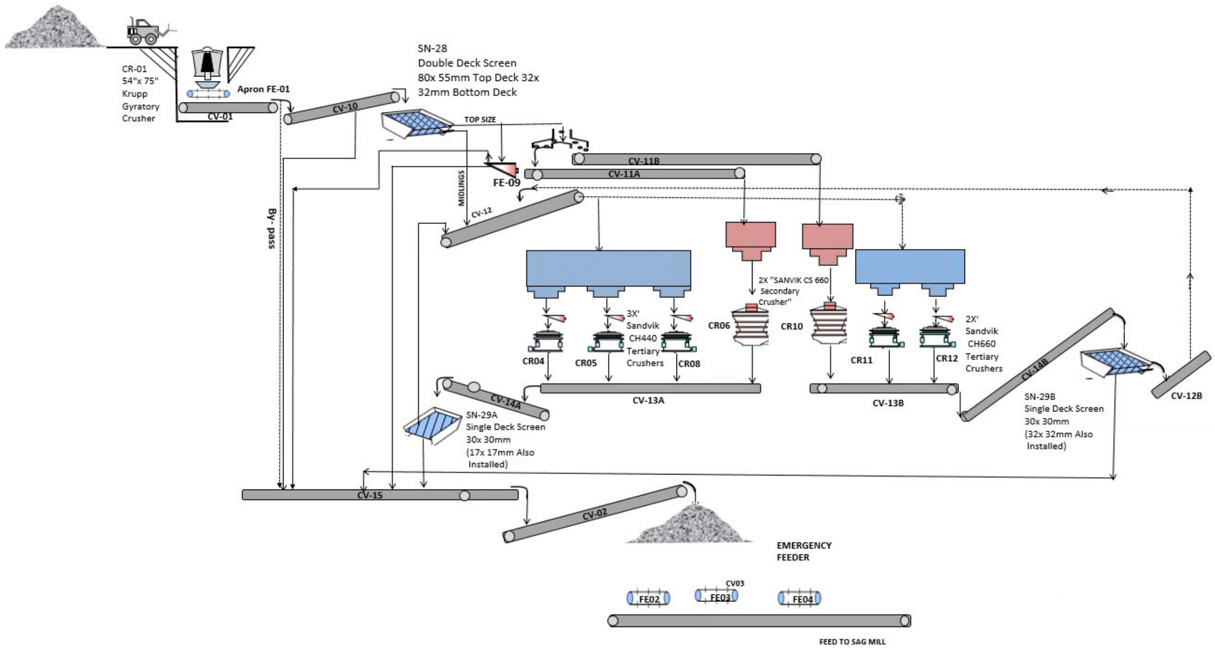

Figure 2—Damang crushing circuit flowsheet

COMMINUTION CIRCUIT DESCRIPTION

Ore is reclaimed from the stockpile via two apron feeders, with a third emergency feeder available. The feeders discharge onto the SAG mill feed belt. The SAG mill feed together with crushed pebbles are fed into the SAG mill.

An Ø 8.0 m x 5.46 m effective grinding length (EGL) SAG mill has a 5.8-megawatt (MW) motor and is operated in open circuit. The mill motor was equipped with a slip energy recovery variable-speed drive; however, it is currently operated at fixed speed, 12 revolutions per minute (rpm) (79.2% Critical Speed [Nc]). The SAG mill discharges over a trommel with 12 mm x 30 mm slotted apertures. The trommel oversize is then washed on a dewatering screen with a 5 mm aperture prior to being crushed by a cone crusher Metso HP500 and fed back to the SAG mill. The trommel and dewatering screen undersize gravitate into the SAG mill discharge hopper before being pumped to the cyclone feed hopper (ball mill discharge hopper).

An O/F ball mill, Ø 6.10 m x 9.0 m EGL, 5.8 MW receives feed from the cyclone U/F. The ball mill discharge passes through a trommel and into the cyclone feed hopper where it is combined with the gravity tail and SAG mill screen undersize before being pumped to the cyclone cluster for classification. The cyclone cluster consists of seventeen 400 CVX cyclones. The cyclone O/F reports to the CIL trash screen, while the cyclone U/F is split, with a portion going to the gravity circuit and the remainder to the ball mill feed chute. The gravity circuit has two trains, each includes a scalping screen and a 48-inch Knelson concentrator. The scalping screen oversize and Knelson tails are recombined and flow into the cyclone feed hopper. The main milling circuit equipment along with the classification cyclone design is shown in Tables 2 and 4, respectively, with Table 3 detailing the major screens in the circuit.

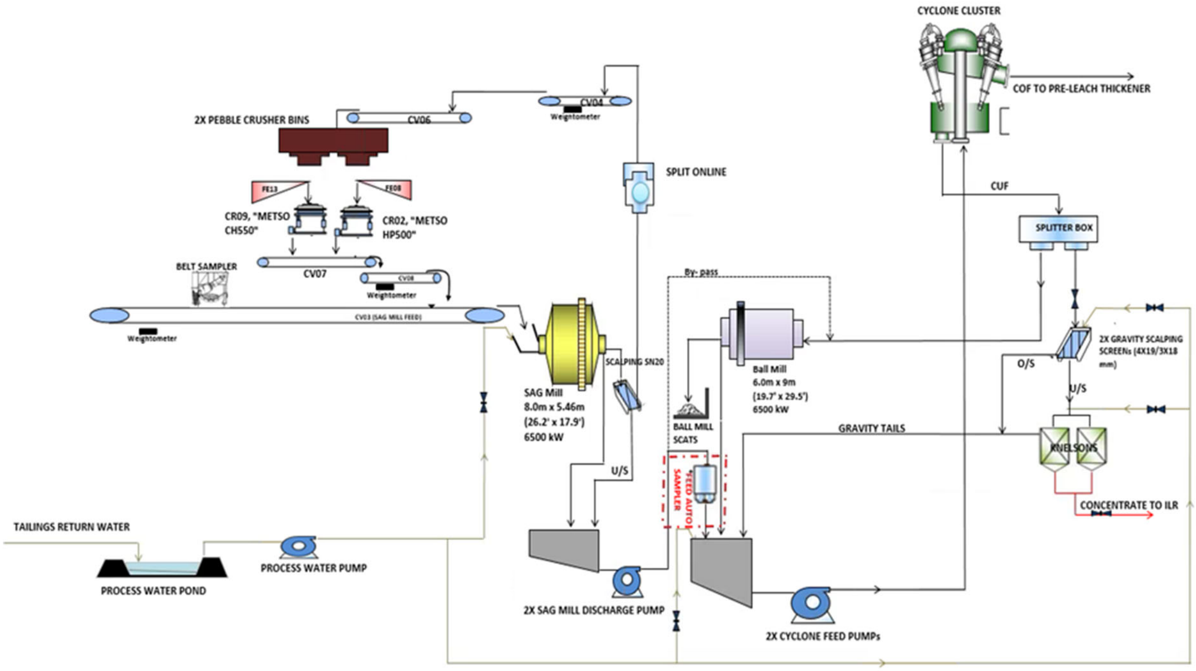

Figure 3—Damang milling circuit flowsheet

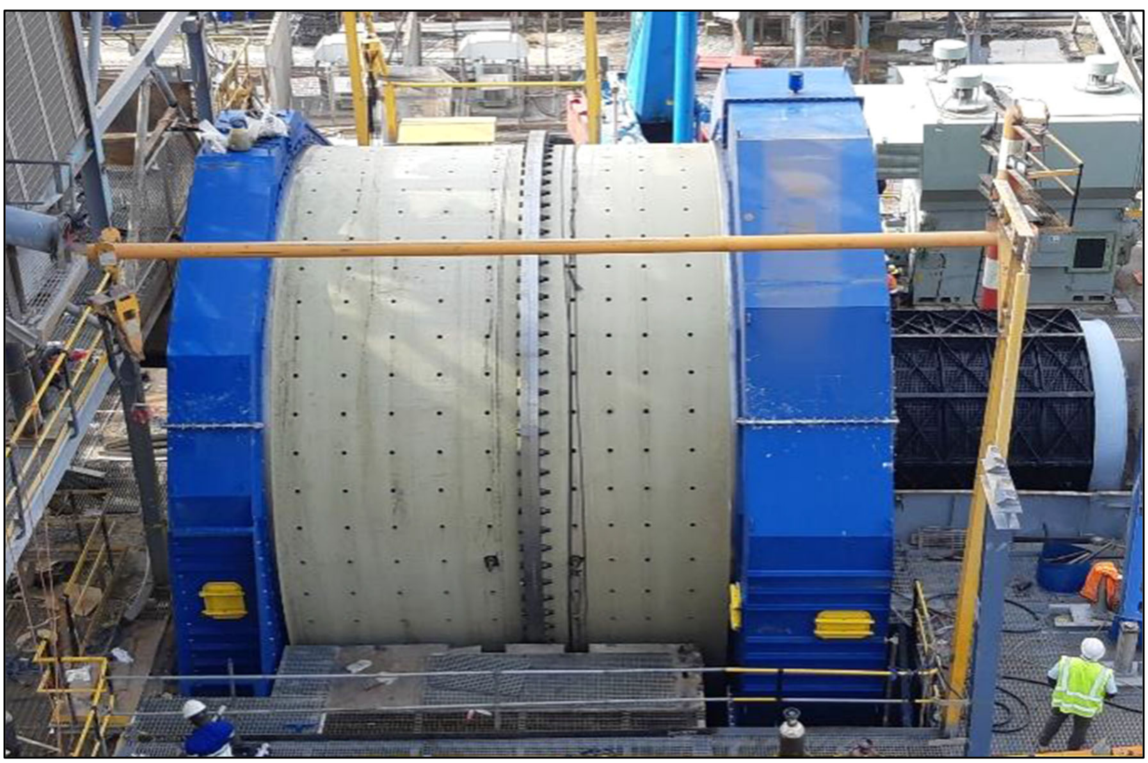

Figure 4—Damang SAG mill

Table 2—Major comminution equipment—milling

Description	Unit	SAG Mill	Ball Mill
Diameter	m	8.00	6.10
Effective Grinding Length	m	5.46	9.00
L : D Ratio		0.68	1.49
Discharge		Grate	Overflow
Mill Speed	rpm	12.0	15.8
	%Nc	79.2 (Fixed)	75 (Fixed)
Grate Aperture	mm	40 (26-off)	
Grate Open Area	%	9.653	
Maximum Ball Charge	%	15.0	35.0
Maximum Load	%	32.5	
Trommel / Screen Aperture	mm	12 x 30 / 5	15 x 30
Motor Size	MW	5.8	5.8

Table 3—Major screening equipment in the circuit

Parameter	Unit	Value
Crushing Circuit Double Deck Screen (SN-28)		Double Deck Inclined
Size	m	3.6 x 7.3
Top deck		
Aperture	mm	80 x 55
Bottom deck		
Aperture	mm	32 x 32
Crushing Circuit Single Deck Screen (SN-29A and SN 29B)		Single Deck Inclined
Size	m	3.05 x 7.32
Aperture	mm	30 x 30
SAG Mill Discharge Screen 1		Trommel
Length	m	2.425
Diameter	m	2.765
Aperture	mm	12 x 30
SAG Mill Discharge Screen 2		Single Deck Inclined
Width	m	1.804
Length	m	5.351
Aperture	mm	5 x 5
Ball Mill Discharge Screen		Trommel
Length	m	2.425
Diameter	m	2.765
Aperture	mm	15 x 30

Table 4—Classification cyclone details

Description	Unit	Cyclones
Make		Warman
Model		Cavex—400CVX
Number (Operating / Total)	qty	13—14 (21)
Inlet Diameter	mm	94
Vortex Finder	mm	140
Spigot	mm	90—100
Pressure	kPa	100—120

Operating Data

The Damang ore is predominately fresh ore categorised into four lithologies; blanket sandstone, conglomerate, mafic intrusion, and phyllite. Comminution data available for the project are presented in Table 5. The Bond ball mill work index (BWi) is moderate, with a wide range of competency. The sandstone and mafic intrusion are the dominant lithologies of the current feed, which are both highly competent. This combination of ore parameters benefited well from pre-crushing of the feed to improve overall energy efficiency, due to the relative ease of ball milling compared to the high resistance to impact breakage.

Table 5—Damang comminution testwork

Criteria	Unit	Apr 2009 (1)	Apr 2009 (2)	Nov 2010	2012 Blanket Sandstone	2012 Mafic Intrusion	Oct 2013	Survey Dec 2017	Survey Feb 2018
Ai	g	-	-	-			-	-	0.7
BWi	kWh/t	15.7	15.9	16.6	17.6	14.9	16.3	-	12.6
Closing Screen	µm	106	106	106	75	75	-	-	150
CWi	kWh/t	22.9	-	27.9	19.8	31.9	25.0	34.2	-
A		73.9	64.5	62.0	100	100	67.5	59.8	74.7
b		0.4	0.6	0.72	0.29	0.27	0.46	0.77	1.05
A x b		29.6	38.7	44.6	29.0	27.0	30.9	46.0	78.4
ta		0.3	0.4	0.44	-	-	0.25	0.51	0.88
DWi	kWh/m^3	9.1	7.5	5.91	9.45	10.61	-	5.0	3.0
Ore SG		2.8	2.8	2.71	2.74	2.86	2.8	2.35	2.32

Notes: CWi = Bond crushing work index; DWi = drop-weight index; g = grams; kWh/t = kilowatt hour per tonne; µm = micrometer; kWh/m^3 = kilowatt hours per cubic meter; Ore SG = Ore Specific Gravity.

The operating work index is presented as a function of throughput normalized for power utilisation (Figure 5). A tight correlation demonstrates a total circuit power constraint rather than a SAG mill constrained circuit (Butar et al., 2019).

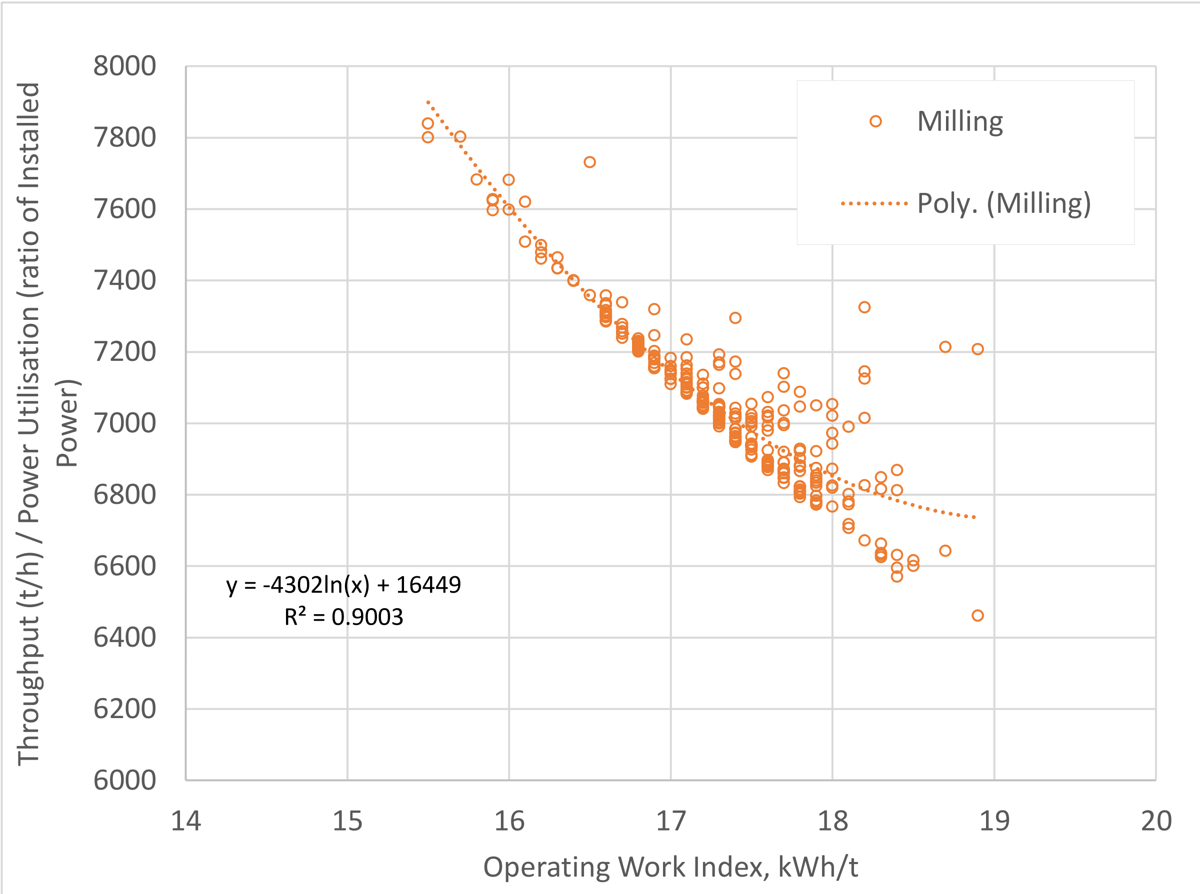

Figure 5—W_{io} vs. throughput / % utilized power

This relationship is useful in demonstrating that SAG mill performance is more conducive to a primary ball mill, with increased throughput rate simply translating to a coarser transfer size rather than an accumulation of rock load. Following on from this fact it became evident that the traditional way the mill circuit was controlled—throughput rate set-point adjusted to maintain a mill weight set-point, was no longer possible. Rather, the circuit throughput needed to be controlled directly to grind, while maximising grinding efficiency in each stage in line with ball milling principles. This change in operating strategy and its implications on the SAG mill set-points took some time for the team to adjust to, as will be discussed later.

A summary of the baseline production data is presented in Table 6.

Table 6—Production Data

Description	Unit	Baseline (Jun 20—Jun 21)
Mill Feed	wet t/h	576
Mill Feed—Scat Removed	wet t/h	564
SAG Feed Dilution	m³/h	175.1
Calculated SAG Density	% Solids	76.7
SAG Power	MW	5.0
SAG Weight	t	134.4
BM Power	MW	4.8
BM Discharge Dilution	m³/h	51.2
Pebble Crusher Feed	wet t/h	53.0
Pebble Crusher Power	kW	35.9
Cyclone Pressure	kPa	112.4
Cyclone Feed Flow	m³/h	1,326
Cyclone Feed Density	%Solids	64
Grind P_{80}—Leach Feed	µm	106
Daily Recovery	%	92.5
SAG Specific Energy	kWh/t	8.3
BM Specific Energy	kWh/t	8.0
Total Specific Energy	kWh/t	16.3
Operating Work Index (W_{io})	kWh/t	18.2

Note: P_{80} = 80% passing; t/h = tonnes per hour; kPa = kilopascal; µm = micron; kWh/t = kilowatt hours per tonne.

Optimization Objectives and Phases

In late 2021, Orway IQ were engaged to assist in achieving the site's targets for the comminution circuit. The primary objectives that the site team wished to achieve were as follows:

- Trial operating at a finer cyclone O/F in the range of 80% passing (P_{80}) 95–106 microns (µm) to see if the recovery benefits predicted by leach testwork could be realised in practice. The grind had historically averaged P_{80} 106 µm during the 30%-70% ore blend ratio of oxide and fresh respectively; however, the P_{80} had increased to 120 µm prior to commencement of optimization. This was largely a result of difficulty in maintaining power draw in the mills.
- At least maintain the current throughput rate while reducing the grind, then increase throughput rate as far as possible once the target grind had been achieved.
- Reduce the instability around the cyclone operation, in particular the frequency of roping that occurred in some of the cyclones around the cluster. This occurrence required frequent operator intervention, which only provided temporary relief. The roping led to excess material reporting to the

trash screen oversize, blow-outs in the leach feed grind, and increased solids settling in the downstream circuit.

MillROC was implemented to guide the optimization project. Fundamental to the approach was applying critical success factors to overcoming the challenges of change, and improvement management against the risk that around 70% of improvement efforts fail to achieve their intended results (Smith, 2002). Conventional consulting from static data usually presents circuit analysis and modelling results linked to recommendations that are then left to the site team to implement, mostly unsupported. In addition to delivering the conventional consulting outputs, MillROC supports the site team with the implementation phase with the benefit of global optimization experience and benchmarking. In addition, critical success factors for change-management include having a project sponsor within the client's organisation for management buy-in appointing site-based champions for the initiative to act as change agents, and ensuring a multidisciplinary team actively takes part in the engagement, while finally linking the improvement efforts and changes made to the business bottom line in terms of cash-flow. MillROC includes implementing a live-circuit mass balance, real-time circuit analysis, and key performance indicator (KPI) dashboards to develop a more detailed understanding of the circuit constraints, and to facilitate a collaborative approach to analysis and implementation of recommended improvement initiatives. The coaching element is included to ensure that improvements are sustained over time.

Following the findings from a detailed baseline study, the optimization plan was split into three categories as shown in Figure 6.

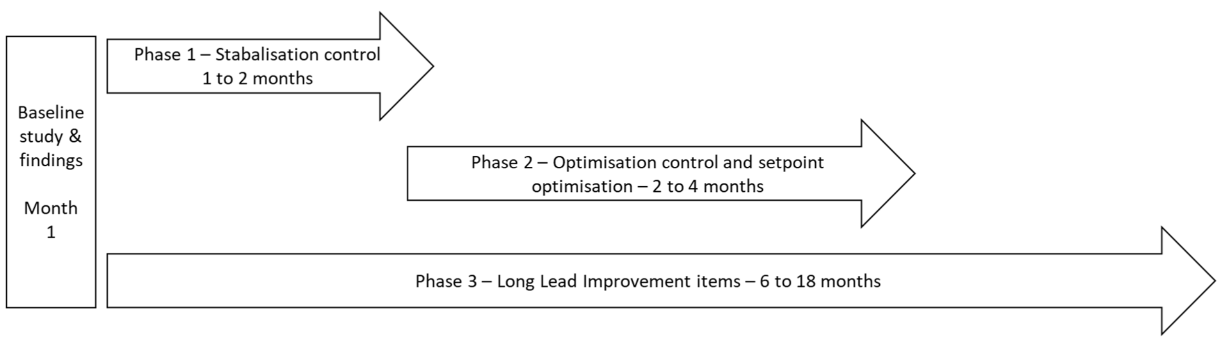

Figure 6—Phased optimization approach

The optimization activities were structured into Phases and guided by the findings of the detailed baseline study, as well as the real-time analysis performed on process data supported by operational context from the site team. This enabled the site team to implement the required circuit changes with remote consulting support delivered by Orway IQ. This was done via weekly meetings and online chat group discussions which allowed for coaching to be delivered while the implementation was happening. The online platform can be accessed from anywhere, allowing the consultant to view real-time data as changes are being made. This results in an informal and more distilled means of providing advice, hastening the results achieved via conventional consulting and providing more confidence to the team during the implementation. The weekly round-table meetings were generally used to debrief, review data from the previous week's activities and formulate a plan going forward. The team consisted of representatives from each unit of the operation—engineering and maintenance, operations, process control and instrumentation, and metallurgy—and the consultant. Other stakeholders, including other departments, were brought in when required to escalate issues and increase the collaborative power of the team when solving more complex problems. Monthly reports were used to track progress and present cost–benefit analysis to the larger business group, where a higher level of authorisation was required to implement changes.

Each optimization aspect was managed as a project and had a champion (or champions) which were site-based and ultimately owned by the site team. The project champion was responsible for change management and roll-out of their respective improvement actions. Education of plant operators was an integral part to the success of the project, who were welcome to attend meetings to give their suggestions and share observations at various stages of the project. This interdepartmental collaborative approach to process optimization was key to many of the achievements made by the Damang team, a role that would historically rest with the technical metallurgists alone. Further, through the coaching gained during the various implementations, the original team members from the Damang team are now sharing their expertise at other operations in the business where similar issues have been identified.

Each phase of the optimization is detailed below. Phases 1 and 2 occurred consecutively, with Phase 3 carried out in parallel to the other two Phases.

Phase 1—Stabilisation Control

This phase consisted of three control areas which were intended to achieve automated stabilisation in the circuit: forming the foundation for all other optimization activities. These loops not only removed the need for frequent operator intervention to maintain stability during normal process upsets, but they also allowed for previously uncontrolled key process variables to be operator selected. The loops were also designed to complement each other and allow the system to automatically converge to the required point in the throughput–grind relationship for the available power draw and incoming ore hardness. Previously, the operator attempted to force the desired grind size from the cyclones without consideration of the factors that determine grind produced—mill power input and feed properties. Attempting to force a cut point from a cyclone that is not in equilibrium with what the circuit can deliver results in a recirculating load that spirals out of control until a physical constraint is met. The excess flow through the ball mill resulted in loss of power draw, further exacerbating the state of imbalance. The control philosophy developed for the Damang circuit to address this imbalance is summarised below.

BALL MILL CYCLONES

There are numerous control philosophies for cyclones, and no single approach will be appropriate in all applications. Given the specific issues at Damang pertained to roping (high U/F density), and when, later, cyclone feed pump capacity limitation was identified, a control approach that allows for tight control on U/F density and that minimises flow around the circuit was required. A constant-pressure approach was selected, which fixes the pressure set-point (flow) around a circuit and allows the density to fluctuate. With full control over the operating pressure, the operator can fine-tune this set-point over the life of the spigots to maximise U/F density without encroaching on roping. This optimises the water split (minimizes fines reporting to U/F), while also controlling flow to the pump constraint (upgrade due Q1 2024). This approach also works well where the throughput rate is controlled directly to a grind size, as the cyclone feed-density adjusts automatically as the throughput rate changes to converge to the grind size that is achievable with the available power. This removed the need for the operator to adjust a cyclone feed density set-point, and also resulted in a circuit that self-balances for any given combination of power draw, ore hardness, and feed size. This can be contrasted against a constant-density approach, which requires the throughput rate to be adjusted in order to conform to the overarching throughput–grind relationship. In that scenario, grind is the controlled variable at the expense of throughput, which the client did not want in this case, as maintaining throughput was the primary requirement.

Cyclone operation was originally unstable and labour intensive, with frequent manual switching of cyclones to cope with roping around the cluster. The grind was also variable as a result, with frequent grind excursions and prolonged instances of grit reporting off the trash screen. The original control had pump speed controlling hopper level, and water addition to the hopper in manual. The loops implemented were pump speed to control to a cyclone feed-pressure set-point, and water addition controlling hopper level. The number of cyclones online is rarely adjusted—only when there is a significant step-change in throughput. The following observations were made:

- Ball mill cyclone control was fully implemented by the site operations team with no requirement for an expert control system. This stage was critical in achieving the site team's primary objective of achieving a finer grind without reducing the throughput rate, and importantly, having control over the levers available to them to adjust the grind in a controlled manner.
- Significant improvement in grind stability, with eradication of grind-blowouts above 150 µm (Figure 7).
- Reduction in incidents of roping/grind reporting to trash screen as reported by site team observations. This will improve agitator life and CIL tank volume.
- Reduced need for operator intervention in constant switching of cyclones to try to manage roping and coarse flow to the O/F events.
- Reduction in circulating flow around the circuit, increasing pump life and mill power draw at the same charge (Figure 8).

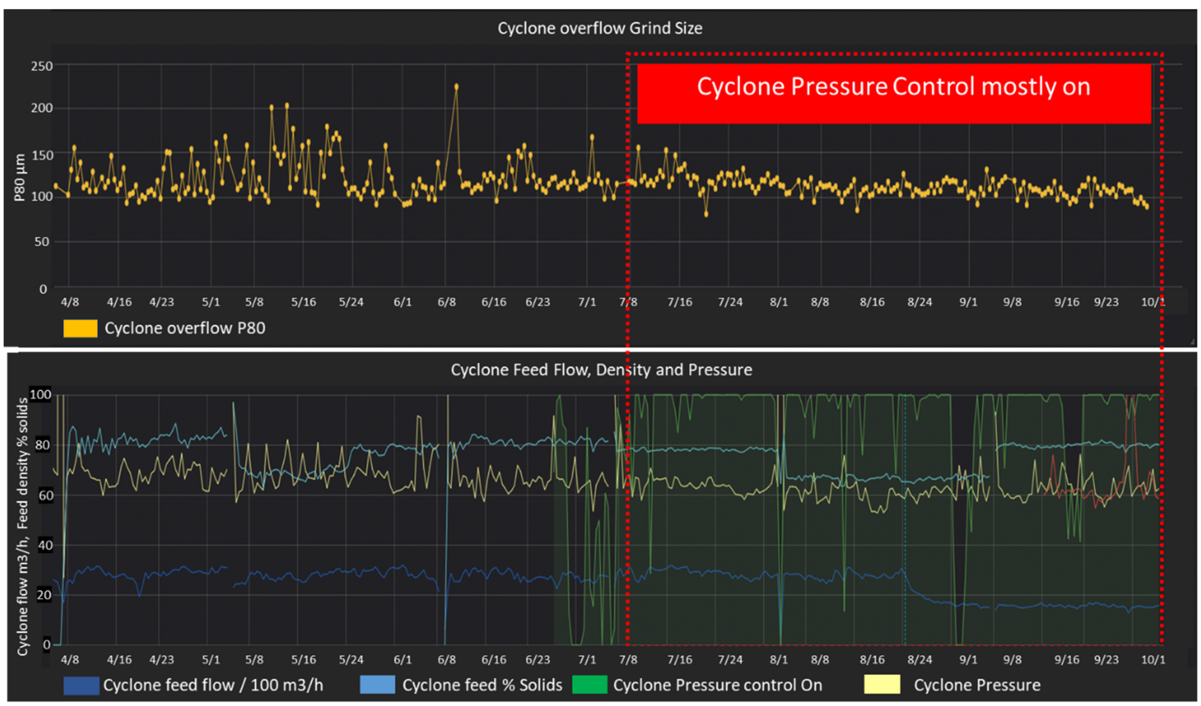

Figure 7—Six-month trend for leach feed grind (top) and cyclone control running (bottom)

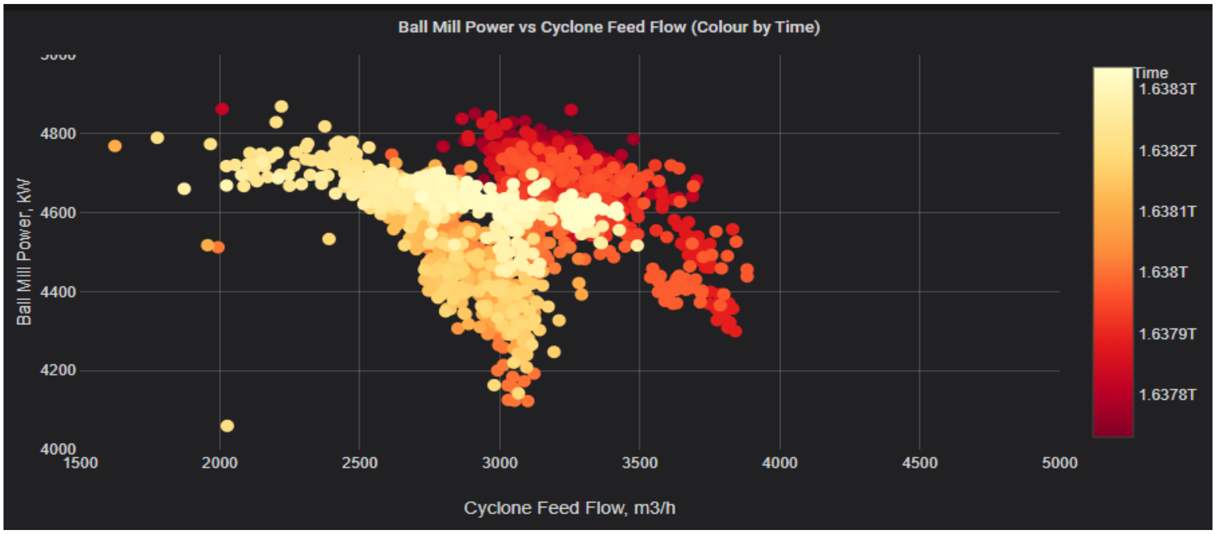

Figure 8—Ball mill power draw vs cyclone feed flow—October

SAG MILLING DENSITY

SAG feed water addition was originally manually selected by the operator. This resulted in cycling of milling density, as the pebble crushing is conducted in batches to ensure choke-feed conditions through the oversized units. During the crushing period, additional solids were introduced to the feed into the SAG mill which resulted in a cycling range of in-mill density across the pebble crushing cycle. To reduce the instability this caused, the water addition was automated to maintain a constant-density set-point in the SAG mill. This was based on a mass balance calculation that factored in the change in solids addition caused by batch pebble crushing.

The constant pressure ball mill cyclone control having already been implemented handled the water fluctuations automatically, by simply reducing water addition to the hopper to offset the additional SAG mill product water entering the circuit. Following the implementation of this control, the following improvements were noted:

- More stable SAG mill volume fill and impact of shoulder on toe, as depicted by the MillSlicer data (Figure 9).
- Reduced and more stable pebble rate, resulting in improved breakage seen in Figure 8 (higher average maximum intensity).
- Toe in higher position, indicating fewer instances of load washing out, which exposes shell plates to ball impact. This will have long-term benefit on reduced liner wear and grinding media consumption.
- More Stable SAG mill power for a given charge level (Figure 10).

Figure 9—Mill Fill with improved density, before and after control

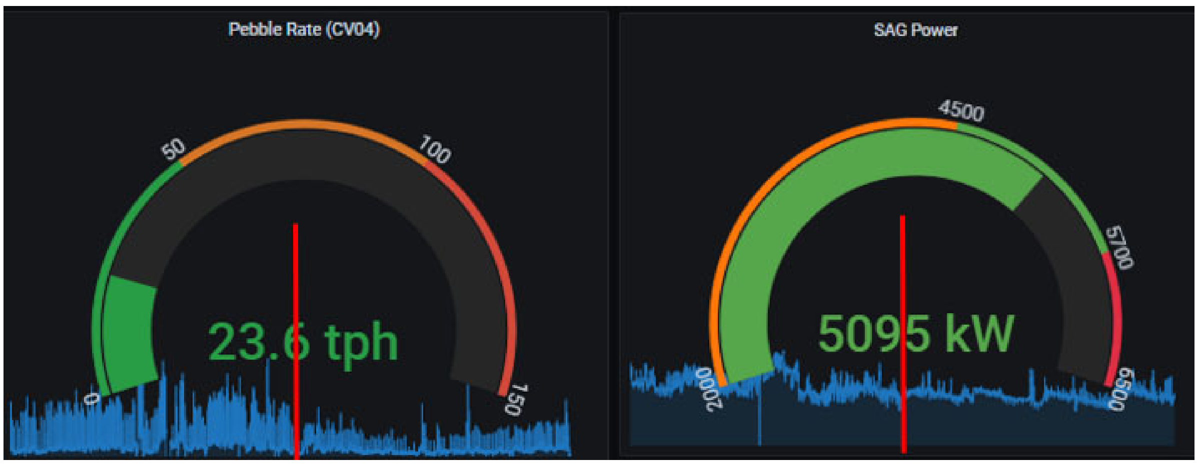

Figure 10—Scats and power with improved density stability, before and after control mod

SAG CHARGE

In a conventional SAG mill, feed rate is automatically adjusted to maintain a target SAG mill weight set-point which is provided by the operators with the intent of maintaining the desired optimum percentage volumetric filling. This was existing in this circuit; however, it was rarely required, as the tertiary crushed feed does not build an autogenous load. The mode of operation was adjusted to accommodate what the circuit had essentially become—a two-stage ball-milling circuit—by increasing the operating ball charge in the primary mill. This allowed for a higher and more sustainable power draw to be achieved. The control philosophy was modified such that the throughput rate is controlled directly to grind, and only toggles to a SAG mill weight set-point during excursions towards the upper weight limit. This occurred occasionally when the tertiary crushing plant was bypassed for maintenance and the mill received predominantly primary crushed feed for a period.

Phase 2—Optimization Control and Set Points

This phase used the stability created in Phase 1 to adjust set-points in a controlled way. The throughput was typically controlled to cyclone O/F grind, which was capped to prevent the throughput rate from dropping below a selected minimum (in that case the grind set-point was increased). This was relatively straightforward in Damang's case, as the circuit is essentially a two-stage ball mill, so there was no need to use throughput to manage the primary mill load. Where the primary mill is a semi-autogenous mill, the stability loops from Phase 1 become the slave loops of Phase 2. Controlling throughput to grind in this case was also simplified with the installation of an online particle-size analyzer. In many plants where this is lacking, the cyclone feed density can be used as a proxy for inferring grind size where a constant pressure control-philosophy is implemented. This stage also focused on adjusting set-points around the circuit to maximize power utilization and efficiency, and in addition balance the energy requirements across each comminution stage.

During Phase 2, some changes proposed were associated with increased operating costs, and therefore required up-selling to the greater management team. To do this, the MillROC team utilised a value driver tree (VDT) to motivate for required budget changes. This was set up at the commencement of the optimization activities and used to evaluate the economic impact of every proposed change. This allowed assumptions to be presented transparently, and be scrutinised by the greater organisation, where a higher level of authorisation was required. After a change was implemented, the VDT was revisited by the team to verify that the change was delivering on the expected total contribution change. Where the VDT indicated that a change would deliver a negligible or marginal improvement, that change was discarded. This was a simple but effective means of keeping focus on the most significant change drivers over the course of the optimization. The changes made are described below.

THROUGHPUT GRIND MASTER LOOP

This loop used a moving average derived from the newly commissioned online particle-size analyzer to automatically adjust the plant throughput rate to maintain a target cyclone O/F grind P_{80}. If a higher or lower throughput rate was desired, the grind set-point could simply be adjusted. However, the primary mode of operation was intended to be controlling throughput at the most economical target grind, which will change in response to changing ore properties and global market conditions. The grind size was reduced from 120 µm to 106 µm for three months. Test work anticipated a recovery change of 2%–3%; in reality, only 0.5% was achieved, at best. This was used in conjunction with the throughput–grind relationship for the combined power draw and circuit efficiency at the time (Figure 11). A cost–benefit analysis indicated that this step-change is not economically optimal for the current state of the project, as the throughput lost was approximately 50 t/h at the finer grind (total contribution loss of 8.4%). For some ore types however, the test work indicated that the gold recovery was not grind sensitive between 106 and 125 µm, and only became grind sensitive below 106 µm. Given the mill feed was varying blends of the aforementioned ore types, the site team decided to trial operating at P_{80} 95 µm. This was still underway at the time of compiling this report.

Figure 11—Damang throughput–grind relationship @ W_{io} 16.4 kilowatt hours per tonne

OPTIMIZATION OF SET-POINTS

Following the improved stability, the following set-points were adjusted:

- Increased SAG and ball mill ball charges to increase power draw. This resulted in an increased media consumption rate, however the VDT analysis indicated that the additional production gained at the higher average power draw would offset this, which was realised after the change was made. The initial VDT prediction indicated an overall contribution change increase of 6%, with 3.7% realised at the time of writing due to the lower-than-predicted recovery at the finer grind. It is envisaged this will be fully realized once the optimal throughput and grind set-points are fully optimised at the end of the current fine-grind trial. Figure 12 shows the average monthly mill power draw since the commencement of the MillROC engagement.
- The tertiary crushing circuit screen aperture was increased from 25 mm to 30 mm. The Crushing circuit was de-bottlenecked without reducing mill throughput.
- Addition of 80 mm balls to the SAG mill to assist with fine grinding. This was an interim solution pending the installation of 30mm discharge grates.
- Increased throughput rate set-point to maintain target grind (to be automated in a master loop in future).
- Reduced average cyclone operating pressure from 110 to 95 kPa, to cut ball mill flow and reduce roping. Benefits in terms of wear can be expected linked to the lower slurry velocity within the pumping and piping system.

- Increased SAG mill-density set-point to 79% solids to improve grinding efficiency. Made in conjunction with other changes to achieve the target grind.

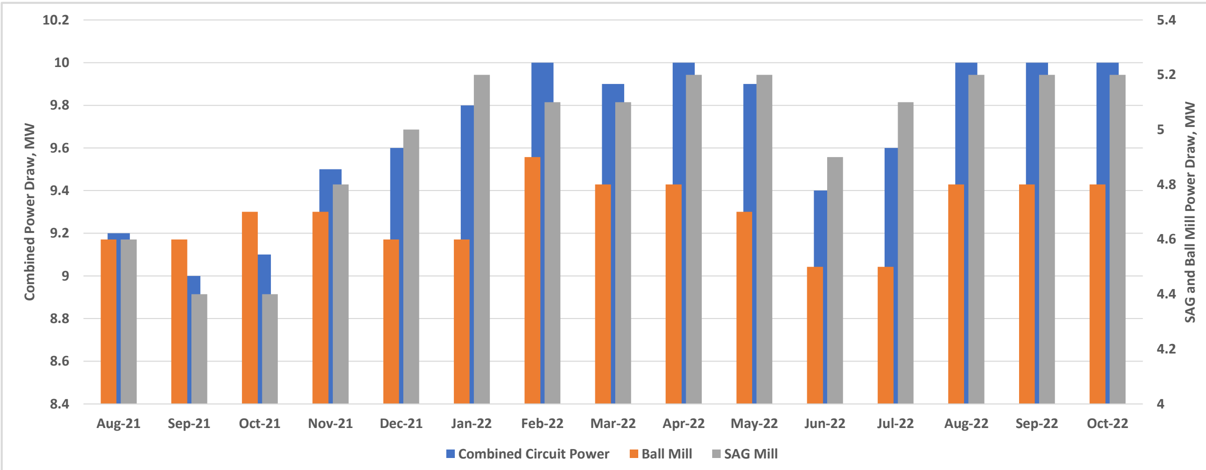

Figure 12—Mill power draw across the optimization period

Long-Term Projects

Long-term projects were typically long-lead items, and changes that took an extended time to implement and significant operating time to assess. In the case of Damang, that included:

- SAG mill liner design review. The SAG mill is fitted with a MillSlicer, a shell-mounted vibration sensor for advanced mill load analysis, which consistently indicated that when new, the lifter face angle of 26° was too aggressive for the relatively low operating volume (17%–20%) and high fixed operating speed (79% Nc) as shown in Figure 13. A face angle of 30°–35° was recommended.
- Change of SAG mill grate aperture from 40 mm to 30 mm to retain finer steel media in the primary mill. This was intended to reduce media consumption in the SAG mill and assist in utilising power to produce a finer transfer size. The pulp lifter design has also been modified from radial to curved to improve power draw by reducing the slurry volume in the mill. Installation of these items is still pending.
- A review of the power draw lost to packing was also conducted, with a cost–benefit analysis indicating that the hi-lo design required to address this was not economically beneficial. This was primarily due to the reduced life expectancy when the protective packing is removed, based on historical trial data. A modified design that increases lifter spacing was instead adopted, which also incorporates the revised face angle to better suit the lower operating volume. It is envisaged that this combination may offset the higher wear experienced without packing, as the charge will no longer be impacting the shell places. Installation of this was still pending.

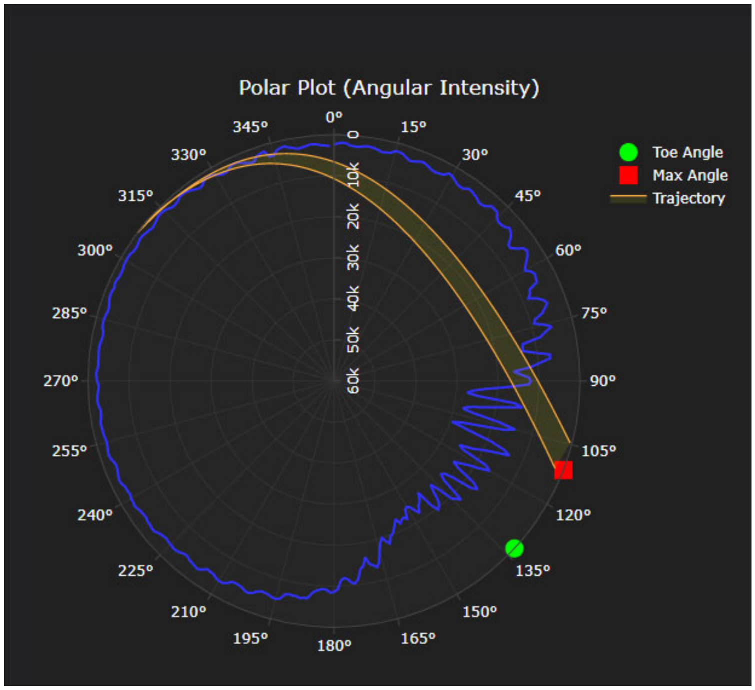

Figure 13—MillSlicer data indicating higher shoulder impact point (max angle) than toe

Results and Conclusions

The combined effect of the described changes was not only a sustainable increase in power draw, but also an improvement of energy efficiency. Comparing the key operating parameters from the baseline until current, it is evident that the primary objective of achieving a finer grind without sacrificing throughput rate was met. The change in grind has been gradual, with the implementation of Phase 1 not commencing until June 2022, allowing for the grind to be decreased in a controlled way. The throughput has recently been increased, as the grind target has been exceeded. The operation now has full control over the throughput–grind balance in the circuit, without experiencing cyclone instability during transitioning of set-points. The variability in cyclone pressure was reduced from 15% to 2.5%. Fewer cyclones are operated, and roping has been eliminated. The grind variability decreased by more than half, with finer average grind and increased throughput rate of 5.7%.

Analysis of the circuit operating work index (W_{io}) showed a reduction in operating work index from around 18.2 kilowatt hours per tonne (kWh/t) to 16.8 kWh/t. This indicates an improvement in circuit efficiency of 7.6%. Below is a summary of the key achievements at the time of writing:

- Reduction in grind variability and finer average grind, exceeding the original target (Table 1)
- 5.7% increase in throughput (Figure 8)
- 7.6% reduction in energy requirements, reflected in the increased throughput rate and finer grind
- Improved circuit stability, greatly reducing incidences of cyclone roping operator intervention.

Table 7—Baseline versus results to date

Parameter	Unit	Baseline		Oct 2022	
		Average	Std	Average	Std
Feed Rate	wt/h	575	48.8	608	41.7
SAG Power	kW	5,044	177	5,120	207
Ball Mill Power	kW	4,770	235	4760	129
Grind P_{80}	µm	106	2.8	95	1.2
Cyclone Feed Density	%	79.6	3.49	71.2	2.28
Cyclone Pressure	kPa	119	18	113	2.8
W_{io}	kWh/t	18.2	0.817	16.8	0.711

Improvement and change initiatives are often challenging, with success rates in industry quoted at 30% (Smith, 2002). The Damang optimization project faced the same risks of failure during the initial months of running trials, in the months between December and June 2022, as the key KPIs did not reflect the expected performance change (Figure 14). This can typically lead to a loss of confidence in the approach, resulting in the improvement effort being abandoned prematurely. In the case of Damang the initiative was well motivated, with real-time analysis and evaluation of the trials performed leading to an ever-growing confidence in the operational team's understanding and belief that applying first principles correctly within the operational reality will eventually deliver the desired outcome. As can be seen in the months from August to November 2022 the initiatives grew in maturity and started complimenting each other, resulting in a significant step-change in throughout performance and efficiency for a mature circuit like Damang.

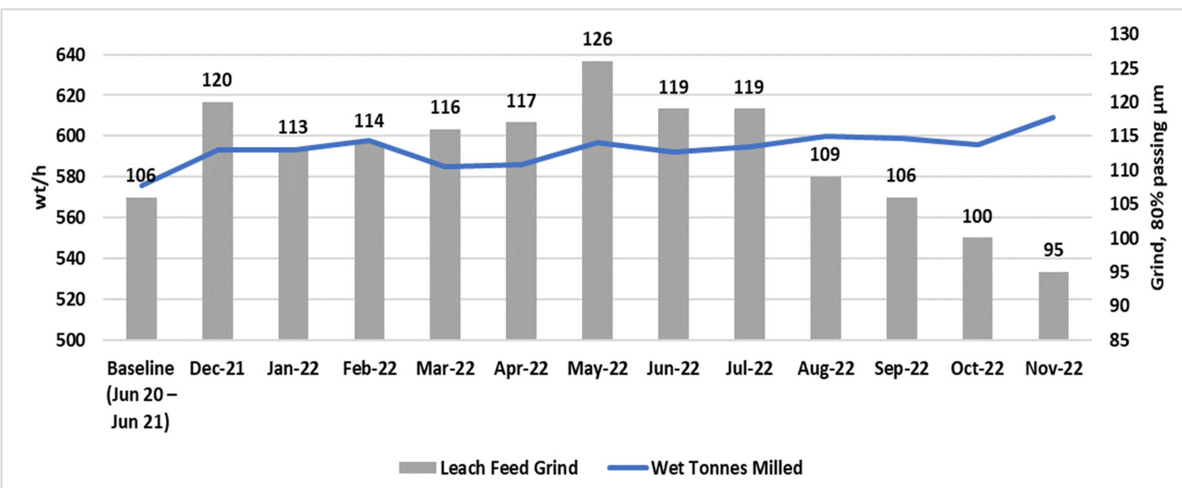

Figure 14—Damang throughput and grind trend

Ultimately, the real benefit from the optimization engagement can be measured on two fronts. Firstly, in terms of operational capacity, the site team are now able to control where they would like to operate along the throughout versus grind curve to suit the most economic operating point for the business and can now focus on establishing the economic relationships with recovery and costs. Secondly, in terms of skills development and growth the site team have taken up the challenge to re-establish the first principles of comminution and process control within the production context, something that so often becomes faded when incorrect perceptions drive behaviour to achieve top-down goals for output. The benefit of an operation aligned with focussing on efficiency in real time and making decisions based on the overall economic impact down the mining value chain is significant and establishes a standard for others to strive towards.

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