Methodology for Assessing the Benefits of Grind Control Using PST Technology for True On-Line Particle Size Measurement

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ABSTRACT

Despite the recognized significance of ground product fineness on both line capacity and downstream process performance (typically flotation), less than 10% of mineral ore concentrators today use particle size measurements in automatic control applications for the final product particle size.

Although "near-line" particle size measurement instrumentation has been in place for several decades and is commonly installed in most modern concentrators, its availability and low measurement frequency have typically been inadequate for reliable use in automatic control. Their low availability is often due to problems with slurry sampling and transport systems required to deliver samples to the measurement instrument.

Recently an innovative technology for real-time particle size measurement has been developed by CiDRA Minerals Processing, under its commercial name CYCLONEtrac™ PST, already proven in several commercial installations, demonstrating near 100% availability with minimal maintenance, thus overcoming the limitations of previous technologies.

Investment decision makers require convincing, reliable estimates of the expected economic value that automatic grind control projects would deliver. This paper presents a methodology for estimating such value from the installation of the new PST particle size measurement technology, capable of tracking particle size on each individual hydrocyclone overflow stream, adding unique new options for improved process stability and performance. Based on actual plant operating records, accumulated over long periods of time, the evaluation approach described here assesses and highlights the significant potential process improvement to be expected from this unique PST technology.

As an extension of previous work, this paper presents the key operating criteria that permit increasing mill throughput and optimizing the production of valuable metal by identifying the optimal grind size. As this normally requires operating closer to the process physical boundaries, accurate real-time particle size measurement, such as those provided by the PST System, become essential for the practical achievement of the maximum potential value of every operation. For further illustration, data from three different copper grinding/flotation plants are shown and compared.

INTRODUCTION

Owners and operators of mineral ore concentrators constantly search for the most economically attractive way to increase the output of valuable metal; say, copper. A logical approach is to identify a key parameter that has the greatest impact on the performance of multiple stages of the process, and then use a holistic analysis methodology to determine how this key parameter can be controlled to optimize the final output of these multiple stages.

Final ground product size is widely recognized as such a key parameter. However less than 10% of the mineral ore concentrators today use real-time particle size measurements for automatic control of the final product size due, to a large extent, to the inherent limitations of existing technologies, prior to the recent introduction of PST.

The "near-line" particle size measurement instrumentation that has been used for decades has typically suffered from low availability because the fundamental measurement technologies were developed for other less-demanding industries and then adapted to the harsh environment of the typical mineral concentration process.

The PST technology, commercialized in 2015, is the only technology expressly designed for true on-line measurement of the final ground product size on the overflow of each individual hydrocyclone, almost continuously, avoiding the always cumbersome challenge of taking representative slurry samples, thus overcoming several limitations of legacy technologies. Its simple acoustic-impact technology, rugged design and absence of moving parts has solved the problem of low availability and need for recalibrations, thereby making real-time measurement and automatic control of ground product size a practical reality.

To assess the potential economic benefit of implementing this PST-based measurement and control system, the authors previously developed a methodology for determining the optimum final ground product size that produces the maximum Net Metal Production (NMP) (Maron et.al. 2017) defined as the amount of valuable net metal produced per unit time. The method uses historical daily or hourly plant data for a minimum period of one year, ideally longer. Since that initial work, data sets from two additional plants have been analysed. In all three cases the analyses have shown that although there are significant potential gains from only reducing the process variability in product size, there are additional larger potential gains obtained from coarsening the product size which enables increasing the throughput of the plant, therefore proportionally increasing the NMP. However, this must be done in a stable and controlled manner to avoid downstream problems with material handling and to prevent roping conditions with individual hydrocyclones. The PST system provides the necessary information, not previously available, to more closely approach these process barriers in a safe operational way.

In this paper, we will briefly review the PST technology, then examine three specific paths available to increase process performance, i.e. to maximize NMP, showing the key role of reliable ground product size measurements. We will then briefly present the methodology used to determine the product size that maximizes NMP. Finally, we will discuss three actual different examples of applications of this methodology.

This approach to increasing NMP focuses on the secondary grinding or ball milling for a good reason. In the 1980s and 1990s the typical bottleneck in the grinding circuits of ore concentrator plants was the SAG mill. However, significant improvements to SAG mills over the last decades have now shifted the bottleneck to the ball mills. Thus, the ball mill classification circuit is the process area where the greatest potential NMP improvement can be obtained, with significant economic benefits.

IMPACT-BASED REAL-TIME PARTICLE SIZE MEASUREMENT OF CYCLONE OVERFLOW STREAMS

Acoustic impact-based particle size tracking is a unique method for measuring and controlling a reference product mesh size in cyclone overflow streams. The implementation of this technology is centered upon a sensor probe that is inserted into the overflow slurry stream via a two-inch (50 mm) hole in the overflow pipe. Particles within the slurry stream impact the surface of the probe generating travelling stress waves within the probe. A sensor converts these travelling stress waves into an electrical signal and proprietary signal processing techniques convert these signals into a particle size measurement that is output every four seconds. The sensor is constantly in contact with many particles in the slurry stream, thus obtaining information from orders of magnitude more particles than traditional sample based technologies. Also, because of the location of the sensor downstream of the hydrocyclone and the presence of an air core at that point, the sensor produces no change in the back pressure seen by the hydrocyclone and thus does not affect hydrocyclone performance. The probe has a useful life of approximately 18 months due to the abrasive wear caused by the direct slurry impact. The probe life is related to the particle hardness and size which is obviously finer in the overflow stream compared to the feed stream, thus enabling an acceptable probe life. Currently the software provides a single reference mesh size to be incorporated into process control strategy. Figure 1 shows the main components of the PST system.

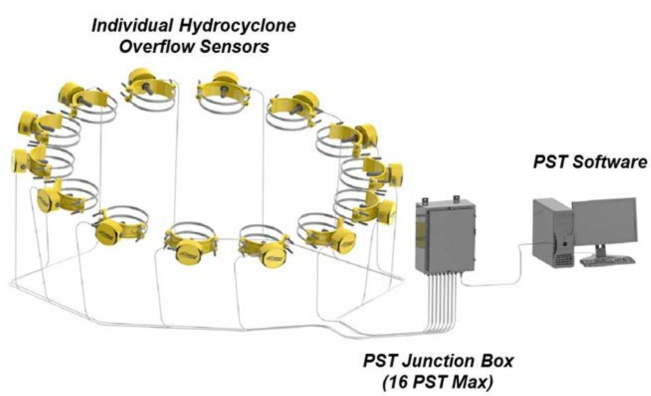

Figure 1 PST mounted sensor head (left), and system with interconnections (right)

IMPROVING PROCESS PERFORMANCE AND THE KEY ROLE OF PRODUCT SIZE

The value analysis methodology, presented later, shows that to achieve the maximum increase in NMP – which is directly linked to net cash flow from the operation – we should increase throughput and coarsen the final product size, despite a possible decrease in recovery. The throughput equals the ratio of power to specific energy. And the well-known Bond's Law relates specific energy consumption used in size reduction to the feed and product sizes by a factor known as the Bond Work Index (W_i), which is a property of the ore (Bond, 1985). These two relationships can be combined, as shown in Equation 1, to show three parallel paths to increase throughput using the existing circuit, where Wi is replaced by the 'operational work index' (W_{io}) which is the actual energy per ton as measured in the plant. Ideally, W_{io} should be less than W_i for an efficient grinding operation. A detailed explanation of these paths is well known and has been presented on various occasions, including by the current authors (Sepulveda, 2017), and are summarized in the following three subsections of this report.

$$T = \frac{P}{E} = \frac{\overbrace{(1/W_{io})}^{\text{Classification "Effectiveness"}} \bullet \overbrace{P}^{\text{Input}}}{\underbrace{10\,(1/P_{80}^{0.5} - 1/F_{80}^{0.5})}_{\text{Grinding Task}}}$$

Equation 1 Bond's Law showing opportunities to maximizing throughput (T)

Increase mill power draw

The first path to increase throughput as shown by Equation 1 is by increasing the power (P) drawn by the ball mill. The well-known relationship shown in Figure 2 indicates how this can be accomplished. It follows that one should be increasing the mill charge level (J) and/or the mill speed (N_c) whenever possible.

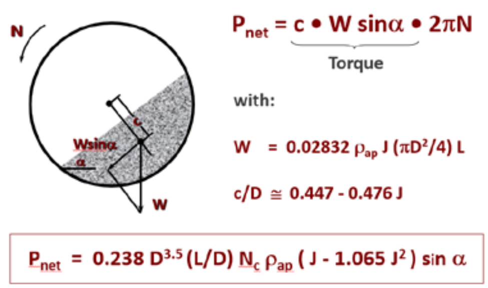

Figure 2 Hogg & Furstenau Model for Mill Power Draw

Increase classification effectiveness

The second path to increase throughput as shown in Equation 1 involves the operational work index (W_{io}) which is affected by the response of the classifiers in their closed-circuit interaction with the ball mill. The W_{io} appears as a reciprocal in Equation 1, thus representing the "effectiveness" of the classification, i.e. how the classifiers contribute to reduce the tons processed per unit of energy consumed. A more effective operation is that where the W_{io} is reduced to its minimum possible value. This means that for optimal energy efficiency and throughput of an effective grinding process, it is required that the content of fine particles in the mill charge be as low as possible for a given grinding task, thus reducing W_{io}. This may be achieved by operating the circuit under the following three operating conditions, which are sometimes referred to as the "Fourth Law" criterion.

- Minimum % Solids Overflow, only limited by the total water availability,
- Maximum % Solids Underflow, only limited by the undesirable 'roping' condition,
- Maximum Circulating Load, only limited by the capacity of both the pump(s) and the mill itself to transport the required volume of slurry.

The collective goal of these three operating conditions is for the hydrocyclones to remove fine particles from the circuit as soon as they are reduced to the target size. In this way, the energy of the mill is directed to grind the coarse particles that have not yet reached the final target grind size, rather than being used to overgrind particles that have already reached the final target size and should not be present in the mill.

Relax grinding task

The third and most effective way to increase throughput (T) is to relax the grinding task, which in Equation 1 is represented by the denominator that contains the feed size (F80) to the ball mill section and the product size (P80) discharged through the cyclones overflow. Equation 1 shows that bringing the F80 and P80 closer together, i.e. making the feed size smaller and/or making the product size coarser, will produce increased throughput (T). A graphical representation of the grinding task, and the empirical relationship known as Bond's Law, are shown in Figure 3 (left), where W_{io} represents the effective hardness of the ore. In the NMP optimization methodology we focus on coarsening the P80, which has a greater effect on increasing throughput than reducing the F80 size, as shown in Figure 3 (right).

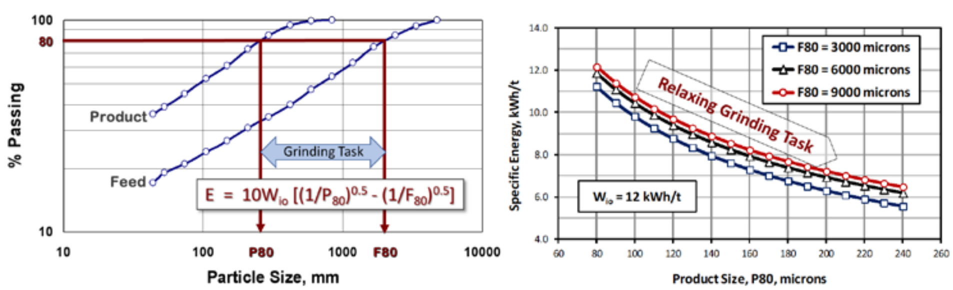

Figure 3 The 'Grinding Task' (left), and the effect of relaxing it (right)

However, as the P80 and throughput are increased, a reliable real-time measurement of product size like the one provided by PST becomes extremely valuable for implementing this approach while avoiding problems as downstream process limits are approached. A typical process limit is when hydrocyclones enter a so-called roping condition as their underflow discharge capacity is exceeded. Figure 4 shows such an example of ball mill classification circuit being pushed to higher throughput and higher particle size – as measured by PST – until the point at which a hydrocyclone exceeds its operating limit and enters a roping condition. The detrimental effect on the stability and performance of all the other cyclones in the battery is clearly seen, as the battery sends a large volume of coarse material to downstream flotation. The data was obtained after the installation of a PST system but before it was used for control. The most relevant learning from this experience is that "one wrong cyclone corrupts the whole battery of cyclones".

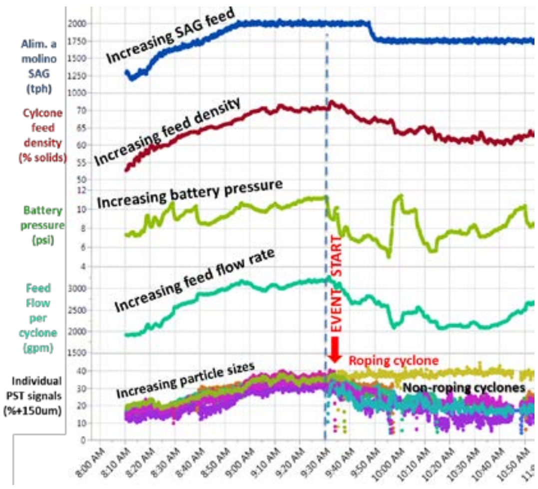

Figure 4 Hydrocyclone enters roping condition when process limit is exceeded

VALUE ASSESSMENT METHODOLOGY

The objective of this methodology is to quantify the value of incorporating the PST on-line particle size measurement into the automatic process control system for a grinding/classification circuit using normally available historical plant data. The methodology uses daily data over a long enough time (ideally over 1 year) to obtain a high-level assessment of the general plant operating performance, mainly focusing on throughput (T), and recovery (R) which are used to calculate the net production of valuable metal (NMP) – the primary generator of cash flow – giving the final objective function for process optimization purposes, as determined by the simple expression:

$$NMP = h\ T\ R$$

Equation 2 Objective function for calculating Net Metal Production (NMP)

where h represents the head grade of valuable metal being recovered.

Inherent in this methodology is the usual observation that throughput (T) and recovery (R) are a strong function of product size, thus product size is chosen as the independent variable. Therefore, NMP is also a strong function of product size, thus there should exist an optimal product size that maximizes NMP and cash flow. Therefore, accurate measurement and control of product size is here highlighted as a necessity for effective process control. Correlations of throughput and recovery to other variables such as feed grade and ore hardness must also be examined in every case, whenever the proper information is available. Finally, operational plant constraints (like, maximum tonnage or flowrates, product coarseness limitations for slurry transport, etc.) should also be taken into consideration as they may limit the maximum NMP values to be consistently obtained.

Throughput, Recovery and NMP vs Product Size

The minimum input data set consists of the following four parameters, sampled at least once daily for a minimum of one year: weight percent passing a target grind size (e.g. P80 or % + target mesh size), throughput per unit time, feed grade, percent net metal recovery. Once the data set is cleaned by filtering, the throughput (T) and Recovery (R) are plotted vs Target Grind Size as shown in Figure 5 (left), which typically show centrally weighted data clouds that make trend detection very unreliable. This is addressed by using a data binning technique that places equal weight on each product size bin, as seen by the throughput and recovery plots in Figure 5 (right).
The filtered throughput and recovery are then verified; i.e. throughput should show an increasing tendency with increasing particle size, and recovery should show a peak recovery at a unique particle size, both as predicted by basic comminution and flotation practice. NMP can now be calculated, and its maximum identified as shown in Figure 5 (right).

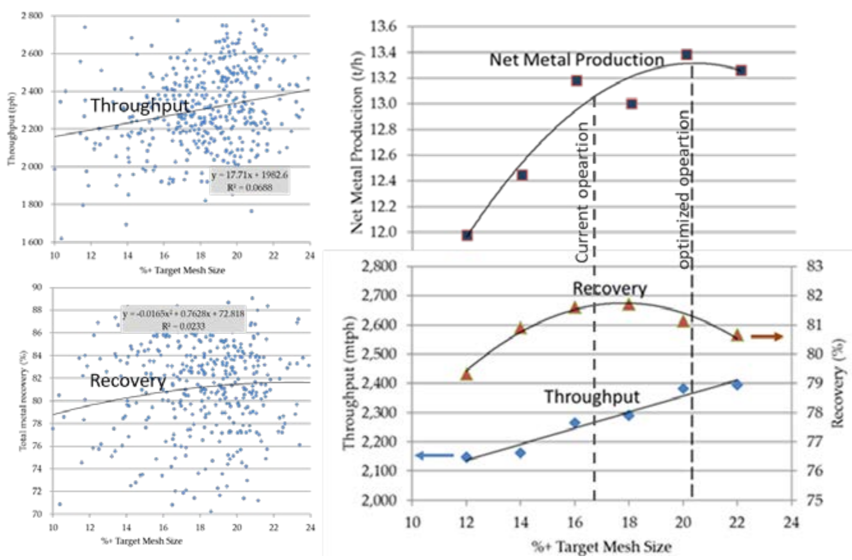

Figure 5 Throughput & Recovery unfiltered (left), with data binning (right) with Net Metal Production (NMP) objective function per Equation 1.

In general, an important conclusion that can be drawn from the data, as shown in Figure 5 is that the maximum NMP is normally achieved by increasing throughput by coarsening the product size, usually at the expense of sacrificing some recovery. From this important conclusion comes a challenge. How to measure grind size in a continuous reliable way so that these measurements can be incorporated in the automatic control system strategy, and thus prevent violating the downstream process limitations imposed by particle size and or material handling capabilities. Figure 6 (left) shows the actual particle size distribution without real-time particle size control, and the expected reduced variability and increased product size achievable by using real-time particle size control such as PST. Figure 6 (right) shows the potential incremental NMP improvements by only reducing size variability at the current product size, and then coarsening the product size to a higher target size.

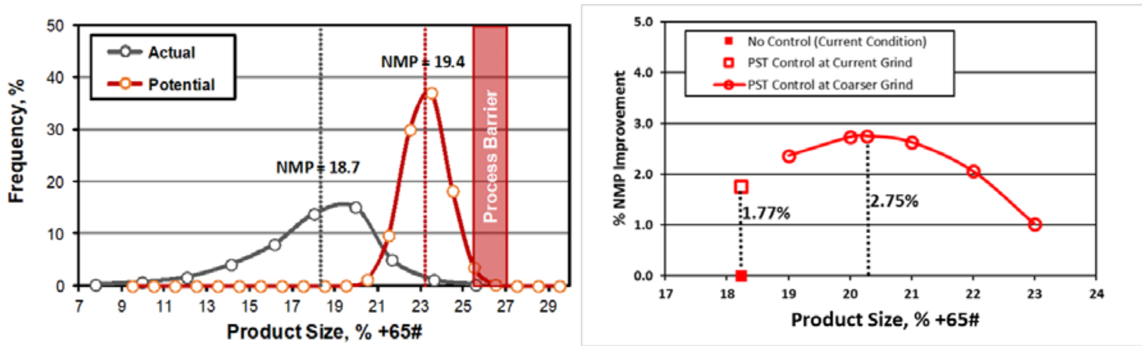

Figure 6 Actual and potential size distribution histograms and resultant NMPs (left), and associated potential percent NMP improvement (right).

Comparison of Product Size Control in Three Plants

In addition to the data set analysed above, data sets from two additional SABC circuits were analysed. To compare and benchmark the performance of plants without real-time product size control, normalized histograms of the product size distributions for the three plants are shown together in Figure 7 (left). For better comparison, the x-axis is normalized to the average product size and the y-axis is normalized to the percent of total number of readings. The data is plotted without the filtering of data binning to reveal more of the data structure. It is interesting to observe that the natural process variability appears similar in all cases, considering that these are all large porphyry copper operations with similar grind-classification circuits that do not include particle sized-based control strategies. It is to be expected that under particle size control strategies, the variability would be significantly reduced.

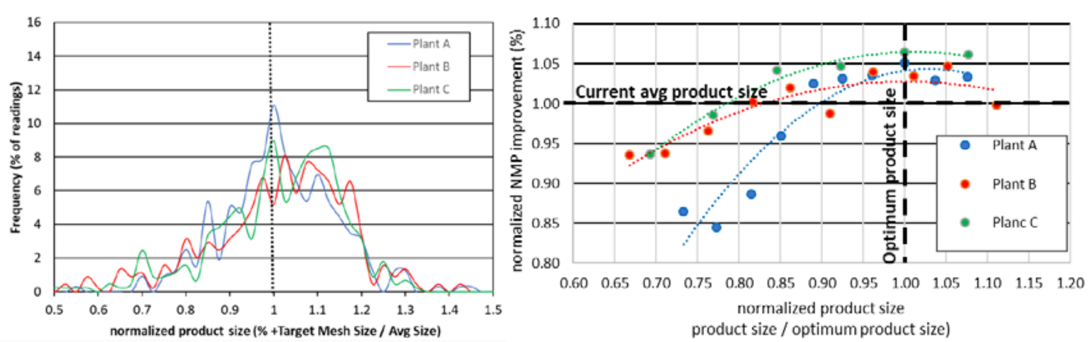

Figure 7 Normalized product size distribution without real-time size control (left); normalized NMP improvement

Figure 7 (right) shows the normalized NMP improvement for the plants, indicating that the current product size is normally in the range of 80% to 90% of the optimum size to achieve maximum NMP, and the expected NMP improvements are 3% to 6% if the current average product size is increased to the optimum size.

CONCLUSION

Final ground particle size determines plant throughput and recovery, and thus the production of valuable metal that drives cash flow. The absence of a reliable real-time particle size measurement has for decades limited the implementation of automatic particle size control strategies that can enable mineral concentrator plants to maximize the production of valuable metal. The new highly reliable PST real-time particle size measurement technology now enables plants to implement control strategies that permit them to grind coarser, increase throughput, and optimize metal production, thus more closely approaching process limits while monitoring and controlling product size to avoid downstream problems. We have shown the fundamental operational strategies that should be implemented to maximize valuable metal production, and a simple methodology to estimate the resulting economic benefits. Data from three plants has shown a typical variation in product size from processes without automatic control based on real-time particle size measurement. Data also shows that significant increases in valuable metal production of several percentage points are possible.

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