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

Robert Maron*[1], Christian O'Keefe[1], Jaime Sepulveda[2]
1. CiDRA Minerals Processing, USA
2. J-Consultants, Ltd. Chile

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 real-time 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 associated with problems with slurry sample collection and handling systems required to present the samples to the size measurement instrument.

Recently, an innovative technology for real-time, on-line particle size measurement has been developed by CiDRA Minerals Processing, under its commercial name Particle Size Tracking (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 will 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, thus adding significant new options for improved process stability and performance. Based on actual plant operating records, accumulated over long periods of time, the evaluation approach herein described assesses and highlights the significant potential contribution to be expected from this unique PST technology.

*Corresponding author: CiDRA Mineral Processing Inc., Managing Director Latin America, 50 Barnes Park North, Wallingford, CT 06492. Phone: +1 860 638 9928. Email: rmaron@cidra.com

INTRODUCTION

Optimizing the metallurgical performance of an existing industrial-scale mineral processing plant as a function of grind product size is an important but often complex task. Changing the grind product size in a full-scale plant and observing the effects on flotation is a direct way, but the real effects can be masked by the multiple and unexpected disturbances common to grinding and flotation circuit operations (McKay, 2014). Simulators for both grinding and flotation have been developed and are very useful, but the integration of both can be complex, and they are still only models of the full-scale industrial plant and thus have inherent limitations (Schwarz, S. 2013). Methods have been developed using a series of laboratory tests conducted on industrial circuit samples that have also proven useful and gained acceptance (Bazin, 1994) (Edwards, 1999).

These three methods, and combinations of the above are certainly useful but involve considerable time and expense. In addition, they introduce uncertainty in the results due to the limitations of simulations, differences between plant and laboratory tests, and extrapolations from data taken from small sample sets and over small time frames. But often it is desirable to obtain an assessment of performance of an existing plant as a function of grind product size with less time and expense, and with more confidence that the results are representative of the industrial scale operation.

The methodology presented herein uses typically available historical plant data over a long time period to assess the current performance, and predict the performance improvement that may be possible if automatic control of the grind product size is implemented by the addition of reliable on-line particle size measurement technology.

IMPACT-BASED REAL-TIME HYDROCYCLONE PARTICLE SIZE MEASUREMENT

Principle of Operation

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 (Figure 1). 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.

Figure 1 CYCLONEtrac PST particle sizing sensor mounted on hydrocyclone overflow pipe

Plant Implementation of CYCLONEtrac PST Technology

The plant implementation of the PST particle sizing system includes a measurement probe with its associated electronics on each cyclone overflow pipe, a junction box that consolidates the processed signals from the individual sensors, and sends them to a computer that is typically located in the control room. Final processing takes place in that computer and the resulting particle size information is transferred to the plant system via an integrated OPC server. Currently, the software provides a single reference mesh size that is to be incorporated into the overall process control strategy. This system is outlined in Figure 2 (Cirulis, 2015).

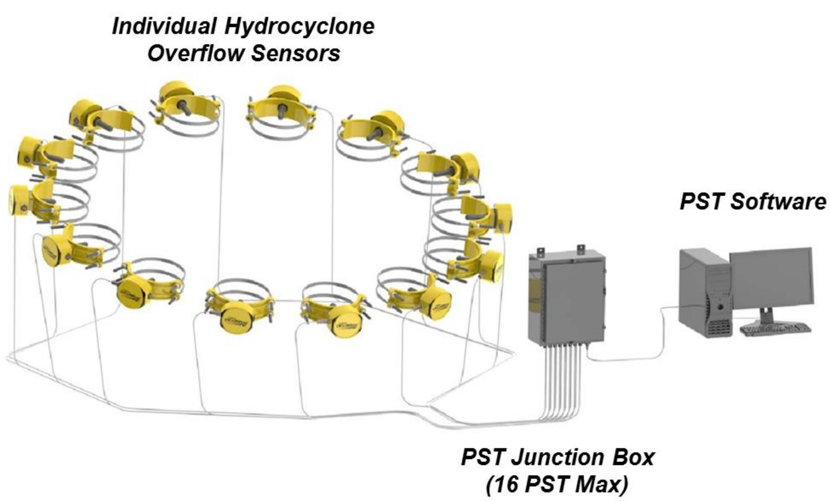

Figure 2 PST plant scale installation diagram

On-line impact-based PST or alternative "near-line" cyclone overflow particle size measurement methods, whether laser diffraction, ultrasonic or caliper, all require empirical calibration by correlating their signals against reference particles or actual slurry samples analysed with standard laboratory procedures (Wills, 2016). The impact-based CYCLONEtrac PST also requires calibration to compensate for influences from cyclone type and sensor installation location. To ensure a good composite calibration that can be applied across all the cyclones in a cluster, calibration samples must be taken from the overflow of each cyclone in a cluster. Once such calibration takes place, it does not have to be performed again when the probe is replaced due to wear, as long as the same model of replacement probe is used. In addition, samples must be taken beyond the expected operating range of the cyclones to ensure accurate measurements when the cyclone is operating outside its normal operating range. Calibration ranges must cover above and below the usual operational conditions including but not limited to roping events, startups, shutdowns, and grind outs. This avoids the measurement uncertainty that occurs when calibration models are used to extrapolate measurements beyond their calibrated range. For rapid processing of samples, a single sieve size is used with a custom wet sieving procedure to generate a calibrated number such as percentage of material passing or retained by a reference sieve size, e. g. X% +100#.

Experience shows that the resulting calibrated signals exhibit a standard deviation that is less than 4.5 percentage points from the corresponding true values. An undetermined but significant portion of this standard deviation can be attributed to the sample collection procedure. Cyclone overflows typically have limited access for sampling so a full cross-stream sample is normally difficult. Instead plunge cuts or partial cross-stream cuts are performed. As a way of example, the results from the commissioning at a phosphate concentrator is shown in Figure **3** (O'Keefe, 2016).

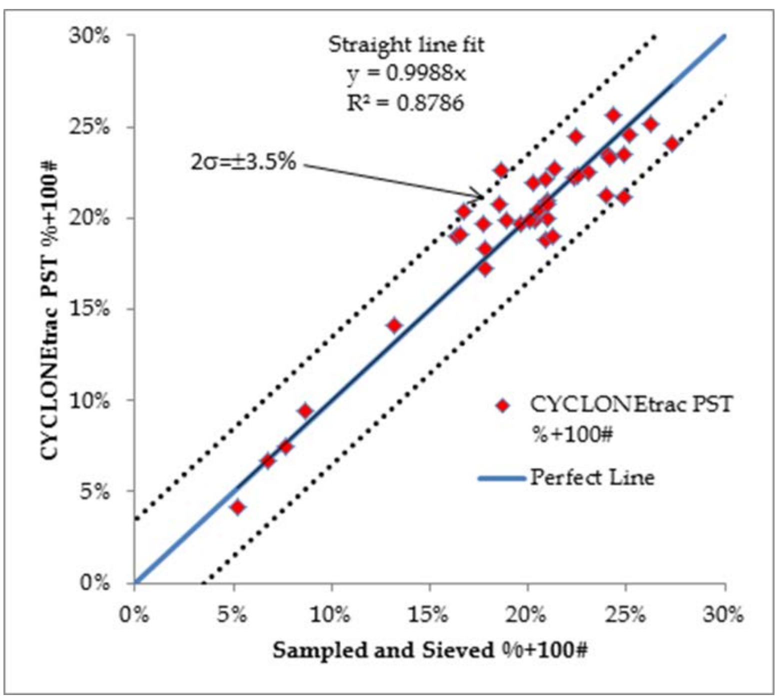

Figure 3 Example of PST results from single cyclone compared to sampled and sieved measurements

VALUE ASSESSMENT METHODOLOGY

Objective

The objective of this work 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 period (ideally over 1 year) to obtain a high-level assessment of the general plant operating performance, mainly focusing on throughput (T), recovery (R) and net production of the valuable metal (NMP) to be the final objective function for process optimization purposes, as determined by the simple expression:

$$NMP = h\ T\ R \qquad (1)$$

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

Inherent in this methodology is the usual observation that throughput (T), recovery (R) and NMP are strongly correlated to ground product size, in such a way that there would exist in every application an optimal grind size that maximizes NMP; that is, the net value to be achieved from the operation. Therefore, better measurement and control of grind 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. This methodology is significantly simpler than others that rely on laboratory tests and sampling from an industrial circuit (Bazin, 1994) (Edwards, 1999).

Input data set

Daily operating records are to be obtained for a minimum of 6 months with one year or more preferred. The quality of all data is important, but particularly the product size data. The frequency and method of obtaining the slurry samples should be well understood, and ideally should use a modern well-designed automated sampler that obtains samples every two to 4 hours, which are then combined to produce a daily composite sample. The composite samples should be processed in a metallurgical laboratory using proper quality control to obtain the grind product size. This is typically defined by a single number, the P80, which may be readily obtained from a full particle size distribution measurement. However, for convenience, the percent passing a single mesh size is typically used, and the mesh size chosen is typically the approximate P80 size. An example of the Input Data Set and the calculated NMP is shown in Figure 4, constructed on the basis of Equation 1 above.

INPUT DATA						CALCULATED
Date	Size (%+Mesh#)	Throughput (tph)	Feed Grade (%Cu)	Recovery Total (%Cu)		NMP (tph)
2-Jan	16.8	2,775	0.69	82.1		15.7
3-Jan	17.3	2,381	0.60	77.5		11.0
4-Jan	20.7	2,864	0.57	79.0		12.8

Figure 4 Example, input data set and calculated output

Data filtering, Analysis and Data Binning

Days with obviously faulty data are first eliminated. The primary grinding capacity indicator is the average dry tons of ore ground per actual operating hour (tph) for each day. Special attention must be given to days of low % plant utilization, since on these days the tph averages may easily be outside normal operating ranges. The objective of this data filtering method is to be left with maximum number of reliable data points.

Because most plants run at a nominal performance point, the data points for each day tend to be clustered around a central range as can be clearly seen when the data is plotted. However, this centrally weighted cloud of data makes it difficult to detect an underlying trend. Data binning is a technique for dealing with this problem because it places equal weight on each bin, rather than equal weight on each data point (Wikipedia, 2017). The equally weighted bins can more accurately reveal the underlying trend in the data, providing there are sufficient data points per bin across the entire range of interest. As an example of how non-binned data can give misleading results, if most of data points are concentrated in a central region where the underlying trend is mostly flat compared to the non-central regions, then the trend fitted to the non-binned data will be flat because the data points outside the central flat region will have relatively low influence and be unable to reveal the underlying trend. In this case, where we are searching for trends in throughput, recovery and NMP related to product size, the data was binned to the product size as shown in Figure 5. It was found that equal widths of 2% +Target Mesh Size (TMS) produced the most statistically valid results.

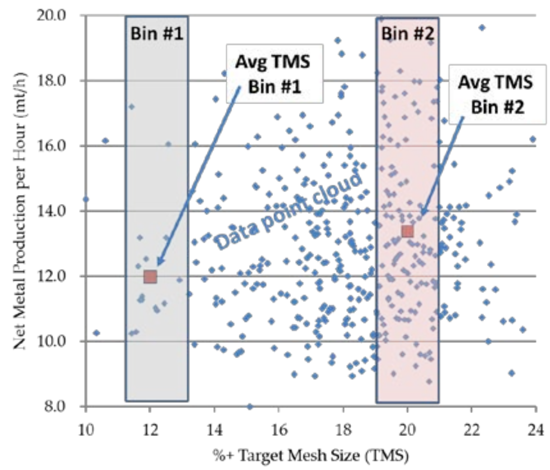

Figure 5 Example of data binning; non-binned points and average from binning

Throughput vs Product Size

The first basic correlation to examine is the relationship of ore throughput vs. product size as shown in Figure 6. Typically, this relationship will show that a coarser grind size (higher % + TMS) corresponds to a higher throughput. This graph shows the grinding circuit is typically operating between 15% and 25% +TMS with a corresponding throughput increase at coarser product size.

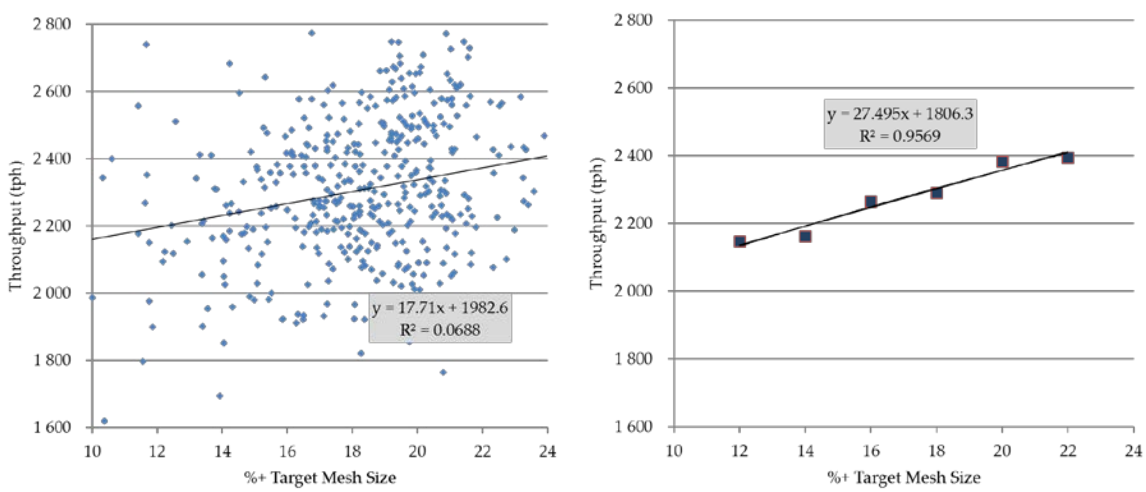

Figure 6 Throughput vs Product Size, with and without data binning

As indicated, the bin averages shown on the right plot reveal an acceptable (high R^2) linear trend for the throughput vs. TMS correlation, which could not be as clearly observed in the left plot showing all data points with their natural day-to-day process variability. As described previously, the high uncertainty of fitting a regression line to the cloud of points without using data binning means that the slope of the regression line in the left graph is very unreliable as indicated by the very low R^2

value. However, when data binning is used in the right graph the slope can be considered reliable as indicated by the high R^2 value.

Recovery vs Product Size

The next basic correlation to examine is the relationship of recovery (of the target metal) to product size as shown in **Figure** 7. Typically, the relationship will show a maximum recovery at a particular product size, with lower recovery in the finer and coarser size ranges due to losses in flotation recovery.

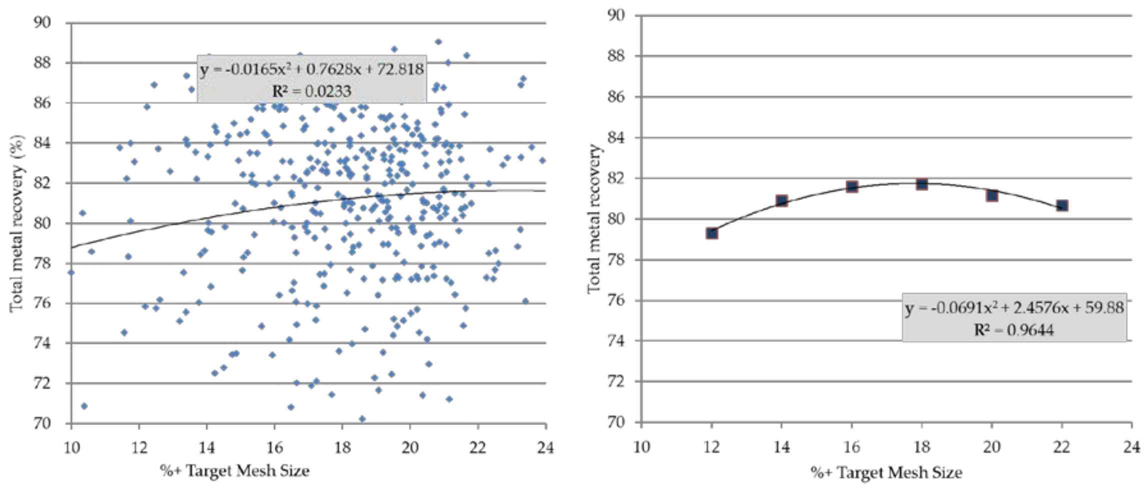

Figure 7 Recovery vs product size

Again, bin averages show a clear correlation trend which is hard to identify directly from the raw data.

Net Metal Production (NMP)

Having examined the relationships of throughput and recovery vs product size, the NMP can be calculated using the data binning technique previously described, as illustrated in Figure 8.

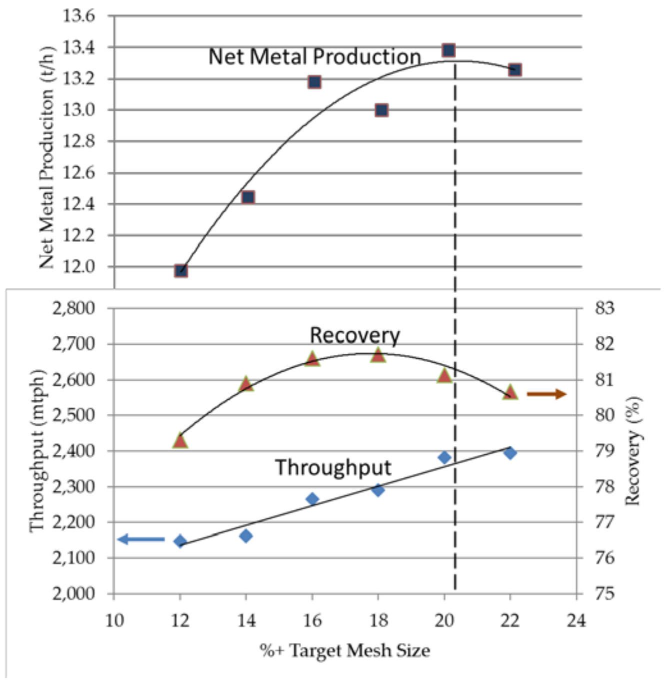

Figure 8 Net Metal Production (NMP) objective function (top) per Equation 1

Net Metal Production Gain from Improved Product Size Control

Average NMP for the example operation is 13.05 tph using the current product size measurement and control strategy. If the plant were to operate at the peak of 20.3% +/- 1% of TMS, the NMP would increase by 2% to 13.3 tph as illustrated in Figure 9. Furthermore, it is well recognized that process stability relates to improved overall circuit performance (Wysowl, 2017). In other words, there is more gain in NMP to be achieved by reducing process variability through better product size control than has been shown in the previous analysis.

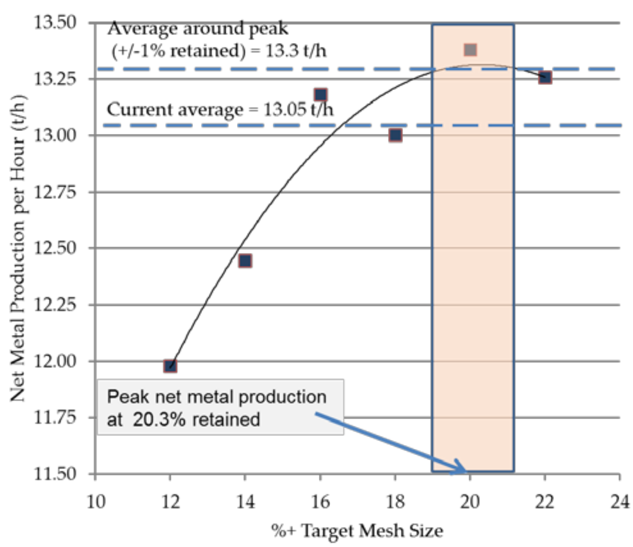

Figure 9 Net Metal Production optimized by operating at +/-1% of 20.3% +TMS

SUMMARY AND CONCLUSIONS

Availability of reliable product size measurements is key for the effective operational control of grinding/classification systems, particularly in cases where the following downstream stage is selective flotation concentration. As discussed in the present publication, CiDRA's PST technology is being shown to be most valuable in providing true on-line particle size information which, properly incorporated into the respective overall system control strategy, allows for the continuous maximization of the attainable process benefits.

Recognizing that product size is strongly correlated to both line throughput and valuable metal recovery, it is then possible to assess the target product size set point that will maximize at all times the objective function defined as the Net Metal Production (NMP) rate, to be expressed in tons of valuable metal produced per operating hour.

In the value assessment methodology here proposed, "data binning" techniques were found to be very useful and illustrative in the analysis of actual operational records, normally affected by fairly large normal process variations and unplanned instabilities which tend to obscure the underlying interactions amongst the most relevant process conditions.

An important advantage of the here described methodology is that it relies only on existing plant-scale data and does not involve the execution of cumbersome laboratory work.

The 2% increase in Net Metal Production predicted by this analysis, plus whatever benefits can be achieved from reducing process variability by incorporating PST technology in the control strategy, is consistent with increases previously reported from existing PST installations.

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