Grind process control using real-time tracking of +150um coarse material in individual cyclone overflows

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ABSTRACT

The purpose of a mineral comminution circuit with a ball mill running in closed-loop with a hydrocyclone classification battery is to feed the downstream process with the target pulp particle size. Maintaining the optimal particle size in the flotation feed can significantly improve plant cash flow. In particular, reducing the amount of coarse material is often a major challenge. Existing instrumentation to provide on-line particle size measurement is considered standard equipment in most modern concentrator plants. However, its very low availability, in spite of high maintenance requirements, and its relatively slow update rate have made it difficult to use the information for real-time automatic control of the grind and classification circuit to achieve the target particle size for the flotation feed.

This paper introduces two novel and robust technologies developed by CiDRA Minerals Processing that address this challenge by providing high reliability and very low maintenance systems for on-line measurement of coarse material in the overflow of individual hydrocyclones. The first system is noninvasive and measures pebbles and rocks greater than 6mm. The second system is a wetted sensor design with no moving parts and provides a real-time trend of the desired target grind size parameter, such as P80 or %+150 um.

Both systems have simple robust designs and measure in the primary overflow stream of the individual hydrocyclone. They do not require sampling and associated sample transfer piping circuits that are prone to plugging, thus avoiding high maintenance requirements.

The second system will be described in detail along with its implementation in a robust control scheme in a major copper concentrator in North America. Plant data will be shown that demonstrate that the very high availability, achieved with very low maintenance, has enabled improved process control, thereby maintaining throughput and ball mill target power while reducing grind size.

Keywords:

Classification, Process Instrumentation, Particle Size, Hydrocyclones, Comminution

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INTRODUCTION

In mineral beneficiation involving grinding, mineral recovery and grade are strongly dependent on the particle size being delivered to downstream beneficiation processes. An optimal or target grind size is established based on the desired plant economics. This paper presents a solution to the challenge of maintaining the optimal particle size in the flotation feed. In general, reducing the amount of coarse material whilst maintaining throughput can significantly improve cash flow. Due to the process and equipment designs, this coarse material challenge typically comes in two forms. The first form involves the unwanted delivery of extremely coarse or oversize particles, such as pebbles and rocks several millimeters or larger in size, to the flotation circuit. This is often caused by specific events, such as broken trommel screens on mill discharges, various hydrocyclone classifier malfunctions, or excessively high hydrocyclone feed density. The second form of coarse material challenge involves the unwanted delivery of coarse particles that are only slightly above the target size for the flotation feed, which would typically be in the 100 um to 200 um range. This is usually caused by poor control of the grinding process or deficiencies in hydrocyclone classification. The first challenge of very coarse material exists to varying degrees in many plants, while the second problem is a generic challenge that exists in most plants.

These two related solutions have been implemented at a large copper concentrator in the USA, hereafter refered to as "the Concentrator," to address these long-standing challenges (Cirulis & Russell, 2011). These solutions have been enabled by novel instrument technologies (Gysling, Loose & van der Spek, 2005). The real-time novel instrumentation involves robust sensors that are mounted on the overflow pipes of individual hydrocyclones thus providing information on the performance of each individual hydrocyclone as well as the entire hydrocyclone battery or cluster (O'Keefe, Maron, & Gajardo, 2007). These systems provide real-time overflow product size information, including the detection of pebbles/rocks in the overflow and the tracking of overflow particle sizes that enables immediate corrective action by operators or various control strategies.

Both solutions have been deployed at the Concentrator, and the second will be described in detail. Included will be the problem statement, system design, control strategy, installation and maintenance, validation data, and real plant data examples. The convention used in this paper for particle size is as follows: "pebbles" are particles 6mm – 12mm and larger in diameter; "rocks" are particles larger than 12mm in diameter.

METHODOLOGY

Problem statement – Grind control enabled by CYCLONEtrac^{SM} PST

Valuable mineral recovery is strongly linked with the particle size distribution of the material delivered to the flotation circuit. Recovery of liberated and middling +150 micron material is significantly lower than that of -150 micron material. This is in part due to decreased mineral liberation and limitations in the ability to recover coarse particles by flotation.

The ability to make value based decisions on the trade-off of throughput and recovery relies on the ability to measure the particle size reporting to the flotation, called the grind size. In order to achieve optimal throughput and recovery, the flotation feed grind size must be controlled and stabilized in real-time. Currently, there are three methods for determining grind size at the

Concentrator with varying levels of accuracy and frequency. These are: lab sieve analysis on rougher flotation head samples, online sampling of the hydrocyclone battery consolidated overflow, and Marcy© Scale procedure.

The sieve screening of samples from the rougher head is considered the most reliable measurement of the particle size distribution that is being presented to the flotation rougher cells. Unfortunately, the sampling and processing time results in a 24-hour delay on results. This delay makes it difficult to use the grind size information for real-time process control and decision making. Further, the rougher head feed is a combination of multiple ball mill hydrocyclone overflows and, therefore, does not represent the performance of any individual ball mill circuit. Thus, the rougher head stream samples cannot be used in a ball mill control strategy for real-time particle size control.

The on-line sampling system and ultrasonic particle size monitors were installed on each hydrocyclone battery in 2004. These systems periodically draw a very small sample from the consolidated overflow of the hydrocyclone overflow. The sample is then conditioned and particle size is measured using an ultrasonic particle size monitor. Since installation, the instruments have proven to be maintenance intensive, and, as a result, utilization has dropped significantly.

The Marcy Scale procedure, based on a procedure outlined by B.A. Wills (1988) "A rapid method for measurement of fineness of grind," is used by the operating crews to get an indication of the grind size at a moment in time. The procedure is relatively quick to perform; however, it is subject to sampling and procedural errors, resulting in inaccurate particle size measurement. Further, the manual nature of the procedure prevents it from being used for automatic process control.

Ideally, in order to achieve optimal grind process control, a real-time accurate measurement of particle size is needed and must be coupled to a robust automatic control system that can maximize the value of the grinding operation in the presence of changing operational conditions and scenarios. This particle size measurement system should provide an indication of the particle size for the hydrocyclone battery as well as for each individual hydrocyclone. The system should not require sampling or have moving parts, and should require low maintenance and be robust.

In the absence of a real-time particle size indicator, pressure as well as density measurement and density control are typically used to control the cut size. Historically, the cyclone feed density control philosophy at the Concentrator was to maximize water addition to achieve the minimum density possible within constraints. The cyclone feed density meters were not needed in this philosophy, so the attention to calibration and maintenance declined. As a result, confidence in the density values also declined. Over time, the highest constraint for the ball mill circuit, and often the complete grinding line, became the cyclone feed pump capacity. The constraint was addressed by upgrading the cyclone feed pump impellors and motors. In parallel to pump upgrades, cyclone feed density meters were brought back to an acceptable accuracy range through calibration and reorientation, and a control strategy was developed to allow control to an operator target setpoint, in turn helping reestablish confidence in the measurements.

Solution for maximizing value through grind control

Real-time grind size optimization requires three critical components. First, key drivers in the process must be accurately measured in real-time. This includes density and particle size with the latter now fully met with the CYCLONEtrac PST system. Second, the process must be stabilized using closed-loop control strategies. Third, the process must be driven to an optimal setpoint. At the Concentrator the ball mill and hydrocyclones are in a closed-loop circuit. The primary drivers of hydrocyclone efficiency are feed density and operating pressure. However, throughput, ore hardness, and recirculating load are key variables for grinding efficiency. To address the second critical component of grind size optimization, a control scheme has been developed that uses the real-time PST measurement to stabilize hydrocyclone overflow +150um (100 mesh). The basis of control relies on manipulating hydrocyclone feed density within other circuit constraints as seen in Figure 1.

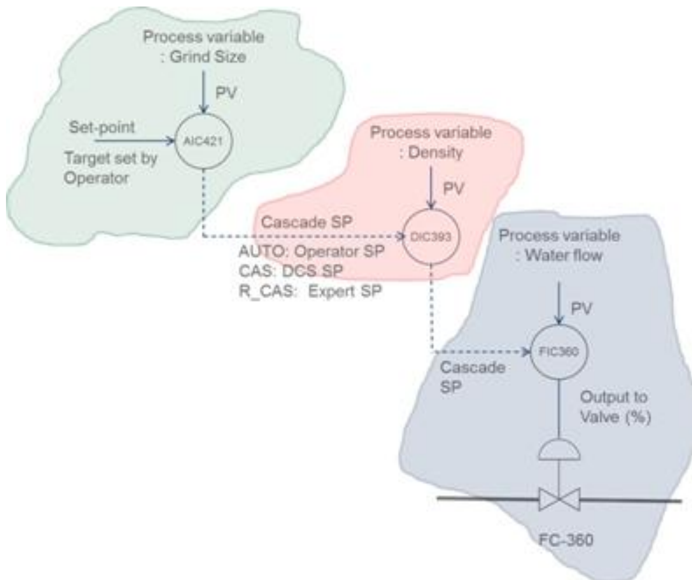

Figure 1 Cascaded control loops used to optimize grind value

Figure 2 shows grind size stability under automatic control. The natural variability of grind size is shown by the CYCLONEtrac PST signal on the left of Figure 2. The grind size is driven to a setpoint by observing the PST signal and manually adjusting the feed density. Without automatic control the grind size fluctuates while the density remains constant. Finally, the right portion of the graph shows the grind size stability under automatic control. The control system automatically adjusts the density setpoint to maintain grind size at setpoint.

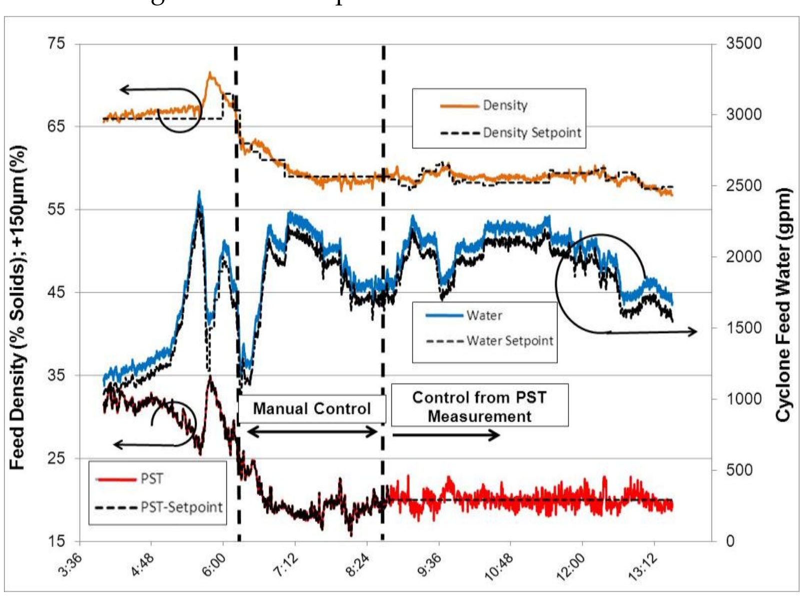

Figure 2 Manipulating density for PST control

The closed-loop grind size control scheme can now be used to maintain a target ball mill power draw and recirculating load to achieve optimum grinding efficiency, thus preventing ball mill overload and hydrocyclone roping conditions. Plant testing has proven that it is possible to maintain throughput and ball mill target power draw while reducing grind size, a tradeoff shown generically in Figure 3. In fact, analysis of several months of data has shown that using PST in closed-loop control it was possible to shift the actual Grind Size vs Throughput line downward as shown in Figure 3, thus enabling value-based trade-offs between grind size (recovery) and throughput.

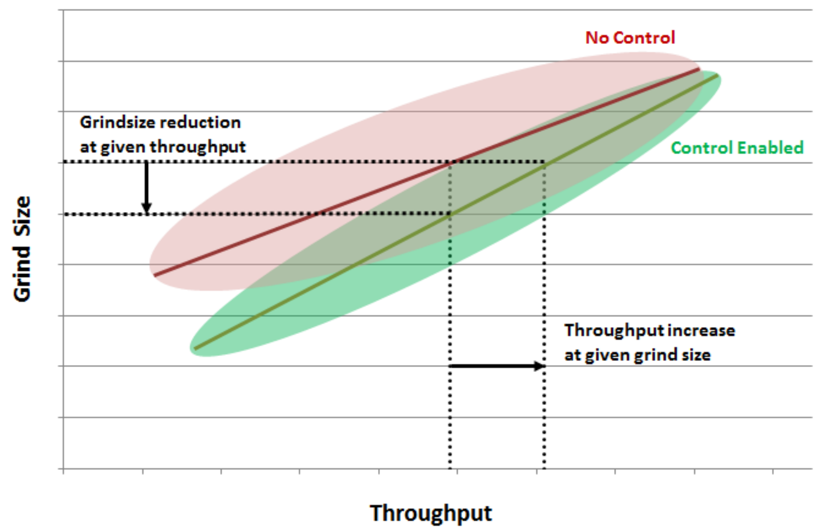

Figure 3 Generic tradeoff bewteen grind size and throughput

Figure 4 shows how the SAG mill tonnage remains constant while the hydrocyclone battery overflow stream percentage +150 micron drops significantly at the same time maintaining the target power draw. The key enabler for the reduction in grind size in this case was the underutilization of the ball mill indicated by an above target power draw. Once the feed density was reduced to increase the recirculating load, both ball mill power and cyclone overflow particle size fell.

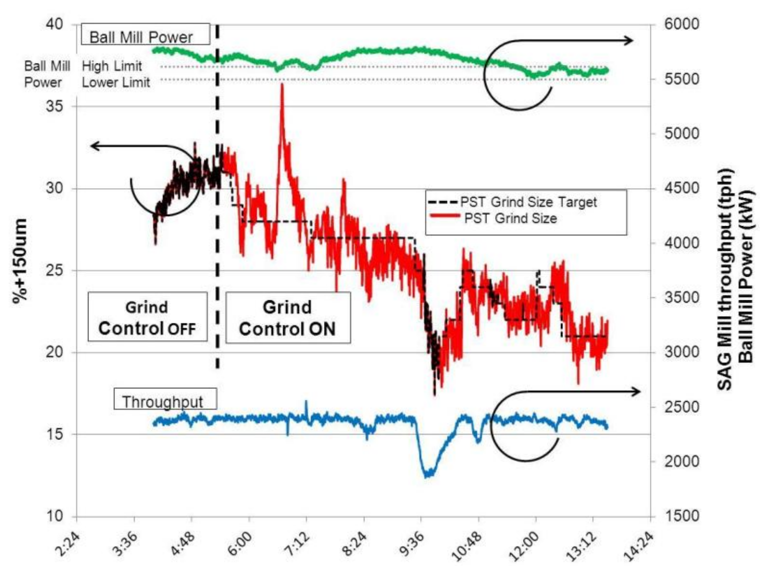

Figure 4 Reduction of grind size with constant TPH and target ball mill power

In order to maintain target particle size and power draw, the cyclone feed density and the particle size target are manipulated. Figure 5 below shows both the particle size and cyclone feed density changes to maintain ball mill efficiency.

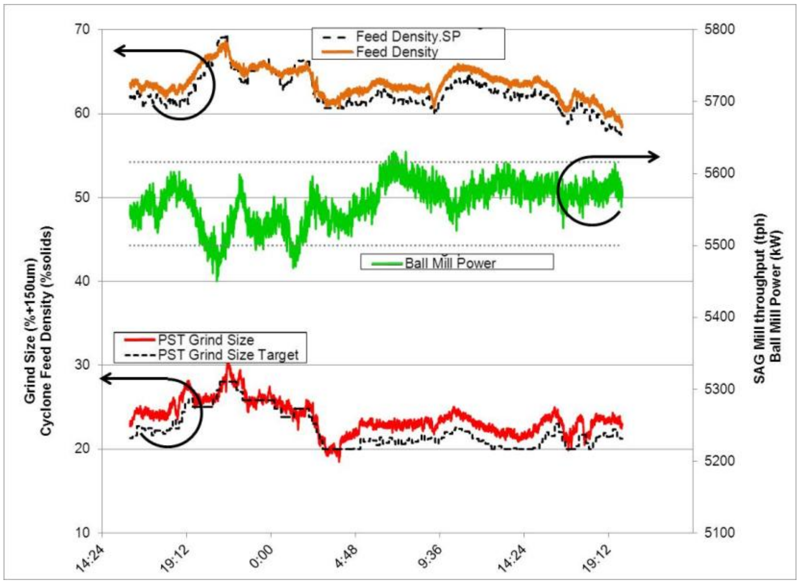

Figure 5 Example of particle size tracking leading to density setpoint changes and then to ball mill power draw

Sensor system – Grind control enabled by CYCLONEtrac^{SM} PST

Sensor System Description

The CYCLONEtrac PST system at the Concentrator consists of 88 sensor probe assemblies seen in Figure 6 (one for each hydrocyclone), eight junction boxes (one for each battery), and a control room computer as demonstrated in Figure 7. The sensor probe assembly is made up of a hardened proprietary probe that penetrates into the overflow pipe and is in contact with the overflow stream, and an integrated electronics package that is protected by a sealed metal enclosure. The probe itself is coated with an extremely hard layer for wear resistance. As the slurry stream hits the probe, it effectively “listens” to the impacts of individual particles. The impact response is processed by the on-board electronics in order to derive the particle size distribution in the slurry stream. The sensor probe assembly is powered by 24V and communicates to a junction box using MODbus protocol.

Figure 6 Left, CYCLONEtrac PST sensor. Right, CYCLONEtrac PST sensor installed on pipe

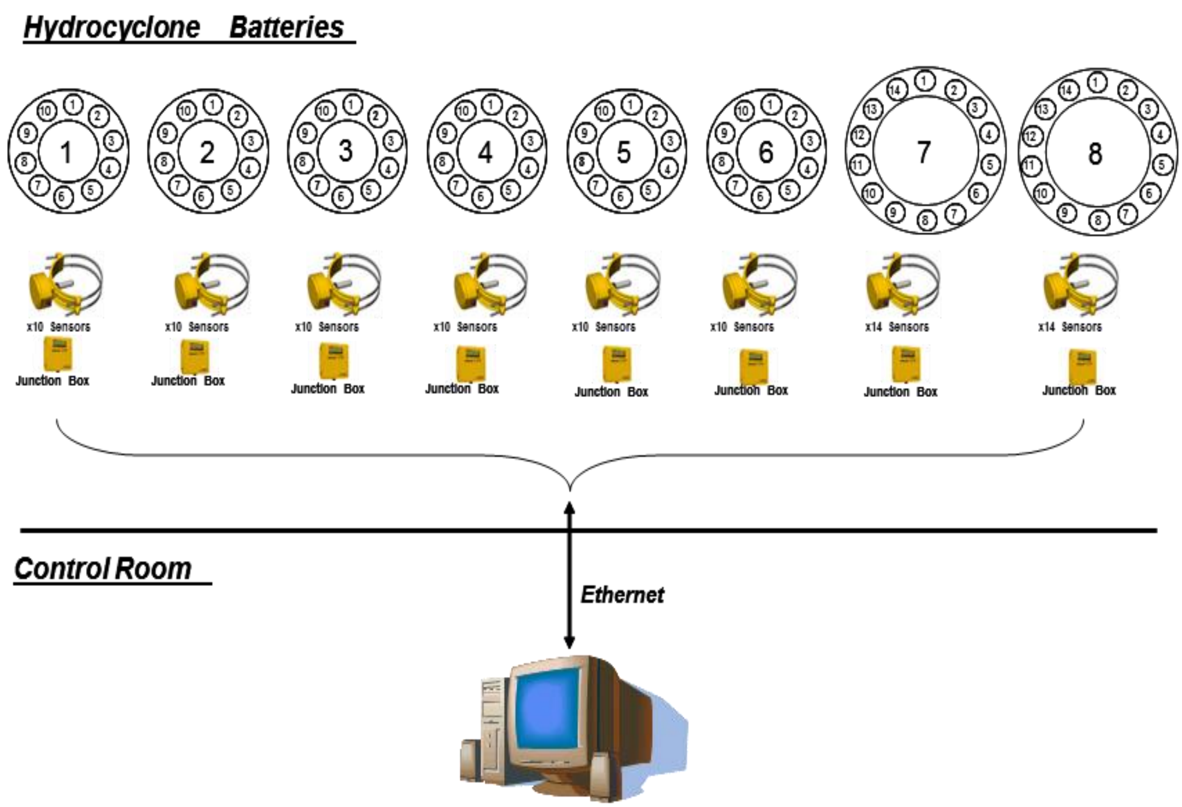

Figure 7 Schematic of CYCLONEtrac PST system installed at the Concentrator

Each junction box can interface with up to 16 sensor probe assemblies, providing both DC power and communications. The junction box takes MODbus communications from each sensor probe assembly and translates that into information over an industrial Ethernet network to a computer in the control room. The control room computer collects the measurements from each device and then passes the measurement to the Concentrator's Distributed Control System (DCS) via an OPC tunnel.

Sensor system validation

After the CYCLONEtrac PST system was installed at the Concentrator, a sampling campaign was undertaken to validate the performance of the system. CiDRA and the Concentrator personnel worked closely to bump the hydrocyclone and grind circuit operating conditions over a range of grind sizes. During the validation campaign more than 130 samples were collected from individual hydrocyclone overflow streams. Sieve analysis was performed on the samples and the results compared to the output of the PST system. The particular particle size distribution feature of interest at the Concentrator is the percent of material over 150 micron (100 mesh). As stated earlier valuable mineral recovery drops significantly for grind size that is greater than 150 micron. As such, the PST system was tailored to provide a direct real-time indication of the percent by weight of the stream that is +150 micron.

Figure 8 shows the real-time signal from the CYCLONEtrac PST system with the validation sieve samples overlaid. During the validation campaign the sampling variability was determined to be ±3.1% absolute. This variability is indicated on Figure 8 by the error bars. Figure 9 shows all 130 validation samples comparing the sieve analysis percent +150 micron to the PST readings. The validation campaign has demonstrated that the PST system is capable of predicting the percent +150 micron with ±6.3% absolute uncertainty. With consideration for sampling variability and sieve analysis precision, the results of the validation campaign give CiDRA and the Concentrator confidence that the PST system will provide a real-time grind size measurement that can be used for value-based decision making and process control.

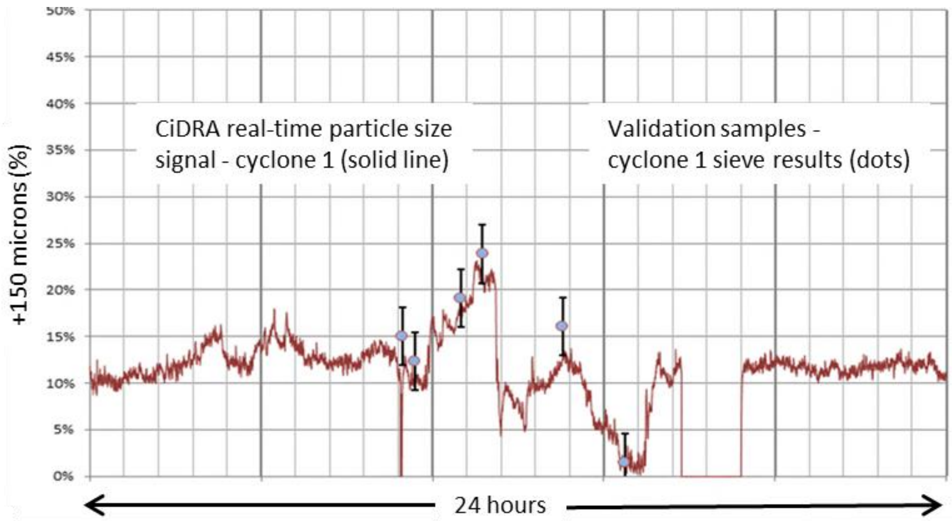

Figure 8 Hydrocyclone 1 CiDRA CYCLONEtrac PST signal vs. validation sieve samples

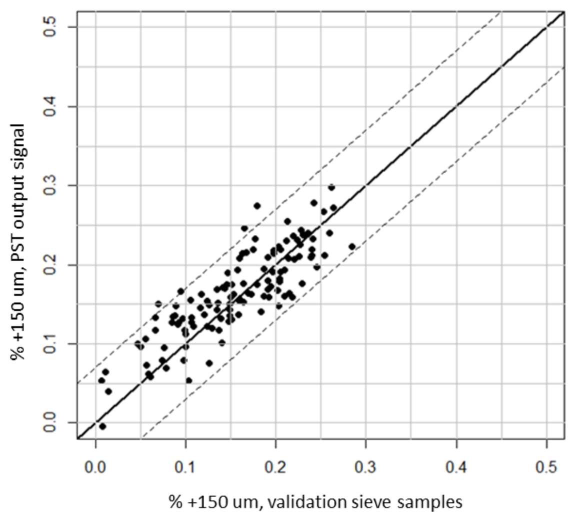

Figure 9 Percent Mass Fraction +150 micron, CYCLONEtrac PST output vs. validation sieve samples

System Installation and Maintenance

The CYCLONEtrac PST system was installed easily with no need to shut down a battery, which could result in lost production. Individual overflow pipes were removed one-at-a-time for the drilling of the 2-inch diameter hole. The rubber lining did not create problems for drilling, and no damage to the liner was detected. The entire drilling procedure, including drill-fixture setup but not including pipe removal time, was about 45 minutes. Following drilling, a plug saddle assembly was installed, and the pipe was reinstalled on the cyclone.

Once on the overflow pipe is remounted to the cyclone, the plug saddle assembly is removed and replaced by the saddle containing the probe assembly, which takes approximately 15 minutes and requires removal and tightening of only four bolts. The entire saddle probe assembly is IP 67 rated and, therefore, is extremely rugged, being totally protected against dust ingress and protected against water ingress from high pressure jets or short periods of immersion.

Probe life demonstrated in the Concentror has been one year due to the wear resistant coating, thus exceeding original expectations.

In general, the Concentrator Maintenance Team has judged the PST system to be far superior in ease of maintenance and reliability to the older on-line particle size sampling and measuring system that had dropped to a low utilization level because of the intense maintenance required. In fact, we have seen that in many plants these systems have stopped being used at all because of the high cost and difficulty associated with maintenance.

CONCLUSION

A long-standing problem in concentrator operation is robustness of instrumentation, particularly instruments related to real-time detection and measurement of coarse particles in the grind circuit product arriving to flotation. One class of widely used existing instrumention requires sampling systems that are prone to blockages and resulting maintenance, and measuring instruments whose robustness is often less than acceptable and requires a high level of maintenance. This combination has meant that these systems are rarely used in real-time closed-loop control of the grinding and classification circuit. The two systems described in this paper provide very robust, low maintenance solutions that not only reduce maintenance costs compared to existing instrumentation, but by virtue of its very high availability now enable an improved level of real-time closed-loop control that can deliver significant value.

We have shown that the Concentrator has implemented solutions to two long-standing challenges related to coarse material in hydrocyclone overflow streams. Both solutions are complete, turn-key systems based on novel instrumentation technologies that have been developed and validated in a partnership between the Concentrator and CiDRA over several years. The first solution enabled by the CYCLONEtrac OSM provides real-time information that has been used to develop operating practices that have eliminated maintenance due to unplanned shutdowns of the flotation circuit due to flotation cell blockage. The second solution enabled by the CYCLONEtrac PST system has been used to develop first generation closed-loop control logic for controlling % +150 micron flotation feed to a finer grind size while maintaining target grind line throughput. This has been used to optimize ball mill grind efficiency, balance plant-wide milling, and to make value based decisions between throughput and mineral recovery. Plant data have been presented showing operational examples that demonstrate how the very high availability of the PST system since its commissioning, achieved with very low maintenance, has delivered significant value.

The grind control system developed by the Concentrator using CiDRA's CYCLONEtrac PST system is proving to be very effective in enabling grind circuit control at the Concentrator and has led to value based control strategies incorporating throughput, particle size, and recovery trade-offs. Improvements in the grind circuit efficiency from the new grind control system have led to reduction in grind size of around 30% at the same throughput, or when upstream is not constraining the ball mill circuit, a throughput increase of up to 10% at the same grind size have been achieved. The Concentrator management are predicting a four percent reduction in copper losses resulting from the use of this system. This has been achieved with an instrument availability of close to 100%. The lesson learned from this work is that there now is a viable low maintenance alternative to existing technologies that addresses the long-standing problem of measurement and control of the grind circuit product arriving to flotation. Additionally, when compared with existing particle size analyzers and their associated sampling systems, both of which are often expensive to maintain, the PST system can provide lower Total Cost of Ownership and superior value, even when the cost of periodic probe replacement due to abrasive wear is included.

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