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ABSTRACT 260

Process optimization at Rio Tinto Kennecott using real-time measurement of coarse material in individual hydrocyclone overflow streams

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ABSTRACT

The presence of unwanted coarse material in flotation feed streams negatively impacts both recovery and throughput of concentrator plants. The detection of this coarse material is a long-standing problem in mineral processing that has been poorly addressed by existing instrumentation systems.

This problem has been overcome by the development of two new systems that detect in real-time the presence of coarse material in the overflow stream of individual hydrocyclones. They both use sensors mounted to the overflow pipe of the hydrocyclone and provide a robust and maintenance-free system measurement that enables corrective actions through operator intervention or automatic control strategies.

One system is non-invasive and detects very coarse material 6mm or greater in size. The other system uses a wetted sensor and detects coarse material down to a lower size limit of approximately 100 um. Both systems have been commercially deployed. The systems will be described in detail. Validation data and typical plant data will be shown.

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INTRODUCTION

In mineral beneficiation involving comminution and subsequent flotation, mineral recovery is strongly dependent on the proper particle size being delivered to flotation. The optimum particle size must be neither too fine nor too coarse. This paper presents a solution to the challenge of maintaining the optimal particle size in flotation feed. In general, reducing the amount of coarse material can significantly improve recovery and throughput of a plant. Due to the process and equipment designs, this coarse material challenge typically comes in two forms. The first form involves the unwanted delivery of very coarse particles, 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 problem that exists in most plants.

Two related solutions based on novel instrumentation technologies are presented that have been developed to address these long-standing challenges. They involve robust sensors that are mounted on the overflow pipes of individual hydrocyclones to detect the presence of coarse material in real-time. These systems provide real-time overflow product size information that enables immediate corrective action by operators or various control room strategies.

Both solutions have been commercially deployed and will be described in detail, including the specific problem each addresses, system designs, 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; “sand” is particles 100um – 200um and larger in diameter.

OVERSIZE MONITORING SYSTEM (OSM)

Problem Statement – OSM

Many operators place a premium emphasis on asset management, which becomes necessary when increasing operating efficiency. However, the need to extract maximum value from the grind plant means that maintenance intervals will be stretched as long as possible. Additionally, maximizing the return on equipment investment requires operating the plant at the highest throughput possible without compromising safety, excessive equipment wear or reduced recovery. This presents a wide variety of operating conditions as one asset approaches the need for maintenance while others are new or recently refurbished. Hydrocyclones are one such asset that will report extremely coarse material, such as pebbles, to the overflow when not operating as designed. Pebbles reporting to the overflow are usually passed directly to the flotation system. Pebbles in the flotation feed reduce the economic performance of the concentrator by reducing valuable mineral recovery, reducing volumetric efficiency in the flotation cell, and in some cases by blocking the flow path in the flotation cells leading to partial or complete plant shutdown. It has also been noted that pebbles will damage equipment downstream of the grind circuit or cause blockages in pipelines and thickeners.

Detection of pebbles in the consolidated overflow from a hydrocyclone battery via acoustic sensors or traditional particle size monitors suffers from reduced sensitivity, slow update rates, and an inability to discern which hydrocyclone is passing the pebbles. Determining the exact source of the oversize material can be complicated and time consuming for a busy operations crew and usually has to be manually performed. While troubleshooting, the oversize material continues to report to the flotation circuit, resulting in considerable disruption to the flotation circuit until the offending hydrocyclone is taken offline.

With support from Rio Tinto, CiDRA has developed and commercially deployed a new technology for monitoring individual hydrocyclone overflow lines for pebbles and the associated increase in P80. This technology detects pebbles (6-12mm range and larger) passing through the hydrocyclone overflow. By monitoring the overflow as opposed to the underflow, these pebbles are detected irrespective of the cause, whether it is due to a plugged apex, a roping condition, certain operating conditions, damage to the hydrocyclone, or wear in the hydrocyclone. This technology enables the operators to greatly reduce the length of time in which pebbles pass through the overflow (pebble events). It allows the plant personnel to identify hydrocyclone damage or excessive wear and to ascertain whether or not a grind circuit is the cause of the pebble event.

System Design – OSM

One of CiDRA's core competencies is the measurement of acoustic information through the wall of a pipe (Gysling, Loose & van der Spek, 2005, and O'Keefe, Maron & Gajardo, 2007). CiDRA has used its expertise to develop the CYCLONEtrac OSM system. It has been observed that pebbles have a significant probability of striking the inside of a hydrocyclone overflow pipe as they pass through such a pipe. Even in the presence of rubber liners, sufficient mechanical energy in the form of acoustic waves is transferred from the striking particle through the liner and into the wall of the pipe. The OSM system uses CiDRA's proprietary distributed acoustic sensor mounted on the outside of the pipe, which is tightly mechanically coupled to the pipe without couplant. The particle-induced acoustic wave travels through the pipe wall and is converted by CiDRA's proprietary sensor to an electrical signal. A unique algorithm extracts this very low level signal from the background noise to identify a pebble event. The system reports the rate of these pebble events and sounds an alarm when rate thresholds are exceeded. By using a distributed acoustic sensor as opposed to a point sensor, the probability of detecting a pebble passing through and striking the inside of the overflow pipe is greatly increased.

Installation and Maintenance – OSM

The installation process consists of 1) cleaning and possibly sanding of the pipe to remove material buildup, paint splatters, and other high points; 2) wrapping the sensor band around the pipe and cinching it tight using its captive screws; 3) covering the sensor band with a water tight cover and attaching the sensor band cable to the preamplifier built into the sensor cover; 4) mounting transmitters and power/communication junction boxes; 5) connecting power/communication lines between the sensor heads and the transmitters and between the transmitters and the power/communication junction boxes; 6) supplying power to the junction boxes; and 7) connecting an Ethernet line between the junction boxes and the CYCLONEtrac computer, which would typically be placed in the control room. Pictures of the installed system are given in Figure 1. The installation process is non-intrusive and allows for the hydrocyclone battery to remain operational during installation.

Figure 1 Installed CYCLONEtrac OSM System at Kennecott with transmitter and junction box (upper left picture), sensor head (upper right picture), and a completely instrumented hydrocyclone battery (bottom picture)

Due to the non-intrusive nature of the instrument, no regularly scheduled maintenance is required nor are there any inherent wear mechanisms present in the instrument. The sensor head is reusable and may be reinstalled when an overflow is replaced. No calibration or zeroing is required when reinstalled.

Data Validation – OSM

The CYCLONEtrac OSM system has been commercially deployed at Rio Tinto Kennecott's concentrator in Utah, USA since 2010 (Cirulis & Russell, 2011). The system has been fully validated and adopted by the plant. Three years of plant operation were used to validate the performance over both normal and abnormal operating conditions, including many pebble and sand events. During this time trends for individual hydrocyclones and the consolidated trend of each battery of hydrocyclones were used to adjust thresholds and alarms, thus balancing sensitivity against false alarms. Proper setting of thresholds has allowed the operators to effectively control the separation process via manual intervention. While the system displays the trend of various sizes of coarse material, the minimum material size for repeatable detection of individual particles is approximately 6 to 12 mm (Fig. 2).

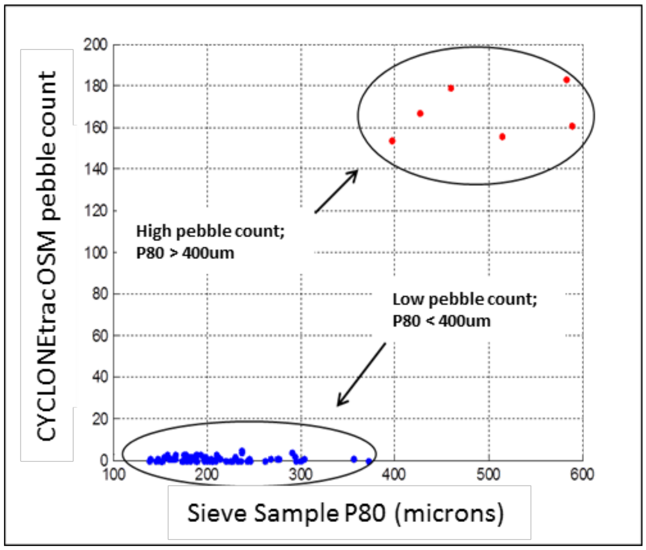

Figure 2 During field validation, 78 sieve samples were analyzed and compared to OSM pebble counts. The shift in the P80 due to the increased mass flow of extremely coarse particles corresponds to pebble events. In this figure the red circles are periods in which pebble events were occurring, and the blue circles are periods in which the system indicated no pebble events were occurring.

Control Scheme – OSM

With the CYCLONEtrac OSM system now fully deployed and integrated into concentrator operations, operators receive actionable information. This information provides the operator with the ability to determine if there is an issue with the performance of an entire battery or with an individual hydrocyclone. An HMI (human-machine interface) in the control room displays trends on the aggregated performance of each hydrocyclone battery.

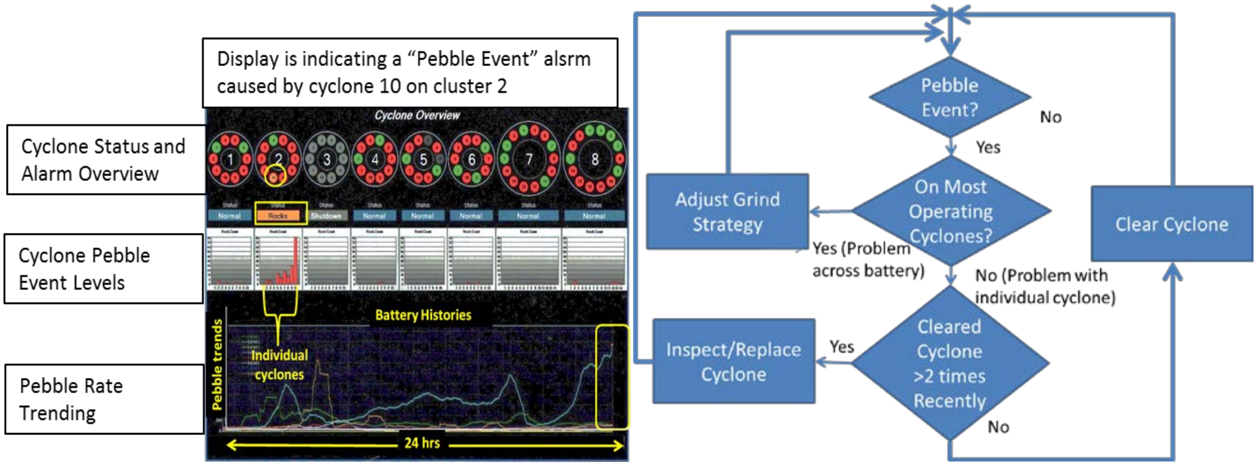

Figure 3 Left, display is indicating a "Pebble Event." Right, sample flow sheet.

The operator discriminates between the two types of events by consulting the event level trends for the individual hydrocyclones in that battery. If a single hydrocyclone is indicated as the cause (Fig. 4), then the offending hydrocyclone may be isolated, and an alternate is placed in operation. In other cases multiple hydrocyclones are responsible for the rapidly increasing large particle event trend of a hydrocyclone battery. In this case the operator can adjust operating parameters (e.g. hydrocyclone feed density) to return the system to steady state (Fig. 5).

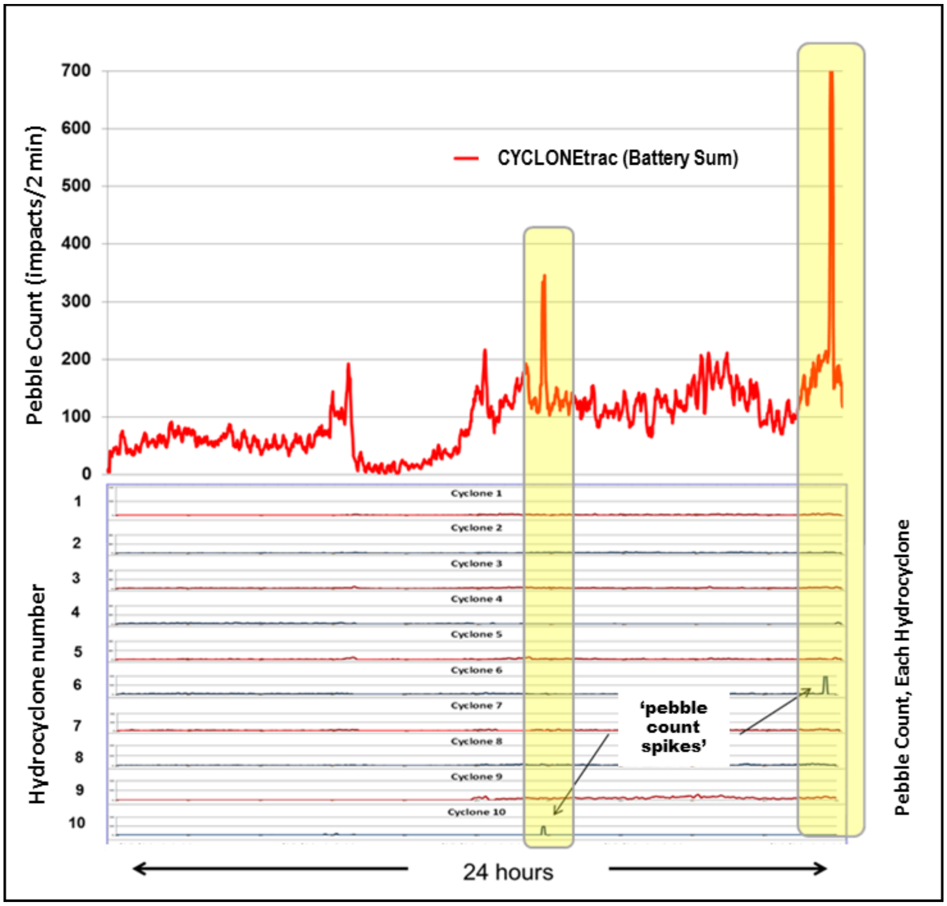

Figure 4 Single hydrocyclone causes combined overflow of the battery to display a spike in the coarse material trend.

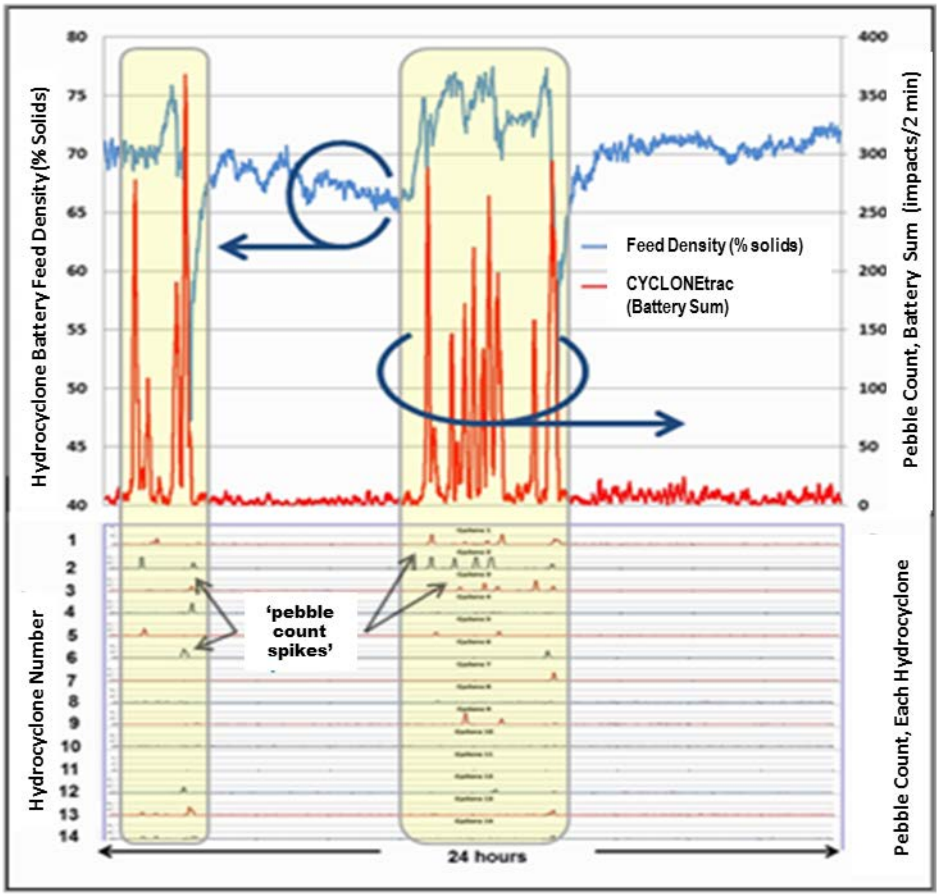

Figure 5 Multiple hydrocyclones cause the combined overflow of the battery to display spikes in the coarse material trend, which is coincident with increases in feed density to the battery.

Conclusion – OSM

Over several years of commercial operation at Kennecott the OSM system has proven to be valuable in detecting excessive amounts of pebbles in the hydrocyclone overflow stream, enabling immediate corrective action, thereby helping to prevent any serious blockages in the rougher flotation or tailings circuits.

PARTICLE SIZE TRACKING SYSTEM (PST)

Problem Statement – 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 +150um material is significantly lower than that of -150um 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 around throughput and recovery relies on the ability to measure 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 Kennecott with varying levels of accuracy and frequency. These are: lab sieve analysis on rougher head samples, on-line sampling of the hydrocyclone battery consolidated overflow, and Marcy© Scale procedure.

The sieve screening on samples of the rougher head feed is considered the most reliable measurement of the particle size distribution that is being presented to the flotation rougher cells. At Kennecott 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. Additionally, the sampling and processing time results in a 24-hour delay of results. This delay makes it difficult to use the grind size information for real-time process control and decision making.

The on-line sampling systems and ultrasonic particle size monitors were installed at Kennecott on each hydrocyclone battery in 2004. These systems periodically draw a 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 Wills (1988), is used by the Kennecott 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.

In order to achieve optimal grind process control, a real-time accurate measurement of particle size is needed. At Kennecott a CIDRA CYCLONEtrac Particle Size Tracking (PST) system has been installed to serve this purpose. The CYCLONEtrac PST system offers the advantage of real-time particle size tracking on individual hydrocyclone overflows. Multiple particle size measurements are statistically processed to form a robust indication of the particle size generated by the ball mill circuit. The system does not require a stream sampling system and is low maintenance.

System Design – PST

The CYCLONEtrac PST system consists of sensor assemblies, junction box, and a control room computer. The sensor assembly is made up of a ruggedized probe that 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 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

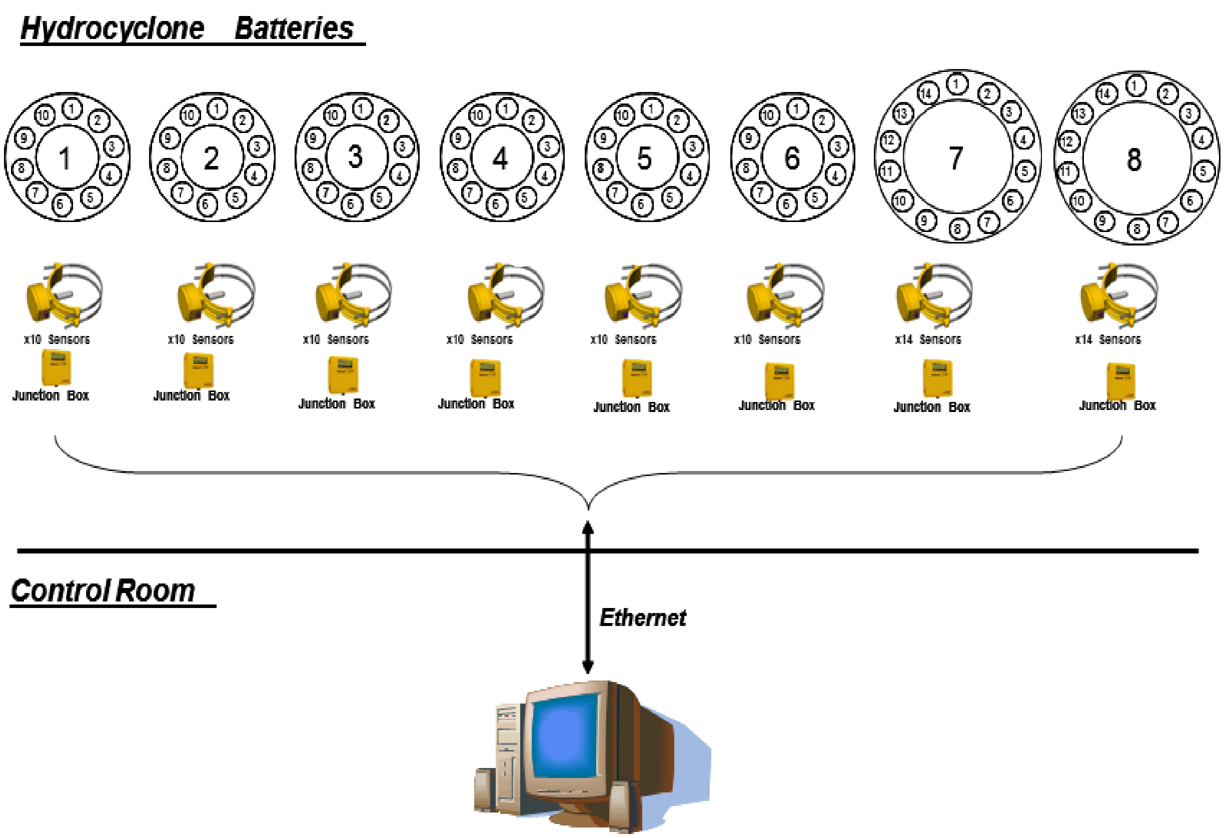

Figure 7 Schematic of CYCLONEtrac PST system installed at Kennecott

Each junction box can interface with up to 16 sensor assemblies, providing both DC power and communications. The junction box takes MODbus communications from each sensor 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 Kennecott Distributed Control System (DCS) via an OPC tunnel.

Existing overflow pipes are modified using a portable magnetic drill. The PST probe is then inserted through the hole and secured in place with a simple pipe tap style saddle. If a PST unit is not available a plug saddle unit is available so the overflow pipe can be returned to service with limited impact to hydrocyclone availability. Typically, a hydrocyclone battery has a number of available hydrocyclones that are not in use. This allows installation of the PST devices without grind circuit downtime.

Installation of a PST unit on an already drilled overflow pipe can take as little as 10 minutes. Once a PST is installed, there is virtually no impact on overflow operation. There are two reasons for this. First, the probe occupies a very small surface area compared to the cross sectional area of the pipe. Second, the cylindrical shape of the probe creates minimal flow disturbance.

System Validation – PST

After the PST system was installed at Kennecott, a sampling campaign was undertaken to validate the performance of the system. CiDRA and Kennecott 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 Kennecott is the percent of material over 150um (100 mesh.) As stated earlier, valuable mineral recovery drops significantly for grind size that is greater than 150um. As such, the PST system was tailored to provide a direct real-time indication of the percent by weight of the stream that is +150um.

Figure 8 shows the real-time signal from the 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 +150um to the PST readings. The validation campaign has demonstrated that the PST system is capable of predicting the percent +150um with ±6.3% absolute uncertainty. With consideration for sampling variability and sieve analysis precision, the results of the validation campaign give CiDRA and Kennecott 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.

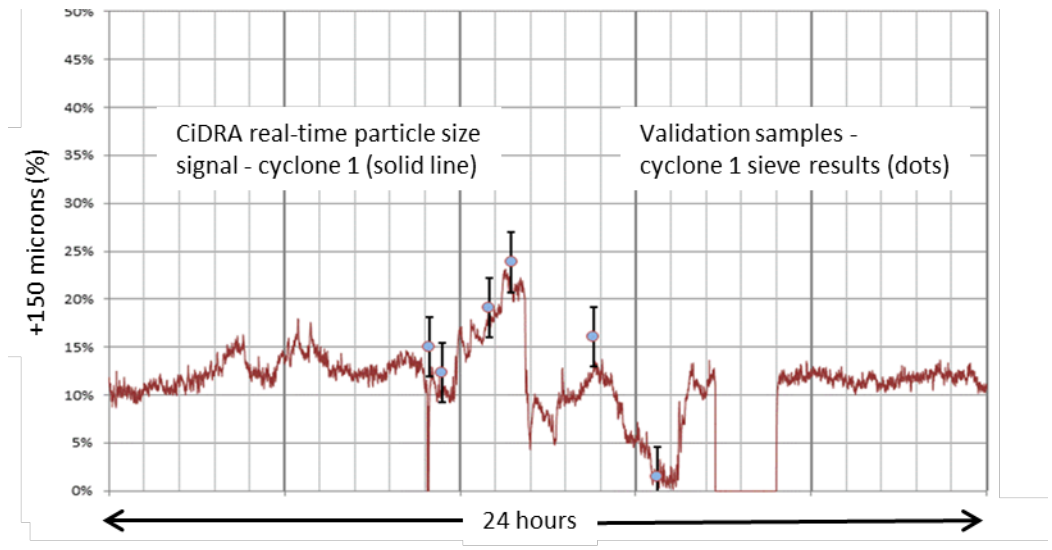

Figure 8 Hydrocyclone 1 CiDRA signal vs. validation sieve samples

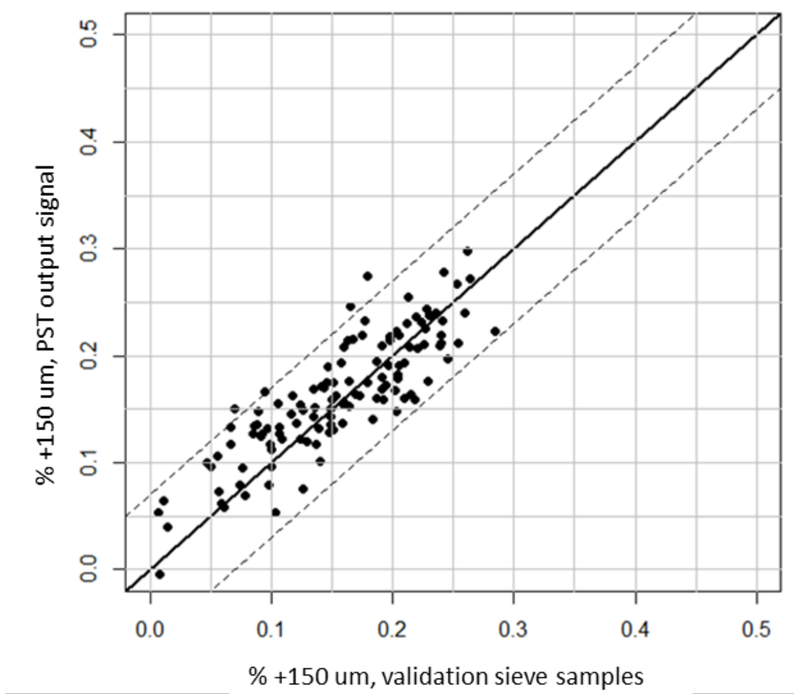

Figure 9 Percent Mass Fraction +150um, PST output vs. validation sieve samples

Control Scheme - PST

Real-time grind size optimization requires three critical components. First, key drivers in the process must be measurable in real-time. This criterion is 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 Kennecott 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. Figure 10 shows grind size stability under automatic control. The natural variability of grind size is shown by the PST signal on the left of Figure 10. 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.

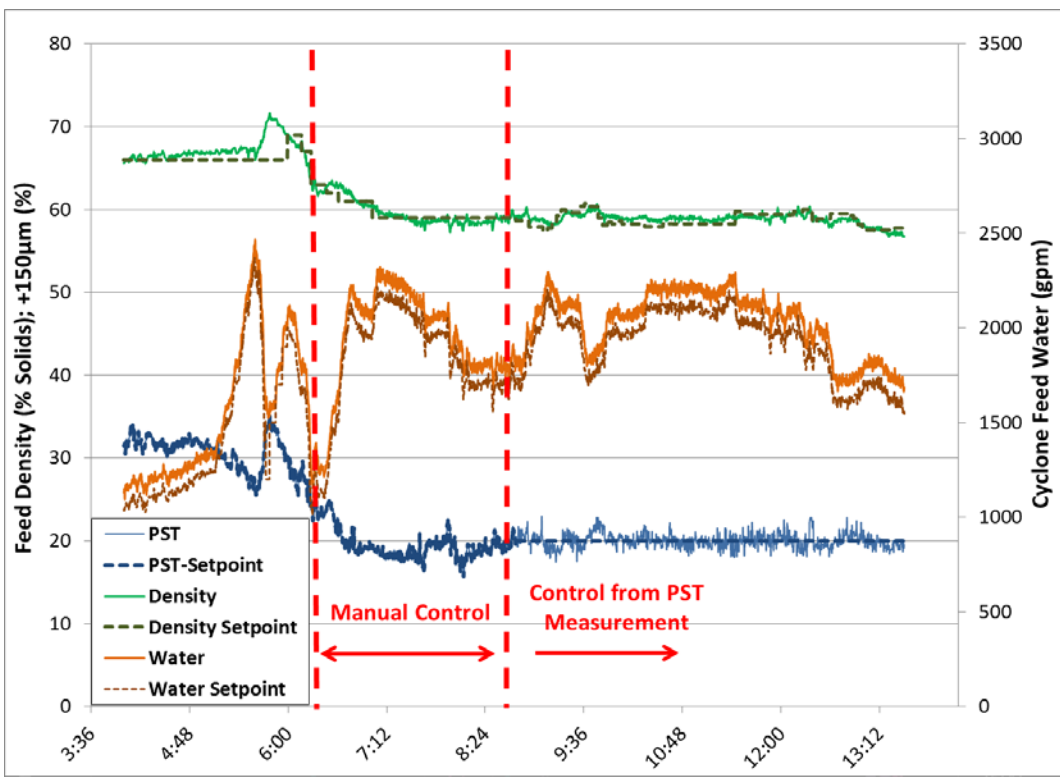

Figure 10 Manipulating density for PST control

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. Testing has proven that it is possible to maintain throughput and ball

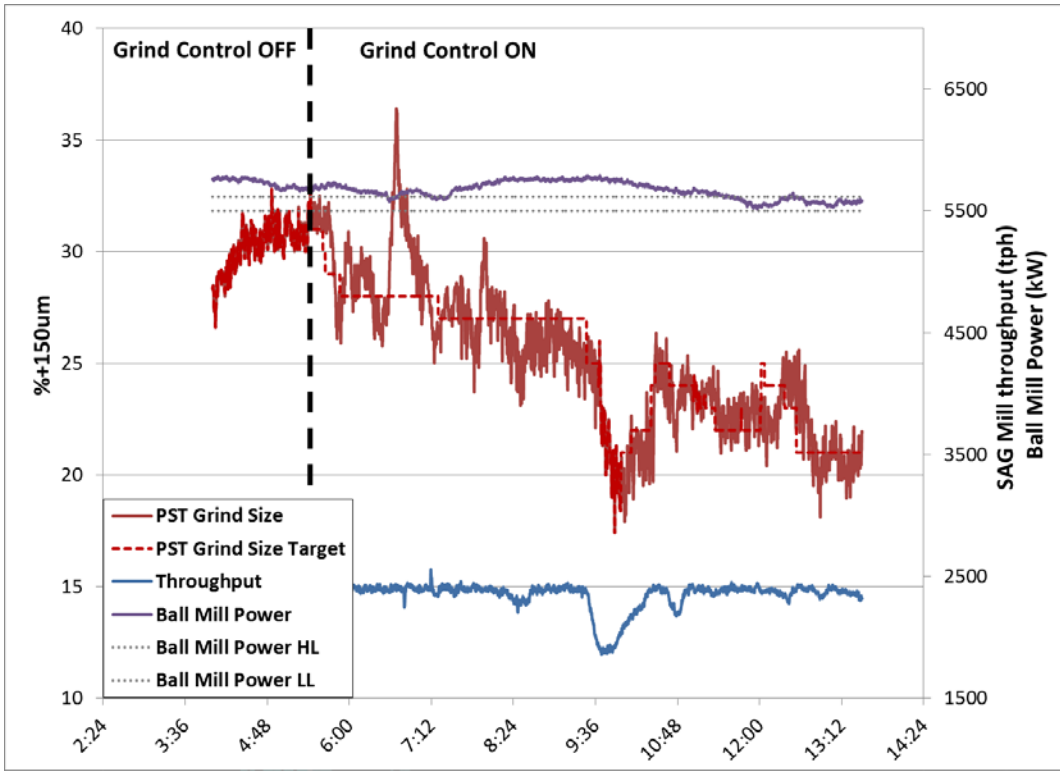

Figure 11 Reduction of grind size with constant TPH and target ball mill power

mill target power draw while reducing grind size. Figure 11 shows how the SAG mill tonnage remains constant while the hydrocyclone battery overflow stream percentage +150um drops significantly at the same time maintaining the target power draw.

Conclusion – PST

While this first generation control scheme is relatively simple, the PST system is proving to be very effective in enabling grind circuit control at Kennecott and will ultimately assist value based decision making with respect to throughput, particle size, and recovery trade-offs.

CONCLUSION – GENERAL

Two novel systems have been presented that provide solutions to the long-standing challenge of coarse material in hydrocyclone overflow streams. Both solutions, OSM and PST, are complete, turn-key systems based on novel instrumentation technologies that have been developed and validated in partnership with Kennecott at the Copperton concentrator over several years. The real-time information provided by the OSM system has been used to develop operating practices that have eliminated flotation circuit shutdowns due to flotation cell blockage. Likewise, the real-time information provided by the PST system has been used to develop first generation closed loop control logic for controlling % +150um flotation feed to a finer grind size while maintaining target grind line throughput. Further control system development is underway to optimize ball mill grind efficiently, 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 systems are used to deliver value.

ACKNOWLEDGEMENTS

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