Grind Circuit Optimization at Rio Tinto Kennecott using real-time measurement of individual hydrocyclone overflow stream particle size enabled by novel CYCLONEtrac^{SM} technology

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ABSTRACT

A typical mineral comminution circuit includes a ball mill running in closed-loop with a hydrocyclone battery. The job of the grind circuit is to reduce the size of the ore such that the downstream separation process can achieve the desired mineral recovery and quality while maintaining plant throughput and cost efficiency targets. Under grinding the ore will produce a coarse P80 stream and reduce the plant recovery and in extreme cases may in fact plug the downstream recovery process. Over grinding the ore will produce a fine P80 which will reduce recovery, plant throughput and adversely impact cost efficiency. The challenge is to control the ball mill and hydrocyclone battery circuit so as to maximize value by balancing plant recovery, throughput, and cost efficiency in the face of changing ore conditions and equipment health.

Rio Tinto Kennecott has been successful in significantly improving grind circuit performance by implementing real-time closed-loop grind control to enable direct control of the grind circuit P80 as well as real-time monitoring of individual hydrocyclones. Dedicated cross-functional work teams designed and implemented standard operating and control strategies that utilize existing density, flow and expert control technology along with the newly developed CiDRA CYCLONEtrac OSM and CYCLONEtrac PST systems. Real plant data will be presented as well as a description of the enabling technology.

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1. 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.

Rio Tinto Kennecott has implemented two related solutions to address these long-standing challenges. These solutions have been enabled by novel instrument technologies. 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. 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 Rio Tinto Kennecott and will be described in detail. Included will be the problem statements, system designs, 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.

2. CONTROL OF PEBBLES/ROCKS REPORTING TO FLOTATION

2.1 Problem Statement – Pebbles/Rocks

Hydrocyclones are high throughput and relatively simple devices with a high capacity to size ratio for classifying particles. They are commonly used in a closed circuit with grinding mills, typically ball mills, to control the material size sent for downstream enrichment. The need to extract maximum value from the hydrocyclones means that maintenance intervals will be stretched as long as possible, including using a maintenance interval philosophy based on replacement or refurbishment only upon failure. 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 hydrocyclone approaches the need for maintenance while others are new or recently refurbished. Due to both changes in the plant operating conditions and to wear or damage, the hydrocyclones may not operate as designed, resulting in pebbles and rocks reporting to the overflow. Pebbles and rocks reporting to the overflow are usually passed directly to the flotation system. Pebbles and rocks 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 and rocks will damage equipment downstream of the grind circuit or cause blockages in pipelines and thickeners.

Detection of pebbles and rocks 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 or rocks. Determining the exact source of these pebbles and rocks can be complicated and time consuming for a busy operations crew and usually has to be manually performed. While troubleshooting, the pebbles and rocks continue to report to the flotation circuit, resulting in considerable disruption to the flotation circuit until the offending hydrocyclone is taken offline. Screens are sometimes used on hydrocyclone overflow streams to prevent the pebbles and rocks from continuing downstream. This scenario does not provide a means to detect the pebbles and rocks, or a means to discern their source. The use of screens for this purpose is not necessarily a viable option due to the increased capital costs, operating costs, and space requirements.

2.2 Rio Tinto Kennecott Solution for Control of Pebbles/Rocks Reporting to Flotation

With support from Rio Tinto, CiDRA developed and deployed a new technology (CYCLONEtrac OSM) for monitoring individual hydrocyclone overflow lines for pebbles/rocks and the associated increase in P80. This technology detects pebbles and rocks (6-12mm range and larger) passing through the hydrocyclone overflow. By monitoring the overflow as opposed to the underflow, these pebbles and rocks 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.

The information from these sensors is sent to the control room where the operators constantly monitor the overflow status of each hydrocyclone through a dedicated display seen in Figure 1 that provides the following information:

1. Individual hydrocyclone status
2. Alarm status on a battery
3. Current pebble/rock rate for each hydrocyclone
4. Historical trending of pebble/rock rate for each hydrocyclone

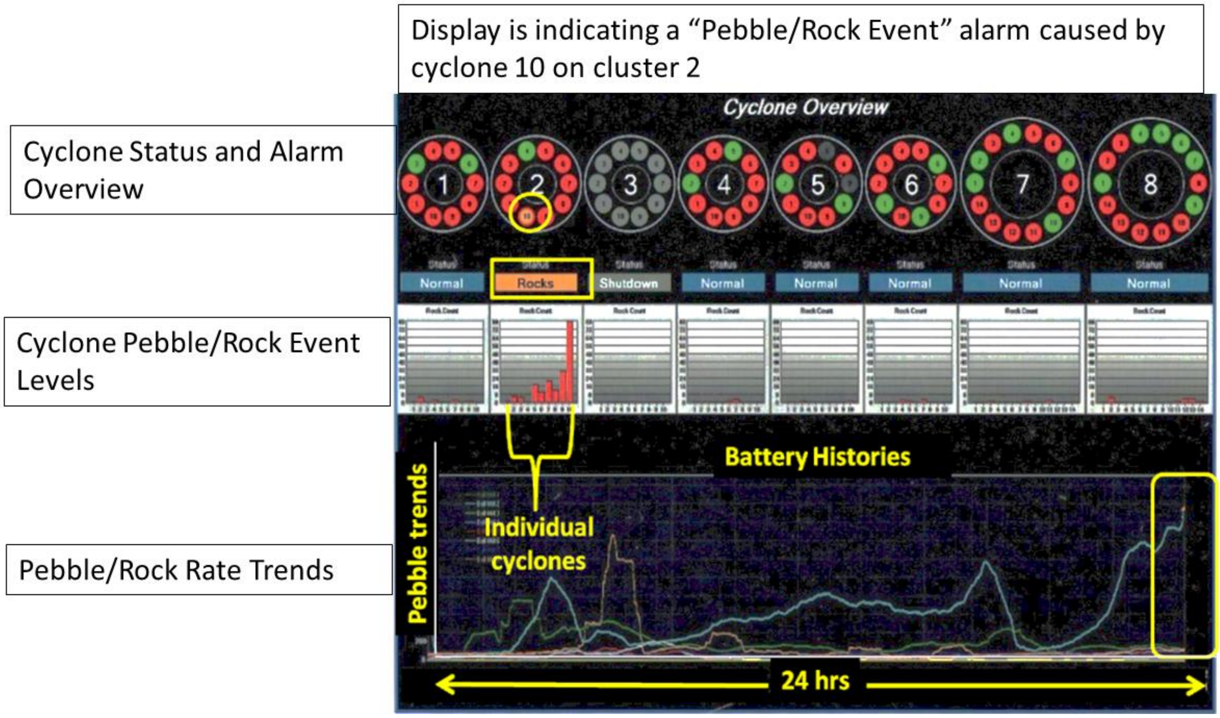

Figure 1 CYCLONEtrac OSM display with battery and individual hydrocyclone pebble/rock status

The operators use this information to determine if there is an issue with the performance of an entire battery or with an individual hydrocyclone. 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 (Figure 2), 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 pebble/rock 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 (Figure 3).

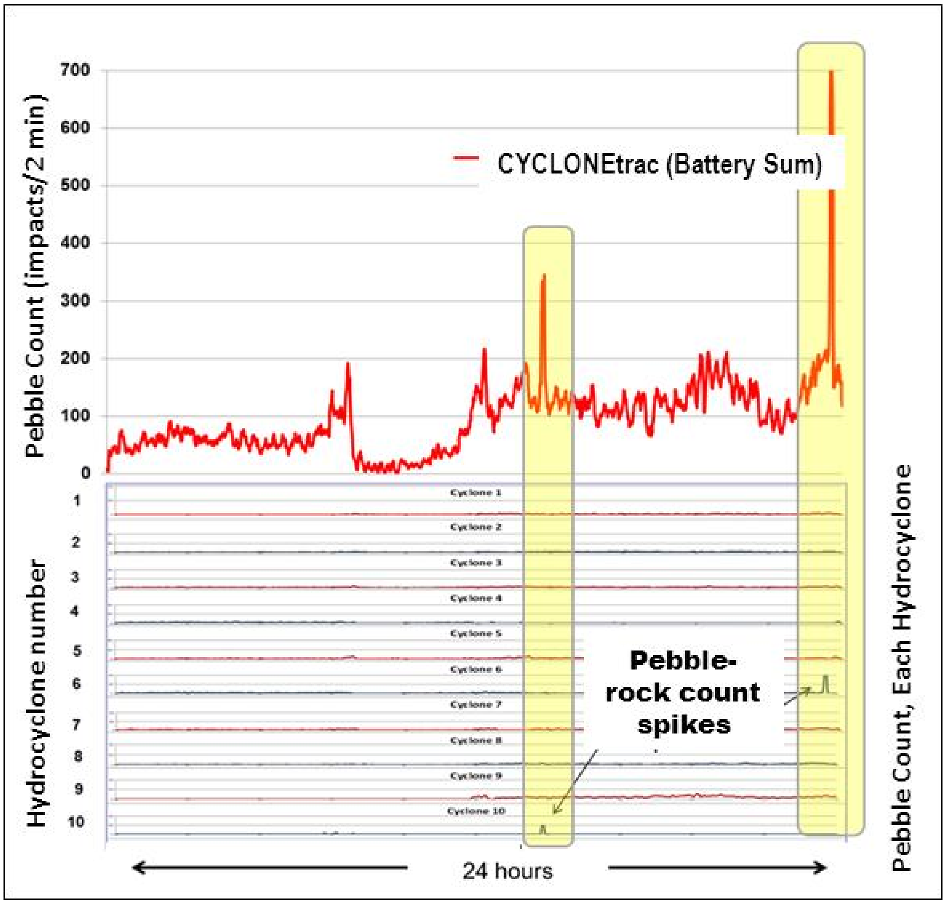

Figure 2 Single hydrocyclone causes combined overflow of the battery to display a spike in the pebble/rock trend.

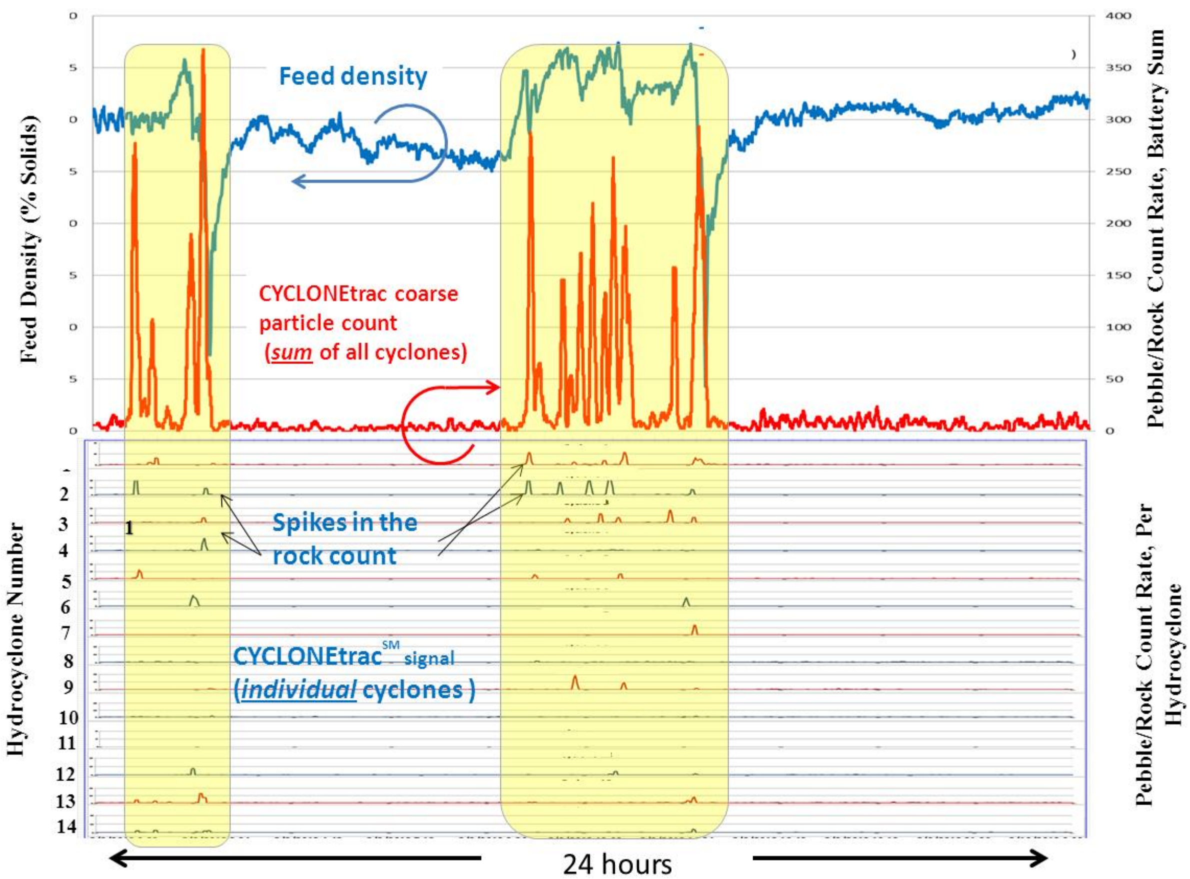

Figure 3 Multiple hydrocyclones cause the combined overflow of the battery to display spikes in the pebble/rock trend, which is coincident with increases in feed density to the battery.

During the development of the CYCLONEtrac OSM system, control room operators were consulted on a regular basis to gather feedback on displays, trends and alarming. With support from the technical team at the concentrator, pebble/rock events were investigated to determine the optimum response to such events and whether the OSM alarm thresholds were set appropriately. A control and response strategy was then developed and operations personnel were trained during the implementation phase. The control system is manually implemented and follows the procedure show in Figure 4

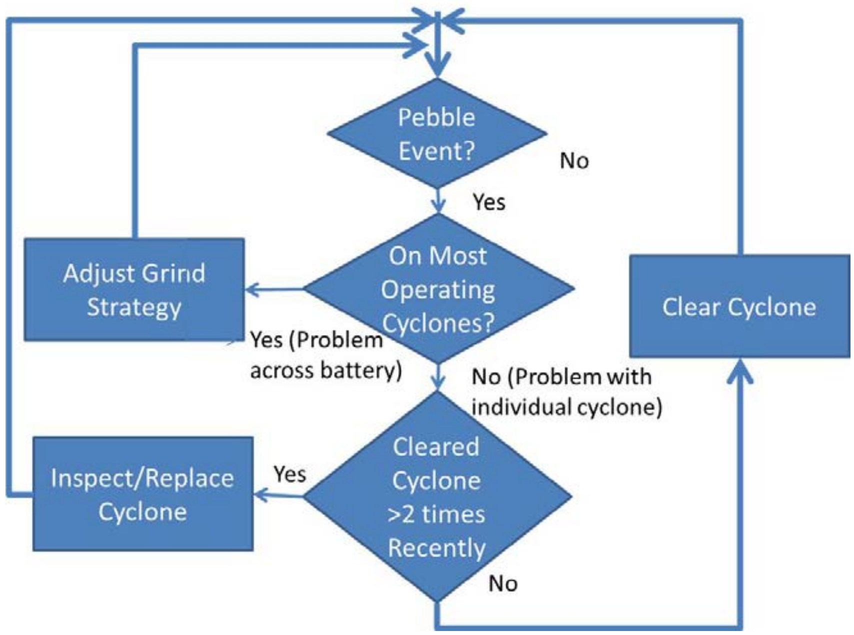

Figure 4 Manually implemented control and response strategy

2.3 Sensor System – Control of Pebble/Rocks Reporting to Flotation

One of CiDRA's core competencies is the measurement of acoustic information through the wall of a pipe (Gysling et al, 2005, and O'Keefe et al, 2007). CiDRA has used its expertise in this area to create the CYCLONEtrac OSM system. The physical premise for this sensor is based on the observation that pebbles or rocks have a significant probability of striking the inside of a hydrocyclone overflow pipe as they pass through the 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 through the pipe wall to the outside wall of the pipe. In CiDRA's CYCLONEtrac OSM system, a proprietary strain sensor is tightened mechanically onto the outside of the pipe. The particle-induced strain or the acoustic wave strains the pipe wall thus straining the sensor and creating an electrical signal characteristic of the particle. A unique algorithm extracts this very low level signal from the background noise to identify the passage of a group of pebbles or rocks within a short time period known as a rock event. The system reports the rate of these rock 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 or rock passing through and striking the inside of the overflow pipe is greatly increased.

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 resistant 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. Photos of the installed system are given in Figure 5 in which the upper right hand photo shows the sensor head installed on the overflow pipe, the upper left hand photo shows the transmitter and power/communication junction box, and the lower photo shows a complete battery system. The installation process is non-intrusive and allows for the hydrocyclone battery to stay operational

Figure 5 Installed CYCLONEtrac OSM System 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 so if an overflow pipe is replaced the sensor head is removed from the pipe and installed onto the new pipe. No calibration or zeroing is required when reinstalling.

The CYCLONEtrac OSM system has been commercially deployed at Rio Tinto Kennecott Utah Copper's Copperton concentrator in Utah, USA since 2010; Cirulis et.al. (2011). Throughout the development of the CYCLONEtrac OSM system, real-time acoustic data for both normal and abnormal operating conditions were recorded, including many rock events. The recorded time series data was utilized to develop and optimize a proprietary algorithm that detects and displays the changes in rock event trends for individual hydrocyclones and the consolidated trend of each cluster of hydrocyclones. Evaluation of the trends allowed thresholds and alarms to be set 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 (Figure 6).

Figure 6 During field validation, 78 samples were analyzed and compared to CYCLONEtrac OSM pebble counts. Shown is an example of material collected during a pebbles/rocks event.

2.4 Plant data

Implementation of the CYCLONEtrac OSM system has significantly reduced the number of rock events at Rio Tinto Kennecott Utah Copperton concentrator, as demonstrated by the reduction of downtime events needed to clean out flotation rows. Downtime of the flotation rows has reduced, and there has been a noticeable reduction in component wear. The flotation cells in the rougher-scavenger section are Wemcos, and the reduction in coarse particles within the flotation row has improved the performance of the cells particularly from allowing the false bottom to perform as designed.

2.5 Conclusion – Control of Pebbles/Rocks Reporting to Flotation

CYCLONEtrac OSM technology and operator involvement permits the operators to greatly reduce the length of time in which pebbles or rocks pass through the overflow (rock 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 rock event. Over several years of commercial operation at Rio Tinto Kennecott the CYCLONEtrac OSM system has proven to be valuable in detecting excessive amounts of pebbles and rocks in the hydrocyclone overflow stream, enabling immediate corrective action, thereby helping to prevent any serious blockages in the rougher flotation or tailings circuits.

3. GRIND CONTROL THROUGH HYDROCYCLONE PARTICLE SIZE TRACKING

3.1 Problem Statement – Grind Control Enabled by CYCLONEtrac 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 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 Rio Tinto Kennecott 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 is typically used to control the cut size. Historically, the cyclone feed density control philosophy at Rio Tinto Kennecott 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 and 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 set point, in turn helping re-establish confidence in the measurements.

3.2 Rio Tinto Kennecott – Solution for Maximizing Value Through Grind Control

3.2.1 Control Scheme – Grind Control Enabled by CYCLONEtrac PST

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 Rio Tinto 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 as seen in Figure 7

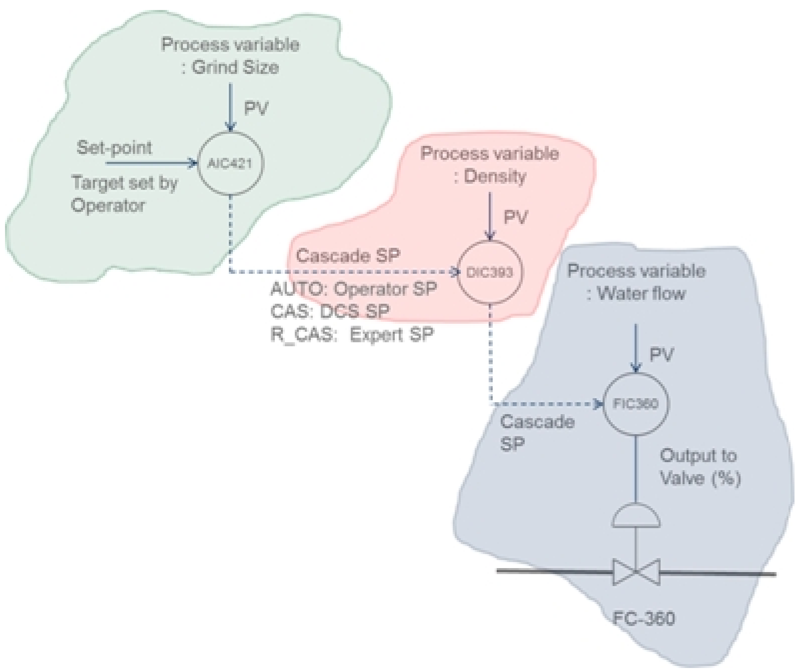

Figure 7 Cascaded control loops used to optimize grind value

Figure 8 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 8. 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.

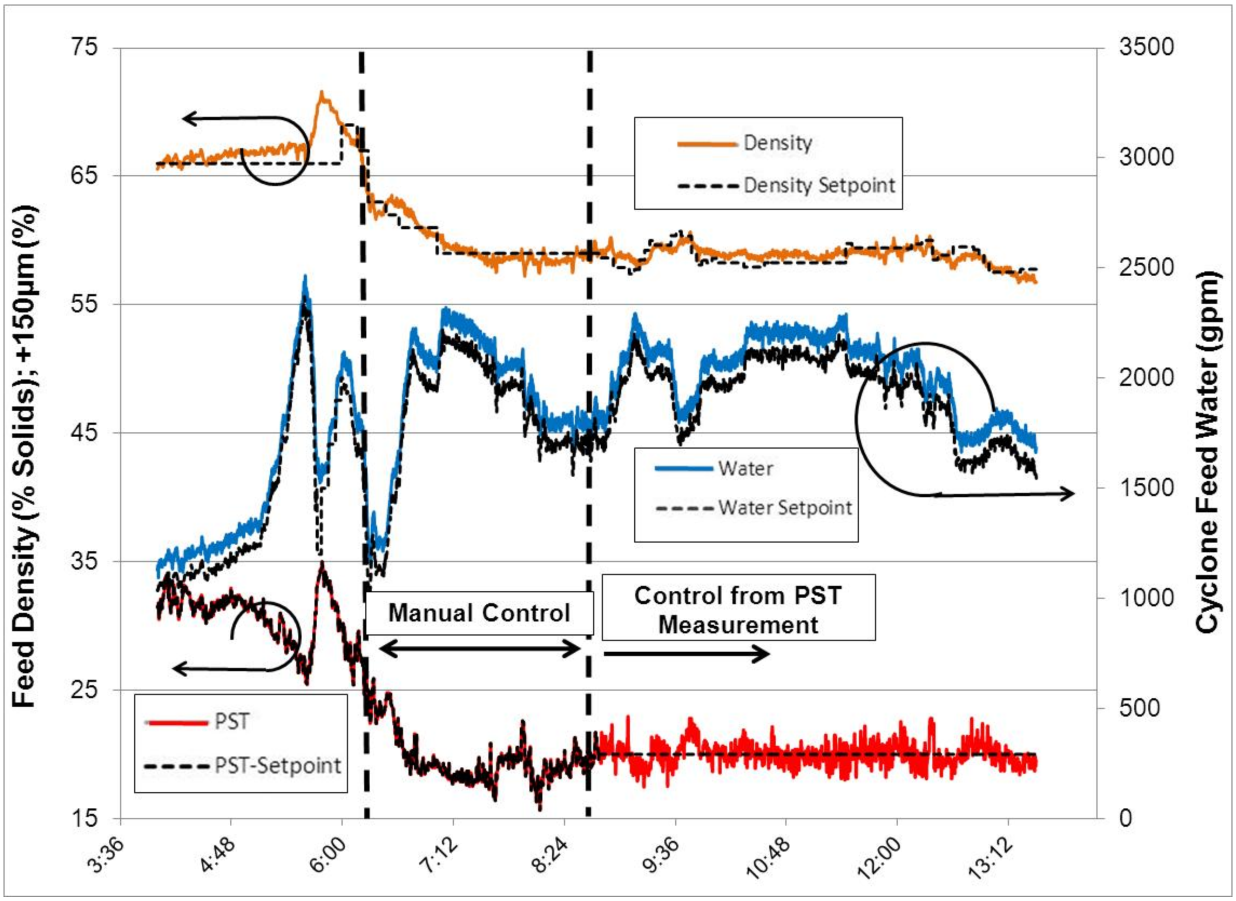

Figure 8 Manipulating density for PST control

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 mill target power draw while reducing grind size. **Error! Reference source not found.** 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 fall.

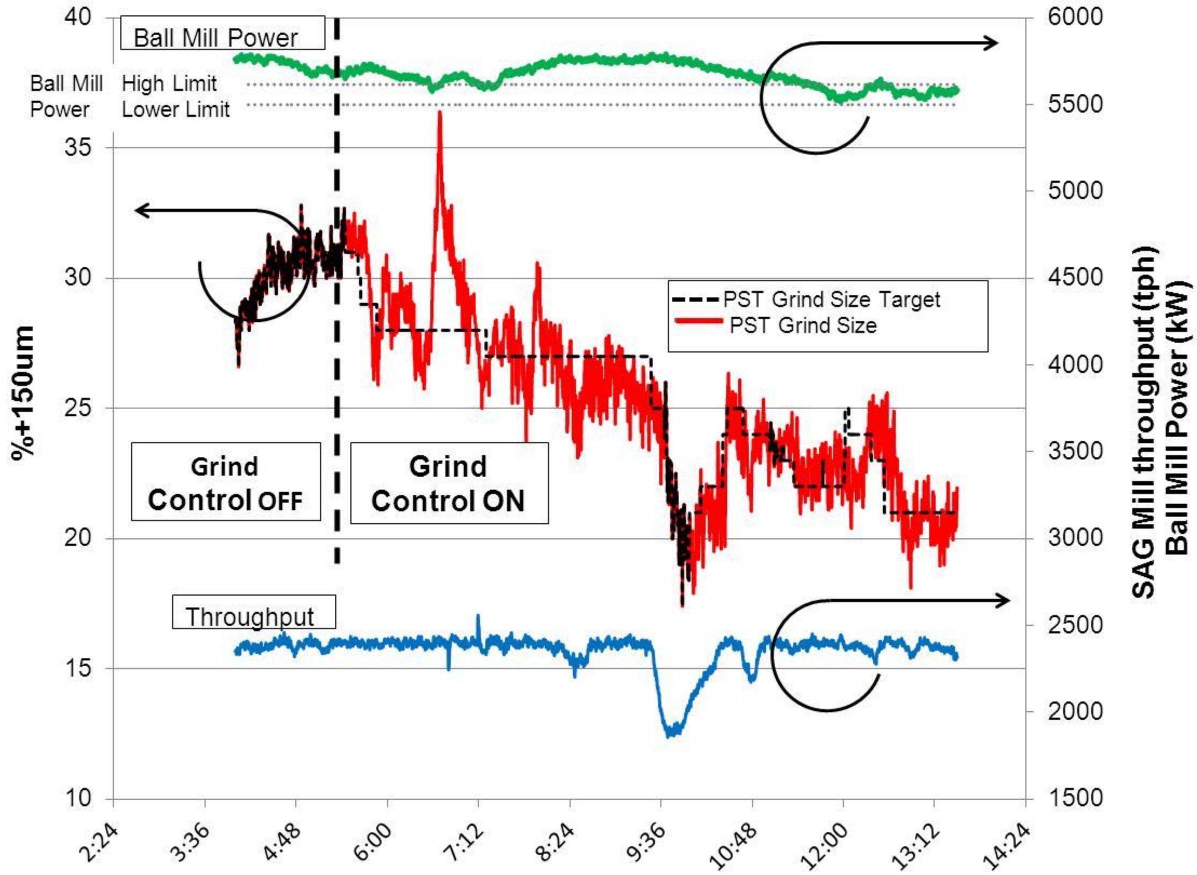

Figure 9 Reduction of grind size with constant TPH and target ball mill power

In order to maintain target particle size and power draw, the cyclone feed density and the particle size target are manipulated. Figure 10 below shows both the particle size and cyclone feed density changes to maintain ball mill efficiency.

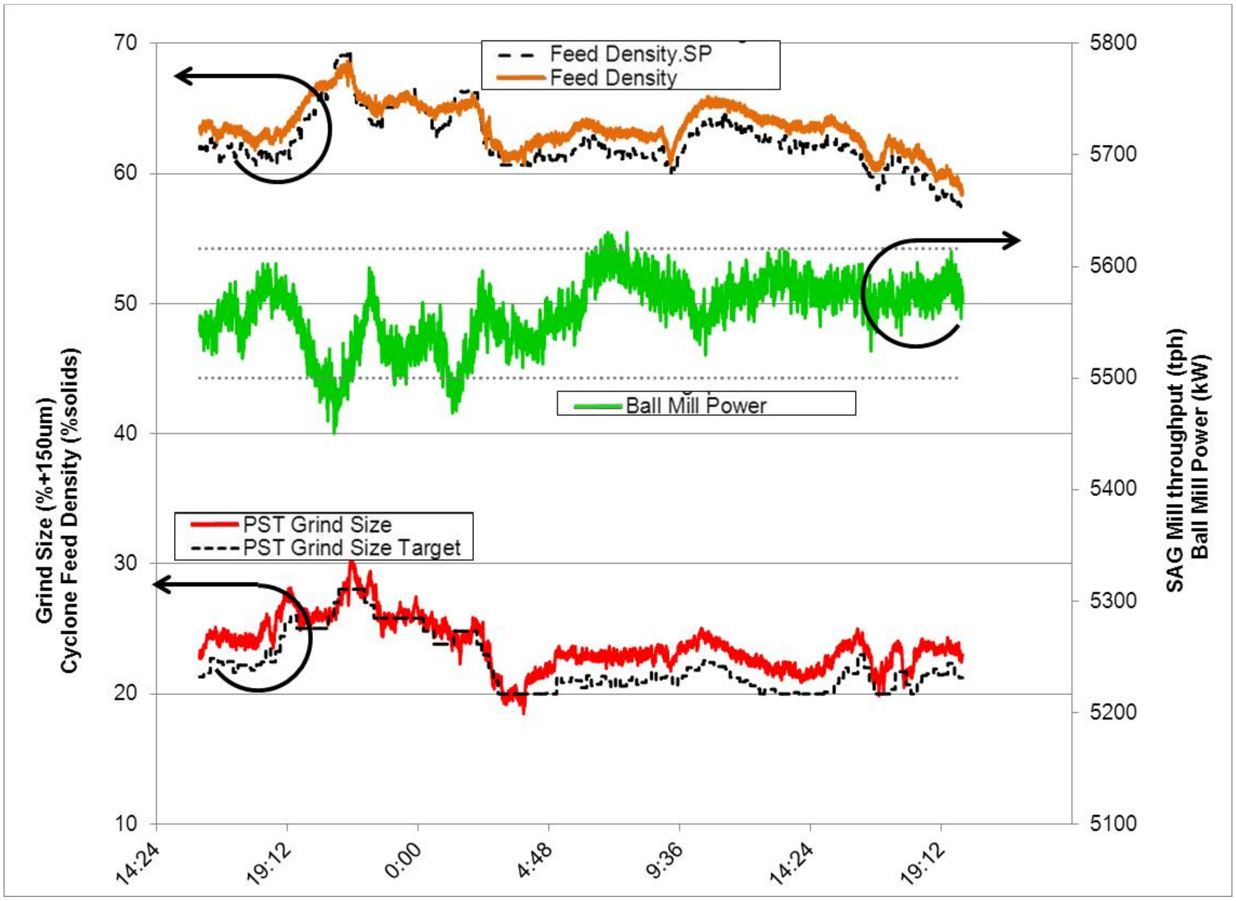

Figure 10 Example of particle size tracking leading to density setpoint changes and then to ball mill power draw

3.3 Sensor System – Grind Control Enabled by CYCLONEtrac PST

3.3.1 Sensor System Description

The CYCLONEtrac PST system at Rio Tinto Kennecott consists of 88 sensor probe assemblies seen in Figure 11 (one for each hydrocyclone), eight junction boxes (one for each battery), and a control room computer as demonstrated in Figure 12. 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 11 Left, CYCLONEtrac PST sensor. Right, CYCLONEtrac PST sensor installed on pipe

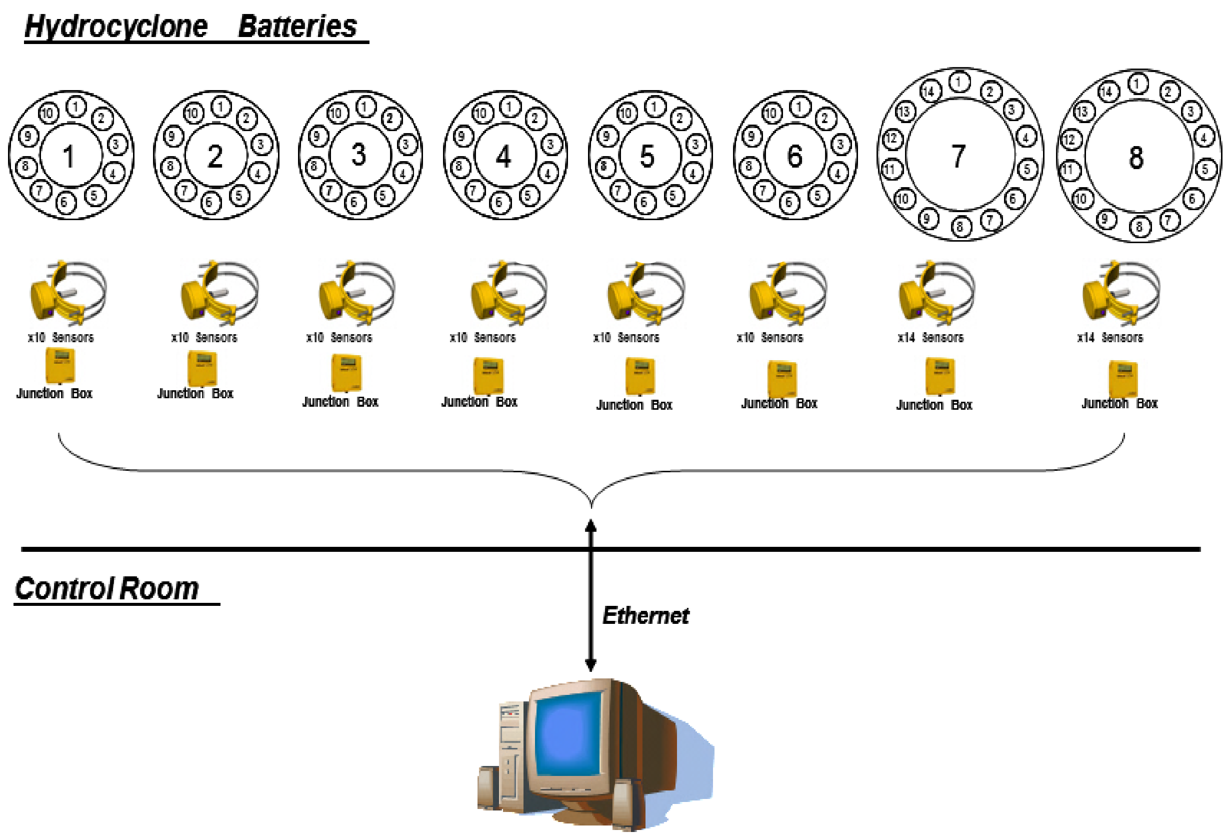

Figure 12 Schematic of CYCLONEtrac PST system installed at Rio Tinto Kennecott

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 Rio Tinto Kennecott Distributed Control System (DCS) via an OPC tunnel.

3.3.2 Sensor System Validation – Grind Control Enabled by CYCLONEtrac PST

After the CYCLONEtrac PST system was installed at Rio Tinto Kennecott, a sampling campaign was undertaken to validate the performance of the system. CiDRA and Rio Tinto 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 Rio Tinto Kennecott 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 13 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 13 by the error bars. Figure 14 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 Rio Tinto 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.

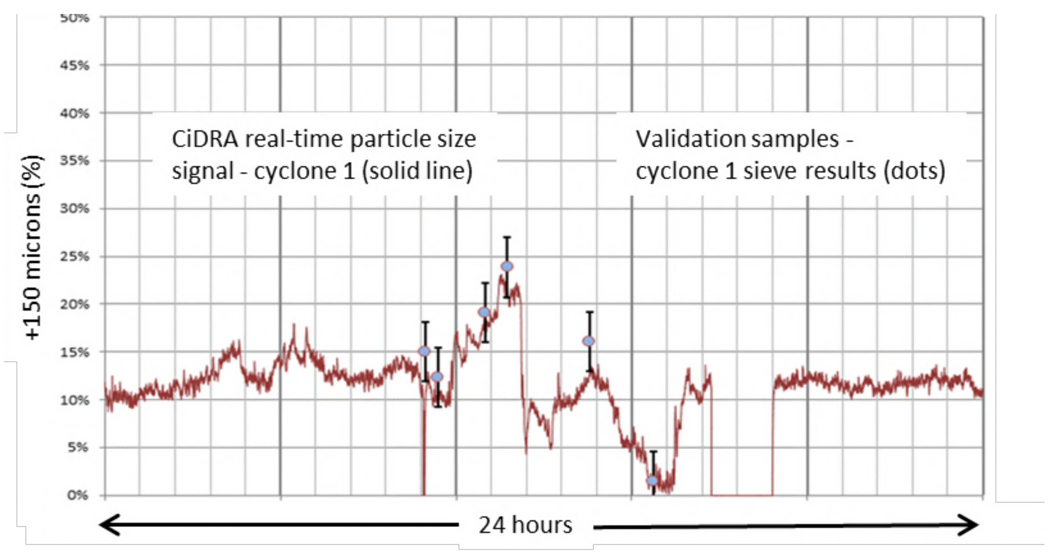

Figure 13 Hydrocyclone 1 CiDRA CYCLONEtrac PST signal vs. validation sieve samples

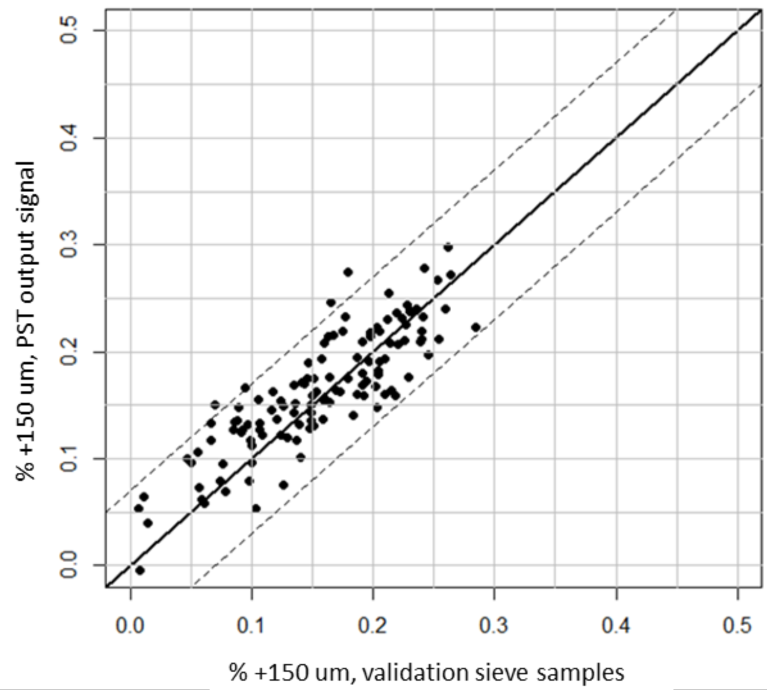

Figure 14 Percent Mass Fraction +150 micron, CYCLONEtrac PST output vs. validation sieve samples

3.4 Conclusion – Grind Control Enabled by CYCLONEtrac PST

The grind control system developed by Rio Tinto Kennecott using CiDRA's CYCLONEtrac PST system is proving to be very effective in enabling grind circuit control at Rio Tinto Kennecott 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.

4. CONCLUSION – GENERAL

Rio Tinto Kennecott 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 Rio Tinto Kennecott 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 flotation circuit shutdowns 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 systems are used to deliver value.

ACKNOWLEDGEMENTS

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